Development of a Participatory Virtual Studio for Ecological Planning

a case study of wildfire simulation in ecological planning

ZHAO Yibin

A Thesis Submitted to Fulfill

the Partial Requirements for the Degree of

Master of Philosophy

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Abstract

Abstract of thesis entitled:

Development of a Participatory Virtual Studio for Ecological Planning

a case study of wildfire simulation in ecological planning

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Web GIS, Wildfire, Decision making, Public participation

One way to improve the quality and acceptability of decisions and reduce the considerable expense of unnecessary delay and legal conflicts is to make information more accessible and available to both the general public and the professionals alike, in order to involve them in the decision-making progress. Web based multi-criteria evaluation (MCE) integrated with Geography Information System (GIS) has proved to be functional in securing the general public's preference for one spatial problem among alternative choices. Virtual Reality (VR) technology is applied in an online environmental simulation for landscape design simulation to provide an immersive virtual environment (VE).

The rise of the Internet and the World Wide Web (WWW) over the past decade has created many opportunities for its use in a variety of fields. One area where the Web may be used is in the enhancement of participatory democracy in environmental decision-

making. However, most of the currently available Internet applications over the Internet do not serve well in solving spatially referenced environmental decision-making problems. With the advance of Distributed Geographic Information (DGI), GIS services have begun to appear on the Web ranging from simple demonstrations and references to GIS use, to more complex online GIS and spatial decision support systems.

This study investigates the potential of enhancing the viability of a specific ecological plan by enabling the participation of both the professionals and the general public with a Virtual Studio over the Internet. System users are enabled to perform the decision making process---see, plan and do---smoothly with friendly graphical user interfaces. Wildfire behavior simulation is selected as a case study, using data from Mopanshan Mountain, Sichuan Province, China to simulate the fire behavior. Multi-tier system architecture is built to demonstrate the concept of the Virtual Studio.

This study developed a prototype Virtual Studio system over the Web to evaluate the potential of using new information technologies to help decision makers to involve those affected people regardless of geographical and physical constraints in particular spatial decision problems. However, the diagram, "Web GIS + Application model", presented in this paper could act as a template for further spatially referenced, public policies related environmental projects. Widespread use of these opening systems will ameliorate the decision-making progress, increase democracy and make public involvement easier and more practicable. At the same time, this study broadens the application of Web GIS in the field of environmental planning.

Concomitantly, some potential application areas of this system are addressed. Limitations of this research and proposals for future research are also discussed in this paper.

摘要

国际互连网（因特网）在过去十年的飞速发展为很多领域的发展创造了契机。一些从社会科学角度出发的研究表明，互联网可以被用于与环境相关的决策中以提高这些决策的公众参与程度。但是，这些研究成果大多不能用于解决有空间因素在内的一些决策问题。分布式地理信息服务（DGI）的发展使得基于网络的复杂空间分析和决策支持成为现实。在空间规划和决策中，为提高决策的质量和可接受性，其中一种方法就是让该方面的专家和此决策影响到的公众参与到决策过程中来。以往的研究表明，以 DGI 技术为基础进行的多目标评估（MCE）与网络地理信息系统（Web GIS）在网络上的结合可以用于研究公众在空间问题上的取向和偏好。

为研究新的信息技术以及 GIS 的发展对空间决策特别是生态规划的影响，以及如何利用这些新技术在空间规划中提高专业人士以及公众的参与，本研究采用 Web GIS，Java 和 XML 等技术，建立了一个基于互联网的实验性的虚拟工作室（Virtual Studio）。本研究选取了野火对一个地区的生态安全规划的影响为特例建立此系统。 基于互联网使得此系统更为开放，在此系统的帮助下，用户可以在图形用户界面（GUI）的帮助下很容易的参与的此空间决策的过程，在任何一台有因特网接入的电脑上，完成决策背景知识获取，野火模拟，野火模拟结果显示，用户决策和参加关于本决策问题的专题讨论，完成“看-规划-做”（see-plan-do）的决策过程，而不是象传统的公众参与那样到决策机构参加公众会议或填写调查问卷。

在此系统的辅助之下，专业人士可以就规划方案、技术等专业问题提出自己的比较专业的见解，而普通公众用户则可以利用该系统了解到项目的详细空间信息，同时也可以以文字或图形方式反应自己对项目的看法。

本研究选取了中国四川省磨盘山地区为研究区。

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In CUHK

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Chapter 1 Introduction

1.1 Research background and problem statement

The rise of Geography Information System (GIS) is one of the most important events in the history of Geography in the 20th century. One of generally accepted definition of GIS is that it is an advanced computer toolbox for input, storage, editing, manipulation, analysis, visualization and output of spatial data (Longloy & Goodchild, 1999). GIS technology has progressed rapidly during the past decade. It has been developed from the mapping toolbox and information management system to a functional spatial analysis package for both geographers and the professionals from other application fields.

In the 1980's and early 1990's, the focus of most research and development activities was placed on the development of single-user systems. Many of the vital issues in geographic information systems today are not primarily technical issues. As GIS develops and plays an expanding role in the way we manage, analyze, and understand spatial phenomena, the societal consequences of GIS come to the forefront of research in GIS. "GIS and Society" becomes important not only for its role in understanding the impact of existing technologies on society, but also because it engages and gears new technologies for scientists and the public who increasingly have access to GIS and its analytical capabilities. Research on GIS and society, then, can play an important role in the future development, implementation, and evaluation of GIS and related geographic methods (Krygier 1998). Increased public involvement in the definition and analysis of questions tied to location and geography is the domain of public participation GIS (PPGIS)

(Schroeder 1996; Carver 1998; Stonich 1998; et al.). The PPGIS approach facilitates the meaningful introduction of appropriate forms of spatial information and related technology for widening participation in the policy making process (NCGIA, 1996).

The "public" in public participation may include both professionals and laypersons. Primarily, professional participation will first improve the quality of the planning project. Though the comments and suggestions of allied professionals, decision-makers are able to consider as many related factors as possible during the planning process. For example, in the planning of a conservation park, economists will input suggestions regarding the potential impact of establishment of the park on the local tourist industry, while professionals from regional planning will focus on the methods or models which might be chosen for the planning project.

There is also a growing public demand for access to information and meaningful dialogue between themselves and government, leading to greater opportunities for public participation in the decision making process. Ideally this kind of planning project should take into account the views of all those who have a legitimate interest in the matter at the issue. In the classic paternalistic model, the government invites a few people to participate in a process in terms defined by the government in accordance with their needs or solicits opinions by use of written material such as brochures, letters and questionnaires.

In this traditional mode, participants have to spend time traveling to set venues or complete questionnaires with very few background information. The classic approach will certainly exclude most affected peoples' views, since the public tend to be apathetic about most policy issues do not clearly and directly affect themselves. Even when the outcome may have personal ramifications, they are unlikely to become involved unless they are convinced that such involvement is likely to make some difference (Sewell and Coopock, 1977). This shortcoming of the classic approach has necessitated a new participation approach, i.e. to seek out a new technique to draw as many of the affected individuals as possible into the decision making process, and to provide understandable tools to enable both professionals and the general public to fully and successfully participate in the aforementioned process.

Public participation GIS (PPGIS) has been widely used in solving a variety of community planning problems. On the other hand, public participation demands from group-based environmental decision-making requires the distribution of GIS service, especially when "semi-structured public policy issues are addressed" (Armstrong 1994). The rise of the Internet and the World Wide Web (WWW) has created many opportunities for those involved in GIS and decision support research. In the last couple of years, many GIS have appeared on the web giving the general public access to both systems and data, which is so called Web GIS or Internet GIS.

This research concentrates on the problems arising from an environmental planning project. Security pattern is a term related with the concept of sustainable development.

Security patterns are potential spatial patterns, composed of strategic portions and positions of the landscape that have critical significance in safeguarding and controlling certain ecological processes. Components of security patterns have the quality of initiative, coordination and efficiency, and are, therefore, strategically important in landscape change in biological conservation (Yu 1996).

Wildfire is often portrayed to be one of the major forestland disasters. A large quantity of forest is lost to wildfire every year all over the world (see Table 1.1 & Table 1.2). With the exception of controlled fires, forest wildfires are not only a disaster to the forest itself but also sometimes to the whole ecosystems. Wildfire plays important roles in the forest ecosystem. Wildfire (1) adjusts the successional pattern of the forest; (2) modifies conditions affecting wildlife; (3) influences the mosaic of age classes and vegetation types; (4) alters the numbers of trees susceptible to disease and insects; and (5) both reduces and creates further fire hazards (Kilgore 1993). Therefore, security patterns may be destroyed by wildfire.

Ecological security planning should be conducted in a forest ecosystem to reduce the wildfire danger to ecological security. Planning contents may include measures such as fire-fighting equipment allocation within forest, new path blazing and residential area allocation, etc. Most planning issues in the planning will affect local residents; therefore, public involvement and reciprocal communication between the government and citizens is necessary to reach a consensus on the long-term planning.

Table 1.1 Forest fire statistic data in Sichuan province since 1956 (source: Yi and Cai, 1995)

Year (19--.)	Burned forest area (ha)	Burned forest area (ha/year)	‰
56-60	192936.3	38587.1	4.82
61-65	156736.8	31347.4	3.92
66-70	98328.6	24582.2	3.07
71-75	119499.9	23899.9	2.99
76-80	73179.1	14635.8	1.83
81-85	31460.8	6292.2	0.79
86-90	7448.9	1489.8	0.19
Total	773904.4	159697.4	19.97
Average	96738.1	19962.2	2.50

Table.1.2 Hill Fires in the Country Park System of Hong Kong

Fire Season	*No. of fire reported*	*Area affected (ha)*	*No. of trees affected*
1969-1970	852	346	214000
1970-1971	366	106	48000
1971-1972	809	152	300000
1972-1973	339	109	66000
1973-1974	1149	1372	1510000
1974-1975	266	228	63000
1975-1976	836	1733	558000
1976-1977	1212	2295	1102000
1977-1978	535	485	7860
1978-1979	501	452	43000
1979-1980	934	2596	553000
1980-1981	1259	820	16000
1981-1982	839	1580	140000
1982-1983	Data not available	Data not available	Data not available
1983-1984	434	5246	218000
1984-1985	208	915	77000

1985-1986	306	5414	541000
1986-1987	281	1303	80000
1987-1988	217	1416	74400
1988-1989	234	2037	97400
1989-1990	160	1332	84000
1990-1991	184	2244	89400
1991-1992	107	1094	158300
1992-1993	221	2713	193400
1993-1994	155		86200
1994-1995	96		42000
1995-1996	181		74000
1996-1997	89		46400
1997-1998	54		18600

Source:

1. Unpublished data from the Country Parks Authority, Agriculture and Fisheries Department
2. .Fung, T. and Jim, C.Y. (1993) An assessment of hill fire impact in country parks with SPOT HRV images and GIS. *Proceedings of Symposium on Remote Sensing in Environmental Research and Global Change.* Commercial Press, Hong Kong, pp. 334-341 and 145-148
3. Fung and Jim (1998) Assessing and Modeling Hill Fire Impact in Country Parks with SPOT HRV Images and GIS. *GeoCarto International* 13(1): 47-58.

1.2 Research objectives

The primary motivation behind this research is to find a reliable method of increasing the level of participation of both professionals and the general public in the environmental planning process, using GIS technology and other new rising Information Technologies. A prototype online virtual studio system is developed for the pilot study.

This study takes Mopanshan mountain (Sichuan Province, China) as its research area. Wildfire is one of the major disaster risks in this area (see Table 1.1). Therefore all planning decision for this region should take wildfire into account. This research sets up a public participatory Virtual Studio to study the effect of wildfire on the ecological

planning process. Web GIS and other Information Technology (IT) technologies are employed to develop this system. This Virtual Studio is used to demonstrate how to construct an online participatory system for environmental planning. Based on this analysis, two interrelated goals are to be achieved: development of an online Virtual Studio for participation and the experience of integrating Web GIS and application models.

1.3 Methodology

As with any software project, certain steps must be completed in order to construct this online Virtual Studio system. A software engineering approach is employed throughout the process of development.

This process is divided into the following 5 steps: definition of the application area, user requirement analysis, feasibility analysis, user interface design, and system development. In this study, the introduction of an application model and a spatial database into our Virtual Studio system leads to two more procedures: database construction and application models adaptation.

Firstly, a requirement analysis includes user requirement analysis and functionality analysis. User's possible operation requirements when applying this system are addressed on the basis that all the functionality is aimed at helping users to perform the participatory decision making process smoothly. This is referred to as functionality requirements analysis. Another part of requirement analysis is the requirement of user

interface, focusing on how to supply user-friendly interfaces to attract more users. In this phase, Web GIS platform and developing language are selected.

The second step in the study method is feasibility analysis, that is, concentrating on which technologies maybe applied to achieve these requirements or develop these tools. User interfaces design is the third step. Here, required user interfaces are identified. Related technologies are also addressed at this time.

The database on the server side in this Virtual Studio system contains spatial data and non-spatial data. Spatial data of the study is digitized with ESRI GIS software package ArcInfo or ArcView and imported into the database. Adaptation of the application model, Rothermel's wildfire spreading speed model (Rothermel 1972), is an important and complex work for this study. This study aims to demonstrate the concept of a Virtual Studio with a prototype system whose intent is to increase public involvement in the environmental decision-making process. Consequently, the focus is NOT on the accuracy of the wildfire spread. In this paper, therefore, Rothermel's wildfire rate of spread (ROS) model is simplified to produce a smooth system performance. Similar work is done on the fire area boundary spread algorithm.

Based on the aforementioned analysis, the last step is to assemble the user interfaces, database, Web GIS and Web server in a Virtual Studio system to serve the public online participation.

1.4 Significance of this study

Firstly, this study attempts to find a new approach to secure participation of both professionals and the general public in the environmental decision making process, using Web GIS and new emerging IT technologies. Most of the existing participation approaches follow a paternalistic, government-dominated model, a tradition that is stronger in most governments in those of the west. But with the Virtual Studio I developed in this study, information becomes more accessible and participation process becomes more open. Furthermore, since this Virtual Studio can be accessed through the Internet, the geographical constraints on public participate in the decision-making process are reduced. Whether or not, wise decisions are make following use of the Virtual Studio, the pubic are more likely to accept the decision if they have been active participants in the process. This study should significantly affect the decision making process of those governments who apply it.

Secondly, this study provides experience of integrating of an environmental model and Web GIS. Taking wildfire spreading model as the case study and the ESRI ArcIMS as the Web GIS platform, I developed a template in this study for further endeavors. Although the system developed in this study is a prototype, it addresses not only most of the issues of integrating application models and GIS together on the Internet, and it is the next generation of online mapping service.

Finally, with the aim of securing and increasing public involvement in ecological security planning, a prototype participatory Virtual Studio system has been developed. In addition

to the initial motivations of developing this Virtual Studio, it can also be adopted for general education and scientific research. Non-professional users may gain general knowledge about wildfire spreading in defined scenarios.

1.5 Organization of the thesis

This thesis consists of six chapters. In the next five chapters, the following issues will be addressed: GIS, online Virtual Studio system design, wildfire simulation, public participation and some conclusions resulting from this study.

Chapter 1 explains the existing problems of the current environmental decision-making process and outline the conceptual framework of this study. Brief history, public participation issues, Web GIS and wild land fire study are reviewed in Chapter 2. Chapter 3 summarizes system user requirements, followed by a feasibility analysis of all these items. This chapter focuses on the requirement and feasibility analysis of the Virtual Studio system. Chapter 4 deals with adaptation and development of wildfire simulation models. Firstly, there is a brief description of the study area: Mopanshan Mountain, Sichuan Province, China. Rothemel's ROS model is adapted in this case study. The fire area boundary spreading simulation follows Chapter 5 discusses the public input in public participation. Chapter 5 switches focus from fire simulation on the server side to the user interface on client side. Chapter 6 is the concluding chapter summarizing the study. Potential application areas of this Virtual Studio other than wildfire simulation are addressed. Limitations and further work of this study are also presented.

Chapter 2 Literature review: wildfire behavior simulation, Web GIS and public participation GIS

2.1 Introduction

Natural hazards take an increasingly heavy toll of life and property over the past decades, leaving a much larger number of homeless and destitute. The newspaper headlines constantly remind us of the human and property losses that we suffer from wildfire, severe storms, earthquakes, and other disasters. However, if we can predict the course of these events beforehand, management strategies can be developed to minimize hazards adverse consequences.

The ability of forecasting the progress of a large wildfire would significantly reduce human suffering, loss of life and destruction of property, on the other way, controlled prescribed burning have been becoming a significant tactic for forest management activities from timber harvest scheduling to reforestation and thinning operations. This is also the reason for that so many natural hazards research projects are carried out all over the world. One of the most efficient ways to forecast the crisis is to study the behavior of them, describe the crisis event progress with some mathematic language in a spatial way and then simulate the progress in certain temporospatial scales.

Within these research groups focusing on hazards mitigation, those who study natural hazards from a spatial aspect and use the up to date geo-information technology as their analytical tools have got some significant achievements. A participation approach situates GIS analytical tools within an expanded framework communication and discussion, opening opportunity for participation of both the professionals and the general public.

PPGIS is conceived broadly as an integrative and inclusive process-based set of methods amenable to public participation from multiple viewpoints. Technical developments have made PPGIS possible. The advent and popularity of World Wide Web (WWW) have created many opportunities for those involved in IT. It also raised a new research agenda for the research in hazards mitigation, like public participation and the new technology of Web GIS.

2.2 Investigating wildfire behavior

As moving focus to wildfire behavior, I will firstly examine the classification of wildfire. Fire does not spread in one way only, but in many, heavily nuanced by particular circumstances. A fire in sawgrass burns differently than a crown fire in lodgepole pine or a surface fire through hardwood leaflitter. Generally, there are 3 types of wildfire according to the vegetation layer in which the fire is burning: ground, surface, and crown fire (Pyne et al., 1996) (see Figure 2.1).

Surface fire spreads by flaming combustion through fuels at or near the surface-grass, shrubs, dead and down limbs, forest needle and leaf liter, or debris from harvesting or land clearing. Crown fire burns the tree crowns. They are often dependent on surface fires and are invariably ignited by surface fires. Ground fires are fires in subsurface organic fuels, such as duff layer under forest stands, Arctic tundra or taiga, and organic soils of swamps or bogs. Ground fires burn underneath the surface by smoldering combustion and are most often ignited by surface fires.

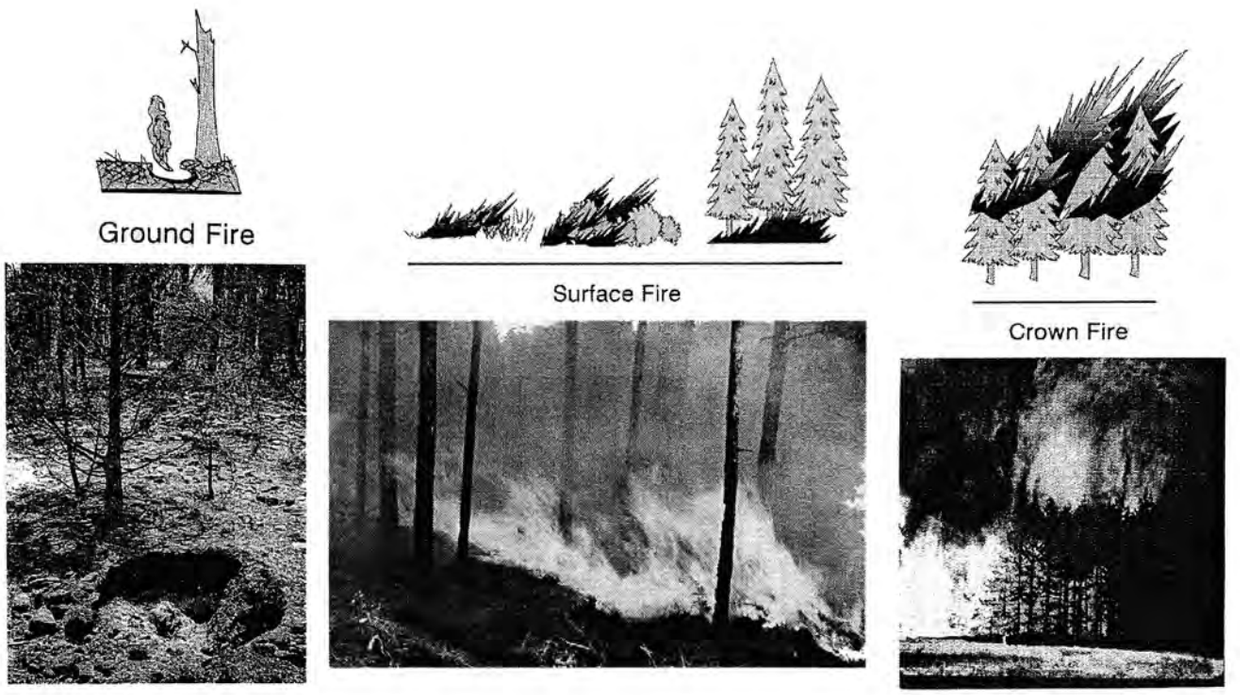

Figure 2.1 Three types of wildfire according the vegetation layer it is burning in (Pyne et al., 1996)

There are two kinds of fire behavior predictions and it is important to identify the difference between them. A *fire danger rating* is an estimate of burning conditions anticipated over a large area at a particular time, usually early afternoon of the following days. A *fire behavior forecast* is an estimate of the rates of spread and other fire behavior characteristics to be expected on a particular wildfire or prescribed fire over some future time period, usually the next work period or planned burning period. The fire danger rating is generalized for fuel type and topography, while fire behavior forecast is fuel and site specific.

Though these two kinds of fire behavior predications may use the same input data, and even process the data through the same equations, the two are not interchangeable unless

the relationships between the rating standard and such other variables as fuel and humidity are known. When these interrelationships have been precisely studied, fire danger ratings can be used for site-specific predictions with fair reliability (Chandler et al., 1991), but when they are not, reliance on fire danger tables can give misleading results (Rothermel & Deeming, 1972)

In one way, predicting fire behavior on a going fire is easier than either fire danger rating or writing a prescription for a prescribed burn. In this paper we focus on the site specific fire behavior forecast.

2.2.1 Fire environment

Fire behavior is a product of the environment in which the fire is burning. Countryman (1972) presented the concept of the fire environment-the surrounding conditions, influences and modifying force that determine the behavior of a fire. Topography, fuel, weather, and the fire itself are the interacting influences that make up the fire environment. This is illustrated as a fire environment triangle with the fire in the center (Figure 2.2).

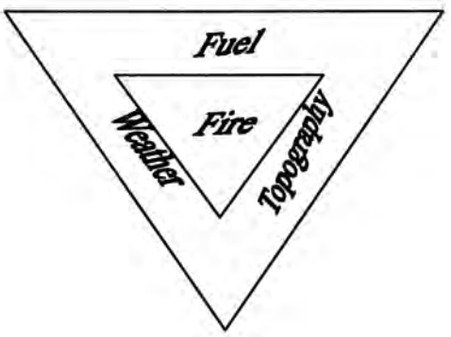

Figure 2. 2 The fire environment triangle illustrates the influencing forces on fire behavior: fuel, weather, and topography. The fire in the center signifies that the fire itself can influence the fire environment. Modified from Countryman (1972)

The changing states of each of the environmental components: fuel, topography, and weather-and their interaction with each other and with the fire itself determine the characteristics and behavior of a fire at any given moment. Changes in fire behavior in space and time occur in relation to changes in the environmental components. From a wildland fire standpoint, topography does not vary with time, but can vary greatly in space. The fuel component varies in both space and time. Weather is the variable component, changing rapidly in both space and time.

Topography

Topography includes the elements of slope steepness, aspect, elevation and configuration of the land. Variations in topography can cause dramatic changes in fire behavior as a fire progress over the terrain. Although topography may not change in time, it affects the way in which fuel and weather change. The fire environment triangle symbolizes this interaction among the elements. Topography modifies general weather patterns, producing localized weather conditions that in turn affect fuel type and moisture content.

