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A SYSTEM DYNAMICS APPROACH FOR SUSTAINABLE DEVELOPMENT IN THE MIYUN RESERVOIR AREA, CHINA

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ABSTRACT: Miyun Reservoir was designated as the water source of Beijing City in 1982. Since that time, socio-economic development in Miyun Area has been slowing due to the restriction of severe environmental standards. More and more attention from the public and government has been paid to the regional sustainable development. And an effective planning for the local society management system is urgently desired. In this study, a regional sustainable development system dynamics model, named MiyunSD, is developed for supporting this planning task. MiyunSD consists of dynamic simulation models that explicitly consider information feedback that governs interactions in the system. Such models are capable of simulating the system's behavior and predicting its developing situation of the future. For the study case, interactions among a number of system components within a time frame of fifteen years are examined dynamically. Three planning alternatives are carefully considered. The base run is based on an assumption that the existing pattern of human activities will prevail in the entire planning horizon, and the other alternatives are based on previous and present planning studies. The different alternatives will get different system's environmental and socio-economic results. Through analyzing these dynamic results, local authorities may find an optimal way to realize the objectives that the regional environment will be well protected and at the same time the economy will be rapidly developed.
KEY WORDS: Miyun reservoir; sustainable development; model; policy; management; system dynamics

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1 INTRODUCTION

With the rapid socio-economic development, water resource is becoming the critical concern facing both the governments and the public in China. Under the requirement of regional sustainable development, the authorities have been undertaking the enhanced stresses for effectively responding to the concern. Generally, effective economic and environmental management regulations and policies are very helpful for dealing with this dilemma. Meanwhile, in order to give these regulations and policies, the authorities were acquired a sound understanding to the local social system and its internal components affecting sustainable development. These components are very complicated including economic, resource and environmental system components changing over time. To express the complexity and dynamic state, system dynamics (SD) was considered to be an appropriate approach. It can predict the consequences of different policies and regulations through simulating the behaviors of the complicated social system (GILL *et al.*, 1996). With the analysis of different consequences, the authorities could also choose a set of optimal policies to solve the existing issues.

The SD is one method that is used to study the behaviors of complicated systems (WANG, 1994). The SD model comprises several dynamic simulation subsystems, which are capable of incorporating individual system components within a general framework. The method could comprehensively analyze information feedbacks between the components and is beneficial to find a good way to treat with the problems in a system with simulation models. Since Forrester founded SD in 1961(FORRESTER, 1961), many scientists had started the study of this method. It has been widely applied to a number of socio-economic system plannings and some researches focused on environment(FRANCISCO *et al.*, 1993; NAILL *et al.*, 1992; GUO *et al.*, 2001; FANG

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and YU,1999).

In this study, MiyunSD is developed for regional sustainable planning in Miyun Reservoir Area. It is very useful for recommending policy decisions in socio-economic and environmental management.

2 STUDY AREA

Miyun Reservoir Area is located at 40°13′–40°48′N and 116°39′–117°30′E in the northeast part of Beijing City. It starts from Chengde County and Xinglong County, Hebei Province in the east, reaches Huairou County in the west, connects Pinggu County and Shunyi County and borders Luanping County, Hebei Province, covering an area of 2223.6km^2. Miyun Reservoir stands in the center of Miyun Area with an area of 224km^2 and a storage volume of 4.375 billion m^3 (Fig.1).

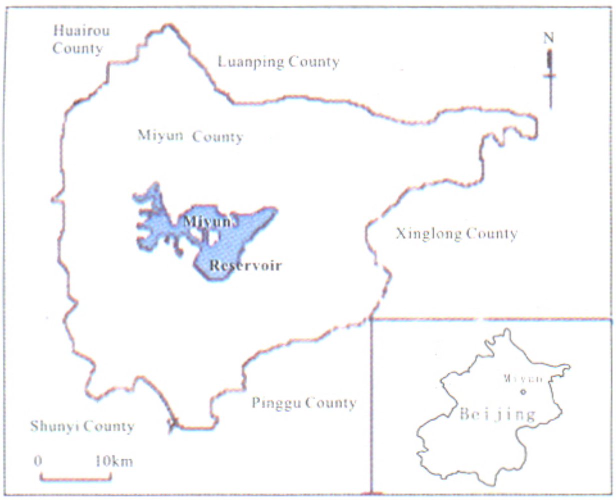

Fig. 1 The study area

In the area, there are fourteen rivers, three medium and seventy-three small reservoirs besides Miyun Reservoir. With the groundwater supply, the total water supply amounts to 1.012 billion m^3. Because of consecutive drought, the quantity, especially that of Miyun Reservoir, had been decreasing rapidly. By 2000, Miyun Reservoir had only a storage volume of about 1.7×10^{9}m^3, which means serious shortage of water re-source would take place both in Beijing City and in Miyun Area. In the meantime, owing to the rapid eco-nomic development and population growth in Miyun Area, water requirement was still growing in. In this way, research on how to adjust the structure of production and distribute water resource reasonably has aroused the local authorities′ attentions (QU et al., 2002). This study is a part of the research focused on above concerns.

