Developing a Suitability Index for Residential Land Use: A case study in Dianchi Drainage Area

by

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

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Abstract

The conflict between residential land and agriculture land in China is increasingly sharpened, especially when some urban development began to sprawl to the suburban and rural areas. In order to plan land resources properly, land suitability assessment is often conducted to determine which type of land use is most appropriate for a particular location.

The main objective of this study is to examine how land suitability assessment methods could be used in land planning processes in the Dianchi Drainage Area (DDA) in Southwest China to identify where future residential development should be located. The 1991 Toronto Waterfront Plan and the more recent 2005 Ontario Greenbelt Plan are examined and used to develop a framework which describes the potential for land suitability assessment in the DDA. Data limitations did not permit a suitability analysis to be completed for the DDA, however a description of methodologies for conducting residential land suitability analysis and required data are presented based on a review of relevant literature. The paper concludes with a discussion of the feasibility of land suitability in the DDA and other areas in China and also suggests opportunities for future research.

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Chapter 1
Introduction

1.1 Background

With the increasing demand for land, land use planning and land evaluation have become more important as people strive to make better use of the limited land resources. Land evaluation is the process of assessing land performance for specified purposes (Rossiter, 1996). Land suitability assessment, a typical analysis approach for land evaluation, is the process of determining the fitness of a given tract of land for a defined use (Steiner, 1991). It is an indispensable part of land evaluation in the process of land use decision-making.

Since the 1950s, land suitability assessment has been used in land evaluation processes in several western countries (Wu, 2000). In the beginning, there was no conformity in the standards and methods used in land suitability assessment. Since land evaluation approaches differed from country to country, information exchange was rather difficult. It was not until 1976 that the fundamental document for land evaluation, proposed by the FAO (Food and Agriculture Organization of the United Nations), "A framework for land evaluation", was published. The framework described the procedures of land evaluation and the classification of land suitability. A universally accepted and systematic standard for land suitability assessment was the most important contribution of this framework. After "the Framework for Land Evaluation" was published, the FAO developed specific land evaluation frameworks for irrigation, grazing, and rainfed agriculture. Since the 1990s, land evaluation has become a synthesis of the land capability and land suitability assessment in many countries (Wu, 2000).

Land suitability assessment was introduced to China at the end of 1970s. In the past several decades, land suitability assessment has been adopted as an important part of land use planning in rural areas, urban areas, and the fringe of urban and rural areas. In China, land suitability evaluation for a given crop is the most widely used aspect of land suitability assessment (Fang and Liu, 2004).

One of the shortcomings of current land suitability practice in China is that it is focused primarily on agricultural issues, such as cultivated lands as well as specific crops (Liang, 2001). In comparison, land suitability assessment has played a very limited role in the process of urban development. Urban sprawl, urban edge development and rural development are some of the serious land use problems which should be given more attention in most Chinese cities. Land suitability assessment can help planners to select appropriate areas for government activities, residential land use, industrial land use, and so on. By taking the results of land suitability assessment into consideration properly, the planners and decision makers can plan the future land use planning properly and maximize benefits from the use of land resources.

Along with the development of computer technologies, Geographic Information System (GIS) developed rapidly in the past twenty years. Since the 1990s, GIS have been applied to land suitability assessment for managing spatial data and presenting visual results.

The issue of land suitability assessment will be examined in this thesis with particular reference to the Dianchi drainage area in South-west China. Dianchi Lake, the biggest fresh water lake of Yunnan Province, is located in the watershed area of the Changjiang, Zhujiang and Honghe Rivers. Known as "pearl of the high land", Dianchi Lake is over 40km in length and 12.5km in width. Dianchi Lake plays a key role in maintaining the equilibrium of the regional ecosystem. Unfortunately, increasing human activities have led to domestic and industrial pollution, land abuse, erosion processes, land reclamation shore land, over fishing and introduction of exotic edible fish species since the late 1960s. As a result, the lake ecosystem has been transformed into a turbid water body. Recently, Dianchi Lake was listed as one of the major lake restoration and protection sites in China (Liu, Chen and Mol, 2004). The government aims to promote the Kunming City image and optimize investment environment by ameliorating regional ecological problems through a series of comprehensive ecological measures (Government of Dianchi, 2005).

The Dianchi drainage area, which is located in the centre of Kunming Municipality, has experienced rapid economic development. With this rapid development, the conflict with urban sprawl of future development and land use is more obvious when considered in light of sustainable ecological development. As a result of lacking proper planning, some industrial factories and government construction are built around the lake which has eventually caused more serious pollution. The pollution of Dianchi Lake has restricted the sustainable development of the entire drainage area, and the larger Kunming Municipality. This research focuses on the sustainable and rational use of land resource in the Dianchi drainage area.

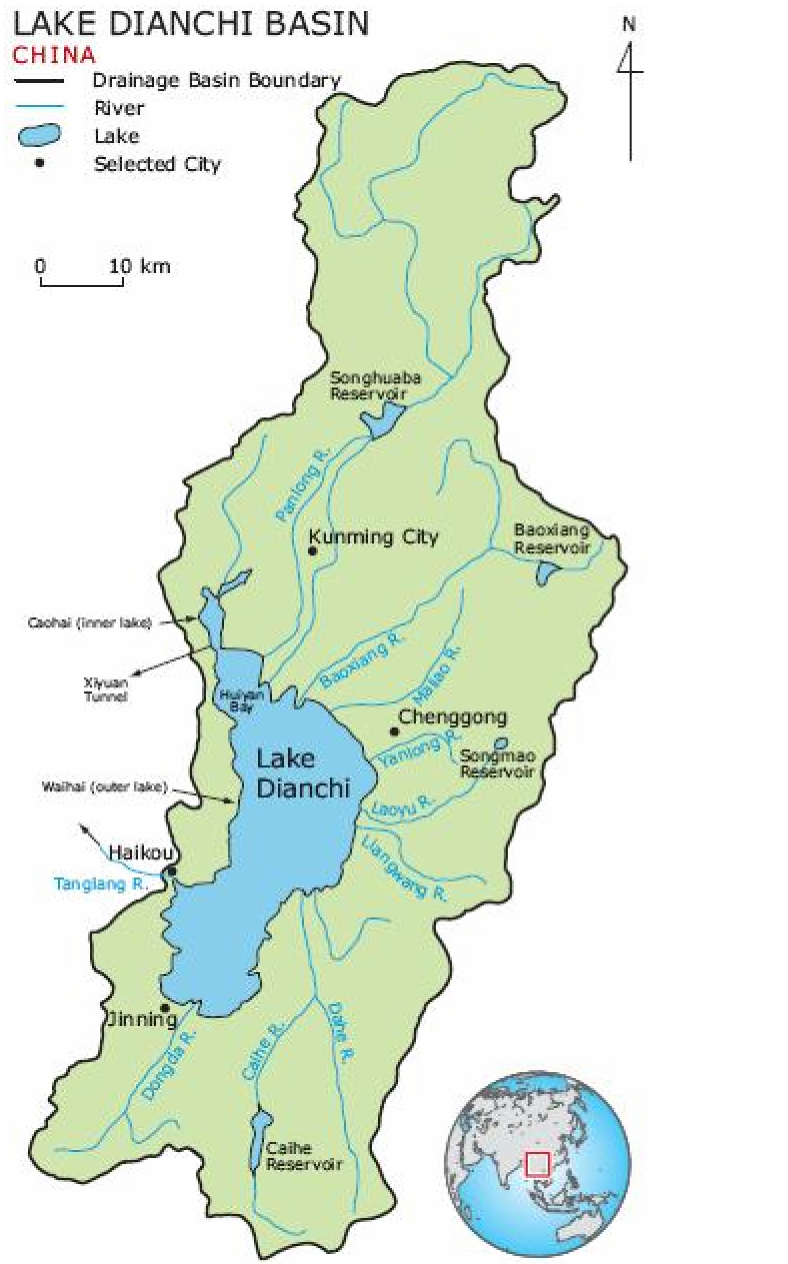

Figure 1-1 Location of the DDA in China source (Jin et al., 2006)

1.2 Thesis Objectives

The primary purpose of this study is to describe how land suitability assessment methods that have been used in North America can be used to identify suitable lands for future residential development in the Dianchi drainage area. This thesis has the following four objectives:

1. To assemble a comprehensive review of the literature concerning land suitability analysis, land use planning, and geographic information systems;

2. To examine land use planning in Greater Toronto Area and use it as material for developing a conceptual framework for understanding land evaluation;

3. To design and develop a methodology for conducting GIS-based land suitability assessment within the regional planning context of southwest China based on the past developed country experiences;

4. To identify the key barriers in using GIS-based land suitability assessment in regional planning in China.

In the process of achieving these objectives, the thesis focuses on relevant bodies of literature. In Chapter Two, the thesis introduces land suitability assessment, land use planning, and geographic information systems and explores their inter-relationships. This discussion forms the foundation on which the thesis is built. Based on the literature review, the approach of land suitability assessment used in this paper will be described to achieve the third objective.

The second objective focuses on land use planning in the Greater Toronto Area (GTA) that includes the Greater Toronto Area Regeneration Plan (Crombie, 1992) and the new

Greenbelt Plan (Government of Ontario, 2005). The GTA has been selected as a case study of the comprehensive planning for sustainable urban development. The purpose of examining the GTA situation is to identify the key issues driving the land use planning process and to help build a conceptual framework for understanding land evaluation. This framework will also serve as the foundation for the study work related to China context.

The third objective is to build a suitability assessment model for residential land use based on a summary of the literature and the experiences learned from Greater Toronto Area Planning study. Since the GTA has a similar physical environmental to the Dianchi drainage area, it is anticipated that the GTA approach to sustainable urban planning and integrated planning can be used to form the future planning in the Dianchi drainage area. As noted earlier, much of the land suitability assessment worked completed in China has focused on the land suitability for given crops which have to be grown in special soils or has specific climatic needs (Fang and Liu, 2004). Based on the approaches other researchers used in suitability assessment, this study builds a new approach for residential land suitability assessment that will fit not only the Dianchi drainage area but also the regions surrounding many other developing cities in China.

Finally, the study concludes with a summary of the barriers and future works of the application of land suitability assessment in China and opportunities for future research.

1.3 Organization

This thesis consists of six chapters related to the process of understating, using, and advancing land suitability assessment. Chapter One is a general introduction of the research. Chapter Two introduces the theoretical background relating to land use and land suitability assessment. Chapter Three analyzes the land use planning in the GTA. Chapter Four describes a methodology related to land suitability assessment and designs a feasible approach for land suitability assessment. Chapter Five discusses how the residential land suitability assessment should be done in the Dianchi drainage area in terms of the lessons and experience learned from the study of land use planning in the GTA. In Chapter Six, it concludes major findings, further recommendations and future research direction regarding this study.

Chapter 2
Literature Review

Based on the objectives of the thesis, this chapter reviews the conceptual and theoretical foundations of land use planning with particular focus on land suitability assessment and the role of GIS in land evaluation and the land suitability assessment. Section 2.1 focuses on the introduction of land use planning including the definition and the process of land use planning. As a major component in the land use planning process, land suitability assessment is introduced in Section 2.2. GIS, a new technical support, played a key role in current land suitability assessment that is introduced in Section 2.2 as well. In the last part of this chapter, the development of land evaluation and land suitability assessment in China are presented and compared with some other western countries.

2.1 Land Use Planning

2.1.1 Land use planning procedure

Land use can be defined as “the human manipulation and alteration of the land” (Alison, 2001). Land uses include settlement, cultivation, pasture, rangeland, recreation, and so on. In recent years, limited land resources in some countries could not meet increasing demands for land. In many developing countries, the demand for land becomes more pressing every year due to factors such as technical charge, economic development and population increase. According to the guidelines published by FAO (1993), land use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land use options. The purpose of land use planning is “to select and put into practice those land uses that will meet the needs of the people best while safeguarding resources for the future” (FAO, 1993). Land use planning is applied to solve problems of conflicts between certain land use and sustainable environmental development. The 1987 Brundtland Commission Report promoted the concept of sustainable development, which was to become the central theme of the report.

Reasonable land use planning procedures are basic prerequisites for successful long-term land use development. Land use planning needs an integrated procedure to achieve this objective. The procedure of a relative comprehensive land use planning in “the Guidelines for Land Use Planning” (FAO, 1995) which includes land suitability assessment is illustrated in Figure 2-1. Each step represents a specific activity, or set of activities, where outputs provide information for subsequent steps.

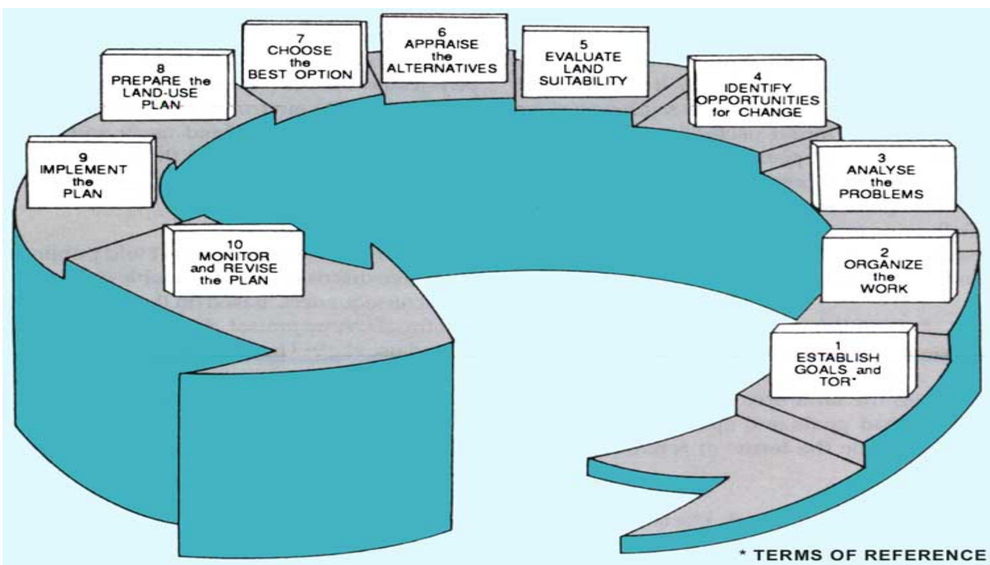

Figure 2-1 The steps of land use planning (FAO, 1993)

Step 1 to step 4 are the foundation of the land use planning. They include establishing the goals of planning according to the needs of land users and the government and organizing the work plan of the planning group. Then land planners will analyze the existing land use problems and seek a variety of reasonable solutions, at last selecting the most promising one based on the consensus of land users, planners and decision-makers. During this process, planners and decision-maker will know about the problems of the planning area and identify the objectives they want to achieve.

The fifth step is evaluating land suitability. For this step, the planner will find out which areas of land are best suited for the specified kind of land use. First, the planners need to determine the requirements of a given land use type and conduct surveys to map land units with their physical properties. The land use type is a kind of land use described in terms of its products and management practice (FAO, 1993). The planners may modify the existing land use. Second, the planners compare the requirements of the land use type with the properties of the units to arrive at a land suitability classification. Mapping land units and their characteristics, setting limiting values for land use requirements, and matching land use with land are the basis for this procedure. Lastly, the planners need to map land suitability for each land use type. The sixth step is appraising the alternatives. The evaluation carried out so far has been essentially in terms of physical suitability. In the seventh step, the planner has to summarize the results obtained from the previous steps and the decision-maker has to choose the best land use option that meets the planning goals.

At the eighth step through the tenth step, the planners will present and implement the plan. The decision makers and the government may introduce regulations and plans to the land users to help the plan implementation. At the last step, the decision-maker and the planner will see how well the plan is implemented. For this way, the planning process comes full circle.

Van Ranst et al. (1996) suggested that derivation of physical land suitability should be a prime requisite for land utilisation planning and development. The suitability guides decisions on land utilisation for optimal utilisation of the land resources. The development of land use planning has included the use of long term strategic comprehensive plans at the local and regional level in the past decade in many countries. Their purpose is to indicate in broad terms the preferred dominant use of land for the foreseeable future, to provide coordination of individual decisions about smaller parcels of land and to allow efficient expansion of infrastructure and services (McDonald and Brown, 1984). Land suitability analysis expresses how well a land unit matches the requirements of the land utilization type, and is seen as an appropriate way to quantify land development constraints and opportunities and help planners cope with the land use plan design problem (Wu, 2000; Hu, 1995; McDonald and Brown, 1984).

2.1.2 Challenges for current land use planning

Land use change is a growing problem confronting policy, planning and decision making at all levels. It links problems and opportunities in urban and metropolitan communities to the larger issues of economic growth and environmental quality (Skole, 2002). Land use change is the critical connection between economic, housing, policy, jobs, and environment and so on. The frontier expansion and population growth has primarily accelerated land use change in recent centuries (Adger and Brown, 1994; Richards, 1990).

