Journal of Environmental Sciences Vol. 16, No. 1, pp. 120—125, 2004

ISSN 1001—0742
CN11 - 2629/X

Article ID: 1001-0742(2004)01-0120-06 **CLC number**: X144 **Document code**: A

A grey multi-objective programming approach for sustainable land-use in the Miyun Reservoir Basin, China

GUO Huai-cheng[1], ZHANG Zhen-xing[2], YU Yong[1]

(1. College of Environmental Sciences, Peking University, Beijing 100871, China. E-mail: hcguo@ces.pku.edu.cn; 2. College of Environmental Science and Forestry, State University of New York, 1 Forestry Drive, Syracuse NY13210, USA)

Abstract: Miyun Reservoir is the most important water source to Beijing City. Land-use of the basin plays a great role in the protection of water resources. Hence a sustainable land-use planning is required to optimize land-use structure and protect water resources in the basin. Based on the complete land-use system analysis in Miyun, a grey multi-objective programming to basin land-use(GMOPBLU) model was developed and applied to land-use planning. Two alternatives were produced and analyzed by means of interactive adjustment and scenario analysis. The results showed the GMOPBLU model is a valuable approach for basin land-use planning.

Keywords: system analysis; Miyun; optimization; model; land-use planning

Introduction

There are a lot of lakes and reservoirs in China. Most of them are facing two problems, too many sediments resulting from soil erosion and heavy water pollution from all kinds of pollutants. These two problems are closely correlated with land-use since it introduces soil erosion and non-point source pollution. Therefore, basin land-use planning is a pressing issue for these basins. Actually, recent years witnessed the increasing employment of basin land-use planning. Zou *et al*. (Zou, 1999) made a successful agricultural land-use planning for the Erhai Basin. Adinarayana *et al*. (Adinarayana, 1995) reported a method to land-use planning in a hilly watershed using geographical information systems. Wilson(Wilson, 1995) studied the relationship between land-use and water balance.

Land-use system is a complicated dynamic system and a grey system that has the general characteristics such as dynamic, multi-objective and information insufficiency(Wang, 1992). Grey multi-objective programming (GMOP) is a powerful approach to planning for this kind of system since it can handle multi-objective property with MOP method and deal with information insufficiency with grey number. Moreover, it employs dynamic prediction method to address the dynamic property. In fact, grey linear programming has been extensively used since Deng brought up the concept of Grey System in 1982. Deng(Deng, 1989) used it to do water resource prediction and planning. It was also employed in the countryside socio-economic development planning in China(Zhang, 1989). Deng(Deng, 1990) summarized the employment in all kinds of research fields.

Miyun Reservoir is the most important water source to Beijing City. Hence a sustainable land-use planning is very useful to manage water resource in the basin. In this study, a comprehensive method including System Analysis, GMOP and Scenario Analysis is applied to the land-use planning in the Miyun Reservoir basin in Miyun County. Based on land-use system analysis, the conceptual relationships of the basin were got, and then the GMOP to Basin Land-use (GMOPBLU) model was developed. The solutions of the model can be interpreted for generating decision alternatives and conducting further risk analyses(Wu, 1997). After solving the model, Scenario Analysis was utilized to interpret the numerical results, which was useful to select the optimal alternatives. An Interactive Adjustment method was proposed for obtaining the indispensable intervention from stakeholders and decision-makers during modeling and solving process.

1 System analysis

The Miyun County, with east Longitude 116°39′44″—117°30′25″, and north latitude 40°13′10″—40°48′, lies in the northeast part of Beijing City, the capital of China(Fig. 1). It covers an area of 2228.7 km^2. The total population is 4.26×10^5. The Miyun Reservoir, the biggest reservoir in North China and the most important water source to Beijing, is located in the central Miyun. The reservoir has an area of 224 km^2 and a storage volume of $43.75 \times 10^8 m^3$. From 1982, the reservoir has been providing water supply for the socio-economic development of Beijing. The land-use in Miyun has a serious impact on the water resource and water environment in the basin. Hence Miyun sustainable land-use planning is not only required and valuable for Miyun but also for Beijing City.