3 MIYUNSD MODEL

The MiyunSD is such a model that gives complicated interactions among a good many system components and formulates modeling equations by a PD (Professional Dynamo)-compatible language. At the same time,an elaborate flow diagram linking each subsystem is very necessary to understand the MiyunSD thoroughly.

Fig.2 shows the flow diagram for Miyun social system. This model consists of five subsystems whose names are described as follows.

3. 1 Population Subsystem

The total population (TP) in Miyun Area could be divided into two groups called resident population and floating population respectively. In the two groups, resident population is the sum of agriculture population (AP) and non-agriculture populations (NAP). Both of them are considered as auxiliary variables, which vary with the birth rate (BR), the death rate (DR) and net immigrants from external system per year (NIP) or net emigrants from Miyun social system per year (NEP). The birth rate almost keeps steady because of the exe-cution of local birth control policies. And the death rate is decreasing with the improvement of living standard. The immigration has also a tendency of rising due to the favorable turn of economic situation. Moreover, the variation of floating population is related to the local e-conomic situation and the policy of population manage-ment.

It is noticeable that resource factor (RF), pollution factor (PF),economic factor (EF) and social factor (SF) all play a significant role in calculating the birth popu-lation, death population and immigration population—three rate variables.On the grounds of above classifica-tion, the following main SD equations for TP, AP and NAP might be built.

TP: L, TP. K=TP. J+DT * (B.JK +MB. JK–D. JK)
R, B. KL=TP. K * BR * RF
R, D. KL=TP. K * DR * PO
R,MB.KL=CMBN * TP. K * EF * POLIC
NAP: A, NAP. K=TP. K * UPTR.K/100
AP: A, AP. K=TP. K–NAP. K

where "*" is the multiply sign; "+" is the plus sign; "–" is the subtraction sign; "." is the extension sign. The explanation of all signs appear in the below formulae is as same as that of above sentence.