Slope steepness has a direct affect on flame length and rate of spread (ROS) of a surface fire. Whether the wind or slope has the greatest effect depends on their relative force. A strong wind can push a fire down slope.

Aspect is the direction a slope is facing. Aspect affects fire behavior through variations in the amount of solar radiation and wind that different aspects receive.

Fuel

Fuel is always consumed in a fire. Fine fuels, such as dead grass, needles, and small twigs, are mostly consumed in the flaming fire front. Consumption of large dead and down fuel and of the duff is important in evaluating smoke production, fire intensity and suppression considerations and fire effects.

The influences of fuel to wildfire behavior lie in two ways: fuel type and the spatial pattern of fuel complex (including fuel loading, fuel moisture, and combination of different fuel type) on fuel bed. Salazar's (1985) research have showed the sensitivity of the fire behavior simulation to the fuel types (fuel model); both rate of spread (ROS) and flame height will vary linearly with fuel loading in the same fuel type; for example, when fuel loading doubles, rate of spread and flame height will also double. This rule is strictly accurate only in fuel beds that are near their optimum packing ratio and in which the degree of compaction is not greatly affected by loading. A high canopy density can reduce vaporizing of water in fuel bed and soil; subsequently a high canopy density will increase humidity and reduce the ratio of ignition.

The stylized fuel models most widely used and accepted for fire behavior simulation are the Northern Forest Fire Laboratory (NFFL) or Fire Behavior Office (FBO) models (Anderson 1982; Rothermel 1983; Burgan and Rothermel 1984). They differ in their fuel particle size class loadings and surface-area-volume ratios, fuel bed depths, moisture content of extinction, and wind reduction factors. Following is the definition of type 5 in NFFL fuel model.

Fuel Model 5 - Brush (2 feet)
Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. Usually shrubs are short and almost totally cover the area. Young, green stands with no dead wood would qualify: laurel, vine maple, alder, or even chaparral, manzanita, or chamise.

From: Anderson, 1982

Fuel model values for estimating fire behavior	
Total fuel load, < 3-inch dead and live, tons/acre	3.5
Dead fuel load, ¼ -inch, tons/acre	1.0
Live fuel load, foliage, tons/acre	2.0
Fuel bed depth, feet	2.0

Figure 2.3 Definition of fuel model

Varieties of fuel models are developed to describe fuel attributes according to the requirement of GIS. Vegetation types vary according to latitude and longitude, that's why there is a massive workload before a wildfire behavior simulation system is adapted from location A to B. In fact, different purpose can lead to different fuel description models as well even at the same location, for example in USDA Forestry Service there are two fuel description models: NFDRS is well suitable for planned fire management actions: pre-suppression, suppression, detection, and prevention while the 13-type NFFL model is designed for site-specific fire behavior predictions with BEHAVE (Andrews, 1986). To

create fuel model for a specified area, Brown et al (1982) developed a useful sampling method for estimating fuels for wildfire (Pyne et al., 1996)). With this method fuel data can be sampled, which are again input data for mathematical fire spread model developed by Rothermel (1972). Table 2.1 is used for data summarizing for each fuel type in fieldwork of data sampling.

Table 2.1 Sample description table

Fueltypes / *sampling data*	*Downed woody material* / *Litter*	*Herbaceous vegetation* / *Shrubs*	*Trees*
	Frame 30 cm x 60 cm		Square 3.5 x 3.5 cm
Depth	5 measurements in each frame		Height of trees < 2 m
Dead fuel loading; classes: Ø<0.6 cm, 0.6<Ø<2.5 cm 2.5<Ø<7.5 cm	cut and ovendried	none	Basal branch diameter up to 2m, hight of trees <2m
Live fuel loading; classes: woody and herbaceous both Ø<0.6 cm	none	cut and ovendried	Basal branch diameter up to 2m, hight of trees <2m
surface-area-to-volume-ratio	measurements of particles		

Weather

Temperature, relative humidity and precipitation affect fuel moisture. Wind is a dominant influence on fire behavior. It is also one of the hardest elements to predict due to variability of wind speed and direction and the influences of topography, vegetation, and local heating and cooling.

In fact, fuel type and weather are the two most important factors for a fire behavior prediction system and fire risk assessment system. A detailed discussion about fuel type model will be given in following contents. But, all these factors contribute to the fire behavior during a wildland fire; They (shape and ROS) are a result of all these factors.

Take topography and wind for example, there are several ways that topography can affect wind, which can be put into three categories: mechanical, turbulent, and frictional.

2.2.2 Ignition

A wildland fire goes through several stages: ignition, transition to a spreading fire, acceleration or buildup of spread rate, and spread at a steady-state rate. Wildfire start from lightning strikes and from a variety of human causes including discarded cigarettes, sparks form equipment, and arched power lines; and it is both a natural event but frequently induced by human carelessness or even arson (Fung and Jim 1998). Generally speaking, ignition is determined by the relationship between the heat available from the ignition source and the heat required to bring the fuel to ignition.

2.2.3 Fire spread

There is a need to characterize rate of spread (ROS) and intensity of wildland fire, including both wildfire and prescribed fire. In the planning stages, these information is used to define the conditions under which a management ignited prescribed fire will be conducted, to both achieve the stated objectives of the burn and remain control of the fire. Predicted spread rate and intensity are used during a wildfire in determining suppression tactics.

Rate of spread (ROS) is the forward ROS at the head of the fire; while the backing ROS is much less, the flanking ROS is intermediate. As mentioned previously, fire behavior is a combination of its environment elements: wind, topography, fuel, etc, ROS can vary

considerably due to changing conditions, and is generally taken to be an average value over a period of time.

2.3 Modeling wildfire with GIS

2.3.1 Modeling fire behavior prediction

The pioneering fire spread model was developed by Rothermel (1972). Rothermel's model enables the forecasting of the fire's speed of propagation and intensity mathematically. This model can be easily coded with any computer programming languages which make it possible to simulate the wildfire in a very complex fire environment with large computer. This model is the basis of all United States-based fire behavior simulations by computer programs such as FIRECAST (Cohen 1986). Rothermel's fire behavior model is so far the most authoritative that it is adopted by both U.S. Department of Agriculture Forest Service and Canada Department of Agriculture.

Other than Rothermel's mathematic model, there are some other methods to predict wildfire behavior, for example the method of Markov process is used to describe the wildfire spread process (Anderson et al, 1982). But most of these models are either weak of spatial prediction or not suitable for computer based simulation.

Rothermel's model consists of a set of flux equations for the physical and chemical reactions within fires. Spread is determined by measuring differences in fluxes. Most of the physical and chemical constants for the equations, such as the thermal content of

various fuels and the relationship between spread rates and fuel densities, have been determined experimentally by more than fifty years of cumulative work.

Three groups of parameters are important to the forest fire spread, in order to determine the ROS:

- Fuel particle properties (heat content, mineral content and particle density);
- Fuel array arrangement (loading by size class, mean size, and fuel bed depth);
- Environmental parameters (wind velocity, fuel moisture content and topography).

Based on Rothermel's model, Anderson (1983) developed the currently accepted model of combustion geometry, and his ideas have been incorporated into some fire prediction system such as BURN. Anderson built upon some classic results by Fons (Pyne et al., 1996), which included the results of 198 wind tunnel combustion chamber experiments, and a number of well-studied wildfire. By least squares fits of log regressions of wind speed and amount of forward spread, Anderson produced a set of equations that describe the fire geometry as a bi-centered ellipse, allowing the computation of fire area and total perimeter as well as maximum fire width, since the length-to-width ratio of the fire is a function of wind speed. Thus, as long as fire remains (1) as discrete, single-centered, uncorrelated spread sequences; (2) unaffected by major differences in fuel; (3) in unchanged wind; and (4) uninfluenced by topography other than forward spread gradient, Anderson's geometric model (and by implication, Rothermel's general model) will provide a good estimate of fire behavior.

One of the difficulties to set up the GIS database for wildfire behavior simulation is how to represent fuel layers properties with the previously mentioned layer-view concept. In most cases what we care is how wildfire will behave under given vegetation condition and fuel loading. Fuel description models are used to modeling information such as: vegetation type, heat content, fuel bed depth, etc.

Weather data are input as runtime environment parameters. End users can define a scenario by comprising three sets of input parameters: landscape files (DEM, feature layers, etc), runtime environment parameters and ignition locations. Graphical User Interface (GUI) is often used to wizard users to perform the aforesaid operations. Outputs of a GIS-modeled wildland fire behavior simulation system include two types of data set as well: spatial and non-spatial. Spatially referenced information as fire front is often displayed in a GUI, while text is suited for the representation of non-spatial data set including ROS, fireline intensity.

Derived from areas of traditional database systems, semantic data models, and object-oriented programming, object-oriented concept is used to model wildfire as entity-view object acting on layer-viewed object (DEM, fuel bed et al) (Yuan, 1993; Leung et al 1999).

2.3.2 Focusing on the system

The continued emphasis on security and resource protection has increased the need for more accurate and reliable tools for wildfire management. For many years, forest fire

management personnel have utilized fire behavior model such as BEHAVE (Andrews, 1986) to aid in predicting fire behavior and subsequently mapping probable scenarios of fire spread during a given time period. But most of these tools are non-spatial fire behavior tools (Weinstein et al. 1995). BEHAVE is capable of predicting fire characteristics for a given area, and the output is inherently non-spatial. In other words, the spread rates, flame length, fire line intensities, are applicable only so long as the specified fuel type, topographic, and weather related parameters do not vary.

GIS are increasingly used for inventory, analysis, understanding, modeling and management of natural environment (Goodchild et al., 1996). In this manner, GIS is seen as a way to link numerical models with spatial database to provide understanding and prediction in the form of attractive, easy-to-read graphs, maps and multi-media demonstrations (Burrough, 1998). GIS representation adopts layer-view concepts to model the world. Such ground features, as river, topology data, and land cover, in the real world are input into geo-referenced database as thematic layers or coverage, while wildfire can be seen as an actor that interacts with the background layers on which it acts. Weather data, including wind direction, wind speed and moisture, is the run time environment parameters. This conceptual framework is the basis of modeling wildfire with GIS. There are always 5 components within these systems as shown in Figure 2.4.

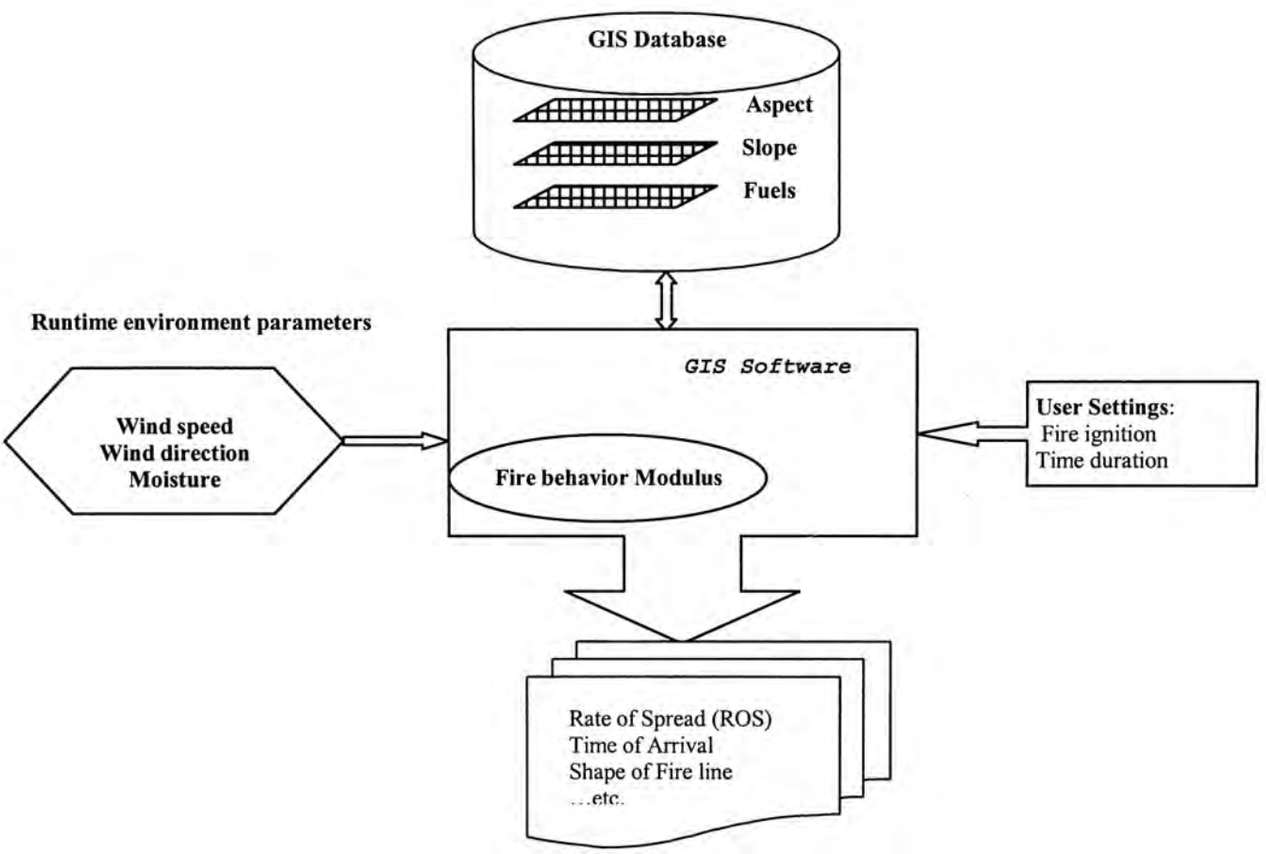

Figure 2.4 Concept demonstration of a GIS based fire simulation system

- A GIS database to store spatial background information;
- A interface for to setup runtime environment parameters: weather data;
- Tools to help initialize user settings: time duration, fire ignition;
- A fire behavior model embedded GIS system;
- Output representation tools to display outcome of the system;

Some practical systems have been created to utilize GIS to model wildfire behavior in a spatial manner. A successful example is FIREMAP (Vasconcelos & Guertin, 1992). It is a simulation system designed to estimate wild fire characteristics in spatially non-uniform environments and simulate the growth of fire in discrete time steps. This simulation system integrates Rothermel's behavior prediction model (Rothermel 1972) with a raster-based GIS. The outputs can be displayed as digital maps (Vasconcelos et al., 1992). FIRE! (Finney, 1993) is the first model that integrates advanced waved-based fire simulation methods with widely utilized GIS platform in an easy to use, fully graphical environment. FIRE! fire simulation application brings fire modeling capabilities to the ArcInfo GIS environment with a C++ engine FARSITE (Fire Area Simulator)(Finney, 1993). A GIS & remote sensing-based Canadian Wildland Fire Information System (CanFire) is a national fire intelligence system developed by the Canadian Forest Service (CFS) (Lee 1996) (see Figure 2.5).

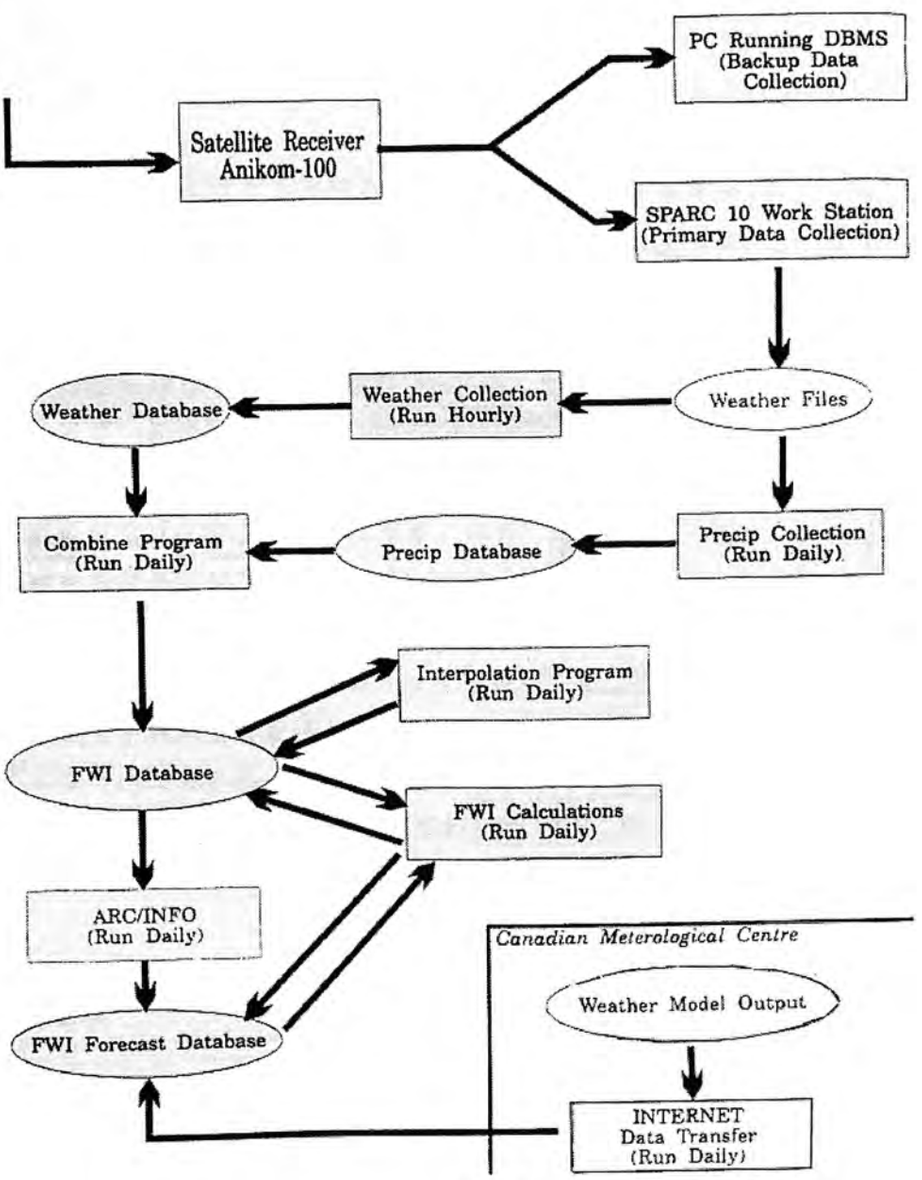

Figure 2.5 Data flow diagram for the CFS wildfire information system (Lee 1996)

2.4 Emergence of the Web GIS

Web GIS is derived from Distributed Geographic Information (DGI). DGI simplifies access to geographical information and can be used to spread spatial information to a multitude of users. DGI applications range from simple, pre-drawn maps on a Web page to network-based collaborative GIS in which GIS users at remote locations share common data and communicate with one another in real time (Plewe 1997). The technologies that developed to make DGI applications possible include servers, clients, and network communication and the system architecture has developed into a multi-tiered client/server model.

Generally speaking, there are two ways to set up a Web GIS Web site. One solution is to develop the whole web site components with the tools from Information Technology, including the web server software, GIS workbench, such as technology from IT Java Virtual Machine (JVM), JDBC, OLE technology are often used to construct a Web GIS website. Growing Web GIS industry, including software and data, has provided reliable commercial Web GIS products, such as USGS, ESRI™ MapObject, ESRI™ ArcIMS, AutoDesk™ MapXtrem, etc. These products are often used to set up a web GIS website, just like the "centamap" website in Hong Kong (see http://www.centamap.com/).

Traditional standalone GIS limits the information flow between users and the information provider. Continuous technology innovations in Information Technology lead to not only great popularity of Internet but also raise new challenge to geographers. According to the research (Lin & Zhang, 1998; Carver, 1999), spatial analysis applications such as

investment environment analysis and Multi-Criteria Evaluation (MCE) can be integrated into an open environment via Internet with Web GIS to enable the end users to perform a spatial analysis for handling specific spatial problems.

2.5 New agenda from public participation

The terminology of public participation means that the individual has the right to be informed and consulted and to express his or her views on government decision matters that affects him personally. The overall goal of public participation is to build trust and credibility, to keep emotions, human energy, and conflicts focused on substantive issues and solutions. Public participation provides an opportunity for all interested to become informed and involved, and to influence program development and implementation.

2.5.1 Public Participant, computer and WWW

Public participation at the outset appeared in social science research. Four levels of public of public participation in social science research can be identified (Carver, S.). These can be defined as:

1. public access to result of social science research through any available medium (*the informed public*);
2. public use of social science research for the benefit of the individual, social groups or wider community (*public as user*);
3. public participation in social science research as the subject of study, whether as an individual or member of a wider population (*public as subject*); and

4. public involvement in social science research through defining research objectives, agendas and carrying out research (*public as researcher*).

Existing published literature on the use of computer graphics for improving public participation in social science research is rather limited, but even more limited when specific to the potential of the Internet. The literature that is available in this field falls into one of two emerging categories. The first, which appears to dominate the current focus of research, relates to the debate surrounding the benefits, pit-falls and practicalities of using the WWW as a tool for carrying out social surveys. The second area relates to research, which has either taken place or is underway and illustrates actual cases where the WWW has been used for survey research.

Schmidt (1997) and Coomber (1997) discuss the benefits, potential and solutions to using the WWW for survey research. Mumford (1996) goes on to discuss the technical issues of using graphics on the WWW although not necessarily as part of on-line surveys. The work undertaken by Wherrett (1997) in landscape preference and Carver et al. (1997) on the siting of Britain's nuclear waste offer insights into the use of graphics on the web for social science based research. An area within the Internet community that is receiving increasing amounts of attention and research is that of 3D virtual environment. For instance, the benefits of publishing a survey on the web range from increased population access to saving time and money and providing dynamic and interactive surveying. As the web community continues to increase, sample populations will become larger and therefore biases will, in time, decrease. This kind of survey, as Coomber (1997)

mentioned, will overcome the problems associated with sample biases. Surveys can also be focused at particular groups who are interested in very specific issues. Of all the web-based surveys that they have conducted, most have graphics, either to demonstrate concepts, or to improve attractiveness to respondents.

Carver et al (1997) discuss the need to develop "easy-to-sue graphic user interfaces" if participation in social science research over the Internet is to gain any momentum. Sophisticated Internet based system will only be popular if they provide the participants with the types of interfaces that they can understand.

2.5.2 Public Participant GIS

The terminology of PPGIS was initiated in a workshop convened in July 1996. The PPGIS Workshop, sponsored by the National Center for Geographic Information and Analysis (NCGIA), was held at the University of Maine July, 1996. The *Report to Initiative 19* was published as part of the Scientific Report of the NCGIA Initiative 19 Specialist Meeting, titled *GIS and Society: The Social Implications of How People, Space, and Environment Are Represented in GIS.* The principal motivation for the workshop was discussion of a "GIS 2" at the Initiative 19 *GIS and Society* meeting.

Because public participation GIS (PPGIS) is a bridge concept, concise definition of its definition of its dimensions is unlikely and probably not desired. Rather, PPGIS may be seen as a new window through which to view the whole of GIS practice in its social

setting. The general goal of PPGIS is to encourage new layers of capability within GIS and new connections to technologies and processes outside present GIS practice.

Contexts for introducing public participation GIS would include community economic development, environmental dispute resolution, participatory planning, and other activities involving public collaboration. Technologies chosen or developed to support this approach can be designed to document and record the problem resolution process, etc. the publics include: neighbors, concerned citizens, technical experts, media, activists, elected officials, business and industry, and local, state government regulators (Nyerges and Barndt, 1997).

2.6 Summary

Based on the review above, the participation of both the professionals and the general public has been proved to be an essential phase in planning decisions. But few studies have been conducted on what roles new technologies such as Internet, Web GIS, Java, etc, play as effective media for public participation in environmental planning.

Rothermel's model is a fire behavior model based on physics law and mathematic induction. From the review of study on wildfire, we can see that Rothermel's wildfire behavior model is a authorized, long-term developed model. Rothermel's model is also a mathematic model that can be easy deployed for large computation on computer. These are the main reasons for this study choose Rothermel's model as the base of wildfire behavior simulation.

