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A Nonlinear Dynamics Approach for Urban Water Resources Demand Forecasting and Planning

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1. Introduction

Over the past decades, controversial and conflict-laden water allocation issues among competing domestic, industrial and agricultural water use as well as urban environmental flows have raised increasing concerns (Huang & Chang, 2003); Particularly, Such competition has been exacerbated by the growing population, rapidly economic growth, deteriorating quality of water resources, and shrinking water availability due to a number of natural and human-induced impacts. A sounding strategy for water resources allocation and management can help to reduce or avoid the losses which are caused by water resources scarcity. However, in the water management system, many components and their interactions are uncertain. Such uncertainties could be multiplied not only by fasting changes of socioeconomic boundary conditions but also by unpredictable extreme weather events which caused by climate change. Thus, water resources management should be able to deal with all challenges above. Therefore, an effective integrated approach is desired for urban water adaptive management.

Many methods, such as stochastic, fuzzy, and interval-parameter programming techniques, have been employed to counteract uncertainties in different fields of water management and have made great progresses in managing uncertainties in model scale. Water resource is an integral part of the socio-economic-environmental (SEE) system, which is a complex system dominated by human. In order to reach a sounding decision, it is necessary for decision-makers to obtain a better understanding of the significant factors that shape the urban and the way the water resources system reacting to certain policy. Therefore, study of sustainable water resource management should be based on general system theory that addresses dynamic interactions amongst the related social-economic, environmental, and institutional factors as well as non-linearity and multi-loop feedbacks.

System dynamics (SD) aims at solving of complex systems problems by simulating development trends of the system and identifying the interrelations of each factor in the system. This will help to explore the hidden mechanism and thus improve the performance of the whole system. Hence, after proposed by W. Forrester (Forrester, 1968), SD model has been widely used in global, national, and regional scales for sustainability assessment and system development programme (Meadows 1973; Mashayekhi, 1990; Saeed, 1994). Due to

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the complexity of problems in the water system, the use of dynamic simulation models in water management has a long tradition (Biswas 1976; Roberts et al., 1983; Abbott and Stanley, 1999; Ahmad & Simonovic, 2004). The development journaey of several sections of applying system dynamics as a tool for integrated water management system analysis can be traced as from focusing on water system itself, to having a strong economic examinations on feedback relationships between industry and water availability, and then to having interaction with population growth (Liu et al., 2007). The above development make SD model has the flexibility and capability to support deliberative-analytical processes effectively. Meanwhile, SD and Multi Objective Programme (MOP) integrated model as an extension of the previous SD applications has been presented and used in urban water management in recent years, which takes into account both optimization and simulation (Guo et al, 1999; Zhang & Guo, 2002). This chapter will introduce a nonlinear dynamics approach for urban water resources demand forecasting and planning based on SD-MOP integrated model.

2. Uncertainties in Urban water system

2.1 Urban water system analysis

Generally, urban water system could be divided into four subsystems, i.e., social subsystem, economic subsystem, environmental subsystem and water resources subsystem. The relationships and interactions are complicate, as Fig. 1.

