Internet GIS for Air Quality Information Service for Dalian, China

by

Lisai Shen

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, 2005

AUTHOR'S DECLARATION FOR ELECTRONIC SUBMISSION OF A THESIS

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

Since the 1970s, environmental monitoring in China has formed a complete web across the country with over 2000 monitoring stations. China State Environmental Protection Administration (SEPA) has published an annual report on the State of the Environment in China since 1989. The Chinese government began to inform the public of environmental quality and major pollution incidents through major media since the late 1990s. However, environmental quality data has not been adequately used because of constraints on access and data sharing. The public and interested groups still lack access to environmental data and information.

After examining the current air quality reporting systems of the US Environmental Protection Agency and the Ontario Ministry of Environment, reviewing current Internet GIS technology and sample websites, this thesis developed an ArcIMS website to publish air quality data and provide background information to the public for the city of Dalian, China. The purpose is to inform the public of daily air quality and health concerns, and to improve public awareness of environmental issues. A better-informed and educated public will be more likely to voluntarily conserve the environment in the long run.

The development of this thesis can satisfy most basic expectations. However, due to the limitation of current Internet products like ArcIMS, symbology and connection with outside databases are not adequate. In addition some regular GIS analysis functions are not available to Internet GIS products.

This development can be further improved to serve other environmental data to the public with better interactivity through coding. Similar Internet GIS products can be used in other Chinese cities to report their air quality data. For internal data sharing and reporting within the government, an open, interoperable distributed GIService is recommended, which is believed to be the future of Internet GIS.

ACKNOWLEDGEMENTS

First I would like to thank EcoPlan China project for giving me the opportunity to do research in an area that has long been my interest. I really appreciate support and encouragement from Dr. Geoff Wall and Dr. David Wood.

I would also like to thank Scott MacFarlane of Mapping, Analysis, & Design (MAD) for giving me valuable suggestions and help during the implementation of my project. I brought him lots of ‘trouble’ because normally I am the only one using ArcIMS in the lab.

My thank goes to Tom, Kathy, Harry, Yuzhu and Catherine for taking the time to giving me feedback and great suggestion, to Sunah for sharing her data and friendship.

I really appreciate that my committee member Dr. Peter Deadman gave me valuable critiques and suggestions during his busiest term.

My greatest thank goes to my supervisor, Dr. Douglas Dudycha, for his valuable input, time, edits, ideas and suggestions. Without his patience, encouragement and understanding, this thesis would not have been possible.

Last but not least, I would like to thank my families and friends here and in China, for their unconditional love and support, for their tolerance and understanding. I am deeply grateful!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

The environmental issues we are facing today, from global warming, ozone depletion, acid rain, to desertification, mainly come from industrialization, urbanization and other human activities. Environmental management per se, “is not about managing the environment; it is about managing the activities of corporations, institutions, and individuals that affect the environment” (Thompson, 2002). Environmental management tries to balance economic development and human activities with the conservation of the natural environment in order to achieve sustainable development. It is a systematic approach involving legislation, monitoring, assessment, auditing, evaluation, and prediction.

With a population of 1.3 billion and rapid industrialization, China’s environment has been under tremendous pressure to provide enough food and energy. “Wide spread deforestation, recurrently intolerable air pollution, ubiquitous water contamination, excessive losses of arable land, and a drastic decline of biodiversity” are some examples of environmental degradation that China is facing today (Smil, 2004. p141).

Since the 1970s, environmental management and monitoring systems have been developed and improved in China. Environmental laws, regulations, and standards were gradually constructed and improved. Monitoring technology and instruments have constantly been upgraded to keep up with international standards. Environmental degradation has been controlled or slowed to a certain extent. However, with one fifth of the world’s population to support and a rapid economic growth, it is an unimaginable challenge for China to achieve a clean environment and sustainable resources.

Thanks to the funding of *Ecoplan China* project, I had the opportunity to conduct my research in a fast-growing Chinese city. Ecoplan China is an environmentally oriented program awarded by the Canadian International Development Agency. The main purpose of this program is to "establish sound human capital and institutional capacities to design, implement and monitor integrated environmental policies and programs" in coastal communities in China (EcoPlan China, 2003).

1.1 Problem Statement

In most countries, environmental management and monitoring is mainly a governmental activity. The government collects data, sets up laws and regulations and assesses activities that may concern the environment. The public follows the rules and enjoys the quality of life. Do the public have the right to know everything that may concern their quality of life and health? It is not the same case in every country. Countries like the USA provide easy public access to a large amount of environmental quality data. While in China, limited amounts of data are available and free, others are under control or must be purchased with the government's permission.

Traditionally in China, the government agencies that collected and produced the data had the sole right to the data even though public taxes funded the cost. Data sharing within government agencies was not smooth because of both technical and organizational obstacles. The result was that environmental data (and other data), which cost a lot to collect and process, were poorly used because of strict ownership. Under such circumstances, the public could get little access to the environmental data because they were kept as 'confidential' and for internal use only.

Luckily the Chinese government has gradually improved its opening policy and has begun to inform the public of environmental quality and major pollution incidents. The China State Environmental Protection Administration (SEPA) has published an annual report on the State of the Environment in China since 1989. Major environmental remedial actions are broadcast on TV and published in newspapers and on the Internet.

However, direct data access for the general public and interested groups is still very limited. While part of the environmental data is still kept outside the reach of the public, part of the data is for sale at a considerable price. This obstacle is hindering the public from knowing about their living environment and critical health concerns in time, holding them back from actively protecting themselves from pollution damage and conserving the environment. Citizens with little or no formal education may not understand the harmful effects of pollutants. If the government could go further to inform and educate the public, to improve public consciousness and encourage public participation in environmental issues, environmental management could be a much easier job. After all, responsibility for conservation of the environment lies with every citizen, not only the government.

This paper identifies some of the existing problems with the current environmental managing and monitoring system, with the understanding that environmental authorities in China are already aware of and are addressing some of these problems, which include:

- Environmental quality data are not adequately used because of constraints on access and data sharing;
- The public and interested groups still lack access to environmental data and information;
- Public environmental education and participation is at a relatively low level compared with most developed countries. Some people seek economic benefits without considering environmental consequences.

1.2 Objectives of the Thesis

Although this paper will address internal data reporting problems among environmental agencies, the main goal is to provide an improved approach for the general public to access environmental data and related information in an up-to-date and low-cost way by utilizing the Internet and GIS technology. This approach will serve an environmental education purpose as well as informing the public. It is believed that only when overall environmental education is improved will the public more actively participate in environmental issues. People with better environmental consciousness will voluntarily conserve the environment in the long run. Conservation of water and power, as well as garbage recycling are among the many things that the public can do in everyday life to save the environment. Better-informed and educated citizens can also avoid unnecessary damage from polluted air, water and food. Furthermore, an informed public not only makes contributions to the environmental management plan, but active participation will allow exploration of alternative or even innovative ideas about environmental management plans (Bates & Caton, 2002). The specific objectives of this thesis are to:

- Develop an Internet GIS website for air quality information service for the general public for Dalian;
- Provide website users with background information related to air quality and health concerns;
- Discuss the suitability of Internet GIS products in serving environmental quality data to the public;
- Discuss possible solutions for internal data sharing within government agencies

The case study for the research is Dalian, China. Air quality data will be used as sample data. The website designed will provide up-to-date air quality data to anyone with Internet access. Interactive maps and database queries will be provided together with other functionalities. Background information and educational material are provided to the public for reference.

1.3 Study Location

Dalian is located at the southern tip of the Liaodong peninsula in northeast China. It stretches from 120°58' to 123°31' east longitude and 38°43' to 40°10' north latitude. With the Qianshan Mountain range passing through from north to south, the Dalian area abounds with mountains and hills. With a coastline of 1906km, Dalian is surrounded on three sides by Bohai Sea and Yellow Sea (see Figure 2-1) (Dalian Municipal Government, 2004).

With an area of 12,574km^2 and a population of 5.58 million (2002), Dalian is one of the largest cities in Northeast China. Although inhabited 6000 years ago, the city changed its name many times in history. It has a unique culture and collection of architectures from its recent history of wars and colonization in the mid-19th to mid-20th century (Dalian Municipal Government, 2004).

Figure 1-1: Location of Dalian

(Courtesy of Microsoft MapPoint)

Dalian became a center of heavy industry in the late 1950s and 1960s. Its industry was mainly composed of manufacturing, petroleum refinery, chemical engineering, metallurgy, textile and electronics. During the 1970s Dalian was developed as China's leading petroleum port. It has been an important ice-free seaport for northeastern China both commercially and strategically due to its special location. Dalian harbour is the third largest in mainland China and the largest in terms of international trade. Recent growth of Dalian started after 1984, when Dalian was approved to be a coastal open city with a special economic plan, enjoying provincial level decision-making authority. The economy began booming in mid 1990s, when the average annual economic growth was around 10% and soon it became a famous city with prosperous economy and beautiful environment despite its relatively small size among major Chinese cities (Dalian Municipal Government, 2004).

Located in the northern temperate zone, Dalian is one of the best-known summer resort and tourist cities, with favorable climate and distinct seasons. As a medium-sized city in China, Dalian is well known for its fresh air, beautiful flowers and grassy squares, which are seldom seen in other northern Chinese cities. Every year it hosts international conventions and exhibitions that attract thousands of visitors from all over the world.

1.3.1 Administration and City Planning

The municipality of Dalian includes 3 county-level cities, 1 county, 6 districts and 4 special opening zones (Figure 1-2).

- Cities and county: *Wa Fangdian city, Pu Landian city, Zhuanghe city and Changhai county*
- Districts: *Zhongshan, Xigang, Sha Hekou, Gan Jingzi, Lu Shunkou and Jinzhou*
- Special zones: *the Development Zone, the Free Trade Zone, the Hi-Tech Industrial Zone and the Golden Pebble Beach National Holiday Resort*

Based on its location, history and economic development, the city of Dalian defines its function as an international harbor, a district trade centre, a tourism resort, a financial and information centre. Despite the city's history as a heavy industrial base, the government of Dalian specifically promotes its clean environment to attract tourists and investors. The city began re-planning and re-structuring in the early 90s. Industries in the downtown area and along coastlines were moved or re-structured. The emptied land was used for residency, parks or lawns. New zones have been developed for high-tech industries, free trade and recreational facilities. Some major planning and actions are still underway to renovate the coastal area, and to develop a multi-centre open structure Dalian. (Dalian Urban Planning Bureau, 2003)

1.3.2 Environmental Management and Monitoring in Dalian

The Dalian Environmental Protection Bureau (DLEPB) is responsible for overall environmental issues in Dalian, including preservation of natural areas, pollution control, management of solid wastes, environmental bylaws and education. The Dalian environmental quality and major industrial pollution sources. Under DLEMC, there are eleven monitoring stations scattered in districts and counties of Dalian. In 2002 alone, over 1.3 million environmental quality monitoring data were collected (DLEMC, 2004). Details of environmental quality monitoring and reporting will be discussed in Chapter 2.

Figure 1-2: Administration of Dalian

1.4 Structure of the thesis

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

Chapter 2 introduces environmental monitoring and air quality monitoring with a focus on the system and situation in China and Dalian. Air Quality Index reporting systems of US

EPA, Ontario MOE, China SEPA and Dalian EPB are examined in terms of their advantages and limitations.

Chapter 3 reviews literature on current Internet GIS technologies. Comparison of traditional GIS and Internet GIS is presented. ArcIMS from ESRI is introduced in detail together with examination of sample sites. Then Internet GIS in China is discussed including current applications and problems.

Chapter 4 builds from previous chapters by presenting a description of data and conceptual design for the air quality monitoring website developed for this thesis. First user needs are identified for the web-GIS application. Next data sources, data processing and database design are described. Then conceptual design of the application is discussed followed by the implementation of the demonstration project.

Chapter 5 presents and discusses the results based on the development and customization of the ArcIMS website. Based on defined objectives, the project is assessed in terms of achievements and limitations, problems encountered as well as maintenance and updating issues.

Chapter 6 presents conclusions derived from the results of the thesis. Future enhancement of this project is discussed and recommendations are presented on extending of the use such Internet GIS solutions.

CHAPTER 2

AMBIENT AIR QUALITY MONITORING AND REPORTING SYSTEMS

This chapter first introduces the function and objectives of environmental monitoring, air quality monitoring and air quality index (AQI). Then the AQI reporting systems of the US EPA and Ontario MOE are examined in terms of what information is available and what functionalities are provided on the website.

Environmental monitoring systems in China, including reporting systems, air monitoring standards, and networks are carefully examined in order to provide background information for the study of Dalian's situation. Problems with the existing internal data reporting system are also addressed, followed by discussion of the AQI public reporting system by the China State Environmental Protection Administration (SEPA). Then Dalian's environmental condition and environmental monitoring system are introduced, followed by a detailed examination of AQI reporting from Dalian Environmental Protection Bureau (DLEPB).

Four AQI reporting systems in the USA, Ontario, China SEPA and Dalian EPB are assessed based on selected standards; the purpose is to define which aspects of Dalian's AQI report can be improved.

2.1 Environmental monitoring

Environmental monitoring is defined as "the process of repetitive observing, for defined purposes, of one or more elements or indicators of the environment according to pre-arranged schedules in space and time, and using comparable methodologies for environmental sensing and data collection"(Munn, 1973). As a fundamental process in the environmental management system, environmental monitoring provides basic data for analysis, comparison, assessment and decision-making.

Reasons for environmental monitoring can be one or more of the following: " (1) to assess general environmental conditions, (2) to establish environmental baselines, trends and cumulative effects, (3) to document environmental loading, sources and sinks, (4) to test environmental models and verify research, (5) to determine effectiveness of environmental regulations, (6) to educate the public about environmental conditions, and (7) to provide information for decision making" (Mitchell, B. 1998, p261). Although there are many reasons for monitoring the environment, two basic objectives of monitoring were: firstly to define the state of the environment and thus to provide a basis for predicting its future state; and secondly to determine whether there is a present risk to human health and welfare (IAEA 1965).

Depending on the targets, environmental monitoring includes monitoring of principal environmental features such as: air, water, land, noise, ecosystem, radiation etc, supervisory monitoring of pollution sources (concentrations, total quantities, etc.). In this thesis, the discussion will focus on ambient air quality monitoring.

2.2 Air Quality Monitoring

2.2.1 Air Pollution and Its Risks

Air pollution is "at least as old as the first fire" (Goklany, 1999, p9). But for thousands of years it has not become a major concern until the modern urbanization and industrialization in the 19th century. Smoke was the first issue that connected human mortality to air pollution and in the early 20th century it was put into abatement control in local regulations in the United States. In later years, other pollutants such as sulfur dioxide ($SO_{2)}$, particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NOx) also caught the public attention following a series of air pollution episodes that caused excess deaths and sickness. Early nation wide regulations included the Clean Air Act (1965) in the U.K, Air Pollution Control Act (1955) and Clean Air Act (1963) in the United States (Goklany, 1999).

Air pollution is defined as "a state of the atmosphere in which substances that harm human or plan health or corrode materials exist in concentrations above their normal or background levels" (Bates, D. V. & Caton, R.B. 2002, pp50). Pollutants of ambient air may come from natural (volcanic eruptions) or anthropogenic processes such as industrial emissions and automobiles.

The complexity of air pollution comes from not only the multiple sources or multiple pollutants, but also from the complex dispersion and transformation of the pollutants in the air that is influenced by meteorological and topographical factors such as temperature, humidity, wind direction and speed (Clench-Aas, J. 1999). An example of the aggravation of air pollution by the interaction of the two factors is the infamous Los Angeles smog. In the summer, inversion conditions take hold in the Los Angeles basin area when subtropical high pressure meets cool air from the ocean. Secondary pollutants including ozone are formed under sunlight following photochemical reactions by pollutants from automobiles and other sources. The situation is aggravated by the poor dispersion resulting from inversion and topographical barriers (mountains) and finally leads to smog in LA area. This photochemical smog reduces visibility and can result in a series of adverse reactions in the respiratory system, aggravate asthma and even cause lung damage (Godish, 1991).

Air pollution can lead to hazards in varied scales from reduced visibility, acidic deposition, to global warming, which concerns almost all the living creatures on the earth. Ambient air pollution can cause damage to vegetation, injury to livestock, serious endangerment to public health including illness and deaths. Human reactions to air pollution include irritation reactions such as headache and dizziness to more serious damage to kidney, liver or even lung cancer (Figure 2-1). Xu, Gao et al's study (1994) showed a highly significant association between SO_2 and daily mortality in Beijing, especially in winter. Doubling in SO_2 was significant for chronic obstructive pulmonary disease (29%), pulmonary heart disease (19%), and cardiovascular disease (11%). Both SO_2 and PM were found to be significant predictors of total daily mortality in summer. Generally speaking, children and elderly people are most vulnerable; people with respiratory diseases are more vulnerable than healthy people (Godish, 1991; Hansen, 1991).

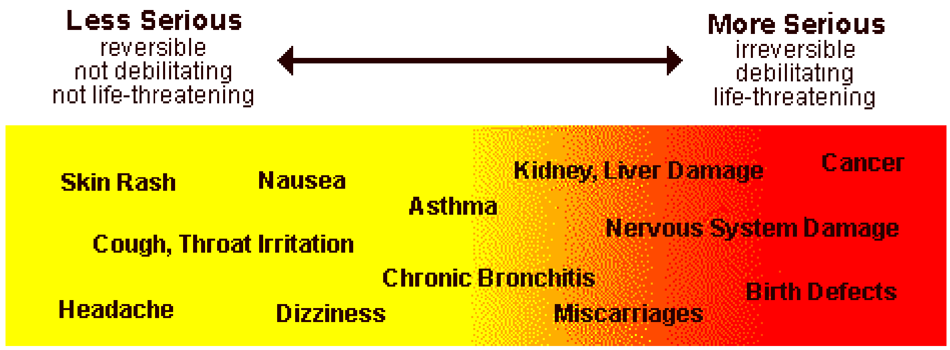


Figure 2-1: Health Risks of Air Pollution

(Air Risk Center, US EPA, 2001)

2.2.2 Air Quality Monitoring

With increasing concern about the effects of air pollution on health and the environment, systematic air quality monitoring first started in major industrial countries such as UK, USA in the 1950s (Goklany, 1999). As a powerful tool for identifying air quality problems, air quality monitoring is the basic part of an integrated approach to air quality management that includes legislation, assessment and prediction.

Air quality monitoring is defined as "a programmatic, long-term assessment of pollutant levels and, by implication, air quality at various locations within a defined geographical area" (Godish, 1991, p214). However, the purpose of monitoring is not merely to collect data or determine compliance with standards, but to provide information to enable policy makers and planners to make informed decisions on managing and improving the air quality, to inform the public about air quality and raise awareness (Hester & Harrison, 1997).

In ambient air quality monitoring, contents and items monitored have been changing since its inception, which reflects the evolution of air monitoring in terms of related knowledge and focus at different stage. At present, the five principal air pollutants commonly monitored are: sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and particulate matter (PM). These items are most frequently monitored for general air quality purposes because they have a direct adverse impact on human health and activities. Monitoring of these items is normally continuous and automatic if conditions permit. Depending on specific requirements, other monitoring items may include volatile organic compounds, radiation and heavy metals (Godish, 1991; Hester & Harrison, 1997)

2.2.3 Air Quality Indexes

Concern about health impacts is a major reason for reporting air quality and air pollution to the public. Besides, “public opinion, access to information, and free publication are essential components of the politics of air pollution control” (Bates, & Caton, 2002, p7). Instead of directly monitored data, air quality indexes have been developed as a simple method to inform the general public about air quality and pollution conditions. Index values are calculated from the monitored pollutant concentrations, which are not as intuitive or easy for the public to understand (Thom & Ott, 1976).

Air Quality Index (AQI), also known as Air Pollution Index (API) or Pollution Standard Index (PSI), has been widely adopted to report air quality in Canada, the USA, Australia and many European and Asian countries. The purpose of API is to report daily air quality to the public and to associate air quality with health effects. Normally the larger the index value, the greater the level of air pollution and the greater the health concerns.