Wildfire is a geographical phenomenon that changes in time and space. Therefore we can model it with GIS. The state-of-the-art Web-based GIS technology can play an important part in the development of PPGIS. Moreover, PPGIS would be capable of managing and integrating all components, data, GIS service, application models and participant contributions from one interface.

If we can integrate Web GIS, wildfire behavior models, Internet and public participation together in one system, it will be an effective, functional tools to handle problems in environmental planning that require public participation require.

We can take many advantages from this integrative online system.

- Quality, "unbiased", information that is structured in a manner that allows the public to gain both a rapid understanding of complex problem and explore topics in depth if they wish.
- The ability for the public to add their own information to the above knowledge, discusses the problems with others, and forms a consensus. On the web such material can be in a wide set of formats: text, video and pictures, audio, 3D worlds.
- The ability of the public to examine the spatial data involved in the decision. And further than this, for them to manipulate the data to examine a number of complex "what if" scenarios and to examine how these complexities develop.

- The ability for the public to then research an informed decision on the given problem, submit this decision to those responsible for implementing it, see the results, and gain feedback as to the reasons for the final choice.

In addition the web provides the following advantages:

- Web based projects are not time-limited in the same way as public participation meetings: although they should be limited to a specified period to maintain community and organizer interest, and to fit with a planning schedule.
- The web provides access to groups that cannot reach public participation meetings: the blind, deaf, and those with mobility difficulties.
- The web allows for the understanding of public understanding. Those who wish to provide information to the public can track what their pre-informed decisions are, how they alter, what paths they take through the provided and public-supplied knowledge, thus allowing such systems to be improved.

Chapter 3 System design: requirements analysis and feasibility analysis

3.1 Introduction

This chapter will deals with two topics: system requirement analysis and feasibility analysis. At the beginning of this chapter, there is a system requirement analysis of this Virtual Studio with software engineering approach. Then, bi-directional conceptual system architecture is constructed. Followings is the designing data flowchart based on open system architecture. Discussions on how to represent the fire spread scenario and how to provide a graphical user comments submit toolbox with the state-of-the-art technology is also presented, including Extensible Markup Language (XML), VRML, Java 3D and the web GIS method. At last, a developing solution based on analysis of existing technology and commercial software is addressed. Some related researches in this research area are also surveyed in this chapter, including works undertaken in the University of Leeds and University of Maine.

Wildland fire behavior simulation in this study is to support the decision-making in the planning of ecosystem by collecting comments from affected public and related professionals. Functionality of this system must help user to complete these operations; therefore requirements analysis can be addressed by the analysis of following "how to?" and "what?" items:

- How to secure a "Open participation environment" or "participatory virtual studio"?

- End users of this system can be anyone all over the world and with various platforms (or Operating System), thus how to make the system globally accessible regardless of users' geographical location and platform they use?
- Before the users participate in the decision-making processes, the problem that how to make it easier for the end users to understand the problems in the planning must be resolved;
- How can the users simulate a wildfire and get a visualized simulation result;
- End users may have comments on the draft plans. Comments of the end users may be textual or graphical; therefore user comments collecting tools both in textual and graphical format is needed.
- Peoples affected by the planning often want to negotiate with the authority about some the planning. The general public also need to learn professional knowledge from both the professionals and the planners. How to secure a 2-way flow of information between the user and the planners?
- How to manage all these information: spatial data, non-spatial data and related metadata?

3.2 Analysis of functions requirement

3.2.1 Holding a meeting over the Internet

Public participation has been taken for granted in environmental and regional planning to get a consensus decision.The participation we take for granted always become perfunctory and frustrating in traditional approaches. It also becomes perfunctory for government officials who receive masses of letters on a controversial project knowing

that the general public lack the authority to make changes in the project based on the concerns expressed in the letters. And it is frustrating for the people who write, because they feel their letters are paid no attention. Common practices in traditional methods of public participation involves the public, or at least those with an interest, attending planning meetings which quite often involves an atmosphere of confrontation. Less vocal majority causing public meetings to be dominated by individuals who may have extreme views can discourage participation. These views may not necessarily represent the wider opinions of local people. Planning meetings often tend to take place at specific times that can limit the numbers of people who are able to attend. The restricted time and the actual geographical location of public meetings can further restrict the possibility of widespread attendance. Physical access to such meetings can lead to the exclusion of the disabled, the elderly and infirm as well as those who maybe deaf.

There are many advantages of a Web-based approach to local, regional and national public participation events. Because of the great popularization of Internet at the end of 20^{th} centenary and its mass access, if we can provide public meeting on the Internet, the meetings are restricted by neither geographical location nor time. Access to the information about the issues being discussed is available from any location with the Internet access. The information is also available at any time of the day thus avoiding the problems associated with holding meetings only at specified time. The concept of a "24/7" (i.e. 24 hours a day, 7 days a week) access opens up opportunities for more people to participate in public consultations. With a Web-based system the public is at the end of a telephone line that enables them to make comments and express their views in a

relatively anonymous and non-confrontational manner compared with the traditional method of standing-up in front of a group of strangers.

3.2.2 Understanding the problems in a interactive and immersive environment

In decision-making process, the first and the most important stage for the users is to comprehend the planning problem. The depth of the general public's response is constrained by lack of information of the planning project. And there is always a lake of approach for the public to present their views. Taking an ecological planning in a country park as an example, before the planners or decision-makers can do something about the ecosystem, a detailed study area environment description is necessary. Conventional description methods include textual based specifications, photos, and some multimedia contents like video or audio. According to Batty et al (1998), a virtual environment offers many benefits to spatial problem representation and environmental modeling. Apart from some professionals from various fields, most of the end users of this system are the general publics who have very few expert experience and knowledge to spatial problem, However, it will be a hard job for these users to read the obscure jargons in the textual description. Several pieces of research in the past have questioned the public's ability to understand a map that is essentially a "birds-eye" view of a place (Monmonier 1996, Keates, 1996). Many people do not instantly recognize a location when it is presented to them as an aerial view. This is no longer a problem when presenting the environment in a 3D manner. Web-GIS enable the user to click on a feature on the map and be interactively informed what feature it is. 3D representation of the study area provides

immersive understanding of the planning problem. A toolkit containing zoom in, zoom out, pan, and identify tool will assist the user on navigation and visualization.

As I mentioned in Chapter 2, the traditional wildfire behavior simulation system try to represent or predict the spread of a wildfire in a specific boundary. Inputs of a wildfire behavior simulation system generally include two types of data: fuel bed data, and weather data, which exclude the spatial variability of fire behavior on different slop, aspect. If integrated with GIS, wildfire simulation system enables the simulation over a spatial environment. Another essential benefit from GIS is that the GIS provides efficient functionality of spatial data management. Moreover, GIS assists planners to quickly meet the demand of graphical user interfaces of the public. People that have only vague pictures will find their way of presenting their ideas. Actually, it is often hard for the general public to imagine the outcome of planners' design based on maps, therefore discussions or other well-organized communications can often invigorate their inspiration for what visual environment they desire.

3.2.3 Sharing ideas among all users

There are potential conflicts between the planners and the local inhabitant. Public participation has proven qualified to dilute the conflicts and enhance cooperation between the planners and local citizens. Meaningful communications among the general public, the professionals and the government are the inherent elements in the participation process where the users have opportunities to shape decisions (Susskind 1994). A Web-based system is unique in its ability to provide a 2-way flow of information between

public & system/decision maker. But users may want to do some graphical revising or suggestions to the draft plan and want to get an instantly visualized outcome of the revising. Very few attempts have been conducted to offer users graphical commenting tools.

3.2.4 Maintaining spatial and non-spatial datum with GIS

To perform the wildfire simulation there are three types of important issues to be addressed: spatial, quantitative and qualitative. Spatial issue indicates where to ignite the fire. As mentioned in Chapter 2, fire behavior is a product of the environment in which the fire is burning (Pyne et al., 1996). Topography includes the slope steepness, aspect, elevation, and configuration of the land. Although topography may not change in time, it shows its contribution on the fire behavior in two ways: it affects the way in which fuel and weather change. The wildfire simulation in this study only considers point source fire (Pyne et al., 1996). Another set of variables of the fire simulation is weather data: wind direction and wind speed.

Spatial database maintenance is the basic functionality of a Web GIS. Web GIS can fulfill more complex jobs than the previously mentioned, for the reason that GIS grants users a ready-to-use and efficient way of 'map thinking'. One of the successful work that attempts to facilitate the public to participate in an environmental decision-making process is conducted by the Centre for Computational Geography, School of Geography, University of Leeds, UK (Kingston et al., 1998) (Figure 3.1). User can use 'Zoom' and 'Pan' tools to browse the digital map of the study area. Users can even select specific

area that meets specific criteria with an 'Find' tool developed with extended Structured Query Language (SQL), which is an easy to use query language similar to natural language. After a tour in the project website, with the help of graphical user interface, users can have some idea about the planning problem background environment, including the vegetation distribution of the study area, characteristic of ground truth, and features such as rivers, roads and residential area.

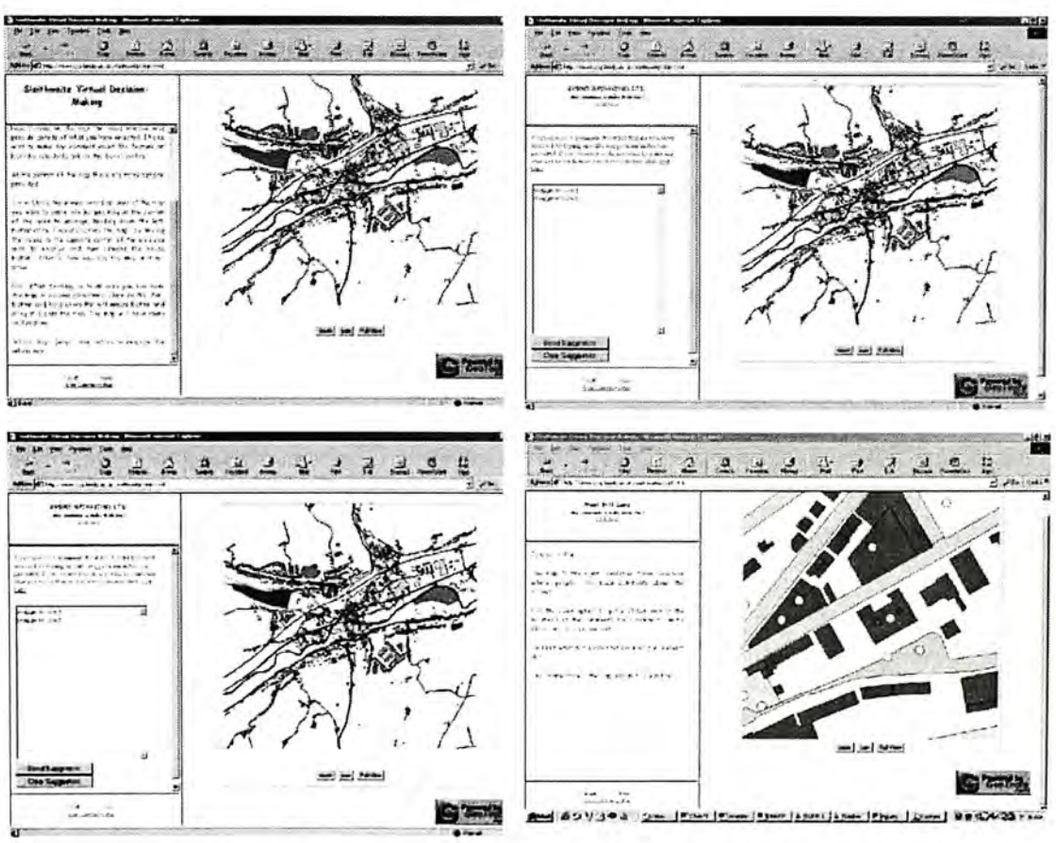

Figure 3.1 Virtual Planning project in Leeds
source: http://www.geog.leeds.ac.uk/

3.3 A host of solutions

3.3.1 Finding the balance between client/server

Participation of the professionals and the general public is an interactive process; therefore, this system must have a bi-directional mechanism, an information flow between the general users (the professionals and the general public) and the planners for draft planning revising. Client/server architecture is often considered to carry out complex request processing in a distributed environment, and client/server architecture has been proved rather functional on Internet (Plewe 1997). In Internet environment, users' operations on the client side are often composed as a Uniform Resource Locator (URL) request in HTML pages. To do complex network based collaborative GIS operation, additional GIS components are added in client side or server side depending on what service the system intends to provide.

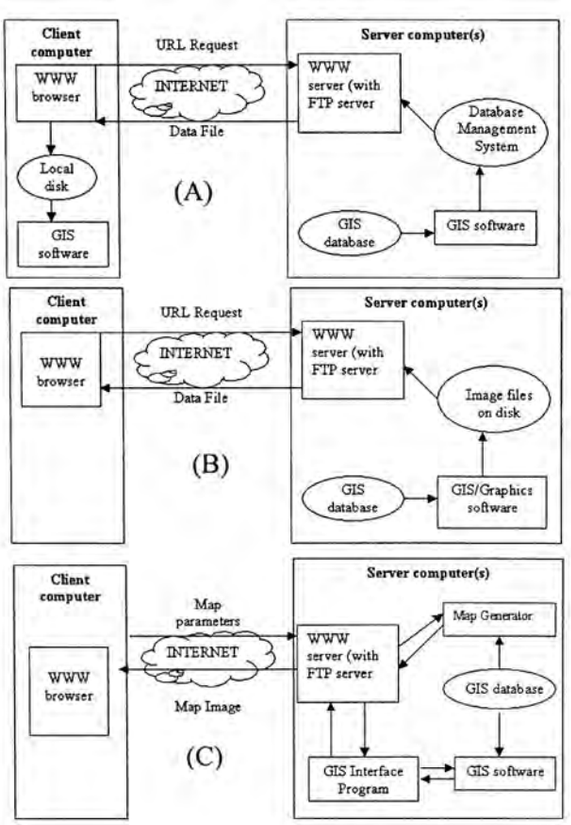

Figure 3.2 Three types of Internet GIS service

(A) Raw data downloading online GIS service
(B) Static map displaying online GIS service
(C) Dynamic map browser online GIS service

(Plewe. B *GIS Online*)

Software is available for both Web browsers and servers that can handle at least some of the computing involved in network based geo-referenced analysis. System developer will need to decide which elements of the system will be located on the server computers and how much system computation will refer to the users' computers. Other factors, such as computer performance and network flow rate, should be considered when constructing a network-based system.

To provide a functional and smoothly service designers have to find the balance between the breadth and depth. For example, a thick client allows flexible and powerful analysis, but it is dramatically influenced by network traffic. Endless waiting limits audience of the system, and can be a nightmare to maintain. A thin client/heavy server setup uses considerable a mount of network bandwidth to send the map data, and is generally limited to simple applications. However, thin client/heavy server architecture can be used by many more people, including those not willing to download and install a thick client just to just your service.

Based on these analyses, I designed a multi-tiered architecture for this system as shown in Figure 3.3.

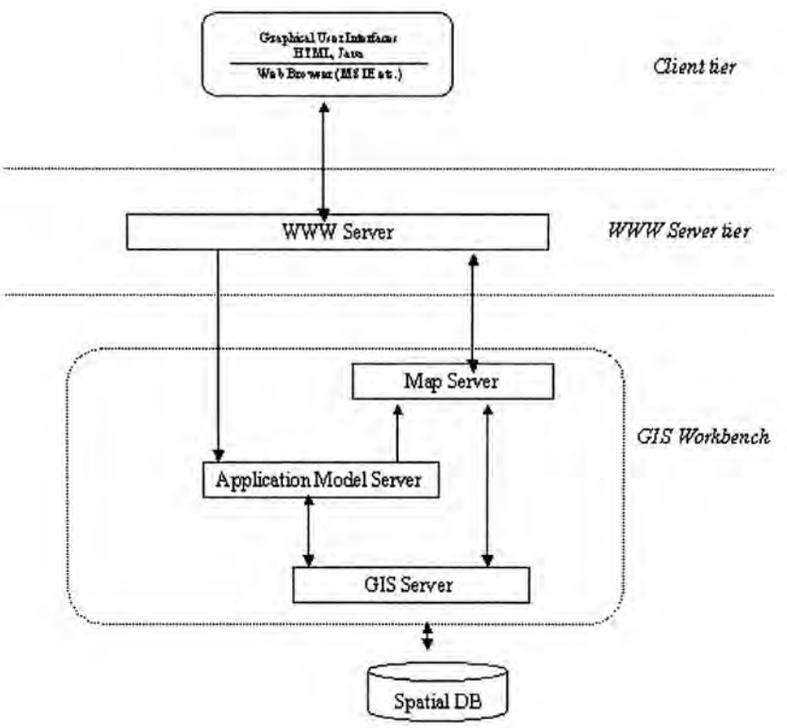

Figure 3.3 Multi-tier architecture of the virtual studio

3.3.2 Design of user interfaces

A typical environmental decision-making progress is usually represented at a staff level (by those with the most technical knowledge), in professional manner, with dull jargons. The planners and the professionals from affected research fields always have a strong knowledge background about the computer system, however this is always a barrier for the general public. Since the popularization of Microsoft Windows operating system on PC, the Windows style graphical user interfaces are getting more and more acceptance by the general public. Hence, user interface here should be in a convenient style as Windows with graphical user interfaces (GUI).

There is a very limited published literature on the use of computer graphics to improving public participation in social science research, but even more limited when focusing on the potential of the Internet. The literature available in this field falls into one of two emerging categories. The first relates to the debate surrounding the benefits, pit falls and practicalities of using the WWW as a tool for carrying out social surveys. The second area relates to research, which has either taken place or is underway and illustrates actual cases where the WWW has been used for survey research. Mumford (1996) discussed the technical issues of using graphics on the WWW although not necessarily as part of on-line surveys. Generally speaking, these works should be the superficies of using of Windows style graphical user interface to secure the general public involved in some decision-making or public preference capturing process.

The next part of user interface is wildfire simulation user interfaces. Some check boxes and blanks will be set by the users to initial the fire environment: wind direction, wind speed, etc. To select the ignite point, what users need to do is just a mouse click on the Digital Elevation Map (DEM) with a point-selecting tools. Then the user can start the fire simulation with a mouse click. Computation of the progress of fire behavior simulation conducts in some background threads. Simulation outcomes will be then added as maps overlaid over the DEM for user's instant view.

Last but not the least, users may have some suggestions or comments on the plans. User comments submitting tool and comments collecting tool will empower users to shape user's comments in textual or graphical format. Textual suggestions can be embedded in

HTML and sent to the server side, which will be reviewed by the planner as reference to revise their draft plans. Users can also submit graphical comments with "Map Notes" or "Edit Notes" tools (ESRI technological white paper). These graphical contents can be displayed and overlaid on the digital map. They will then be sent as a XML script to the server side.

3.3.3 Offering online geographical analysis with Web GIS

Demand exists for online maps browsing and online geo-spatial query for this system. A professional solution is to set up a Web GIS website. Since here what we focus is not on Web GIS developing. The online maps browsing and online geographical analysis are served by commercial Web GIS software.

After several years of development, there are many choices when you plan to order Web GIS software. Table 3.1 is a comparison of some latest released leading commercial Web GIS software packages. (Table 3.1)

Table 3.1 Latest released Web GIS software

(Data source: technical white papers from software manufacturer or related technical web page)

Manufacturer	Web GIS product	Supporting data source	User operating object	Architecture	Platform (server side)	Platform (client side)	Database connectivity	Re-developing mechanism	Price
ESRI	ArcIMS 3.0	Vector (shapefile, ArcInfo coverage file, Raster	Static map in image format	Multi-tier client/server	Windows NT or Unix with Web Server	MS Windows NT or Unix with Web browser	ODBC, JDBC supported	Java, JavaScript,	800 -1500USD
ESRI	MO IMS	Vector (shapefile, ArcInfo coverage file, Raster (image data)	Static map in image format	Client/server	Windows NT Web Server	MS Windows NT with Web browser	ODBC supported	MapObjects1.0 and Visual Basic	800-1200 USD
AutoDesk	MagGuide 5.0	Vector (AutoDesk files), Raster (image data)	Vector data or static image	Not available	Windows NT server or Windows2000 Professional	Windows with Web browser	ODBC supported	API with Visual C or Visual Basic	Not available
Intergraph	GeoMedia WebMap	Most Vector and Raster image data	CGM graphics file or JPEG file	Client/server	Windows NT with IIS 4.0	MS Windows with Web browser	ODBC supported	Java, JavaScript, Visual Basic	Not available
MapInfo	MapInfo MapXtreme Java Edition 3.1	Vector (MapInfo MIF files), Raster (image data)	Not available	Muti-tier client/server	Windows NT or Unix with Web server		JDBC-ODBC bridge supported	Java, Visual Basic	Not available

This figure illustrates that:

1. Most of these products have client/server architecture, and support ODBC or ODBC-JDBC bridge which empower them to integrate with commercial Database management systems such as Oracle, SQL Server or Sybase. All these products have a extending mechanism, which enable end users to develop their own applications with computer compiled language or script language based on the Web GIS (i.e. AML, MapBasic.).
2. Product of AutoDesk is designed for architecture and urban planning visualization applications on the Internet. Although it has a qualified data format supporting these data source, it is not designed for the complex spatial analysis over the Internet. But in my study, there are many spatial analysis requirements, so it can not be applied for the development platform in this study. WebMap from Intergraph has the most broadest data format supporting; but its Microsoft Windows-based technologies exclude itself for multi-platform application.
3. ESRI develop two Web GIS products, MapObject Internet Map Server (MOIMS) and ArcIMS 3.0. Many Internet mapping services are available on the Internet developed with MOIMS. Most of these services are developed with MOIMS and MapObject1.0. For example the CENTAMAP website in is developed with MOIMS, MapObject and Oracle Database system (http://www.centamap.com/). However, this Web GIS product does not provide a user modifiable (in fact, what the user operate on is just a snapshot of the spatial database and takes no effect on the physical database) mechanism, which is vital for this virtual studio system.

4. Another Web GIS product from ESRI is ArcIMS. It is multi-tier client/server architecture based Web GIS software (see Figure 3.3). As Web GIS software, it has standard Web GIS functionality and friendly user interface. ArcIMS can integrate with standard relational database system smoothly. Additionally, with the help of ArcSDE ArcIMS can support almost every spatial database. ArcIMS provides two platform independent client side viewers: Java Viewer and HTML Viewer. ESRI authorize ArcIMS developers to customize the client side HTML and Java Viewers with JavaScript and Java language. Applications can be developed with Java. These user applications will be put on the server side as server program or Java Applet that can be downloaded by the client side and run with the ArcIMS to provide complex spatial functionalities.
5. In this study, I propose to develop a textual/graphical user feedback submitting toolbox and feedback maintaining tool. Fortunately, ESRI extends standard Extensible markup language (XML) and develops ArcXML to define metadata of a map on Internet. ArcXML can be used to develop a graphical user feedback toolbox with the least workload for me in this study.
6. Spatial data is at the heart of every Internet mapping project. Original data format of my case study are all in ESRI shape file or ArcInfo coverage format. Shape file can be directly added into ArcIMS map service. Additionally, using ArcSDE for Coverages, spatial data in other ArcInfo format (ArcInfo coverage file, e00 file or grid file) can be accessed and operated.
7. The last but not the least, I have 3-4 years experience of using ESRI products and I am familiar with the development skills of developing with ESRI products

which plus the possibility of I choose ESRI product as the development platform for this study.

Source coding is always a burdensome job in any project. Fortunately, there are many GIS open source code available on the http://www.uk.ac.leeds.ccg.shapefile/ is an extensible Java package that user can include it in their own Java program to read ESRI shape file. To reduce workload, this project extent this Java package to fulfill the shape file operation. Accordingly, here I chose ESRI ArcIMS as the Web GIS platform to set up this virtual studio system.

