International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

Interim Report **IR-04-056**

Projections of Water Demand under Changing Land Use in Beijing Municipality

Ming Zhang (zhangm@iiasa.ac.at)
Gerhard K. Heilig (heilig@iiasa.ac.at)

Approved by

Leen Hordijk (hordijk@iiasa.ac.at)
Director, IIASA

October 5, 2004

Projections of Water Demand under Changing Land Use in Beijing Municipality

Ming Zhang, Gerhard K. Heilig

Sustainable Rural Development, International Institute for Applied Systems Analysis, Laxenburg, Austria

Abstract:

Beijing Municipality, as one of the biggest economic-concentrated areas in China, has suffered from an extremely serious water deficiency for decades. Excessive access to water resource has not only broken the water balance, but has also brought about some serious problems to regional environment, such as the frequent cut-off discharge, the shrink of wetlands, the exhaustion of ground water resources and the deterioration of water quality. Except for the climate change in physical dimension, unlimited industrial enlargement, extensive agricultural irrigation, continuous improvement of living standard and increasing ecological demand constitute the main factors in human dimension to influence the change of balance between water supply and water demand. Land-use changes might be the best concept to combine all these factors for they could reflect the changes both in physical conditions and in social economy.

This working paper focuses on the relationship between sustainable water-use and land-use changes in Beijing Municipality. Rather than taking a more traditional, static approach of forecasting future use based solely on per capita consumption rates and/or population statistics, the analysis documented in this study is based on models of future land-use changes. Both spatial and temporal distribution models are applied to project the future land-use changes in Beijing. The resulting water demand per land-use type can be useful tools for forecasting water demand in the area as well as actual water supply. The feasible recommendations on regional water-use policies will be put forward accordingly.

Contents:

List of figures:

List of tables:

1. Introduction

The yearly report on urban development in China in 2002-2003 shows that the main economy of China is concentrating gradually on the huge cities, especially towards the three great city groups in the Pearl River Delta, Yangtze River Delta and area around Bohai Sea[1](see Figure 1.1). In 2003, over 38% of the national GDP is contributed by these areas. Compared with the Pearl River Delta and Yangtze River Delta, the area around Bohai Sea, as a new center for treasure concentrating, is still in its preliminary shape. However, the current rapid economic growing and concentrating tendency is apparent and the concentrating potential is huge. More attentions to the inner co-operations are paid such as the union of airports in Beijing and Tianjin, the outside moving of the Capital Steel and Iron Corporation and the research on the "Great Beijing" planning in Beijing, Tianjin and Hebei province, which means that the unification process is quickening. The continuous growth of economy often exerts more and more pressure to resources and environment, and in return the resources and environment will restrict the economic development to a great extent. Especially in the area around Bohai Sea with both resource shortages and environmental threatening for a long time, the rational allocations and protections of resources and environments have already become the bottleneck for the regional sustainable development. Among them, the water scarcity and water quality are regarded as the most important factors.

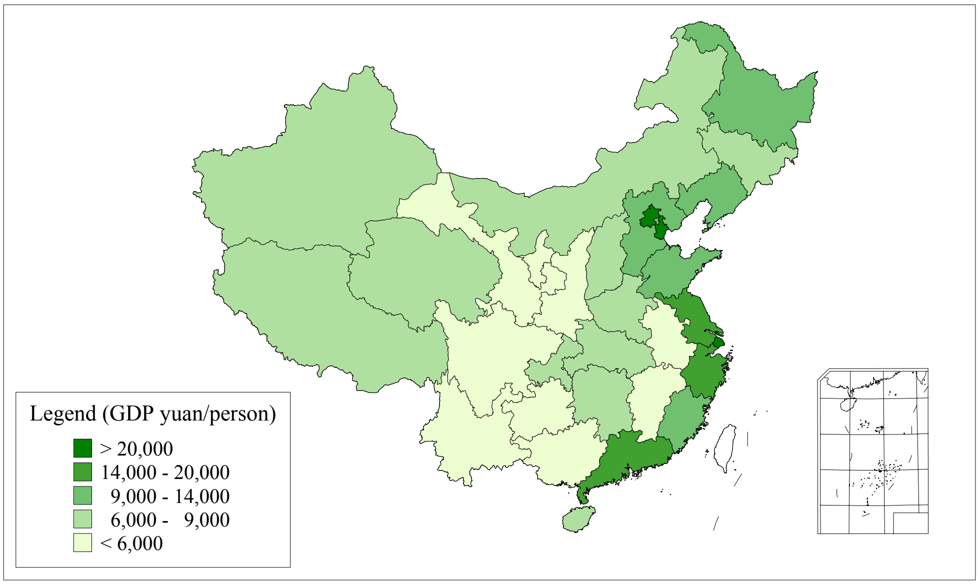

Figure1.1 The distributions of Per capita GDP in China in 2002

In general, the water resource in China could basically meet the requirement of economic development currently. However, due to the uneven distribution of water resources, the situation of water shortage is very serious in most northern areas and some cities along the seas. The water resources play more and more important role in restricting the economic growth in those areas.

[1] From the concept of human geography, Beijing Municipality belongs to the economic region around Bohai Sea.

Figure1.2 shows the current distribution of water resources in China in 2002. It can be seen that there are 18 provinces with the water resources less than 1700 cubic meters per capita, the commonly received critical value for water shortage in the world. The areas with the most serious water scarcity are Haihe river basins, Ningxia and Shanghai, where people could only share the water resources less than 300 cubic meters per capita, which is only 60% of the international standard for extreme water shortage (500 m^3/person). Beijing Municipality is just among those areas.