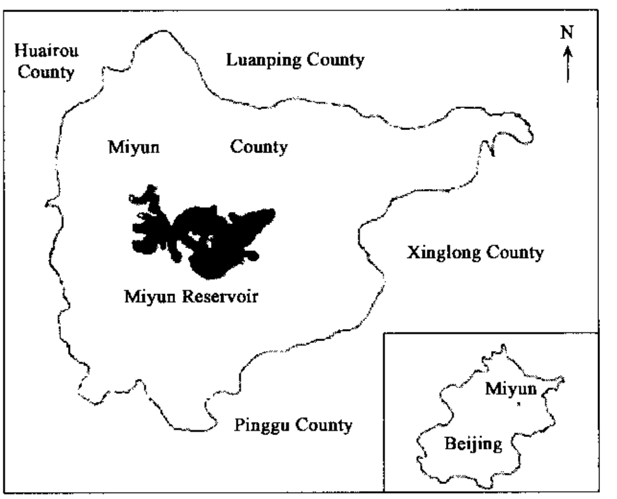

Fig. 1 The study area

To construct the mathematic model, complete analysis of system characteristics and relationships among subsystems and factors is required

Foundation item: The Beijing Science and Technology Committee(No. PK99-21)

(Guo, 1999; Zhang, 2001). Land-use system is a complicated system that is intertwined with economic, population, environment and resources. Therefore, the study system was divided into six subsystems: land-use, population, rural economic, urban economic, environment and resources subsystems based on the natural and economical features. Generally, the land-use system has many characteristics, such as multi-objectivity, dynamic and information insufficiency.

These characteristics result from the interrelationships and interactions among the system factors and subsystems.

1.1 Land-use subsystem

Land-use is the core of land-use system analysis and planning. The key issue in the analysis of land-use subsystem is to analyze land resource features and the problems of land-use. There are nine major types of land in Miyun, which are cultivated land, horticulture land, grassland, woodland, rural residential, urban residential, transport, water area and unused land. The special land is not concerned in the study since its area is small and almost never changed. Miyun is a hilly county so that the basic characteristics of land resource include: having a width of land types which are mostly located in banded regions, much land suitable for forestry and few fitful for agriculture, the low quality of cultivated land, and lack of reserve land. The cultivated land area has been decreasing for a long time period with the economic development and urban expanding. The horticulture fluctuated intensely in the past 20 years for lack of good planning and changing market. Woodland and transport are increasing steadily in the last 10 years.

1.2 Population subsystem

Total population includes non-agricultural population and agricultural population. For land-use planning, it is very important to analyze the tendency of population change and the relationships between population and land-use. 78.3% of the population resided in rural area but only 39.7% of the total labour force was engaging in agricultural activities in 1999. This indicated that the urbanization was left behind of industrialization. The population residing in rural area has been decreasing and the number living in mountains is lowered intensely. The number in urban residential has been increasing little by little. In general, the total population had been increasing slowly and the more people moved to urban residential. Hence more urban residential was needed and more job opportunities in urban were required.

1.3 Rural economic subsystem

Planting, livestock husbandry and forestry are principal components in this subsystem. Planting is the basics of rural economic and provides feedstuffs for livestock husbandry. However, the produce had a limit since the cultivated land was few. The water consumption of planting was so giant that planting impacted on water resources closely. Due to the low economic benefit, the importance of planting is declining. Livestock husbandry can provide a lot of meat and milk products for Miyun and Beijing City. Most of these products are marketable foods. Moreover, the ground of livestock husbandry was more dependable since more feedstuffs were produced by planting and forestry. Therefore, livestock is becoming the major industry in rural economic subsystem.