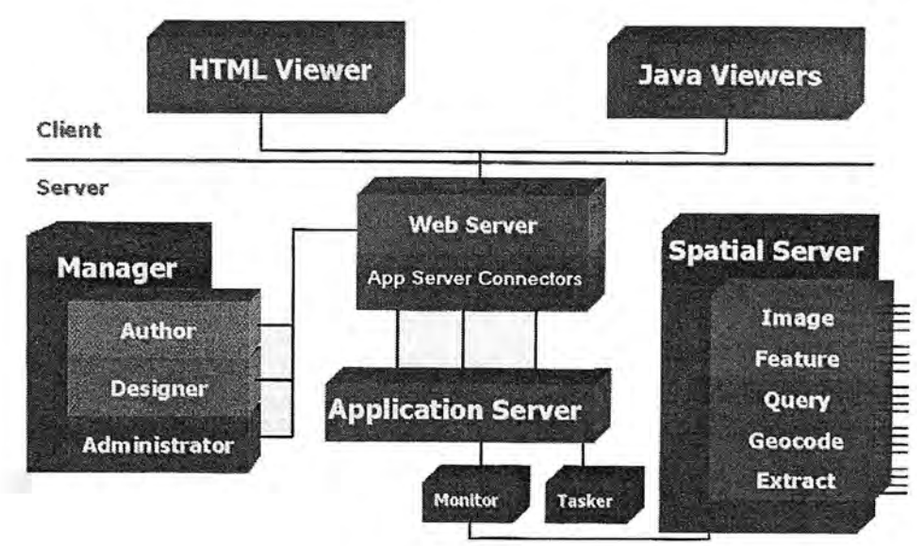

Figure 3.4 ArcIMS: Multi-tier client/server architecture based Web GIS (from ESRI technical document).

3.3.4 Visualization of fire behavior

Based on a balanced client/server architecture designing, a Web GIS server will be located on the server side. Hence another important component of the system, the fire visualizing modular, will be located on the user side. Users will first initialize the system simulation parameters, these parameters will then be sent to the server. Simulation computation will perform on the server by a Java Application.

3.3.5 3D DEM representation on Web

3D scene offer more benefits to help GIS users to visualize the geo-referenced information than 2D GIS (Batty, 1998). There are two types of method to represent a DEM in 3D scene: traditional GIS and virtual reality method. Traditionally, elevation maps are converted into specific 3D data format such as 3D shape file, TIN file, etc, and then displayed with GIS software. The newly developed virtual reality (VR) method try to simulate the real 3D world as close as possible with additional computer graphics equipments, like head mounted display, digital glove input device video and audio devices, so that users can navigate within the 3D virtual environment (Batty, 1998).

These two methods are not suitable for network environment. Firstly few general public users have these professional GIS software and are not familiar with these complex data format conversion. Secondly, even fewer people can afford these expensive professional equipments. Last but not the least, these 3D data files are always large in size, and there are always many files that users need to download. Long time data transferring on Internet will certainly reduce the amount of audiences.

Virtual reality modeling language (VRML) is one of the solutions to overcome aforesaid difficulties. VRML is a language or a file format for describing 3D objects or "world" to be experienced on the Internet (http://www.vrmlsite.com/). With VRML authors can construct entire worlds, with links to text, audio or video files, HTML files or links to other VRML worlds. Any Web browser that has a VRML plug-in pre-installed can view a VRML model. These plug-in software is available on Web and free for downloading. Following is a VRML example (Figure 3.5 and Figure 3.6). Furthermore, developers have more flexibility to customize the VRML model with Java language. With VRML what users need is just a computer with Internet access to browse a 3D digital elevation map on the Internet.

Figure 3.5 A VRML DEM model

```
#VRML V2.0 utf8
#
Group {
  children [
    WorldInfo {
        .........
    }
    NavigationInfo {
      .........     }
    Background {
      .........     }
    Fog{
       .........
       }

    Viewpoint {
      .........
       }
    DirectionalLight {
      .........
    }
    Inline { url "dem011.wrl" }
  ]
}
```

Figure 3.6 Script of the VRML

3.4 Summary

Begining with requirement analysis of this Virtual Studio, followed by feasibility analysis, this chapter deals with the problems: "what do we need and how do we get them?". Based on these analysis, ESRI ArcIMS is choosed for the development platform in this study. Java and ArcXML are selected to develop user applications in this system. To lessen the workload in this study, I deployed the Java open source package from the University of Leeds for the operations on shape file in this system.

Chapter 4 Simulating the wildfire

Wildfire risk or wildfire behavior prediction has been studied for many years (e.g. Rothermel 1972; Wang et al., 1983; Salazer 1983; Andrews 1986; Zheng 1988; Chandler 1991; Diogo 1994; Zhao 1995; Lee 1996.). All these studies show that fuel bed, configuration of topography and wind are the three most important factors that should be considered in the wildfire study. Fuel bed varies with longitude and latitude from place to place. Consequently, Rothermel model should be modified when it is applied for local wildfire study.

According to the studies of Rothermel (1972) and Countryman (1972) simulation of wildfire should include both wildfire behavior simulation and fire environment simulation, therefore following contents in this chapter will deal with two problems: fire environment simulation and modeling of wildfire behavior.

4.1 Physical Setting of experiment area and data preparation

4.1.1 Physical Setting of experiment area

As it is said, one of the best ways to validate a theory is to do experiment. Chinese Academy of Forestry Science (CAFS) conducted one forest fire study at state level in 1991 in Sichuan province, China. With the help of local government and local forest fire fighters, professionals from CAFS chose an experiment area to perform the forest fire experiment.

Experiment area of the wildfire study is on Mopanshan Mountain, surrounded by Yalongjiang River. Mopanshan Mountain lies in Liangshan Zhou, Sichuan province, China. The whole territory lies between Latitudes N27°40' and N27°46', Longitudes E102° and E102°8'. Experiment site in this study is Mopanshan Mountain (Figure 4.1). Total fire experiment area is 1.1 km^2 . Experiment area lies on the north margin of north sub-tropics. The average total rainfall is 1100mm. The precipitation also shows seasonal changes. The driest month is from January to March, with an average value of 20mm per month.

Most wildfire in this experiment area occurs during the dry season, from November to April. Some of these fires are natural event but frequently induced by human carelessness or even arson.

Table.4.1 Forest fire statistic data in Sichuan province since 1950'
(source: Cai and Yi, 1995)

Year (19--)	Burned forest area (ha)	Burned forest area (per year) (ha)	‰
56-60	192936.3	38587.1	4.82
61-65	156736.8	31347.4	3.92
66-70	98328.6	24582.2	3.07
71-75	119499.9	23899.9	2.99
76-80	73179.1	14635.8	1.83
81-85	31460.8	6292.2	0.79
86-90	7448.9	1489.8	0.19
Total	773904.4	159697.4	19.97
Average	96738.1	19962.2	2.50

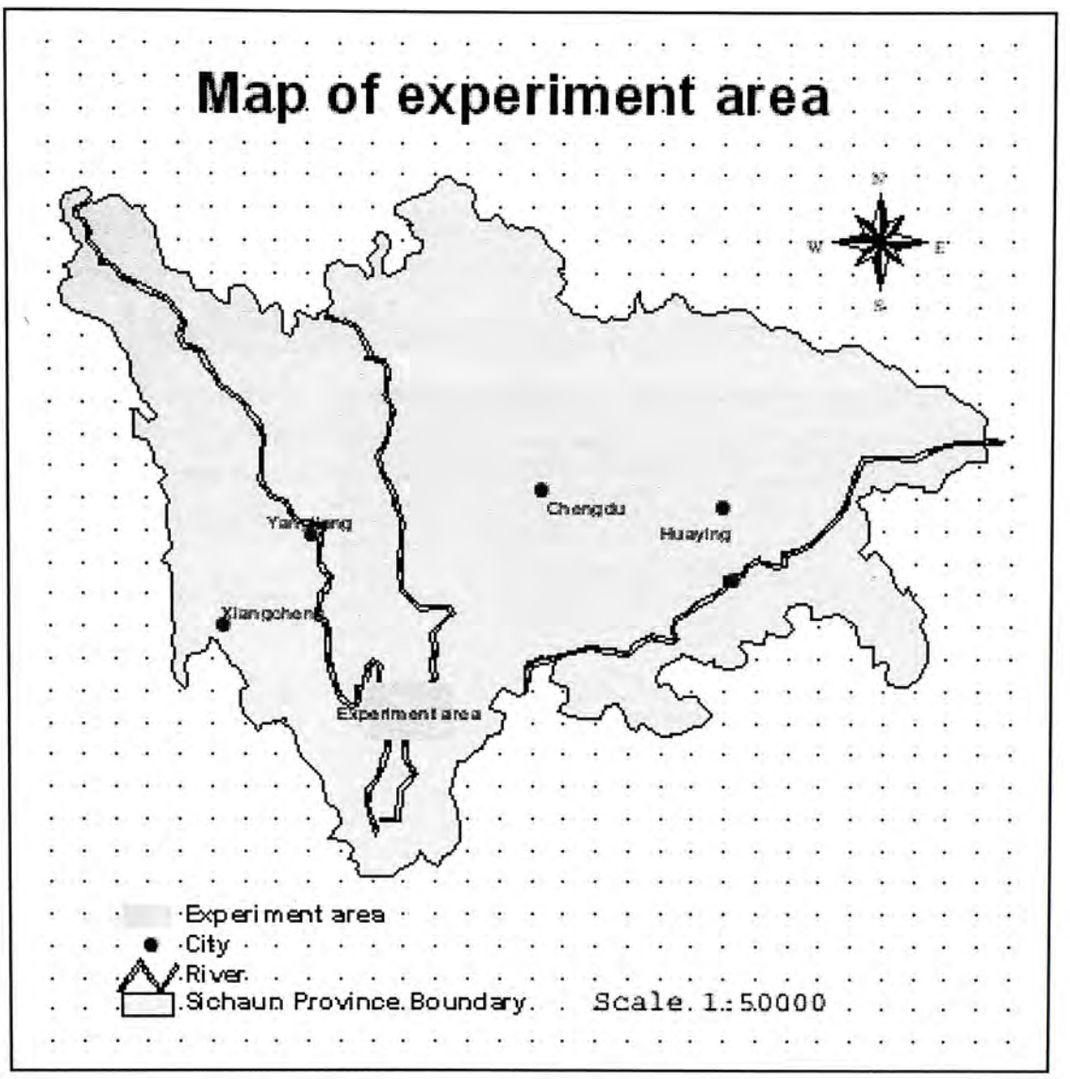

Figure 4.1 A map of experiment area

Vegetation is the carrier of fire burning and fire spreading. Impacts of vegetation to forest fire vary with forest type, canopy density, and growth stage. 64.7% of total area of the experiment area is covered with Yunan pine, and 34.1% of which are grown Yunnan pine, 52.6% are growing Yunnan pine. High canopy density can reduce vaporizing of water in fuel bed and soil; subsequently high canopy density will increase air humidity and reduce the possibility of ignition.

The highest peak in Mopanshan mountain range is 2731m in height from sea level. The lowest site in the experiment area is 1180m in height. Figure 4.2 is a 3D digital elevation map of the experiment area.

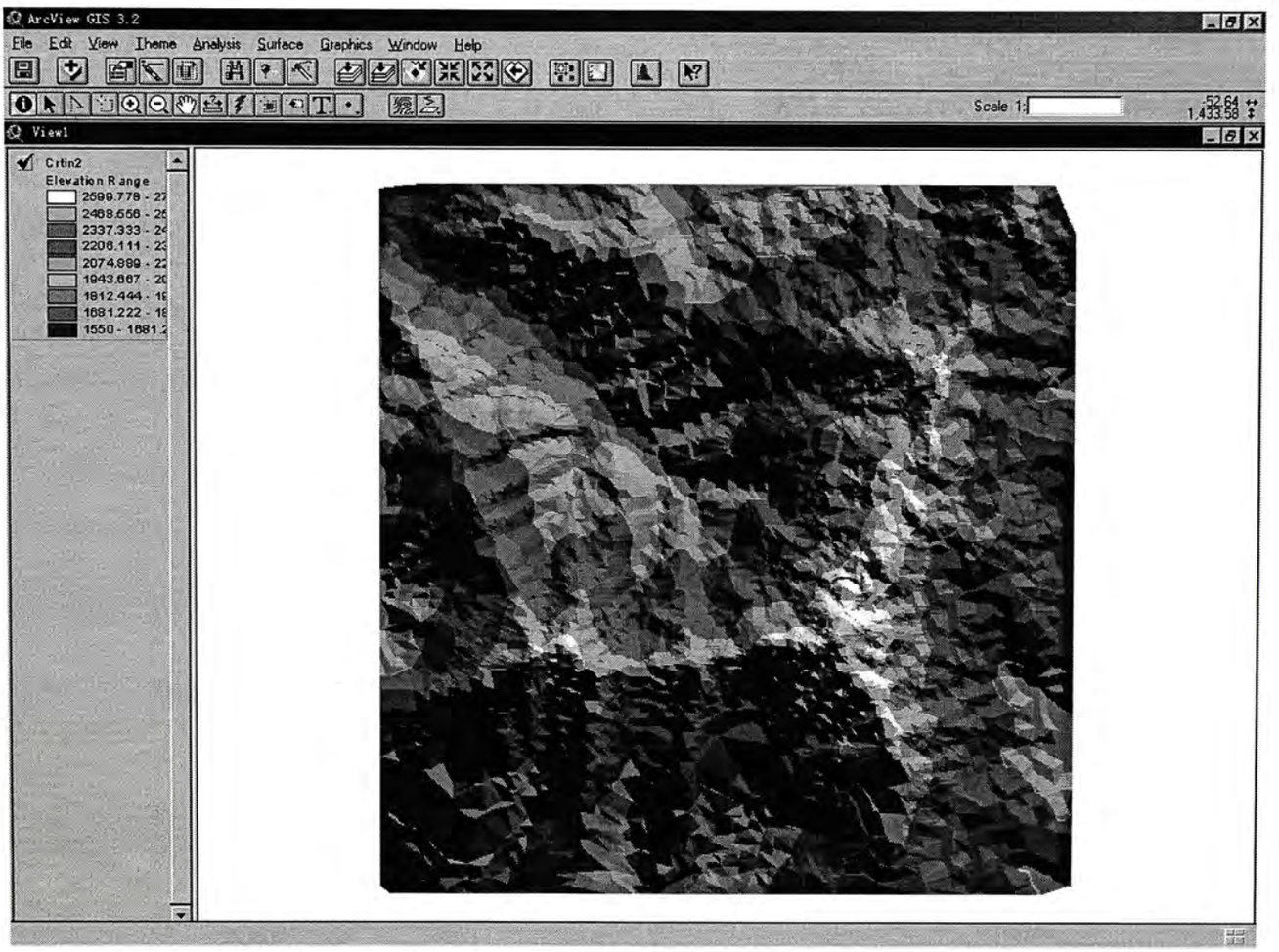

Figure 4.2 3D Digital elevation model of experiment area

4.1.2 Data preparation

Basic data sets in this study include weather data (air temperature, air humidity, rainfall), features of ground truth (rivers, roads, residential area, etc), configuration of topography (elevation map), and wildland fuel bed data. Furthermore, forest fire history data are also collected for temporal study.

Weather data are collected from local observations. These data include monthly average relative humidity (ten years), air temperature and rainfall statistic data within 15 days before the forest fire experiment.

Elevation map of experiment area in scale of 1:5000 is first scanned and then digitized with ESRI ArcView 3.2 GIS software. Other feathers such as river network, roads, and residential area are subsequently digitized. Some feather attributes data like river title, residential site title are input by editing the attribute table of each thematic map with ArcView GIS software. These digital maps are originally stored in ESRI shape file format. Some of these digital maps are then converted into ArcInfo coverage format for topology construction and following spatial analysis.

Fuel is consumed in a fire. Fuel bed here indicates fine fuel, such as dead grass, needles, and small twigs, duff and associated downed woody fuel. Yi Haoruo and Ji Ping's (1994) experiment of forest fire in China proved that ROS of forest surface fire mainly depend on the characteristic of fine readily combustible material such as dry twigs, dead grass, and needles. Duff layer is a term that refers to organic forest horizons (fermentation and humus layers) that accumulate above mineral soil. Once ignition occurs the fire begins to

burn downward and laterally, if conditions are favorable for sustained smoldering. Duff layer is consumed in lateral fire spread (often below the surface). Therefore, consumption of duff layer takes little effect on the ROS; ROS is mainly affected by the consumption of fine fuel.

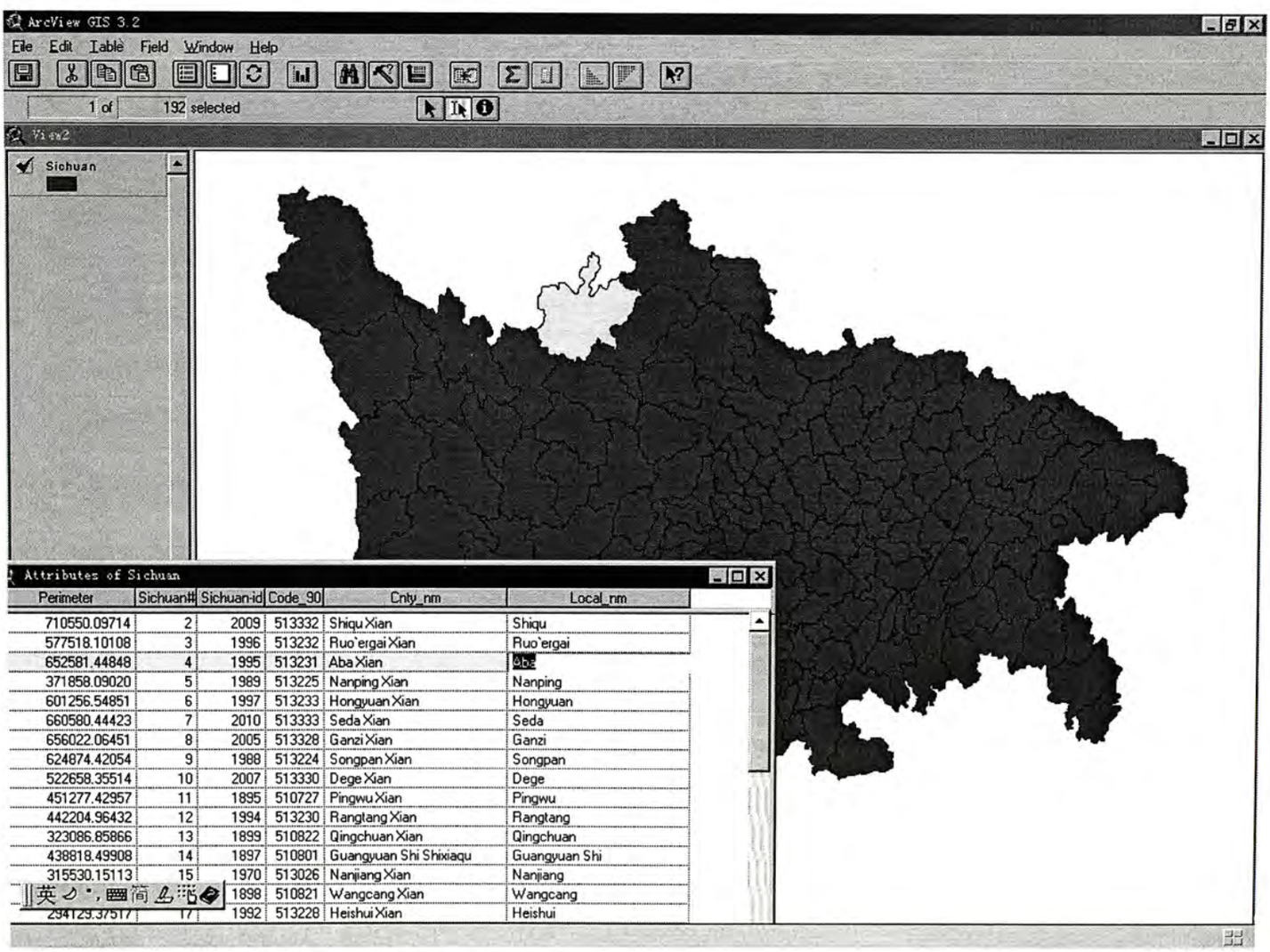

Figure 4.3. Attribute data inputting with ArcView GIS software.

Based on this notion, sampling works were conducted by CAFS in the Yunnan pine forest of experiment area. Later experiment of low heat content menstruating was done in the lab of CAFS. Here, the author directly makes use of these experiment result data in this study.

Table 4.2. Heat content of different Yunan pine forest in experiment area.

Forest type	Heat content of combustible (10^{10} J)	Heat content of fine fuel (10^{10} J)
Rough Yunan pine	1.7848	1.7466
Shrub Yunan pine	1.8002	1.7758
Indeciduous Yunnan pine	1.8007	1.8071
larchen	1.7955	1.7921
Handonggua Yunnan pine	1.8119	1.8035

Weather data are collected from local weather observation station or measured at the experiment area by researchers from CAFS. Weather data here contain three types of data: air temperature data, rainfall data, and relative humidity data. Rainfall and air temperature data on and 15 days before the forest fire experiment day are collected. Monthly average relative air humidity of the experiment area within 10 years is collected to get an kriging daily average relative air humidity of the experiment area. Monthly relative air humidity Kriging is performed with Surfer software from Golden software, Inc.

Table 4.3. History forest fire burned area and corresponding relative humidity. (Unite million ha, %) (source: Cai and Yi, 1995)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*
Burned Area	3.3	15.3	22.7	15.7	10.2	1.1	N/A	N/A	N/A	N/A	0.004	0.2
Relative Humidity	51	46	41	45	56	73	75	75	75	74	66	59

4.2 Adaptation and formularization of the Rothermel's fire behavior model

Wildfire behavior index includes the rate of fire spreading (ROS), fire intensity, etc. These indicators are the basic of the wildfire behavior simulation, the fire fighting and the fire lost estimation. Wildfire behaviors have been proven a very complex progress. The best-known model in forest fire spread is the one developed by Rothermel (1972, 1983). It allows the forecast of the ROS and the reaction intensity knowing certain properties of the fuel matrix and environmental conditions in which the fire will occur. This study is not to achieve a accurate fire behavior simulation result, as we mentioned in chapter 1 and chapter 3, consequently, all analysis in this study will concern about surface fire into consideration. Rothermel's model is simplified for this case. Localization and simplification work are based on the following assumptions:

- Rothermel's (1972, 1983) model is the representative of the fire's speed of propagation.
- Small-scale winds like slope winds that caused by local temperature difference are ignored in this case.

- Vegetation is homogeneous within each cell.
- Effect of topography on wind speed and direction is ignored.
- Since data of configuration of each fuel particle is not available, effect of fuel particle on fire behavior is brought into fire spread equation as a constant that got from lab experiment data. This constant is fit only for data set in this experiment area.

For a surface fire, fuel bed, general configuration of topography and wind are three most important factors that should be considered. In this manner, rate of fire spreading can be estimated from following expression:

$$RS = f(fuel_particle, fuel_array_arrangement, wind, fuelmoisture)$$

or

$$R = A \times K_f \times K_{mt} \times K_g \times K_w$$

and

A is an empirical parameter, a combination invariable that decided only by the fire environment;

K_f is a value that decided by fuel bed;

K_{mt} is a value that decided by the weather (air temperature and air humidity);

K_g is a value that decided by the configuration of topography;

K_w is a value that decided by the wind;

Following are specifications of each variable in the ROS function.