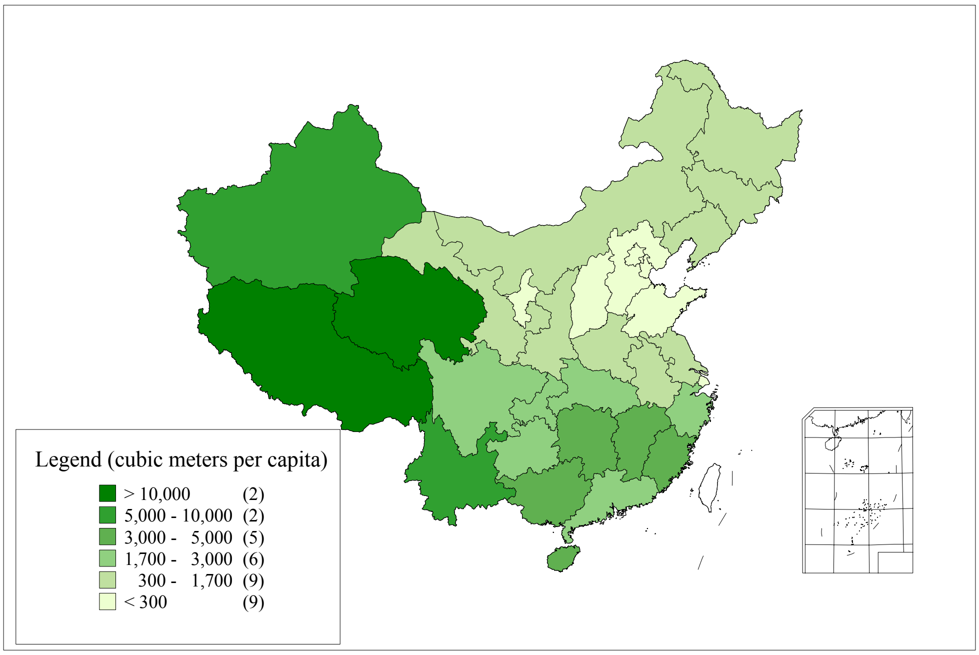

Figure1.2 The distribution of water resources in China in 2002

The strong contrast between the economic development and water scarcity in Beijing area can also be found easily from this figure. Undoubtedly how to deal with this problem not only influences greatly the sustainable development in this area, but can also decide whether the economic concentration could be continued. That is also the reason why we choose this area as our representative study.

As noted, Beijing Municipality is the capital city of the People's Republic of China. It is one of the 4 municipalities of the People's Republic of China, which have a provincial-level status, and is under the direct control of the central government. Beijing is one of the largest cities in China, second only to Shanghai as the nation's biggest. In administration, the municipality governs 18 county-level divisions: 16 districts and 2 counties. The political importance makes Beijing Municipality enjoy high status to water consumption while among the inner different counties, the disputes of water use still existed for a long time.

The total population of Beijing municipality in 2003 was 14.56 million, of whom about 11.49 million had Beijing hukou (registered permanent residence) and 3.07 million were on temporary residence permits. In addition, there is a large but unknown number of migrant workers who live illegally in Beijing without temporary residence permits.

In hydrological regionalization, Beijing lies in the Haihe River Basin and it belongs to the monsoon climate region with semi-arid and semi-humid climate in temperate zone. The annual average temperature is 10-12̊, the annual mean rainfall from 1956 to 1998 is 595mm and the total annual amount of water resource is 4.33 billion m^3 (including the amount flowing from other regions). The water resource per capita is less than 300 m^3, which is only 1/8 of the national level, 1/30 of the world level. This level is far lower than the internationally accepted limitation for water shortage, 1000 m^3. The land in Beijing covers 16807.8 km^2 with the water-consumed population over 14 million. As the political, economic and cultural center of China, in recent 20 years, with the rapid urban expansion, the urban population and economy have developed with an unprecedented speed. Such developments are exerting a stronger and stronger pressure on the water resource, although the planned use and water saving technologies are spread and promoted greatly.

To estimate current water demands and project future water demands, an accurate historic water-use pattern and water usage records are necessary. Water management institutions generally make long-term plans based on several independent methods, each with different assumptions and different data sources. One way is the regional projections based on the per capita water consumption. It is easy to be carried out but not related to economic trends such as major shifts from low- to high-density land/water uses, and local regulatory influence on land-use changes. Another way is extrapolation of historic water consumptions in different sectors. In different sectors, the corresponding water-use situations are projected according to different factors. For lack of the balanced consideration about the structural impacts among different factors, it can also only reflect the approximate demand for the near future. The other way is known as the land-use method. Based on how land is expected to be used and how much water is required by projected land-use types, the future water demands are forecast comprehensively. For this method analyze and model not only the physical environment but the human dimension of these processes as well, it produces the most accurate long-term forecasts. It is also chosen in our study as the main methodology. The other two ways mentioned above will also be applied as the complementary checks for our major projection.

The main method in our research could be simplified to a simple equation as follows:

$Dw = Al * Fd * Fw * Fc$
Dw: water demand
Al: area of land-use type
Fd: factor of water demand
Fw: factor of weather normalization
Fc: factor of water conservation

So the resulting water demands consist of three parts: 1) the area of different land-use types; 2) the amount of water which is used on the area for a given land-use type; and 3) adjustments for weather conditions and water conservation.

The water consumption data come from the statistical yearbook of water resources in Beijing city. The land-use data are based on the remote sensing images at the scale of 1:100 thousand, which derived from the resource and environment database in Chinese Academy of Sciences.

2. Current and historic water use

Generally speaking, in those areas with more water resources, the total water use is also high. However, in China, due to the diverse climate types, production structure, water-use styles and uneven distribution of population, the water utilization situation does not coincide with the distribution of water resources. For example, in the eastern basins with the humid monsoon climate, water resources are relatively more abundant than the northwestern arid areas. For most population concentrate in the eastern China, the actual water use per capita in eastern basins is less than that in the west. However, as the main water consumer, agricultural production mainly distributes in the northern part extensively, which causes the tremendous demand for water use in the northern basins, especially in the Haihe River, Huanghe River and Huaihe River Basins. Beijing is such a dramatic representative.

2.1 Historic use trends

Figure 2.1 shows the historic water-use trends in China since 1980. As can be seen from the figure, on the level of river basins, the water utilization trend is quite different. In the northern river basins, except for the northeastern river basins, there is a declining trend of water use per capita from 1980 to 2001. Simultaneously, in the southern river basins, water use has not changed dramatically except that there is an increasing trend in southwestern river basins. Totally speaking, through the obvious change from 1980, the water use per capita in southern river basins has arrived at a relatively stable phase, while in the northern river basins, the water use per capita is still declining during these 5 years.