1.4 Urban economic subsystem

Urban economic subsystem, including industry and human service, is the major component of Miyun economy. Industry was the major pollution source, though it always brought huge economic benefits to the whole system. Especially, the water consumption and wastewater discharge by industrial activities usually threatened the water quality and quantity in Miyun. The industry production was developing well after recent adjustment of industry. Considering the special mission of protecting Miyun Reservoir, developing service, including tourism, was a good choice. In fact, the output of service was increasing fast.

1.5 Resource subsystem

To the development of Miyun County, the proper allocation and supply of natural resources are a key issue since the water resource is the bottleneck of it's development. Human being, industry, agriculture, livestock husbandry and forest, all of them depend on enough water resource. Therefore, the study focused on water resource in this subsystem. Solving the conflicts between water supply and demand are a crucial factor for allocating land and economic development. The total available water resource amount has been decreasing in recent years because of climate change. The actual water consumption had been also reduced due to the lack of water supply, economic structure adjustment and using new technology.

1.6 Environment subsystem

Because Miyun Reservoir is the key water resource to Beijing City, protecting water environment and water resource are a major task for Miyun land-use planning. Soil loss, nitrogen loss and phosphorous loss are the key problems for the reservoir. All of these three problems were very pressing in 1980's but became less serious. The wastewater is also a focus problem for protecting the water environment. The wastewater generated from human living and industry production is enlarged. It must be under the wastewater treatment capacity to meet the requirement by Beijing City.

2 Model description

According to the land-use system analysis and the strengths of GMOP, GMOP method was considered to be a good choice for sustainable land-use planning in Miyun. To solve this problem, a GMOPBLU model was developed according to the characteristics of land-use system.

2.1 General GMOP model

A general GMOP problem may be formulated as follows:

$$\max(\min) f_k(x) = \otimes(C_k)X^T,\ k = 1,2,\cdots,u,$$

$$s.t.\quad \otimes(A)X \leqslant \otimes(B);\ X \geqslant 0.$$

Where X is the decision variable vector; $\otimes$ indicates the coefficient is grey;

$$\otimes(A) = \begin{bmatrix} \otimes(a_{11})\Lambda & \otimes(a_{1n}) \\ \Lambda & \\ \otimes(a_{m1})\Lambda & \otimes(a_{mn}) \end{bmatrix};$$

$$\otimes \quad \otimes(B) = [\otimes(b_1), \otimes(b_2), \Lambda, \otimes(b_n)]\ \otimes(C_k) = [\otimes(c_{1k}), \otimes(c_{2k}), \Lambda, \otimes(c_{nk})].$$

The major characteristic of GMOP is the introduction of grey system theory, which considers system information is insufficient and the process is dynamic. GMOP indicates the grey degree with the grey interval number. Hence GMOP can handle information insufficiency effectively with grey numbers and addresses multi-objectivity through MOP method. The generic algorithm to grey linear programming is to get a series of deterministic linear programming by transforming the grey coefficients to the deterministic. Then, a series of deterministic MOP are produced when solving a GMOP model. In this study, off-target tolerance level method(Zou, 1997; 1998; 2000) was utilized to solve the resulting MOP sub-models.

2.2 GMOP to basin land-use(GMOPBLU) model

Based on the system analysis and GMOP method, 9 major land-use types were considered in the model and the total planning period includes 2 terms. All coefficients were grey but the symbol was discarded for convenience. The GMOPBLU model was developed as follows:

2.2.1 Objective functions

Economic benefit maximization (economic objective)

$$\max F_1 = \sum_{i=1}^{9}(B_i \times x_i);$$

Soil loss minimization (environment objective)

$$\min F_2 = \sum_{i=1}^{9}(SL_i \times x_i);$$

Forest area maximization (ecology objective)