1. K_{mt} : Temperature and humidity indicator

Generally K_{mt} is a combined statistical value that provides an indication of the condition or direction of the air temperature and humidity. This indicator is used to describe the combined effect of air temperature and humidity to fuel bed. This value can be gotten from following equations.

$$K_{mt} = e^{-T_t} \times T_m \quad \text{.....(1)}$$

and

$$T_t = \sum_{i=1}^{15} \frac{S_i + 0.1}{\sum_{j=1}^{i} t_j + 20} \times 8 \quad \text{.....(2)}$$

$$T_m = \frac{1}{25.3 \times m^{5.6} + 1} \quad \text{.....(3)}$$

T_t is an air humidity-air temperature index adapted from meteorology. T_m is another temperature-humidity index that was first introduced into ROS equation by Yi and Cai (1995). One advantage of this new introduced index is that it takes variation of air temperature-humidity according to season and geographical location. And m is daily average relative humidity that results from the kriging of monthly average relative humidity data set in table 4-1. S_i is rainfall (mm) value on the no. i day before the day of forest fire. If it is rainy on day i, S_i equal to rainfall (mm) value, if cloudy, S_i equal to 0.02, and if sunny, S_i equal to 0. t_j is the air temperature at 2:00 PM on the no. j day before the day of forest fire. e is the base of the natural system of logarithms, having a numerical value of approximately 2.7183.

There are some basic hypotheses contained within these equations. Firstly, in dry hot weather, humidity of fuel particle will decrease. Secondly, effect of rainfall on fuel

particle humidity will reduce as time going by, and this effect will disappear 15 to 20 days after the rainfall (Cai, 1995).

2. K_f: Fuel bed indicator

K_f is an indicator that indicates the heat content of fine fuel, amount of fine fuel, particle density and type of each fuel particle properties. And configuration of this indicator represents the fuel array arrangement.

$$K_f = \sin(h_f \times B) \quad \text{.....(4)}$$

h_f is fuel bed depth (from soil surface to fuel surface). B, an empirical constant, equals to 0.18 in this case.

3. K_g: Topography indicator

According to the study conducted in Canada Forest Service Department (1988) and Wang (1983) following equation can define affect of topography to forest fire behavior:

$$sf = e^{3.533(\frac{\sigma}{10})^{1.2}} \quad \text{.....(5)}$$

$$\sigma = 10tg(\alpha) \quad \text{.....(6)}$$

So

$$sf = e^{3.533 \times tg^{1.2}(\alpha)} \quad \text{.....(7)}$$

and α is the gradient angle of this point or this cell, as shown in Figure 4.4.

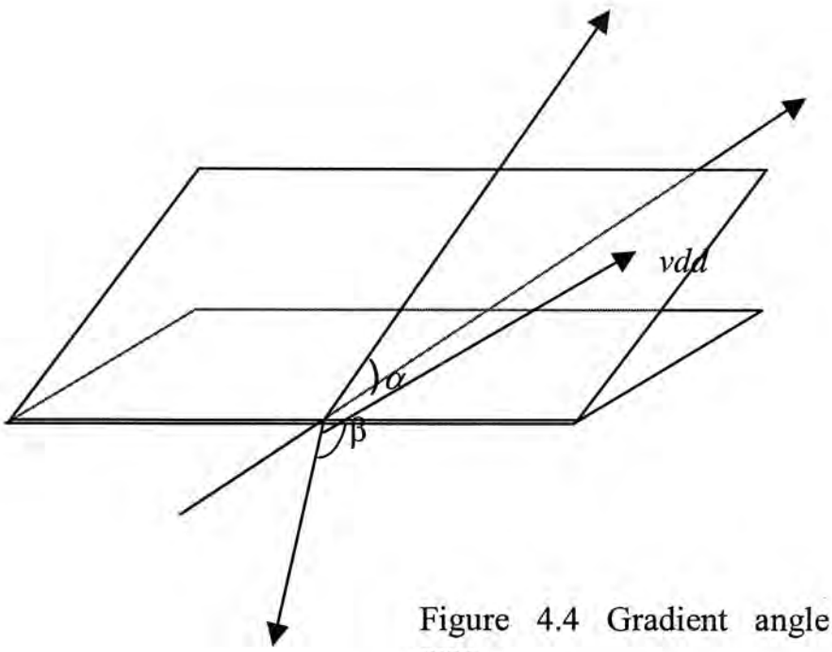

Figure 4.4 Gradient angle sketch map.
α: slope gradient angle
β: aspect angle

Vdd is the direction of fire spreading to be calculated (see Figure 4.4).

A higher *sf* value implies that configuration of topography at this point will have a stronger negative influence to the speed of fire spread.

From the forest fire experiment in Sichuan province, Yi and Cai (1994) found that equation (7) serve well when the slope angle is less than 15°, but this equation overestimate at cells where the slope angle is greater than 15°. Therefore Cai calculates the constant in this equation (3.533), and found that it should change corresponding to slope angle. So they modified equation (7) with the experimental data they got the forest fire experiment in Sichuan province.

$$K_f = e^{(-0.057 \times sd + 3.65) \times tg^{1.2}(\alpha)} \quad \text{.....(8)}$$

Figure 4.5 illustrate the relationship between slope angle and topography indicator K_f.

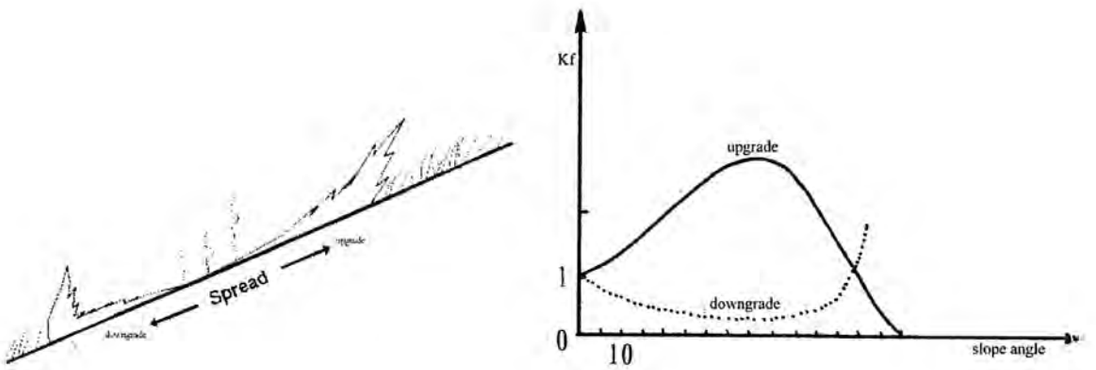

Figure 4.5. Relationship between slope angle and K_f in term of both upslope and downslope (Pyne et al., 1996).

4. K_w: Wind indicator

Wind direction and speed are paramount in determining rate of spread and what direction it goes, they are obviously very important factors in both the control of wildfire and a prescribed burn. Wind manifests its effect to fire behavior in two ways: to change the mode of heat transfer and exchange and to dry the fuel bed by carrying off the evaporated moisture. In direction of wind direction, fire spread speed has a negative relationship with wind speed; consequently K_w also have a negative relation with wind speed.

$$K_w = \propto V$$

$$\Rightarrow \Delta K_w \propto \Delta V$$

$$or \quad \Delta K_w = c \times \Delta V$$

$$\Rightarrow \int \frac{dK_w}{K_w} = \int c dV$$

$$\Rightarrow K_w = K_0 e^{cv}$$

$$\Rightarrow K_w = e^{cv}$$

V stands for wind speed. c is a empirical parameter.

Mao and Wang (1983) calculate the empirical parameter c with their experiment data:

$$c = 0.1783$$

Consequently, we consider the effect of wind (speed and direction) on fire spread in different directions.

$$K_w = e^{0.1783 \times V \times \cos(Vdd - Wdd)} \quad \text{.....(9)}$$

Vdd is the direction of fire spreading to be calculated (see Figure 4.4). Wdd is wind direction angle.

To sum up all the effect of topography, wind, fuel bed and weather on fire spread, following expression is used to illustrate the complex relationship.

$$RS = f(fuel_particle, fuel_array_arrangement, wind, fuelmoisture)$$

$$\Rightarrow RS = A \times K_{mt} \times K_f \times K_g \times K_w \quad \text{.....(10)}$$

Cai and Yi (1994) calculated the value of A with experiment data set that they got from the forest fire experiment conducted in Mopanshan, Sichuan. Outcome of their calculation is that A equal to 1.4 in this case. Hence, expression (10) can be revised as following:

$$RS = 1.4 \times K_{mt} \times K_f \times K_g \times K_w \quad \text{.....(11)}$$

4.3 Fire spreading algorithm.

Before calculation of fire area boundary spread, there must be a map of Rate of Spread (ROS). A ROS map is always a grid digital 'map', each cell in the map correspond to one numeric value to describe the ROS when there is a fire in this cell. Flow chart in Figure 4.6 shows the procedure of how to get a ROS map.

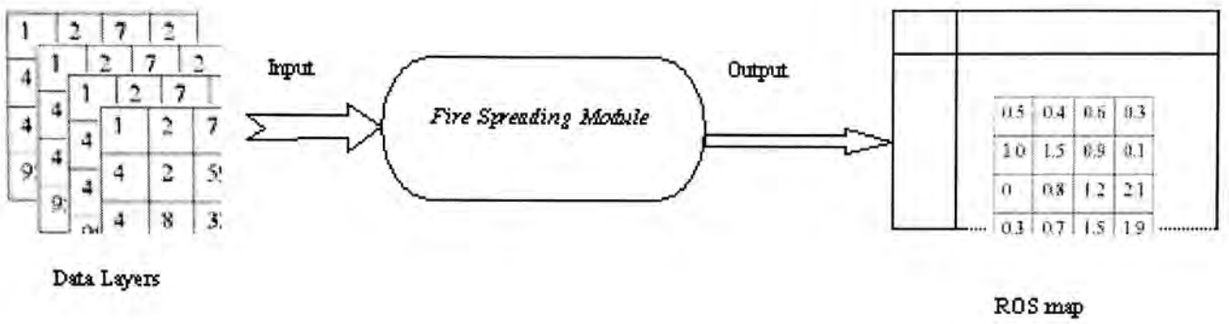

Figure. 4.6 ROS map flow chat

There are many algorithms that try to modeling the spread of fire boundary, such as eight-direction boundary interpolation algorithm, boundary extrapolation algorithm, maze routing algorithm and even Markov process, etc. Recent years, cellular automata (CA) algorithm is also introduced to modeling wildfire spreading in a two dimensional manner (Diogo & Goncalves, 1994; Fujioka, 1999); with consideration on feasibility, reliability and workload, I adopted boundary extrapolation algorithm for this case study. With the aid of GIS, fire environment information such as digital elevation map, fuel bed description information, and weather data are input as basis of fire spread behavior simulation.

The proposed model is based on the following assumptions:

- There are eight independent wind directions.
- In each time step, each cell can only propagate fire to only one of the eight adjacent cells.
- Only cells with fire already extinguished or without vegetation are not subject to fire propagation.

The presented method requires the definition of the vegetation matrix of the selected area of simulation. Therefore each cell has its characteristics, defined by several layers of information corresponding to vegetation (Since in this case study there is no hope to get vegetation or fuel model data in this selected area, and to simplify the computation, we assume that each cell in the study area is covered with fuel except lakes and rivers. And effect of fuel to the fire behavior is introduced into the model as a fixed value (Cai & Yi 1994)) and several physical variables:

- Air temperature
- Air moisture
- Wind velocity
- Wind direction
- Topography characteristic

Fire ignition may start in one or more cells, while for this study we only concern one manner: fire ignition starts in one point (one cell or several adjacent cells). In the manner of boundary extrapolation algorithm, Fire area boundary is presented as boundary of a dynamically spreading object. Each may then have one of three possible states: 1. Unburned; 2. Unburned with no capacity to propagate; 3. Fire with capacity to propagate (burning); and 4. Burned. For each model interaction, there is a propagating cell and eight adjacent cells as in Figure 4.7.

i+1, j-1	i+1, j	i+1, j+1
i, j-1	i, j	i, j+1
i-1, j-1	i-1, j	i-1, j+1

Figure. 4.7 Cell and its neighbors

Fire boundary can be defined as a set of cells that: 1. have at least one adjacent burning cell; 2. with capacity to burn and propagate to adjacent cells. In Figure 4.8 cell A is an element of boundary cell set, while cell B does not belong to the boundary set.

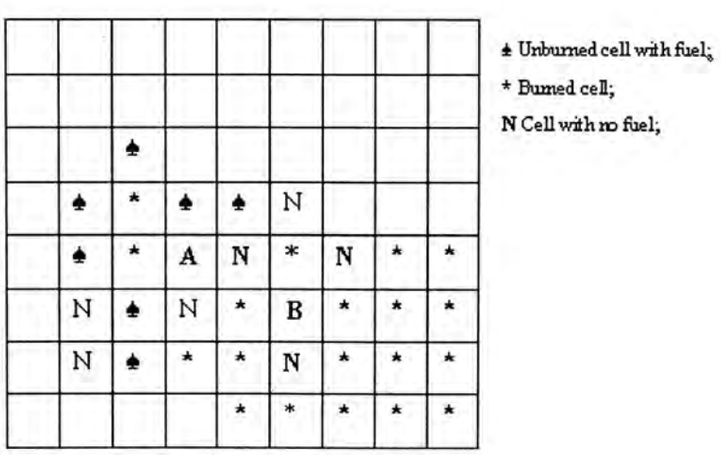

Figure.4.8 Determining of boundary cell.

Figure.4.9 shows seven steps of getting boundary line.

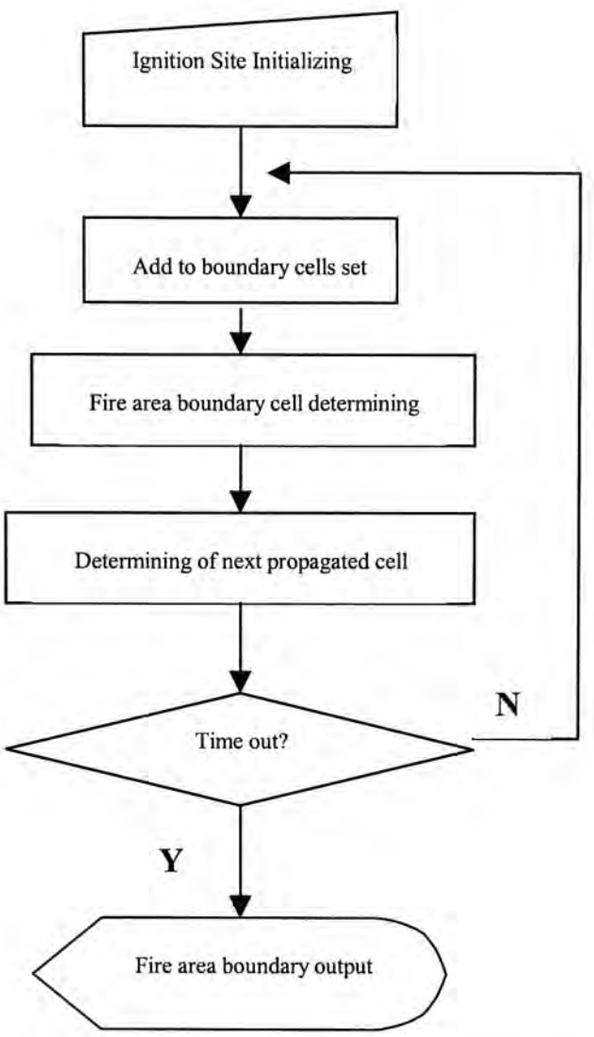

Figure 4.9 Flow chat of boundary line determination

Ignition points are firstly added to the fire boundary cells set followed by a fire area boundary cells determining as shown in Figure 4.8. The next step is a determining of next propagated cell. This step is to determine the propagated cells adjacent to the ignition points. In this study, the wildfire simulation is divided into time steps, and the system outputs a simulation result at the end of each time step, so the users needs to set up a simulation time. To this system, the user needs to tell the system how many time steps will be in the simulation. After the determining of next propagated cell there is a time out

checking. If time out, the fire area boundary is outputted. If no, the determined fire area boundary cells are added into the fire area boundary cells set and the system will start a new loop.

4.4 Defining wildfire with Object Oriented Design (OOD) method

Design is about managing complexity: a design method helps you to split big projects into manageable chunks that will fit in your brain. The Object-oriented design is not the only type of design. However, OOD is best to stick with just one and wait until you have grasped that before looking at other methods. In the manner of OOD, problems are modeled using objects. Objects have:

- Behavior (they do things)
- State (which changes when they do things)

For example, a car could be an object. It has a state: whether its engine is running, and it has a behavior: starting the car, which changes its state from "engine not running" to "engine running". In object-oriented design, complexity is managed using abstraction. Abstraction is the elimination of the irrelevant and the amplification of the essential.

In the manner of object-oriented design, a wildfire can be seen as an actor that changes fields on which it acts. Contrarily, the fields can be seen as a platform where resources are and that partially determine behavior of the wildfire. Wildfire behaviors can be represented as methods and encapsulated inside the *wildfire* objects.

Java is one of the pure object-oriented programming languages developed by Sun™ for distributed environment. This study chooses Java for source coding. Following pseudo code describe main body of a fire object.

```
/**calculates the Fire behavior according to the Rothermel mode */
class Fire {
 /** CLASS VARS*/
 private boolean hasFuel = false;
 double wdr  = 0;          // wind direction [Degree in eight directions]
 … … …
/** Methods **/
public void verify() {       // Enforce Verification
   checkFuel();
   checkNodata();
  }
public void checkNodata() {
  … … …
  }
public void checkFuel() {
  … … …
        }
  }
public boolean hasFuel() {
```

```
  return hasFuel;
 }
public boolean hasNodata() {
  return hasNodata;
 }
... ... ...
public Fire() {
  ... ... ...
 }
public double getRos() {     // get the rate of spreading (ROS).
  ... ... ...
 }
 /**Calculates the Rothermel equations**/

public void calc() {
   try {
     if ((hasFuel) && (!hasNodata)) {
       calcRothermel();
     }else{
       checkFuel();
       checkNodata();
       if ((hasFuel) && (!hasNodata)) {
         calcRothermel();
```

```
    }else{
      ros = Double.NaN;
    }
   }
  }catch(Exception e){
   e.printStackTrace();
  }
 }
 private void calcRothermel() throws Exception {
 ... ... ... ...
 }
}
```

These pseudo code defines an object with Java language: Fire. Environment parameters such as wind direction, wind speed, fuel, are enclosed in the Fire object as public data members. Fire behaviors such as ignition, spreading, propagating, are defined as public methods. These public data members and methods can be called by other Java program to carry out the communications between two objects.

4.5 Summary

Most issues about fire behavior, ROS calculating, fire area spreading, fire map display, fire object defining, etc., are addressed in this chapter. Figure.4.10 is a general diagram of data flow in the fire simulation module in this virtual studio system.

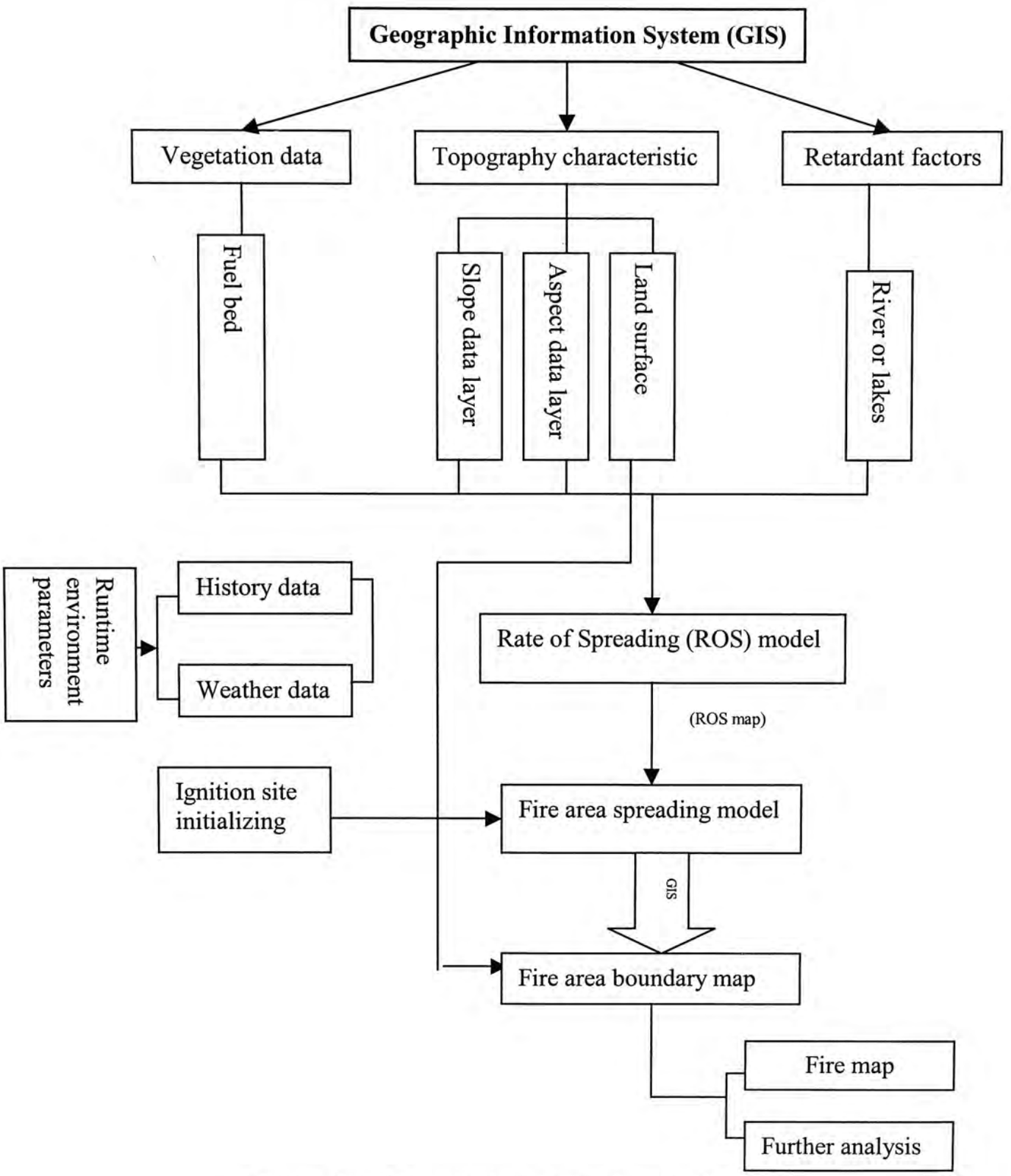

Figure 4.10 Overall data flow chat in fire simulation

Chapter 5 Participation process with interactive tools empowered by IT technologies

Commonly, a decision making process can be divided into three steps: see-plan-do. As mentioned in chapter 3, up to date technologies from Information Technology (IT) industry are employed to develop some components of this Virtual Studio. These components include user interfaces on the client side and the interactive communications among all users (the general public, the professionals) and the planners. Following contents in this chapter will cover three components of this Virtual Studio:

- See---components that help the general public users and the professionals from affected research fields to understand background information of the project;
- Plan--- wildfire simulation scenario defining panel that help users on the client side of the equation to initialize run environment parameters of a wildfire;
- Do--- components that help users to express their views towards the problem or project;

A set of integrated toolbox, composed by background information description components (in both spatial and non spatial ways), wildfire simulation scenario defining panel, users feedback submitting administrator toolboxes, and user discussion bulletin board, has been developed in the Virtual Studio to aid the users in the decision making process.

5.1 Comprehending the problem in an interactive way

Figure 5.1 to Figure 5.6 are snapshots of two sets of user toolkit. Tools shown in Figure 5.3 to Figure 5.6 empower end users to browse spatially referenced database about the

study area in the manner of both text and digital map, furthermore analysis tools in Figure 5.2 aid users to perform some basic spatial analysis such as buffering, feature searching, and spatial query. All these tools can be accessed with Microsoft Internet Explorer over the Internet.