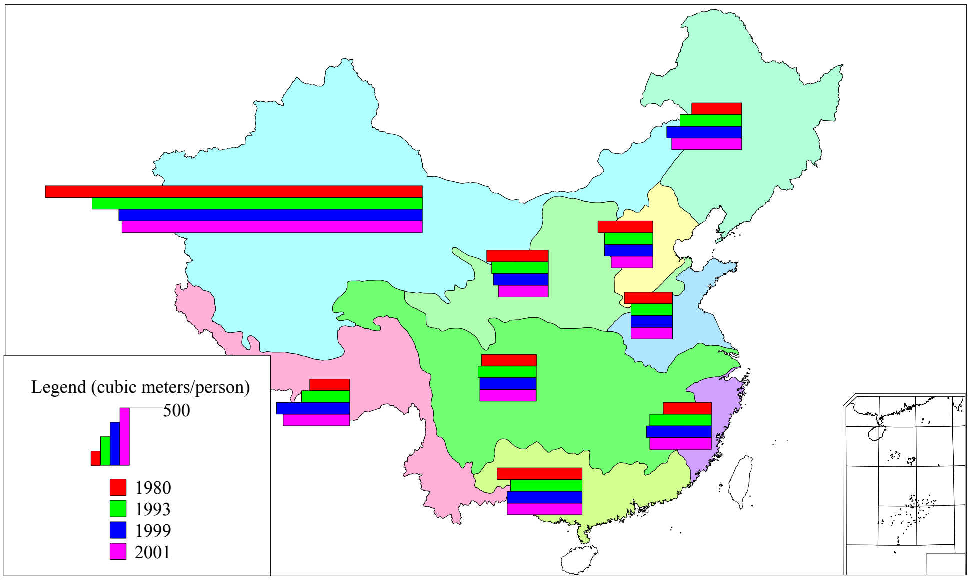

Figure 2.1 The change of water use per capita in China since 1980

Figure 2.2 shows the change of water use in Beijing from 1988 to 2002. With the decrease of agricultural water use and industrial water use, the domestic water use increased dramatically. The total water use fluctuated unsteadily but gradually decreased in recent years.

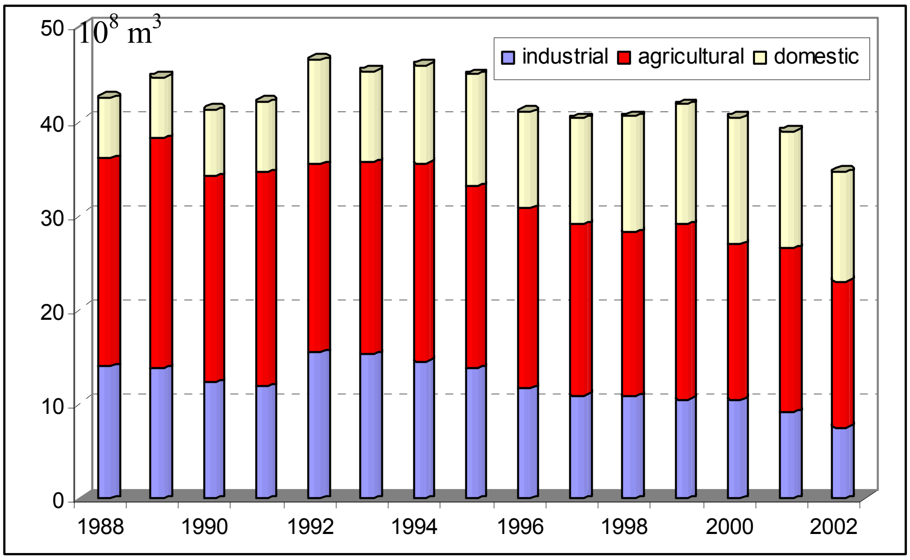

Figure2.2 The change of water use in Beijing from 1988 to 2002

2.2 Current water use

In 2002, the detailed water use situation in Beijing can be seen in Figure 2.3. The user with the biggest water consumption is still agricultural sector, which account for 45.1% of the total water use (farmland irrigation accounts for 35.1% and other agriculture accounts for 10%). Domestic water user is the second biggest sector, which accounts for 31.3% of the total water use (urban domestic water use is 26.9% and rural one is 4.4%). Industrial water use occupied 21.8% and the environmental water use occupied the remained 2.3%.

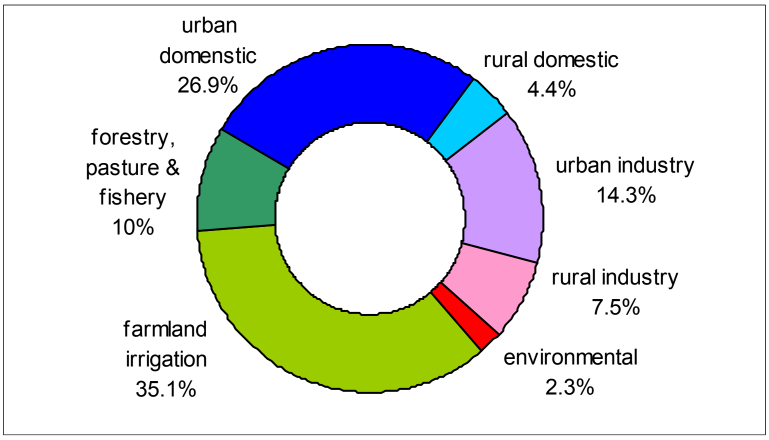

Figure 2.3 The current water-use patterns in 2002

After continuous adjustment for agricultural structure, reallocation of the water-consuming industries and reform of water price systems and policies, the current total water usage pattern tends to stable relatively. However, with the rapidly increasing population and economy, the ratio of water use by industry and domestic life will surely be increasing in the future years.

3. Historic and current land use

3.1 Historic land-use change

The main land-use data sources in our research are digital images of Landset-TM in Beijing in 1988 and 2000. Through the geometrical correction, error correction and validation on the spot, the precision rate of patch process is over 98%. Taking reference of the national land-use type classification, six kinds of land-use types are classified in our research: cultivated land, forest, grassland, water, industrial and residential land and unused land.