Land resources in some developing countries face pressures from continuing land degradation and increasing numbers of people. Sometimes the conflict between different kinds of land use is inevitable, especially in developing countries, which can further intensify the imbalance between land use and human activities and the degradation of land resources (Cai, 2004). Urbanisation, defined as urban population proportion of the total population, is growing rapidly and has impacted significantly on spatial urban development, especially on urban land use (Yeh, 1997). Rapid urban population expansion and urban sprawl in the developing world has been discussed well in recent years (McDaniel and Alley, 2005). As both urban land and rural land are resources in need of effective planning because of their importance in social and economic development, people migrate from rural areas to urban centres for more working opportunity and income. Sprawl is a spatial problem which links issues in the central city and the rural landscape. The need for effective land use planning is one of the consequences of the rapid urban population expansion and urban sprawl. In metropolitan areas urban sprawl is also related to negative impacts of poverty and social inequities, while in rural areas it involves the irretrievable loss of farms, rural livelihoods, and open space (Skole, 2002). Over the last two decades, along with economic growth throughout the world there has been considerable land use change and development in the suburban and rural fringe of many metropolitan areas (Meine and Zhang, 2005; Ryan and Hansel, 2004). The trend of farmland loss is particularly evident in rural and suburban communities outside major urban centers. Since social-economic conditions have changed greatly, urban and suburbs land development is now an emerging issue that needs to be addressed.

Effective land use planning is necessary in order to ensure the orderly growth and development of both urban and rural areas. The process of expansion to the suburban fringe reflects some new environmental and landscape problems. The overall decision-making process must incorporate the entire suite of factors, including transportation infrastructure, population growth and distribution, economic growth and distribution, location and quality of jobs, location of retail, commercial and residential development, land values which change and development, and changes in the landscape and environment (Skole, 2002). These factors need to be considered in their current form and consideration should be given to how they may change in the future. The future development of each area should be in accordance with a comprehensive plan for land use prepared for the entire metropolitan region, in order that future generations will not be saddled with an inefficient arrangement of land uses.

Land use change in China is an increasingly important issue confronting a range of stakeholders and policy makers at all levels of government. There is a pressing need for China to use its limited land resources more efficiently and effectively because of its growing population and the urbanization effects associated with globalization processes (Shen et al., 2002). China has much more pressure in preserving its land resources because of the rapid urbanization process (Li and Yeh, 2004). The rapid urbanization process caused an unprecedented rate of urban land expansion in China over the last two decades (Li and Yeh, 2004; Seto and Kaufmann, 2003). The intensified land use conflict and rapid depletion of agricultural land resources emerged as the result of the new policy and fast development of land use and economy in many fast growing cities. Many land-related problems have been identified, including agricultural land loss, water pollution, soil erosion, and an increase in the magnitude and frequency of flooding in recent years (Li and Yeh, 2004; 1999). In particular, fast urban expansion has triggered the loss of a large amount of agricultural land in many fast developing areas in China. On the other hand, what has distinguished China from the universal norm is the way in which institutional changes have influenced so profoundly the decisions to use land and subsequently the peculiar patterns of land use (Lin and Ho, 2003).

China's problems of urban sprawl, however, are quite different from those of other countries. In developed countries, rural areas are attractive for prospective residents because of the quality of life associated with these communities (Ryan and Hansel, 2004). However, in China, the people move to the urban area for more work opportunities and more earning, due to the economic gap between urban and rural areas. This leads to the continuous sprawl of the urban-rural fringe area for the purpose of accommodating more rural population. Another point of China's urban-rural area is that sometimes the industrial land is the first step of the land use expansion, which differs from other countries, as the residential land use is the first step of the expansion. China faces different problems and needs to find different solutions. How to speed up the rural development, shunt the urban population and narrow down the income gap between the urban and rural areas have all become major problems. Rural land faces expansion of the urban area and dispersal of rural development. Hence, the rational land use in the urban and rural fringe areas is a new challenge for land use planning in China.

2.2 Land Suitability Assessment

2.2.1 What is land suitability assessment?

Land provides the basic physical environment for welfare of the human beings and other terrestrial life forms and is also an important source of wealth (Alison, 2001; Rossiter, 1996; Adger and Brown, 1994). In general, land suitability describes "the fitness of a given parcel of land for specific uses" (FAO, 1976). Land suitability assessment is a planning approach to avoid environmental conflicts by the segregation of competing land uses (Eastman et al., 1993). Initially, this tool was developed as a means of relating spatially independent factors within the environment and, consequently, provided a more holistic view of their interactions (Steiner et al., 2000).

Land suitability is determined by both the fitness of the land for a particular use and the values and interest of the stakeholders in a region (Steiner et al., 2000; Bojórquez-Tapia et al., 1999). The objective of land suitability assessment is "to assist decision makers in finding the most appropriate locations or pattern of locations for fulfilling the goals for the involved stakeholders" (Bojórquez-Tapia et al., 1999). Now, suitability assessment helps land managers make decisions and establish policies for the utilization of particular land areas. It is a strategic process directed at the evaluation of the natural resources, and the regulation of human activities in a region (Steiner, 1991).

Suitability refers to a specifically defined usage or practice, such as suitability for corn, suitability for golf courses, or for particular government building schemes. Suitability techniques are essential for informed strategic decision-making (Steiner et al., 2000; 1991). There are generally two kinds of land suitability assessment approaches. First, the qualitative approach is used to assess land potential at a broad scale or is employed as a preliminary method for more detailed investigation (Baja, 2002; Dent and Young, 1981). The results of qualitative classification are given in qualitative terms, such as highly suitable, moderately suitable, and not suitable. The qualitative factors could not use the numerical score to present. Second, the quantitative approach is using parametric techniques involving more detailed land attributes which allow various statistic analyses to be performed (Baja, 2002; 2001). Recently, most studies combined the qualitative and quantitative approaches in the process of land suitability assessment. The compositive technology including expertise, mathematic model and GIS has been used in the land suitability assessment (Malczewski, 2004; Yang and Jia, 2002; Chen, 2002; Bydekerke et al., 1998).

The approach to land suitability assessments is similar in most case studies. In general, the assessment process is made up of three steps. The first step is selecting the influencing factors and grading the weights and relative values for the factors. The second step is incorporating the maps and database in GIS. The last step involves calculating the suitability score of each land parcel for the given use and making the land suitability map. The primary result of land suitability assessment is the land suitability maps of specific use that can have a substantial influence on designing the plan. A set of land use suitability maps will be very helpful for land use planners and land managers to make complex decisions when they must take into account sustainable development and economic competitiveness (Joerin et al., 2001). Another result of land suitability assessment is the description of major land use types relevant to the area. Land suitability assessment also provides the relevant management and improvement specification for each land utilization type with respect to each land mapping unit for which it is suitable. The information on the reliability of the suitability estimates which is directly relevant to planning decision is given as the result of land suitability assessment. It also includes the subsequent work directed towards improving the land suitability classification, by indicating weaknesses in the data and aspects which might require further investigation (FAO, 1993; FAO, 1976). Another commonly purpose for using land suitability information in land use planning design is to select the most suitable land to allocate with the pre-plan.

2.2.2 GIS as a technique applied in land suitability assessment procedure

Geographical Information Systems are commonly described as computerized information systems for the acquisition, storage, manipulation, analysis, and display of geographically referenced data according to user-defined specifications (Subaryono, 1996; Laurini and Thompson, 1992; Maguire, 1991). GIS provide a common framework for integrating and analysing multiple datasets based on geographic location. GIS are widely available in both proprietary and public domains and vary considerably in their mapping and analytical capabilities. They provide computer-based processes of analyzing spatial data to derive information for environmental assessment and economic development programs. The most powerful characteristic of GIS is its ability to analyze spatial data based on descriptive attributes. In short, the primary goal of GIS is to take raw data and transform it, via overlay and other analytical operations, into new information which can support decision-making processes. The major benefits of using GIS can be concluded as: 1) improved convenience and accuracy of spatial data; 2) more productive analysis; and 3) improved data access.

Natural resources management, especially in North America, has a long history of using GIS (Tomlinson, 1987). Now the fact that capability of GIS coupled with its availability in the marketplace makes the systems attractive for a wide range of activities, particularly those concerned with geographic location as an important factor. Most GIS implementation started in North American and western European countries early in the 1980s. In contrast, GIS was first introduced into developing countries during the 1990s in previously experimental or project based applications (Taylor, 1991). Yeh (1991) mentioned that it is necessary to improve the institutional arrangements related to the application of GIS rather than the technology in developing countries. The successful implementation of GIS will depend on a clear understanding of the functions and needs of planning that are related to system applications.

With the development of GIS, largely fuelled by the needs for efficient spatial inventory, urban managers increasingly have at their disposal information systems in which geographic data are more readily accessible, more easily synthesized, and more readily applied to issues of land use planning (Garriga and Ratick, 1996). GIS has the capability to integrate spatial data of relevant environmental and socio-economic factors to allow a comprehensive assessment to be made (Ren, 1997). GIS technician process spatial data through GIS and present the result to decision makers and planners. Participatory planning schemes have been integrated with GIS through multi-criteria and multi-objective decision making procedures (Joerin, 2001; Bojórquez-Tapia et al., 1999).

Land suitability assessment is one of the contributions of GIS application. GIS technology has been used to assess the criteria requested to define the suitability of land (Joerin, 2001). GIS combined with qualitative and quantitative methods for suitability analysis that can provide the necessary tools for the integration of both social and ecological data into a meaningful database. In the process of suitability assessment, GIS supported spatial assessment is based on weighting relevant factors (or map layers in a GIS database), such as slope, elevation, soil types, existing land use and social service. Senes and Toccolini (1998) combine UETs (Ultimate Environmental Thresholds) method with map overlays to evaluate land suitability for development. The UETs are: "the stress limit beyond which a given ecosystem becomes incapable of returning to its original condition and balance. Where these limits are exceeded as a result of the functioning or development of particular tourist or other activities, a chain reaction is generated leading towards irreversible environmental damage of the whole ecosystem or of its essential parts"(Kozlowski and Hill, 1993; Kozlowski, 1986).

Over the last twenty years, GIS-based land use suitability techniques have increasingly become components of urban, regional and environmental planning activities (Malczewski, 2004; Brail and Klosterman, 2001; Collins et al., 2001). Hall et al. (1992) also use map overlays to define the suitability for particular crops. Another kind of GIS application is incorporated with expert knowledge in the process of suitability assessment (Plant and

Vayssieres, 2000; Bydekerke et al., 1998; Keechoo and Tim, 1996; Johnson and Cramb, 1991). Bydekerke et al. (1998) used expert knowledge and GIS in land suitability assessment for cherimoya. Plant and Vayssieres (2000) implemented a state transition model of oak woodlands with the combination of expert system and GIS. Other approaches of implementing land suitability assessment model include a multiple criteria analysis (MCA) methods (Pereira and Duckstein, 1993). Bojórquez-Tapia et al. (1999) combined GIS and multi-criteria analysis (MCA) for the assessment of the aquaculture, agriculture, biological conservation and fisheries. GIS and MCA can help the planners to avoid opposition and reduce objections that are mandatory prerequisites for social acceptance of land planning procedures (Van Lier, 1998). Bojórquez-Tapia (1994) presented a GIS-based multivariate application for land suitability assessment with a public participation base. Their works include spatial structure and competing land uses. In this study, the author adopted the approach of combining the expert system and GIS for land suitability assessment.

Another useful tool for geographic analysis and land use evaluation is remote sensing. “Remote sensing (RS) is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information” (Canada Centre for Remote Sensing, 2004). During the process of digitally interpreting and analysing the images, the user can extract information of the target for the particular use. The purpose of RS is to assist the user to solve a particular problem by revealing the useful and new information from the images about the target. Since the beginning of 1990s, RS and GIS have flourished in North American, and then have been applied in many fields in China. GIS and RS have been widely used in the process of land evaluation that improved the measures of land evaluation. GIS and RS also have been applied to integrate analysis of regional data set for land suitability assessment of particular cultivated crops based on soil properties and water resource availability (Yamamoto and Sukchan, 2002; Kalogirou, 2002). GIS and RS have been more frequently used in the studies of land suitability assessment for the agriculture development in China particularly after 1990s (Chen, 2002; Cheng 2001; Wu, 2000; Hu, 1995).

2.3 Land Suitability Assessment Development

2.3.1 Land suitability assessment in the western countries

The development of land use planning has a long history in the western countries. The early land assessment in western countries aimed at land taxation, such as the Storied Index Rating in United States in 1937. The United States Department of Agriculture (USDA) introduced its "Land Capacity Classification" in 1961. It was based on the characteristics of land and has been used broadly in agricultural land evaluation. It reflected the limitations of current land use and the gradual change of the productivity. The USDA introduced the "Land Evaluation and Site Assessment" (LESA) in 1981 to evaluate the impacts of proposed federal projects involving agricultural land conversions. LESA was created as an approach to assist local officials to identify farmland for protection by considering not only soil quality but also other factors that affect agricultural practices and then rating farmland sites on a relative scale for decision making (Pease and Coughlin, 1996). LESA is a point-based approach for rating the relative importance of agricultural land resources based upon specific measurable features.

Combined with forest measures and rangeland parameters, LESA provides a technical framework to numerically rank land parcels based on local resource evaluation and site considerations (USDA, 2004). Along with the rapid development of GIS technology, GIS have been frequently used in the process of land evaluation in the LESA in U.S..

Comprehensive efforts at land evaluation began in the 1960s in Canada with the Canada Land Inventory (CLI) program. The 2.6 million square kilometres mapped include the Atlantic province and substantial portions of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, and Quebec (CLI, 2004). This classification focused on agriculture land use, but also for forestry, stock raising, recreation, tourism and natural protection. Ecological zoning was used in the process of land suitability assessment for each kind of agriculture product. Furthermore, the researchers from the University of Guelph (Centre for Resource Development, 1984) presented the procedure of land evaluation. As a whole, the land evaluation in Canada, including the approaches, methods and practicability, is in an advanced stage compared with other countries in the world and has its own influence internationally.

In the studies of North America and Europe, there are many approaches to land suitability assessment. It is worth mentioning that the mix of qualitative/quantitative approaches in the process of calculation for suitability has been frequently applied in the western studies in recent decades. Expert knowledge and GIS are indispensable parts of land suitability assessment procedures. Land resource professionals have the advantage of standardized and systematic methods for characterization and extrapolation (Rojas, 2004), such as the study of Johnson and Carmb (1991) used for the suitability assessment in urban fringe area.

2.3.2 Land suitability assessment in China

Land use management and policy

As a country with an ancient civilization, China has a long historical record of adapting land to different uses. Since the People's Republic of China was founded, land development has been particularly dynamic. Since the 1950s, the planning and construction of cities have been intimately linked with the nation's economic policies and political ideology. The early 1950s witnessed a period of chaos in urban development in the P. R. China. In this period, all lands were owned by the state. The central government and provincial governments had strict control on land use planning. Peasants were not allowed to change land use types under the planned economy. The central government instructed municipal authorities of cities where urban construction was to take place for both short-term and long-term urban development, with specific reference to spatial expansion (Ding, 2003; Fung, 1986). Municipal governments acquired and reserved vast suburban territories for future development. Individual construction units of government departments, municipalities, and state enterprises freely built on whatever site they desired (Ding, 2003; Lin and He 2002). These sprawling urban developments were confined in key-point cities, as well as the urban fringe areas of cities. Also in this period, the survey of cultivated land resource was taken by the local officer and farmers (Lin and He, 2002). However, this survey was taken without the professional direction of land evaluation and the focus of the survey was on arable land (the land which is used for planting crops such as grain crops, vegetables and other economic plants and is cultivated quite often). A shift in urban policies occurred during the 1960s. The central government de-emphasized the development of large metropolitan cities and assigned top priority to build the small settlements that integrated residences, industry, and agriculture (Fung, 1986).

Since the adoption of the “open door” policy in 1979, China gradually shifted from planned economy to market economy as the result of economic reform (Li and Yeh, 2004). Land and property sectors are under transformation as they begin to play important roles in the economy, the land use system has gradually evolved. The largest change in land management policy and practice was the introduction of a leasehold system that includes land use rights, land taxation and use fees, farmland protection, land administration and regulations on land markets (Ding, 2003). After 1979, foreign investors began to explore China market, which made the old land use tenure system conflict with the increasing demand for land. The first innovation in the land tenure system was presented in the special economic development zones in the early 1980s. It permitted foreign investors to lease land for a certain period of time without removing state ownership. One of the most significant changes to land policy occurred in 1986 with the establishment of the Bureau of Land Administration. The Bureau was in charge of land policy reform, land allocation and acquisition, monitoring development, comprehensive land use plans, and implementation of land laws (Ding 2003; Lin and He 2002; Jiang 2001).

After the “The Provisional Regulation on the Granting and Transferring of the Land Rights over State-Owned Land in Cities and Towns” was passed by the State Council in 1991, land users were allowed to transfer, rent, and mortgage the land use right (Valletta, 2001). The government has benefited from the land policy reforms so much that sale of land use rights now account for up to 1/3 of a city's revenue. The trend of farmland disappearance has been further fostered by the recent introduction of a land system in which farmland can be expropriated cheaply from farmers and then sold to commercial users at a much higher price (Lin and Ho, 2003). Since 1990, many urban areas have developed rapidly due to economic development which resulted in substantial expropriation of farmland on the urban fringes. From 1986 to 1995, Li (1997) found that 31 large cities had expanded their urbanized areas by more than 50 percent. In response to concerns regarding the loss of farmland, the central government passed the "Basic Farmland Protection Regulations" in 1994. The farmland protection law not only creates urban villages surrounded by urbanized areas but also controls urban sprawl by requiring developers to make payments in compensation for the losses of farmland (Ding, 2003; Lin and He, 2002).

Hence, the framework for land use planning has been particularly useful in the developing countries in terms of rapid urbanization and urban growth.