Commonly used API indexes include five principal air-monitoring items: SO_2, CO, O_3, NO_2, and PM2.5 (or PM10)[*]. For daily reporting purposes, the item with the highest API is selected as the primary pollutant for the day and its API value is used as the API for the day. However, due to different regulations or standards, an API value may have different meanings in different systems (Table 2-1). For example, an API value of 97 is moderate and acceptable air condition in USA, but it signifies poor air conditions under the Ontario API system (USEPA, 2004; MOE, 2004). In the Great Britain, both the original concentration and AQI for pollutants are reported (UK Department for Environment, 2004). While in Australia,

[*] PM2.5 refer to particles with diameter less than 2.5 micrometer. PM10 refer to particles with diameter less than 10 micrometer. Normally finer particles are considered to be linked to serious health problems. Depending on the country or system, either of both items can be monitored.

AQI has not been widely used across the country (Department of the Environment and Heritage, Australia. 2004).

Table 2-1: Comparing of AQI Adopted in Different Countries

Country	AQI scale	AQI and Air Quality /Pollution level	Notes
USA	1-500	0-50 Good; 51-100 Moderate; 101 to 150 Unhealthy for Sensitive Groups; 151-200 Unhealthy; 201-300 Very Unhealthy; 301-500 Hazardous.	Uniform AQI across country, Report by central as well as local government.
Canada	1-100+	0-15Very Good; 16-31 Good; 32-49 Moderate; 50-99 Poor; 100+ Very Poor.	Uniform AQI across country. Several provinces report separately.
Great Britain	1-10	1-3 Low; 4-6 Moderate; 7-9 High; 10 Very high	Uniform AQI across country, report by central government at one website
Australia	1-150+ (Victoria) 0-50+ (New South Wales)	1-33 Very good 34-66 Good 67-99 Fair 100-149 Poor 150+ Very poor 0-24 Low 25-49 Medium 50+ High	Only report AQI in two states, not uniform AQI across the country yet.
China	1-500	0-50 Excellent; 51-100 Good; 101-150 Slightly polluted; 151-200 Light polluted; 201-250 Moderate polluted; 251-300 Moderate-heavy polluted; >300 Heavy polluted.	Uniform AQI across country. Report by central as well as some local government.

(Source: US EPA, 2004; MOE, 2004; SEPA, 2004; Department of the Environment and Heritage, Australia. 2004. , UK Department for Environment, 2004)

2.3 Air Quality Data Reporting System in the USA and Ontario

In order to compare with the situation in China and the city of Dalian, this thesis will first examine the air-monitoring data reporting situation in the USA and Ontario in terms of current reporting system, accessibility and availability of history data.

2.3.1 AQI Reporting System in the USA

In the United States, environmental data sharing and publishing are highly encouraged by the government. Public access and use of data have become very convenient in most states. Programs like the *Environmental Monitoring for Public Access and Community Tracking (EMPACT)* were set up to "help communities bring people up-to-date local environmental information they can understand and use in making daily decisions about protecting their health and environment." The result was "people in over 160 communities in 39 States now have current and accurate information about environmental conditions in their communities." (EMPACT, 2004)

Air pollution indexes have been used in the United States and Canada since 1970. However, in the early years, indexes used by different agencies showed great diversity and lack of consistency (Thom & Ott, 1976). A nationally uniform Air Quality Index (then called the Pollutant Standards Index) in the US was first established by Environmental Protection Agency (EPA) in 1976 (EPA, 1999). The index received major revision and got the current name in 1999. AQI was divided into six categories, ranging from 0 to 500. Each category corresponds to a different color and a different level of health concern (Table 2-2) (EPA, 1999).

Any metropolitan statistical area (MSA) with a population over 350,000 is required to report AQI to the public (US EPA, 2004). In addition to traditional media such as newspaper, radio and TV (USA Today and The Weather Channel), AQI is also reported at a specific website *AIRNow* (AirNow, USEPA, 2004). AIRNow officially began with US EPA in 1998. It was a web mapping system created to report real-time air quality data. State/local agencies send their hourly air quality data to EPA headquarter, and EPA will turn these data into maps and products for the web site and the media. At present AIRNow provides daily

AQI forecasts to over 300 cities across the US (Johne, Sep 2004). Major information and functions of the website include:

Table 2-2: AQI Range, Health Concerns and Colors Used by the U.S. EPA

Air Quality Index (AQI) Values	Levels of Health Concern	Colors	Explanation
When the AQI is in this range:	***...air quality conditions are:***	***...as symbolized by this color:***	***What it means:***
0 to 50	Good	Green	Air quality is considered satisfactory, and air pollution poses little or no risk.
51 to 100	Moderate	Yellow	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people. For example, people who are unusually sensitive to ozone may experience respiratory symptoms.
101 to 150	Unhealthy for Sensitive Groups	Orange	Members of sensitive groups may experience health effects. This means they are likely to be affected at lower levels than the general public. For example, people with lung disease are at greater risk from exposure to ozone, while people with either lung disease or heart disease are at greater risk from exposure to particle pollution. The general public is not likely to be affected when the AQI is in this range.
151 to 200	Unhealthy	Red	Everyone may begin to experience health effects when AQI values are between 151 and 200. Members of sensitive groups may experience more serious health effects.
201 to 300	Very Unhealthy	Purple	AQI values between 201 and 300 trigger a health alert, meaning everyone may experience more serious health effects.
301 to 500	Hazardous	Maroon	AQI values over 300 trigger health warnings of emergency conditions. The entire population is more likely to be affected.

(US EPA, 2004)

- **Air Quality Conditions** - National and regional real-time ozone air quality maps covering 44 US States and parts of Canada. These maps are updated every hour (Figure 2-2).
- **Air Quality Forecasts -** Nationwide daily air quality forecasts provided by State and Local Air Agencies for over 275 major US cities (Figure 2-3).

- **Where You Live -** Direct access to current AQI conditions (air quality maps and animations), AQI forecasts of selected region or city (Table 2-3). Many useful website links to state and local information are available at the webpage.

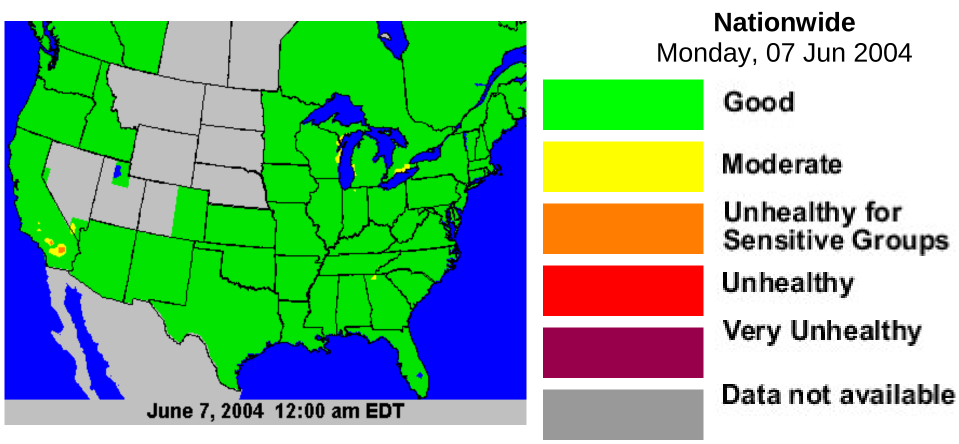


Figure 2-2: US AirNow OZONE AQI Sample Map

(Adopted from AirNow, USEPA, 2004)

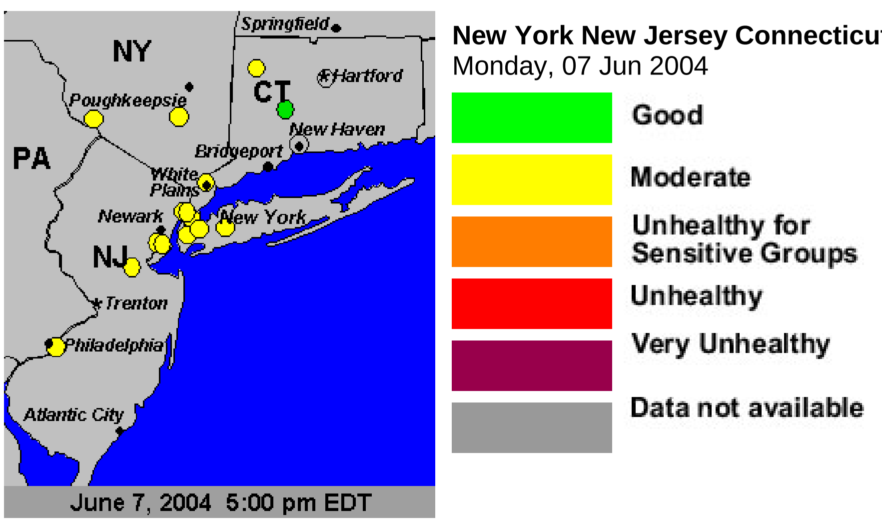


Figure 2-3: US AirNow PM2.5 AQI Sample Map

(Adopted from AirNow, USEPA, 2004)

Table 2-3: Sample Report: City Air Quality Forecasts and Data for Albany, NY

Albany		
Today's Forecast	**Air Quality Conditions**	**Tomorrow's Forecast**
Air Quality Index (AQI) **Primary Pollutant: Particles (PM2.5)** — Good Health message: No health impacts are expected in this range. (Detailed Forecast)	current conditions yesterday's conditions archives	**Air Quality Index (AQI)** **Primary Pollutant: Particles (PM2.5)** — Good Health message: No health impacts are expected in this range. (Detailed Forecast)

(Adopted from AirNow, USEPA, 2004)

Other information or functions available at the website include:

- Detailed information about AQI. In fact a special guide is prepared for the public: *Air Quality Index: A Guide to Air Quality and Your Health.*
- Information about monitored pollutants and their health concern.
- Historic data and map archive can be dated back to 2002
- Ozone maps for major national parks

AirNow is a very resourceful website. AQI data and maps are always updated. Related and useful local, regional and national links are all provided for the viewers. Informational and educational materials concerning AQI are comprehensively listed for all levels of viewers, including teachers and school children.

In addition to AQI reporting, other air monitoring data can also be reached at EPA AirData webpage (http://www.epa.gov/air/data/index.html). Ten years historical air quality data for the whole U.S. or a selected city are available for downloading. These monitoring data are in original concentrations instead of AQI value. Reports and maps can be queried based on users' own criteria. Data about monitoring sites, monitors or a summary report are also provided at the website.

2.3.2 AQI Reporting in Ontario, Canada

In Canada, there is no single website providing air quality reports for the whole country as in the United States. Every province or region has its own air quality reporting system, although the AQI range and standards remain the same. The Environment Canada website (http://www.ec.gc.ca/envhome.html) provides links to each of these reporting systems. For this thesis's purpose, Ontario's air quality reporting system will be examined as an example.

Ontario began air quality monitoring since the early 1950s starting with only sulphur dioxide (SO_2). In the later years carbon monoxide (CO), suspended particulate (SP), total reduced sulphur (TSP), Nitrogen Oxides (NOx), Ozone (O3) and particulate matter (PM) were gradually incorporated into the monitoring system. Now Ontario has a network of 37 air-monitoring stations across the province. Concentrations of six major pollutants - carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide, fine particulate matter and total reduced sulphur are constantly tracked (Bitzos, Sep 2004; MOE, 2004).

In 1988, Ontario adopted the Air Quality Index (AQI) system to provide media (radio, TV etc.) information to the public on air quality (MOE, 2004). The AQI standard and scale (Table 2-4) are different from that used by U.S.EPA. AQI ranges from 0-15 (very good) to 100+ (very poor).

Table 2-4: Ontario AQI System

API Value	Air Quality	Representing Color	
0-15	Very Good		Blue
16-31	Good		Green
32-49	Moderate		Yellow
50-99	Poor		Orange
100+	Very Poor		Red

(Adopted from MOE, 2004)

The ministry's air quality web site (www.airqualityontario.com) was established May 1, 2000 to provide the public with AQI reports, air quality forecasts, air quality publications and general information on air quality. Since May 2000, the web site has had approximately 27 million hits (Bitzos, Sep 2004). A sample map showing Ontario Air Quality with representing colors are showed at Figure 2-4. A sample AQI forecast for Ontario cities is shown in Table 2-5.

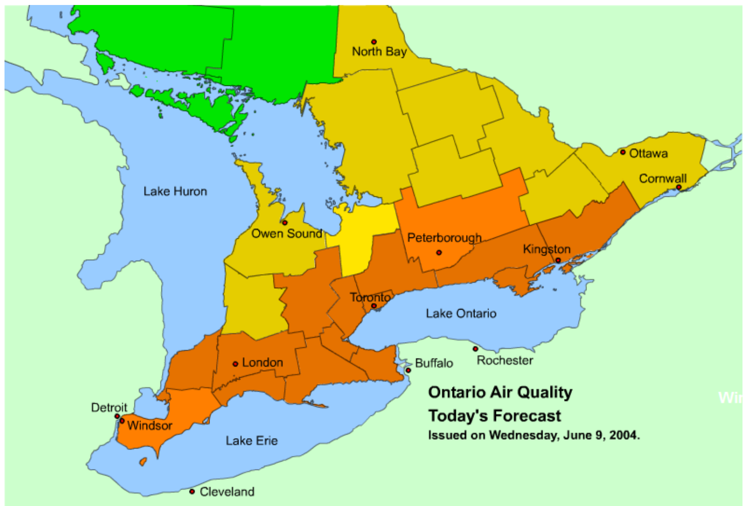


Figure 2-4: Ontario Air Quality Forecast

(Adopted from MOE, 2004)

Table 2-5: Sample Air Quality Report for Ontario Cities

For Monday, June 7, 2004, 3:00 PM

Station Name	AQI	Category	Cause
BARRIE	37		Fine Particulate Matter ($PM_{2.5}$)
BRAMPTON	43		Ozone (O_3)
CORNWALL	28		Ozone (O_3)
WINDSOR DOWNTOWN	51		Ozone (O3)

(Adopted from MOE, 2004)

For some Ontario regions, 3-day air quality forecast is available at the website. Other related information that can be found at the Ontario air quality reporting website includes:

- Information about AQI;
- Information about monitored pollutants and their health concern;
- Historic AQI data for 2003 and 2004.

The air quality reporting system in Ontario is simple and straightforward, easy to understand for most viewers. However, related information and links are limited compared with US EPA website. Historical data is only available from 2003. No detailed information about monitoring sites or monitors is provided. Original concentration data are not yet available at the website. However, Ontario MOE is ready to provide data upon request by the public.

2.4 Environmental monitoring in China

Modern environmental monitoring in China was started in the 1970s when environmental protection was recognized as a basic national policy for the first time. Systems of environmental monitoring and management were developed and refined in the thirty years thereafter. In the 1970s, environmental monitoring was mainly concerned with the checking of discharge (e.g. effluents, emissions and waste residue) from major industries. Systematic monitoring of air, water and noise began in the 80s. In the 90s a complete monitoring web across the country was established and monitoring organizations were divided into four levels (Wu, 1999).

2.4.1 Environmental Monitoring System

The top level Chinese government agency responsible for environmental monitoring and pollution control is the State Environmental Protection Administration of China (SEPA), the counterpart of Environment Canada or U.S. EPA. Under SEPA, there are two systems of management and monitoring organizations spreading across the country: the environmental protection administration system and the environmental monitoring system. Both systems are divided into four levels: state, provincial, municipal (city) and county level (Figure 2-5).

Environmental protection agencies are responsible for overall environmental issues, which include environmental regulation and standards, environmental planning, natural resources conservation, environmental impact assessment, environmental monitoring and environmental education. Environmental monitoring agencies are specifically responsible for environmental quality monitoring that includes air, water, noise and ecosystem etc. The entire environmental monitoring system in China includes (Wan, 2002):

- China National Environmental monitoring Center (CNEMC),
- Provincial environmental monitoring centers (38),
- Municipal environmental monitoring centers (391), and
- County-level environmental monitoring stations (2229).

Each monitoring organization, except the one at state level, is under the supervision of the upper level monitoring station and the same level environmental protection administration. It has the responsibility of reporting to both its direct superiors (Figure 2-5). Some selected key cities must report to CNEMC at the same time (SEPA, 1996a). Up to 2002, there are 2230 environmental monitoring stations across China, including 474 automated air-monitoring systems in 179 cities (Wan, 2002).

2.4.2 Environmental Monitoring Data Reporting System

The standard reporting was mainly in paper format before 1989. Depending on the content and frequency, the reports could be classified as briefing (emergency situation), monthly data report, quarterly data report, annual data report, environmental quality report (1-year and 5-year) and pollution-source monitoring report. The format of the reports included data and literal report. Data referred to tables and spreadsheets based on raw data; literal report referred to written reports based on monitoring data and analysis (SEPA, 1996a).

Special software was developed in 1989 allowing the input of local monitoring data directly at individual workstations following the format specified by the software and loaded on diskette for transmission. Reporting frequency remained unchanged (SEPA, 1996a). Until 1997 the modern way of communication began to take shape in the monitoring system.

Direct transfer of data became possible at higher level monitoring stations or major cities. However, it has not been possible to "generate a single nationally unified environmental data and information transmission system for the large annual volume of administrative data" (Wu, 1999).

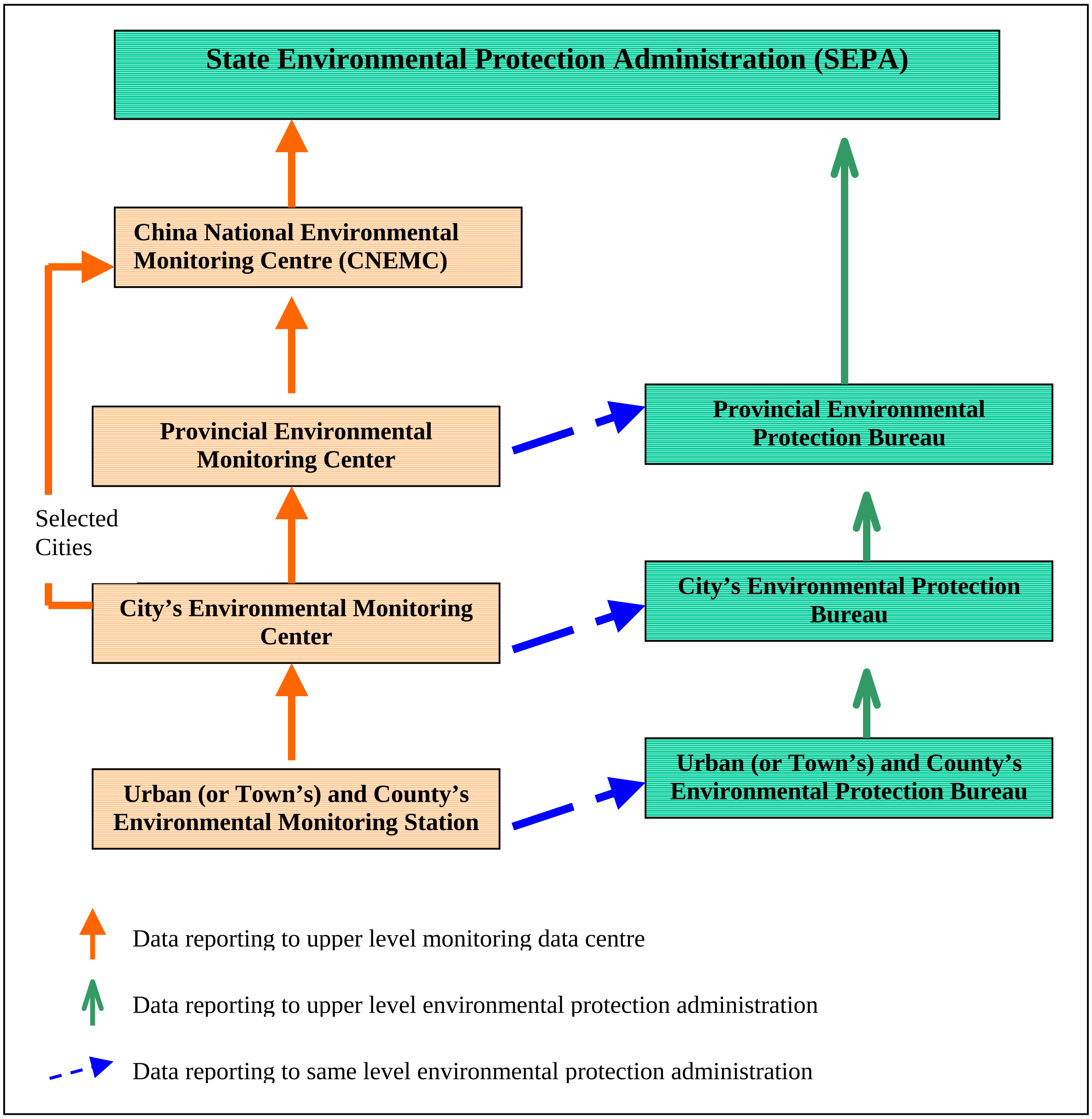


Figure 2-5: Environmental Protection Organizations and Data Reporting System in China

2.4.3 Air Monitoring Standards

The *Law of People's Republic of China on the Prevention and Control of Air Pollution* was issued in 2000. Before that, a series of *National Standard of Ambient Air Quality Monitoring Methods* have been developed and published as handbooks or criteria in the past 30 years. These standardized methods are used for sampling and analysis of major chemicals and particles in the air and are followed by all the monitoring stations nationwide, which ensures the quality and comparability of the monitoring data across 2000 plus monitoring stations in China.