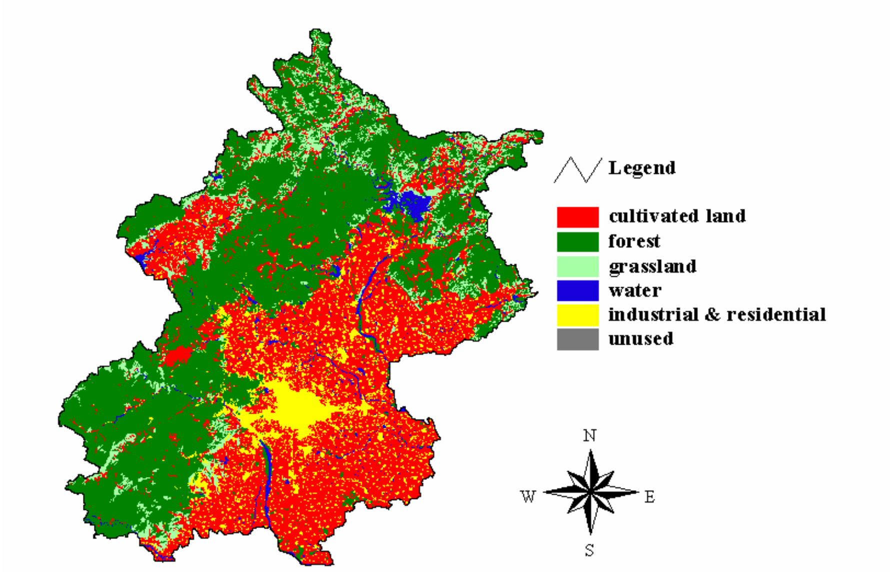

Figure 3.1 The land-use map in Beijing Municipality in 1988

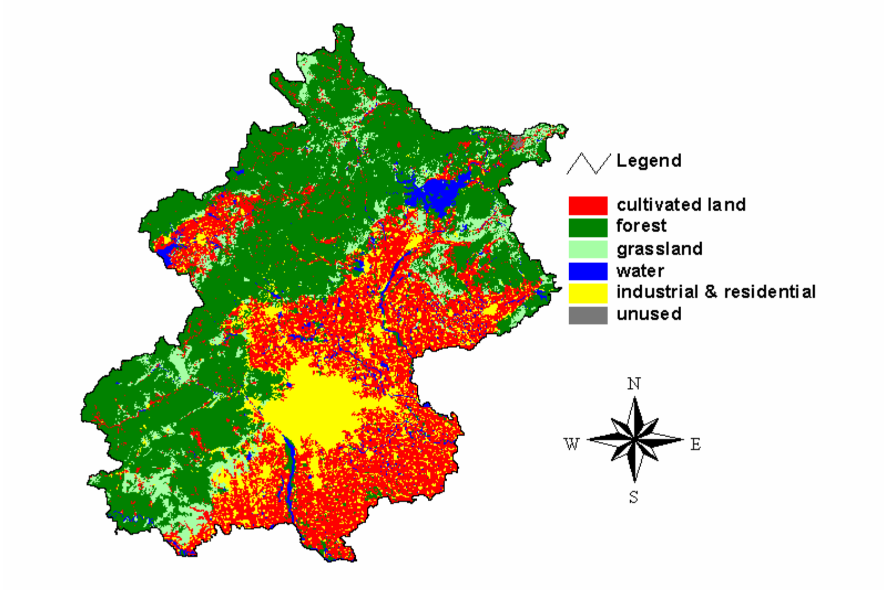

Figure 3.2 The current land-use map in Beijing in 2000

From the remote sensing based land-use map, we extracted the different land-use data in these two time points (Figure 3.1 and 3.2). It can be seen easily that the total land-use structure is mainly controlled by cultivated land, forestland and urban built-up land. Figure 3.3 Shows the changes of land-use types from 1988 to 2000. During the 12 years, cultivated land decreased dramatically and the urban built-up and industrial land increased obviously, which means that the rapid urbanization of Beijing Municipality also brought about the huge occupation of cultivated land. The forestland increased which coincides with the continuous efforts by the municipal government through ecological projects on returning cultivated land to forestland and grassland in recent years. For the other land-use types, they changed very less excepted that the water increased relatively more.

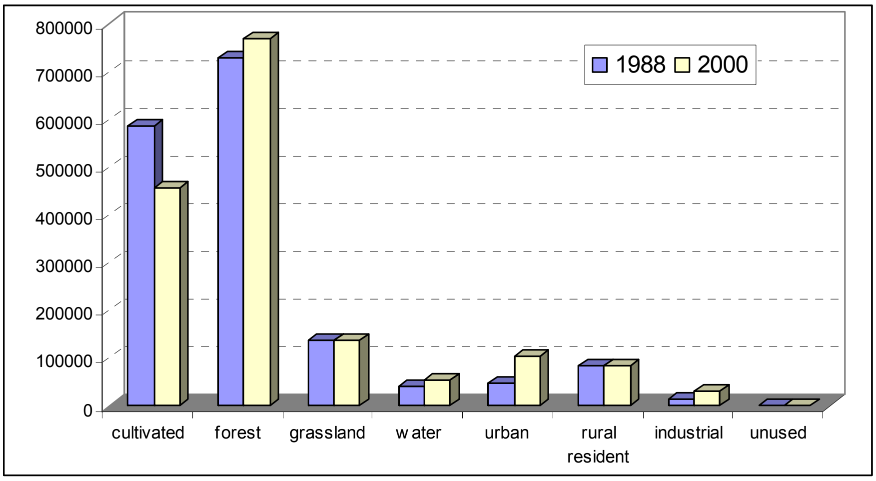

Figure 3.3 The land-use changes in Beijing from 1988 to 2000

3.2 Current land-use pattern

Through Figure 3.4, the characteristics of current land-use pattern in Beijing Municipality in 2000 can be seen. Forestland and farmland occupied the majority of this area and they totally account for 83.2% of the total land area combined with the grassland. The total land area of urban built-up, transportation, industry and rural residential land occupied 13.3% of the total land area.