Land use planning and land suitability assessment

Land use planning in its real terms has been implemented in China since the end of 1970s. Before this period, the field study of land resources and the collection of statistics related to land resources were the main objectives of land use planning. Since the 1980s, economic development has been hastily conceived and located wherever it was expedient at the moment, with little regard to their effect on the character of the surrounding land use (Cai, 2004). The physical characteristics of a unit of land frequently constrain its suitability for special uses. Currently most case studies of land use planning in China focus on current demand for the lands. The future trend of land use planning will not only focus on current demand for the land, but also consider potential problems in future years. It will help the government to solve the current conflicts of land use and economic development, and develop the sustainable land use. The beginning of the 1980s was a preparative phase for land use planning in China. Based on the framework of FAO, the Chinese Academe of Science published the criteria of cartography and classification for a 1:1,000,000 map of land resource in China (Zhang, 2003). From the 1990s till now, land evaluation has been experienced a boom period. Land evaluation considers not only the physical environment but also the socio-economic in the evaluation process. The objectives of evaluation are more diversified, such as agriculture land evaluation, tourism land evaluation, urban land evaluation, and so on.

Land suitability assessment has been widely applied in the process of land use planning in China since the 1990s. It has been used broadly for agriculture evaluation since agriculture is the primary industry in most areas of China. The result of land suitability assessment is not only a part of land use planning, but also is directly utilized in the land management (Wu, 2000). Most of the land suitability assessment case studies are focused on small cities or the undeveloped areas of a city. The objectives of suitability assessments in China can be divided into two groups. First, considerable effort is dedicated to assessing current agriculture lands, such as the arable lands, forestlands, garden lands, then determines the suitability of the current use for the land unit (Dai, 2003; Chen, 2002; Cheng, 2001; Wu and Chen, 2000; Wu, 2000; Hu, 1995; Liu, 1995). The results indicate if the existing use of land unit is rational or if the ways of using the land need to be changed. Furthermore, land suitability assessment serves overall land use planning by helping to determine the best future use of each parcel and helping to constitute policies and regulations for future land use. The second objective is applied to one or more kinds of particular crops (Wang, 1997). Evaluate all kinds of lands in the study area to determine the suitability of a certain agriculture product. The results presented illustrate the potential productivity of given crops and also analyze the future economic benefits of specific crops.

A lot of studies have been based on selecting suitability factors and calculating their weighting for importance according to input from professional experts, planners, scientists and government officers (Zhang, 2003; Chen, 2002; Cheng, 2001; Wu, 2000; Wang, 1997). The development of methods for land suitability assessment is divided into two phases in China. The first period was in the 1990s when the GIS technology was not so broadly used. Qualitative analysis was used widely in the assessment process (Liu, 1995). From the end of 1990s, GIS and remote sensing have been used in most land suitability assessments. The quantitive methods have been used in the process of calculating the weighting and compositive suitability of the factors (Dai, 2003; Zhang, 2003; Chen, 2002; Cheng, 2001; Wu, 2000; Wang, 1997; Hu, 1995). Several mathematical methods have been quoted especially the Analysis Hierarchy Process (AHP) which has been used for weighting factors in many studies (Dai, 2003; Wu, 2000; Hu, 1995).

In conclusion, during the past ten years, research on land evaluation in China has witnessed much progress in theory, methodology and application. Firstly, much attention has been paid to integrated consideration of social and economic factors as well as natural elements which are used in land evaluation, and to those methods which make a close combination of qualitative approach with quantitative one. Secondly, land suitability assessment has received more rapid development. Thirdly, the evaluation for cultivated land including the grading and valuation was popularly carried out almost in whole country. However, land evaluations for residential and industrial use still are less developed research fields. At the same time, much effort has focused on evaluation of urban land following the rapid development of land markets in urban areas in China since the early 1990s, and a number of new ideas have emerged and some new land evaluation methodologies have been developed. Fourthly, some new fields of application of land evaluation have appeared, such as the land evaluation for land degradation control in ecologically fragile regions and for land consolidation in urban and rural areas. In addition to land evaluation for sustainable land use, the development of indicator systems has become a focus of research in land evaluation. Finally, several advanced approaches such as Artificial Neural Networks (ANN) and Genetic Algorithms have been used experimentally land evaluation even as conventional methods such as the AHP were still used (Zhao and Chen, 1998; Yang and Jia, 2002). In addition, GIS has been popularly used in land evaluation, especially in land suitability assessment.

2.3.3 New trends and opportunities in land suitability assessment

Decades have past since the FAO developed its land suitability assessment framework and goals of suitability assessments have expanded beyond the original agricultural land focus. To date, land suitability assessment has been applied in many fields. While studies in developing nations have focused largely on agricultural lands, most western studies are focused on a specific purpose. McDonald and Brown (1984) evaluated the land suitability for urban fringe areas for particular use of urban use, such as recreation, conservation and horticulture. Joerin, Theriault and Musy (2001) provided an example of the suitability of land for housing and accounted for economic competitiveness. Steiner et al. (2000) combined the biophysical and social factors with the land suitability assessment of watershed region. The objectives of this paper are low-density housing suitability, industrial development suitability and commercial development suitability analysis, which are quite different with the former studies of land suitability.

The land suitability assessment has been used in a broad way in land use planning. The processes of land suitability assessment are similar for different kind of use. For agricultural land purpose, there are a lot of principles (FAO, 1976; 1993) that the planners can used to build assessment system. The framework of FAO (1976; 1993) is not a strict instruction manual, but indicates alternative ways of proceeding and it is intended that users should be selective in taking those elements which fit their needs, and adapt them as required. This qualitative approach for land evaluation was chosen, as compared to approaches using dynamic simulation models, since the latter require a host of accurate data on land and land use. For agricultural land suitability assessment, a particular crop has its own growing environment that needs detail information of soils, such as slope, moisture of soil, depth, type of soil and climate limitations. For other general kinds of land use, such as residential land suitability assessment, the planner cannot rely on an evaluation system. According to a standard guide, most studies for other types land suitability assessment are based on the experience from specialists and literature review based on the particular situation of the study area.

The application of the results is the contribution of land suitability assessment to land use planning. The land suitability groups are associated with the environmental conflicts in the sense of the relative suitability among groups, so that land uses can be allocated in a pattern that maximizes consensus among the stakeholders (Bojórquez-Tapia et al., 1999). Most studies directly used suitability maps in land use planning to show where the potential suitability for the given use exists. The decision makers and planners can effectively develop the new projects. The government can constitute the new policy for the land use development.

With the rapid development of participatory land use planning, land suitability assessment will encounter more challenges (Fagerstrom et al., 2003; Sawathvong, 2003; Amler et al., 1999). FAO (1991) experience has shown that through participatory programs and activities, it is possible to mobilize local knowledge and resources for self-reliant development and, in the process, reduce the cost to governments of providing development assistance. Land professionals are not the only participants in the process of land suitability assessment. According to Cools et al (2003) and Rojas (2004), farmers who are best at understanding the local environment have developed land use systems that are well adapted to the potentials and constraints of their land.

As a consequence, potential new gateway functions of land suitability assessment for land use planning have been put on the agenda of policy makers and planners. The trends of land suitability assessment are supported by multiple fundamental trends in computer approaches.

Recent advances in information technology especially Internet and Artificial Intelligence (especially fuzzy logic techniques) have urged the development of new approaches to the GIS based land use suitability analysis (Openshaw and Abrahart, 2000; Carver and Peckham, 1999). Nevertheless, land suitability assessment is more than a GIS-based procedure, it also involves participatory approaches in which planners deal with constituencies and complex urban problems.

2.4 Summary

This chapter introduced definitions, issues, and trends related to land use planning and land suitability assessment. Land use planning should not be limited by the original land utilization, but be determined by its own characteristics, its situation of ecological environment and its social need. As a step of land use planning, land suitability assessment should be used help achieve sustainable development, prevent land resources degradation, minimize adverse environmental impacts, and ensure efficient use of land resources.

Based on the literature review, most suitability assessments in China are focused on agriculture, the suitability of cultivated land and forestland, and especially the suitability for a particular crop. For other usages, suitability assessment is rarely conducted. Typically the study areas of the existing research are mostly in rural areas. Compared with western studies, current land suitability assessment in China lacks an integrated database for land resources. Different departments own different kinds of data for one region that reduces the veracity of the results of evaluation. Conducting the residential land suitability assessment for the Dianchi drainage basin is an experiment of this research field.

Chapter 3

The Case Studies of Greater Toronto Area

The reference from international experience will contribute to land use planning in the Dianchi drainage area. This chapter is an examination of land use planning in the Greater Toronto Area (GTA) based on the Report of Royal Commission on the Future of the Toronto Waterfront (1991) and the Greenbelt Plan (2005). The first part of chapter introduces the basic environment of the GTA and land use planning in the Waterfront Report. Section 3.2 discusses the key issues considering in the planning process in the Greenbelt Plan. The objective of this chapter is to build a framework for understanding land use planning which will serve as the foundation for the study in the DDA. This framework will provide guidance concerning the factors that should be considered in land use planning beyond those presented by the FAO framework. These factors considered in the GTA case studies are related to the urban development and agriculture protection and will help to select the influencing factors for residential land suitability assessment in the DDA.

As discussed in Chapter 2, land use planning is applied to solve conflicts between land uses for certain purposes and sustainable environmental development. The plans for the GTA are considering the linkage between land use development with environment, agriculture system, hydrologic system, settlement areas and infrastructure. The Toronto Waterfront Plans emphasised adding the factor of environmental protection into the process of land use planning. The Greenbelt Plan considered the agriculture land protection, natural hydrologic system protection, and future settlement area expansion. Chapter 2 described the goal of land use planning as an indication of a preferred future land use or combination of uses. The Greenbelt Plan is an entire plan for future land use development. The Greenbelt Plan demonstrated the policies related to future agriculture land development, settlement lands expansion and non-agriculture land use in different areas. The policies illustrated in the GTA plans will help to establish the land development policies in land use planning in the DDA.

3.1 Introduction of the GTA

The City of Toronto covers an area of 641 km^2 and is bounded by Lake Ontario to the south, Etobicoke Creek to the west, Steeles Avenue to the north, and the Rouge Rive to the east. The Greater Toronto Area (GTA) extends beyond the city boundaries and, as illustrated in Figure3-1, includes the regional municipalities of Durham, Halton, Peel and York and covers an area of 5,868 km^2. Both the Toronto City and the GTA are parts of a larger, natural ecosystem known as “the Golden Horseshoe area”.

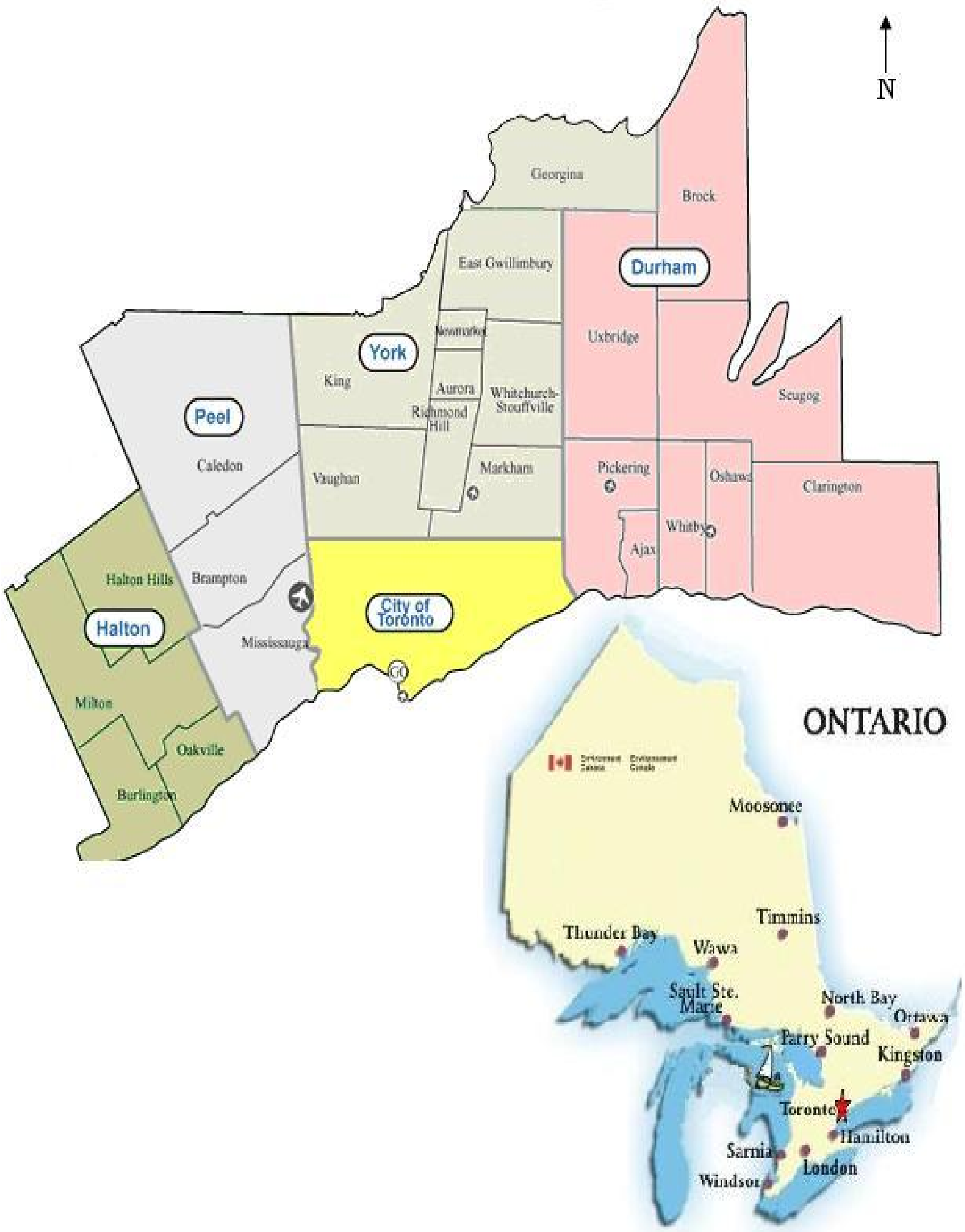

Figure 3-1 The map of the Greater Toronto Area (www.greater.toronto.ca).

The map below is the key map of Toronto in Province Ontario.

In comparison with many other international urban centres, the GTA offers a high standard of living. But the forces of suburbanization that have characterized growth there are seriously eroding its social, environmental and economic structure (Doering et al., 1991). The GTA is selected as a specific representative of comprehensive urban land planning in western country for helping to develop an appropriate residential land suitability assessment process in the Dianchi drainage area. The GTA as the centre of Ontario, even Canada, has a long history of land use planning and it has a comprehensive process of the urban planning for future development. In terms of the physical characteristics, the GTA and the DDA both include substantial water bodies (i.e. Lake Ontario, Dianchi Lake which requires land use planning in both regions to consider water resource protection. In the social environment aspect, the GTA is the capital of the Province Ontario and has five million people in the area, on the other hand, the DDA is located in Kunming which is the capital of Province of Yunnan and has six million people in the area. Also, both the GTA and the DDA is the central economic center for the province. This similarity in social environment makes it possible and important for the DDA to consult the key issues considered in the GTA's land use planning process as references for its future land planning. Hence, identifying what are the key issues driving the long-term land use planning in the GTA is the objective of this chapter. How to use the experience learned from the GTA to the DDA planning process will be discussed in next chapter.

3.2 The Future of the Toronto Waterfront Reports

3.2.1 Introduction of the Reports

On June1 1988, The Royal Commission on the Future of Toronto Waterfront began its work as a national inquiry with the Honourable David Crombie as Commissioner. The Commission's mandate was to "make recommendations regarding the future of the Toronto Waterfront, and to seek the concurrence of affected authorities in such recommendations, in order to ensure that, federal lands and jurisdiction serve to enhance the physical, environmental, legislative and administrative context governing the use, enjoyment and development of the Toronto Waterfront and related lands" (Watershed, 1990). The study area for the report is the Greater Toronto Bioregion which is bounded by Lake Ontario, the Niagara Escarpment, the Oak Ridges Moraine, and includes several watersheds that drain into Lake Ontario (www.toronto.ca, 2005). The Commission had released three reports that included Interim Report, Watershed Report and Regeneration Report. Planning for Sustainability (Doering, et al., 1991) is a particularly important report towards integrating environmental protection into land use planning. Establishing land and water use management strategies are two parts component of the reports.

3.2.2 Land use planning in the Reports

Most of the lands within Toronto City have been developed. Land use planning in the GTA Regeneration Plan emphasized integrating environmental protection to ensure that land use planning can achieve the objective of ecosystem approaches in the planning process. For the land use part, protection of agriculture and rural lands in relation to urban growth should be considered in the plan. Geological features, habitats of rare species, woodlots, and river valleys should be protected as significant natural resources.

In “Planning for Sustainability” (Doering, et al., 1991), the Commission explored ways to integrate environmental protection into land use planning to acknowledge the interrelatedness of economic and environmental processes. Official plans focusing on environment considerations will give developers a greater degree of certainty and predictability, and guide landowners in the matter of appropriate land uses. The developers should be encouraged take both the environmental sensitivity and economic development into account in their decision making process and the two factors should govern their land use decisions. In order to provide a clear and applicable guidance as a reference in the decision making process, an official plan must include provisions for assessing the environmental considerations, such as: (Doering, et al., 1991)

1. Protection of surface water, ground water, air and soils from contamination through such conservation strategies as storm water management and user pay. Groundwater protection can be encouraged by promoting permeable surfaces, retention ponds, vegetation, and other such measures that minimize run-off. Shorelines and fisheries should be also protected

2. Protection of natural resources of local and regional significance, including wetlands, geological features, tributary streams, habitats of locally/regionally rare species, woodlots and river valleys and the links between them. Protection of such resources could be achieved by requiring the inventories that be made of such features and targets. Areas of provincial significance should also be protected.