The first ambient air quality standard of China was issued in 1982, later replaced in 1996 by *Ambient Air Quality Standard of China* (GB3095-1996). This standard distinguishes three categories of air-quality functionality zones (SEPA, 1996b):

- Class 1: natural preservation area, scenic area and other special areas;
- Class 2: residential, commercial, cultural, rural, general industrial area and mixed area;
- Class 3: special industrial area.

For each class it establishes corresponding standards and concentration limits for 10 major air pollutants, including SO_2, CO, O_3, PM10, NO_2, etc. This standard is helpful in defining a rough air function zone division for urban areas, making the air quality more manageable and standards more achievable. However, the situation gets complex sometimes in mixed areas. Defining air-quality zones alone is not sufficient for analyzing any change or describing or differentiating air quality in the same zone.

SEPA adopted an air quality index system in 1997 to further classify air quality and simplify the reporting. Table 2-6 lists the threshold API values and their corresponding concentrations for five major monitoring pollutants. China's current API classification followed the 500 series. For API values below 200, the class 1-3 standards as set out in Ambient Air Quality Standard of China (GB3095-1996) are applied. For values above 200, US EPA classification system is used. API value range and its corresponding air quality class and health effects are listed in Table 2-7.

Table 2-6: API Value and Corresponding Pollutant Concentrations in China

(Unit: mg/m^3)

API	SO_2 (daily average)	NO2 (daily average)	PM10 (daily average)	CO (hourly average)	O3 (hourly average)
50	0.050	0.080	0.050	5	0.120
100	0.150	0.120	0.150	10	0.200
200	0.800	0.280	0.350	60	0.400
300	1.600	0.565	0.420	90	0.800
400	2.100	0.750	0.500	120	1.000
500	2.620	0.940	0.600	150	1.200

(Adopted from SEPA, 2004)

Table 2-7: API and Air Quality Grading in China

API	Air quality Description	Grade	Effects to health	Measures suggested
0-50	Excellent	1	Daily activities are not affected	
51-100	Good	2		
101-150	Slightly polluted	3A	The symptoms of the sensitive groups will be aggravated slightly, while the healthy people may experience some stimulating symptoms.	The cardiac and respiratory system patients should reduce strength draining and outdoor activities.
151-200	Light polluted	3B		
201-250	Moderate polluted	4A	The symptoms of the cardiac and lung disease patients will aggravate remarkably, and their exercise endurance will drop down. The healthy crowds will normally experience some symptoms.	The aged, cardiac and lung disease patients should stay indoors and reduce physical activities.
251-300	Moderate-heavy polluted	4B		
>300	Heavy polluted	5	The exercise endurance of the healthy people will decrease; some of them will have strong symptoms. Some diseases may appear earlier.	The aged and patients should stay indoors and avoid strength draining; the ordinary should avoid outdoor activities.

(Adopted from SEPA, 2004)

2.4.4 Air Monitoring Network

In 1999, 350 out of China's 666 cities had started regular air quality monitoring. 103 selected monitoring stations comprised the National Air Quality Monitoring Network, while others were in the Provincial Air Quality Monitoring Network. Objectives of the Network are to "obtain a general idea of the air quality situation in China and its long-term changing trends; to observe that individual cities meet the national standards; to evaluate the results of pollution control and management measures; and to provide a scientific basis for environmental policy-making and urban development planning" (Wu, 1999).

Three basic types of operational modes are adopted in the monitoring network:

- Continuous automatic monitoring;
- Continuous automatic (24-h) sampling with laboratory analysis;
- Manual (intermittent) sampling with laboratory analysis.

Most air monitoring was performed manually before 1998. By 2002, 474 automated air-monitoring systems had been set up in 179 cities. Compulsory items for automatic air monitoring include SO_2, NO_2 and PM10. CO, O_3 and organic compounds are optional items depending on the nature of the monitoring site (Liu & Zheng, 2000).

2.4.5 Air Pollution Index Reporting

From June 5, 2000, 42 major Chinese cities (including Dalian) began to report API to the public on China Central TV station (CCTV). This event was regarded as a big step in the opening process of environmental data in China. It was the first time the public had direct access to information about their living environment. By June 2004, API report at SEPA's website have included 84 cities (SEPA, 2004). The report includes Air Pollution Index (API), primary pollutant and air quality level (Table 2-8).

At SEPA's website, queries can be made to get historical data for a selected city. For the city of Dalian, the data are available from June 5, 2000 when the report first started. Examples of query results for Dalian are listed in Table 2-9. Other information available at SEPA's website includes:

- Background information about API: range, corresponding concentration and health concerns;
- Simple statistics for selected cities and selected period.
- An English version of all the reports and background information;

Table 2-8: Sample Air Quality Report for Selected Chinese Cities

City Name	Date	Pollution Index	Primary Pollutant	Grade
Beijing	2004-06-08	100	PM10	2
Tianjin	2004-06-08	84	PM10	2
Shijiazhuang	2004-06-08	84	PM10	2
Dalian	2004-06-08	72	PM10	2
Taiyuan	2004-06-08	69	PM10	2
Hohhot	2004-06-08	68	PM10	2
Shenyang	2004-06-08	85	PM10	2
Shanghai	2004-06-08	122	PM10	3A
Lhasa	2004-06-08	13	--	1

(Source: SEPA, 2004)

Table 2-9: Query Results of Dalian Air Quality from July 10 to 20, 2003

Date	API	Primary Pollutant	Air Quality Grade	Air Quality Condition
2003-07-20	69	PM10	II	Good
2003-07-19	32	--	I	Excellent
2003-07-18	26	--	I	Excellent
2003-07-17	48	--	I	Excellent
2003-07-16	46	--	I	Excellent
2003-07-15	39	--	I	Excellent
2003-07-14	59	PM10	II	Good
2003-07-13	61	PM10	II	Good
2003-07-12	67	PM10	II	Good

2003-07-11	66	PM10	II	Good
2003-07-10	63	PM10	II	Good

(Source: SEPA, 2004)

Compared with AQI report in the U.S.A and Ontario, the API report in China is rather basic. Without the use of differentiating colors or maps, reporting API in text and table is not very intuitive or impressive. Related information and links for the public are still very limited.

2.4.6 Problems with Current Environmental Data Reporting System in China

There are several problems with the existing internal data reporting system:

1) Lack of effective communication between same level monitoring stations and stations belonging to different administrative jurisdictions. The current reporting system is based on the hierarchical organization of the system itself. The flow of the information is two-directional, up and down. Problems may arise, say, for example, if pollution in a river crossing several administrative districts involves monitoring stations of different levels and municipalities. Accurate analysis of the source and distribution of the pollution may not be possible if the total relevant data are not available.

The sharing of environmental quality data has many advantages over a stand-alone analysis of local data for the obvious reason that pollutants are mobile within air, water and other media. An ideal environmental information system should be a net, i.e. each member in the net should be able to share its data with all other members within the same net system provided the proper management of the system and proper security measures.

2) Low-efficiency reporting. For cities with daily API report, data communication has been much improved in efficiency. For other monitoring stations, the regular reporting frequency is 3 months, i.e. quarterly report to their direct upper level. Considering the levels involved, the real report time from a small town to the National Environmental Monitoring Center is about 4 months, to SEPA around 5months. For cities with automated monitoring

systems the report is due monthly to the central environmental monitoring station and it takes 1 and a half months to reach SEPA (SEPA, 1996a).

3) Lack of openness in its emergency response system. Here emergency includes major pollution accidents and natural disasters that may cause major impacts on the environment. According to the current reporting system, the only formal reporting of emergency is by briefing to local government, upper level monitoring stations and SEPA within 24hours (SEPA, 1996a). Although emergency phone calls are widely used between organizations, such reporting system is not good enough due to its inefficiency to inform the public, other related departments or neighboring counties. Public health and the environment might be endangered, especially when the emergency involves acute toxic pollutants, the deadly results might be irreversible.

2.5 Air Quality Monitoring in Dalian

2.5.1 General Condition of Environment in Dalian

Due to the amazing growth of the economy and the expanding of the city of Dalian since 1990s, environmental quality and monitoring became an important issue for the municipal government and the public. The local government promotes the beautiful and clean environment of Dalian as one of the major attractions for tourists and investment from home and abroad.

In many parts of China, modernization and economic prosperity has been achieved at the price of the environment. Not so much in Dalian, whose natural beauty is still one of its biggest attractions. Historical and exotic architectures, skyscrapers, grassy squares, seaside parks, and fresh air are all within reach in a modern yet well-preserved city.

According to the annual *Report on the State of the Environment in Dalian* (hereafter referred as Report) by the Dalian Environmental Protection Bureau (DLEPB), the general environmental quality of the air, water and noise has been improved from 1990s in Dalian. Drinking water sources are well protected and drinking water is of good quality (DLEPB, 2004).

However, major environmental pollution can still be witnessed in the water and air. From the Report for 2002, water quality in coastal areas suffered pollution from nitrogen and oil, which caused two small-scale red tides*. In some popular seawater swimming places, Ecoli bacteria pollution was still very common; Pollution in some rivers was out of control and major indexes such as COD, and oil exceeded regulation standards in Fuzhou river and Dengsha river. (DLEPB, 2002)

Air pollutants in Dalian came from coal burning in power stations and factories, vehicles and natural dust. Major pollutants include SO_2, NO_2 and PM10. Air pollution was always more serious in winter and spring due to the sandy wind from northwest of the region in these seasons (DLEPB, 2002).

According to SEPA standard (SEPA, 1996b) as discussed in 2.4.3, Dalian classifies its air function into three-class zones. Each class follows its own air pollution standards. The majority of Dalian area falls into Class 2, which follows the standard for residential, commercial, general industrial and mixed area. Coastal water and surface water are classified into five function categories, and seven different standards are set for noise level (DLEPB, 2004).

2.5.2 Environmental Monitoring in Dalian

As introduced in 1.4.3, DLEMC is responsible for environmental monitoring in Dalian District along with several monitoring stations under it. At present nearly 200 items are monitored in air, noise, surface water (rivers and reservoirs), ground water, seawater, soil, and biota. DLEMC collects and analyzes environmental data and/or samples, and regularly reports to DLEPB and Liaoning Provincial Monitoring Center (DLEMC, 2004).

At present, there are 11 automated air-monitoring systems (the last one set up in Wafangdian in Nov, 2002) and around 400 noise-monitoring kits distributed in major

---

* Red tide: An extraordinary bloom of certain algae resulting from eutrophication that causes reddish discoloration of coastal ocean waters.

transportation and residential areas of Dalian, data are linked directly to a database in DLEMC from the monitoring sites. Most monitoring of water quality is still manual, i.e. samples are taken and measurements are made either in situ or at labs. On-line monitoring has also been set up for trial at some major industrial pollution sources for wastewater and smoke discharge (DLEMC, 2004).

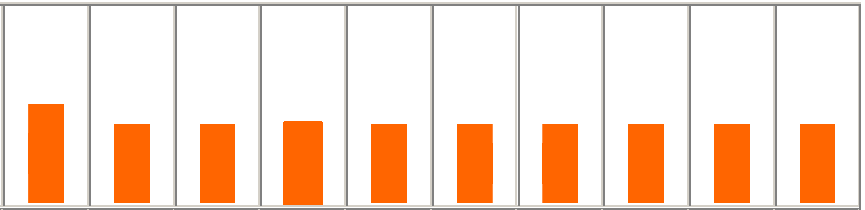
2.5.3 Air Pollution Index Reporting in Dalian

Daily reports of air quality in 10 automatic sites can be found at the website of Dalian Environmental Protection Bureau (DLEPB, 2004). API, primary pollutant and air quality conditions are published, similar to reports at SEPA's website. Historical data for any site can be dated back 10 days. An example of the air quality report (DLEPB, 2004):

2003-07-22 Gan Jinzi

- Air Pollution Index: *50~60*
- Primary pollutant: *PM10*
- Air quality condition: *good*

Table 2-10: A Comparison of API for 10 monitoring sites in Dalian at July 22, 2003

Air Pollution Index										
Site	Gan Jingzi	Zhou Shuizi	Xing Hai #3	Qing Niwa Bridge	Fu Jiazhuang	Qi xianling	Lv Shun	Jin- zhou	Develop-ment zone	Golden Pebble Beach

(Adopted from DLEPB, 2004)

Comparison of API in charts for each site for the current day is also published (Table 2-10). Except for API report, no background information concerning the index or its health concern is given out at DLEPB website. No warning is given out for sensitive groups either.

Lacking of relative knowledge would definitely decrease the effectiveness of reporting itself. The public may only have a general idea by comparing the numbers, but may not be able to get insight knowledge from the website. Historical data over 10 days are not available. Comparison of monthly change or seasonal change would also be impossible for any interested group.

2.6 Comparing of AQI Reporting Systems

Based on the above discussion of four AQI reporting systems in US, Ontario, China SEPA and Dalian, AQI reporting systems were evaluated based on selected criteria: use of differentiating colors, use of map, update frequency, easy of use, availability of background information and historic data, etc. (Table 2-11)

Table 2-11: Comparing of Four Air Quality Index Reporting Systems

	Dalian EPB	**China SEPA**	**Ontario MOE**	**U.S. EPA**
Use of Color to Differentiate air quality level	No	No	Yes	Yes
Use of Map	No	No	Yes	Yes
Update Frequency	Daily	Daily	Daily	Per hour for ozone map
Database Query	No	Yes, simple	Yes, simple	Yes, complex
Background Information	No	Some	OK	Very complete
Related links	No	Almost no	Limited	Very complete
History AQI Availability	10 days	From 2000 if available	From 2003	From 1998 if available; Summary report from 1993
Original Data	No	No	No	Summary report from 1993
Easy of Use	Easy	Easy	Moderate	Complicated
Major Function	Informational	Informational	Informational & Educational	Informational, Educational and Research purpose
Target Group	The public	The public	The public	The public and other interested groups

From the above comparison, it is obvious that US EPA has the most advanced and informative AQI report on the website, where colors and maps are widely used and background information is very complete. Ontario MOE has similar report format to EPA's, except that history data and related links are very limited. On the other side, Dalian EPB can do a lot to improve its AQI report, such as provide enough background information about AQI, and about health concerns of different air quality grades. Colors and maps can be used to make the results more distinct and impressive. SEPA's report provides more data and background information and possibility to do simple queries, but the format of report is rather similar to Dalian's, only using tables, bars and words.

2.7 Use of Air Quality Information

Although air quality indexes are mainly used to inform the public of health related concerns, this timely and understandable information can also be used by NGOs, government agencies and private sectors.

Many individuals voluntarily modify their activities according to the air quality level, especially those sensitive groups that include children, elderly people and people with asthma, chronic lung disease, cardiac illness, etc. People tend to limit their outdoor activities, reduce physical activities or avoid high pollution area. Some individuals will consider air pollution issue while planning for moving (Thom & Ott, 1976).

Besides health concerns, there are many choices citizens can make to help reduce air pollution, such as using energy-efficient appliances, recycling waste, and taking public transit instead of driving. Well-informed citizens will also support and lobby the government to take stricter controls on emissions from factories and vehicles (USEPA, 2004).

Many municipalities are taking measurements to clean the air. Beijing has been replacing coal-burning heating systems with electricity since late 90s (China Youth, 2001). Local government is also in the process of replacing taxis and public transit buses with more efficient, low-polluting models for its "Azure Sky Plan" (Xinhua News Network, 2004).

Air quality problems are also influence public decision-making. Ontario Public Health Association urged the government to phase out coal-fired power plants because of smog, acid rain and concerns with global climate change (OPHA, 2002). Such action would need the federal, provincial and municipal government to work together. The objectives of the suggested action were to:

1) Reduce overall demand for electricity by increasing energy efficiency;

2) Encourage generators directly, and indirectly through consumers, to switch to cleaner fuels and emission-free technologies; and

3) Establish or maintain standards to protect public health and the environment from specific air pollutants emitted from coal-fired power plants in both the local and regional air sheds (Stratos, 2001).

The private sector has also made efforts for many years to look for new energy sources: high efficiency and less pollution. Solar power, hydropower, wind farms and nuclear power are all possible solutions, although each has its own limitations (White, 1993). Cleaner production and better energy efficiency in industrial processes also help reduce emissions. Alternative fuel vehicles (AFVs) powered by electricity, natural gas/propane and alcohol have been designed to reduce petroleum usage and improve air quality (Tompkins, etc. 1998).

To conclude, a well-informed public and society will consider the environmental costs (damages) resulting from its action. Environmental concerns must be incorporated into decision-making processes, into policies and regulations. This is necessary to conserve the environment and in turn the human's benefits in the long run.

2.8 Summary

This chapter reviewed related concepts in environmental monitoring and air quality monitoring. Environmental monitoring systems in China and Dalian were examined in detail together with discussion on existing problems. AQI reporting systems of US EPA, Ontario MOE, China SEPA and Dalian EPB were then assessed to provide a basis for conceptual design. Air Quality information can be used by individuals, government and private sectors to conserve the environment and human's benefits.

In the next chapter literature on Internet GIS technologies are reviewed and some sample sites powered by a leading commercial product (ArcIMS) will be examined.

CHAPTER 3

GIS AND INTERNET GIS

In this chapter, concepts of GIS and Internet GIS are presented, followed by comparison of traditional GIS and Internet GIS. Types of Internet GIS technology and products are reviewed with focus on ArcIMS from ESRI. Finally Internet GIS in China is discussed in terms of current application and problems.

3.1 Geographic Information Systems

Geographic information systems (GIS) are "computer programs for acquiring, storing, interpreting, and displaying spatially organized information" (Green & Bossomaier, 2002), or as Cowen (1988) put it: "a decision support system involving the integration of spatially referenced data in a problem-solving environment."

GIS had its origins in many different disciplines and is characterized by widespread application in many areas including cartography, geological surveys, environmental management, and urban planning. Three major aspects of GIS include cartographic ability, database management, as well as analysis and modeling, which explain the diversity of applications of GIS (Maguire, 1991).

GIS is a relatively new technology starting in the 1960s. After innovation in early years, GIS began its commercialization in the 1980s. Generic GIS products experienced the change from command-line interfaces to graphical user interfaces, from mainframe GIS to desktop GIS, an evolution heavily influenced by the progress of computer technology and Information Technology (IT). The rise and boom of the Internet during the 1990s revolutionized the dissemination of information. GIS has inevitably been influenced in three major areas: data access, spatial information dissemination, and modeling/processing. Distributed GIS and Open GIS[*] conceptions have begun to reshape the development of GIS

---

[*] Open GIS enables and encourages sharing of data, resources, tools, and so forth between different users or applications. The objective of Open GIS, as specified in *Open GIS Guide* is "technology that will enable an application developer to use any geodata and any geoprocessing function or process available on ``the net'' within a single environment and a single work flow." (Open GIS Consortium)

and exploit new possibilities for the GIS industry (Maguire, 1999; Longley etc. 2001; Peng & Tsou, 2003).

