

Reclamation and Reuse of Municipal Wastewater and the urban Sustainable Development

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Abstract: The municipal wastewater reclamation and reuse is a system which relates to many fields, such as society, economics and environment. Thus, a System Dynamics (SD) method was employed to develop the complex system and the SD model of the municipal wastewater reclamation and reuse (MWRR) system is built in the paper. The characteristics of the function and the structure of the MWRR system are discussed through analyzing the factors and their correlation which influence the MWRR system. At the same time, the application examples of the SD model are showed in the paper. The SD model was then used for the MWRR planning of an arid city in western China. A medium and long-term development trend of the system in the city was predicted as well. It is illustrated that the demand volumes of fresh water resource can be reduced if reclaimed water is used. Thus, it is very important to the urban sustainable development.

Keywords: municipal wastewater, reclamation and reuse, sustainable development; system dynamics model

1. INTRODUCTION

The connotation of the urban sustainable development is trying for harmonious development among urban population, resources, environment and economics through urban construction and management, which will not only create well conditions for the contemporary townsman developing urban economics, society and environment, but also supply basement and guarantee for the offspring developing the city continuously. However, the Urban sustainable development is a kind of development which achieving unification among urban economics, society and ecosystem.

Water resource is an important basic prerequisite for sustainable development of a city. Water resource becomes deficient along with the increase of population and the aggravation of water resources pollution in recent years. The shortage of water resource would impede survival and development of human being; therefore, it is particularly important to solve the water problem. Especially, the problem is more pressing the arid cities in western China. As an effective approach to the shortage of water resources, municipal wastewater reclamation and reuse has received a lot of attention. At the same time, it accord with the principle of sustainable development. The municipal wastewater reclamation and reuse (MWRR) is a system problem which relates to many fields, such as society, economics and environment. In this paper, with consideration of many factors affecting MWRR and analysis of the relationship between these factors the System Dynamics (SD) method was employed to develop a dynamic and non-linear SD model for the MWRR system. Then, the SD model was applied for simulation and prediction of the MWRR system in a city of the western area in China.

2. THE METHOD FOR STUDY

System dynamics (SD) is founded in 1956 by professor Jay.W.Forrester in MIT, which is a subject used for analyzing and studying the information feedback system. SD could realize emulational simulation by virtue of computer. Its primary function is to supply a tool which could realize moderate and long term forecast and strategy analyzing. Its outstanding characteristic is that it can deal with the system problems, such as high-level, non-linear, and multiple feedback etc; and it is applicable to the problem of complicate systems varying with the time^[1]. SD has been applied to many kinds of fields, such as the development of social economics, the decision-making of enterprise development, the forecast of the supply and demand of water resource, the carrying capacity of regional water resource etc.^[2, 3]

In the SD model, the rate equation is primary because it describes the varying rule of the level variable. In fact, the rate equation is a kind of expression of Euler numerical integral. It is commonly expressed:

$$L.K = L.J + DT \cdot (IR.JK - OR.JK)$$

In the formula: L.K, L.J are level vectors;

IR.JK, OR.JK are rate vectors.

Through transmuting the above formula, following equation is deduced:

$$\frac{L.K - L.J}{DT} = \frac{DL}{DT} = IR.JK - OR.JK$$

The SD model is a one-rank differential equation groups which are determined by the above equation.

3. BUILDING THE SD MODEL

3.1 The MWRR system analysis

In view of the characteristics of MWRR system and the improvement of hierarchical and discernable degree, the model is divided into three subsystems: the Reclaimed Water Supply System, the Reclaimed Water Demand System and the Urban Supply & Demand System. Moreover, The three subsystems are interdependent.

Many factors that influence the system are considered in the MWRRS system, but the wastewater reuse volume, the reclaimed water demand volume and the urban water shortage volume are main variables of the MWRR system. The urban district is defined as the boundary of the model, along with consideration of investment, consumers' acceptable degree, policy, city programming, etc. According to the divided three subsystems, the basic structure of the model is analyzed as follows.

$$\prod(S) = \{S_1, S_2, S_3\}$$

In the formula,

S_1 is the Reclaimed Water Supply subSystem;

S_2 is the Reclaimed Water Demand System;

S_3 is the Urban Supply & Demand System.