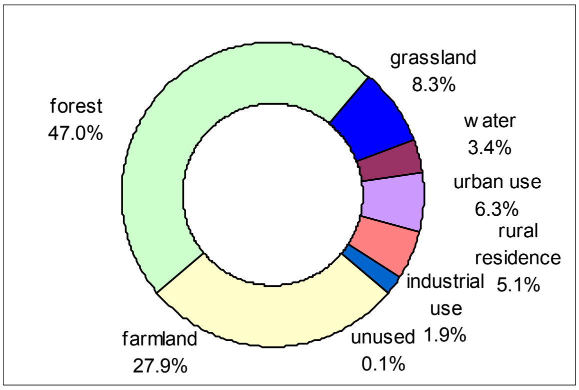

Figure 3.4 The current land-use pattern in Beijing in 2000

4. The relationship between water use and land use

Our way of determining the water usage for Beijing Municipality is by undertaking an econometric analysis. This methodology, which has been used by traditional water service agency in the past, evaluates projected land-use trends within its total area. The demographic trends and other factors affecting the water demand are also taken into account.

4.1 Climate changes in Beijing Municipality.

When future water demand is projected, the regional climate change should always be considered for climate factors, especially the rainfall plays an important role in the formation and distribution of local water resource. In the semi-arid area such as Beijing Municipality, the limitation of precipitation definitely exerts an pressure to the total water use in this area.

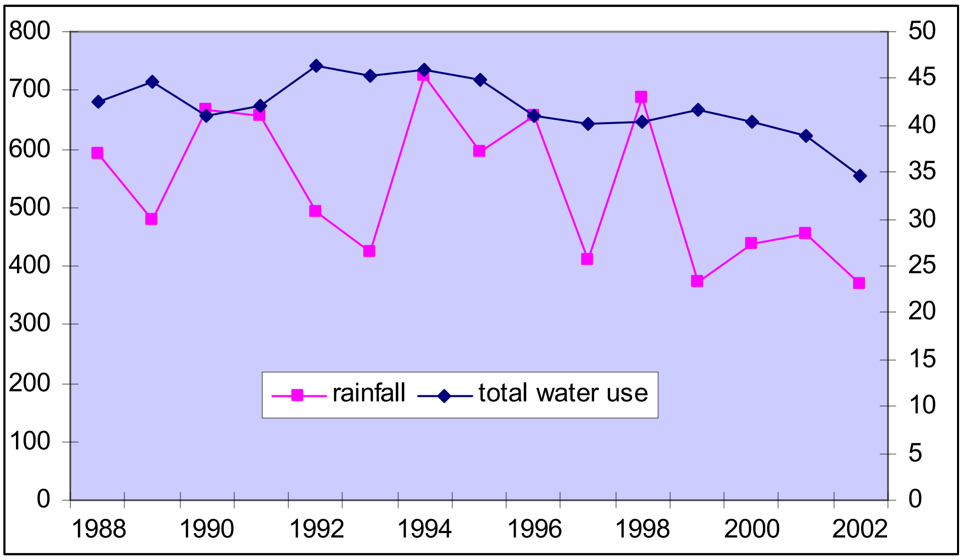

Figure 4.1 The changes of rainfall and total water use from 1988 to 2002

Figure 4.1 Shows the effects of rainfall on historical water consumptions in Beijing. It can be seen from the figure that with the decreasing trend of rainfall since 1988 despite some fluctuations, the total amount of water use is also decreasing simultaneously. In general, less water was consumed when there is more abundant rainfall. However, in recent year, despite the continuous drought years, the total water consumption decreased year by year, which means that the influence of precipitation on total water use is decreasing. Human activities, such as land-use style, and human water use behavior play more and more important role in the total water use.

4.2 Water conservation

In recent years, the Beijing municipal government has recognized that water conservation has become an increasing important factor in water supply. It has direct effects on water consumption. Actually, water conservation mainly connected with the water management and water policies. In order to manage the water resource effectively and meet the needs by rational allocation and sustainable utilization of water resources, integrated water resources management in both urban and rural areas as a brand new management mode was born. Over the recent years, in order to meet the needs of social and economic development and alleviate the urban water shortages, the municipal has established through studies the water affairs bureau which undertake the unified management for flood control, water resources, water supply, water use, water saving, wastewater discharge, waster-water treatment and reuse so as to manage water resources in both urban and rural areas as a whole. Integrated water affair management is a new mode for water resources management, suitable for the economic and social development and sustainable water resources management in China, thus having a broad horizon for development.

On the other hand, the municipal government is actively trying to decrease the unnecessary water use and water waste through the water law formulations. From August 1st 2004, the municipal government formally adjusted the collection standard for water resource fee and disposal fee for waste water. The water supply prices of water conservancy and tap water are also adjusted accordingly. Among them, the price of domestic water usage increased from the previous 2.9 yuan per cubic meter to 3.7 yuan per cubic meter. The increasing percentage of 27.6% in price will definitely decrease the current universal state of water waste. The increasing profits will be used to develop, protect, maintain and store up water resources, spread the measures of water saving and collect the funds for South-north water diversion.

4.3 Current relationship ratios between land-use type and water use

Table 4.1 Current relationship ratios between water use and land-use

land-use type	water use (100 mn cu.m.)	land use (ha)	water use / land use (cu.m/ha)
cultivated land	12.16	456741.42	2662.34
other agricultural land	3.29	961381.35	342.22
rural residential	1.53	84273.89	1815.51
industrial & urban construction	17.64	134375.05	13127.44

By 2000, the big-scaled adjustment for industry and agriculture have been almost finished through several years' effort by the municipal government and the current water usage patterns are relatively stable, so we take the current ratios as the reference relationship for the future projection.

5. Modeling on future land-use change

There are a lot of different methods on land-use change projections. In our research, we applied both the spatial and temporal distribution model to project the future land-use changes in Beijng Municipality. They are Markov matrix and Modified GTR model respectively.