3.2 Internet GIS

"Internet GIS is the framework of network-GIS that utilizes the Internet to access remote geographic information and geoprocessing tools" (Peng & Tsou, 2003, p12).

Instead of Internet GIS, other similar terms often used include: on-line GIS, Distributed Geographic Information (DGI), and Web GIS. However, some minor differences exist with the use of these terms. Internet GIS and on-line GIS both refer to the use of the Internet to access remote geographic data and geoprocessing tools; Web GIS specifically refers the use of World Wide Web (WWW), one of the many applications on the Internet; Distributed GIS or DGI has the broadest meaning which includes both wired Internet GIS and wireless mobile GIS (Plewe, 1997; Peng & Tsou, 2003).

3.2.1 History of Internet GIS

The short 'history' of Internet GIS is inseparable from the development of Internet itself. In 1993 Internet growth exploded with the appearance of Mosaic, the first World Wide Web browser supporting multimedia, which was regarded as a significant milestone for the Information Revolution (Thoen, 1999). In the same year, Steve Putz of the Xerox PARC center published the first prototype web-GIS. As an early experiment in interactive web services, the PARC Map Viewer (http://mapweb.parc.Xerox.com/map, no longer maintained) served more than 150 million maps (Longley, 2001). Users without any specialized software or data could view digital maps through a standard web browser with Internet connection. As the pioneer of web-GIS, PARC Map Viewer prompted many GISers to take advantage of the web and inspired major software vendors to develop their Internet GIS software products. By 1996 major vendors, including Autodesk, ESRI, Intergraph and MapInfo, all introduced their first Internet GIS products (Plewe, 1997; Longley etc. 2001).

3.2.2 Traditional GIS vs. Internet GIS or DGI

Traditional GISystem consists of a single software package, plus data on a single machine. This stand-alone model, which lacks software compatibility and networking capability, can no longer meet the requirements of complicated situations, which are often multi-disciplinary, multi-platform, multi-software and multi-user. Internet GIS separates the user interface, data storage and processing, which are normally on a single machine in traditional GIS; thus it is able to provide interoperability, reusability, and flexibility, which are impossible to realize in a stand-alone GIS (Green & Bossomaier 2002). Some advantages of Internet or distributed GIS over traditional mainframe and desktop GIS include:

- World-wide access
- Much more accessibility-easier and faster access expands potential GIS users
- Data, information or service distribution can be anywhere, anytime to desktop computers, laptops, PDAs or cell phones.
- No proprietary GIS products are necessary; people who couldn't afford expensive GIS software can access free data and services or pay a minimum cost;
- Eliminate duplication of data collection and simplify the updating of data and information;
- Able to combine data and information from many different sources including local data
- Improve the efficiency of GIS database management and reduce the cost of GIS database maintenance;

(Plewe, 1997; Green & Bossomaier, 2002; Peng & Tsou, 2003)

Some major differences between traditional and distributed GIS are listed in Table 3-1. Although Internet GIS has many advantages over the traditional model, it is still at an early stage of development. At present it is not possible to provide the same functionality as traditional GIS since analysis functions are still very limited compared with desktop GIS.

Table 3-1: Traditional vs. Distributed GIS

Traditional GIS	Distributed GIS
• Data needs to be gathered separately in large volume and at high cost; • Duplication of effort due to lack of communication and sharing system; • Proprietary GIS software is required for all users; • GIS operations can only be available locally; • Maintaining and updating the information separately costs money and effort. • The cost and availability of GIS data and software limit the potential pool of GIS users	• Data can be published and shared; the overall cost of data collection and maintenance can be largely reduced; • Avoids duplication because of a sharing system; • Patent software is not necessary for all users; • GIS services can be leased, subscribed or purchased through Internet; • Increase the potential volume of available information, distribute the workload, simplify the updating of information; • GIS users are greatly expanded due to the flexibility and lower cost.

(Plewe, 1997; Green & Bossomaier, 2002; Peng & Tsou, 2003)

3.2.3 Types of Internet GIS

Plewe (1997) distinguished types of Distributed Geographic Information (DGI) by characteristics of the sites. In the order of least to most complex to create and use, the DGI applications were classified into 7 types:

- **Raw Data Download**: users must have their own GIS software. GIS work is done off-line with the data downloaded;
- **Static Map Display**: pre-designed maps published in graphic images like GIF, JPEG or PNG format, no interaction with the map;
- **Metadata Search**: simple spatial queries to lookup metadata database;
- **Dynamic Map Browser**: Maps are created ‘on the fly’ according to the scale, location or themes specified by the audience;

- **Data Preprocessor**: similar to raw data download, but with extra data-format processing according to users' requirements; GIS software required;
- **Web-based GIS Query and Analysis**: functions normally available with a desktop GIS: spatial and attributes queries, overlays, buffers etc. Most of the processing will be at server side;
- **Net-savvy GIS Software**: client side is a desktop GIS that can make use of live data from the network. The server only delivers data.

Although Plewe talked about architecture of different services, his classification did not mention the technology behind the DGI applications. The distinctions between some of the types are not very clear. Many sites may have more than one of the above functions. After Plewe's book published in 1997, lots of development and new technology appeared in Internet GIS. Peng and Tsou (2003) described the different types of web mapping in terms of the technology evolution (Figure 3-1).

- **Static Map Publishing**: uses simple Web publishing technology, a two-tier client/server model. Maps are graphic images embedded inside the HTML page. The server can only provide ready-made files. Users have no interaction with the map except clicking. The AQI forecast map at Ontario MOE website is an example (Figure 2-4).
- **Static Web Mapping:** adopts a three-tier model with the help of Web forms and Common Gateway Interface (CGI). Limited interaction such as zoom/pan, simple queries and simple analysis are available. All requests are handled at server-side.Example: the Xerox PARC Map Viewer mentioned in 3.2.2 is the first prototype service. Other usable websites include the Atlas of Canada provided by Natural Resources Canada (http://atlas.gc.ca/site/english/index.html), and the popular MapQuest (http://www.mapquest.com).
- **Interactive Web Mapping:** this is the leading Internet GIS model at present, adopted by most commercial Internet GIS products such as GeoMedia, MapXtreme, ArcIMS etc. It provides most interactions between the user and the geographic objects on the map, much more functionality than Static Web Mapping. At client side, dynamic HTML, plug-ins, Java applets, and ActiveX controls are used to improve

interactivity. While at server side, servelets, ColdFusion and Active Server Page (ASP) are used to extend the capabilities of CGI.

At present the limitations of interactive web mapping include its inability to create new datasets, such as extracting a subset of original data; and the difficulty of updating existing datasets because it normally requires the use of desktop GIS software that creates the datasets in the first place, as the format of the dataset is always linked to a particular patent software.

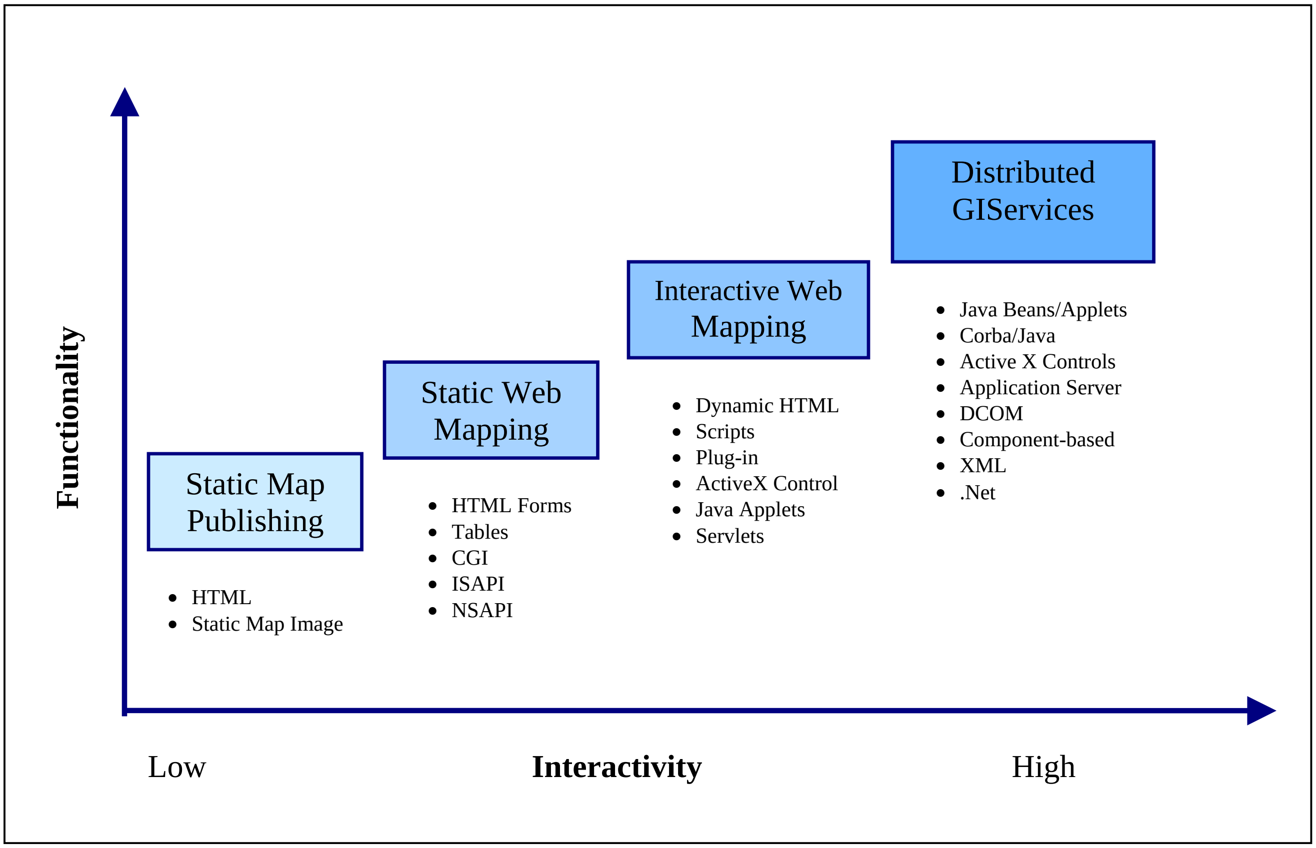


Figure 3-1: Evolution of Distributed GIS

(Source: Peng & Tsou, 2003. p152)

- **Distributed GIServices:** refers to "a specific software framework where GIS components on the Web client side can directly communicate with other GIS components on the server, without going through an HTTP server and CGI-related middleware" (Peng & Tsou, 2003. P.153). A truly distributed GIS is composed of distributed components; the components are mobile, open, interoperable, and searchable; Data are distributed and interchangeable.

"The development of the distributed component shifts the software paradigm from a monolithic, feature-heavy approach to a flexible, modularized, and plug-and-play approach" (Peng & Tsou, 2003: p209). The adoption of distributed GIS will have a significant impact on not only the GIS community, but also other fields that adopt GIS technology and the general public. As pointed out by Peng & Tsou (2003. p208), there are NO distributed GIS products at this time. Distributed GIServices are the next generation of Internet GIS, a future development for the current GIS products.

3.2.3 Internet GIS: Tools and Products

Depending on the users' access to the source code, Internet GIS tools and products can be classified into two categories: open source and proprietary products. The former is also known as " free software", and the latter can be used to denote all commercial software (Working group on Libra Software, 2000).

3.2.3.1 Non-commercial Open Source Tools

Open source requires software to be free redistribution, technology-neutral, provide source code, and with no restriction on other software (Open Source Initiative, 2004). Most non-commercial open source tools are java based. Advanced and popular ones include: Web-Mapper *(http://www.web-mapper.com)*, MapServer (*http://mapserver.gis.umn.edu)*, OpenGL (*http://www.opengl.org)*, and GeoTools (http://www.geotools.org).

These open source tools are normally supported on a wider range of hardware platforms and software environments. They offer more functionality, flexibility and are more scalable compared with current proprietary software. However, they normally need much more technical skill to implement. Developers need to be able to identify other required software components, configure the desired features and compile the application. A thorough understanding of core Web technologies and spatial information management expertise are also quite necessary for developers (Anderson, 2003).

3.2.3.2 Commercial Non-Open Source Products

All major GIS vendors provide their own web GIS products: Intergraph Corp's GeoMedia, MapInfo Corp.'s Map Xtreme, AutoDesk Inc.'s MapGudie, and ESRI's ArcIMS, etc. Although appearing to be similar, these systems are based on "different underlying views of geographic data and technologies". Some of the differences include: "using map prepublishing vs. direct data access; client-level requirements; geographic analysis accessible from the web; and data and platform restrictions" (Limp, 1997). These products are normally easier to implement and do not require as much experience as open source tools. They are more general-purpose tools, the scalability and extension for modification of which is relatively limited. Last but not least, the licensing fee for the proprietary products have to be taken into consideration by any organizations that are interested in developing their own web GIS projects.

3.3 ArcIMS

As mentioned above, ArcIMS from ESRI is one of the leading Internet GIS products on the market. It is used for "delivering dynamic maps and GIS data and services via the Web" (ESRI, 2004a). Due to availability, ArcIMS version 4.0.1 will be used in this thesis work. The following discussion of the architecture and major components will be based on this version of ArcIMS.

3.3.1 Architecture

After early Internet solutions ArcView IMS and MapObject IMS, ESRI developed its newest web-mapping package ArcIMS with much improved performance and stability. A three-tier architecture is implemented in ArcIMS which includes presentation, business logic and data storage tiers (Figure 3-2). The presentation tier is the interface that users can access, analyze and interact with the maps and data. ArcIMS provides three standard viewers, one HTML viewer and two Java viewers. The business logic tier is used for handling requests and administering the ArcIMS site. Four major components are the Web Server, ArcIMS Application server, ArcIMS application server connectors and ArcIMS Spatial Server. The ArcIMS site management applications provide access to components in the business logic tier for authoring maps, administering ArcIMS services and Spatial Servers, and designing Web sites. The data Tier includes data sources available for use with ArcIMS (ESRI, 2003).

3.3.2 ArcIMS Applications

ArcIMS consists of three major applications: Author, Administrator and Designer. Author is used to define the content and appearance for a map that the user wants to publish on the Internet. The outcome from Author is a map configuration file (.AXL file) containing all the definitions of the map layers and symbology. The AXL file is written in ArcXML, an extensible markup language (XML) used specifically for creating Web-based products in ArcIMS (ESRI, 2003; ESRI Virtual Campus, 2004a).

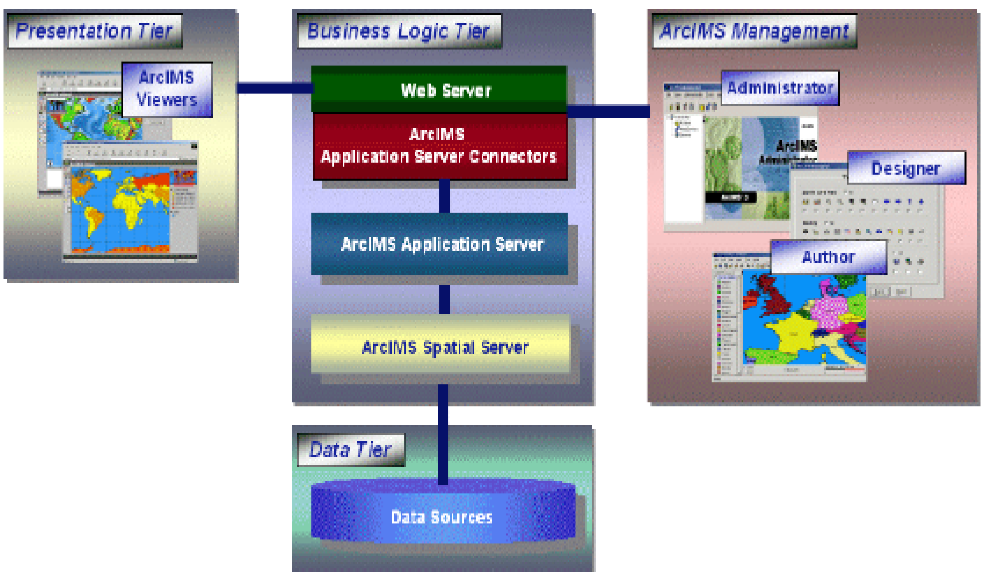


Figure 3-2: ArcIMS Three-Tier Architecture

(Source: ESRI, 2003, p1)

After authoring the map, a map service can be created and started in Administrator. Administrator also manages the website, folders and servers and monitors the performance of the website. The Designer can create websites that allow users to access map services. Either a HTML or a Java viewer can be chosen and tools and functionalities provided at the viewer can be defined at Designer (ESRI Virtual Campus, 2004a).

3.3.3 HTML Viewer vs. Java Viewer

The viewer is the interface that audience will see and use to interact with the map. A major decision to make while creating an ArcIMS application is to choose a proper client viewer. ArcIMS provided three standard viewers that can be generated using ArcIMS Designer: Html Viewer, Java Standard Viewer and Java Custom Viewer. The choice is largely dependent on who is the audience, how much processing will be allowed at the client side, how much time and “trouble” the audience would take to view the map and data. General speaking, Html Viewer has lower requirements at the client side, less functionality and is easier to use. Java Viewer has more functionality and more processing at the client side, but normally requires downloading a plug-in or applet before viewing or interacting with the map (ESRI, 2003; ESRI Virtual Campus, 2004a). The differences between these viewers are listed in Table 3-2.

Other options provided by ArcIMS include building viewers with one of the ArcIMS application server connectors: the ActiveX connector, ColdFusion connector or Java connector. In addition, a free map viewer ArcExplorer can be downloaded from the ESRI website. It can be used on its own with local data sets or as a client to Internet data and map servers (ESRI, 2003).

Table 3-2: Comparing of ArcIMS Standard Viewers

	HTML Viewer	**Java Viewers**
Browser support	Internet Explorer or Netscape version 4.x or higher; Can be embedded into any HTML website;	The Java Custom Viewer is supported only on Internet Explorer version 4.x or higher; The Java Standard Viewer is supported on Netscape and Internet Explorer versions 4.x and higher.

Client side	Little processing, Thin/Light client;	Needs JRE, Java 2 plug-in or applet support; Thick/heavy client; More processing is supported
Server side	Almost all processing	Serve data
Map service support	Only one main image service and an overview map service	Image and/or feature service
Functionality	Less	More, including adding EditNotes, Maptips and MapNotes
Customizable	Highly customizable; code is completely open for developers to edit and customize	Java Standard Viewer: No; Java Custom Viewer: Yes
Able to use local data?	No	Yes
Comments	Efficient and easy to use; Good for general public use	More functionality and complicated; Good for intranet use

(ESRI, 2002a, 2003; ESRI Virtual Campus, 2004a)

3.3.4 Sample Sites of ArcIMS Applications in Environmental Monitoring

Several sample sites powered by ArcIMS were reviewed below. These websites were devoted to different subjects in environmental area with different degrees of customization.

3.3.4.1 Conservation Atlas of Wetlands in the St. Lawrence Valley, Canada

This map viewer (http://carto.qc.ec.gc.ca/website/WetlandsAtlas/viewer.htm) is created by Canadian Wild Life Service to “develop a portrait of the wetlands of the St. Lawrence Valley … in order to favor bird conservation by helping land managers to make decisions about land use and bird habitat conservation” (Canadian Wild Life Service, 2003). This viewer is very similar to the standard HTML viewer. Little customization is performed. It is simple and clear, suitable for general public use (Figure 3-3).

3.3.4.2 OakMapper webGIS

OakMapper (http://kellylab.berkeley.edu/OakMapper/viewer.htm) is used for assessing and monitoring Sudden Oak Death (SOD) in California. The site uses ArcIMS and ArcSDE. With the OakMapper, the audience will be able to (CAMFER, 2003):

- View current distribution of SOD throughout California. Zoom, view, and search monitoring data for SOD in California;
- Perform geographic queries. Data can be viewed and spatially queried by address, county, zip code and congressional district.
- Create a custom map. Selected layers can be exported or printed by the user.
- Log, report, and record occurrences of trees with possible SOD. This website allows submission of the location and condition of trees with symptoms of SOD directly to the database.
- Find education material on SOD. Information sheets, pest alerts, and other educational material about SOD are provided at the web page.