3. Design guidelines can be used to enhance streetscapes and rural landscapes, as well as unique architectural features. The purpose is to create liveable, human-scale cities and take into account urban design and density goals. Heritage conservation could be a part of this consideration.

4. Protection of agricultural and rural lands in relation to urban growth.

5. Promoting the concept of “net environmental gain”. Developments should be assessed for their potential to contribute positively to rehabilitating the environment, by restoring damaged habitat and natural areas and revegetating areas, among other measures.

6. Evaluating transportation networks with a view to enhancing and encouraging public transit and de-emphasizing private automobile use. The transportation networks should also be considered in promoting air quality objectives.

The Royal Commission on the Future of the Toronto Waterfront stated that the present system of land use planning and environmental management did not provide sufficient environmental protection (Doering, et al., 1991). Based on this situation, the Royal Commission on the Future of the Toronto Waterfront have discussed the ways in which the philosophy and principles of the ecosystem approach could best be integrated into environmental and sustainable land use planning. Planning for sustainability also means becoming a way of the connection between land use, resource use, and pollution of environment. Regeneration Report of the Toronto Waterfront (Crombie, 1992) proposed a framework for ecosystem-based land use planning that is to provide a means of evaluating the social, economic, and biophysical components of ecosystems and the interactions among them.

3.3 The GTA Greenbelt Plan

3.3.1 Introduction of the Greenbelt Plan

The increasing commercial needs and growing population require more lands for commercial practices and housing units. Since the last decade, the increasing demand for urban land areas is a world wide phenomenon that naturally accompanies population and economic growth. The geographical growth of urban areas, called "urban sprawl", has become a heated issue in Ontario (Cox, 2004). Under this situation, the Ontario government has expressed its commitment to fighting the growth of urban land areas. It focuses on establishing a "greenbelt" inside which development would not be permitted and efforts to force urbanization towards the periphery and away from the core area are encouraged (Cox, 2004; Bartleman, 2003). The Greenbelt Task force recently designated an area of 7,000 km^2 running from south-east of Peterborough to the Niagara Peninsula as a "Greenbelt", which is shown in Figure 3-2. The area of Greenbelt Plan focuses not only in the GTA area but also in Hamilton and Niagara Peninsula that make up of the "The Golden Horseshoe" area. This area is bigger than the study area in Toronto Waterfront Reports (1991).

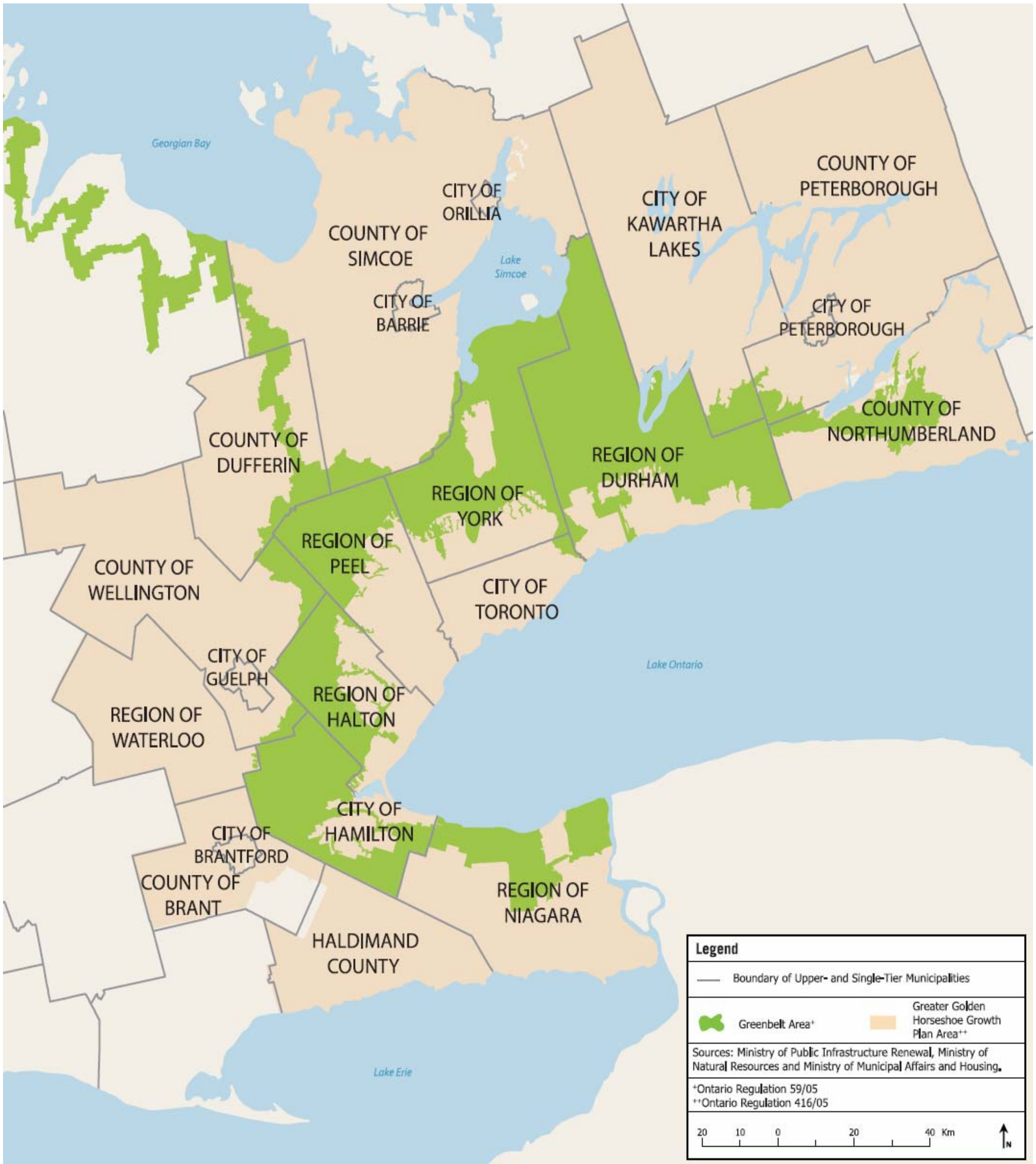

Figure 3-2 The Golden Horseshoe area

(Source by: http://www.pir.gov.on.ca/userfiles/HTML/cma_4_44867_1.html)

The Greenbelt is the key to permanently protecting greenspace and containing urban sprawl in the GTA area. The Greenbelt Plan provides open space and recreational, tourism and cultural heritage opportunities to support the social needs of a rapidly expanding and increasingly urbanized population. The Greenbelt Plan is governed by the planning policy and regulation, of various levels of government and agencies, which work collectively to manage and guide land use within the Greenbelt. The goals of Greenbelt Planning proposed a permanent connected agricultural and environmental system which supports existing communities and conserves the natural resources critical for a thriving economy (The Planning and Economic Development Committee, 2004). The Greenbelt Plan is an overarching strategy that will provide clarity and certainty about urban structure, where and how future growth should be accommodated and what must be protected for current and future generations (Greenbelt Plan, 2005). It also identifies where urbanization should not occur in order to provide permanent protection to the agricultural land base and the ecological features and functions occurring on this landscape.

3.3.2 Key policies for land use in the Greenbelt Plan

The Greenbelt Plan sets out policies related to (Greenbelt Act, 2005): 1) land use designations; 2) transitional matters that may arise in implementation of the Greenbelt Plan; 3) land use change in Protected Countryside; 4) the long-term viability of agriculture in Protected Countryside; and 5) the identification of major land use areas and the provisions of parks and open space. The Protected Countryside lands identified in this Greenbelt Plan are intended to enhance the spatial extent of agriculturally and environmentally protected current lands while at the same time improving linkages between these areas and the surrounding major lake systems and watersheds. The Protected Countryside of this Greenbelt Plan is made up of an Agricultural System and a Natural System, together with a series of settlement areas.

Agricultural System:

The Agricultural System provides a continuous and permanent land base to support long-term agricultural production and economic activity. The Greenbelt Plan provides a series of policies for protecting agricultural lands based on facilitating both environmental and agricultural protection. The delineation of the Agricultural System was guided by a variety of factors including a land evaluation area review which assessed matters such as soils, climate, productivity and land fragmentation, the existing pattern of agriculturally protected lands (Greenbelt Plan, 2005). The agricultural system is comprised of specialty crop areas, prime agricultural areas and rural areas. Since the protected area in the plan included the Niagara Peninsula, special crop areas are the Niagara Peninsula Tender Fruit and Grape Area and Holland Marsh. For protecting specialty crop areas, lands within specialty crop areas shall not be redesigned for non-agricultural uses. Prime agricultural areas are lands designated within municipal official plans that included areas of prime agricultural lands and additional areas where there is a local concentration of farms which exhibit characteristics of ongoing agriculture. Prime agricultural areas shall not be redesignated for non-agricultural uses except new or expanding live stock facilities shall comply with the minimum distance separation formulae. Rural areas are characterized by a mixture of agricultural lands, natural features and recreational and historic rural land uses. Rural areas provide the primary locations for recreational, tourism, institutional and resource-based commercial/industrial uses. Rural areas also contain many existing agricultural operations, so new agriculture uses and agriculture-related use are allowed and permitted in rural areas. In rural areas, settlement area expansions are permitted. The plan does not allow for non-agricultural uses on, or the urbanization of farmland in the greenbelt. The plan restricts that agricultural uses where the severed and retained lots are intended for agricultural uses and provided the minimum lot size is 40 acres within specialty crop area and 100 acres within prime agricultural areas. Greenbelt protection will increase land values in the long term. The values of agricultural lands are not designated for urban development or any other non-agricultural uses. The Agricultural Advisory Team recommended the government will explore ways for providing the sector with the necessary support and investment to plan for a viable and prosperous future.

Natural Heritage System

The natural system considers the natural heritage and water resource system. The Protected Countryside includes several areas of hydrologic significance that are incorporated into the Greenbelt function together with other hydrological features. In the Natural Heritage System, new development or site alternation will have no negative effect on key natural heritage features[1]or key hydrologic features[2] or their functions. Connectivity along the system and

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[1] Key natural heritage features include significant habitat of special concern species, fish habitat, wetlands, life science areas of Natural and Scientific Interest, significant valley lands, significant woodlands, significant wildlife habitat, sand barrens, tallgrass prairies and alvars.
[2] Key hydrologic features include permanent and intermittent streams, lakes, seepage rivers, springs and wetlands.

between key natural heritage features or key hydrologic features located within 240 meteres of each other is maintained or enhanced. Municipalities should consider the Natural Heritage Systems connections within settlement areas when implementing municipal policies and plans.

Water Resource System is made up of both ground and surface water features. These areas of hydrological significance are incorporated into the Greenbelt function together with other hydrological features within the Greenbelt. All planning authorities shall provide for a comprehensive, integrated and long-term approach for the protection, improvement or restoration of the quality and quantity of water.

Settlement Areas

Settlement areas in the Greenbelt support and provide economic, social and commercial function to agricultural areas. The Greenbelt Plan considered the settlement areas in different area and population size, then divided settlement areas into Towns/Villages and Hamlets. Towns/Villages have large concentrations of population and development in the Protected Countryside and are the focus of development activity. Hamlets are smaller than Towns/Villages and have lesser concentration of development. Most Towns/Villages have full municipal water and sewer services or a combination of private and municipal water services, but Hamlets are serviced with individual on-site sewage and water services.

For Towns/Villages, municipalities will continue to support the long-term vitality of the settlements through appropriate planning and economic development approaches which include modest growth that is compatible with the long-term development of the settlements area and the capacity to provide sewage and water services. Modest settlement area expansions may be possible for Towns/Villages according to municipal sewage and water services and implementing the requirements of other provincial and municipal policies and plans. For Hamlets, the Greenbelt Plan permits infill and intensification of Hamlets subject to appropriate water and sewage services. Notwithstanding the policies above, all settlement area expansion shall not extend into Natural Heritage System and specialty crop areas, and maintain the rural and existing character of the settlement area.

3.4 Lessons Learned

3.4.1 Toronto Waterfront Reports

Because the Future of the Toronto Waterfront Reports published earlier than the Greenbelt Plan and worked for general plan in the GTA area, the land use planning in the report especially the "Planning for Sustainability" (Doering, et al., 1991) focused on how to integrate environment protection into land use planning. The report suggested the planning and approval process requires proper and accurate prediction and assessment of significant effects on the environment in the process. The environmental factors that are considered in the Planning for Sustainability Report can be used as a reference for selecting factors to be used in the process of DDA land suitability assessment, such as air, soils, waters, woodlands, groundwater system, agricultural lands, heritage landscapes, geological features, parks and open spaces.

3.4.2 Greenbelt Plan

The Greenbelt is an overarching strategy that will provide clarity and certainty about urban structure, where and how future growth should be accommodated, and what must be protected for current and future generations. The policies of agricultural system, natural heritage system and settlement area in the plan are also suitable for land use planning in the DDA. The policies also indicated that it's necessary to point out what kind of land are not permitted for residential use before selecting suitable lands for residential use in land suitability assessment process in the DDA.

Agriculture system

The Greenbelt Plan divided the agriculture lands into three different kinds based on their importance. Specialty crop area is one of the most important kinds of agriculture land that shall not be permitted for any other non-agriculture land use purpose. In the DDA, it is also necessary to identify what kind of lands are the most important lands in the area like the specialty crop area in the Greenbelt Plan, and this kind of land could not be switched to any other land use type for other purposes. The Greenbelt plan also prohibited the prime agricultural areas to be redesignated for non-agricultural uses except new or expanding live stock facilities, which has to comply with the minimum distance separation formulae. However, in rural areas, settlement area expansion is permitted. In the DDA, it also will be helpful to divide the agriculture lands into different classes in terms of their importance to the agriculture. The future residential land expansion shall occupy the less important agriculture land, whose occupation will not affect the whole agriculture system.

Natural Heritage System

Protecting the current Natural Heritage System is another point in the Greenbelt Plan that will also work in the DDA. Because protect the hydrologic system is a significant work in the DDA, the policies in the DDA should grant permanent protection to the natural heritage and water resource systems that sustains ecological and human health. The future new land development in the DDA should avoid the degradation to the quality or quantity of surface or ground water and protect the fish habitat. The future residential land development should have appropriate water and sewer service and should not have any negative impact on the biodiversity of the Natural Heritage System.

Settlement area

For the settlement area, the DDA faces two major problems. The first is how to develop the current rural area and the second, how to restrict urban sprawl. The policies in the Greenbelt Plan indicated that different development policies should be introduced for different size of settlement areas, and also pointed out the policies on the infrastructure for the settlement areas that need to be considered as influence factor for residential land suitability assessment in the DDA. The DDA should apply different policies in urban area, urban rural fringe area and rural area. Urban area has comprehensive transportation system and sewage and water service system, but the population density in urban area is higher than other districts. Hence, the residential area expansion should not be permitted in urban area. The policies for town/village development in the Greenbelt Plan will be suitable for urban rural fringe area development in the DDA. The rural areas are the emphasis of residential land development in the DDA and the policies for rural areas can take into consideration the related policies for Hamlet in Greenbelt Plan.

Infrastructure

The Greenbelt Plan also provides a series of policies for Infrastructure, which is an important feature for the residential land use planning in the DDA. Infrastructure includes sewage and water system, sewage treatment systems, waste management systems, electric power generation and transmission, telecommunications, transportation facilities, oil and gas pipelines and associated facilities. These features of infrastructure should be considered as influencing factors for residential land suitability assessment in the DDA. Some policies in the plan are also suitable for the DDA areas, such as: 1) existing infrastructure must be maintained; 2) new infrastructure is permitted if it supports existing agriculture and rural settlement areas; 3) the construction and expansions of infrastructure practices shall minimize the negative impacts and disturbance of the existing landscape; 4) new or expanding infrastructure shall avoid key natural heritage features or key hydrologic features; 5) any sewage and water servicing installation is planned and constructed to minimize surface and groundwater disruption.

3.5 Summary

In short, the land use plans in the GTA focused on using land more effectively, reducing stress on the land environment, promoting a more compact urban form to reduce urban sprawl, and maintaining healthy soil conditions for relocated. The policies in the GTA area are helpful for considering land use planning in the DDA. Next chapter will introduce the methodologies in land suitability assessment studies. Combining with the experiences learned from the Reports for the Future of Toronto Waterfront and the Greenbelt plan, next chapter will examine how land suitability assessment methods could be used in residential land use planning the DDA.

Chapter 4
Methodology

This chapter focuses on parametric approach methodology of GIS-based suitability assessment. The first section describes the basic concept in land suitability assessment. Section 4.2 introduces the methodologies that widely used in the suitability assessment studies and their strongpoint and shortcoming. Section 4.3 examines how land suitability assessment methods could be used in land planning processes in the DDA.

4.1 Data and Methodology Review

4.1.1 Database

The key element for this GIS work is the design of the database. The basic database should consist of detailed information including soil attributes, road network, river network, geology map, DEM (Digital Elevation Model)[3] and land use map. Maps in raster format could use for analysis. When land suitability is assessed in a raster GIS environment, each land unit in the database is valued according to its quality for a given use, and each thematic layer represents an evaluation criterion for the process of evaluation (Bojórquez-tapia et al., 1999; Eastman et al., 1995; Pereira and Duckstein, 1993). The Table 4-1 shows the types of data that have been used in recent suitability assessment studies. Since the data used varies in terms of the study objective, the table lists the objective of each suitability assessment, the study area and the features modeled in the database.