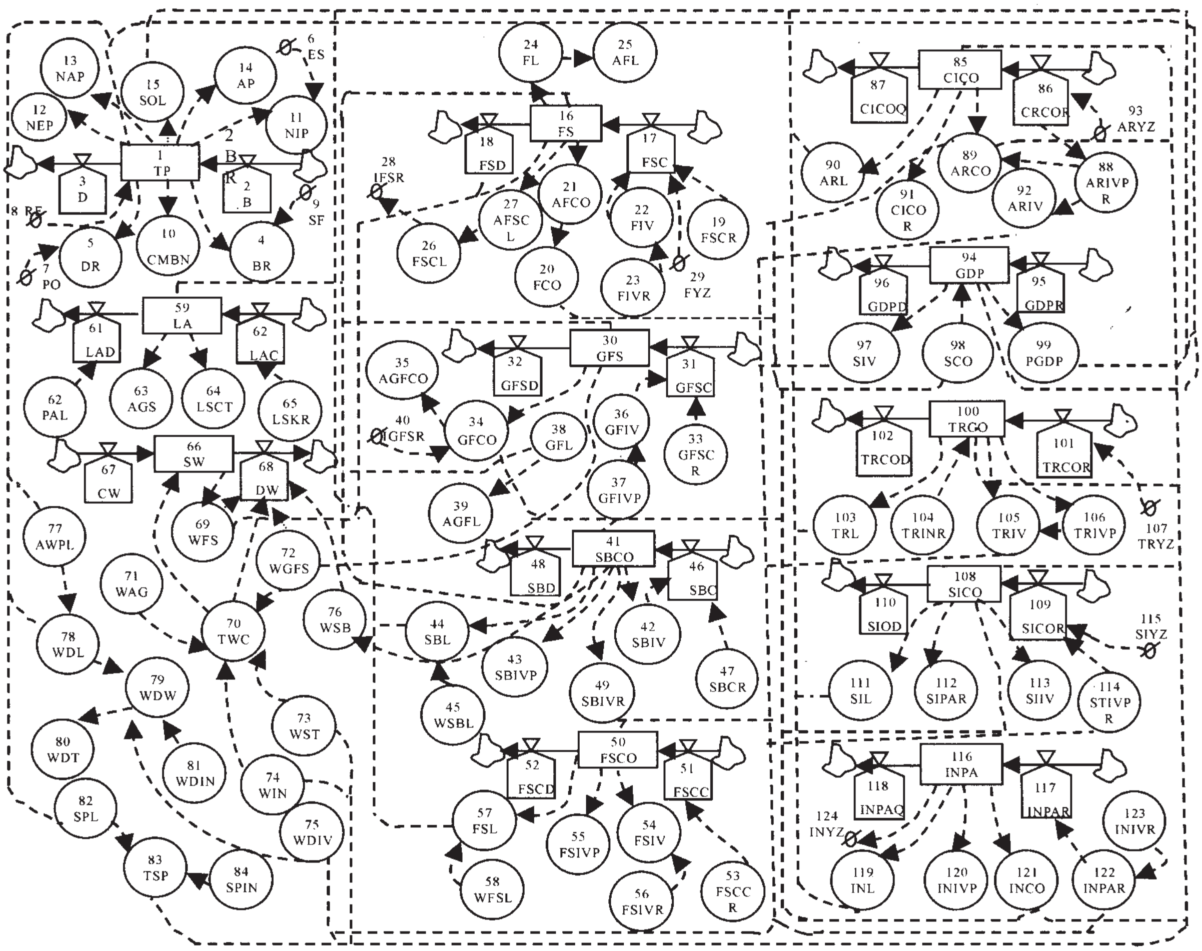

Fig. 2 Flow diagram for Miyun social system

1. Total population; 2. Birth population; 3. Death population; 4. Birth rate of total population; 5. Death rate of total population; 6. Influence coefficient of economic development; 7. Influence coefficient of pollution; 8. Influence coefficient of resource situation; 9. Influence coefficient of policy making; 10. Temporary stay population from external system per year; 11. Net immigrants from external system per year; 12. Net emigrants from Miyun social system per year; 13. Non-agriculture population; 14. Agriculture population; 15. Amount of social labor force; 16. Arable land area of cereal crops; 17. Increased arable land area of cereal crops per year; 18. Decreased arable land area of cereal crops per year; 19. Increased rate of the arable land area of cereal crops; 20. Total output value of cereal crops; 21. Advantage output value of cereal crops per unit area; 22. Total investment for cereal crops production; 23. Investment proportion to cereal crops production; 24. Amount of labor force occupying in cereal crops production; 25. Amount of labor force occupying in cereal crops production per unit area; 26. Total yield of cereal crops; 27. Advantage yield of cereal crops per unit area; 28. Irrigative constant to cereal crops land; 29. Generalized index to the advancement of agricultural science and technology; 30. Arable land area of industrial crops; 31. Increased arable land area of industrial crops per year; 32. Decreased arable land area of industrial crops per year; 33. Increased rate of the arable land area of industrial crops; 34. Total output value of crop cultivation; 35. Advantage output value of crop cultivation per unit area; 36. Total investment for crop cultivation; 37. Investment proportion to crop cultivation; 38. Amount of labor force occupying in crop cultivation; 39. Amount of labor force occupying in crop cultivation per acre; 40. Irrigative constant to the arable land; 41. Total output of stock raising; 42. Total investment for stock raising; 43. Proportion of total investment to total output for stock raising; 44. Amount of labor force occupying in stock raising; 45. Amount of labor force required to attain 10 000 yuan RMB output value of stock raising; 46. Increased output value of stock raising per year; 47. Increased date of output value of stock raising; 48. Decreased output value of stock raising per year; 49. Investment proportion to stock raising; 50. Total output value of fishery industry; 51. Increased output value of fishery industry per year; 52. Decreased output value of fishery industry per year; 53. Increased date of output value of fishery industry; 54. Total investment for fishery industry; 55. Proportion of total investment to total output for fishery industry; 56. Investment proportion to fishery industry; 57. Amount of labor force occupying in fishery industry; 58. Amount of labor force required to attain 10 000 yuan RMB output value of fishery industry; 59. Arable land area; 60. Increased arable land area; 61. Decreased arable land area; 62. Arable land area per capita; 63. Land area for agriculture occupation; 64. Land area for industry occupation; 65. Assarted rate for wild land; 66. Total water demand; 67. Increased water demand; 68. Decreased water demand; 69. Water consumption for cereal crops irrigation; 70. Total water consumption; 71. Water