This map viewer has been moderately customized. Tools bars have been added with names and enhanced with new functionality; buttons with links to other related web pages are also added to the viewer (see Figure 3-4). It provides much more information and functionality compared with the standard viewer.

3.3.4.3 Air Quality Monitoring Locations Idaho DEQ

(http://mapserver.deq.state.id.us/Website/emissions/viewer.htm)

Idaho Department of Environmental Quality (DEQ) published their ambient air monitoring sites and data on an ArcIMS powered website. Each monitoring item becomes a separate layer in the map, such as SO_2, O_3 and PM2.5. Queries can be made to acquire location, elevation and monitoring type about each monitoring site. Real time PM 2.5, ozone data and PM2.5 AQI are available at the website (see Figure 3-5). Plus PM2.5 10-day data are also provided in charts.

The only problem found with this website is every time a map is refreshed, it returns to the default setting and customer settings such as scale, selection of active layer or query results will be lost.

The above three examples of ArcIMS applications show different degree of customization, different information and functionality provided at the websites. Ideas can be borrowed during research design for this thesis, such as what kind of information and functionality are normally required at such website, how much difference will customization make to improve the layout and functions of the website, etc.

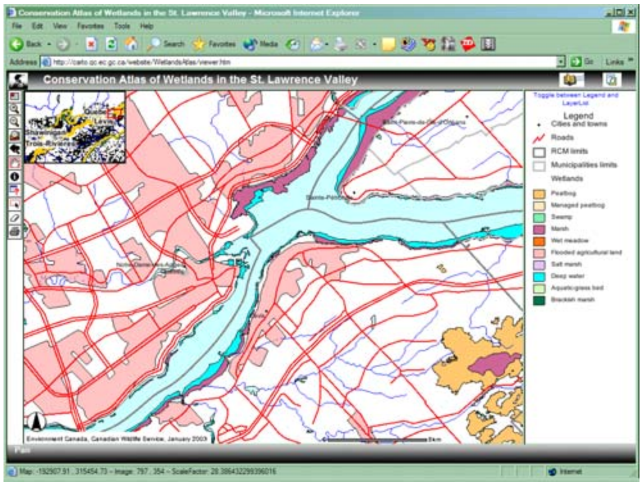


Figure 3-3: Conservation Atlas of Wetlands in the St. Lawrence Valley

(Source: Canadian Wild Life Service, 2003)

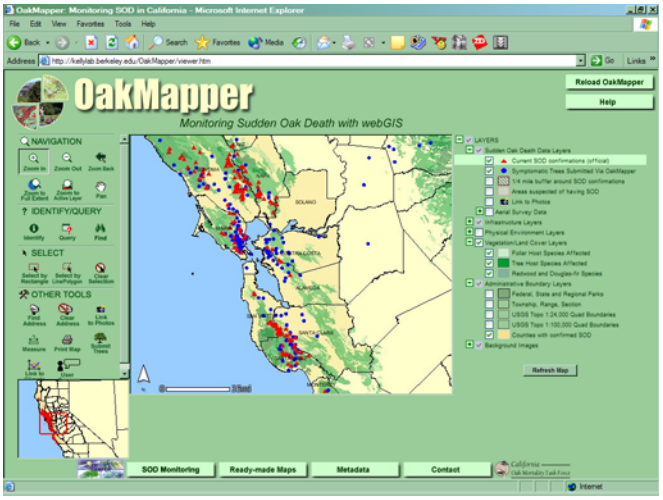


Figure 3-4: OakMapper webGIS

(Source: CAMFER, 2003)

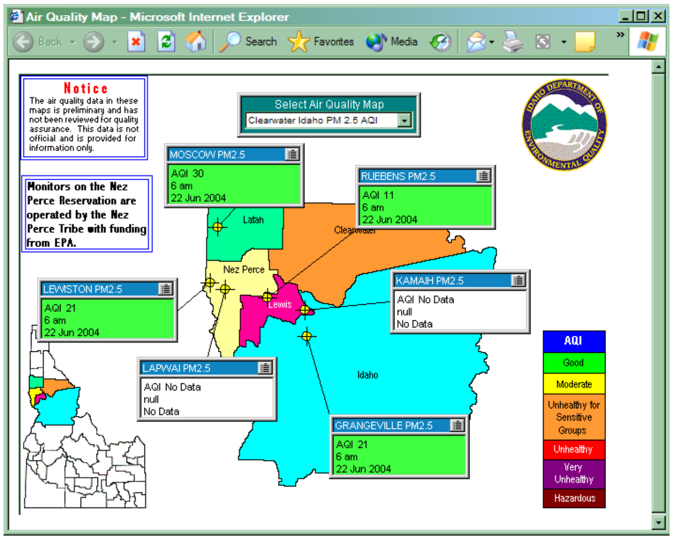


Figure 3-5: Real time PM 2.5 data for Idaho

(Source: DEQ, 2004)

3.4 Internet GIS in China

Research on GIS technology and applications were started in the early 1980s in China, grew rapidly in the 90s and commercialized to certain degree in several areas including basic map production and land management by the end of last century. At present it has been widely applied to resource management, urban planning, transportation, education and many other areas (Cao & Hu, 1999; Kong, 2001).

3.4.1 Internet GIS Applications

Intranet based GIS has been used in some central or local government LAN* (local-area networks) or WAN (wide-area networks), such as the Dalian Environment Management Information System used in DLEPB and DLEMC. These networks are for internal use only and not accessible to the general public.

* **LAN & WAN**: LAN (local- are network) is a computer network that spans a relatively small area. Most LANs are confined to a single building or group of buildings. However, one LAN can be connected to other LANs over any distance via telephone lines and radio waves. A system of LANs connected in this way is called a wide-are-network (WAN). (Jupitermedia Corporation, 2004)

Web-Based GIS is mainly used by big cities in their official website and some commercial websites. Basic functions are for the general public to locate streets, hotels, banks, government agencies and major attractions. Examples are listed in Table 3-3.

Generally speaking, most of these WebGIS sites belong in the static web-mapping category as discussed in 3.2.3. Only limited interaction such as zoom/pan, simple queries are available. Some require downloading a plug-in or Java applet at the client side. This may retard potential users without their own computer, or with slow Internet connections. Because these components normally need authorization to install and may take quite some time to download before the website can be first used.

Table 3-3: Internet GIS Application Samples in China

Service Name	Providing Maps of	Website	Functions	Note
Digital Beijing	Beijing	http://www.digitalbeijing.gov.cn (include an English version)	Static web mapping	Free
SMIWMap	Shanghai	http://smi.stn.sh.cn/webgis/index.htm	Static web mapping	Free
N/A	Guangzhou	http://www.gz33.com/map/	Static web mapping	Free
ChinaQuest	Many cities in China	http://www.chinaquest.com/	Except static web map for many cities, also providing SMS*, WAP**, and PDA*** maps for Shanghai area.	Monthly/Annual fee

3.4.2 Existing Problems for Internet GIS in China

As with many resources on the Internet, Internet GIS relies on an open and data-sharing environment. However, as with many other information systems, GIS in China inevitably faces the major problem of data availability and data sharing. Although the infrastructure of the Internet is well established and the popularity of the Internet is growing

* SMS: ***S**hort **M**essage **S**ervice*, SMS is a service for sending short text messages to mobile phones.

** WAP***: W**ireless **A**pplication **P**rotocol*, a secure specification that allows users to access information instantly via handheld wireless devices such as mobile phones, pagers, two-way radios.

*** PDA: P*ersonal Digital **A**ssistant,* a handheld device that combines computing, telephone/fax, Internet and networking features. (Jupitermedia Corporation, 2004) at a fantastic speed, the geographical information and resources are still very limited in related Chinese websites (Ma, 2001).

Many organizations (most are government agencies) produce their own databases with repeated work in data collection and processing. Although an improved data sharing system would reduce the cost and benefit everybody in the long run, obstacles still remain. The major problems comes from:

- Standardization of data and quality control may increase the cost for data processing and updating for the data producer;
- Lack of a system to realize cost distribution between organizations and users;
- Copyright protection. Lack of related laws and regulation to protect the ownership of data, especially on the Internet.
- Security reasons. Chinese Surveying and Mapping agencies who produce basic geographic maps for China have controls over detailed geographic information for national security concerns.

(Song, 1999; Ma, 2001).

In addition to technical and management problems, coordination between organizations is even more complicated. Data sharing needs people to change their long-term isolation idea of data producing and ownership. People have to realize that only an open and sharing environment could maximize the profit of GIS data and increase the governments' efficiency. Government should play a bigger and more active role in establishing a better data sharing system, as they are the major GIS data producers and users (Kong, 2001).

3.5 Summary

This chapter introduced GIS and its development, Internet GIS and its history. Then traditional and Internet GIS were compared with focus on the benefits of distributed GIS. Types of Internet GIS were reviewed based on two classifications.

Internet tools and products were briefly reviewed followed by detailed introduction of ArcIMS, the software used in this project. The architecture, applications and standard viewers of ArcIMS were carefully examined. After that three ArcIMS sample sites were presented with different degree of customizations. In the end GIS/Internet GIS in China was discussed including current application and problems. The next chapter presents the research design and implementation of the demonstration project in this thesis.

CHAPTER 4

DEVELOPMENT OF AIR QUALITY INFORMATION SERVICE FOR DALIAN

The previous chapter identified available web GIS solutions and reviewed several existing websites that used ArcIMS technologies to publish environmental information. This chapter describes in detail the data, methods and operational design of the air quality monitoring website developed in this thesis. First user needs are identified for the web-GIS application this thesis tries to develop. Next, data used for the research are described, including data sources, data collection and processing and database design. Then the conceptual design of the application is presented followed by the implementation of the demonstration project.

4.1 Identify Needs of Potential Users

Each website, like any product, has its target audience in the market. Different users may have different needs for the data and functionality provided by the website developed for this thesis. There are many ways to classify the audience, such as by professionalism, education/training and purpose of visiting. Depending on the facilities and software in possession, education and previous related experience, the potential users for this development were classified into three major groups: novice, intermediate and advanced users. From novice, intermediate to advanced, users tend to have more experience, background information or education in the related area (GIS and environmental), higher technology devices and facility (computer, Internet connection etc.), and more possibility of access to professional GIS software, more sophisticated requirements of the website (Hedge, 1998).

Advanced users: may be environmental staff or professionals from the government or academia. Most of these users have their own professional GIS and database software. Normally they will need to be able to: perform complex queries based on time, location and other attributes; analyze pollution distribution and trend; and most of them may need to download data and metadata for further analysis at their local computers.

Novice users: many may come from the general public who normally do not have any professional software or experience with GIS, or may even never have heard of GIS. They may simply want to get environmental information from the website on an irregular basis. They may need to do some simple queries depending on their own purpose. They may also want to be able to input their own option, or report an unusual situation. They want the website to be user-friendly, easy to navigate and the map process won't take too much time as many of these users may not have high-speed Internet connections.

Intermediate users: these users are defined in between the environmental staff/professionals and the general public in terms of their interests and involvement. They may have special environmental concern because of their own business, or they may be some environmental conscious group or communities, high school teacher or university students. They may need to extract certain data from the website and produce their own results due to their organizational requirements. Therefore they need to combine the data with their individual methods such as environmental modeling, application of distribution models or environmental risk assessments.

The website designed for this project could not accommodate all the above needs from different users group, at this time it is intended to be more public oriented for the following reasons:

Advanced users normally have easier access to environmental data and professional software that would enable them to perform complicated functionalities at local computers or LAN. At the same time, the functionality provided by current commercial Internet GIS products (such as ArcIMS) is still very limited compared with desktop GIS software. It can hardly provide any complex analysis or process of the spatial data except simply queries, buffers, find and search functions. Even if the project could be able to accommodate their requests at the server side, the time and bandwidth needed to download or wait for the processing may limit the website's popularity. Same as any websites, the speed could be a retard for frequent users.

The major targets of this development are novice or general public users who may not otherwise have much access to environmental data or information. These users may have computers and dial-up Internet connections or even high-speed connections at home, at work place or Internet bars. They have no professional GIS software, not much idea of what GIS is or any related training. As stated in Chapter 1, this website is mainly designed to improve public awareness, to encourage general involvement in environmental quality monitoring and management. It is preferred that the website does not have much limitation on web browsers and does not need plug-ins, applets or any run time environment to scare away its potential users.

Meanwhile, this website may partly accommodate intermediate users by providing them background information, related environmental links, air quality data, some stored queries and summary of history data. But due to the limited data available at present, the website may not be able to satisfy all their needs, for example, to download original air monitoring data instead of AQI.

4.2 Data and Database

Two major types of data are needed for this ArcIMS website publishing air quality data: basic geographic data and daily air quality data for Dalian. Dalian local agencies were contacted for the availability of the required data. Although digital geographic data for Dalian area were ready at Dalian Surveying and Mapping Agency, they had not been obtained for this project for economical reason. Similarly, DLEPB could not provide historical air quality data or original concentration data for free even only for research purpose. Therefore, Internet became the major source of data for this project.

4.2.1 Geographic Data

Most geographic data for the Dalian Area were downloaded from the Internet. Maps downloaded from Sino-Map Press were originally scanned from published paper maps in China. See Table 4-1 for data layers and data sources. Satellite imagery was downloaded from Earth Science Data Interface and was already geo-referenced. Four Landsat Themaitc

Mapper images were processed by a fellow graduate student Kim Sunah to form a mosaic for the Dalian area using PCI Geomatica.

GIS data layers as listed in Table 1 were screen digitized based on downloaded maps in .tiff format, creating several layers in shapefile* format. Shapefiles store vector data and their attributes. These files were all geo-referenced based on Dalian Satellite imagery. Afterwards attribute data were added to the tables. Tools used for data processing included PCI Geomatica (9.0.3), ArcGIS 8.3 (ArcCatalog, ArcMap, ArcToolbox).

Table 4-1: Maps Layers and Sources for Dalian

Data Layer Name	Source
Dalian district boundaries	Sino-Map Press, 2004
Administration	Sino-Map Press, 2004
District centers	Sino-Map Press, 2004
Major Highways	Sino-Map Press, 2004
Key landmarks	Sino-Map Press, 2004
Railway	Sino-Map Press, 2004
Satellite Imagery	Earth Science Data Interface, 2004
Air Monitoring Sites	DLEPB, 2004

For point features like air-monitoring sites, exact locations in coordinates were not available. The points were screen-digitized according to reference map or even estimated so they were only approximate and should not be treated as the exact location (for several sites only the district they belong to were known).

4.2.2 Air Quality Data

Since DLEPB or DLEMC would not provide air quality data, DLEPB website (DLEPB,2004) became the only source for air quality data based on air pollution index. As described in 2.5.3, Air Pollution Index, Primary Pollutant and Air Quality Condition for 10 automatic monitoring sites were published at the website. The data were updated daily and

* Shapefile: is a format created by ESRI to store vector data. Shapefiles can only store one kind of geometry per layer, such as point, line or polygon. One shapefile consists of a minimum of three files: main file (.shp), index file (.shx), and a database file (.dbf).

history data could be dated back for about 10 days. Data collection had been on a continuous basis for half a year in order to gather enough data for demonstration and analysis purpose. Air quality data were copied from the website and stored in Microsoft Excel table for later processing.

4.2.3 Database Design

The database used to store air quality data was Microsoft Access 2000 because of availability and the relative smaller scale of the demonstration project. Air quality data were captured from the DLEPB website, stored in Microsoft Excel spreadsheet first before they were transferred into Access database. The reasons for this process are:

- The original data are published in Chinese characters, which have to be translated into English version first.
- The original data captured have missing or repeated data; modifications are needed before data can be input into working database.
- The format of the original data is not in accordance with the table designed in Access database.
- Excel tables can be easily directly linked to Access tables as long as they satisfy certain conditions.

Two tables were created in Access, *Dalian_Air_Monitoring_Sites* and *Dalian_AirData*. The first table was used to store information about the monitoring sites: ID, name, location and other descriptions if available. The latter was used to store the daily air monitoring data, including the published API range, primary pollutant and air quality grade for each site. Since the original data from Dalian EPB site only contained API that cannot be used for statistical analysis directly, three numerical fields were added to the second table: API_high, API_Low and API_Mid, which represented the daily highest, lowest and median API value respectively. In order to join the table to shapefiles later, an auto-number field called OID was also added to the *Dalian_AirData* table. This was due to the fact that Site_ID alone could not be used as the unique identifier for any record unless a sample data was combined, because one site has one set of air quality data record per day. A one-to-many relationship could be established between two tables based on the common Site_ID field (Figure 4-1). The rationale in designing the database in this way lies in the following points:

- To separate the information for the monitoring sites and the monitoring data so that maintenance and updating are more efficient.
- Less redundant data, which saves space and makes management and queries more efficient.
- A one-to-many relationship makes it possible to query both tables at the same time in Access.

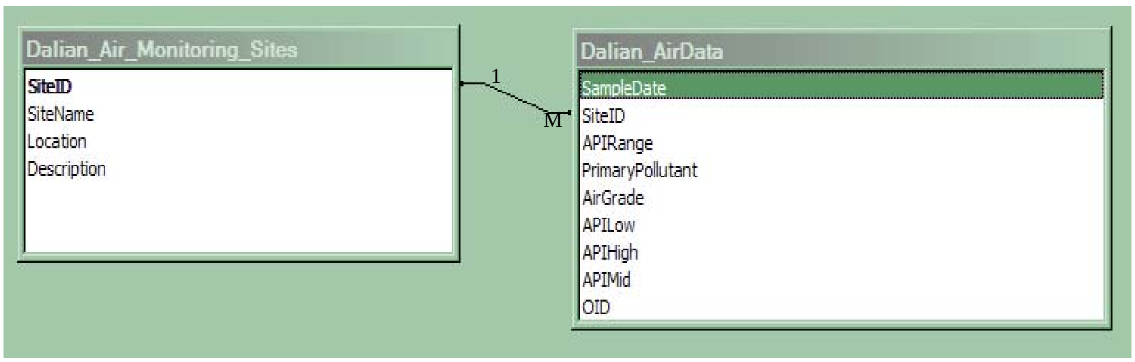


Figure 4-1: Relationship of Two Tables Created in MS Access

4.2.4 Database Query

Some simple queries that can be made to the database include:

- For a certain monitoring site (or sites), query the records within a certain period of time in order to create a subset of data;
- For a certain monitoring site (or sites), query the dates that API exceeds certain limits. Table 4-2 lists the results of a query that has all the records for Site Zhou Shuizi with APILow larger than 80. This query was based on two tables *Dalian_Air_Monitoring_Sites* and *Dalian_AirData*, connected by a one to many relationship.

Table 4-2: Sample Query Results from Access Database-1

APILow> 80 for Site 2 (January-April, 2004)

SiteID	APIRange	APILow	SiteName	SampleDate
2	90-100	90	Zhou Shuizi	1/30/2004
2	90-100	90	Zhou Shuizi	2/1/2004
2	100-120	100	Zhou Shuizi	2/26/2004
2	100-120	100	Zhou Shuizi	3/9/2004
2	120-140	120	Zhou Shuizi	3/10/2004
2	100-120	100	Zhou Shuizi	3/12/2004
2	100-120	100	Zhou Shuizi	3/28/2004
2	90-100	90	Zhou Shuizi	3/29/2004

Summary queries include statistical calculation of maximum, minimum, average API values for a certain site (or sites) for a period of time, e.g. monthly, seasonal or yearly summary. Table 4-3 lists the summary for every site for March 2004. Count represents actual days that have valid API records in the database (There are missing data from the web source). Note this query was only performed on *Dalian_AirData* table alone so site names were not available.