5.1 Markov matrix

Markov matrix is named after A.A. Markov, who produced the first results (1906) for these processes. He discovered that the change of some events have very close relationship with the recent states of these events while they related less with their long-term states. That is to say, the future knowledge of decisions and values are assumed to be a function only of the current state. Markov matrix is widely used in land-use change modeling.

In Markov process transfer matrix, the state probability is a basic concept.

$P_k = P_0P^k$

P_k : The state probability after the transfer of k times.

P_0 : the initial state probability

P : the probability matrix of state transfer

Since we have got the land-use maps through remote sensing images in two time points, we could easily extract the transition state matrix through GIS overlay technology.

Table5.1 Transition state of land-use types during 1988~2000 (ha)

	cultivated	other agricultural land	rural residential	urban and industrial
cultivated	420879.1222	89699.16298	22870.18037	52103.93165
other agricultural land	30106.39812	867212.9584	2200.061775	4494.170954
rural residential	5241.140646	3230.484067	58526.90186	16761.05559
urban and industrial	519.9509675	1182.449393	677.5393813	61016.95017

(Spatial analysis through GIS overlay with the land-use maps in 1988 and 2000, CAS, R & E database)

With Table 5.1, we could calculate the initial state probability matrix, then, in Excel program, through the MMULT function measurement, the future states of different land-use through N years' changes could be achieved. The results show that in 2010, the area of cultivated land, other agricultural land, rural residential land and urban industrial land will be 355791.974ha, 1021317.93ha, 85837.92ha and 173823.88ha respectively.

5.2 Modified GTR model

The original spatial models on land-use changes to combine natural factors and human factors are based on the land rent theory of Ricardian and Von Thunen. The main research object is urban land (Smith and Dennis, 1987; Stark, 1988 and Labmin, 1994).

These models aimed to gain the maximal economic profits so they paid more attention to classical economic analysis while they neglected the internal mechanism of Land-use changes.

GTR (Generalized Thunen-Ricardian) model is the extension of the tradional land rent models, which is developed by Konagaya, et.al(1999). It regards urbanization as the main driving force of land-use changes. Local natural conditions are considered in the model.

Our spatial model is mainly based on Generalized Thunen-Ricardian Model. Apart from the urbanization, we brought the agricultural development into our model. So in this modified GTR model, there are three main explanatory variable groups simultaneously. That is to say, urbanization, agricultural development and location play the most important roles in the process of land-use changes. The future urban built-up land, agricultural land and natural covered land are projected.

The model expression is demonstrated as such the equations as follows:

$$\begin{cases} K_i(c) = K_{0i}(c)\{\exp[a_1(c)\times Y_i + a_2(c)\times X_i]\}\times\{\exp[a_3(c)\times E_i + a_4(c)\times S_i]\}\times\exp[a_5(c)\times R_i] \\ \sum_{c=1}^{3} K_i(c) \equiv 1 \end{cases}$$

Among them：i-county number (i =1,2,3,⋯,56);
c-land-use type (1=cultivated land; 2=construction land□3=natural land);

Ki-Percentage of land-use type; K0i-constant;

Yi-Influenced index by the central city in each county; Xi-population rate of non-agricultural; Ei-average elevation of county i; Si-percentage of area with the slope below 25 degree of coutny i; Ri-agricultural output per capita in county i.

Figure 5.1 shows the basic framework and data sources of Modified GTR model. Different explanatory variables derive from different datasets, through the parameter estimation and model check, the future projection can be got.

According to above equation and framework flow, we could simulate the relationship expressions of cultivated land, built-up land and natural land accordingly.

$$K_i(1) = 0.021[\exp(0.056Y_i - 0.331X_i)][\exp(-0.002E_i + 0.354S_i)][\exp(-0.136R_i)]$$

$R^2 = 0.638$

$$K_i(2) = 0.626[\exp(-0.254Y_i + 0.193X_i)][\exp(0.001E_i - 1.294S_i)][\exp(0.101R_i)]$$

$R^2 = 0.619$

$$K_i(3) = 0.047[\exp(1.522Y_i - 0.209X_i)][\exp(-0.008E_i - 2.679S_i)][\exp(-0.281R_i)]$$

$R^2 = 0.589$

In order to check the precision of simulation, we compared the projected value and the investigated value. For the investigated value of land-use in 2000, we applied the remote sensing image data in 2000 as the reference, compared with the projected value by our GTR model simulation. Figure 5.2 shows the comparison of cultivated land between the investigated value and projected value in Beijing in 2000. It can be seen the result and precision of simulation is satisfactory.