$$\max F_3 = x_2 + x_3.$$

2.2.2 Constraints

(1) Total available land $\sum_{i=1}^{9} x_i = TL$; (2) Maximal land area suitable to planting $x_1 \leqslant LSCP$; (3) Unusable land $x_9 \geqslant UL$; (4) Constraints from other social-eco planning: minimal agriculture land-use $\sum_{i=1}^{4} x_i \geqslant MAL$; minimal cultivated land(from basic cropland protection policy) $x_1 \geqslant MCL$; minimal woodland $x_4 \geqslant TL \times t/t'$; maximal urban residential land $x_6 \leqslant MURL$; maximal transport land-use $x_7 \leqslant MTL$; ratio of agriculture land-use $x_1 : x_2 : x_3 : x_4 = A_1 : A_2 : A_3 : A_4$; minimal grain production $s_1 \times x_1 + SI - SO \geqslant S$; (5) Constraints from the present land-use: present urban residential land-use $x_6 \geqslant CURL$; present transport land-use $x_7 \geqslant CTL$; (6) Total population $P_1 \times \sum_{i=1}^{5} x_i + P_2 \times x_6 \leqslant T_p$; (7) Resources constraints: labor force involved in agriculture $L_{1i} \times \sum_{i=1}^{9} x_i \leqslant L_a$; labor force involved in non-agriculture $L_{2i} \times \sum_{i=5}^{9} x_i \leqslant L_c$; water resource $\sum_{i=1}^{9}(b_i \times x_i) \leqslant W$; (8) Environment constraints: maximal allowable soil loss $\sum_{i=1}^{9}(SL_i \times x_i) \leqslant MASL$; maximal allowable nitrogen loss $\sum_{i=1}^{9}(NL_i \times x_i) \leqslant MANL$; maximal allowable phosphorous loss $\sum_{i=1}^{9}(PL_i \times x_i) \leqslant MAPL$; maximal allowable wastewater discharge $\sum_{i=1}^{9}(WW_i \times x_i) \leqslant MAWW$; (9) Technique constraints $x_i \geqslant 0$: where x_1 = cultivated land(hm^2); x_2 = horticulture land(hm^2); x_3 = grassland(hm^2); x_4 = woodland(hm^2); x_5 = rural residential (hm^2); x_6 = urban residential (hm^2); x_7 = transport(hm^2); x_8 = water area(hm^2); x_9 = unused land(hm^2); B_i = GDP per year in unit area of land-use type i (RMB Yuan/hm^2); SL_i = soil loss per year in unit area of land-use type i (kg/hm^2); TL = total land area (hm^2); $LSCP$ = maximal land area suitable planting(hm^2); UL = unusable land(hm^2); MAL = minimal agriculture land-use from social-eco development planning(hm^2); MCL = minimal cultivated land from basic cropland protection policy(hm^2); t = woodland coverage percentage(%); t' = transformation coefficient; $MURL$ = maximal urban residential land-use(hm^2); MTL = maximal transport land-use (hm^2); A_1, A_2, A_3 and A_4 = proportion of agriculture land-use structure; s_1 = grain production in unit area(t/hm^2); SI = grain import (t); SO = grain export(t); S = grain demands(t); $CURL$ = present urban residential land-use (hm^2); CTL = present transport land-use (hm^2); P_1 = predicted population density in countryside(person/hm^2); P_2 = predicted population density in urban (person/hm^2); T_p = predicted total population (10^3 person); L_{1i} = labor force use in unit area of agricultural land-use type i(person/hm^2); L_{2i} = labor force use in unit area of non-agricultural land-use type i(person/hm^2); L_a = available labor force for agriculture(10^3 person); L_c = available labor force for non-agriculture (10^3 person); b_i = water demand in unit area of agricultural land-use type i (m^3/hm^2); W = total water resource supply(m^3); $MASL$ = maximal allowable soil loss (t); NL_i = nitrogen loss per year in unit area of land-use type i (kg/hm^2); $MANL$ = maximal allowable nitrogen loss (t); PL_i = phosphorous loss per year in unit area of land-use type i (kg/hm^2); $MAPL$ = maximal allowable phosphorous loss(t); WW_i = wastewater discharge per year in unit area of land-use type i (kg/hm^2); $MAWW$ = maximal allowable wastewater discharge (t).