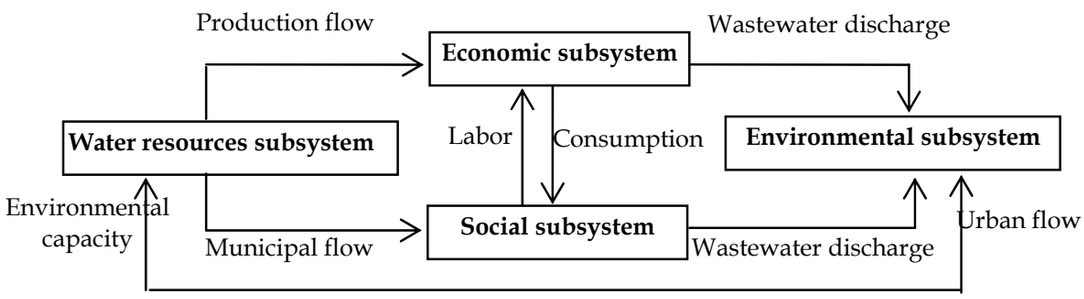

Fig. 1. Urban water management subsystems and relations

2.2 Uncertainties of urban water management system analysis

Urban water resources demand forecasting and planning are two important parts of urban water integrated management. Commonly, integrated water management should provide a framework for integrated decision-making and could be consists of system analysis, action results forecast, planning formulate and implementation, and evaluation and monitoring the goals and effects of implementation. At the system analysis stage, information collection and investigation are the basic work. A system structure is built based on a careful consideration of interactions among factors and subsystems. Long-term and short-term goals, problems, and priority focused will then are identified with both experts and stakeholders take part in. At the forecast stage, simulation model and evaluation model will be set up. Fixing on parameters and variable values of models and listing alternative solutions are the key process of the stage, based on field investigation, literature review and interviews with local stakeholders. Then according to the simulation and evaluation results of the alternatives, the selected solution can be identified and the corresponding desired actions can be determined.

Implementation and re-evaluation can't be separated completely. Management and re-evaluation is the mechanism that improves management goals and practices constantly.
Uncertainties limit the forecasting ability of and thus influence the quality of decision making. They can be categorized into four types : (1) intransience uncertainties caused by fasting changes of urban socioeconomic conditions; (2) external uncertainties caused by the stress of factors beyond the urban boundary (Liu, 2007); (3) uncertainties associated with raw data and model parameters driven from outdated or absent issues news, events, or statistic data; and (4) uncertainties arising from multiple frames (e.g. people's cognizing/ perceiving technique/ability advance, world and ethical view change) (Jamieson, 1996; Pahl-Wostl, 2009). The above uncertainties are associated with all four stages, the details as Fig. 2.