Table 4-3: Sample Query Results from Access Database-2

Summary of API for 10 Sites in March 2004

SITEID	COUNT	MAX	MIN	AVG
1	27	140	60	90
2	27	140	50	83
3	27	140	60	83
4	27	120	50	77
5	27	140	40	71
6	27	120	50	74
7	27	120	50	75
8	27	140	50	76
9	27	140	50	72
10	27	120	40	68

(Note that **MAX** is based on API_high, **MIN** on API_Low and **AVG** on API_Mid respectively.)

4.2.5 Connecting the database to ArcGIS

ArcGIS can work well with Microsoft Excel and Access. For Excel tables it normally requires an Open Database Connectivity (ODBC) connection and sometimes reformatting of the data (Pratt. 2004). It is easier for ArcGIS to work with Access tables. Tables can be accessed directly in ArcMap or ArcCatalog. Joins and relates can be created if the tables have a common field with a shapefile attribute table.

The attribute table for the shapefile *Air Monitoring Sites* can be joined with *Dalian_AirData* or other summary tables based on field Site_ID. Normally a 1: 1 relationship can be used to symbolize or label in ArcView or ArcMap. However, in ArcIMS, joined tables can only be used for labeling, not for symbology. In order to symbolize API values or air quality grades with designed colors in the map, currently these values have to be put into the attribute table of shapefile *Air Monitoring Sites*.

Based on the one to many join, other tools like identify or query can be used to check *Dalian_AirData* table. This makes it possible to provide users with history data linked with any monitoring site in the map viewer.

4.3 Conceptual Design of the Project

4.3.1 Objectives of the Project

Based on previous analysis of the needs from major target user: the general public, the specific objectives of this thesis project are to:

1) Design a Web GIS application based on ArcIMS technology from ESRI;
2) Provide interactive tools for users to view Dalian map layers and air quality data;
3) Provide query tools so that people can check history data;
4) Generate summary tables and graphics to compare data ;
5) Provide users with enough background information and help so that people without special training could use the website and data;
6) Provide information on health concerns related to air quality grades and provide warnings for serious air pollution;

7) Provide links to related environmental agencies to interested organizations and people;
8) Provide feedback channels to make comments or suggestions, which can encourage public communication and participation;
9) Serve as an educational website for teachers and students or anyone interested in environmental issues.

4.3.2 General Organization of the Application

This web-based application consisted of two major parts: a general introduction website *Dalian Environmental Quality Information Guide*, and a map viewer powered by ArcIMS to report and query air quality data named *Dalian Air Quality Data Viewer*. The general website was developed by Microsoft Frontpage; and the map viewer was created using ArcIMS technology and customized with Html, JavaScript and ArcXML. Although the core was the map viewer, the Guide provided background information and supporting material for people interested in related topics in Dalian.

4.3.2.1 Dalian Environmental Quality Information Guide

This Guide was designed to provide comprehensive background information related to environmental quality issues in Dalian for interested users. Major components included introduction to environmental quality of Dalian, introduction to map viewer, report of air quality data, introduction to EcoChina project and links to related websites and data sources. A link to and from the map viewer to this website was provided. First time users are encouraged to browse this website first before using the map viewer as it provides a detailed introduction and instructions to fully understand and utilize the tools and data at map viewer.

4.3.2.2 Dalian Air Quality Data Viewer

This map viewer provided several map layers for Dalian including air quality monitoring sites. Air quality index for each site was symbolized with different colors so that users can easily tell the air quality by viewing the map. The Viewer also provided query tools, hotlinks, and graphics for users to get further information about air quality and its health concerns.

4.3.3 Selection of the Viewer

As discussed in 3.3.3 ArcIMS provides three standard viewers: Html Viewer, Java Standard Viewer and Java Custom Viewer. Based on previous comparison and target user group analysis, Html viewer is chosen for this project. The advantages of Html viewer over Java viewers are:

- Html is the most widely accepted and supported language on the Web;
- Widest browser support;
- Requires the least client-side processing of any of the ArcIMS Viewers;
- Does not require Java 2 plug-in or Applet support as a Java Viewer would;
- Much lighter or thinner client compared with Java Viewer, much less processing at the client side;
- Viewer can be easily and extensively customized;
- Best solution for image service.

All these advantages suit our preference of developing a public-oriented website instead of a professional one. The disadvantages of an Html viewer as listed below will not have much influence on our expectations as most of these lacking abilities are not normally required from a public user, although they are good to have as a plus.

- Can only work with one image service;
- Can’t work with feature service;
- User can’t add local data to the website;
- Does not support EditNotes, MapTips, and MapNotes available in Java Viewer.

4.3.4 Functionality Provided at the Map Website

The Html viewer designed with ArcIMS Designer normally provides following standard functions as listed in Table 4-4. In the customization of Dalian Air Quality Data

Viewer (DAQDV), some unnecessary tools need to be removed and other functions need to be added for this project purpose. The following tools will be disabled at DAQDV site:

- Tools that have repeated function: Pan and Pan One Direction;
- Tools not necessary for this project: Zoom to active layer, Measure, Set Units, Locate Address;
- Tool that is tricky to use: Find. “Find” is case-sensitive. The right input needs the user to have some information about the attribute table of the map layer.

Table 4-4: Tools Available to Html Viewer

Map Viewer:	Query:	Project:
Toggle between TOC list and Legend	Identify	Print
Toggle Overview map	Find	
Previous Extent	Search	
Zoom to Full Extent	Query Builder	
Zoom to Active Layer	Clear All Selection	
Zoom Out	Graphic Selection	
Zoom In	Buffer	
Pan One Direction	Measure	
Pan	Set Units	
	Locate Address	

(Adapted after ESRI, 2002a)

4.3.4.1 Specific Functions Required for Dalian Air Quality Data Viewer

Except for above standard tools and functions, some additional functionality are identified for DAQMV:

- Able to query the Access table (containing AQI values) joined with the Air Monitoring Sites (shapefile) based on 1-1 or 1-M relationship;
- Able to symbolize different air quality range or grades;

- Able to show API comparison with bars for 10 sites each day;
- Set up stored queries to simplify some common queries;
- Provide hotlinks for major cities and zones;
- Provide help on use of the website and available tools and data, clarify conditions on using some of the tools, e.g. tools are only available for the active layer;
- Provide statistical data or summary table for each site;
- Provide health concerns associated with different air quality grade and give warnings if API value exceeds certain threshold.

The above functionalities are based on considerations that the website should be able to provide current data as well as history data; different air quality grades are distinctively symbolized on the map for the viewer; users should be able to query database behind the map; not only data, related information (about API and health concerns) are also provided to the user; enough help should be provided for users without previous experience with GIS tools. The tools and help should be easy and accessible for any user.

4.3.4.2 Selection of Map Symbology

Proper use of symbology is always a powerful way to impress map viewers. Compared with desktop GIS software ArcMap and ArcView, ArcIMS has relatively limited options of symbology. Simple symbology was selected for most map layers to make the map clean and tidy, as the key point was to present air-monitoring sites with symbology related to air quality data. Options are different sizes or colors can be used to symbolize the air-monitoring sites.

To follow the conventions used by US EPA and Ontario MOE (Table 2-2, 2-4), colored symbology was adopted to clarify the difference between API ranges or air quality grades. Furthermore, the size differences in points are subtle in this case and hard to quantify in the human’s eyes, so the results may not as obvious as contrast in colors.

4.4 Implementation of the Demonstration Project

4.4.1 Setting up the Website for General Guide

The website of *Dalian Environmental Quality Information Guide* was created with Microsoft FrontPage 2000. It was designed to share environmental related information for the city of Dalian. For the time being, it is focused on available air quality data.

The web pages were designed with a simple and professional look with easiness to navigate. The style and colors also matched the Map Viewer. Five major contents for this website included:

- Introduction to general environmental quality situation in Dalian;
- Background, introduction and guidance to the map viewer;
- Air Quality Data report and history data;
- Links to major data source for environmental quality data in Dalian and China;
- Introduction to EcoChina project;

A text box as well as contact email is provided for users to input comments and suggestions. However, due to management issues with the server, the text box is not able to work for the time being.

4.4.2 Setting up the ArcIMS Map Viewer

A Standard Html Viewer was set up first using ArcIMS applications. Then modifications were made to both map configuration file and Html website files in order to change layout and add specific functions to this website.

4.4.2.1 Creating Standard Html Map Viewer

As described in 3.3.2, ArcIMS is composed of three major applications to setup and maintain the web-GIS website: Author, Designer and Administrator.

First Author was used to select map layers and define their symbology. Two maps were created for Dalian Air Quality Data Viewer. One was the overview map with two layers only to show locations of air monitoring sites based on Dalian administration; the other map was the main map with all available layers as listed in Table 4-1. The output from Author is map configuration file, or AXL file. This file contains all the definitions made in Author for map content and properties.

Next two map services were created in Administrator based on AXL files from Author. Administrator published the map services on a special server Mithra managed by MAD to host ArcIMS map services. The published map services would then be available on the Internet.

Finally the Html website was created with Designer to view and handle the map service created with Administrator. Using the Html viewer template, a map viewer was created with standard looks and tools provided by ArcIMS.

4.4.2.2 Modifying AXL File

As stated above, AXL is created by ArcIMS Author to define map contents. This file is written in ArcXML, an extensible markup language. AXL files are text files and can be edited with text editor like Notepad, WordPad etc. By modifying the AXL file, the layout of the map can be changed to suit customization needs. The following changes were made in modifying map services for Dalian:

- Add or delete map layers, or change the order of the map layers;
- Change the symbology of map layers;
- Change the labeling for map layers;
- Functions that are difficult or unable to add by Author directly:
    - Add the satellite imagery as a layer;
    - Set up join with two related tables;
    - Modify stored query.

Map layer ‘Air monitoring sites’ was connected through a common Site-ID with the Access table ‘Dalian_Airdata’ which stored all the air quality data. History air quality data could then be identified or queried by users.

Three stored queries were set up in the AXL file. To avoid unnecessary trouble for the users, only queries that require inputting numbers were set up because this function is case-sensitive. Any mistake with spelling or case will result in query failure.

4.4.2.3 Modifying Html Viewer Website Files

In order to satisfy specific needs, customization is needed to the standard Html viewer created with Designer. ArcIMS Html website is composed of a series of files recording and managing the layout and functions of the website. These files can be classified into following categories:

- Html files that define the layout of html frames;
- Image files used in the webpage;
- A special JavaScript parameter file - ArcIMSparam.js. This file stores preferences selected in Designer as well as many other variables that affect the Web site's look and functionality.
- The JavaScript folder contains the HTML viewer JavaScript Library, a series of JavaScript files used to create ArcXML requests and process ArcXML responses from the ArcIMS spatial server (ESRI virtual campus, 2004b).

Customization is possible with most of above files. Major customization falls into following categories (ESRI virtual campus, 2004b):

- Change layout
- Inserting own logo
- Modifying toolbar
- Disabling/Adding functionality
- Changing the graphic look

For this project purpose, html files were modified to change the original html frames layout and colors. New images were added to the webpage through proper indexing. Most of the customization were achieved by modifying JavaScript parameter file: to disable or enable certain tools, change the position and look of north arrow or scale bar, set up hyperlinks for certain layer, show or hide certain fields etc. More advanced customization happened at JavaScript files: to change the alert message after the wrong action from users or to change the response action of a certain button.

4.5 Summary

This chapter first identified and analyzed needs of potential users of the proposed development. Then data and database issues for this project were described. Conceptual design of the project was presented including creating a website as an environmental information guide and developing a customized Html map viewer for Dalian area. Finally implementation of the project was described. Next chapter will present results and discussion based on design and implementation described in this chapter.

CHAPTER 5

RESULTS AND DISCUSSION

Chapter 4 presented the conceptual design and implementation of the demonstration project. An ArcIMS Html map viewer *Dalian Air Quality Data Viewer* was created to publish air quality data for Dalian while a general website *Dalian Environmental Quality Information Guide* was set up to provide background information and related links to environmental quality issues in Dalian. This chapter describes in detail the project and discusses problems in development and use.

5.1 Dalian Environmental Quality Information Guide

The website of *Dalian Environmental Quality Information Guide* (http://www.fes.uwaterloo.ca/u/lshen/) was created to provide general information to Dalian's environmental quality issues as well as instruction to *Dalian Air Quality Data Viewer.* A short introduction to the website was provided at the homepage (Fig. 5-1). The major components and contents of the website included:

- Dalian and its environment: The viewers can get information of Dalian's location, administration and general environmental conditions.
- Useful links: provides websites related to environmental agencies in Dalian and China. Besides links, available data and information with each website is also listed in the webpage.
- Introduction to the Viewer: includes general introduction to the Viewer, air pollution index and health concerns related to air pollution.
- Instruction to the Viewer: provides detailed introduction to map layers and tools provided with the Viewer.
- Air Quality Data: this page was supposed to provide historical air quality data for Dalian. Since the Viewer reports daily air quality data, this web page provides historical daily air quality data by month, as well as monthly summary (including

numbers and charts) for each monitoring site. For demonstration purposes, only data in March 2004 for site 1 is listed.

- EcoPlan China Program: As the funding source for this thesis project, a short introduction is provided to the program including links and major contacts. People who are interested in this project will have the chance to get further information.

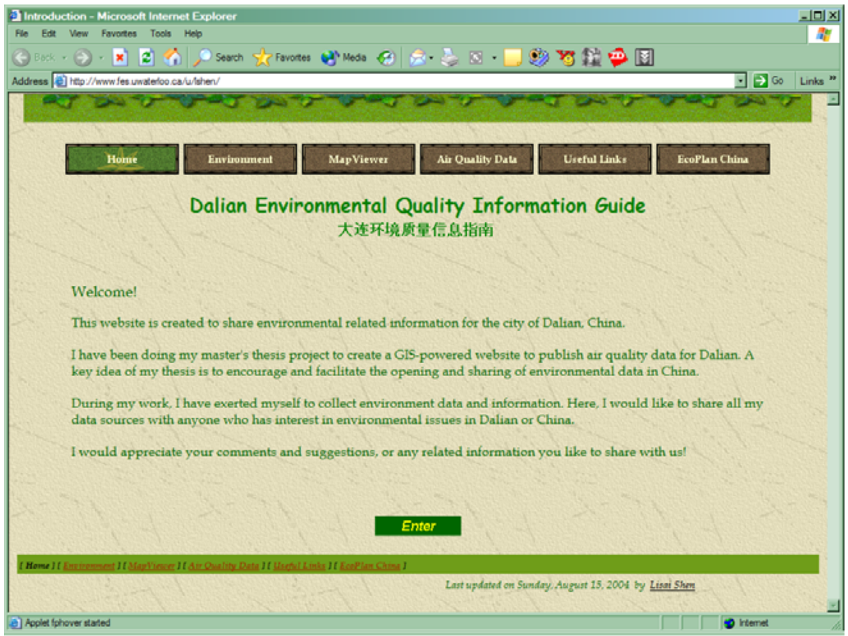


Figure 5-1: Homepage of Dalian Environmental Quality Information Guide

Throughout the web pages, links are provided whenever a related organization is mentioned so that users can easily find the sources of their interested content. This website is not intended to be a complete data depot, nor should it be regarded as so. It serves as a window for people who are interested in air quality issues in Dalian and gives them chance to explore more by providing useful routes.

This website itself could be expanded to incorporate more information, for example, to include other environmental quality data such as water and noise. However, due to the unavailability of other data and time frame for this project, only air quality data is provided.

5.2 Dalian Air Quality Data Viewer

5.2.1 Use of the Viewer

Dalian Air Quality Data Viewer (http://mithra.uwaterloo.ca/website/projects/lshen/dalian/viewer.htm) presents the map of Dalian together with tools to manipulate the map and data (Figure 5-2). In addition to general tools such as zoom in/out, pan, print, users can toggle the overview map, or toggle between map layer list and legend (Table 5-1). Users can follow the link to the Guide website or help documents.

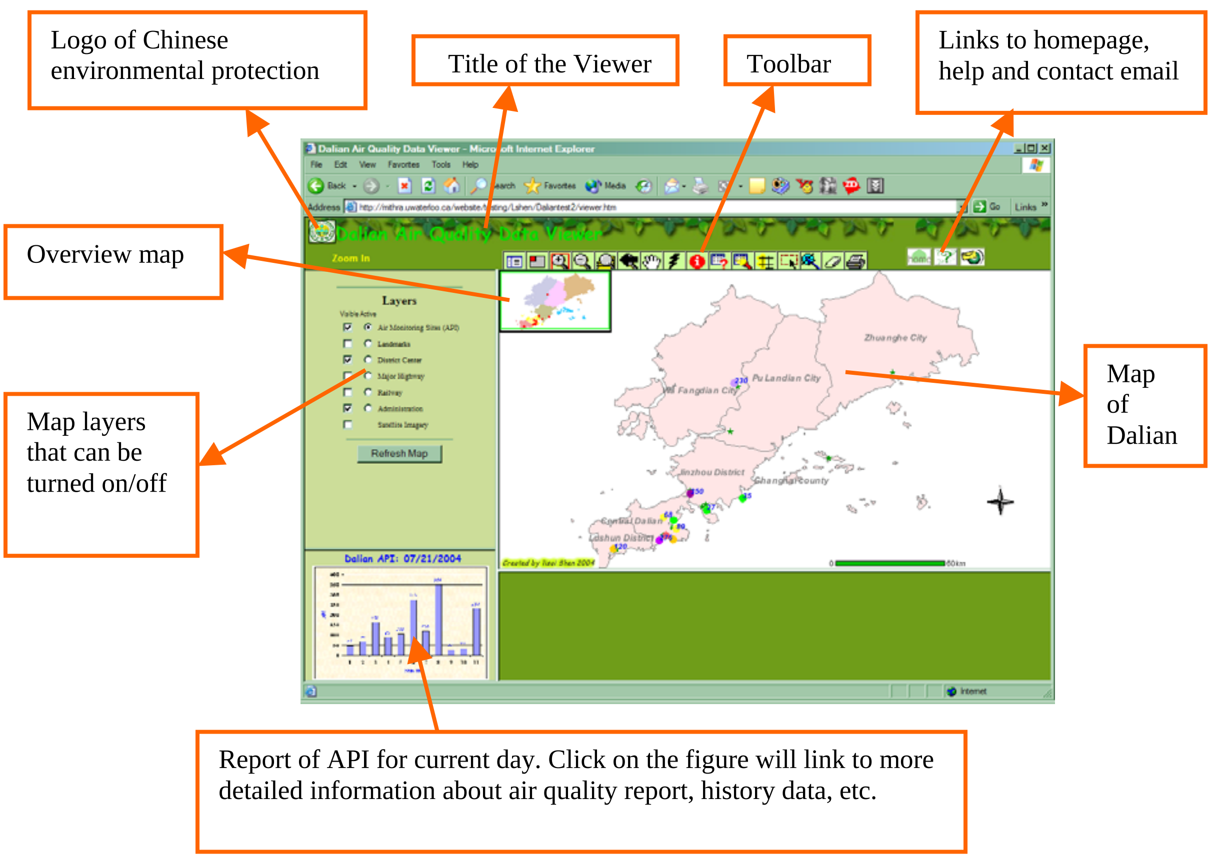


Figure 5-2: Main Components of the Map Viewer

The legend shows the layer name and the symbol used to draw each layer. Only layers visible in a map are listed in the legend. Display the layer list to make map layers visible/invisible and to set an active layer. Use the check box to make a layer visible or invisible on the map. Use selection radio button to make a layer active, only one layer can be active at a time. Note that some tools are based on the active layer, e.g. Find, Buffer, Query, Hyperlink, Select, etc.

The “Identify” tool is very useful when users have questions about any feature in the map; the tool will list the stored attributes for the feature, such as the name for a landmark, area of an administration district. The “Hot link” tool only works for one layer “District Center” because the links are set up only for this layer in the attribute table. It is very easy to expand this property to all other map layers. The “Query”, “Hot link” and “Search” tools only work for the active layer set by the user. Users can fill in single or Boolean query in the form already set by the “Query tool”. History air quality data can be “identified” or “queried” with air monitoring site (Figure 5-3).