3 Results and scenario analysis

In order to insure the practicability and operability of the planning alternatives, scenario analysis method was incorporated into GMOP interactive solving process(Zou, 1997; Zhang, 2002). The preferences of stakeholders and decision-makers were obtained by questionnaire and face-to-face discussions. Scenario I was produced based on the sustainable land-use and social-eco development, which paid more attention on the resource and environment constraints and objectives. On the other hand, some stakeholders and decision-makers indicated their strength preference to economic objective. Thus, Scenario II was created by relaxing resource and environment constraints. The preferences were reflected in the grey coefficients. Scenario I used the lower bound of grey coefficients and the other employed the upper bound. Therefore, the results(alternatives) were different in the two scenarios. After scenario analysis, the more practical and valuable alternative was suggested for decision-making. The model was resolved during two terms(1998—2010 and 2010—2015).

3.1 Land-use structure optimization

Land-use structure optimization is the key task of land-use planning. Hence the land-use structure in two scenarios were completely discussed and analyzed. According to the present situation and developing trend, nine major land-use types were considered in this study.

3.1.1 Cultivated land

In Scenario I, the area and percentage of cultivated land were reduced slowly (Table 1). Some cultivated land was transformed into urban residential land and transport land, and some was returned to woodland to protect the ecology system balance. Even the cultivated land area was decreased the grain production requirement and basic cropland protection policy were still met without improving the unit output of cultivated by using fertilizer. In Scenario II, the area and percentage of cultivated land area were pulled downed quickly (Table 1). This was because the upper bound coefficients of grain production constraints were used to emphasize the economic objective. Thus much high quality cultivated land would be occupied and fertilizers would be overused, which was a serious threat to the sustainable land-use and water resource protection.

Table 1 Land use structure in two scenarios (hm^2)

	1999		2010				2015			
			Scenario Ⅰ		Scenairo Ⅱ		Scenario Ⅰ		Scenairo Ⅱ	
	Area	%	Area	%	Area	%	Area	%	Area	%
Cultivated	23532	10.56	22308	10.01	20000	8.97	21482	9.64	20000	8.97
Horticulture	11114	4.99	12046	5.40	18053	8.10	12545	5.63	17504	7.85
Woodland	107182	48.09	129749	58.22	129214	57.98	134055	60.15	130351	58.49
Grassland	836	0.38	892	0.40	800	0.36	859	0.39	800	0.36
Rural residential	6260	2.81	5577	2.50	6226	2.79	5370	2.41	5881	2.64
Urban residential	4350	1.95	4786	2.15	5600	2.51	5230	2.35	6200	2.78
Transport	1278	0.57	1540	0.69	1800	0.81	1720	0.77	1860	0.83
Water	23009	10.32	23912	10.73	23912	10.73	23009	10.32	23009	10.32
Unused land	45309	20.33	22060	9.90	17265	7.75	18600	8.35	17265	7.75
Total	222870	100.00	222870	100.00	222870	100.00	222870	100.00	222870	100.00

3.1.2 Horticulture

The horticulture land area in Miyun fluctuated intensively because of the conflicts between always changing markets and long production periods. Therefore, a good planning was very important else the production adjustment always left behind the market changes. The horticulture area increased a little in Scenario I (Table 1). The horticulture had good environmental and economic benefits and it also would be located in all kinds of soils without any special requirements. In the meantime, there was a great tradition of horticulture and a lot of big orchards in Miyun. The emphasis later should be in the in-depth processing of fruits while increasing the planting area and improving the quality. In Scenario II, the area jumped up at the first term and them went down a little in the second planning term(Table 1). As indicated in horticulture history, the fluctuation was not a good choice and would break the balance of land-use system.