consumption for agriculture; 72. Water consumption for industrial crops irrigation; 73. Water consumption for service industry; 74. Water consumption for industry; 75. Total investment for wastewater treatment; 76. Water consumption for stock raising; 77. Discharge amount of domestic sewage per capita; 78. Discharge amount of domestic sewage; 79. Total primary wastewater discharge; 80. Proportion of wastewater treatment capacity to total wastewater discharge; 81. Wastewater discharge generated by industry; 82. Amount of household refuse; 83. Total solid waste generation; 84. Solid waste generation amount by industry; 85. Net fixed assets of construction industry; 86. Increased fixed assets of construction industry per year; 87. Depriciated fixed assets of construction industry per year; 88. Investement proportion to fixed assets of construction industry; 89. Total output value of construction industry; 90. Amount of labor force occupying in construciton industry; 91. Increased fixed assets of construction industry; 92. Total investment for construction industry; 93. Generalized index to the advancement of science and techology in construction industry; 94. Gross domestic product; 95. Increased gross domestic product per year; 96. Decreased gross domestic product per year; 97. Total social investment; 98. Total output value of society; 99. Gross domestic product per capita; 100. Total output value of transportation industry; 101. Increased output value of transportation industry per year; 102. Decreased output value of transportation industry; 103. Amount of labor force occupying in transportation industry; 104. Proportion of total investment to total output for transportation industry; 105. Total investment for transportion industry; 106. Investment proportion to transportation industry; 107. Generalized index to the advancement of science and techology in transportation industry; 108. Total output value of service industry; 109. Increased output value of service industry per year; 110. Decreased output value of service industry per year; 111. Amount of labor force occupying in service industry; 112. Economic incoming of service industry; 113. Total investment for service industry; 114. Investment proportion to service industy; 115. Generalized index to the advancement of science and techology in service industry; 116. Net industrial fixed assets; 117. Increased industrial fixed assets per year; 118. Depreciated industrial fixed assets per year; 119. Amount of labor force occupying in industry; 120. Proportion of industrial investment to industrial output; 121. Total industrial output value; 122. Total industrial investment; 123. Investment proportion to industry; 124. Generalized index to the advancement of industrial science and technology.

3. 2 Agriculture Subsystem

By virtue of the need of research, the subsystem can be made up of four modules, which are cereal crops, industrial crops, stock raising and fishery industry. Hence the arable land area of the two former and total output values of the two latter are decided as four level variables. Among these modules, agriculture investment, irrigation water, total agricultural output value, cultivated area and agricultural labor force are chosen as auxiliary variables. They are the keys connecting this subsystem with others. The correlative equations are listed as follows:

L, FS. K = FS. J + DT * (-FSC. JK)
A, FL. K = FS. K * AFL. K
A, FSCL. K = FS. K * AFSCL
L, GFS. K = GFS. J + DT * GFSC. JK
A, GFCO. K = GFS. K * AGFCO. K
A, GFL. K = GFS. K * AGFL
A, GFIV. K = GFCO. K * GFIVP. K
L, SBCO. K = SBCO. J + DT * SBC. JK
A, SBIV. K = SBCO. K * SBIVP. K
A, SBL. K = SBCO. k * WSBL. K
L, FSCO. K = FSCO. J + DT * FSCRR. JK
A, FSIV. K = FSCO. K * FSIVR. K
A, FSL. K = FSCO. K * WFSL. K

The area of cereal crops has an obvious descendent tendency, to the contrary that of industrial crops ascends continually. Accordingly a negative sign is specially put ahead of increasing area of cereal crops (FSC) to denote its descendent character.

3. 3 Industry Subsystem

The main industrial sectors in the study system include construction industry, transportation industry, service industry and other industries. Among the rest, the last item includes all industries except its former three items such as mining industry and metallurgy industry, etc. The following quantities are considered as level variables: 1) total output value of transportation industry (TRCO); 2) total output value of construction industry (ARPA); 3) total output value of service industry (STCO); 4) net industrial fixed assets (INPA). The relevant SD modeling equations are presented:

L TRCO. K = TRCO. J + DT * TRCOR. JK
R, TRCOR. KL = TRCO. K * TRCORR
A, TRIV. K = TRCO. K * TRIVP. K
A, TRL. K = TRCO. K * WTRL
L, ARPA. K = ARPA. J + DT * (ARPAR. JK
− ARPAQ. J)
R, ARPAR. KL = ARCO. K * ARIVR. K
A, ARPAQ. K = ARPA. K * (/ATAR)
A, ARCO. K = ARPA. K * ARINP. K/100
A, ARL. K = WARL * ARCO. K
L, STCO. K = STCO. J + DT * STCOR. JK
R, STCOR. KL = STCO. K * STCORR. K
A, STIV. K = STCO. K * STIVR. K
A, STL. K = STCO. K * WSTL. K
L, INPA. K = INPA. J + DT * (INPAR. JK
− INQ. JK)
R, INPAR. KL = INCO. K * INIVR. K
R, INQ. KL = INPA. K * (/ATIN)