[3] Digital Elevation Model (DEM) is used to refer specifically to a raster or regular grid of spot heights

Author	Objective	Study area	Database
Bojórquez-Tapia (1999)	Aquaculture	Costa Norte, Nayarit	Landsat TM images for vegetation land cover, soil type, landforms, elevation, major roads, and urban areas
Wandahwa and Van Ranst (1996)	Pyrethrum cultivation	West Kenya	soils, landform, rainfall, elevation and administrative regions
Steiner et al. (2000)	Industry, recreation, and low-density housing	Gila River watershed.	Water availability, wild life, vegetation, productive soils, slope, drainage, wildlife interest, microclimate, slope, heavy structure, lawns, access to major roads, access to city water and access to sewer lines.
Bydekerke (1998)	Cherimoya	Southern Ecuador	Precipitation, relative humidity, mean annual temperature, depth, organic matter, contour lines, ecotypes, soil type
Thapa et al. (2004)	Agriculture	Hanoi peri-urban	Landsat TM images for land use map, soils, soil salinization, water resource, road, vegetable market
Van Lonkhuyzen et al. (2004)	Wetland mitigation sites	Illinois, USA	Hydrology, soil, historic condition, adjacent vegetation, vegetation cover, land use
McDonald and Brown, 1984	Urban use, recreation use	Urban fringe areas	Water supply system, economic features, levels of environmental degradation, employment, travel time.
Chen (2002)	Cultivate land, garden land, forestry	Fuzhou City, China	Slope, land use map, land texture, PH, transportation, elevation
Wu (2000)	Paddy field, garden land, construction land	Fuqing City， China	Soil, climate, land from, land use map, land PH value, land texture, infrastructure, road network.
Hu (1995)	Residential area in rural	Hefei city, China	Soil, land use type, environment, landform, land carrying capacity
Shen (1999)	Residential area	China	Slope, schools network, environment, sewer network, road network, hospital network

Table 4-1 The data used in the different land suitability assessment

To all appearances, the data listed in Table 4-1, the basic dataset for general land suitability assessment includes soil, land use type, and slope that are general information of land characteristics. In terms of diversity of the criteria, for different kind of land assessment purpose, the researchers need to collect particular data for specific use in terms of the objective of the study. The data preparation should include data which can be used for two purposes. Firstly, the data used for identifying priority environmental protection lands that will help to identify the priority area demanding protection in spite of the land suitability assessment. For example, the prime agriculture lands should be given priority protection in the GTA case studies, if any land suitability assessment were applied in GTA they should consider excluding the prime agriculture land first based on the data collection of prime agriculture land. Secondly, the data for particularly land suitability assessment should be collected in terms of different criteria that the researcher used.

For residential land urban use, researchers selected a lot of factors related to the local economic, social and physical environment which have been generally used in a lot of cases, such as schools network, water supply system, economic features, environmental degradation, employment, landform, environment factor, sewer network, road network hospital network, water availability, wild life, vegetation, drainage, wildlife interest, microclimate, heavy structure, lawns, access to major roads, access to city water and access to sewer lines (Collins et al., 2001; Shen, 1999; Hu, 1995; McDonald and Brown, 1984).

4.1.2 Overlay mapping

Computer assisted overlay techniques were developed for mapping and combining large datasets. It is the earliest approach for using GIS into land suitability assessment (Murray et al., 1971). The map overlay approach has been typically applied to land use suitability in the form of Boolean operations (Malczewski, 2004). GIS assisted overlay techniques are popular since they are easy to implement within the GIS environment using map algebra operations and are also easy to understand and intuitively appeal to decision makers. Often, the manipulation of multiple data layers is required to achieve the objective of the overlay operation. In a vector-based system map overlay operations are more complex than the raster-based case, as the topological data is stored as points, lines and polygons. For raster data overlay, it is a relatively straightforward operation and often many data sets can be combined and displayed once. In raster overlay, the pixel or grid cell values in each map are combined using arithmetic and Boolean operators to produce a new value in the composite map (Heywood, 1995). The maps can be treated as arithmetical variables and perform complex algebraic functions. In a vector-based system, map overlay operations allow the polygon features of one layer to be overlaid on the polygon, point or line features of another layer. This requires relatively complex geometrical operations to derive the intersected polygons, and the necessary creation of the new points and lines, with their combined attribute values (Star and Estes, 1990). During the process of overlay, the attribute data associated with each feature type id merged. Lai and Hopkins (1989), Heywood et al. (1995) and Malczewski (2000, 2004) suggest that classical Boolean operations oversimplify the complexity of the process underlying land use planning problems by focusing on the facts rather than a right combination of facts and value judgments. However, the major criticism of conventional map overlay approach is related to the inappropriate methods for standardizing suitability maps (Pereira and Duckstein, 1993). The simple overlay mapping approach do not explicitly address indirect effects and difficult to address magnitude of effects.

4.1.3 Parametric approach

This kind of approach for suitability assessment is an evaluation in which experts define the most desirable attributes in terms of measurable factors, the optimum values of those factors, and their relative importance (Stoms, Mcdonald and Davis, 2002). The assessment follows a deductive process and applies to specific sites. The integration of parametric technique with GIS has considerably advanced the conventional map overlay approaches to the land suitability assessment (Malczewski, 2000; Eastman, 1997; Banai, 1993; Carver, 1991). Parametric approaches involve the utilization of geographic data, the decision maker's preferences, and the manipulation of data and preferences according to specified decision rules. The models are often tackled by converting them to single objective problems and then by solving the problem using the standard linear programming methods (Aerts, 2002). The parametric approach is a tool for GIS-based land use suitability analysis that is demonstrated in many studies (Zhang, 2003; Chen, 2002; Wu, 2000; Wu and Chen, 2000; Bojórquez-Tapia, L.A et al., 1999; Hu, 1995; Eastman, 1993; McDonald and Brown, 1984).

The weighted linear combination (WLC) is one of the methods to present parametric approach that involves standardization of the suitability maps, assigning the weights of relative importance to the suitability's maps, and then combining the weights and standardized suitability maps to obtain an overall suitability score (Malczewski, 2004). Two critical elements of WLC are the weights assigned to attribute maps and the procedure for deriving commensurate attribute maps. Weight is the basic concept for parametric approach. The decision maker can directly assign the weights of "relative importance" to each attribute map layer. A total score is then obtained for each alternative through multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the products over all attributes (Malczewski, 2004). When the overall scores are calculated for all of land units, the units with the highest overall score is chosen as highly suitable lands.

The parametric approaches classify and evaluate the influencing factors based on their importance for land suitability. The level of suitability is determined as the sum of the influencing factors scores. The physical evaluation consists of a model that assigns a score to every land unit based on its value on each factor. The suitability S at the K_{th} pixel was computed as follows:

$$S = \sum_{i=1}^{n} W_i C_{ij} \tag{4-1}$$

Where: S is the composit suitability for one land unit;

W_i is the weight of the $i-th$ factor;

C_{ij} is the suitability class value for $i-th$ factor in the j criterion's score of experts rank;

n is the quantity of the influencing factors.

The entire procedure of mathematical calculation is based upon the popular decision-making tool Analytic Hierarchy Process (AHP) as proposed by Thomas Saaty in the early 1980s. AHP is one technique used in parametric methods, and has been incorporated into the GIS-based land use suitability procedures. AHP can be used as a consensus building tool in situations involving a committee or group decision-making (Saaty, 1980). AHP uses a hierarchy of factors where each general factor is subdivided or composed of several contributing subfactors. The method can be operationalized using any GIS system having overlay capabilities and implemented in both raster and vector GIS environments. The overlay mapping allows the evaluation criterion map layers to be combined in order to determine the composite map layer. This technique is also more appropriate for implementation in the vector-based GIS.

There are several problems associated with the parametric approach. First, the input data to the GIS evaluation procedures usually have the property of imprecision and ambiguity. Second, the parametric approach is best used in particular situation. It needs to calculate more objective information from experts and decision makers about factors and weight.

4.2 Basic Concepts in Land Suitability Assessment

4.2.1 Factors

Factor is a general category of information concerning the site being evaluated. The factors often considered in land suitability studies include natural environment factors (e.g. slope, soil type, geologic hazards present, land cover, etc.), built environment factors (e.g. existing land use, planned land use, accessibility to roads, availability of utilities, etc.), economic factors (e.g. land value, tax rate, etc.), and social factors (e.g. population present, jobs present, historical features present, etc).Table 4-1 illustrate the factors that have been used in some land suitability case studies.

4.2.2 Rating

Rating is an evaluation, usually expressed in numerical terms, of how suitable a site is supporting a specific land use. Numeric scores to a total of ten (one as least and ten as most suitable) are assigned to each factor attribute class (classification of factor attribute classes used in assessing site suitability for residential land application). Comparisons between classes were based on their level of suitability with respect to residential land use. Since environment factors for each specific study areas are different with others, there is no uniform standard for rating factors. In parametric approach, the researchers always rated the factors based on the situation of study area, review of literatures and suggestion from experts. For example, a site having a slope of 12 percent may be assigned a rating of 6 when being evaluated on how well it can support a subdivision for residential use in a plain area, however, a slope of 12 percent may be assigned of 3 if study area is in a hilly country.

4.2.3 Weight

Weighting in suitability analysis refers to assigning a numeric value to each factor in order to recognize its relative importance, and usually expresses in percent format (Pease and

Coughlin, 1996). A set of weights are usually used to represent the relative importance of parameters and normalized to a constant as:

$$\sum_{i=1}^{n} W_i = 1 \qquad (4\text{-}2)$$

For example, there are just three factors to be considered in selecting a site for a subdivision of single-family homes: slope of terrain, land price and availability of utilities. You assign weights to these factors to reflect the relative importance you attach to each. The slope might be given a weight of 0.3; land price 0.5; and availability of utilities 0.2.

The weight represents the relative importance of each factor attribute. The weight value for the suitability of one factor used in this research was based on interpretation of published materials as well as several experts. The weights can be determined through methods such as Delphi and the pairwise comparison pioneered in the Analytic Hierarchy Process (AHP) method. The pairwise comparison AHP is popularly used in a lot of land suitability assessment case studies (Dai, 2003; Chen, 2002; Nisar Ahamed, 2000; Wu, 2000; Hu, 1995).

Saaty's (1980) analytical hierarchy process (AHP) is a method to determine the weights, as follows. An importance scale is proposed for pair-wise comparison of factors, based on a large number of experiments. The 9-point scale has been the standard rating system used for the AHP (Table 4-2).

Intensity of relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly or essentially favour one activity over another
7	Demonstrated importance over the other	An activity is strongly favoured over another and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest degree possible of affirmation
2,4,6,8	Intermediates values	Used represent compromise between the preferences listed above

Table 4-2 Scale of relative importance between two elements (Atthirawong and MacCarthy, 2002; Saaty, 2000)

The pairwise AHP calculates the weight values using the following procedure (Saaty, 2000; 1980):

1) Build the estimation matrix for the influencing factors, such as

Matrix	C1	C2	C3
C1	1	2	1/4
C2	1/2	1	3
C3	4	1/3	1

2) Calculate the M_i for each row factor in the matrix.

$$M_i = \prod_{j=1}^{n} b_{ij} \tag{4-3}$$

Where: b is the value of the factor in the matrix;

i is the row of the matrix;

j is the column of the matrix

3) Calculate the

$$\overline{w}_i = \sqrt[n]{M} \tag{4-4}$$

Where: n is the level of the decision hierarchy;

$\overline{w}_i$ is the weight for the i line factor

4) Calculate the weight for each factor as w_i :

$$w_i = \frac{\overline{w}_i}{\sum_{i=1}^{n} \overline{w}_i} \tag{4-5}$$

5) Calculate the CR (consistency ration): this index measures transitivity of preference for the person doing the pairwise comparisons (Saaty, 2000; Eastman, 1997; Aderson et al., 1994).

A pairwise comparison matrix was formulated using the results of previous studies as a guide (Basnet et al., 2001). The pairwise AHP provides a systematic method for comparison and weighting of the multiple criteria by decision-makers. AHP is thought to be a method and planning framework with potential for the suitability assessment. An advantage of AHP is that it is capable of providing numerical weights to options where subjective judgments of either quantitative or qualitative alternatives constitute an important part of the decision process. By using pairwise comparison AHP techniques, value and weight assessment of physical factors can be determined. A consistency ration (CR) of less than 0.05 is maintained the weight determination matrix can be acceptable (Eastman, 1997). Weights worked well in generating valid numerical values for factor suitability. Weights were transferred to the value attribute table of the respective grids as a separate item. These values were easily transferred into the GIS and readily available for manipulation within the GIS analysis environment.

The benefit of using AHP, as opposed to direct calculation of weight using objective comparison, is its ability to calculate the consistency ratio of weight distribution and its consequent evaluation of the weighting process (Eastman, 1997). The AHP also maintains the factor weights sum to one, which is a requirement in using the WLC procedure (Eastman, 1997, Kuiper, 1999, and Basnet et al., 2001). WLC is a compensated method in the sense that a low score on one suitability criterion can be compensated by a high suitability one another.

4.2.4 Score

Score is the numerical total of the calculated land suitability when the ratings and weights for all factors are considered. As described in Eastman et al. (1995) and Pereira and Duckstein (1993), each thematic layer represented an evaluation criterion and grid cells were valued according to their quality for a particular land use. The first step, initially suitability class value and weight are assigned to individual land characteristic and then calculated the suitability score. The score for an individual site is used as a basis for comparing its suitability with other sites.

4.3 Developing a Suitability Assessment Index for Residential Land Use in the DDA

The land suitability assessment in the Dianchi drainage area is a complex analysis process. Considering the current conflict between the urban expansion, economic development and the population increasing in the area, the residential area suitability assessment was selected as the target for this study. The initial work is identifying the prime agriculture lands and environmental protection lands that should be done before the land suitability assessment. The objective of this step is protecting environmental sensitive lands that should not be occupied for other purpose. The process of the residential land suitability assessment was designed as below in Figure 4-1. The information collection includes the data collection, literature information collection and expert knowledge collection. By combining the suggestions from the experts, lessons from the GTA planning and the related information from the literature, the influencing factors which are adopted into the suitability assessment were chosen. Based on the classification of suitability class, each factor has been divided into five classes from highly suitable to permanently not suitable. On the other hand, the available data are gathered together for transformed into digital format. The weight and value of factors should be identified first for calculating the suitability score for each land unit. The suitability map presents the result of the construction land suitability assessment in terms of the land unit suitability scores. The recommendations are given as the last part of the study.

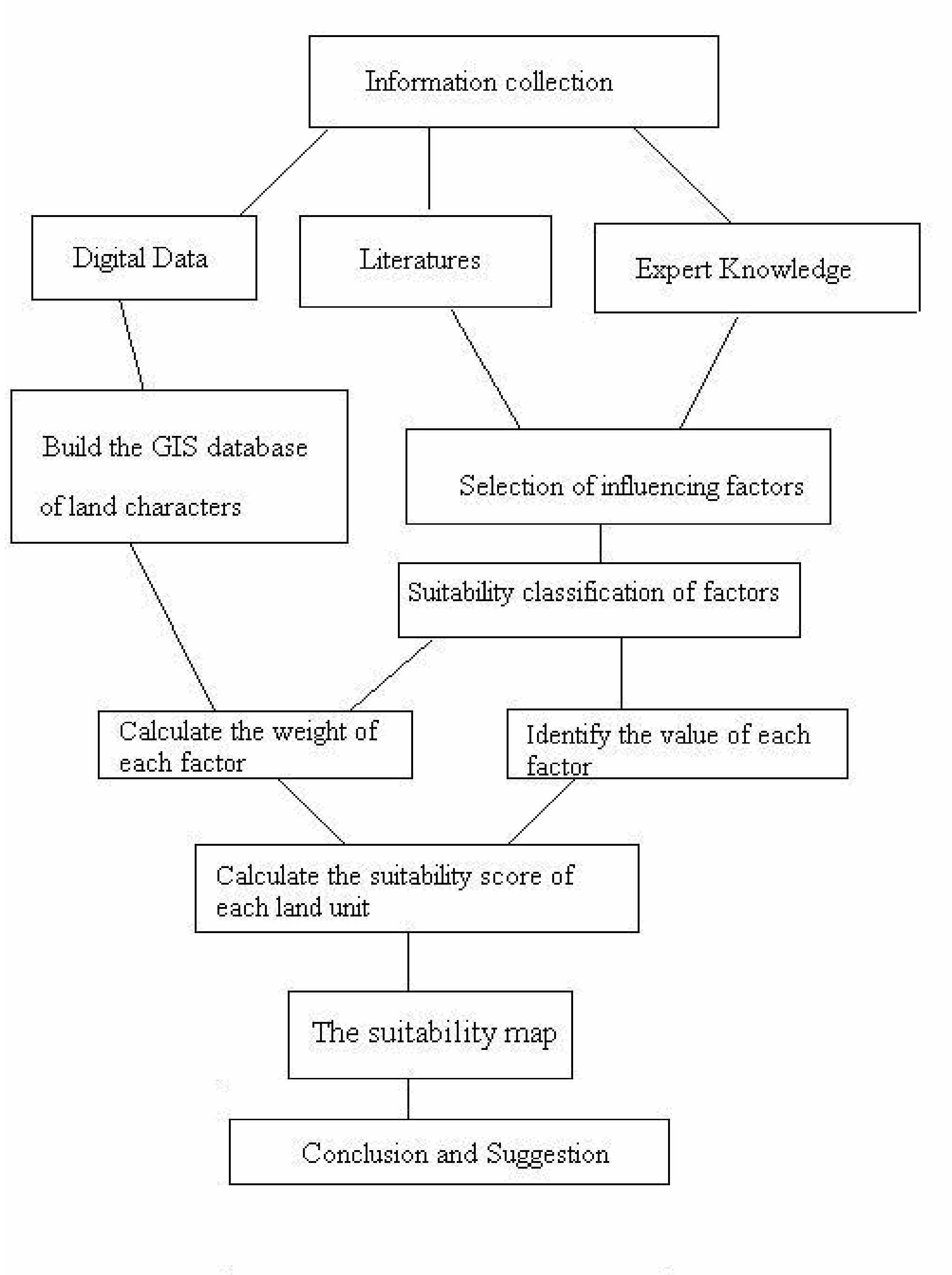


Figure 4-1 The process of suitability assessment in the DDA.