3.1.3 Woodland

In Scenario I, the woodland area increased fast in both planning terms(Table 1). This partly resulted from that some cultivated land was returned to woodland and partly from that many used land would be wooded. The rising woodland would provide more sound ground for environmental protection and water resource protection. On the other hand, it also benefited the forestry production and livestock breeding by providing more raw material and foodstuff. In Scenario Ⅱ, the woodland area was enlarged quickly also but the rate slowed down in the second planning term (Table 1). This was because the economic benefit of woodland was a little lower compared with other land-use types. Since the economic objective is the No.1 preference, the woodland was traded off during the model solving. Basically, the woodland area in Scenario Ⅱ was less than that in Scenario I. Less woodland would threaten the ecology system balance and produce more soil loss, nitrogen loss and phosphorous loss which finally would impact water resource in Miyun Reservoir.

3.1.4 Grassland

Miyun is the major county of livestock breeding. Livestock breeding has been becoming the major industry in countryside. However the livestock is no longer depending primarily on the grassland but on the foodstuff provided by agriculture and forestry activities. Hence the grassland area decreased in the last 10 years. Anyway there are still some riversides suitable for grass. Therefore, the grassland area showed a little difference in both scenarios, steady in Scenario I and slowly downward in Scenario Ⅱ (Table 1). From the land-use system analysis in Miyun, the grassland would be located along the rivers. The percentage of grassland was very low in history and both scenarios. It was not the major factor to livestock breeding also. Hence, grassland would be not very important for Miyun.

3.1.5 Rural residential

In Scenario I, rural residential land area decreased gradually(Table 1). Several factors, including small towns developments, Miyun satellite city expansion and the moving people from the mountains around the reservoir, contributed to this decreasing. The deduction was very valuable for water resource protection of Miyun Reservoir since less people would live in the hills and mountains around the reservoir. The rural residential land area did not change much in Scenario II(Table 1). It is because of bigger population and lack of control of construction.

3.1.6 Urban residential

In this study, the urban residential indicated the combination of urban residential itself and mining area. Due to the rapid expansion of Miyun satellite city, Wongxitun, Taishitun, Gubeikuo, Xitiangezhuang and Henanzai etc., the urban residential land area increased in both scenarios. The mining area was limited because of the policy of controlling mining in Miyun. Hence the mining area had little impact on the total urban residential land changes. The urban residential land area extended fast in Scenario Ⅰ (Table 1). This not only resulted from, but also resulted in the socio-eco development and urbanization in Miyun. Of course, the urbanization usually utilizes the high quality and relatively flat cultivated land which is also close to cities and towns, the major markets of the produce. Therefore, the cultivated land needs more attention. In Scenario Ⅱ, there were more population and more attention on economic objective so that the urban residential land area enlarged more quickly than Scenario Ⅰ (Table 1). This would threaten the stability of agriculture since many cultivated land would be taken.

3.1.7 Transport

The transport land increased quickly in both scenarios, especially in the first term of Scenario Ⅱ (Table 1). In the future 15 years, the transport network would be developed by expanding the highways, national routes, and city routes which connected the Miyun satellite city and other towns. Since there are a lot of hills and mountains in Miyun, transport development is very important to the communication and transportation between Miyun and outsides. On the other hand, some high quality cultivated land would be transformed into transport land, and this also would impact on the habitats of wild life.

3.1.8 Water

There are a big reservoir (Miyun Reservoir), 3 median reservoirs, and more than 20 small reservoirs in Miyun. The water area is big and stabilizes in about 2.3×10^4 hm^2 (Table 1). The stability of water area in Miyun is very important for Beijing City since it is the major water source for the city. Hence it is also the key factor which must be incorporated into the sustainable land-use planning since the sustainable land-use cannot be obtained without the sustainability of Beijing. So the constraints come from the upper system and policy.

3.1.9 Unused

A lot of the unused land area were decreased in both alternatives, especially in Scenario Ⅱ (Table 1). This was because many unused lands would be wooded and the small watershed conservations would also decrease the unused land. It was very valuable for the water resource protection and sustainable land-use. At the same time, many funds would be required for this transformation.