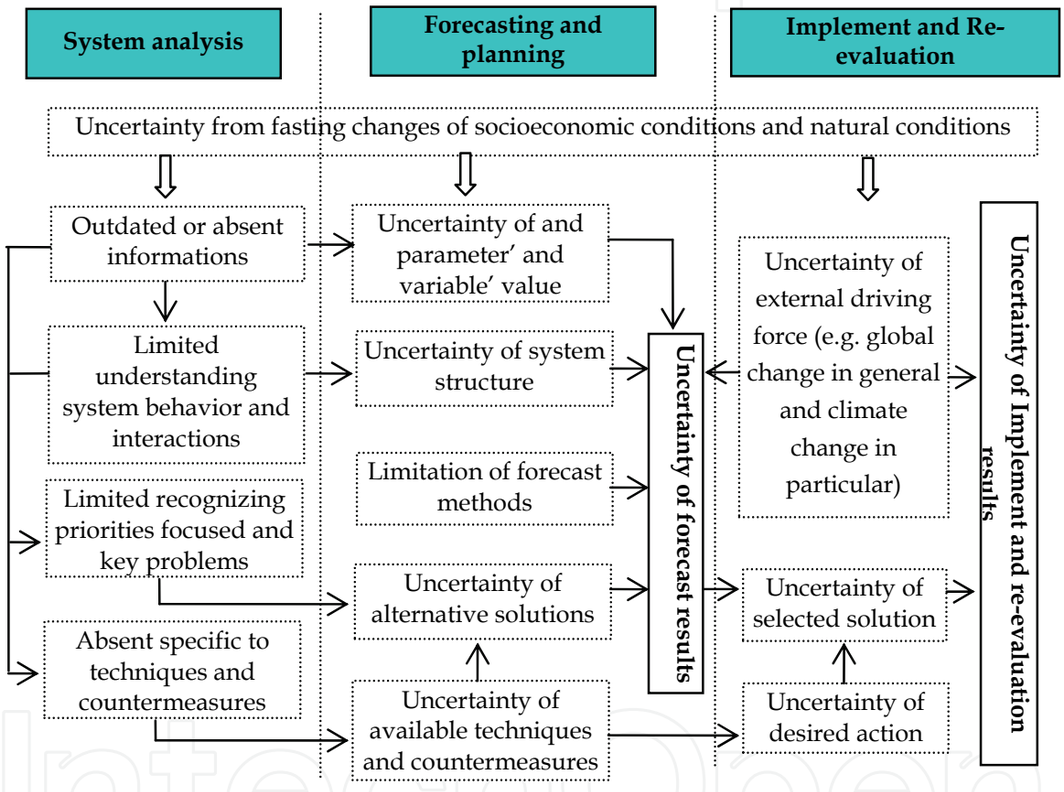

Fig. 2. The uncertainties in urban water management system

We can find that all above uncertainties are raised from the cognitive dimension (e.g. limited understanding system behavior and interactions among composing factors, uncertainty from fasting changes of socioeconomic conditions and change of natural conditions) and technical dimension (e. g. outdated or absent issues news/events/data, absent specific to techniques and countermeasures, limited of forecasting method) two aspects.

2.3 Overlook of counteracting measures to water system uncertainties

Whether we recognize it or not, socioeconomic laws and the natural laws are located in the objective world. So we can say that uncertainty is raised from the limitations of human cognition. Due to human cognitive abilities change, their understanding of the current world and their forecast of the future world will change over time. Furthermore, SEE system

is a complexity system reflecting the mutual and complicated functions amongst the internal elements, which can be characterized by the complicated system structure properties far from balance status and with dissipation structures, as well as the behaviors of which the input-output response shows uncertainty that beyond people's experiential and qualitative cognition. We can be in virtue of SD model as well as interactions between modelers and stakeholders to interact the behavior uncertain from input-output response. The SD model can be run by different scenarios, and thus the optimal scenario can be selected by the analyses and discussions.

However, simulation model could be run in almost limitless scenarios according SEE complex system parameters changed in different policies. Thus it is difficult to simulate all possible scenarios constrained in time and fund. So it is difficult to ensure the optimal level of selected scenarios and its corresponding programme design. Therefore, SD-MOP integrated model (Zhang & Guo, 2002) is proposed to counteracts uncertainties with SD model applying in different scenarios simulation and analysis, and MOP model applying in optimization.

3. System dynamics model

3.1 The basic concepts of SD

The SD model takes certain steps along the time axis in the simulation process. At the end of each step, the system variables denoting the state of the system are updated to represent the consequences resulting from the previous simulation step. Initial conditions are needed for the first time step. Variables representing flows of information and initials, arising as results of system activities and producing the related consequences are named as level variables described as ▭ in the flow diagram, and rate variables described as ⧖. Auxiliary variable means the detailed steps by which information associated with current levels are transformed into rates to bring about future changes. In addition, the symbol ☁ represents the sinks or sources.

Fig. 3 is a sample flow diagram for the total population, in which the total population (TP) is a level variable; birth population (BP), death population (DP), and net migrated population (NP) are rate variables; and birth rate (BR), death rate (DR), and net migration rate (NR) are auxiliary variables.

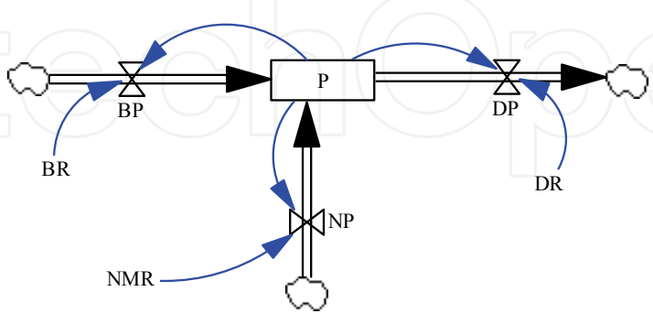

Fig. 3. SD flow chart of population subsystem

In SD level equation, three time points are denoted as J (past) , K (present), and L (future). The step from J to K is referred to as JK and that from K to L as KL. The duration period

between successive points is named DT. Therefore, a level variable could be referred to as LEVEL.J, LEVEL.K, or LEVEL.L at a time point，RATE.JK and RATE.KL will function in the duration period. We can express:

LEVEL.K=LEVEL.J+DT*RATE.JK

3.2 The procedures for applying SD model to simulate target system behavior

The proedures for applying SD model to simulate target system behavior can be summarized into three steps.