A, INCO. K = INPA. K * INIVP. K
A, INL. K = INCO. K * WINL. K
A, INIV. K = INCO. K * INR. K

3. 4 Resource Subsystem

This subsystem focused on water and land principally. And the former is more important for its restriction to the industrial and agricultural development. As a result, the supply and demand of water resource is one emphasis of the model.

The major variables considered include the following items: 1) CTW-available water resouce. It can be estimated according to the capacity of surface water and groundwater. How to distribute actual available water resource will be the highlight considered in this subsystem. 2) TW-water cosumption. It is the sum of water consumption for living, agriculture and industry. Water consumption for living depends on the pridicting total population and the water consumption per capita (180L/person-day) (Water Resource Bureau in Miyun County, 2000). Water consumption for agriculture can be caculated by water consumption for crop cultivation and the counterpart for stock raising. Agricultural irrigation coefficient and the nominal quantity of irrigation water can reflect the local agricultural development level and the ecological construction level. The two variables are crucial inputs involved policy-makings in this subsystem. Water consumption for industry can be caculated by total industrial output value and water consumption emission per unit industrial output. 3) PLS-arable land per capita which is a critical index to evaluate arable land resource. It has a close relation with the total population and arable land area.

3. 5 Environmental Protection Subsystem

It is a vital mission for people in Miyun Area to protect the circumjacent environment well. Two contents have to be taken account which are the control to wastewater pollution and solid waste pollution.

There are six major variables emphasized in this subsystem. 1) WPIN: Wastewater discharge generated by industy, which can be gained through multiplying WPINR (wastewater discharge per unit industrial output) by INCO (total industrial output value). 2) WPIV: It represents total investment for wastewater treatment which varies with the protection level to water resource, the public consciousness and the official attention to environmental protection. 3) WPQ: It means wastewater treatment capacity. 4) WPT: It represents the proportion of wastewater treatment capacity to total wastewater discharge. 5) WSP: It is defined as total solid waste generation including the amount of household refuse (SPL) and solid waste generation amount by industry (SPIN). 6) SPT: It also is a indication to the level of local environmental protection representing the proportion of solid waste treatment capacity to solid waste generation.

4 VERIFICATION AND SENSITIVE DEGREE ANALYSIS

The developed MiyunSD model was verified on the base of the data of 1995 to 1999. The variables being examined can be described as follows: total population (TP), total output value of society (TCO), gross domestic product (GDP), arable land area (LS), total agricultural output value (AGCO), total industrial output value (INCO), water demand (TINCO).

Table 1 shows the verification results. Total population and arable land area have relatively low errors (<5%), while others variables have a relatively high errors (up to 30%). The high errors can be explained with the following three reasons. First of all, the values of parameters in some year couldn't be obtained such as ARIVPR, which will result in the uncertainties of some simulated data. Secondly, the denominations of several parameters in statistical annuals are quietly different, and hence the conversion of parameter values also will bring about the high errors. Additionally, in order to simplify the model, some parameters were adopted annual mean number even if they changed irregularly in a whole year. This method will lead to errors as well.

To make sure of the reliability of recommended policies, sensitivity analyses was necessary to examine the system's response to variations of parameters and/or their combinations. First of all, the concept of sensitivity degree can be defined as follows:

$$S_Q = \left| \frac{\Delta Q(t)/Q(t)}{\Delta X(t)/X(t)} \right| \quad (1)$$

where S_Q is sensitivity degree of state Q to parameter X; t is time; $Q(t)$ represents system state at time t; $X(t)$ denotes system parameter affecting the system state at time t; $\Delta Q(t)$ and $\Delta X(t)$ represent increments of state Q and parameter X at time t, respectively.