3.2 Economic benefit analysis

The economy developed quickly in Scenario Ⅰ, and the rate is about 11.4% in the first term and 7.9% in the second term. In the total planning period, the major GDP came from urban area. The urban residential land and transport land enlargements provided a solid ground for the economic development in urban area. The horticulture expansion and basic cropland protection were the basis for the rural economy. The horticulture, woodland and water area resulted in the balanced eco-system and sustainable environment. Hence the sustainable land-use and development would be achieved finally, which was the objective and start point of sustainable land-use planning.

Table 2 GDP of Miyun in both alternatives (billion RMB Yuan)

	2010		2015	
	Scenario Ⅰ	Scenario Ⅱ	Scenario Ⅰ	Scenario Ⅱ
GDP	10.1	11.5	14.8	17.0
Rural	2.5	2.6	3.1	3.2
Urban	7.6	8.9	11.7	13.8

In Scenario Ⅱ, the economy even increased faster (Table 2). Besides more economic benefits, the price was also higher than that in Scenario Ⅰ. The major difference between the alternatives was the urban economy. Then many high quality cultivated land would be transformed into urban areas and transport lands, which were presented the previous sections.

3.3 Population

Although population is not the major part of land-use planning, it has a great impact on land-use adjustment and socio-eco development. Therefore, the population was presented to analyze and compare the alternatives. In Scenario Ⅰ, the prediction population will be 49.6×10^4 in 2010, which includes 8.7×10^4 of the labor force involved in agriculture activities and 13.6×10^4 in non-agriculture activities; the corresponding numbers in 2015 will be 54.2×10^4, 9.0×10^4 and 16.7×10^4 respectively. The land-use structure in Scenario Ⅰ can meet the remands of this population and the labor force is enough for the socio-eco development.

In Scenario Ⅱ, the prediction population in Miyun in 2010 will be 51.3×10^4, which includes 9.2×10^4 of the labor force involved in agriculture activities and 13.7×10^4 in non-agriculture activities; the corresponding numbers in 2015 will be 55.5×10^4, 9.5×10^4 and 17.4×10^4 respectively. There are more population and labor force in this alternative.

3.4 Environment

Due to the quick expansion of woodland and horticulture, the plant coverage in Miyun moved upward fast in Scenario Ⅰ. This would provide a sound ecosystem and environment for the socio-eco development and beautiful habitats for human being and wild life. The water demand was also under water supply. From the model solving process, the water resource was a key constraint to the sustainable land-use planning. The wastewater discharge was also in the wastewater treatment capacity. The soil loss, nitrogen loss and phosphorous loss decreased in the future which would provide a good basis for the water resource protection.

In the second alternative, the plant coverage also increased quickly (Table 3). Due to more population and quickly developing industry and agriculture, the water demand in Miyun would be greater than that in Scenario Ⅰ. This could threaten the total system stability since it was difficult to supply so much water. The wastewater discharge approaches to the treatment capacity, which was also a problem to water resource protection. The soil loss, nitrogen loss and phosphorous loss would decrease more quickly than that in the first alternative. However, this was due to the more loss of cultivated land.

Table 3 Planning value of environment system

	2010		2015	
	Scenario Ⅰ	Scenario Ⅱ	Scenario Ⅰ	Scenario Ⅱ
Plant coverage, %	63.6	66.1	65.8	66.3
Water usage, $10^6 m^3$	160	160	206	206
Wastewater, $10^3 t$	15460	18090	19510	23130
Soil loss, $10^3 t$	530	440	450	390
Nitrogen loss, t	719	667	406	383
Phosphorous loss, t	89	82	76	71