4.3.1 Environmental protection

For the future development of the DDA, environmental protection around Dianchi Lake is the prime objective and should have priority during urban development. How to apply the environmental protection into residential land use planning in the DDA is the topic which will be addressed in this section.

Local planning tends to neglect the issue of prime agricultural land and the arising conflicts between expanding development and successful farming. Hence, prime agriculture land should be paid more attention as in the GTA case studies. For Example, the specialty crop area is to be protected and is not supposed to be occupied for residential purposes in the GTA case studies, which should be followed by the DDA Planning. The expanding development in rural or urban-fringe areas can directly or indirectly reduce the agricultural potential of the remaining farms. The demands for residential or commercial development sometimes involve direct conversion of farmlands. Development will exhaust the agricultural productivity of the reallocated tract. The government should provide some protection when probable conversions of farm and forestlands into residential and commercial lands are likely to happen. Therefore, before the land suitability assessment of residential lands, it is important to first identify the agriculture land that has high productivity which is not suitable for residential use. In the current DDA, we need to indicate the specialty crop area and prime agriculture land which needs special protection.

The United States Department of Agriculture (USDA) defines prime agriculture land as “land best suited for producing food, feed, forage, fiber, and oilseed crops, and also available for these uses. The land currently could be cropland, pasture land, range land, forest land, or other land but not urban build-up land or water. It has the soil quality, growing season, and moisture supply needed to produce sustained high yields of crops economically when treated and managed, including water management, according to modern farming methods. The criteria for identifying prime farmlands are entirely related to soil characteristics and other physical criteria." By definition, prime agriculture land may be covered with row crops, trees, bushes, grasses, pasture vegetation, or weeds (Bulletin#1 Prime Farmland).

The DDA's production of some horticultural crops accounts a significant percentage of the total Kunming production. In recent years, paddies, wheat and corns have been major economic crops. Other products, including vegetables, tea plants, flowers and fruit trees are expected to become major contributions to the total production of Kunming City. According to the regulations exclusively applied to compensation of lands in "Land Administration Regulations in Yunnan Province, 1999". Vegetable field and paddy field are at the top of the evaluation, followed by Garden field and dry land, while the pasture ranks the last. The DDA doesn't have the special crops land identified as in the GTA. Thus the protection of agricultural land in the DDA is to protect the prime agriculture land. How should prime agriculture land be identified? A definition of prime agricultural land should include these agronomic factors of soils (e.g. filtration rate; drainage; the unimpeded depth of the root zone) and environmental factors (e.g. climate, water quality, land degradation hazard, flood hazard, air quality). These factors are combined so that the value to society from agriculture and the value from alternative uses of the land are assessed. Based on the following steps the productivity of lands and potential value for lands could be examined. The procedure is as follow adapted from “The South Carolina Prime Lands Initiative 2005”:

- determine the relative importance of each major agricultural commodity produced in the DDA;
- identify the land requirements of agricultural commodities that are produced in the areas and area significant to Kunming production;
- obtain relevant physical information;
- identify environmental restrictions to agriculture;
- correlate significant agricultural commodity production with existing relevant map units;
- determine specific land requirements for the continuing viability of existing or potential investments;
- assume lands values with potential return or rents from those lands during convert form prime lands to residential and commercial lands;
- finally, assess the contribution of prime lands to the integrity of the regional ecosystems by determining the role help prime lands play in maintaining watershed quality and providing economic values for area.

Besides prime agriculture land, another kind of land should be attributed the same protection status because of its economic and external values to society. Key hydrological features are prime important type which should be protected in the DDA due to the significance of Dianchi Lake. The Water Resource System in the DDA is made up of both ground and surface water features and their associated functions. The areas to which the urban plans apply contain primary recharge, headwater and discharge areas within the DDA. Using hydrology as a design element begins by identifying and maintaining on-site hydrologic processes, patterns, and physical features (streams, wetlands, native soils and vegetation, etc.) that influence those patterns. Key hydrologic features that are discussed in the Greenbelt Plan includes permanent and intermittent streams, lakes (and their littoral zones), seepage areas and springs and wetlands. In addition to identifying prominent hydrologic features, additional analysis will be required to adequately assess water movement over and through the site including (Curtis, 2005):

- Identify and map minor hydrologic features including seeps, springs, closed depression areas, and drainage swales.

- Identify and map surface flow patterns during wet periods, and identify signs of duration and energy of storm flows including vegetation composition, and erosion and deposition patterns.

- If seasonally high groundwater is suspected and if soil test pits do not provide sufficient information to determine depth to groundwater, map groundwater table height and subsurface flow patterns in infiltration and dispersion areas using shallow monitoring wells.

- Identify wetland category using local jurisdiction regulations and identify hydrologic pathways into and out wetlands.

- Measure existing hydroperiods and estimate future hydroperiods resulting form the proposed development.

In terms of identifying the key hydrologic features, next step should focus on how to protect them. According to the actual environment of the DDA, following protection steps should be adopted to protect the key hydrologic features:

1. Maximize retention of native forest cover and restore disturbed vegetation to intercept, evaporate, and transpire precipitation.

2. Preserve permeable, native soil and enhance disturbed soils to store and infiltrate storms flows.

3. Retain and incorporate topographic site features that slow, store, and infiltrate stormwater.

4. Retain and incorporate natural drainage features and patterns.

5. Prohibit poldering in the protected area of the water body.

6. Prohibit discharging solid wastes and waste water which doesn’t meet the discharging standards into the water body and the river causes which lead to the lake.

7. Wetlands and wetland buffer areas on all plans and delineate these areas on the site with fencing to protect soils and vegetation form construction damage.

8. New development or site alternation is not permitted in key hydrologic features. A proposal for new development or site alteration within 120 metres of a key hydrologic feature anywhere within the protected the DDA requires a hydrological evaluation.

4.3.2 Selecting the factors

The linchpin of land suitability assessment is the selection of the influencing factors since there are too many factors affecting the land suitability. The selection of influencing factors should also consider the objective of suitability assessment. For specific crops, the selection of influencing factors is mostly based on the growth requirement of the crops. For other kinds of suitability assessment, the selection is based on literature reviews and the specialists' suggestions. The number of influencing factors is flexible based on the environment of the study area and the aim of the assessment. The selected influencing factors should have strong effect on the land suitability. It should also reflect the difference of land quality accurately. The influence degree of each influencing factor on the land is quite different. Based on the residential land use situation in China, the apartment, most popular urban dwelling, is the most suitable style for residential use that can accommodate more people while occupying less land in the study area. The full set of the criteria for residential land suitability assessment has been developed and illustrated in Table 4-3. These criteria built in terms of the consideration for building apartment.

Criteria		Description
Physical Environmental	Slope	Slope is one of the basic parameter for land suitability assessment. The slope map is derived from DEM.
	Drainage class	Potential periodic flooding, where land areas are subject to periodic flooding.
	Land use type	Current land use is the crucial indicators for the residential LSA. The specialty-crop lands can not be changed to construction use.
Social Environment	Schools network	The school includes the day care center, elementary school and high school.
	Commodity network	This includes the convenience store, superstore, bank, shopping centre, restaurant, etc..
	Hospital network	The proximity to the hospital is the factor that influenced people's choice.
	Waste management	The management of domestic waste solid. It determined by the number of refuse depot and proximity to refuse collect point.
	Sewer network	The basic requirement for the residential area.
	Main roads network	This part includes the local road network and the intercity transportation network.
Living Environment	Water area	The proximity to the water area is an indispensable parameter for the DDA.
	Riverway network	This parameter is selected based on the suggestions from the experts.
	Population density	High population density will reduce the public's interest.
	Open space	The greenbelt and open space will improve the quality of life.
	Bus routes	The proximity to bus routes.
	Environmental pollution	The current environmental pollution situation includes the water pollution, air pollution, noise that will effect the living environment.
	Water quality	This includes the quality of groundwater and drink water that affect the quality of living environment.
	Proximity to industrial area	The proximity to industrial area will affect the living environment quality.

Table 4-3 The full set of criteria for residential land suitability assessment in the DDA

Most of the physical environmental factors describe the attributes of the soil. Sharp slope is not suitable for residential lands. Since the study area includes Dianchi Lake and its riverway network, the flooding drainage class is another physical environment that influences selecting residential land. Current land use type is a key feature in the residential land suitability assessment. In terms of the study of Section 4.3.1, the prime agriculture land should be protected and prohibited for any other use. The key hydrologic features should be protected based on the lessons learned from the GTA case studies. For other kinds of land use, considering the physical features of soil, most suitable factors should be current residential lands and some kind of economic crop land. On the other hand, water area and unused land are lest suitable for residential land use.

The residential lands are subjected to building a comfortable community for future use. Social environment and living environment are necessary for considering the suitable land for future residential use. The sewage system and waste system are selected in terms of the lessons learned from the GTA case studies. The factors listed in the social and living environment may not collect as map format, like current environmental pollution, but it should be considered by planners during the suitability assessment process before presenting the final suitability map.

4.3.3 The classification of the suitability

The FAO classification model for suitability is widely used in the studies of land suitability assessment in China (Zhang, 2003; Dai, 2003; Chen, 2002; Wu, 2000; Wu and Chen, 2000; Wang, 1997; Hu, 1995) and other countries (Kalogirou, 2002). This model is based on two general suitability orders (suitable and not suitable) which area subdivided into a total of 5 suitability classes (Table 4-4).

Land suitability Orders	Land suitability Classes	Definitions of Classes
Suitable	Highly Suitable (S1)	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce benefits.
	Moderately Suitable (S2)	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
	Marginally Suitable (S3)	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits or increase required inputs, that this expenditure will be only marginally justified.
Not Suitable	Currently Not Suitable (N1)	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
	Permanently Not Suitable (N2)	Land with limitations to sustained use that cannot be overcome.

Table 4-4 The description of land suitability classes (Source by FAO 1993)

4.3.4 Overlay mapping and parametric approach for residential land suitability assessment in the DDA

Each of the methodologies has its own strong points and shortcomings. In terms of particular study area and available database, planners can select the suitable methods for land suitability assessment. In China, most of the researchers selected the parametric approach in terms of limited research data and more understandable for the decision makers.

The overlay mapping and parametric approach are selected for the residential land suitability assessment in the DDA since these two approaches can be adapted for situation where the available datasets are limited. As described in Eastman et al. (1995) and Pereira and Duckstein (1993), each thematic layer represented an evaluation criterion and grid cells were valued according to their quality for a particular land use. The first step, suitability class value and weight are assigned to individual land characteristic and then calculated the suitability score. The selected factors are weighted for a numeric value that indicates their relative importance in determining the suitability of an activity in a given area (Collins et al. 2001). This procedure is necessary in order for every characteristic to contribute with different weight to the final score. To do this, the methodology is based on a hierarchical importance of land qualities and a land quality is described with the land characteristics.

Suitability class ratings:

In terms of the classification of suitability, the factors should be divided into 5 classes based on their attribution and suitable classes. The factors such as slope, proximity to roads, drainage class, and population density can be quantitative classified, on the other hand, the factors like the environmental pollution that could not classified by numbers needs to be qualitative classified by the field work. Ratings are available for each grid cell along with the final classification (S1–N2). The specialists gave the value grades ranking from 1-10 according to the factors' suitability class, while high ratings indicate high suitability class.

These value grades of the attributes were then combined using a combination function, which utilizes criterion weights. For example, the slope is 3 per cent belongs to class S1 that will be given a rating as 9.

Weights:

The AHP has been selected to be effective in problems evaluation involving multiple and diverse criteria, measurement of trade-offs, and with limited data (Satty, 2000; Dai, 2003; Chen, 2002; Thapa et al., 2004). The AHP provides a methodological framework within which the inconsistency in judging the relative importance of factors in a site suitability analysis can be both detected and corrected (Banai, 1993). For the residential land suitability assessment in the Dianchi drainage area, AHP will be a good approach for evaluating the weights for the influencing factors since it only need to collect the suggestions from different experts instead of gather a host of accurate data about land attributes and land use. The comprehensive database is always a weak part in the land suitability study in most areas in China. AHP always used for evaluating weights in the using WLC overlay mapping process (Chen et al., 2005).

To assign the influencing factors in accordance with the importance of each factor, AHP analysis (see Section 4.1.3) is adopted to evaluate the weight of the factors. It needs to prepare a pair-wise comparison matrix by experts in terms of Saaty's AHP (Table 4-2).

Suitability scores

After set up the ratings and weights, the physical evaluation consists of a model that assigns a score to every land parcel based on its value on each factor. The score calculated by the parametric approach model (4-1). After the calculation, each land unit will get an S score. Based on the character of the study area, the grades of S are determined by means of the statistical methods such as the frequency histogram.

4.4 Conclusion

Based on the review of methodologies that others used, Chapter 4 introduces the methodology which can be used for residential land suitability assessment in the DDA and design a full set of criteria for the assessment. Chapter 5 will demonstrate the methodology in the assessment process and discuss the feasibility of the methodologies.

Chapter 5

The Case of the Dianchi Drainage Area

This chapter introduces the current land use situation of the Dianchi drainage area and discusses the feasibility of the residential land suitability assessment process in the DDA. The first section of the chapter introduces detailed information about the natural and socio-economic environment of Dianchi drainage area. Section 5.2 describes the current land use in the drainage basin and the temporal transformation of land use. It also discusses some existing problems in land use in the Dianchi drainage area. Section 5.3 will discuss the feasibility of the residential land suitability assessment based on the lessons from the GTA and literature.

5.1 The Study Area

5.1.1 The physical environment

Dianchi Lake, the sixth largest freshwater lake in China, is situated in the central part of the Yunnan-Guizhou Plateau as shown in Figure 1-1. The lake belongs to the Jinsha River system, with a total volume of 1.56 billion m^3, a surface area of 330 km^2 and a mean depth of 4.7m (World Lakes, 2005). More than 20 rivers flow into Dianchi Lake which serves as the direct water source for Kunming Municipality as well as towns and villages around the lake. The Dianchi drainage basin covers an area of 2920km^2. The land in the drainage area of Dianchi Lake is mainly of mountains, terraces and dammed river valleys. Almost 70% (2030km^2) of the drainage area is highland. Slightly more than 20% (590 km^2) is classed as plains, while the lake itself occupies 10.3% (300km^2) of the whole drainage basin area. Land forms within the basin varied because forms of solution, erosion, denudation and accumulation at different parts with different tectonic structure, stone property and geologic agents (Jin, 2003; Yang, 1995).

The lake region has a very pleasant micro climate as it lies in the wet monsoon climatic belt of northern sub-topic zone. The warm climate and sufficient rainfall are suitable for the growth of various terrestrial and aquatic species. Since the mid 1990s, rice fields have been increasingly converted to more flowers and vegetable crops.

5.1.2 Socio-economic Characteristics

The Dianchi drainage area belongs to the Kunming Municipality administrative division. It includes four urban districts (Panlong City proper, Wuhua City proper, Guandu District, and Songming District) and 38 counties which had a total population of 2.2 million in 2001. All of the administration districts shown in Figure 5-1. The area to the north of Dianchi Lake is the centre for the human activities since Wuhua and Panlong lie directly in the Kunming City Proper. The Guandu District and Songming District are the suburban districts of Kunming Municipality. Wuhua and Panlong are the smallest districts in the whole drainage area, 35% of the total population in the drainage area is found here. Guandu District has 23% of the drainage area population. Xishan District and Songming County have 13% of the population each, while Jinning County and Chenggong County account for 10% and 6% of the total population respectively.