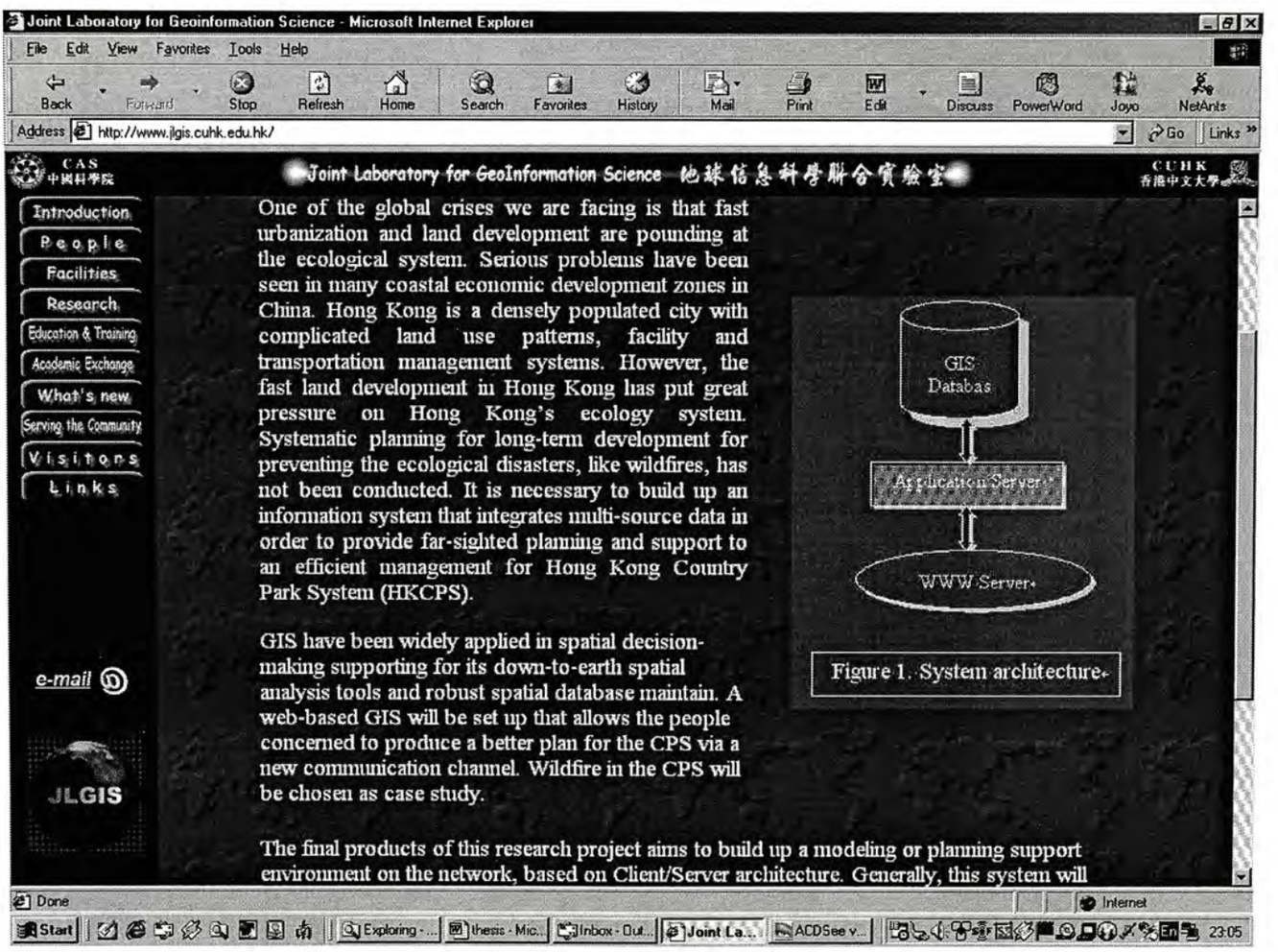

Figure 5.1 Descriptive background information about the project.

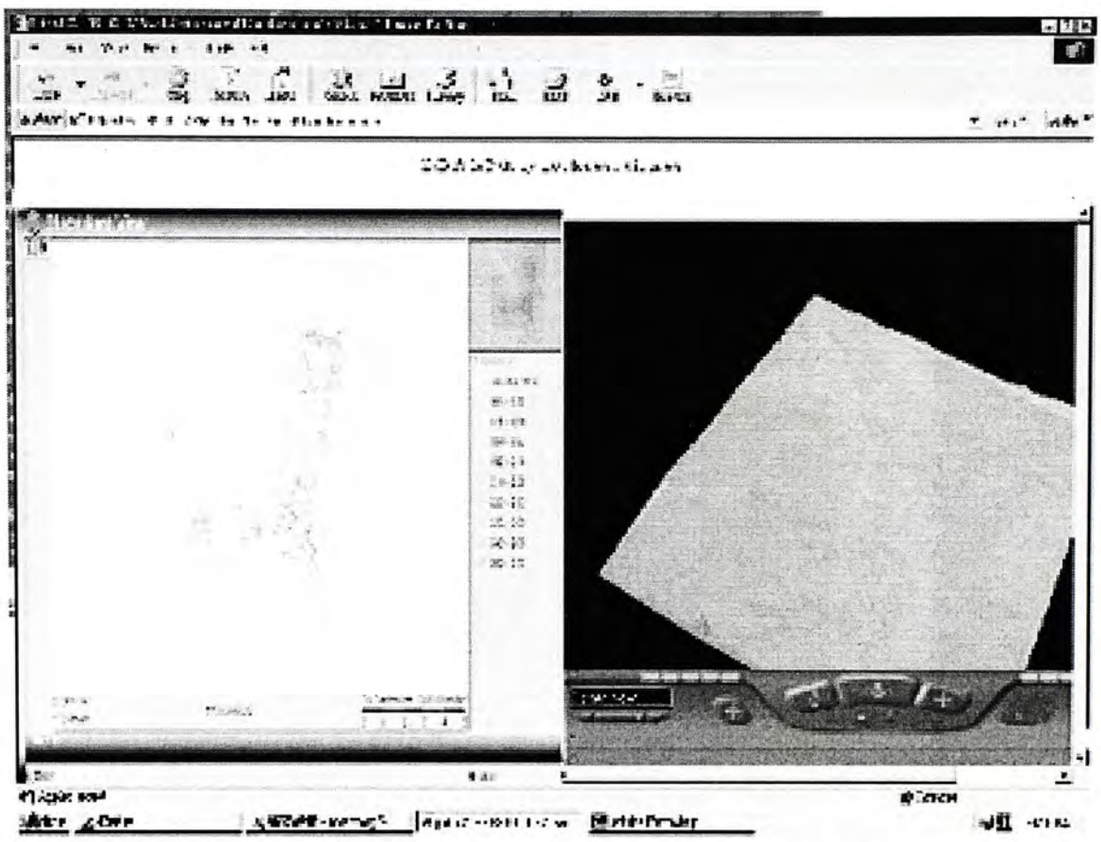

Figure 5.2 2D and 3D environment map browsing tools

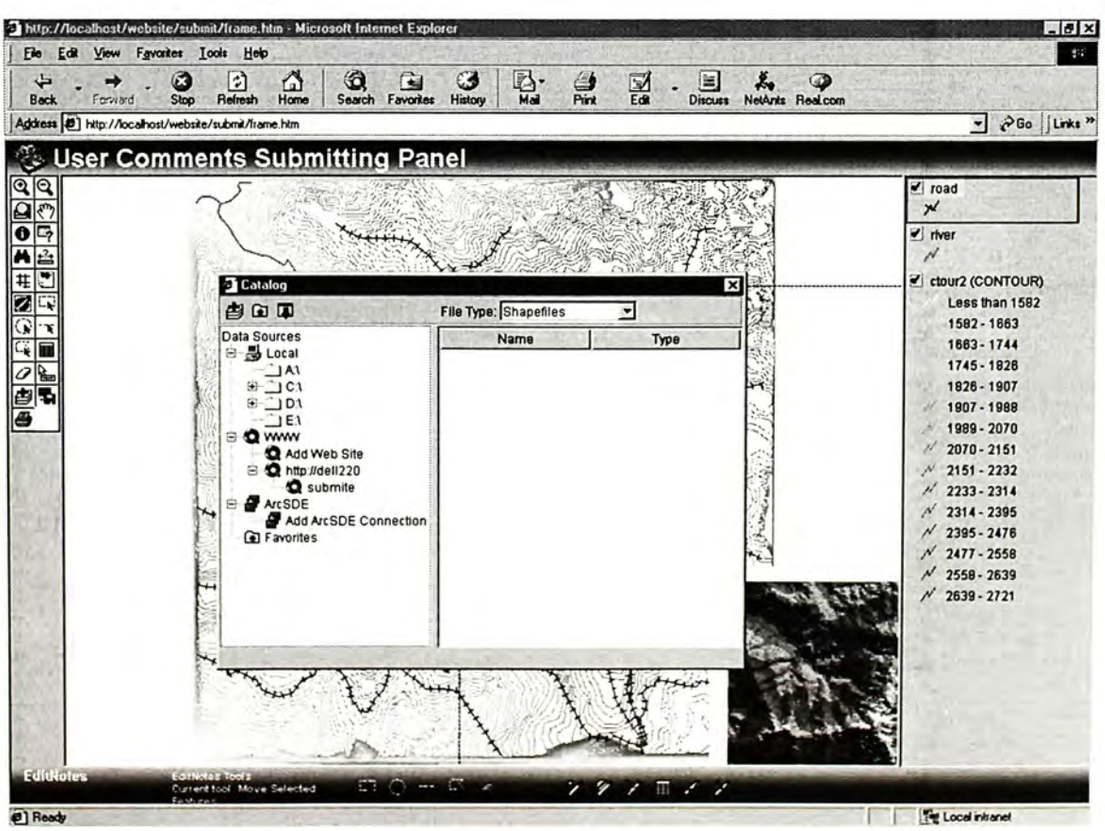

Figure 5.3 Local data adding tool

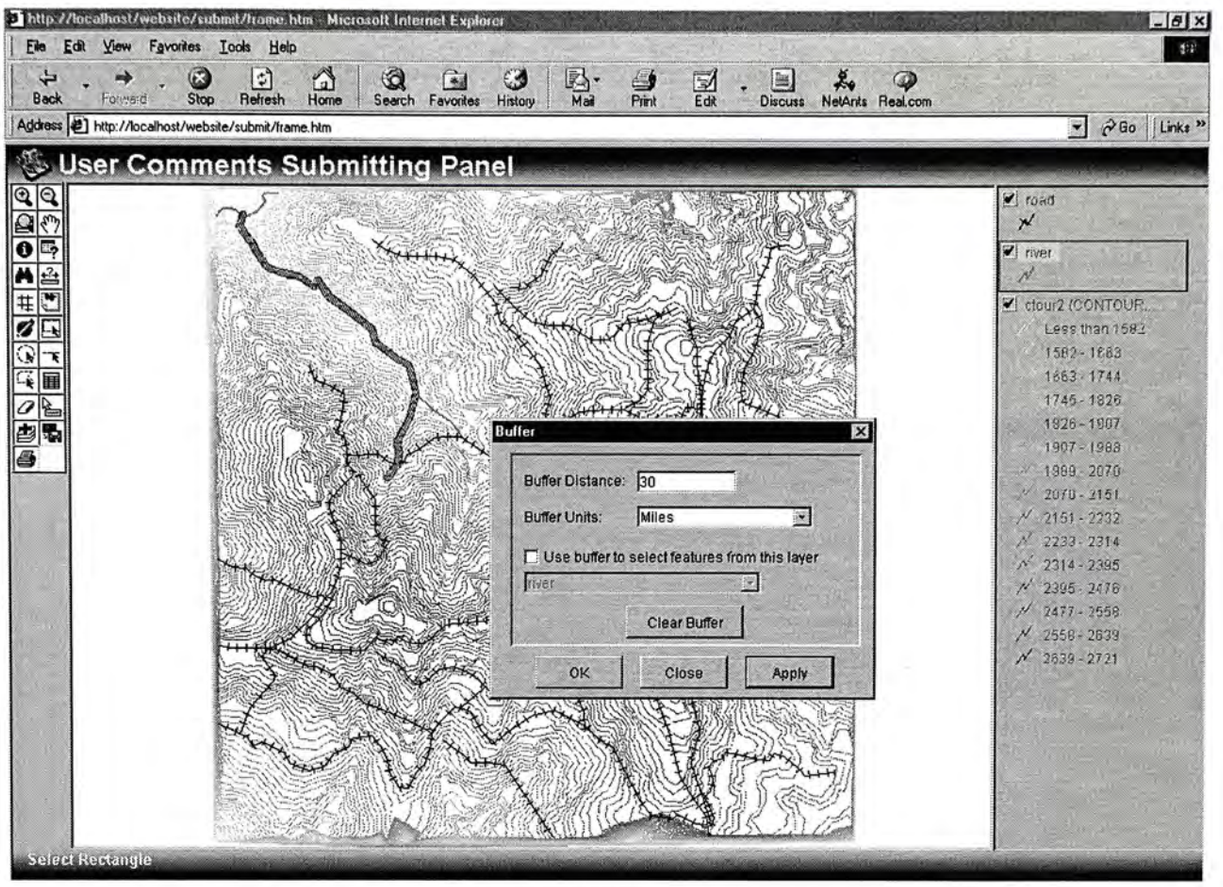

Figure 5.4 Buffering tool

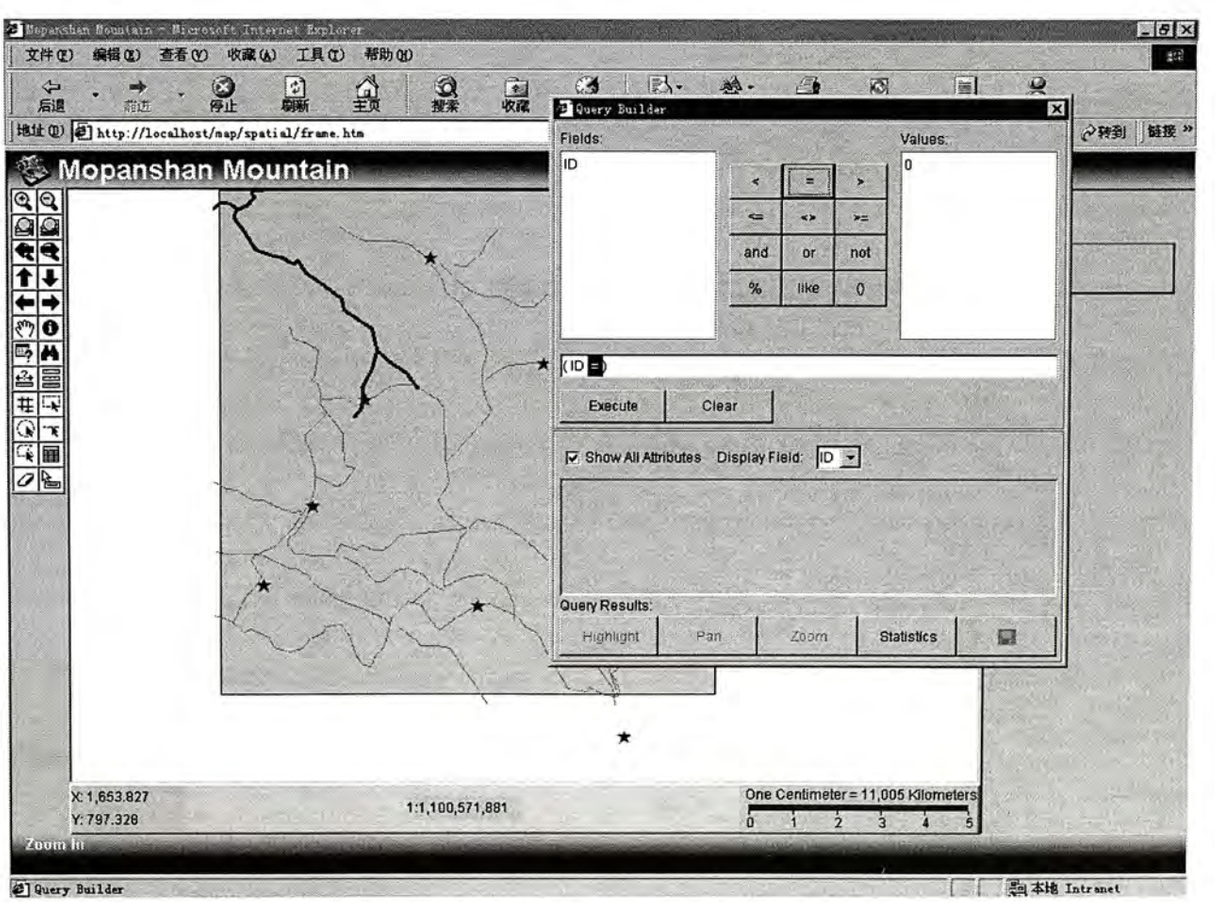

Figure 5.5 Spatial query tool

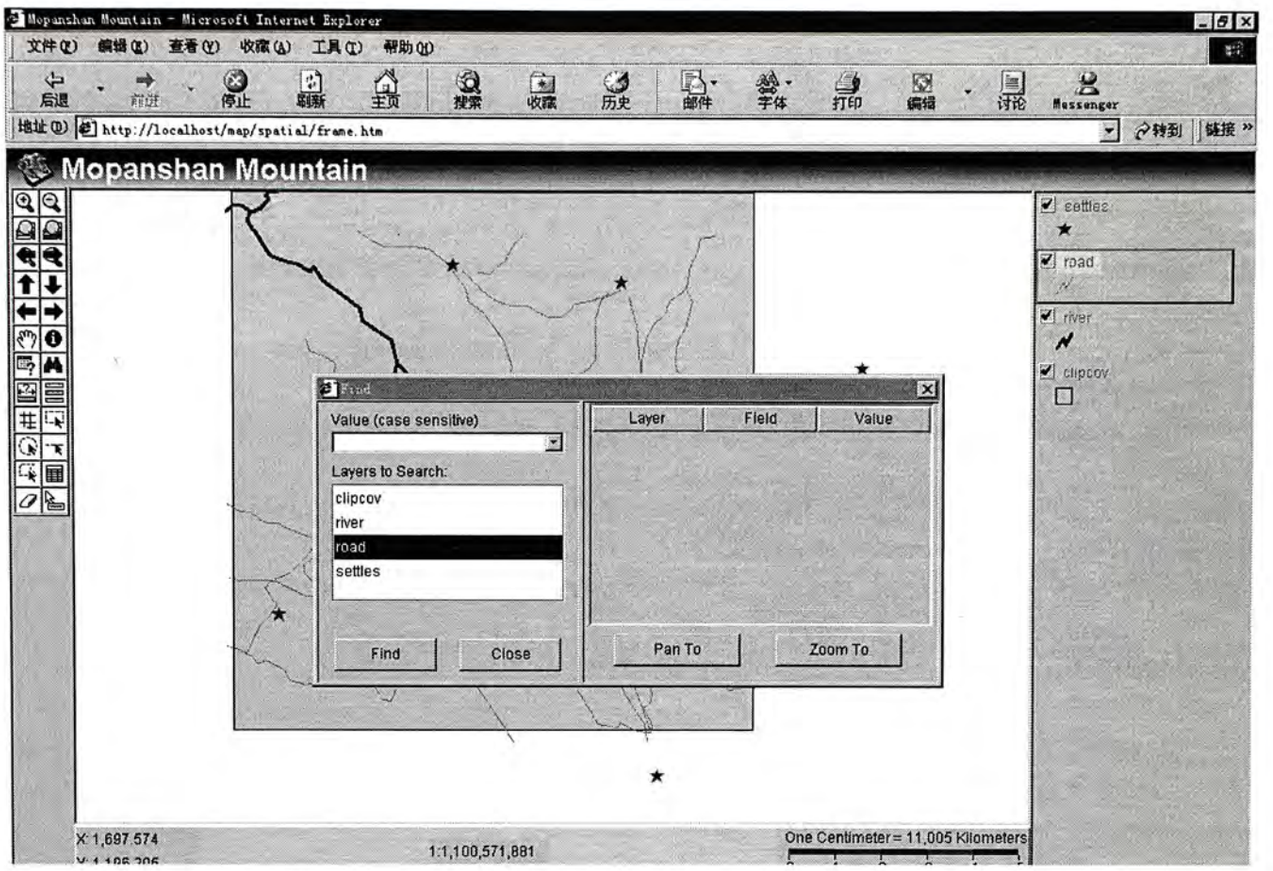

Figure 5.6 "Find" tool

The web page shown in Figure 5.1 contains descriptive information about the project. Users on client side may get a general image about the background and non-spatial information of the project from this page, including initials, objectives, methodologies and significance of the project. Toolbox shown in Figure 5.2 help users to browse 2 dimensional and 3 dimensional digital maps of the study area. This toolbox contain some basic GIS tools such as Pan, Zoom in, Zoom out. These tools have user friendly interfaces that marked with either words or icons. These words or icons marked on the tools make these tools so understandable that even the general users can know the function of the tool easily.

Other GIS spatial analysis tools, such as spatial query, buffering tool, overlay, are shown in Figure 5.3 to Figure 5.6. Tool shown in Figure 5.3 enables the users to add their local data on the digital map, in this way, users may add their own data to the thematic map to perform some temporal study. Buffering tool is shown in Figure 5.4. As a common GIS functionality, this tool enables users to perform buffering operations. For example, if the safe distance from the fireline is 20m, users can know the safe boundary with a buffering operation with distance in 20m. Figure 5.5 is a snapshot of spatial query tool. Users can find geographical features that meet users specific criteria in one thematic map. While the Find tool shown in Figure 5.6 enables users to find specific geographic features within two or more thematic layers.

5.2 Performing wildfire simulation

One of the most important objectives to develop this system is to get the public users' comments to the planning project. As I mentioned in Chapter 2 and Chapter 3, users of this system on the client side include the general public and the professionals. Comments from the general public are often at a basic level. For example, comments from the affected general public may include " I think there should be a road between site A and Site B", but when asking "why", their answer may be very ambiguous---I just think so. However, answers from the professional users always depend on some physical evidences. Therefore, I provide a wildfire behavior simulation functionality in my system to the professional users.

Once the professional users get the general knowledge of the study area and understand the project with tools shown in Figure 5.1 and Figure 5.2, end user may specify the runtime parameters with the wildfire simulation scenario-defining panel (as shown in Figure 5.3) and then carry out a wildfire simulation in the virtual studio. These wildfire simulation systems run environment parameters are sent to the server side. After computation on the server side, wildfire simulation result will be sent back to the end user and displayed as thematic map as shown in Figure 5.4.