Secondly, for n state variables P_i ($i = 1, 2, \cdots, n$), the general sensitivity degree of a parameter at time t is defined as follows:

$$S(t) = \frac{1}{n} \sum_{i=1}^{n} S_{P_i} \quad (2)$$

where $S(t)$ is general sensitivity degree of the n states

Table 1 Verification results

		1995	1996	1997	1998	1999
AP(10000 persons)	Historical data	42.3391	42.4056	42.4263	42.5676	42.5495
	Simulated data	42.3400	42.9200	43.5100	44.1000	44.7000
	Relative error(%)	0.0000	1.2123	2.5506	3.6590	5.0766
GDP(10000 yuan RMB)	Historical data	25.4010	27.4082	25.3656	26.2917	30.6261
	Simulated data	25.4000	26.9500	28.5900	30.3300	32.1800
	Relative error(%)	3.9370	1.6832	12.7040	15.3560	5.0606
FCO(10000 yuan RMB)	Historical data	21.6570	21.5840	18.9360	21.9820	17.6580
	Simulated data	19.3900	18.2300	17.0700	16.9100	16.7400
	Relative error(%)	10.4677	15.5392	9.8426	23.0820	5.1900
TINCO(10000 yuan RMB)	Historical data	57.1151	48.9821	46.1167	45.9819	58.3566
	Simulated data	43.4500	46.3000	50.2200	55.4500	62.2900
	Relative error(%)	23.9200	5.4830	8.9038	20.5930	6.7355
SCO(10000 yuan RMB)	Historical data	67.3925	59.3430	56.0727	56.8604	68.3220
	Simulated data	54.6700	57.6200	61.7000	67.1300	74.2200
	Relative error(%)	18.8720	2.8900	10.0420	18.0600	8.6365
LS(10000 ha)	Historical data	2.4093	2.4064	2.3545	2.3588	2.3560
	Simulated data	2.4157	2.4103	2.3984	2.3917	2.3843
	Relative error(%)	0.0000	0.1594	1.8597	1.3962	1.2131
AGCO(10000 yuan RMB)	Historical data	10.2777	10.3609	9.9561	10.8785	9.9655
	Simulated data	11.2200	11.3300	11.4800	11.6800	11.9400
	Relative error(%)	9.1804	9.3239	15.3150	7.3953	19.7680
INCO(10000 yuan RMB)	Historical data	45.7320	37.4464	32.2024	30.0109	33.1600
	Simulated data	32.5200	33.7900	35.8100	38.7100	42.7000
	Relative error(%)	28.8900	9.7600	11.9940	28.9790	28.7580

to parameter X; n denotes a number of state variables; S_{P_i} is sensitivity degree of state P_i.

In the study system, 22 parameters and 17 variables are qualified for the system sensitivity analysis. Each parameter is increased (or decreased) by 10% per 4 years for the study horizen of 1995 – 2015. According to eqution (), five sensitivity degree values can be obtained for each parameter-variable pair. Their average represents the general sensitivity degree of the parameter to the variable. Then based upon equation (2), an average for 17 variables can be achieved to each parameter, which signifies a sensitivity degree of the parameter to the system behavior. The results of the sensitivity degree analyses are showed in Table 2, from which 7 parametes can be found to have a biger effect on the system with high sensitivity (up to 0.0507) and reversely others have a smaller influence (≤ 0.0018).

5 THREE SIMULATIVE ALTERNATIVES

Under the different planning objectives, many simulative alternatives can be attained through adjusting variables and parameters. In this study, three typical alternatives are compared in detail.

5.1 The First Alternative—Base Run

In fact, the first alternative is a kind of simulation for the system's future according to the existing social development policies. At the present time, agriculture is still key industry of Miyun economy. Stock raising is regarded as the emphasis of agricultural production. For protecting Miyun Reservoir, the standards of local environmental quality are established rigorously. Consequently, although having taken a dominant effect on local development, the industry still grows slowly. According to this kind of socio-economic policies, the running results can be introduced briefly as follows: Total population of Miyun Area will grow from 4.255×10^5 in 1999 up to 4.639×10^5 in 2015. In 2015, agricultural population will still have a relatively big proportion of 59%. Correspondingly, non-agricultural population will only account for 41%. Especially, net migration population will be very small and increase about 2×10^3 per year. The situation can indicate such a fact that if developed according to this alternative, Miyun Area would have a low socio-economic level. As a result, few people will be attracted to come to Miyun Area and serve for it.