3.2 The basic Structure of the SD model

The causality relationship of the MWRR system is shown in Figure 1. Urban water demand contains domestic water demand and industrial water demand, which can be obtained by multiplying industrial production value and water volume needed for each

ten thousand production value. Since most part of water shortage volume is burdened by industry, lack of water will have direct impact on industrial production value. Urban water supply volume is made up of fresh water, self-provided wells and water reuse supply volume. Both the degree of water resource exploitation and the degree of water pollution will restrict further exploitation of water resource — increasing fresh water supply volume. The degree of water shortage reflects the difference of urban water supply and demand (Simonovic, 2002). In one hand, water shortage will influence the increasing rate of industrial production value and slow down the increasing rate of urban water demand. On the other hand, water shortage will increase wastewater reuse volume. As a result, water supply volume becomes larger and the system can get to equilibrium through these plus-minus feedbacks.

There are many factors in the SD model of the MWRR system, such as urban population, economics, the investment of sewage treating equipments, the degree of the users' acceptance, policy, the exploitation and utilization of water resource, water environment pollution etc. 9 level variables, 73 auxiliary variables, 10 rate variables, 7 table functions, 10 primary feedback loops are involved in the model. The diagram of the model is concisely showed as the Figure 1, which is finished by the Vensim soft.

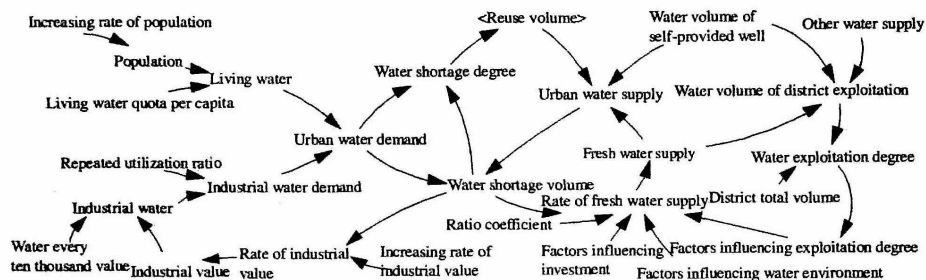


Figure 1 : Causal diagram of municipal wastewater reclamation and reuse system

3.3 Determination of Parameters of the model

With the model established, the first step is to assign all the parameters (constants, initial values of functions and state variables' equation) before simulation. These parameters could be obtained from investigation statistics, and other parameters are obtained through the gray system method GM (1,1), direction extrapolation rule, regression rule and arithmetic average rule. For example, the water consumption per 10 thousands Yuan production value, the ration of water per capitulation for living and the increase rate of population and so on. Then these parameters are input into the model as constants.

3.4 Model Validation

It is necessary to examine the validity of model before its application. Usually, SD model tests include intuitionistic tests, structure evaluation, extreme condition tests, history data tests and sensitivity tests, etc. The first three tests have been verified during the process of model establishment. Sensitive analysis is a method to observe the influence of parameters on system behaviors by calculating the sensitive degree of dependent variables, which corresponding to the variety of independent variables at time. It can be expressed by the following formula:

$$S_{xy}(t) = \left| \frac{\Delta Y(t)}{Y(t)} \cdot \frac{X(t)}{\Delta X(t)} \right|$$

4. THE APPLICATION EXAMPLES OF THE SD MODEL

4.1 Water Conditions in Research Area

Owing to those characteristics — little water resource and precipitation, deteriorating ecological environment and limited water exploitation in west Area of China^[4](Liu, 2000), it is very important and urgent to reuse urban wastewater in the area. In this paper, the city in western China is used as an example for the research. The total water volume of the city is $13 \times 10^6 \text{ m}^3$ —only 684 m^3 per capita which is one third of mean level over the country. 83% of urban water supply volume is supplied from outside of the city. It is very urgent to find new water resources because the degree of water exploitation has get to the maximum in the area. however, The city is a typical city of water resource shortage. Moreover, the ecological balance around the urban area has been severely destroyed. The problem of water resource in the City has been an important factor to restrict urban economic development and ecological construction. In 2000, the urban population was about 73×10^4 and the industrial production value was 64×10^6 yuan.

4.2 Initial Value of Parameters

With the model established, the first step is to assign all the parameters (constants, initial values of functions and state variables' equation). In the model, the initial values of main variables were chosen from the statistics of the City in 2000, and some decision variables' rates were determined by the City programming. Table1 shows some important variables' values in the model.