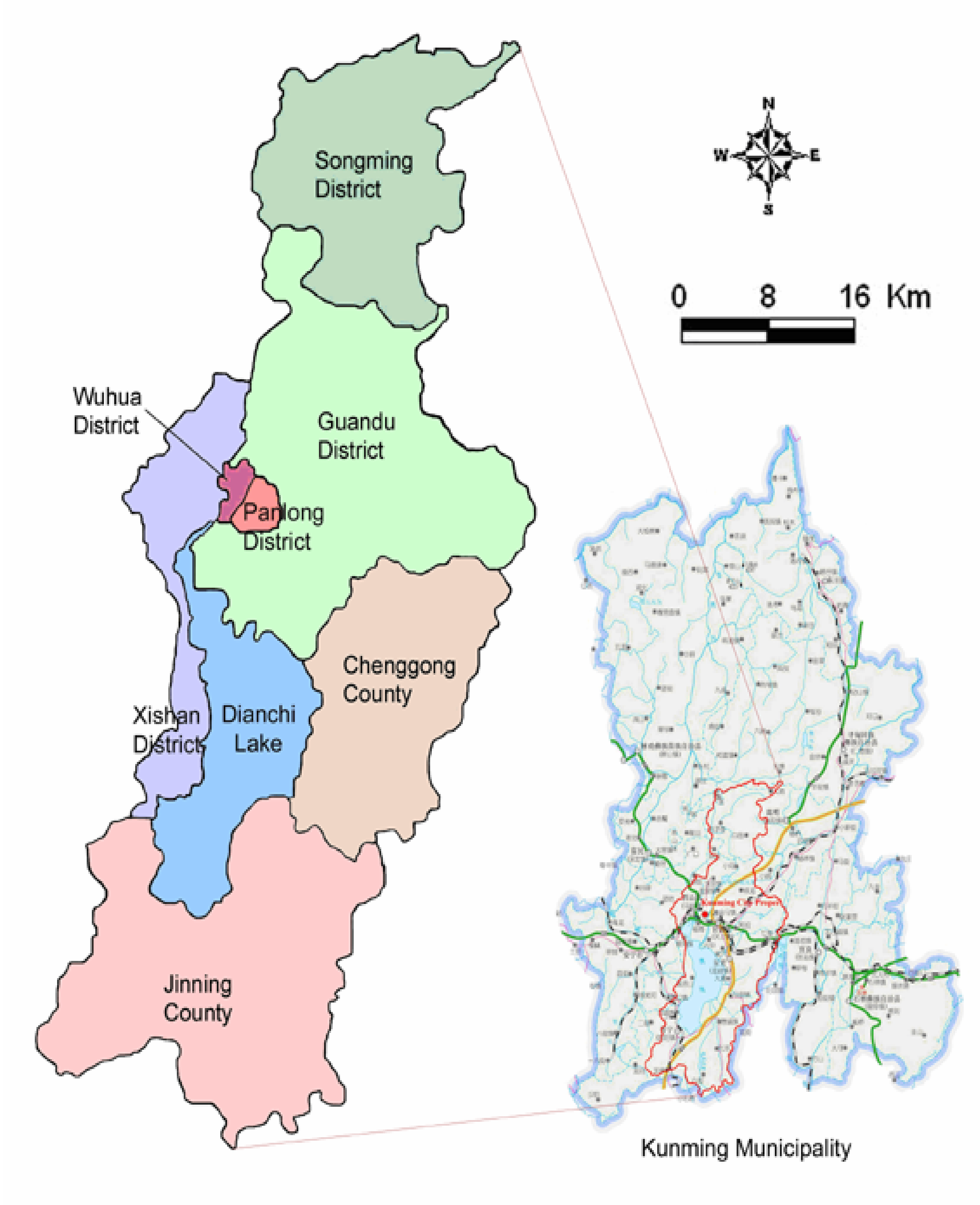


Figure 5-1 The division of the Dianchi Drainage Area

The Dianchi drainage area is under the jurisdiction of Kunming Municipality which is the provincial capital and dominates the industrial and economic development of Yunnan Province. In terms of urban infrastructure, population density and developed industry, the Dianchi drainage area is one of the fastest developing regions in Yunnan Province. The Dianchi drainage area occupies only 18.7% of the area of the Kunming Municipality. However, the agricultural output value and industrial output value of the Dianchi drainage basin accounts for 79.8% and 82.2% of the Kunming Municipality's total (Kunming Agriculture Committee, 2003). As the main economic center, the Dianchi drainage area contributes 80 percents of the GDP (Gross Domestic Product) of the Kunming City. Due to its bountiful natural resources and long-term development, Dianchi drainage area has been the main political, economical, and cultural center of Yunnan Province.

The lake is the core of the drainage area, the area around the water is the central district for the human activities. The treatment of lake pollution and scientific management of the drainage area, as one of the three targets of the water pollution clean-up projects (including the Dianchi Lake, Chaohu Lake, Taihu Lake) of Environment Protection Administration of China, has been given more attention by the government and planners since 1997 (State Environmental Protection Administration of China, 2004). The Yunnan Province government and the Environment Protection Administration of China set up a special bureau for managing the drainage area called the Dianchi Administration Bureau. Water pollution is the core problem of Dianchi Lake. However, the environmental problems caused by water pollution such as the deterioration of the land quality and the pollution of the residential area near the lake, are also affecting the whole drainage area. From now to 2020, Kunming

Municipality will work to construct a new "one lake, four districts”-Kunming City proper, which is centered on Dianchi Lake and includes the North, East, South, West districts (Kunming Science and Technology Bureau, 2005). The whole Dianchi drainage area will be the emphasis for the future development of Kunming Municipality (China news, 2004b).

5.2 Current Situation of Land Use in the DDA

5.2.1 The structure and distribution characteristics of land use

Based on the statistical data of most current land use survey in 2001, the area of Dianchi drainage basin is 292539 hectares. Table 5-1 shows the classification of the land use types. The classification is based on the land use type classification of China (Zhang, 2003).

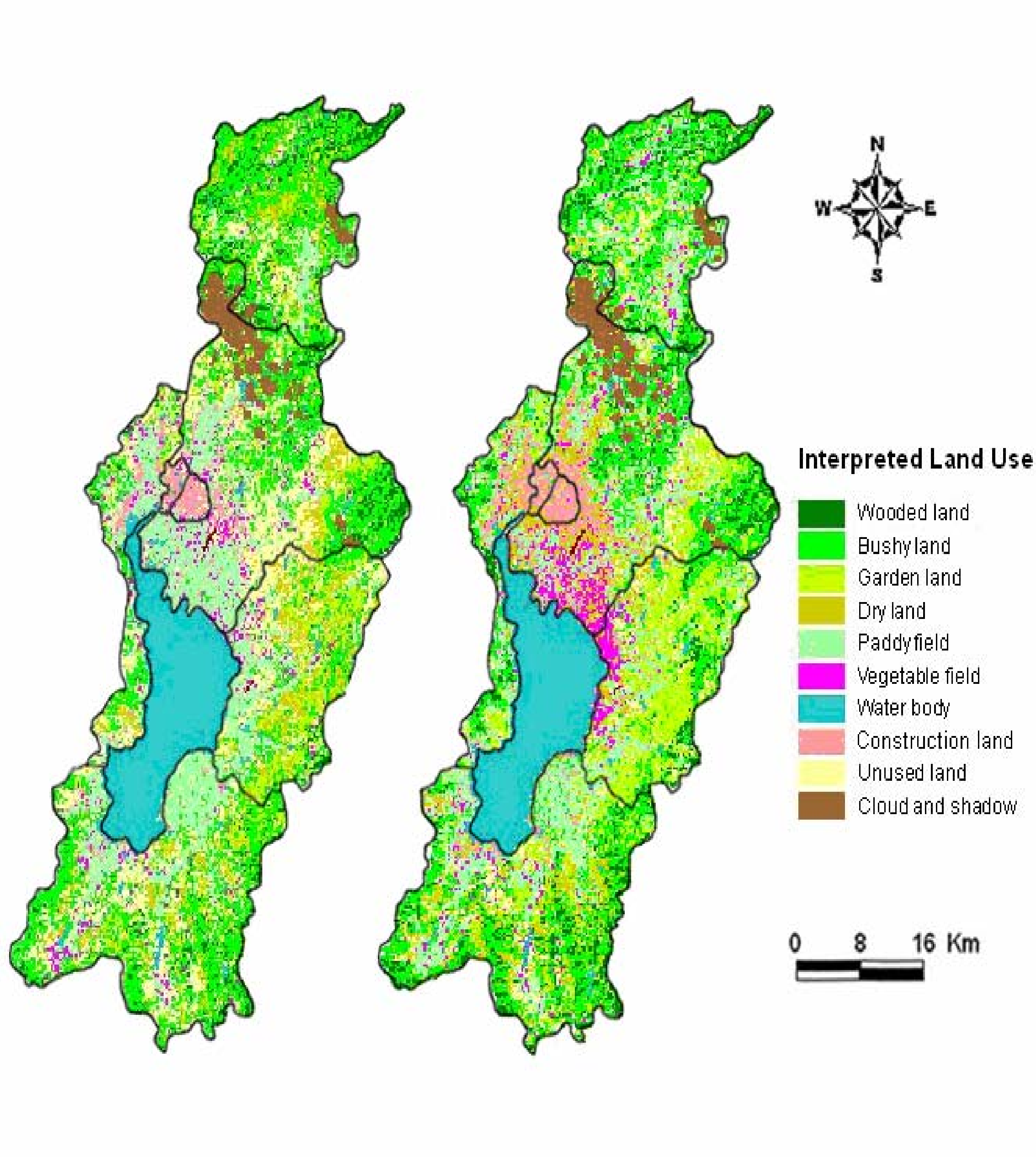
Figure 5-2(b), which was derived from Landsat TM data, shows the distribution of each kind of land use in the Dianchi drainage area in 2001.

Class I	Class II	Description
Agricultural Land	Paddy field	The arable land for planting the aquatic crops.
	Dry land	The arable land for planting the upland crops.
	Vegetable field	The arable land for planting vegetable and flowers all year round, including greenhouses.
	Garden plot	The lands with over 50% coverage[4] with perennial herbaceous and woody plants for fruits, leaves and rhizome.
	Wooded land	The natural woods and planted woods with canopy density[5] above 20%
	Bush land	The bush land with coverage above 40% and the sparse wood land with canopy density between 10% and 20%.
Construction land and Unused land	Construction land	Including the residential quarters land, commercial service land and the public recreation land.
	Unused land	The land with canopy density below 0.1 and covers with rocks
	Water body	The area includes the water body and the area with the coverage of aquatic plant above 20% around the water body.
Cloud and Shadow	Cloud and shadow	Areas obscured from satellite coverage by clouds and shadows

Table 5-1 The classification of land use type

[4] Coverage: the ratio of the plant area to the total land area**.**

[5] Canopy density was expressed as a percentage of light penetrating the canopy (Byers et al., 1984).



(a) 1988 (b) 2001

Figure 5-2 The land use structure of the DDA

Source: Landsat Thematic Mapper data (2001-10)

The forestlands are distributed in the edge area of the Dianchi drainage area. The afforestation rate is relatively low in the water conservation area. The forests have been destroyed and the lands on steep hills have been furrowed for agricultural uses, which has brought on water loss and soil erosion. Agricultural lands have a very high rate of cultivation in the Dianchi drainage area. The plains and terraces are mainly of arable soil. The dry lands are scattered diffusely around the gentle hill and high altitude plain. The waterfront lands of the DDA have been illegally used, which have caused the infilling of much of the lake shore swamp. The illegal exploitation of Dianchi waterfront lands has destroyed the ecosystem around the Dianchi Lake (Gong and Li, 2003). The vegetable fields are distributed around the residential area of the town and villages. The garden fields are distributed between the waterfront area and the high altitude forest area. Most of the unused lands are bare lands in the high altitude area that could cause serious water loss and soil erosion.

In recent years, the economic benefits associated with flower and vegetable cultivation has caused their proportion of land use to increase significantly in the boroughs of Guandu, Chenggong and Jinning. Chenggong borough, in particular, is now the largest producing area of flowers in China (China News, 2004a). The main district of Kunming City proper serves as the core for the Dianchi region with other towns and villages distributed along the roads that follow the waterfront and radiate inland land use. The concentration of urban development along the Dianchi shore has led to the pollution of the Dianchi Lake.

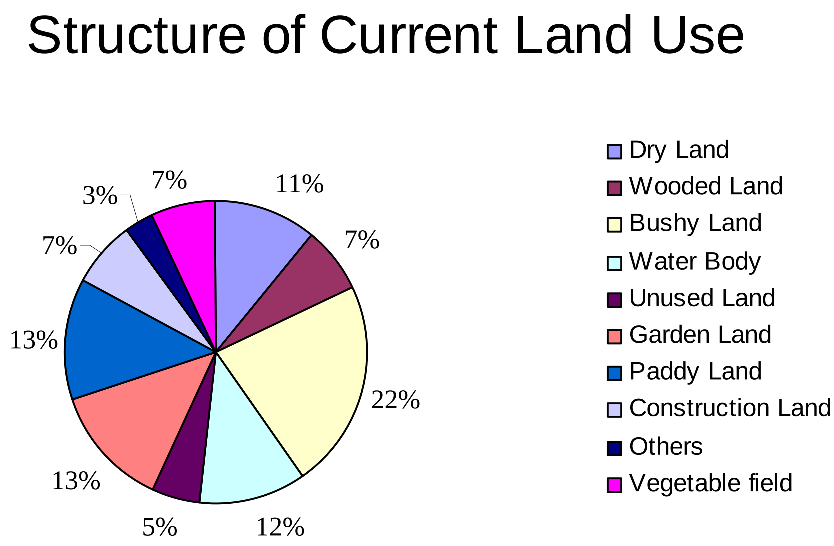


Figure 5-3 The distribution of land use type in the DDA, 2001

The structure of land use is shown in Figure 5-3. We can tell from Figure 5-3 that the forest including wooded land and bushy land occupies 29% is the biggest proportion of the study area (29%). The areas of the arable lands include dry land and paddy land, which occupies 24% of all the lands in the drainage basin. The area of garden lands occupies 12%. The proportion of unused lands occupies 5%. The area of water body occupies 12%. The area of construction lands is 26310 hectare that occupies 7% of the drainage area.

5.2.2 Land use change 1988 to 2001

Figure 5-2 (a) shows the distribution of each kind of the land use in the Dianchi drainage area in 1988. When this figure is compared with Figure 5-2 (a), it is clear that the area of garden fields has been reclaimed around Dianchi Lake from 1998 to 2001. Table 5-2 shows the change of area and proportion of each land use type in the Dianchi drainage area from 1988 to 2001.

	Area (km^2)		Change		Percent of Total Area		Change
	1988	2001	Area	%	1988	2001	%
Total area	2919	2919					
Cultivated land	1069	901	-168	-15.7	36.6	30.8	-5.8
Garden field	222	384	+162	+73.0	7.6	13.2	+5.6
Forest land	879	861	-18	-2.1	30.1	29.5	-0.6
Residential Settlements	102	212	+110	+107.8	3.5	7.3	+3.8
Unused land	213	138	-75	-35.2	7.3	4.7	-2.6
Water body	347	336	-11	-3.2	11.9	11.5	-0.4
Others	87	87			3	3	

Table 5-2 Land use change from 1988 to 2001

From the Table 5-2, shows that the proportion of arable land (collectively paddy field and dry land) and unused lands have dropped from 1988 to 2001, while the proportion of vegetable fields, garden fields and construction lands have increased. Relatively, the change occurred in the amount of forested lands over this period.

The proportion of garden lands increased most notably in the east and north area of Dianchi Lake at the expense of paddy fields. Relaxed state control over the rural economy has allowed farmers to reallocate land away from food grain production to horticulture that promises better profits. Most of the growth of garden lands took place in the DDA since the market demand for cash crops is high and the natural environment is favorable. Flower plantation now is one of the leading incomes for the DDA.

The second phenomenon is most of the new construction land was taken from cultivated land, forest, pasture, and unused land. The agricultural land restructuring has accelerated industrialization and urbanization that caused a drastic loss of cultivated land. Another remarkable expansion of land use was for human settlements and industrial sites. Such an expansion has been clearly driven by the forces of industrialization and urbanization (Lin and Ho, 2003). The residential quarters have risen around the urban edge of the Kunming Municipality since the developed area of the Kunming City Proper expanded to the suburbs in the past five years. The developed area is now 212 km^2 now. The area of construction and residential quarters lands have increased, especially the main urban area has expanded. Along with the sharply increasing population, the Dianchi drainage area is undergoing rapid urbanization. The built area of Kunming City Proper was 40.8 km^2 in 1990, but now it has grown to 140.5 km^2 in 2001(China News, 2004c). Due to the over fast expansion of city land use, the ring-shaped to-be-constructed area came into being the expansion of the city use land has occupied the arable land nearby and thus causes the reduction of arable land.

The exploitation of reasonable and suitable lands for urban construction is an imperative solution for the future land use. Otherwise, government optionally impropriate the cultivate land for construction use will bring a series of ecosystem problems such as the ecotone will be destroyed around the waterfront area, the activities of destroying the forest field can bring serious water loss and soil erosion. The characteristic of the drainage area is the lake, centre of human activities, which makes the land use structure different with the normal inland city.

The change of land use has brought out a series of social problems, economic problems and environmental problems, which have caused the decline of the land quality in the Dianchi area. The over reclamation of the land in the lake area, the reduction of the forest area and the reclamation of the steep hills have threatened the biological safety of the Dianchi drainage area. More seriously, the changes in the land use structure have resulted in the serious pollution in the Dianchi drainage area. Carrying out the sustainable land use of the Dianchi drainage area is the only way to settle these problems. The sustainable land use for the DDA is based on corresponding the proportion and spatial distribution of each kind of land use type with the ecological balance and economic development. The sustainable land use can make the land resource exert its generative and ecological function adequately, and it will help the society to occupy the optimal benefit between economic and ecosystem.

5.3 Feasibility of Residential Land Suitability Assessment in the DDA

5.3.1 Building database

First, we should identify the prime agriculture land and key hydrologic features in the DDA. The data source to identify the prime agriculture land and hydrologic features are collected in terms of the discussion in Section 4.3.1. For the prime agriculture land, the planner should collect the data of major agricultural commodity produced in the DDA that can be obtained from the Kunming Agricultural Bureau. In terms of the significant agricultural commodity production, researchers should obtain relevant physical information and land requirements data from the Kunming Land Management Bureau and the Kunming Environmental Protection Bureau. For the key hydrologic features, the data collection includes the hydrologic features map, the surface flow patterns during wet periods, signs of duration and energy of storm flows, groundwater network and wetland category that can be obtained from the Kunming Water Resource Bureau and the Kunming Environmental Protection Bureau.