The GDP will increase from 3.06 billion yuan RMB

Table 2 Results of sensitivity analysis for Miyun SD model

	FCO	SCO	AP	TWC	TP	FSCO	GDP	WD	SIV	PGDP	SBCO	LA	TWIN	GFS	WDIN	WDW	SOL	Average
BR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0027	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002
FSIVP	0.0000	0.0004	0.0000	0.0000	0.0000	0.0296	0.0000	0.0000	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0018
SBIVP	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0087	0.0000	0.0074	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010
GDPR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5000	0.0000	0.0000	0.0362	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0507
TRCORR	0.0000	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0037	0.0025	0.2100	0.0000	0.0000	0.0042	0.0000	0.0000	0.0000	0.0000	0.0131
ARIVR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0025	0.0003	0.0002
WARL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
SICORR	0.0000	0.0027	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0023	0.0000	0.0000	0.0000	0.0042	0.0000	0.0004	0.0025	0.0000	0.0007
ALW	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
WINCO	0.0000	0.0000	0.0000	0.0021	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0019	0.0000	0.0000	0.0000	0.0000	0.0002
ATAR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000
IFSR	0.0000	0.0000	0.0035	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002
BA	0.0000	0.0000	0.0000	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0007
WSTCO	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0166	0.0000	0.0000	0.0000	0.0000	0.0010
LSDT	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FIVR	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
WINL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0380	0.0022
WDIVR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0640	0.0420	0.0000	0.0066
AFCO	0.0460	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0028
STIVR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0064	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004
INIVP	0.0000	0.0518	0.0000	0.0018	0.0000	0.0000	0.0000	0.0675	0.0535	0.0000	0.0000	0.0000	0.0687	0.0000	0.0463	0.0462	0.0576	0.0231
INIVP	0.0000	0.0159	0.0000	0.0005	0.0000	0.0000	0.0000	0.0208	0.0165	0.0000	0.0000	0.0000	0.0212	0.0000	0.0370	0.0135	0.0174	0.0084

in 1999 to 16.05 billion yuan RMB in 2015. Total output value ratio of agriculture, industry and service industry will be 15∶48∶37. Agricultural output value will keep a bigger proportion compared with that of developed counties.

According to the average statistics value, average water resource capacity will amount to $2.35 \times 10^8 m^3$. While, total water consumption only summed to $1.8 \times 10^8 m^3$ in 2015. So there will be a water resource surplus about $0.5 \times 10^8 m^3$. Moreover, this run results also indicates pollutant emission in the future. In 2015, $2.77 \times 10^6 t$ wastewater and $2.03 \times 10^5 t$ solid waste can be produced which are relatively small capacity.

In a word, this alternative can assure that the reservoir and nearby area would be well protected, but only a low economic output would be realized.

5.2 The Second Alternative

The second alternative is determined according to the desire for local authorities and some experts who hope the Miyun's economy can be increased rapidly. It is suitable for situations when economic development is emphasized.

Compared with alternative 1, total population in alternative 2 will be 1.01×10^5 more than alternative 1 by 2015 and non-agricultural population will make a spring from 9.66×10^4 in 1999 to 3.16×10^5 in 2015. Meanwhile net migration population will also jump rapidly and amount to 9913 in 2015, which indicates the urbanization level of Miyun Area will obviously enhanced grounded on this alternative. What's more, the highest GDP will be achieved through the simulation of alternative 2. That is 2.9×10^{10} yuan RMB by 2015 which is 1.8 times as large as that of alternative 1. Among them, industrial output value and service industrial output value will be remarkably multiplied and will respectively occupy 42% and 50% in the total gross nation product. Reversely, agricultural output value will only have a small portion—only 8%.

This situation will inevitably increase water consumption and the risk of wastewater pollution and solid waste pollution. On the one hand, total water consumption will reach $2.42 \times 10^8 m^3$ in 2015 which is $7 \times 10^6 m^3$ larger than average water resource capacity $2.35 \times 10^8 m^3$. It means that the balance of supply and demand of water resource will be difficult to achieve. On the other hand, wastewater emission and solid waste generation respectively come to $2.21 \times 10^7 t$ and $7.88 \times 10^5 t$ which are much more than those of alternative 1.

In effect, the larger economic amount in alternative 2 is obtained at the cost of clean environment and abundant resource of Miyun Area. In the long run, the implement of this alternative may have a bad impact on future development.

5.3 The Third Alternative

The third alternative offers a balance between economic development and environmental protection after having analyzed simulation results of above two alternatives. This alternative may reasonably embody the willing of the authorities and some experts. Instead of agriculture, high-technology industry will become the key industry in the economical structure of Miyun. Some environmental standards will slightly be slackened. For adapting to the transformation, some economical, resource and environmental parameters will be varied. For instance, compared with the first alternative, INIVR, INYZ, WIN and SPIN will increase to some extent and FIVR, IFSR, FSIVR will a little decrease.