Table 1: Type and value of major variables

Variable name	Unit	Initial value	Variable type
Population	10^4 people	73	L
Industrial value	10^8 Yuan	63	L
Increasingrate of industrial value	%	14	C
Secondary treatment volume	10^4 m^3	3125	L
Area of forest and grass	hm^2	1528	L
Fresh water supply	10^4 m^3	7564	C
Ecology volume	10^4 m^3	388	C

4.3 Model Validation

Model validation is the foundation and premise of model application. This paper describes Model Average Parameter Error (MAPE) test, in which population and green area are chosen as two variables and the index is relative error. The results are shown in Table2. It is illustrated that the variables' simulation values are basically in accordance with the

historical values and the maximal error is less than 10%. So, it is believed that the model simulation value fits well with the factual value. The model is fairly potent and valid for use.

Table 2 : MAPE of major parameters(%)

Index	1996	1997	1998	1999	2000
Population	-0.3	0.06	0.8	0.32	0.01
Green area	-5.6	-0.9	4.2	5.0	3.1

4.4 Analysis of the SD Model Simulation Outcome

The three schemes are designed in the SD Model of the MWRP system. The simulation outcomes reveal the different situations of wastewater reuse system in the City under three different schemes. In this paper, the relationship among wastewater reuse, society, economy and development of the City is analyzed in different aspects, such as wastewater reuse volume and water shortage volume, ratio of reclaimed water supply and demand, industrial production value, and construction investment of wastewater treatment and reuse, etc. Therefore, the third scheme is recommended by the comparison of the three schemes. The simulation outcomes of the third scheme are shown in Table 3.

In the third scheme, as time goes on, wastewater reuse volume goes up steadily and water shortage volume is going down. By 2019, water shortage volume will be zero. By 2010, wastewater reuse volume in the schemes 3 will be $3215 \times 10^4 \text{ m}^3$, and by 2020, will be $10024 \times 10^4 \text{ m}^3$. Water shortage volume will be $51 \times 10^4 \text{ m}^3$ by 2010 and 0 m^3 by 2020. These results indicate that after wastewater reuse, urban water supply volume increases, and water shortage pressure is relieved.

With the development of society and economy and the improvement of wastewater reuse treatment, urban reclaimed water demand is increasing constantly. However, there is a limit of reclaimed water supply volume. In the third scheme it goes up steadily and will be 24% and 54% by 2010 and 2020, respectively.

Since most part of water shortage is industrial water shortage, water shortage degree directly influences industrial production value. Although wastewater reuse volume is different in the second and third scheme, the pressures of urban water shortage are both relieved. The industrial production values in third schemes are almost the same. By 2010 the industrial production values in the three schemes will be 232×10^6 RMB yuan and by 2020 will be 856×10^6 RMB yuan.

One of the important factors, which influence wastewater secondary treatment and reuse volume, is investment. Since the economy in the city in western China is not well developed, it is difficult to increase the investment amount of basic construction. This paper compares the investment amount of wastewater secondary treatment and reuse —the fund needed for the three schemes. It is found that the investment amount order of secondary treatment, the third, By 2010, will be 1.72×10^6 RMB yuan, and by 2020, will be 4.82×10^6 RMB yuan. Like wastewater

secondary treatment, by 2010, the investment of wastewater reuse engineering in third schemes will

be 1.17×10^8 by 2020, will be 1.94×10^8 RMB yuan, respectively.

Table 3 : The simulation outcomes of the SD model

Index	Unit	2006	2008	2010	2012	2014	2016	2018	2020
Industrial production value	10^8 yuan	138	179	232	301	392	509	662	861
wastewater reuse volume	10^4 m ³	1838	2664	3607	4654	5821	7105	8522	10069
construction investment of wastewater treatment	10^4 yuan	9310	13107	17291	22025	27360	32940	38847	45239
construction investment of wastewater reuse	10^4 yuan	2519	3649	4942	6375	7974	9734	11675	13794
water shortage volume	10^4 m ³	273	182	59	26	12	0	0	0
demand volume of fresh water resource	10^4 m ³	55	44	19	23	4	0	0	0

5. CONCLUSION

The model predict the trend of the MWRR system under different schemes. The results of factual operation show:

(1) There is a certain difference between supply and demand of the reclaimed water. The supply and demand ratio of reclaimed water will reach 30% in 2010 and the ratio will rise to 50% in 2020. Therefore, it is obvious that the reclaimed water possesses a great future.

(2) The sutation of municipal water shortage is alleviated and the demand volume of fresh water resource continuously reduced in the city because the increase of the reclaimed water.

(3) The industry Production value will reach 23.2 billion yuan and the value will rise to 86.1 yuan billion in 2020. The increase of production value of industry will speed up after 2010 when the water reuse program will promote the society economics.

(4) The urban economics and basic establishment are relatively imperfect in the cities in Western China; therefore, the sewage program of secondary treatment and reuse would be a process that should proceed step by step.

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