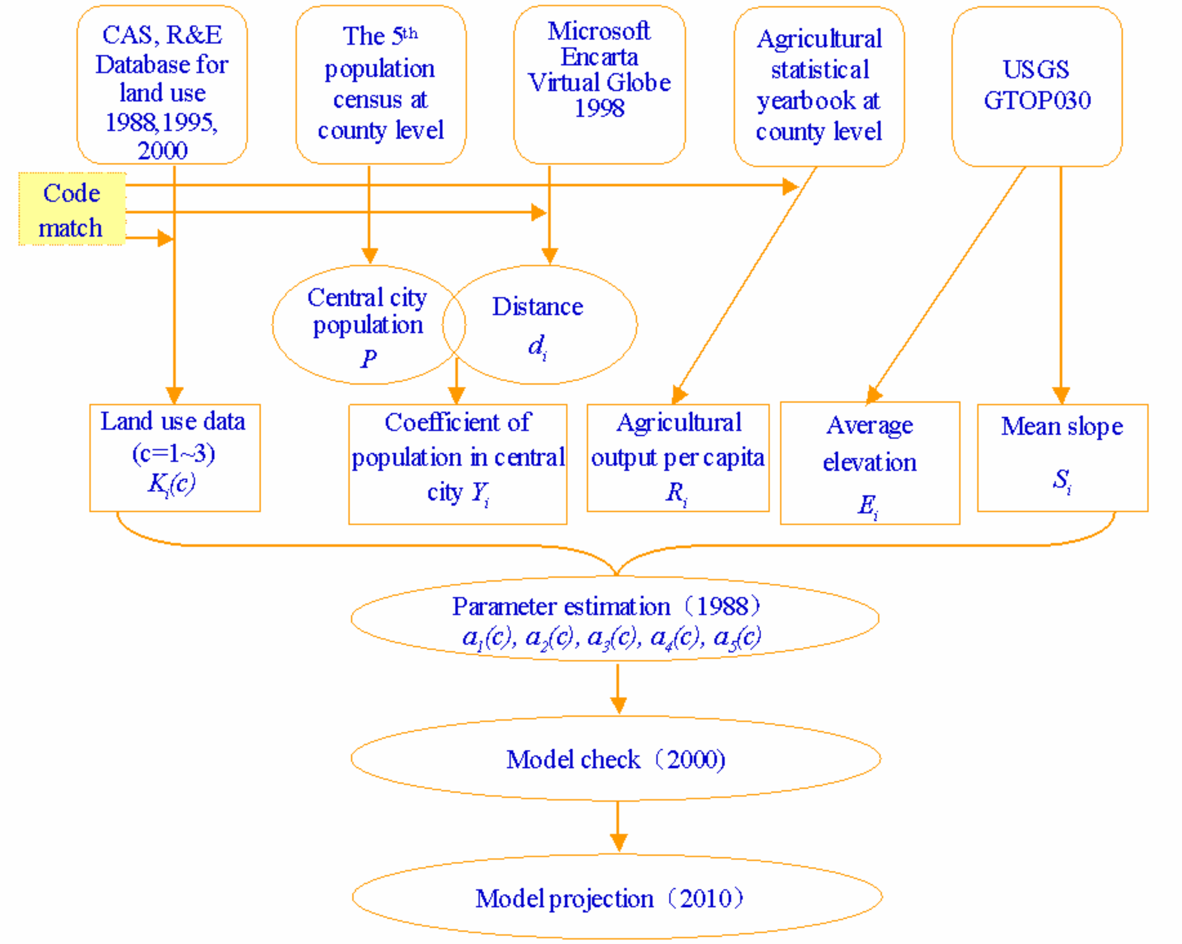

Figure 5.1 the basic framework and data sources of Modified GTR model

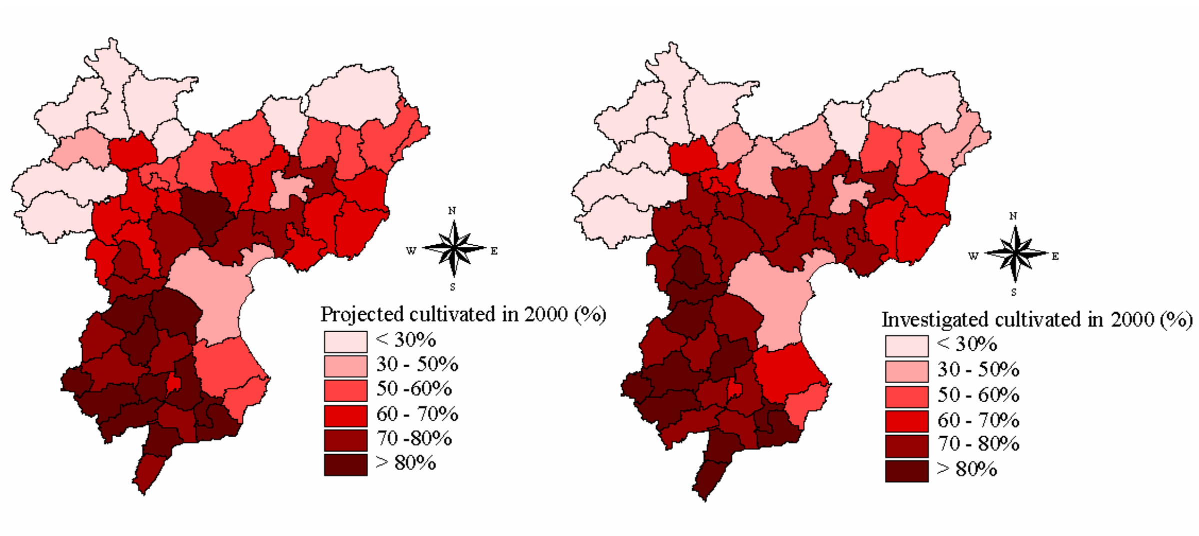

Figure 5.2 the model check of Modified GTR model

6. Prediction on future water use

With our chapter 4 and 5, we could calculate the water demand in Beijing Municipality in the future years. Through our two different kinds of land-use modeling, the different water demands could be compared with each other. Table 6.1 shows the results of water demand projections in 2010 through the Markov matrix and GTR model.

Table 6.1 Results of water demand projections in 2010(10^8 m^3)

	cultivated	other agricultural land	rural residential	urban and industrial	Total
Projection by GTR model	9.16	3.48	33.46		46.10
Projection by Markov chain	9.47	3.50	4.56	24.82	42.34

It can be seen that the projection by GTR model is higher than that by Markov matrix. The difference is 3.76 billion m^3. According to the linear trend of the historical water use, the water demand in 2010 would decreased to 35 billion m^3 (see Figure 6.1), which is mainly attributed by the decrease of water use in recent years in Beijing. However, with the rapid development of the capital economic circle and grand plan for another future economic center in China, the decreasing trend of water use is less possible. On the contrary, the increasing trend seems inevitable.