(1) Construction SD model

The first step of the procedures is constructing SD model through analyses of the total system, and identifying the model validity by historical examination, and sensitivity analysis. Accordingly, parameters and relevance can be modified and confirmed.

(2) Validity examination

Validity examination examination includes direct observation, historical examination, and sensitivity analyses. Direct observation is through SD model run, if there is no obviouse unreasonable simulation results, we can to the historical examination.

Historical examination is checking the error between simulation and reality. The errors of main forecasting level variables are accepted is one of the requirements of SD model being used in reality system.

Another requirement is that the target system responds in lower degree sensitivity to most of the parameters through a series of sensitivity analyses conducted to examine the system's responses to variations of input parameters and/or their combinations. A concept of sensitivity degree is defined as follows:

$$S_Q = \left| \frac{\Delta Q_{(t)}}{Q_{(t)}} \cdot \frac{X_{(t)}}{\Delta X_{(t)}} \right| \tag{1}$$

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

For the n state variables (Q_1, Q_2,…, Q_n), the general sensitivity degree of a parameter at time t can be defined as follows:

$$S = \frac{1}{n} \cdot \sum_{i=1}^{n} S_{Q_i} \tag{2}$$

Where n denotes a number of state variables; S_Q is sensitivity degree of state Q_i; and S is general sensitivity degree of the n states to the parameter X.

If there are some departures from the model validity requirement standards, the SD model should be adjusted until fix to the standards. Then, SD model could be used in target system behavior simulation.

3.3 SD model validity in simulating nonlinear feedback mechanism

Although SD equations are linearity, they simulating in computer can describe nonlinear characteristics produced by multi-feedback when consider temporal dynamic affection.

Figure 4 is a piece of water resources subsystem delay feedback circle- water supply capacity building flow chart, which included two simple first-order delay feedbacks.

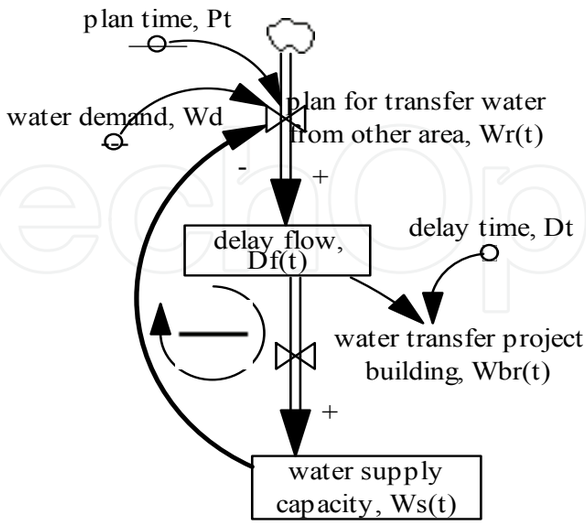

Fig. 4. Water supply capacity flow chart

Plan for transfer water from other area (*Wr (t)*) expression , in which had a first order delay, was shown as the basic divided differences formula: $Wr(t) = (Wd - Ws(t)) / Pt$.

Due to delay time to implement from confirming water transfer scheme to water supply formation, water transfer project building (*Wbr(t)*) could be expressed as a simple first order mater delay function: $Wbr(t) = Df(t) / Dt$.

As known, initialization of *Df (t)* is A m^3, initialization of *Ws (t)* is B m^3, *Wd* = C m^3, *Pt* = a, *Dt* = b. According the above conditions can be established equations (3):

$$\begin{cases} Wr(t) = (Wd - Ws(t)) / Pt \\ Wbr(t) = Df(t) / Dt \\ Wd = \mathrm{C} \\ Pt = \mathrm{a} \\ Dt = \mathrm{b} \\ Df(t)|_{t=0} = \mathrm{A} \\ Ws(t)|_{t=0} = \mathrm{B} \end{cases} \tag{3}$$