The data have to be collected from different government bureaus because different data come from different authorities in charge of its resources. The data may be not available for direct download from the internet but can be obtained from the department for research. The government will assist in collecting the data if the program is organized and has been permitted by the Kunming Dianchi Administration Bureau (www.dianchi.gov.cn), which is in charge of the Dianchi Lake protection and treatment. The Kunming Dianchi Administration Bureau is an administrative agency of Dianchi Lake Protection Committee. Kunming Land Management Bureau (www.kmpg.gov.cn/kmland) has the responsibility to organize the land use planning and land management for Kunming City. The Kunming Planning Bureau (www.kmpg.gov.cn/ghj) is mainly responsible for the city planning as a whole and the permission of construction land. The Kunming Environmental Protection Bureau (www.kmepb.gov.cn) is the department in charge of the environmental protection issues. The Kunming Statistics Bureau (www.km.gov.cn/kmgov) has a comprehensive and accurate population data. The Kunming Agriculture Bureau is a department of the agriculture planning and management (www.kmagri.gov.cn). The Kunming Water Resource Bureau is the management department of water resource use and protection in the Kunming City and the DDA (http://www.kmwater.gov.cn).

Next for the residential land suitability assessment, based on the factors list in Table 4-3 which affects the residential land suitability assessment process, Table 5-4 shows how the data are obtained during the data collecting process. The database for residential land suitability assessment is built upon the collection of these data and transformation into related format so that it can be applied in the GIS process.

Criteria		Source
Physical Environmental	Slope	The DEM is available in Kunming Dianchi Administration Bureau (KDAB)
	Drainage class	The data are available in Kunming Land Management Bureau (KLMB)
	Land use type	The land use type can be transferred from Landsat TM maps that will available in KDAB.
Social Environment	Schools network	The data are available in Kunming Planning Bureau (KPB)
	Commodity network	The data are available in KPB.
	Hospital network	The data are available in KPB.
	Waste management	The data are available in Kunming Environmental Protection Bureau (KEPB)
	Sewer network	The data are available in KPB.
	Roads network	The data are available in KPB.
Living Environment	Water area	The data are available in KEPB.
	Riverway network	The data are available in KPB.
	Population	The data are available in Kunming Statistics

	density	Bureau (KSB).
	Open space	The data are available in KEPB.
	Bus routes	The data are available in KPB.
	Environmental pollution	The data are available in KEPB.
	Water quality	The data are available in KEPB,
	Proximity to industrial area	The data are available in KPB.

Table 5-3 The sources of data for influencing factors

5.3.2 Applying methodologies

The first step that should be taken before the land suitability assessment is identifying the prime agriculture land and key hydrologic features that have environmental protection priority in the process. Based on the discussion in Section 4.1.3 and data collection, the prime agriculture land should be identified as the lands used for major agriculture commodity production and have high contribution to the regional ecosystem and economic values. The key hydrologic features should be protected as not using for other purpose and we also should take some protections steps for hydrologic features in the next suitability assessment process, such as maximize retention of forest cover, preserve permeable native soil and prohibiting poldering in protected area of water body.

The next step is assessing remaining land for residential suitability in the DDA. The prime methodology in the process of residential land suitability assessment in the DDA is the AHP that is used to weigh the factors. The major part of AHP is a group of a committee constituted by specialists that evaluates the weight of each single factor. The specialists group should also take into consideration the opinions of experts, from research institution or university major in land use management and urban planning, and also the opinions of experts in environmental protection and planning from local government.

For the suitability class ratings, Table 5-4 gives the rating classification of part of the factors based on the “Land Administration Regulations in Yunnan Province (1999)”, “Framework for standard system of land and resources (1999)” and related literature reviews. The relative comprehensive factors’ ratings are shown in Appendix A. The factors listed in Appendix A are not necessary for each residential land suitability assessment because the factor selection depends on the data support and the planner.

Factors	Suitability Orders	Suitability class	Classification qualification
Distance to Road	Suitable	S1	< 250m
		S2	250-500m
		S3	500-750m
	Not Suitable	N1	750-1000m
		N2	>1000m
Distance to Riverway network	Suitable	S1	>90m
		S2	70-90m
		S3	50-70m
	Not Suitable	N1	30-50m
		N2	<30m
Distance to water area	Suitable	S1	>2000m
		S2	1500-2000m
		S3	1000-1500m
	Not Suitable	N1	500-1000m
		N2	<500m

Using type of land	Suitable	S1	Construction and Residential quarters land
		S2	Dry land
		S3	Vegetable field, Garden land
	Not Suitable	N1	Wooded land, Bushy land, Paddy field,
		N2	Unused land, Water area
Slope	Suitable	S1	<5°
		S2	5°-8°
		S3	8°-10°
	Not Suitable	N1	10°-25°
		N2	>25°

Table 5-4 The classification of part of the factors

The final work is to put the factors' weights and rating into the calculation of the suitability scores. The suitability map will present five different degrees of suitable residential lands in terms of the distribution of suitability scores.

5.3.3 Feasibility of results

During the course of determining the weight of each factor, the experts, coming from different managing authorities, have different focuses. If their opinions conflict, we can classify the factors to get the final comprehensive results. For example, when environmental protection, residential area development and water protection conflict with each other, we could work out three groups of results according to three different weights given by the experts. Highly suitable lands for residential use would be identified based on the comprehensive weighing of the three results. The results of residential land suitability assessment in the DDA will contribute to planning process and can also be used as a reference for future development. Final assessment result has to be in accordance with the future five year plan of the city. So, the most suitable land will be developed as the possible residential area for next five years. Achieving a rational and sustainable development of the city is the ultimate purpose of land use planning.

5.4 Current Barriers and Challenges for Land Suitability Assessment in China

After designing an entire process for residential land suitability assessment, we can find out some practical barriers during the process, such as selecting the factors, choosing the methodologies, identifying the objectives and collecting the data. The following section discusses how to deal with these barriers in China.

The system of influencing factors and its implementation

In current land suitability assessment, we tend to choose static and independent factors, ignoring dynamic factors and complex factors. We also tend to choose physical ecological suitability factors such as climate, soil, landform, ignoring the soil environment, hydro environment and air environment assessment factors and economic and social factors (Chen, 2002; Wu, 2000; Shen, 1999; Hu, 1995). The results of the assessment can hardly guide comprehensive development in the area. We are limited in the quantity and quality aspect for those factors even for classic influencing factors like soil factors. The biological aspects such as the community diversity are hardly reflected during the assessment as an agricultural land suitability assessment factor. All in all, the system of influencing factors in land suitability assessment should be further implemented for agricultural and construction lands use.

Methods for land suitability assessment

Different mathematic models have their own advantages and disadvantages, and they should be applied into different fields in terms of the data collection and the planner. Fuzzy Logic Methods can provide a dividing line for given targets so that the results of assessment can be in accordance with the facts (Wang, 1997). The parametric Approach makes it easier to obtain samples and is less affected by objective opinions and is relatively more accurate while it demands lots of calculating work (Dai, 2003; Wu, 2000; Hu, 1995). Different models should be combined in the land suitability assessment so that results from different schemes could be compared and explored to achieve an impersonal assessment result.

The refinement of objectives

Current land suitability assessments are mostly applied to urban and rural land planning. But most of the land suitability assessments only take in to consideration the suitability assessment of general divisions such as agricultural lands and construction lands (Zhang, 2003; Chen, 2002; Cheng, 2001; Shen, 1999; Hu, 1995). This kind of assessment can only provide reference for agricultural or construction lands planning. In future research, along with increasing attention on population, resources, environment and sustainable development, we should also plan for specific land uses, such as certain crops or specific commercial land use.

Establishing a technological system

GIS technology should be used to set up a dynamic land utilization database. Research on land utilization status and changes in land utilization should be carried out by the integration of RS, GPS, GIS technologies (Ding, 2003; Lin and He, 2002). Land quality researche should be carried out and form an index system and technical system on land quality research. Land environment focusing the land ecosystem and land environment researches focusing on land degeneration, including land social and economic conditions that should also be carried out.

Land suitability assessments should serve economic development and land planning, especially the land suitability assessments for specified lands including the assessments for agricultural lands and construction sites. We should apply land potential assessment serving the macro decisions especially the long term land potential assessment guaranteeing the food security and economic security. Land assessment serving the land ecological security especially the assessing of eco-environment and economic effects in land use and protection should be done. The land sustainable assessment should apply for sustainable development, especially evaluating the sustainability of the land using system.

5.5 Conclusion

This chapter describes the basic introduction and land use in the DDA. Based on the current situation of the DDA and methodologies described in Chapter 4, Section 5.4 discusses the feasibility of residential land suitability assessment in the DDA. In practice, the collection of data is a complex process that is quite likely to encounter some barriers. Most data are available for research purposes but they belong to different government bodies and use different scales and formats which need to be collected and then transformed according to same scale and related format so that they can be used within a GIS. Further, although the committee of specialists is set up to calculate the weight of different factors and provide results of assessment, when different opinions emerge, we can only adopt the opinion which is supported by most of the specialists. Although land suitability assessment has encountered many problems in China, but along with the implementation of the method and technology of land suitability assessment, it is going to play a more important role in the land sustainable development management and urban planning.

Chapter 6
Conclusion

This chapter summarizes the major findings of the assessment, and then brings forward the recommendations for the land use management in the Dianchi drainage area. Next section presents the limitations and future work.

6.1 Major Findings

With the adjustment of industrial structure due to the pollution of Dianchi Lake and under the pressure of redevelopment in the inner city, the built up areas of Kunming will unavoidably expand. This study is using GIS to assess the suitable land for the residential use.

Compared to the two GTA case studies, it appears that the DDA lacks consideration of environmental protection in the suitability assessment process. The key issues and policies discussed in the GTA studies that identified prominently prime agricultural land, key natural heritage features, settlement areas, and infrastructure in the process of planning. The GTA studies indicated some kinds of lands have priority that should be protected and should not be used for other purpose. Hence, the prime agricultural lands and key hydrologic features are selected to be protected first and are excluded from the process of the residential land suitability assessment in the DDA.

This assessment creates an index of the influencing factors for the residential land suitability based on the literature review. Overlay mapping is the basic method applied in GIS and helps the planners to obtain the final suitability map. The AHP method is one of the methods to combine attribute scores with a weight or preferences that should be used in the process of weight value calculating so that we can avoid some subjective ideas affecting the results and combine the quantitative and qualitative methods. Consequently, it can be concluded that the residential land suitability assessment of the DDA provides a technical basis for sensible land use planning at the regional level.

For the entire land suitability assessment process in the DDA, the environmental protection areas are identified as the first step in the process which is ignored in a lot of past studies. Excluding the important protected areas will benefit the planners in identifying the lands which have top protection priority and should not be taken up for other purposes. For example in the DDA area, the prime agriculture land and key hydrologic features are regarded as protected areas. Even if they are suitable for residential land uses, they can not be used as residential areas because of their environmental protection priority. The land suitability assessment process will assess remaining area for suitability for urban residential land development. This kind of residential land suitability assessment can be widely used in middle-size cities in southwest China. The efforts will help the government to find out the suitable area for the future urban developments by way of effectually use the limited land resource.

6.2 Implications

Residential land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for urban sustainable development. The systematic assessment of land and water potential, alternatives for land use and socio-economic conditions in order to be selected and put into practice those land use will best meet the needs of the people while safeguarding resources for the future. As mentioned in Chapter 2, there is limited literature on the topic of residential land suitability assessment in Mainland China. The future residential land use is increasing not only in middle-size cities, but also in the small cities in China during the urbanization process. By the internal migration from the rural to urban, urban sprawl quickly proceeded in the past two decades and brought on land use conflict (Zhang and Kenneth, 2004). The residential land suitability assessment will help to manage the conflicts between urban land use and agriculture land use. This study provides experiences on the topic of residential land suitability assessment which is seldom used in the urban land use planning in China, by introducing the experience in the Dianchi drainage area. However, the other areas should consider the criteria for the factors based on the different local environment during land suitability assessment process, such as the study area is an inland city so that the distances to the riverway and water body are not necessary. Integrated RS, GIS and AHP in the process of land suitability assessment is an effective way not only for the residential land suitability assessment, but also for agricultural objective. Thapa et al. (2004) have successfully applied this measure in the Hanoi peri-urban agriculture land suitability assessment.

6.3 Limitations

Because of the lack of data and time, there are some limitations in the study. First, in terms of the discussion of feasibility in Chapter 5, the limited database is still a challenge for future studies in China. The first limitation is data requirements and variation in availability of data among different locales. The DDA has its separate Kunming Dianchi Administration Bureau and it falls into the administration of Kunming City government so the relatively comprehensive database could be collected by different bureaus. Other middle-size and small-size countries may not have a comprehensive database and relevant infrastructure data. In this sense, implementing the land data information system is a major task to be worked upon during China’s future land management. Second, there are limited literature reviews about the urban residential lands, which have resulted in a not all-around factors selection since the researchers paid more attention on the land suitability assessment for agricultural purpose. Especially in the Dianchi drainage area, the water pollution is the crucial aspect, the researchers pay less attention on the land use development. For the sustainable development of a city, governors should not only pay attention to the water pollution but also attach importance on the overall development of the city, including the water, land, economic and social development. Third, the land suitability particularly suitable as a planning tool to evaluate and manage cumulative effects at the local level, but data requirements dependent on a time limited historical record.

6.4 Future Research

In the future work, the study would introduce some external methods into the assessment process to eliminate the limitations. Some impersonal mathematic method could reduce the subjective feelings in the process of suitability assessment, such as certain influential factor chosen by some experts is a limitation in assessment. Incorporating other criteria would help to class the suitability class in the assessment based on the detailed data support (Rodrigo et al., 2005; Baja et al., 2001). Environmental impact assessments can be also combined with the suitability assessment for appraising individual projects and inhibiting environmental conflicts.

For land suitability to be more feasible in China, land resources database should be established and implemented in most Chinese cities. If the public has an easy access to these databases, it will contribute to wider public participation into the urban planning process. The government should also ameliorate the land compatibility database, for example, environmental sensitive area and specialty-crop lands should not be transformed into other lands due to its special features. This method will help to improve the efficiency of using limited land resource.

Appendix A

Full set classification of the Influencing factors

Factors	Suitability Orders	Suitability class	Classification qualification
Slope	Suitable	S1	<5°
		S2	5°—8°
		S3	8°-10°
	Not Suitable	N1	10°—25°
		N2	>25°
Drainage class	Suitable	S1	Excellent
		S2	Good
		S3	Fair
	Not Suitable	N1	Poor
		N2	Very poor
Using type of land	Suitable	S1	Construction and Residential quarters land
		S2	Dry land
		S3	Vegetable field, Garden land
	Not Suitable	N1	Wooded land, Bushy land, Paddy field,
		N2	Unused land, Water area
Access to Schools Network	Suitable	S1	<1000m
		S2	1000m-3000m
		S3	3km-5km
	Not suitable	N1	5km-10km
		N2	>10km
Commodity Network	Suitable	S1	>50

		S2	30-50
		S3	20-30
	Not Suitable	N1	10-20
		N2	<10
Access to Hospital Network	Suitable	S1	<1000m
		S2	1000m-3000m
		S3	3km-5km
	Not Suitable	N1	5km-10km
		N2	>10km
Access to Sewer Network	Suitable	S1	Dense
		S2	Good
		S3	Fair
	Not Suitable	N1	Poor
		N2	Very Poor
Waste Management	Suitable	S1	Excellent
		S2	Good
		S3	Fair
	Not Suitable	N1	Poor
		N2	Very Poor
Distance to Road	Suitable	S1	< 250m
		S2	250-500m
		S3	500-750m
	Not Suitable	N1	750-1000m
		N2	>1000m
Distance to water area	Suitable	S1	>2000m
		S2	1500-2000m
		S3	1000-1500m
	Not Suitable	N1	500-1000m
		N2	<500m
Distance to Riverway network	Suitable	S1	>90m
		S2	70m-90m

		S3	50-70m
	Not Suitable	N1	30-50m
		N2	<30m
Distance to Road	Suitable	S1	< 250m
		S2	250-500m
		S3	500-750m
	Not Suitable	N1	750-1000m
		N2	>1000m
Population Density(thousand/ km^2)	Suitable	S1	>15
		S2	10-15
		S3	5-10
	Not Suitable	N1	1-5
		N2	<1
Open Spaces	Suitable	S1	<1km
		S2	1km-3km
		S3	3km-5km
	Not Suitable	N1	5km-10km
		N2	>10km
Bus Route Network	Suitable	S1	<250m
		S2	250m-500m
		S3	50mm-750m
	Not Suitable	N1	750m-1000m
		N2	>1000m
Environmental Pollution	Suitable	S1	Excellent
		S2	Good
		S3	Fair
	Not Suitable	N1	Poor
		N2	Very Poor
Water Quality	Suitable	S1	Excellent
		S2	Good

		S3	Fair
	Not Suitable	N1	Poor
		N2	Very Poor
Proximity to Industrial Area	Suitable	S1	>8km
		S2	5km-8km
		S3	3km-5km
	Not Suitable	N1	1km-3km
		N2	<1km

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