Table 5-1: Tools at the Map Viewer and Their Usage

Icon	Tool Name	Usage
	**Toggle Legend**	Toggles between a standard legend and a layer list. The default map view shows the layer list. The user must select the Toggle Legend icon to display the standard legend.
	**Overview Map**	Toggles the overview map off and on. The points on the overview map are locations of 11 automatic air monitoring sites in Dalian
	**Zoom In**	Select this tool and draw a box around your area of interest to zoom most quickly. For slower zooming simply select the tool and click on the map.
	**Zoom Out**	Draw a box with this tool to control zoom distance. A tiny box will zoom out a great distance. A large box will zoom out a small distance. For slower zooming simply select the tool and click on the map.
	**Zoom to Full Extent**	Zooms to the full view of the map.
	**Zoom to Last View**	Zooms to the previous view. Use this instead of the 'Back' button on your browser.
	**Pan**	Drag the map to move to adjacent areas.

	**Hyperlink**	Select and then click on a feature in the active layer to open another window which leads to another website about this feature. For Dalian map viewer, only hyperlinks for the layer "District Centers" are available at present.
	**Identify**	The Identify tool allows you to get attribute information about a feature by clicking on it. Select and then click on a feature to get basic information from its attribute table.
	**Query**	Query attributes of the active layer after filling in the form. Attributes will shown below the map.
	**Search**	Search features of the active layer after filling in requirements in the form. Only works for “Air monitoring sites” layer at present.
	**Buffer**	Create a buffer around a selected feature or features. First select a feature or features from the active layer then click the buffer button. Enter a distance for the buffer and a layer that you want to highlight features from and then click "Buffer". A new map will be returned that shows the buffer and features that fell within it. Check the "Display Attributes" checkbox prior to buffering to get a list of features that fall within the buffer.
	**Select by Rectangle**	Select features on the map by drawing a rectangle. Then attributes of the selected feature at the active layer will be shown below the map.
	**Select by Line/Polygon**	Select features on the map by drawing line and polygon. Then attributes of the selected feature at the active layer will be shown below the map.
	**Clear Selection**	Clears selected features and returns a fresh map.
	**Print**	Click this button, enter a title for your map, and click "Create Print Page". A new browser window will appear with a map layout. Use the print button on your browser to complete the print operation.

The “Search tool” uses stored queries set up in the map configuration file by the developer. Three stored queries have been set up at present including searching for air monitoring sites by inputting site ID number, or finding air monitoring sites with current AQI value “larger than” or “lower than” the value set by the user.

Users can also select features in the map using “select tools” and then “buffer” certain distance around the selected feature(s). This can be used to estimate the approximate distance from a certain monitoring centre or influence area of certain pollution. These tools will be more useful when combined with modeling tools that are not available for this application for the time being.

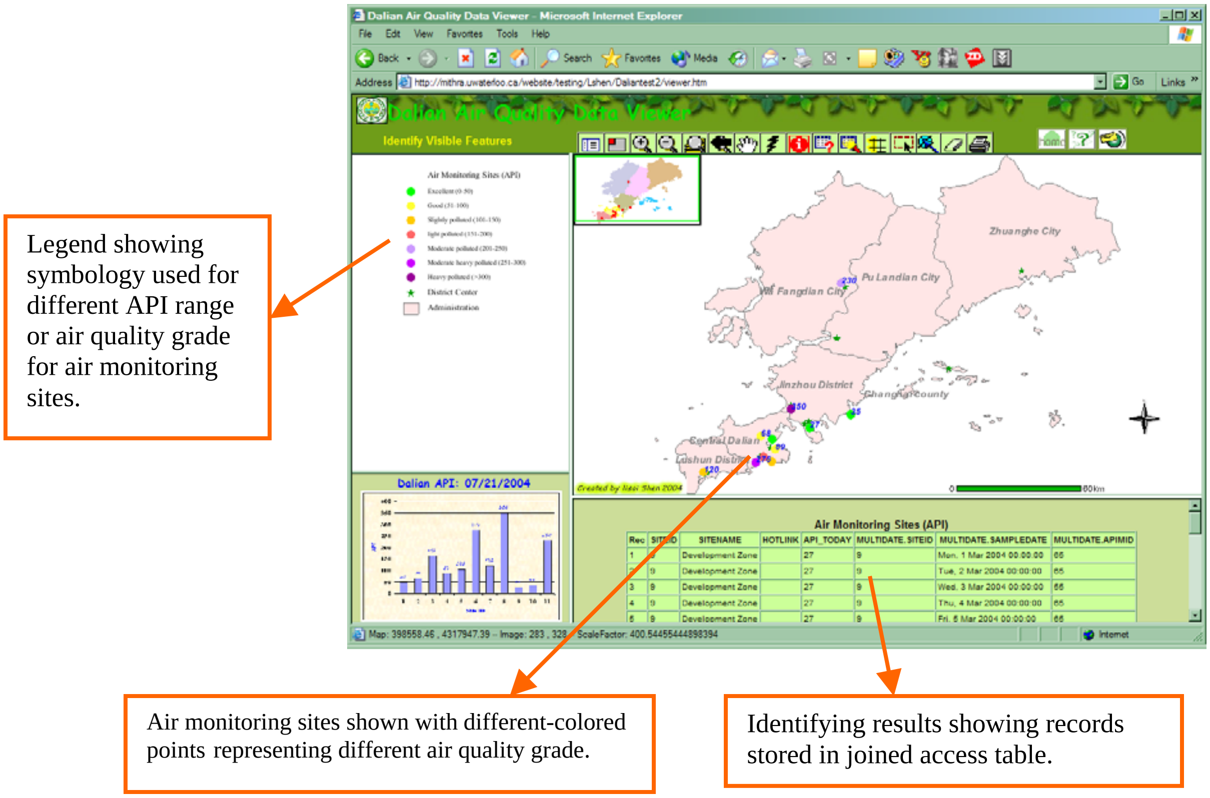


Figure 5-3: Map Viewer Showing Legend and Identifying Results

On the lower left part of the map viewer (Figure 5-2) is the reporting of API for the current day as a bar graph. This was set up to enhance comparison of air quality between different monitoring stations. Qualitative description of air quality in colored symbology is provided as well as quantitative description of API with bar graph. Link behind the bar is a summary report for Dalian area including health warnings. Background information about AQI system and their health concerns published by Chinese government is also provided there.

Most of the tools should not be difficult to follow if the users go through the instruction and use the help files provided at the website. Help message box is provided at occasions when the user doesn't follow the procedure for certain tool or doesn't get the desired results.

Symbology adopted as seen in legend (Figure 5-3) for different API range is similar to that adopted by US EPA because the API systems of the two countries are very similar except that China divided one more class between 200-300 ranges. Similar color system will help to compare air quality between countries. In this project, seven colors were assigned to seven degrees of air quality according to Chinese regulation (Table 5-2).

Table 5-2: Color Symbology Used for API Report for Dalian Map Viewer

API range	Air quality Description	Color Description
0-50	Excellent	Green
51-100	Good	Yellow
101-150	Slightly polluted	Orange
151-200	Lightly polluted	Red
201-250	Moderately polluted	Violet
251-300	Moderate-heavily polluted	Purple
>300	Heavily polluted	Maroon

5.2.2 User Feedback

In order to objectively evaluate the developed website, emails were sent out to 10 potential reviewers who were asked to visit this ArcIMS website and answer designed questions without further instruction. Five feedbacks were received from people with various backgrounds: IT (1), Arts (2), GIS (1) and natural science (1). Except one PhD student in UW who was coming from Dalian, others were all working in Canada. All of them had at least basic computer skills. Most of them had no previous experience with GIS except the one in GIS profession. The evaluation were based on following questions:

1. How much do you understand the website? Do you find it easy to use?
2. Can you find enough help when you feel lost?
3. What problems do you have while using this website?
4. Any improvements you would suggest or any other comments?

All of the subjects thought the website had a good layout and color, and was simple and straightforward to use. They all agreed that the help documentation were quite useful, especially when they had no clue about a tool. People with more general computer skills tended to be more comfortable using the map tools.

From the feedback, it seemed that for people with no previous experience with GIS, it was not easy for them to see what the website was about at first. Using tools was also confusing at first. However, after reading through the background information and help files, all of them seemed to be able to use the tools and play with the data without much difficulty. After practice, everyone seemed to use the website at ease.

Problems reported included some layout change in different resolution. It should be noted to the user that the ideal results for this website is 1024 x 768 for screen resolution. Setting up active layer and layer visibility seemed to be confusing for most users. Many map tools (such as query, buffer etc) can only be used with the active layer. Although these functions are regular GIS and explained in the help file, it is hard to catch on by first time users.

The reviewers also gave back good suggestions to improve the website. Some common ones are listed below:

1. Help info and function can be improved. It would be nice to add tutorials/examples, or to display relevant help based on the current context, so that users do not need to go through the whole instruction and help page for a single question.

To implement first suggestion, one simple way is to make a tutorial with screen captures showing the use of different tools, however, this kind of help information is not flexible or takes time to go through. A better solution might be to provide help with screen-tip. Users can get help document while pointing to a certain tool and help will disappear after mouse moves away. This is flexible and convenient.

2. Highlight selected items on the map when using Identify tools.

This should be able to implement by modifying ArcIMS website files.

3. A Chinese version of the website or at least for the names. Use more pictures of Dalian in background introduction part.

A Chinese version of ArcIMS website is possible once a Chinese version of the software is available. As to pictures, environmental related subjects such as monitoring sites, sand storm or major emission sources can be very complimentary to the websites.

5.3 Discussion on Customization of ArcIMS Html Viewer

As described in 4.4, the map configuration file (AXL file) and the Html Viewer Website Files were modified in order to meet the special needs of this project. The focus of this discussion will be: how easy or difficult is the customization? What are the major problems encountered? Can customization meet all the expected requirements of the project?

AXL is a well-structured file that is relatively easy to modify even for people without much programming experience. By referencing *ArcXML Programmer's Reference Guide* (ESRI, 2002b), jobs like changing the symbology for a map layer should not be a major problem. Setting up stored queries and labeling with joined table would require more study of the syntax and samples provided in the guide.

A major advantage of using a map instead of mere numbers or words is that it can symbolize differences of certain attribute varied by locations. In this project it was expected that different air quality (or API range) could be distinctly symbolized for air-monitoring sites in Dalian. However, it was learned from the ESRI technical support center (ESRI, 2004a) that, at present, ArcIMS 4 is not able to symbolize the map based on data in a joined table. The only solution at this moment would be to store the data used for symbology in the attribute table of monitoring sites, which meant the shapefile's attribute table would also need daily updating. It was an unwillingly change with the original design of separating the air quality data with the air monitoring sites for easy maintenance and updating purpose.

A major bug found with the viewer was when using the query tool; it was not always able to retrieve all the sample values for the users to choose. It works well with most layers. For some fields in a certain layer (such as air-monitoring-sites), it could only retrieve first one or two values for SiteID or SiteName, while it was able to retrieve all the sample date from the joined table. Reasons haven't been determined for this unusual behavior.

Compared with AXL file, modifying of JavaScript files were relatively difficult and tricky. Although *Customizing ArcIMS: HTMLViewer* (ESRI, 2002c) listed JavaScript Library for assistance, it would still take a lot of time to search and modify a single function. Sometimes several files have to be modified in order to change one function.

Overall ArcIMS 4 cannot totally meet the expectations of this project. Symbology and connection with outside tables are the two major disadvantages with its current version. Query function is still limited, as it does not provide any statistical function. The difficulty of customizing largely depends on the experience of the developer. Previous programming skills are a big plus in developing such projects.

5.4 Data and Database Issues

5.4.1 Data Source and Data Acquiring

Most of the data used for this project purpose were collected from the Internet. Two major issues exist with the data: quality and lack of metadata, especially for geographic data. Although for the demonstration project the available data will do most of the work for the time being, higher map quality with detailed information, such as street network and river system, will definitely improve the value of this project. Although good quality geographic data and sources are known to exist in Dalian, the cost has been the major obstacle for acquiring the data for the present.

As to the daily air quality data collected from the Dalian EPB website, the data still have problems of missing or repeating although from a reliable data source. To formally set up this reporting system, a constant co-operation relationship should be maintained with DLEPB and DLEMC, as the latter is the real data collector and processor. The current way of collecting data involves copying, pasting, translation, reformatting etc, which is very time-consuming. It would be preferred to set up an automatic program to "grab" the data every day and put it into the Access database.

5.4.2 Data Updating issue

In order to keep the data up-to-date at the website, daily updating is necessary. First, current air quality data should be added to *Dalian_Airdata* table in the Access database and the shapefile *Dalian_Air_Monitoring_Sites* everyday. API values in the shapefile need to be replaced with current data so that the symbology in the map can the refreshed. Updating the shapefile will need the use of ArcMap or ArcView. ArcView is able to updating shapefiles without stopping the connected map services while ArcMap can't do that.

Second, the bar graph showing current API values for 10 sites as well as verbal report in the map viewer also needs updating everyday. At present, the bar is created with Excel and copying to the html frame. Efforts are still under way to extract data from the attribute table dynamically and create the new bar graph automatically.

Furthermore, at the general guide website where summary and history data are provided, at least a monthly update is necessary to provide a summary of air quality for the past month. This summary is actually done in Access with query functions. The query results can then be exported to a .dbf file and inserted into the html web page.

5.5 Website Maintenance and Updating Issues

At present, the website *Dalian Environmental Quality Information Guide* and the Viewer are located on two different FES servers. The website is on a general-purpose server that can host graduate students' websites. The Viewer, which needs ArcIMS license to run at the server side, sits on a special server managed by the GIS specialist at Mapping, Analysis and Design (MAD). Map files and data that support the map viewer are stored in personal storage place provided by MAD. With data scattered in several places, maintenance and updating has become an issue, especially at the end of each term when MAD renovates the computing facilities and empty personal storage.

Updating the general guide website is relatively easy. It only needs the access to any webpage building tool (Dream Weaver or MS FrontPage) to do the modifying then upload it to the server from any computer with Internet access. However, modifying the map viewer will need to use the limited computers in ES with ArcIMS installed.

Although the problems mentioned above only relate to this project, experience can be learnt for those interested in setting up a similar website: where to store the data, who is responsible for maintenance and updating, do you have the authorization needed to access the server, can you afford to get software license for patent products like ArcIMS and ArcView.

5.6 Accessibility and Performance Issues

The ArcIMS application developed was based on HTML, without ActiveX or Java components. This means that anyone with any type of computer (PC, MAC) could be a potential user of our website.

Due to the server-side processing of data, network speed and bandwidth is certainly a bottleneck to web-GIS applications. The performance of the website will largely rely on the network connection as well as the server, with the former largely uncontrollable. It is important for the service provider to consider the amount of time it will take to refresh the map after each operation by the user.

This thesis didn't discuss the installation and maintenance of ArcIMS servers, website performance-tuning as these tasks were handled by GIS specialist in MAD and running of the ArcIMS server is largely at its trial stage with MAD.

5.7 Summary

This chapter described the results derived from the implementation of the conceptual design and operational methodology discussed in chapter 4. The use and functions of the development were introduced together with problems encountered. Then issues regarding data acquiring, data updating and website maintenance were discussed.

The developed project has met most of expectations although some limitations still exist due to the capability of the software and experience of the developer. Users feedback showed that although people with no previous GIS experience may have problem with the ArcIMS website at first, the background introduction and help file will help them use the tools and data at ease after practice. Help function is expected to be improved and enhanced for use by the general public.

Based on these results, Chapter 6 presents the conclusions of the thesis. A review of the overall effectiveness of the project is discussed along with some recommendations for future research.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter provides a synopsis of central arguments presented in this thesis and outlines the conclusions derived from the results obtained. Recommendations for future research and enhancement of the current project are presented as well as recommendations on extending of the use such Internet GIS solutions.

6.1 A Synopsis of the Thesis

In Chapter 1 problems identified with current environmental management system in China include:

- Environmental quality data not adequately used because of constraints on access and data sharing;
- The public and interested groups lack access to environmental data and information;
- Public environmental education and participation is at a relatively lower level.

Chapter 2 introduced air monitoring and reporting in China and Dalian, compared air quality reporting systems of USEPA, Ontario MOE, China SEPA and Dalian in terms of easy of use, data availability, functionality and use of interactive tools. Limitations of current air quality reporting system in Dalian were evaluated.

Chapter 3 reviewed web-GIS technology, available products with focus on ArcIMS and sample websites. Current status of Internet GIS applications in China was examined with discussion of existing problem.

Chapter 4 described the whole procedure of the project development. Starting from analyzing the user needs, describing the data and database design, then conceptual design and implementation of the project was presented.

Chapter 5 presented the results of the development including discussion of functions, limitations as well as users' feedbacks on using of the developed website.

6.2 Thesis Conclusions

Conclusions from the thesis are presented in two sections, including the overall achievement of the thesis and a critique of ArcIMS for publishing environmental data.

6.2.1 Achievements of the Thesis

Internet GIS is new and fast growing while air quality monitoring and reporting has been going on for decades. The Internet has brought changes to almost every corner of our life as we never imagined before. This thesis approached the environmental data reporting and sharing problem by using the current Internet GIS technology that would enable public access to the environmental quality data by interactive map operation, online help and comprehensive background information. Serving both as a reporting and an educational website, this website is expected to increase public awareness of environmental issues and improve their responsibilities to their own living environment. Not only in fast growing cities like Dalian, there are millions of Internet users who can be expected to benefit from this kind of website in China.

Technology alone is never a decisive factor in the advancing of society. However, modern technology like Internet GIS provides an easy and inexpensive way for the public to access and share environmental information with the widespread of Internet use. It helps to improve public participation in environmental issues and therefore push the government to provide more information and data to the public. The benign circle will improve the environmental management and environmental quality in the long run. Besides public awareness, the availability of environmental quality data is also expected to help planning process and decision-making for both the government and private sector.

6.2.2 ArcIMS for Publishing Environmental Data Purpose

Generally speaking, Internet GIS is a great tool for publishing environmental quality data purpose, because it is intuitive, interactive and timely. Environmental data are dynamic and spatially distributed that GIS can be best employed to express. As a leading Internet GIS product, ArcIMS 4.0.1 was adopted in the project. The Html Viewer was easy to set up and could meet most of the basic needs such as zoom, search, identify features in a map or make simple queries. External data such as historical environmental data in an Access table can be joined to a shapfile and be checked by the user.

However, at this version, ArcIMS is still a ‘viewer’ without typical GIS analysis functions available in desktop GIS. The user is not able to extract new dataset, implement complex query or produce summary or statistical report at the standard viewer. Analysis functions that are very useful for environmental analysis and modeling purpose are not available yet. For example, ArcIMS is not able to perform kriging to interpolate surface from points.

For the image server, the symbology is very limited and it is not able to symbolize features based on attributes in joined tables. Although the extension ArcMap server might be able to provide more options for symbology and better cartographic quality, it does not support attribute tables or relationships (ESRI, 2004b).

Another disadvantage of ArcIMS is its inability to link with external tables directly. Since the Access database is not directly linked to the map service in this project, data maintenance and updating becomes an issue. Compared with shapefiles, geodatabase might be a better choice for organizing data for this project because it is a DBMS standards-based physical data store that supports both personal and multi-user DBMSs. However, ArcIMS image server is not able to support geodatabase feature classes yet (ESRI: 2004b).

Although extensive customization will improve the interactivity and functionality provided at ArcIMS website, it will require experience of the developers or costly consulting services.

6.3 Future Enhancement

This GIS powered website used for publishing air quality data can be enhanced in many ways depending on the availability of data and requirements of the user.

First is to increase available data and information. Detailed land cover and land use data, zoning data can be incorporated as the background information to improve the overall assessment of the air quality. For air quality management and reporting purposes, emission sources are an important part that has not been discussed much in this thesis. Due to the spatial distribution of emission sources, point sources such as industrial and commercial sources can be easily incorporated into this reporting system similar to air monitoring stations. However, mobile sources such as automobiles or line sources, which are composed of transportation network, might need different database structures and analysis tools.

Besides air quality data, reporting of water quality, noise and other environmental quality data can also be incorporated into this website. Water and road systems data will be needed to add to the map dataset. Depending on how to handle the pollution source (as point, line or area source), similar or different database system and analytical tools may be adopted. Except for technological enhancement, the major issue might be to get permission and to acquire the data from relevant government agencies, as local government has not openly published most of these data before.