The overall economic output of this alternative is not significantly lower than that of alternative 2, while improved environmental quality can be attained. For an example, GDP will increase by 15% every year and come up to 2.10×10^{10} yuan RMB in 2015. Total population of this alternative will grow up to 5.47×10^5 in 2015. It ranks the middle position between that of alternative 1 and that of alternative 2. Moreover, water demand of $2.13 \times 10^8 m^3$ can not only assure the effective use of local water resource but avoid the lack of water supply. At last, the relatively lower wastewater emission ($3.89 \times 10^6 t$) and solid waste generation ($4.56 \times 10^5 t$) are preferable.

5.4 Optimum Selection for Three Alternatives

According to the above analysis, the third alternative is thought to be a reasonable selection based on either economic development or environmental protection. It can realize the objective of maximal economic benefit, maximal social benefit and maximal environmental benefit simultaneously. Accordingly, the third alternative, as it were, is the optimal mode. Table 3 shows the simulation results of above three alternatives.

6 CONCLUSIONS

In this study, a regional sustainable development system dynamics model named MiyunSD is developed for socio-economic planning and management in the

Table 3 Simulation results for three alternatives

Variable	Alternative 1			Alternative 2			Alternative 3		
	2005	2010	2015	2005	2010	2015	2005	2010	2015
Total population (10^4 person)	43.9	45.15	46.39	47.32	51.70	56.49	46.74	50.55	54.67
Non-agricultural population (10^4 person)	13.62	16.26	19.02	21.77	26.37	31.64	16.83	20.73	25.15
Agricultural population (10^4 person)	30.33	28.90	27.37	25.55	25.34	24.86	29.92	29.83	29.52
Net migration population (person)	2268	2330	2394	8304	9073	9913	7237	7827	8465
GDP (10^8 yuan RMB)	58.45	98.52	160.5	87.09	178.8	289.6	72.78	129.1	210.3
GDP per capita (10^4 yuan/person)	1.32	2.18	3.45	1.84	3.45	5.12	1.55	2.55	3.84
Total output value of society (10^8 yuan RMB)	98.04	173.1	323.2	160.3	343.1	793.1	130.8	250.7	545.8
Total agricultural output value (10^8yuan RMB)	20.23	30.86	48.59	25.93	40.0	63.05	23.93	36.88	58.44
Total industrial output value (10^8 yuan RMB)	25.19	62.80	154.2	45.80	134.0	398.1	34.90	92.31	271.5
Total service industrial output value (10^8 yuan RMB)	52.63	79.41	120.4	88.54	169.1	331.9	71.97	121.5	215.8
Water consumption ($10^8 m^3$)	1.55	1.67	1.82	1.61	1.90	2.42	1.63	1.86	2.13
Water consumption for agriculture ($10^4 m^3$)	9640	9799	9862	9018	9153	9192	9698	9840	9893
Water consumption for industry and service industry ($10^4 m^3$)	1645	2441	3703	2331	4679	9270	2025	3390	5975
Water consumption for living ($10^4 m^3$)	4259	4417	4580	4715	5199	5732	4572	4991	5448
Total primary wastewater discharge (10^4t)	1212	1480	1848	2046	3252	5576	1664	2380	3532
Wastewater discharge generated by industry (10^4t)	714.9	887.1	1154	1251	2290	4422	1049	1623	2614
Discharge amount of domestic sewage (10^4t)	4259	4417	4580	794.5	962.5	1155.0	614.2	756.5	918.0
The proportion of wastewater treatment to total primary wastewater discharge (%)	51.9	65.6	85.0	68.5	63.2	60.6	58.4	72.0	89.0
Wastewater emission (10^4t)	583.4	508.6	277.0	646	1195	2205	692.6	666.0	389.0
Primary solid waste generation (10^4t)	23.37	29.95	39.26	40.95	64.95	112.80	32.10	46.58	72.58
The proportion of solid waste treatment to primary solid waste generation (%)	47.1	53.3	53.5	29.4	33.9	30.1	34.3	36.5	37.2
Solid waste generation (10^4t)	12.37	13.95	20.26	28.95	42.95	78.8	21.1	29.58	45.58

Miyun Reservoir Area, China. Interactions among a number of system components within a time frame of 15 years are examined dynamically. Three planning alternatives are considered. The base run is based on an assumption that the existing pattern of human activities will prevail in the entire planning horizon, and the second alternative is based on previous planning study. The third alternative is regarded as the optimal mode for it offers the balance of economic development and environmental protection. At the same time, the model can also simulate the economic and environmental implications of different alternatives to the system's environmental and socio-economic objectives. Therefore, the simulation results are directly useful for local authorities to launch feasible policies and regulations in Miyun Area.

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