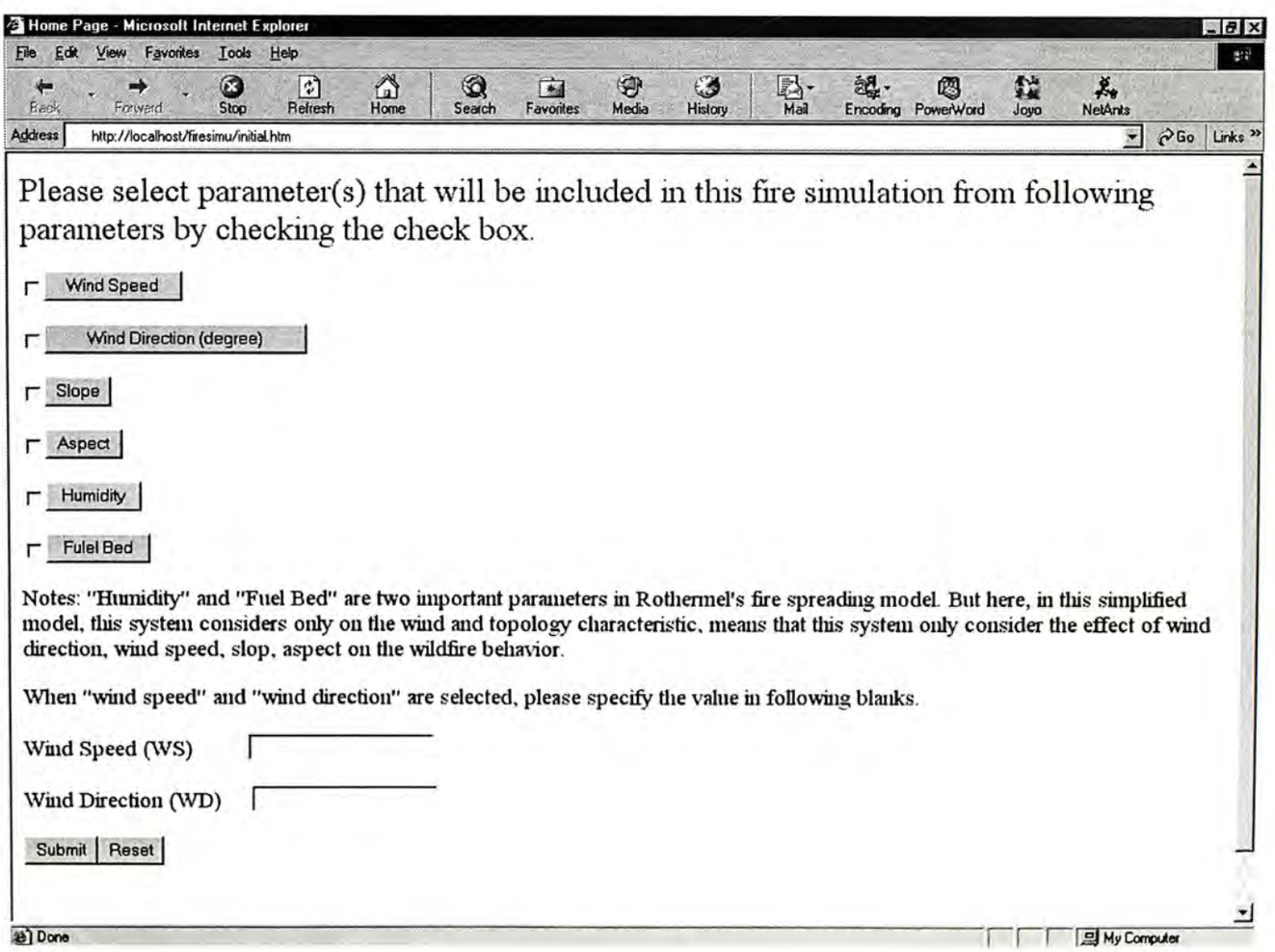

Figure 5.7 Forest fire simulation runtime parameters initializing panel

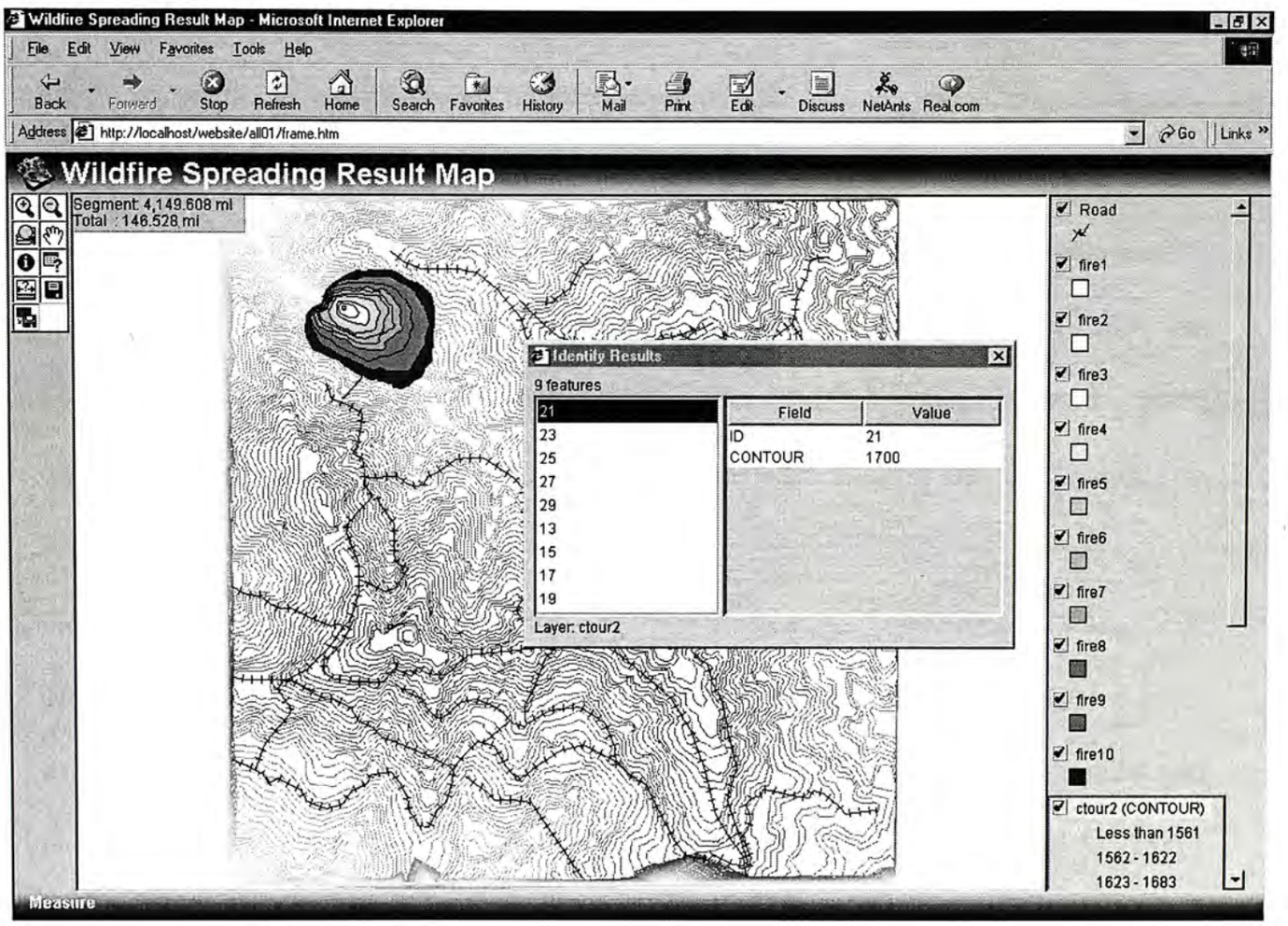

Figure 5.8 Visualization of wildfire simulation result

Based on this fire behavior simulation result map, the professional users can do some spatial analysis such as using the "buffering" tool to get the affected area of the wildfire or use the "find" tool to find the nearest fireplug. Based on these analysis, the professionals can generate their idea of the situation of the security of this area and generate their opinions to the planning project at the same time. These ideas are the base of the professional's comments to the project.

5.3 Submitting of end users comments

Public participation always allows two-way flow of information, which reflects that not only can general public get information from planning authority; also planners can get various comments and suggestions from the general public. For this virtual studio, a two-way flow of information means enhancing the communication between planning authority and the public with a set of functional user feedback submitting tools, in the meantime, two-way flow of information also means idea sharing and data sharing to some extent.

The extraordinary growth of the World Wide Web has been fueled by the ability it gives to authors to distribute electronic documents to an international audience easily and cheaply. Hypertext Markup Language (HTML) and Extensible Markup Language (XML) are two of those recently emerging technologies that are chosen to develop project on the Internet (Armstrong 1994; Lin, Kong et al., 1997; Carver, Kingston et al., 1998; Carver 1999; Openshaw, et al., 1999).

5.3.1 Textual comments submitting

To get the affected users' opinions to the proposed decision or project, the classic method is to invite some people to write down their ideas and submit these feedbacks to the authority. The first feedback submitting mechanism we offered to general public is the ability to express their feedback with online textual feedback submitting tools. Hypertext Markup Language (HTML) is one of the effective web site development methods with the simplest syntax and least workload.

Firstly, an online Guest Book has been developed with HTML for users to submit textual feedbacks. Once users finished data browsing and wildfire simulating, users can input their feedbacks in a text box and then submit their opinions to the project/problem with this system. Users can access this textual feedback submitting tools with Internet browsers, i.e. Internet Explorer or Netscape Navigator, before a computer with Internet access. These feedbacks are then published on an online Guest Book (see Figure 5.5).

This online toolbox provides user on the client side friendly interfaces to express their opinions easily. Even the general public users with insufficient IT knowledge can perform the feedback process smoothly in a free style and non-expectant way. In this process, user will firstly choose the type of his or her submission--- suggestions, comments, or cognitions--- with a mouse click in the multi choice box, and then tell the system what topic his/her feedback is subject to from the pull-down menu: the web site, wildfire simulations, road network plan, etc. A blank text box is provided to user. User may input his/her feedback subject to the topic he/she chose and submits these to the system. User's personal information, i.e. name, the contact information, is also collected in this toolbox if he/she wants a response of his/her feedback to the project/problem from the decision makers. Users' feedback and personal information are sent to the server side via Internet and stored in a log file that will be then reviewed and processed by the decision makers. Concerning the legitimacy of privacy authorizations, these information will not be published on the Internet. Decision makers' response are taken based on the users' personal information collected in the log file.

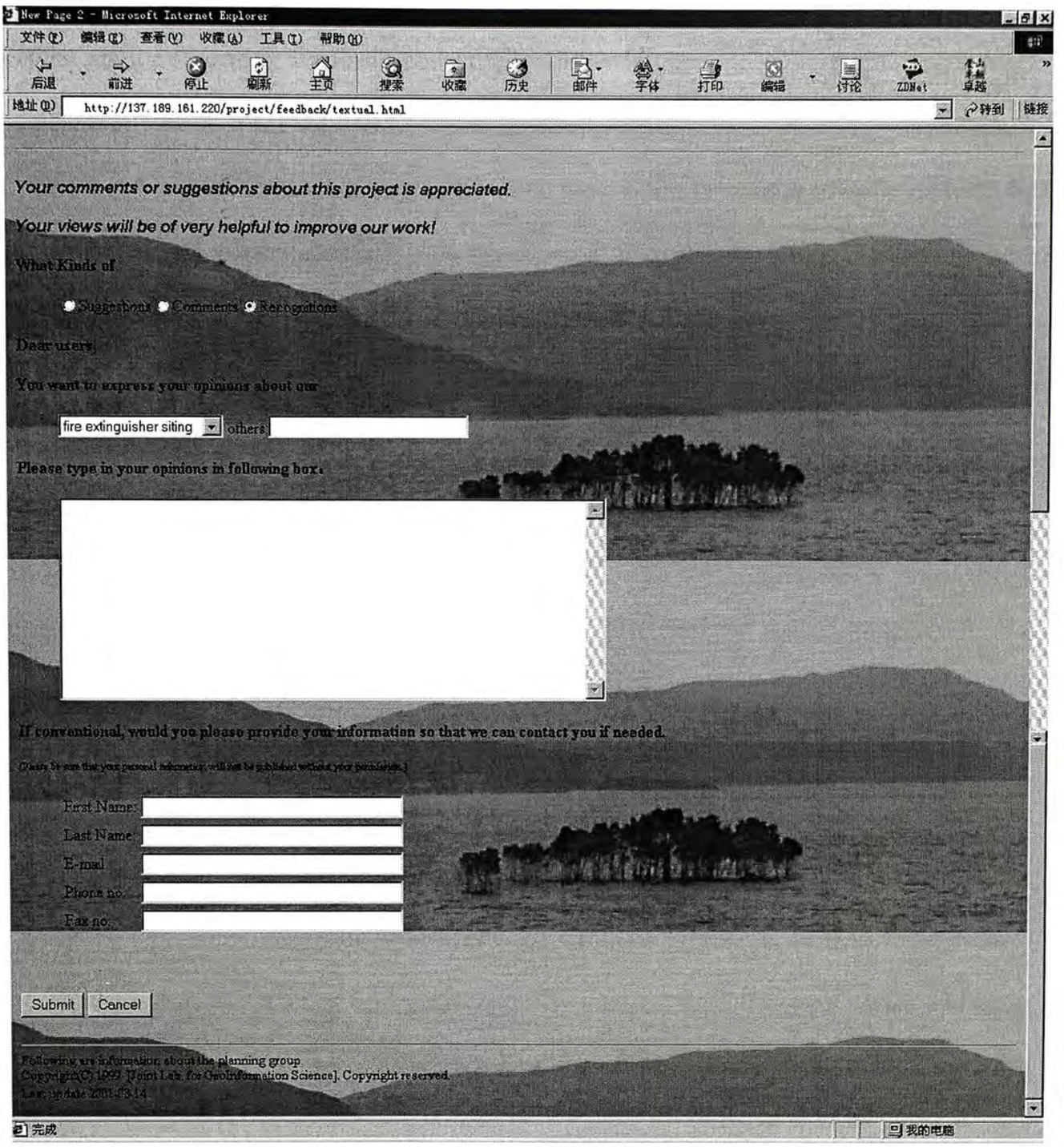

Figure 5.9 Online textual user comments/suggestions submitting tools

(The picture in this figure is a mosaic with two snapshot pictures of the textual comments/suggestions submitting tools web page)

The ability of getting feedback collecting and providing response to public users could potentially be used for conflict resolution or online debate and discussion about particular issues in the decision. In this way, users make their views known, even if their advice are rejected at last, participants may feel they have at least their day in court and are more likely to accept policy decisions (Sewell and Coopock 1977; Bear et al., 1994).

5.3.2 Submitting graphical feedback

5.3.2.1 Extending XML

The reason that it provides a graphical comments submitting mechanism to user in this study is rooted in the inherent spatial nature of environmental project or problem. The planners or decision makers represent most environment information—background information, and plan-- in graphic map. More specifically, these contents are represented into thematic layers in GIS. Consequently, a graphical comments submitting tool will surely be more maneuverable for general public, and non-professional users. As the famous Chinese philosopher Confucius once wrote "a picture is worth a 1,000 words" and can thus relay a lot of information quickly and understandably to a wide audience. This is also one of the most distinguished natures of this Virtual studio that differs from other online survey system. Extensible markup language (XML) is chosen to achieve this mechanism in this research

XML is widely used in many domains. For example, to a GIS specialist, XML can be used to describe metadata of spatial database. As shown within its title, XML is an extensible language that means you can invent and use your own tags and, if you choose,

share them with others. Online GIS service, especially dynamic GIS data access service online, requires an extensible mechanism to publish GIS database service on the Internet.

ArcXML is one of the products that attempt to extent XML to serve dynamic online GIS database. This project is being done by Environmental Systems Research Institute, Inc. ArcXML is employed to develop the most characterful tools in ArcIMS: MapService, MapNotes and MapNotes. Appendix 1 defines a map with one thematic layers: Cites in Sichuan Province (Figure 5.10). (For more information about ArcIMS, please see manual or technical white paper from ESRI™)

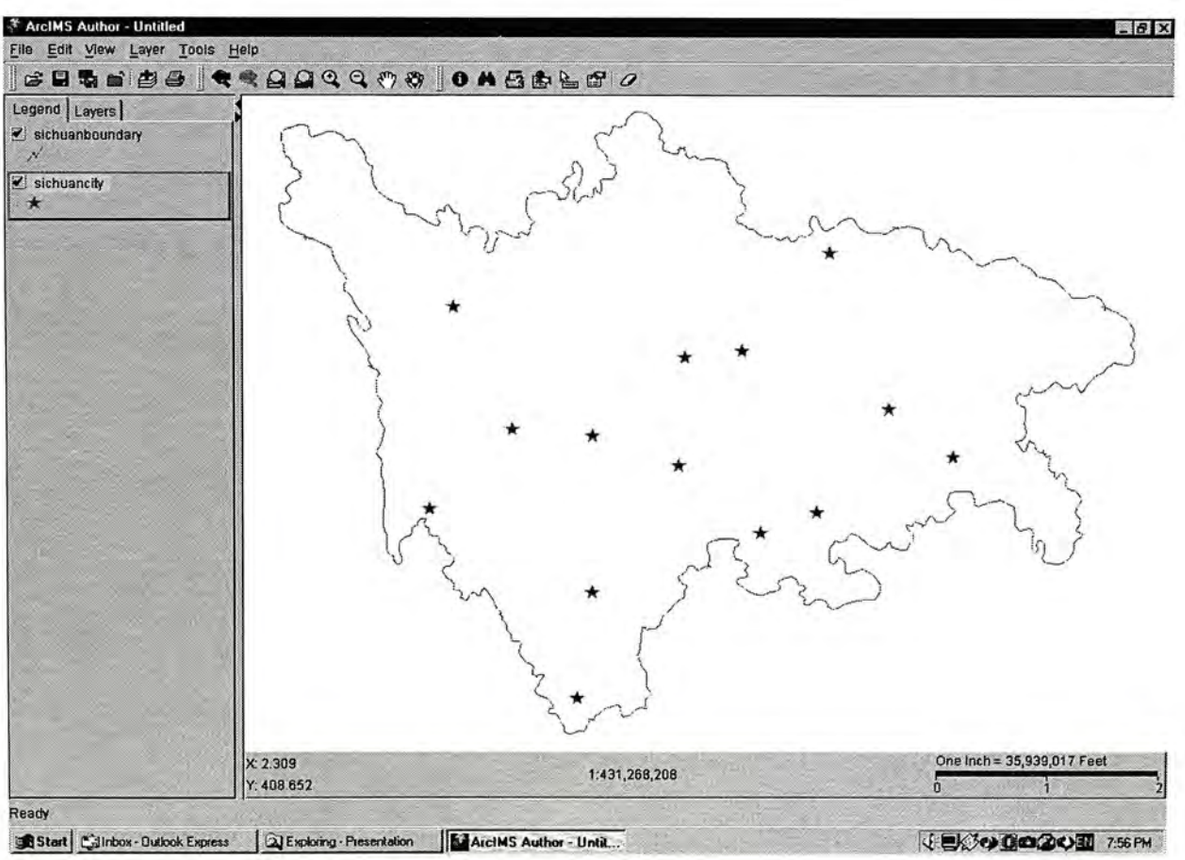

Figure 5.10 Map generated from a map configuration file (appendix 1).

5.3.2.2 Submitting graphical comments with MapNotes and EditNotes

ArcXML is used to construct two of the most functional tools of ArcIMS: MapNotes and EditNotes. The MapNotes and EditNotes tools introduce the idea of collaborative GIS technology---sharing not only data but also ideas about your data with others.

ArcIMS defines MapNotes as what the user enters onto a Web page when browsing digital map with ArcIMS map Viewer. Using MapNotes tool, public users can add notes such as text notes or graphic elements to the map. These user entering is added into a MapNotes layer and then submited to a folder on the server.

EditNotes tool is used to make simple edits to spatial and attribute data. The spatial editing capabilities include adding, moving (of features and their vertices), and deleting of features. These edits are traced by the map Viewer and saved in an EditNotes layer. EditNotes are submitted to a folder on the server.

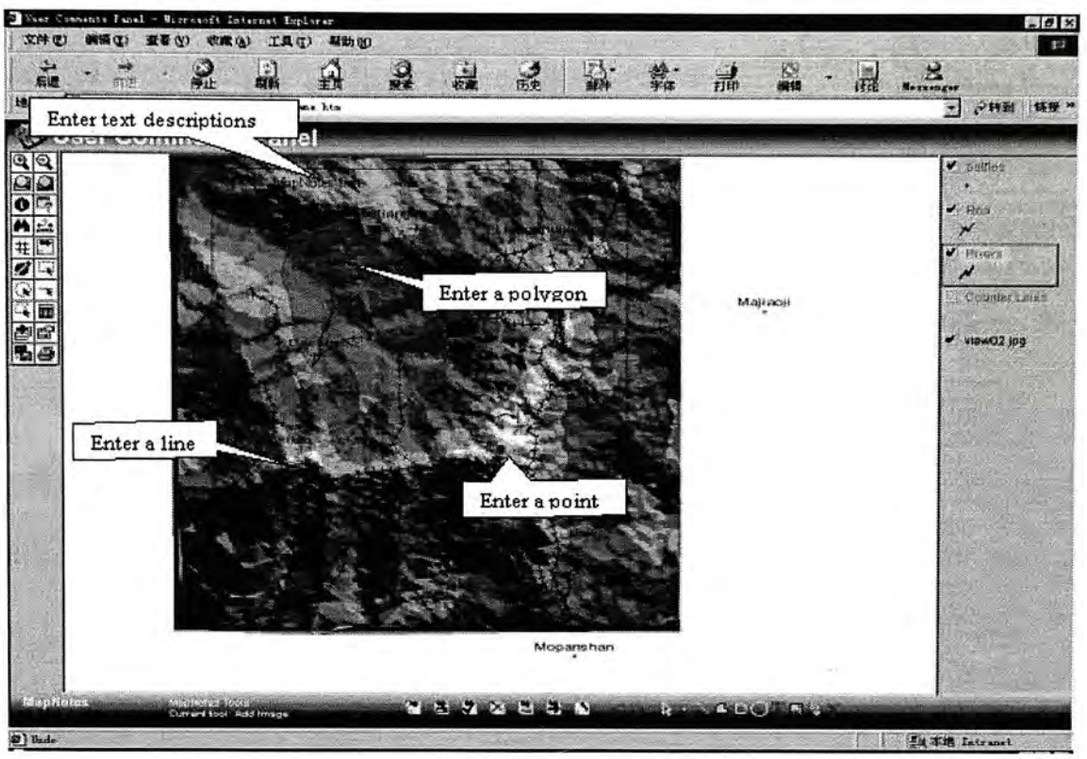

Figure 5.11 User graphic feedback tools: MapNotes tool or EditNotes-1

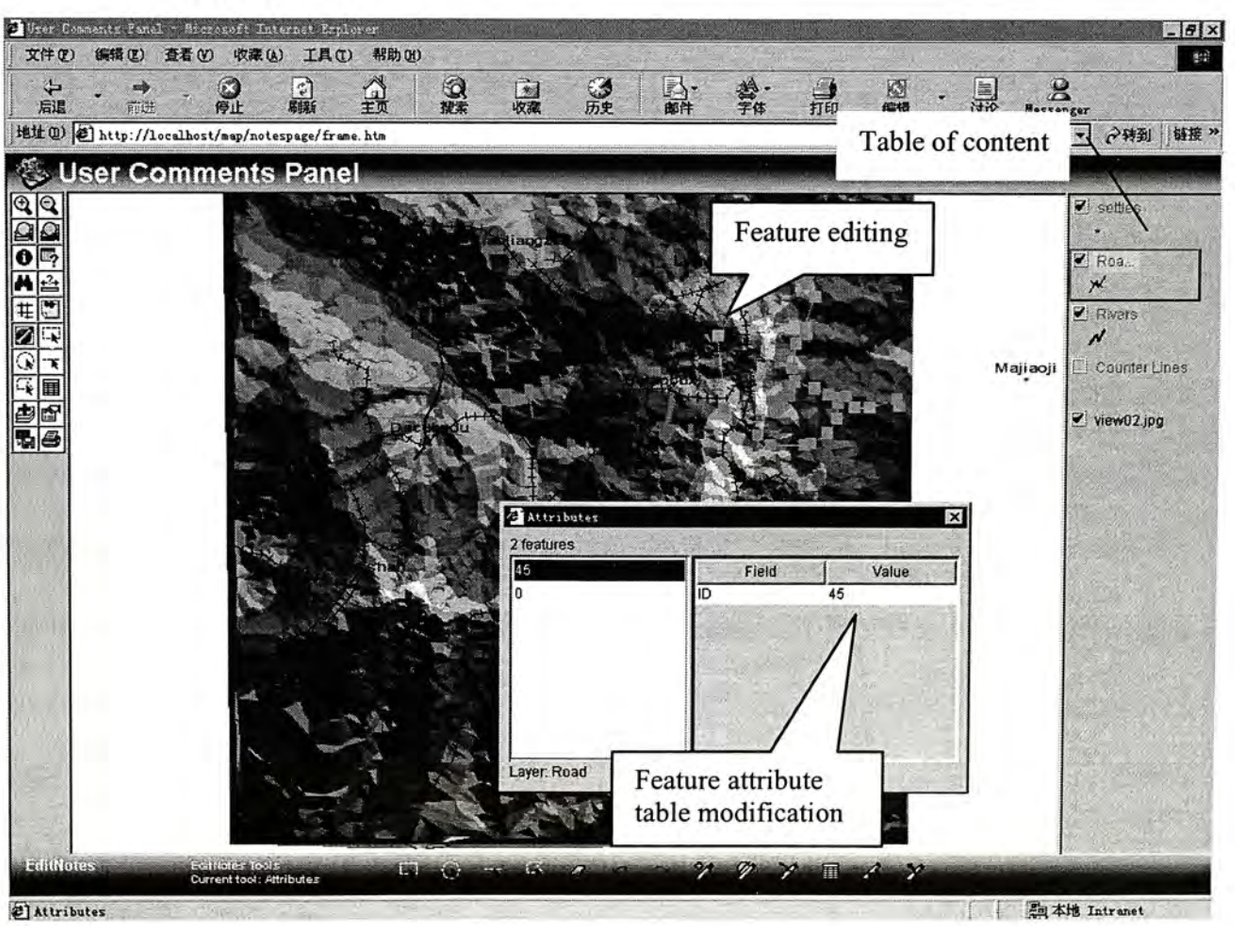

Figure 5.12 User graphic feedback tools: MapNotes tool or EditNotes-2

All related information (data layers) are listed on the table of contents of "User Comments Panel" as thematic map and serve as background map. Users can change the display order of the themes by changing the order of the themes on the table of the contents. Dragging the theme up or down in the table of contents, when the user drop the theme in its new position, the view will automatically redraw in the new order.