Second is to change many manual steps into automatic functions. Many of the steps in maintaining and updating the website can be turned into standard procedures with proper programming, such as data capture, updating of data, charts and tables.

Third is to improve interactivity and functionality. Because of the thin client design, Html Viewer as adopted in this project has relatively fewer functionalities and interactivity. To improve those features, a parallel thicker client can be developed for more experienced and professional users. Java viewer can be adopted which requires Java 2 applet to process data at the client side. Users can render map and query data without going through the server, which means waiting for data transfer every time to refresh the map. Users can also combine local data with the streamed feature data from the server and then use desktop GIS tools to further analyse the data. With the same dataset, different users can choose to use different viewers (thin or thick) based on their needs, facility and experience.

Fourth is to improve help function at the website as required by user feedback. Tutorials/examples can be added to explain the use of tools. Relevant help based on the current context can be displayed for the users so that they don’t need to go through the whole help documentation.

Last but not least is to improve the link of ArcIMS to external database. This in fact is a big issue facing Web GIS providers because of “lacking integration among databases and GISs to enable real-time data processing” (Kolodziej, 2002). Many times the users will need to search and report on the external database, which is not easy from the standard viewer. Solutions include doing some programming by internal staff or consulting companies, or choosing some software products that support linking databases to ArcIMS. Freeance from TDC Group, Rapid Integration Toolkit from Taylor Technologies are examples of such products that declare to “enable nonprogrammers to easily construct professional mapping applications using enterprise databases integrated with map features on an IMS Web platform”, “allowing end-users to search and report on mapping and enterprise databases form a Web platform” (TDC Group, 2004. Taylor Technologies, 2004)

6.4 Recommendations

For people and organizations interested in providing Internet GIS services, a review and investigation of open source tools as mentioned in Chapter 3.2.3.2 is encouraged as these tools offer more flexibility and scalability. And as no cost is associated with the use of software, it is an economical solution for organizations with experienced developers and lower labour costs such as in China.

And since China already has 84 cities to report air quality, these cities can set up their own web GIS website to report local air quality and other environmental data to the public. Meanwhile SEPA can set up a national map service reporting for all the cities with air quality data. The public can easily compare air quality in cities across the country.

With the widespread and frequent use of mobile phones in China, reporting of air quality and health warnings to the mobile phones users through text message and pictures would be a good way to increase the target audience, maybe even greater than the Internet user. The use of mobile GIS in fieldwork and location based services has already become a hot spot for GIS application. Considering China’s large population, personalized mobile GIS service can be another good media to publish environmental quality data.

APPENDIX

A. Satellite Imagery for Dalian Area: Summary of Metadata.

IMAGERY ID	040225	040226	040280	040281
SPACECRAFT_ID				
SENSOR_ID	ETM+			
DATA ATTRIBUTES	Orthorectified			
DATA FORMATS	GeoTiff			
ACQUISITION_DATE	2001-08-11	2002-06-11	2001-09-03	2000-06-12
WRS_PATH	119	119	120	120
WRS_ROW	032	033	032	033
MAP_PROJECTION	UTM			
REFERENCE_DATUM	WGS84			

Detailed metadata can be further checked at Earth Science Data Interface (http://glcfapp.umiacs.umd.edu)

B. Further Discussion - Adoption of Advanced Air Quality Management System and DGIS in China

To improve the overall air quality reporting in China, an advanced air quality management system is needed as reporting is only part of an integrated air quality management system. This kind of integrated system should be able to adopt the modern relational database management system and the distributed geographic information system, because of the multi-spatial scales and multi-temporal characteristics of the domain (Fedra, 2000):

- Air pollution is dynamic and spatially distributed with multi spatial scales;
- Emission sources are distributed or even mobile;
- Multiple source and type of data involved: air quality data, emission inventory, geographical data and meteorological data, etc.

The trend towards managing such a complex problem domain has shifted from authoritarian and technocratic method to participatory decision-making. " The free and open access to this information, has become an important element in the political process" (Fedra, 2000, pp244).

For internal environmental data sharing and reporting in China, an open and interoperable distributed GIS is recommended instead of interactive web mapping as developed in this thesis because of its obvious advantages (Peng & Tsou, 2003):

- GIS components can be easily integrated with other programs;
- Components are distributed, mobile, open and interoperable. Anyone can contribute to the system and benefit from others once they obey the standards;
- Data are distributed and are interchangeable. Authorized users can access any data located anywhere on the Internet. Data from different sources can be integrated.

"An open or interoperable system …is a virtual system or a repository of distributed GIS providers that comply with the same standards. ... all systems will support the same protocol so that they can communicate with each other" (Peng & Tsou, 2003: p221). This open distributed system can incorporate unlimited participating system services and data providers. The catalogue service helps the user to search any available data and services within the system. Using such a system, different government departments can easily share data without considering their location or administration level. Time lag in data reporting will no longer be a problem as any authorized user can get the most up-to-data data. The communications will always be in time. Maintenance is easy as each department only has to update his own database as opposed to updating every copy sent out. Besides, the environmental departments, any data and service providers adopting same rule and standards can share their products.

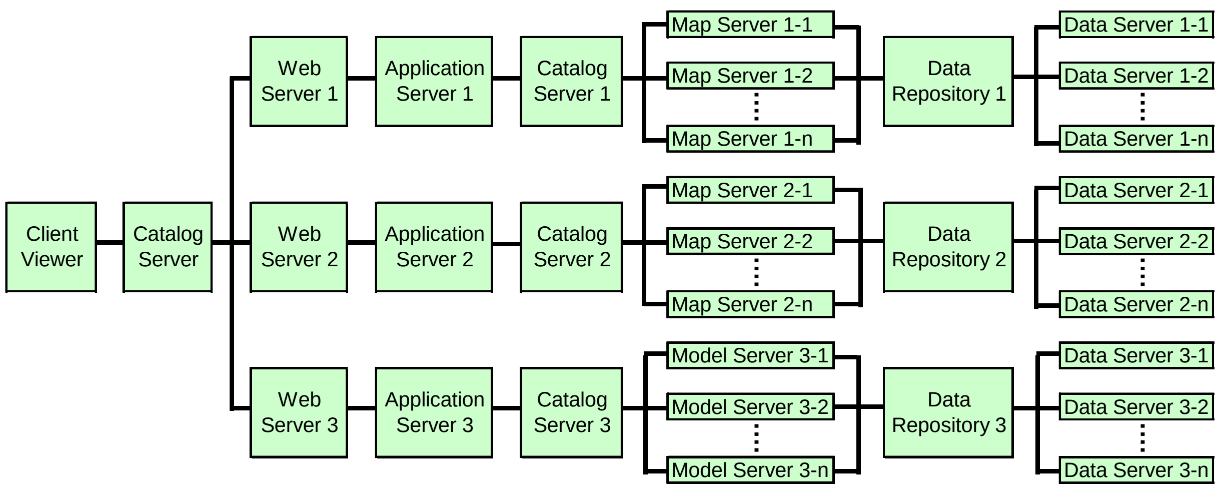


Figure: Architecture Model for An Interoperable Distributed GIS

(Adapted from Peng & Tsou, 2003, p222)

At the clients' side, a user can access and utilize data and GIS component services from any Web site. For example, the user can retrieve meteorological information from site A, land use information from site B, air quality data from site C, GIS analysis tools from site D or modeling tools from site E. The retrieved data and analysis or modeling tool components can be integrated and displayed at one client. The users can not only display information, choose the map rendering, make queries, but also can be authorized to edit and manage data. This is especially useful for environmental fieldwork (Peng & Tsou, 2003).

Different environmental models can also be incorporated into the system as modular and flexible tools. These component models may include emission, photochemical, exposure, meteorological, and health effects models and can be widely used as planning, prediction and decision-support tools (Fedra, 2000; Moussiopoulos, N. 2003).

The adoption of a distributed GIS in environmental management system will allow GIS components to merge with environmental programs and models. The open and independent components can promote the sharing and reporting of widely distributed environmental data. At present, industry standards for distributed GIS are still under construction by OGC and the Technical Committee tasked by the ISO (ISO/TC 211) (Peng & Tsou, 2003, pp257). These new standards are not only changing the whole GIS world, but also influence wide variety of areas that GIS has been applied such as environmental monitoring and management.

BIBLIOGRAPHY

Air Risk Center, US EPA, 1991. Air Pollution and Health Risk - EPA 450/3-90-022. URL: http://www.epa.gov/oar/oaqps/air_risc/3_90_022.html

AirNow, USEPA, 2004. URL: http://www.epa.gov/airnow

Anderson, G., 2003. The Door Opens for Open-Source GIS. GEO World, V. 17 (6)

Aronoff, Stan., 1989. Geographic Information Systems: A management Perspective. WDL Publications. Ottawa, Canada

Bahr H. & Vogtel T (Edt), 1999. GIS for Envrionmental Monitoring. Stuttgart: Schweizerbart

Bates, D. V. & Caton, R.B., 2002. A Citizen's Guide to Air Pollution. 2nd Ed. David Suzuki Foundation, Vancouver

Bitzos, M., Sep 2004. Email Contents from Air Quality Analysis & Reporting, Environmental Monitoring & Reporting Branch, Ontario Ministry of the Environment.

Canadian Wild Life Service, Environmental Canada, 2003. URL: http://carto.qc.ec.gc.ca/website/WetlandsAtlas/viewer.htm

University of California's Center for the Assessment and Monitoring of Forest and Environmental Resources (CAMFER), 2003. URL: http://kellylab.berkeley.edu/OakMapper/viewer.htm

Cao Y. & Hu G., 1999. Current Status of GIS Application in China and Abroad. Computer And Modernization. V. 61 (3)

Chen, S. & Zhong, E., 1998. Perspectives on GIS Development in China. 2nd Annual GIS Infrastructure Planning and Management Conference. Beijing, China

China Youth, 2001. Phase Out Coal Heating in Beijing to Reduce Air Pollution. June 19, 2001. from www.news.sohu.com

Clench-Aas, J. etc., 1999. Air Pollution Exposure Monitoring and Estimating. J. Envireonmental Monitoring. 1999, 1, p 313-319.

Cowen D. J., 1988. GIS versus CAD versus DBMS: what are the differences? Photogrammetric Engineering and Remote Sensinng 54: p 1551-4

Crognale G. (Edt), 1999 Environmental Management Strategies: the 21st Century Perspective. Chapter 11, Effective Risk Management and Communication: Tips on Working with the Public. New Jersey: Prentice Hall.

Dalian Environmental Monitoring Center (DLEMC), 2004. URL: www.dlemc.gov.cn

Dalian Environmental Protection Bureau (DLEPB), 2004. URL: www.dlepb.gov.cn

Dalian Environmental Protection Bureau, 2002. Report on the State of the Environment in Dalian.

Dalian Municipal Government, 2004. URL: http://www.dl.gov.cn

Dalian Urban Planning Bureau, 2003. City Symphony- Concept and Practice of Dalian.

Dasgupta, S & Wheeler, D., 1996. Citizen Complaints as Environmental Indicators: Evidence From China. World Bank Policy Research Working Paper. URL: http://www.worldbank.org/nipr/work_paper/compwp/index.htm#TofC2

Department of the Environment and Heritage, Australia. 2004. URL: http://www.deh.gov.au/atmosphere/airquality/airindex.html

Department of Environmental Quality (DEQ), State of Idaho, 2004. URL: http://mapserver.deq.state.id.us/Website/emissions/viewer.htm

Earth Science Data Interface, 2004. URL: http://glcfapp.umiacs.umd.edu

EcoPlan China, 2003. URL: http://www.fes.uwaterloo.ca/research/china/ecoplan

EMPACT, USEPA, 2004. URL: http://www.epa.gov/empact/

Environmental Systems Research Institute (ESRI), 2002a. Using ArcIMS (v4.0.1). Redlands, California: ESRI

Environmental Systems Research Institute (ESRI), 2002b. ArcXML Programmer's Reference Guide. Redlands, California: ESRI

Environmental Systems Research Institute (ESRI), 2002c. Customizing ArcIMS: HTML Viewer. Redlands, California: ESRI

Environmental Systems Research Institute (ESRI) 2003. ArcIMS Architecture and Functionality. White paper. Redlands, California: ESRI

Environmental Systems Research Institute (ESRI), 2004a. URL: www.esri.com

Environmental Systems Research Institute (ESRI), 2004b. ArcIMS 4.01 Desktop Help

Environmental Systems Research Institute (ESRI) Virtual Campus, 2004a. Learning ArcIMS 4. http://campus.esri.com/

Environmental Systems Research Institute (ESRI) Virtual Campus, 2004b. Customizing ArcIMS 4. http://campus.esri.com/

Fedra, K., 2000. Model-Based Decision Support For Integrated Urban Air Quality Management. In: Longhurst, J.W., Elsom, D.M. and Power, H. (Eds.) Air Quality Management, WIT Press, Southampton

Godish, T., 1991. Air Quality. 2nd Ed. Lewis Publishers.

Goklany, I. M., 1999. Clearing the Air. CATO Institute.

Green, D. & Bossomaier, T., 2002. Online GIS and Spatial Metadata. Taylor & Francis.

Hansen, P. E., 1991. Introduction to Environmental Management, Elsevier

Hegle A. K., 1998. What are Computer Users looking for in A System? Modern Maturity, Nov-Dec Issue, AARP

Hester, R. E. & Harrison, R.M., 1997. Issues in Environmental Science and Technology 8: Air Quality Management. The Royal Society of Chemistry.

International Atomic Energy Agency (IEAE), 1965. Methods of Surveying and Monitoring Marine Radioactivity. Safety Series No. 11. Vienna: IAEA

Johne, W., Sep 2004. Email Contents from US EPA

Jupitermedia Corporation, 2004, URL: www.webopedia.com

Kolodziej, K., 2002. A Safety ".NET"-GIS Web Services Aid Homeland Security. GEO World. Aug 2002

Kong, Y. & Lin, H., 2001. Analyze of GIS Development in China with the Theory of Technology Diffusion. Information of Remote Sensing. 2001(1)

Limp W.F., 1997. Weave Maps Across the Web. GIS World. Sep. p46-55

Liu, F. & Zheng, H., 2000. Ambient Air Quality Monitoring in China. Expert Group Meeting on Capacity Building and Data Intercomparability for Ambient Air Quality Monitoring in North East Asia. Inchon, April 24, 2000

Longley P. A. etc. 2001. Geographic Information Systems and Science. John Wiley & Sons.

Ma, A., 2001. Develop Strategies for Remote Sensing and GIS in China. Science of Surveying and Mapping. V.26 (2):

Maguire, D., 1999. GIS Industry Outlook 2002. GeoWorld, Dec. p. 42-43

Maguire, D. J., 1991. An Overview and Definition of GIS. Geographical Information Systems. 1st edition. John Wiley & Sons.

Ministry of Environment (MOE), 2004. URL: http://www.airqualityontario.com/

Mitchell, B., 1998. Resource and Enviornmental Management. Longman

Moussiopoulos, N., 2003 Air Quality in Cities. Springer

Mun. H., 2002. Service System of Air Monitoring Data Using Internet GIS. ESRI User Conference 2002.

Munn, R.E., 1973. Global Environmental Monitoring System (GEMS). SCOPE Report 3. Toronto: SCOPE

Ontario Ministry of Environment (MOE), 2004. Green Facts: Ontario's Air Quality Index. PIBS 3958e01

Ontario Public Health Association (OPHA), 2002. Beyond Coal: Power, Public Health and the Environment. Toronto, Ontario

Open Source Initiative, 2004. http://www.opensource.org

Peng, Zhong-Ren & Tsou, Ming-Hsiang, 2003. Internet GIS: Distributed Geographic Information Services for the Internet and Wireless Networks. John Wiley & Sons.

Plewe, B., 1997. GIS Online: Information, Mapping, and the Internet. Onward Press.

SEPA (China State Environmental Protection Administration), 1996a. Environmental Monitoring Reporting System. [1996] No.914

SEPA (China State Environmental Protection Administration), 1996b. Ambient Air Quality Standards (GB3095-1996)

SEPA (China State Environmental Protection Administration), 2004. URL: www.zhb.gov.cn

Sino-Map Press, 2004. www.sinomap.com

Smil, V., 2004. China's Past, China's Future: Energy, Food, Environment. RoutledgeCurzon, Taylor & Francis Group

Song, X., 1999. GIS and Urban Planning. Planners, V. 15 (4)

STRATOS and GCSI Inc., 2001. EPG MERS Policy. Instruments Review. Prepared for Environment Canada.

Taylor Technologies, 2004. Rapid Integration Toolkit Available for ArcIMS. From www.Geoplace/ PressRelease

TDC Group, 2004. GIS Software Links Databases to ESRI ArcIMS. From www.Geoplace/ PressRelease

Thoen, W. 1999. How Has the Internet Influenced GIS? GeoWorld, Dec, 1999. p.32-33

Thom & Ott, 1976. Air Pollution Indices. Ann Arbor Science Publishers Inc.

Thompson, D., 2002. Tools for Environmental Management: A Practical Introduction and Guide. New Society Publishers.

Tompkins, M. etc. 1998. Determinants of Alternative Fuel Vehicle Choice in the Continental United States. *Transportation Research Record, No. 1641: Energy, Air Quality, and Fuels 1998*. National Academy Press.

UK Department for Environment, 2004, URL: http://www.airquality.co.uk

US EPA, 1999. 40 CFR Part 58. Air Quality Index Reporting; Final Rule.

US EPA. 2003. Air Quality Index: A Guide to Air Quality and Your Health.

Wan, B. 2002. Ambient Air Quality Monitoring in P.R.China. Better Air Quality in Asian and Pacific Rim Cities. Hongkong Convention and Exhibition Centre.

White, J. 1993.Global Energy Strategies: Living with Restricted Greenhouse Gas Emissions. Plenum Press

Working group on Libra Software, 2000. Free Software / Open Source: Information Society Opportunities for Europe? From http://eu.conecta.it/paper/

Wu, B., 1999. Environmental Monitoring Issues: The Experience of China. Working Group on the state of the Environment Programme of Dialogue and Co-operation with China. OECD/China Seminar on Environmental Monitoring. Beijing

Xinhua News Network, 2004. URL: www.xinhuanet.com

Xu, X, J. Gao, D. Dockery and Y. Chen, 1994, Air Pollution and Daily Mortality in Residential Areas of Beijing, China. Archives of Environmental Health, 49(4), p216-22

GLOSSARY

API	Air Pollution Index
AQI	Air Quality Index
ASP	Active Server Page
CCTV	China Central TV Station
CGI	Common Gateway Interface
CNEMC	China National Environmental monitoring Center
CO	Carbon Monoxide
COD	Chemical Oxygen Demand
COM	Common Object Model
CORBA	Common Object Request Broker Architecture
DCOM	Distributed-Component Object Model
DGIS	Distributed Geographic Information System
DLEMC	Dalian Environmental Monitoring Center
DLEPB	Dalian Environmental Protection Bureau
EPA	Federal Environmental Protection Bureau of the United States
ESRI	Environmental Systems Research Institute, a California-based GIS company
GIF	Graphics Interchange Format
GIS	Geographical Information System
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
ISAPI	Internet Server Application Program Interface
ISO	International Organization for Standardization
J2EE	Java 2 Enterprise Edition
JDK	Java Development Kit

JPEG	Joint Photographic Expert Groups
JRE	Java Runtime Environment
JSP	Java Server Pages
LAN	Local-Area Network
MAD	Mapping, Analysis and Design (Faculty of Environmental Studies, University of Waterloo)
MOE	Ontario Ministry of the Environment
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
NSAPI	Netscape Server Application Program Interface
O_3	Ozone
OGC	Open GIS Consotium
PDA	Personal Digital Assistant
PDF	Portable Document Format
PM	Particulate Matter
PNG	Portable Network Graphics
PSI	Pollution Standard Index
SEPA	State Environmental Protection Administration of China
SO_2	Sulfur Dioxide
SOAP	Simple Object Access Protocol
SOD	Sudden Oak Death
TSP	Total Suspended Particulate
VOC	Volatile Organic Compound
WAN	Wide-Area Network
XML	eXtensible Markup Language