3.5 Comprehensive analysis

A better alternative was selected by comprehensive analysis based on the detailed scenario analysis. From the perspective of land-use, the land-use structure in Scenario Ⅰ was more stable than that in Scenario Ⅱ. At the same time, the cultivated land area was higher in the first alternative. Hence less fertilizer would be needed which was a great benefit for water resource protection. Also it was a policy of Miyun to use less fertilizer. Generally, the first alternative was more sustainable for land-use. In terms of economic benefit, the GDP in Scenario Ⅱ was a little more than that in Scenario Ⅰ. However, this would introduce less cultivated land, more population, more urban residential demands and more funds requirements. Therefore, it was difficult to get enough funds, so many job opportunities and enough grain production. So the Scenario Ⅰ was more feasible. From the view of environmental protection, both scenarios had no big differences. The soil loss, nitrogen loss, phosphorous loss, and wastewater discharge were all under controlled. When analyzing by water resources, the water demand under Scenario Ⅰ was lower than the Scenario Ⅱ, and the problem of excessive exploitation of ground water does not exist. The proper allocation of water resources under Scenario Ⅰ would be more suitable and applicable. The too much water demand in Scenario Ⅱ would make the economic objective difficult to reach and the system unstable.

In general, the first scenario was more reasonable economically, from sustainable land-use view and water resource allocation. Hence Scenario Ⅰ was preferred based on the complete scenario analysis.

4 Conclusions

The land-use system characteristics were analyzed by means of system analysis method. Then, a GMOPBLU model was developed and successfully applied to the sustainable land-use planning in Miyun County. When modeling and solving, the interactive adjustment method was adopted. While interpreting the results, the scenario analysis method was employed to compare the alternatives. All these methods make the system characteristics, multi-objectivity, dynamic and information insufficiency, embodied in the land-use planning. This study showed the GMOPBLU was a powerful approach for sustainable basin land-use planning which incorporated the economic system and environment system. The optimum alternative gave a ground for policy-making of land-use adjustment.

References:

Adinarayana J, Krishna N R, 1995. An approach to land-use planning in a hilly watershed using geographical information systems[J]. Land Degradation and Rehabilitation, 6(3): 171—178.

Deng J, 1990. The grey system theory[M]. Wuhan: Central China University of Science and Technology Press.

Deng Q, Zhou Q, Wang B, 1989. Grey system prediction and decision to water resources[M]. Beijing: Survey and Map Press.

Guo H, Chen B, Huang G, 1999. Characteristic analysis of environmental system in Lake Erhai Basin[J]. Biosystem Studies, 2(1): 23—34.

Wang X, 1992. The introduction to grey system theory[M]. Chengdu: Chengdu University of Science and Technology.

Wilson K B, 1995. Water used to be scattered in the landscape: local understandings of soil erosion and land use planning in southern Zimbabwe [J]. Environment and History, 1(3): 281—296.

Wu S M, Huang G H, Guo H, 1997. An interactive inexact-fuzzy approach for multi-objective planning for water resource system[J]. Water Science & Technology, 36(5): 235—242.

Zhang Q, Wang X, Nie H, 1989. Grey system theory, method and application to rural economic[M]. Beijing: Academic Press.

Zhang Z, Guo H, Chen B *et al.*, 2001. An inexact multi-objective economic environmental planning model for Hemoluo Region, Xinjiang[J]. Journal of Basic Science and Engineering, 9(1): 33—42.

Zhang Z, Guo H, Chen B *et al.*, 2002. Economic-environmental system planning for arid regions in China[J]. Acta Ecologica Sinica, 22(7): 1018—1027.

Zou R, Guo H, Liu L, 1997. Preliminary study on human-machine interactive environmental system planning method under uncertainty for economic zone [J]. China Environmental Science, 17(5): 397—403.

Zou R, Guo H, Liu L, 1998. A multiobjective interactive decision approach based on off-target tolerance level[J]. Journal of System Engineering, 13(3): 41—47.

Zou R, Guo H, 1999. An inexact system planning for agriculture land-use and woodland to harmonize environment and economy [J]. Acta Scientiae Circumstantiae, 19(2): 186—193.

Zou R, Guo H, Chen B, 2000. A multiobjective approach for integrated environmental economic planning under uncertainty[J]. Civil Engineering and Environmental Systems, 17(4): 267—291.

(Received for review September 6, 2002. Accepted December 1, 2002)