Before the users begin to use MapNotes and EditNotes tools, users have already gotten necessary background information about the planning project with the tools illustrated in Figure 5.1 to Figure 5.8. The functionality of the tools shown in Figure 5.11 and Figure 5.12 is to help users to express their comments in a graphical manner. Users' graphical feedbacks fall in two category: adding new items and editing existed features on the draft plan. In my system, I enable the users perform these two kinds of operation with MapNotes and EditNotes tools.

With MapNotes tool shown in Figure 5.11, users can add new items to the draft plan, such as a fire station (point), road (line) or a conservation area (polygon) to the study area according to their opinions to the project. Users can also express their comments to the draft plan by editing the draft plan with the tools shown in Figure 5.12. Users can move a gas station (point) by click (to select the point) and drag (to move to a new place) and change the shape of a road (line) by moving the node on the road as shown in Figure 5.12. In the same way users can edit the shape of a conservation. Users also can edit the attribute of a existed feature with the tool shown in Figure 5.12. For example, one user may think site A is more suitable for a school instead of a store, what he/she need to do is

just click on site A with the feature attribute editing tool, then a dialogue window with pop up. Now this user can modify specified field in the table to change the feature attribute.

All users submitting are saved and stored in folder on the server. Information in the MapNotes folder is retrieved when the Web site is accessed and the MapNotes are opened. Information in this EditNotes folder can be converted to a shapefile, ArcXML MapService file, and viewed with ArcIMS Administrator or other supporting GIS software (see Figure 5.10 and Figure 5.14) (Appendix 2 is a example of user submitted EditNotes contents in ArcXML format.).

All MapNotes and EditNotes submitted to the server are stored in a database on the server side. Either the planners or the public user can retrieve information contained in MapNotes or EditNotes for further analysis. Feedback of user A can be viewed by user B by add user A's MapNotes layer from a MapNotes layer list that is open to all users (see Figure 13). Data and idea are shared in this way. Information contained in this database serve as reference for further draft plan revising and a basis for new idea mining for planning authority. In a sense, all users, including the public and planning authority, are given opportunity to make their idea voiced. Figure 5.14 illustrated a server side administrative tool that help planner to retrieve information contained in the MapNotes or EditNotes.

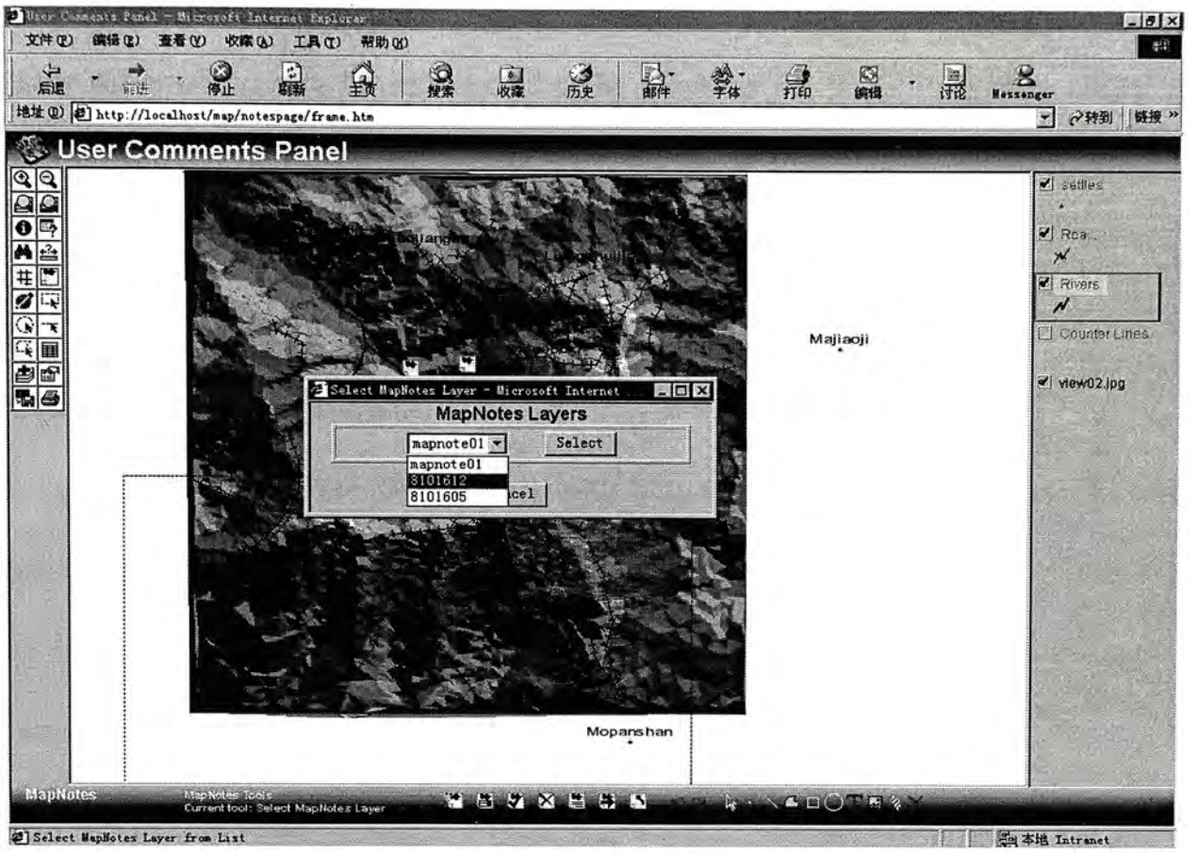

Figure 5.13 Public users may select and view others' submitted MapNotes.

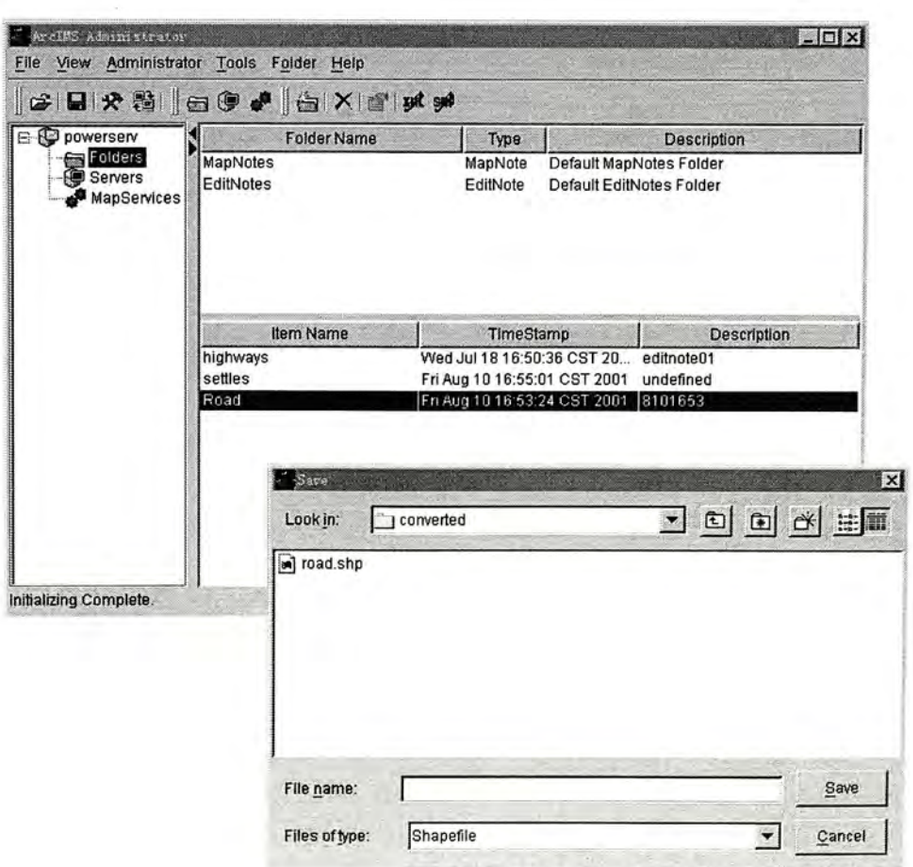

Figure 5.14 Converting a EditNotes to shapefile for administration

All user submissions can be reviewed by the planners on the server side. On of the important usage of these submissions is that they serve as reference when the planners begin to revise the draft plan.

5.4 Discussion bulletin board

Besides the idea sharing mechanism shown in MapNotes, the public users often want a per-to-per discussion where they can discuss a specified topic and get ideas from other users. Discussion bulletin board is another idea sharing/exchanging mechanism that this Virtual Studio provides to the users.

User may firstly fill in some forms online to register as users for this discussion bulletin board, in the meantime, user information is collected and stored in a user information database on the sever, this database will be studied later to mine some hidden knowledge, for example composition of the user group, "who concern what", etc. All registered users can post their own opinions in the discussion bulletin board or read other users' articles. User name or keywords based on search engine are developed to help users find interested articles. This discussion bulletin board is necessary to lead discussions and helpful to hold a stable user group.

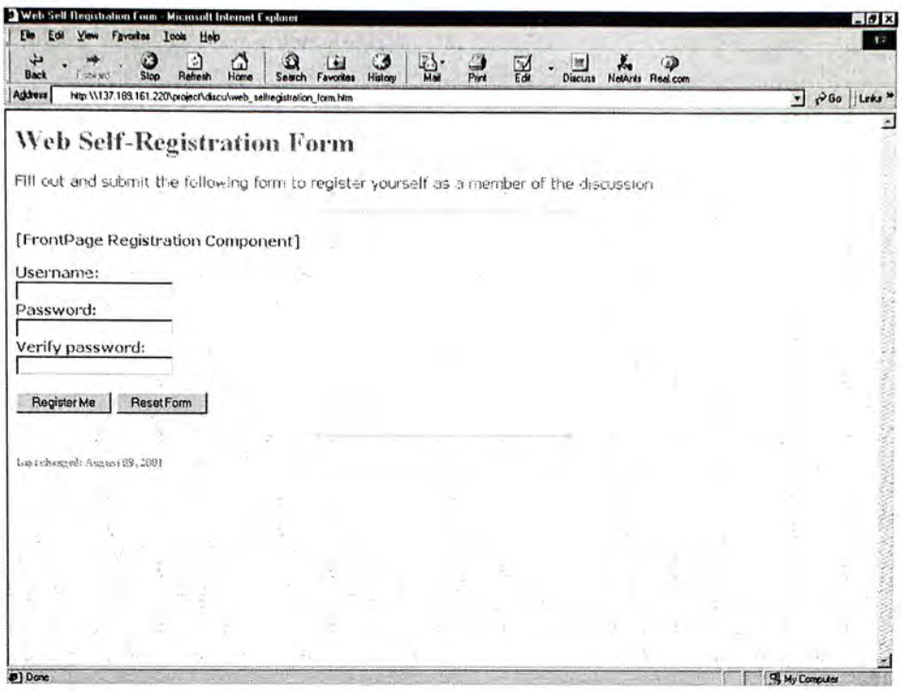

Figure 5.15 User registration form

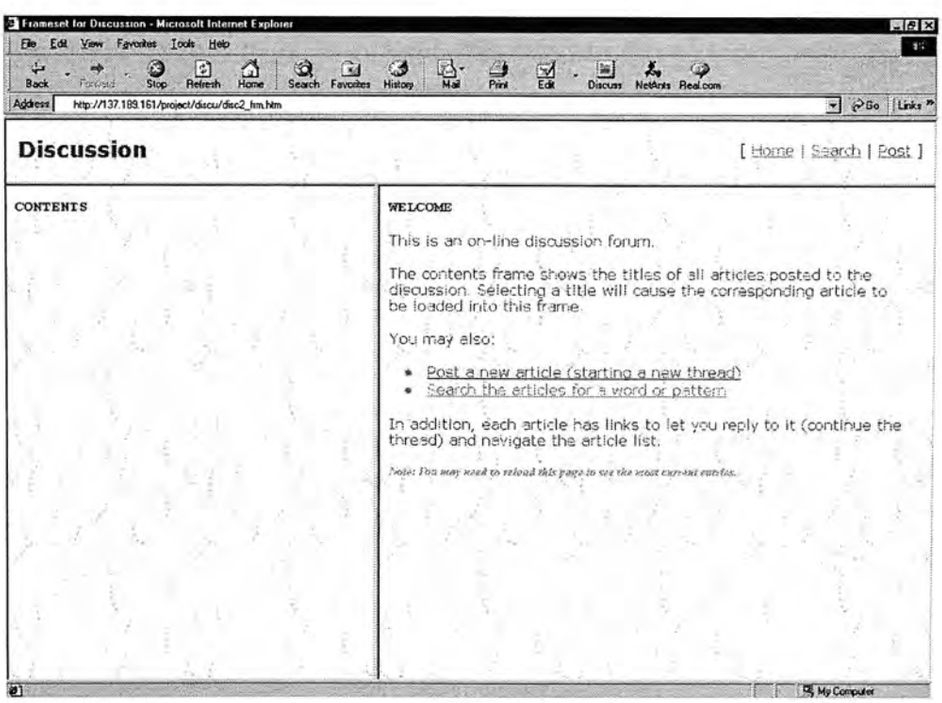

Figure 5.16 Online discussion bulletin board

The professional users and the planners always lead a specific topic in the discussion bulletin board. During the discussion the professionals and the planners distribute their

knowledge and opinions to the general public which will help the planner to persuade the affected general public to accept "right" contents of the planning.

5.5 Summary

In this chapter, I designed some graphical user interfaces to help the users to perform the participation process. Except the administrative tools shown in Figure 5.14, all tools can are available on the Internet. Both the planner and the public users, including the professionals and the general public) can access these tools over Internet at anytime , anywhere. Anybody can participate in the decision process. It seems that they are working in a studio on the Internet. That's the important reason that I called it "Virtual Studio". Some state-of-the-art technologies are used to developed these GUIs. The design of these GUIs is aim to provide the users a friendly interface to participate in the decision making process.

GUI design is fundamental to the development of effective participatory systems. Most web-based interfaces are mouse-driven and based on standard graphical interface devices or 'widgets' such as check boxes, menus and buttons. Text input from the keyboard is minimized. All the main web browsers support this form of interface. Rather, the key problem is user understanding. Whether the system is a simple online questionnaire or an interactive 3D virtual world, the user must be able to understand and be able to interact with the interface. This becomes problematic when designing GUI for public user due to the wide range of computer experience; from absolute novice to expert. If a GUI is too simple, it may not offer the flexibility and functionality required to address complex

visualization problems. Alternatively, if the GUI is too complex, then new and novice users may not understand.

Based on these hypotheses, this Virtual Studio provides public users GUI that focuses on adaptive user-centered interfaces that can profile new users. Some tools in GUI are designed and offered to the public users on Internet. With these tools, users can carry the participation process smoothly in a "see-plan-do" style.

The participation process presented in this chapter, especially the second and third steps---plan and do---involves an element of exploration of a particular problem. In the simulation of a wildfire, users may get knowledge about wildfire spread, while planners may find new problems when discussing with public users and maintaining the user feedback database.

Chapter 6 Discussions and conclusions

6.1 Research limitations and discussions

As this is just a pilot study, the prototype system illustrated in this thesis acts as a concept demonstrator of the Virtual Studio. However, improvements to the system for future use are needed. Firstly, since the aim of the study is not to achieve an accurate fire behavior simulation result, the fire behavior model used here is an approximate and simplified Rothermel model. Secondly, this is a heavy server/light client diagram run on PC. Concurrently control will be another issue when many people participate simultaneously. Upgrading the server computer, getting more parallel server computers or designing a balanced architecture system are three potential ways to solve this problem.

The initial motivation of this Virtual Studio is to secure and increase public participated into the process of an ecology planning, but this Virtual Studio can be adapted for many other potential application area, especially those that require mass access activities.

Firstly, without any modification, this Virtual Studio launches a channel for the decision-making bodies to collect diverse viewpoints about how to improve th ecological security of an ecosystem. For example, problems like where to place a fireplug or wild land fire watchtower in a country park. Secondly, after minor modification work on the spatial database and the project description page, the textual/graphical user comments submitting tools and the online discussion bulletin board are capable of carrying out the job of feedback collection about proposed planning. At the same time, by joining in and leading an efficient and fair discussion, planners can determine the public's grassroots feeling

about a proposed project. The third potential application of this Virtual Studio is in the area of education or scientific research. Although the fire models (ROS model and fire spreading model) I used for this Virtual Studio project are simplified, they are adequate for use in general education. With the inclusion of additional data and the development of more complex models, the use of this Virtual Studio can be extended into the professional arena.

This study evaluates the potential for using new technologies to help decision-makers secure general public involvement regardless geographical and physical constraints in particular spatial decision problems. Widespread use of these opening systems will ameliorate the decision-making process, increase democracy and make public involvement easier and more practicable. At the same time, this study broads the application of Web GIS in the field of environmental planning.

6.2 Conclusions

Public participation is a process of "involving people in particular decisions, problems, projects, or progress" to get 'consensus building'" (Susskind, 1994). Traditionally, the public participation model follows a classic paternalistic approach. In some sense, public participation should take into account, the opinions of all those who may be affected by any decisions make. The increasing sophistication of Internet communication and the rapid growth of the World Wide Web (WWW or Web) over the past decade have created many opportunities for its use in a variety of fields. One potential application of Internet technology is for increased public participation and the enhancement of participatory democracy in environmental decision-making. Most Internet based public participation

application are text-based comments feedback collection tools or just online survey systems that are inadequate for spatially referenced environmental decision-making problems. Their inadequacy stems from their lack of the detailed spatial database necessary in environmental problem solving.

To investigate the effects of new technology from both Internet and geographic information science on decision-making especially environmental planning, this research develops an online Virtual Studio for ecological planning. The effect of wild land fire on ecology security in forest ecosystem is chosen as a case for this study. This online Virtual Studio is accessible via Internet without any geographical constraints. With this Virtual Studio, users may first retrieve relevant non-spatial and spatial information about the problem or project. Then, concentrating on the specific problem users may simulate a wildfire in the Virtual Studio and get the simulation result in real-time, interactive manner. After participating in the simulation, users may have some comments and suggestions about the problem or project. Textual and graphical user comments collecting tools are developed to fulfill this task. Meanwhile, participants may register as permanent users for this web site and join the online discussion forum to exchange views related to the issues of this problem or project.

Based on the above description, it is obvious that web-based public GIS is problem specific. This system combines analytical models and data in such a manner as to allow the client to easily explore the decision space in an interactive and recursive style without requiring extensive prior knowledge of the system being used. Thus, an online public

participatory GIS with regard to environmental planning should include the following items:

1. an information system to manage relevant information about the project/problem;
2. a GIS server to maintain a spatial database behind the system on the server side;
3. specific application models encountered in the decision making process that require public participation;
4. an open system, accessible to the majority of users;

In addition, this paper has demonstrated that with sufficient customization and database, a Web GIS such as ESRI ArcIMS can provide a suitable platform to allow the intuitive presentation of planning information to a public unacquainted with advanced computer technology, but with basic computer and Internet skills

.

This Virtual Studio breaks public participation into a set of online tools. Three steps of public participation, pre-negotiation, negotiation and implementation can be carried out using these tools. This is a one-stop solution to secure public participation in decision-making process. The publics is more likely to participate in the decision-making process with this online Virtual Studio than to attend public meetings or take time to complete paper survey questionnaires in the classic public participation approach. The use of the online Virtual Studio negates the traditional requirement of holding public meetings or sending out paper questionnaires and information booklets. Users do not have to purchase expensive software packages. Accordingly, funds from taxpayers are utilized more publicly and effectively.

So far this study takes fixed data set (fuel type, DEM, etc) for wildfire simulation. However it is expected that this Virtual Studio can be extended and utilized to estimate the impact of different fuel bed (vegetation types) to the fire behavior, and this estimation will act as a guideline for the development of this forest. If we switch our focus to other models in Ecology, models such as minimum cumulative resistance (MCR) model or other models from hydrology can be added as a module into the Virtual Studio. New application models can be combined into this Virtual Studio as independent modules or objects. This Virtual Studio system has an open, extensible architecture, thus other related research and international efforts can be combined in this process.

Web based multi-criteria evaluation (MCE) integrated with GIS have proven useful in determining the preferences of the general public to particular spatial problem among alternative choices (Wherrett, 1997). While this research investigates the potential of enhancing reasonability of a specific ecological plans by enabling public participation with an Internet based Virtual Studio. The diagram of my work, "Web GIS + Application model", may act as a template for further spatially referenced, public policies related environmental planning project.

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Appendix 1.Defining MapService with ArcXML

```
<?xml version="1.0" encoding="Cp1252"?>

<ARCXML version="1.0.1">
  <CONFIG>
    <MAP>
      <PROPERTIES>
      <ENVELOPE minx="34.720816" miny="3.536477" maxx="791.749784"
maxy="578.808864" name="Initial_Extent" />
      <MAPUNITS units="DECIMAL_DEGREES" />
      </PROPERTIES>
      <WORKSPACES>
      <SHAPEWORKSPACE name="shp_ws-0" directory="D:\Data\Forestry" />
      </WORKSPACES>
      <LAYER type="featureclass" name="sichuancity" visible="true"
id="0">
      <DATASET name="sichuancity" type="point" workspace="shp_ws-0" />
      <SIMPLERENDERER>
        <SIMPLEMARKERSYMBOL color="51,102,51" type="star" width="15" />
      </SIMPLERENDERER>
      </LAYER>
      <LAYER type="featureclass" name="sichuanboundary" visible="true"
id="1">
      <DATASET name="sichuanboundary" type="line" workspace="shp_ws-0"
/>
      <SIMPLERENDERER>
        <SIMPLELINESYMBOL transparency="1.0" type="solid" width="1"
captype="round" jointype="round" color="255,0,255" />
      </SIMPLERENDERER>
      </LAYER>
    </MAP>
  </CONFIG>
</ARCXML>
```

Appendix 2.Defining MapNotes with ArcXML

```
<?xml version="1.0"?>

<MARKUP>
  <WORKSPACES>
    <FEATURESERVERWORKSPACE name="ifs_ws-0"
url="http://powerserv/servlet/com.esri.esrimap.Esrimap"
service="submitpage" />
  </WORKSPACES>
  <MARKUPLAYER layername="Road " workspace="ifs_ws-0">
    <MODIFIEDFEATURES>
      <FEATURE featureid="16">
      <ENVELOPE minx="878.308156" miny="1404.959273" maxx="1130.785989"
maxy="1796.431041" />
```

```
      <FIELD name="ID" precision="0" size="8" type="4">
        <FIELDVALUE valuestring="45" />
      </FIELD>
      <FIELD name="#SHAPE#" precision="0" size="0" type="-98">
        <FIELDVALUE>
          <POLYLINE>
            <PATH>
            <POINT x="1032.9180468656368" y="1796.4310405383897" />
            <POINT x="1001.566927843633" y="1792.4972499386706" />
            <POINT x="997.752343019663" y="1765.0799215163859" />
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CUHK Libraries
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