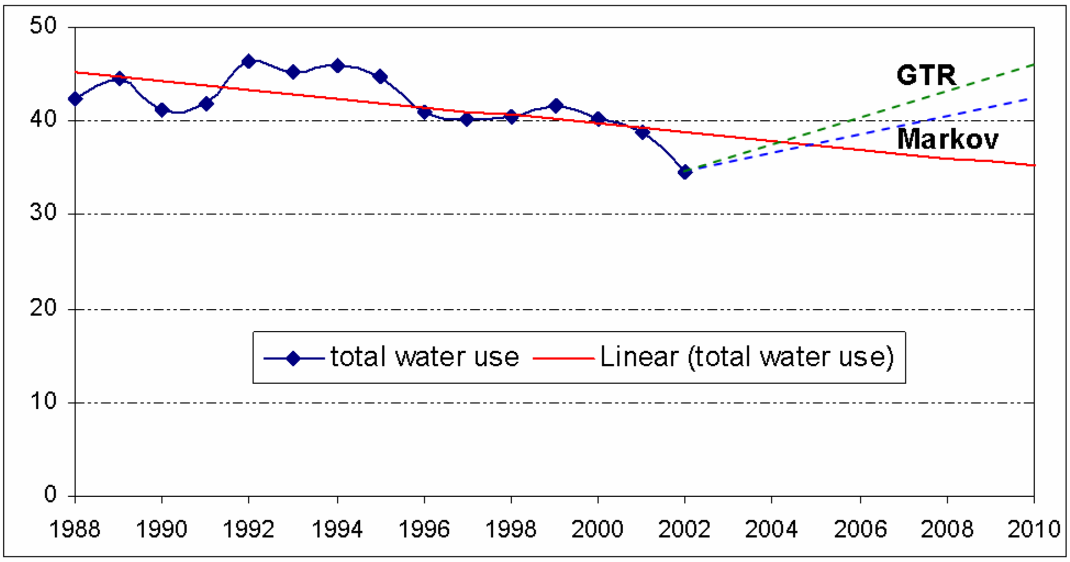

Figure 6.1 The comparisons of trend line and modeling results on water-use projections

In 2001, for lack of water, the municipal government decided to cancel the planting of "Western Beijing Tribute Rice" which have a history of over 1000 years with best quality. In 2002, for continuous over development of ground water, the ground water table decreased by 0.65 meter than the previous year. In 2003, due to the inadequate water supply, Beijing diverted water of 30 million ton from outside for the first time in its history. Compared with the current water supply shortage, four basic conclusions are drawn:

- Water demand will go on increasing
- Water shortage is still serious
- Water diversion from South to North is necessary
- Water saving measures should be long-term policies

7. Suggestions on sustainable water use under changing land use

Aiming at the serious situation on water shortage in Beijing, there are only two basic ways to solve the problem.

1. To insure the successful implement of the South-North Diversion Project

The middle route part of South-North Diversion Project started to be built on December 30, 2003. The establishment will last for 8 years and 92 billion RMB yuan will be invested. According to the plan, the water will be drawn from the Danjiangkou Reservoir in Hanjiang River and arrive at Beijing and Tianjin through Hubei, Henan and Hebei province. It is planned that in 2010 Beijing could be supplied with water of 1 billion cubic meters by this project. Among them, 800 million cubic meters is for urban domestic while the other 200 million cubic meters is supplied for the industrial use. Undoubtedly, this project should be the most effective method to eradicate the water shortage in Beijing. For this project plans to draw water from the main stem of Yangtze River in its future perspective, it also plays an important role in the alleviation of water deficiency and restoration and protection of the environment in Beijing, Tianjin and even the whole North China Plain.

2. To save water

Except to broaden the water sources and divert water, water saving is also an important measure for water shortage problem. In recent years from 1981 to 2002, the water saving amount arrived at 1.5 billion cubic meters. Among them, the exploitation of underground water decreased by a half; the water consumption by 10000 RMB Yuan GDP decreased from 357 cubic meters in 1981 to 20 cubic meters in 2002; the repetition usage rate of industrial water increased from the past 48.57% to the current 88% or so. Since 1981, the municipal government has enacted over 10 local regulations for water saving, which signals that the basic framework for urban water saving has taken shape. Except for strengthening the standard to punish the behavior of water waste and award the one of water saving and spreading the water saving knowledge, the local government has also made the active explorations in the scientific management model for the water-use ratios, improvement of the contents of science and technology in water saving and the application of the regenerated water.

References

Chen Shaojun, Ruan Benqing, and Yang Xiaoliu. 2000. Several questions on water resources development in China, Chinese population, resources and environment, vol. 10, pp. 58-62.

China Gazette on Water Resources in 1997, Ministry of Water Resources in China.

China Gazette on Water Resources in 1998, Ministry of Water Resources in China.

China Gazette on Water Resources in 1999, Ministry of Water Resources in China.

China Gazette on Water Resources in 2000, Ministry of Water Resources in China.

Liang Ruiju, Yang Xiaoliu, and Wanghao. 1998. The situations and prospects of water resources requirement and supply in China, the technology on water conservancy and water-electricity, vol. 29, pp 2-5.

Ma Dianzhen and Zhang Xiangming. 2000. Analysis on the development scenarios of irrigation areas in China, the forum on water questions (journals), vol. 25, pp. 29-35.

The Gazette on Water Resources in Beijing Municipality, 1988-2002.

Wang Dangxian, Wanghao, and Zhang Xiangming. 1998. Analysis on the social economic development and situations on water resources requirement, the forum on water questions (journals), vol. 20, pp. 33-40.

Wang Dangxian, Liang Ruiju, et. al. 2000. The prospect on the development patterns of basins in China in the 21st century. The forum on water questions (journals), vol. 28, pp. 15-24.

Wang Hao. 1998. The water use efficiency and water saving potential in China, Plan on water conservancy, pp. 37-45.

Wang Weizhong. 1999. Analysis on the situation of water resources in China, analysis on the situations of sustainable development in China, the commercial publishing house.

Xu Zikai, Wang Jiansheng, and Yao Jianwen. 1998. Analysis on the features of water resources development and their changing trends in China, Plan on water conservancy, pp. 11-18.

Yu, C. and Yan J. 2002. Excel and data analysis. The publishing house of electronic industry, Beijing. P243-246.

Yuan Ruhua and Pang Jinwu. 1998. The quantitative analysis on the relationship between the water prices and their influencing factors, Review on Water Sciences, vol. 9. pp. 1-5.

Zhang Guoliang. 1999. The requirement and supply of water resources in China in the 21^{st} century, the publishing house of water conservancy and water-electricity.

Zhou, Y. and D.L.Skole. 2001. Cultivated Land Use Change Analysis and Modeling: a Case Study in the East Region of China. CGCEO/RA02-01/w. Michigan State University, East Lansing, Michigan.