Confluence rate was the derivative of the flow to time t. Hereby, it could be obtained the corresponding differential equations (4).

$$\begin{cases} Df'(t) = \dfrac{1}{\mathrm{a}}(\mathrm{C} - Ws(t)) - \dfrac{Df(t)}{\mathrm{b}} & (4\text{-}1) \\ Df(0) = \mathrm{A} & (4\text{-}2) \\ W's(t) = \dfrac{Df(t)}{\mathrm{b}} & (4\text{-}3) \\ Ws(0) = \mathrm{B} & (4\text{-}4) \end{cases} \tag{4}$$

By equations (4), it could be derived the expression of flow, and the following equation could be obtained by on both sides of equation (4-3) of equations (4) derivation.

$$Ws''(t)+\frac{1}{2}Ws'(t)+Ws(t)=\mathrm{C} \tag{5}$$

Solve equation (5), the curve of water supply capacity, the curve of the delay flow , the curve of the plan rate, and the curve of project building could be derivate. Thus the results is according follow three conditions.

1. Condition 1

when $b>\frac{a}{4}$, $\frac{1}{b^2}-\frac{4}{ab}<0$, then $\lambda_{1,2}=-\frac{1}{2b}\pm\frac{1}{2b}\sqrt{\frac{4b}{a}-1}i$

The solution of the equation (5) corresponding homogeneous equation is shown as:

$$W_{s(t)}=e^{-\frac{1}{2b}t}(C_1\cos\frac{1}{2b}\sqrt{\frac{4b}{a}-t}+C_2\sin\frac{1}{2b}\sqrt{\frac{4b}{a}-t}) \tag{6}$$

Seeking the special solution of equation (5):

$$W^{*}_{s(t)}=C \tag{7}$$

According to equation (6) and (7), we can obtain the general solution of equation (5), which is shown as equation (8).

$$W_{s(t)}=e^{-\frac{1}{2b}t}(C_1\cos\frac{1}{2b}\sqrt{\frac{4b}{a}-t}+C_2\sin\frac{1}{2b}\sqrt{\frac{4b}{a}-t}+C \tag{8}$$

$W_{s(0)}$ =B will be into the equation (8). Then,

$$B=C_1+\mathrm{C}\ ,\ C_1=\mathrm{B}-\mathrm{C}$$

From,

$$\begin{aligned}W'_{s(t)}&=-\frac{1}{2b}e^{-\frac{1}{2b}t}((\mathrm{B}-\mathrm{C})\cos\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t+C_2\sin\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t)\\&+e^{-\frac{1}{2b}t}(\frac{\mathrm{C}-\mathrm{B}}{2b}\sqrt{\frac{4b}{a}-1}\sin\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t+\frac{C_2}{2b}\sqrt{\frac{4b}{a}-1}\cos\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t)\end{aligned} \tag{9}$$

$W'_{s(0)}=D_{f(0)}=\frac{\mathrm{A}}{b}$ is into the equation (9). Then,

$$\frac{\mathrm{A}}{b}=-\frac{1}{2b}(\mathrm{B}-\mathrm{C})+\frac{1}{2b}\sqrt{\frac{4b}{a}-1}C_2\ ,\ C_2=\frac{2\mathrm{A}+\mathrm{B}-\mathrm{C}}{\sqrt{\frac{4b}{a}-1}}$$

According to the above, the special solution of equation (5) is shown as the follow:

$$W_{s(t)}=e^{-\frac{1}{2b}t}((\mathrm{B}-\mathrm{C})\cos\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t+\frac{2\mathrm{A}+\mathrm{B}-\mathrm{C}}{\sqrt{\frac{4b}{a}-1}}\sin\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t)+\mathrm{C} \tag{10}$$

The equation (10) is the curve of the Water supply capacity.
From: $D_{f(t)} = bW'_{s(t)}$, then the curve of the delay flow can be obtained as equation (11):

$$D_{f(t)} = e^{-\frac{1}{2b}t}(\mathrm{A}\cos\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t - \frac{\mathrm{A}+\frac{2b}{a}(\mathrm{B}-\mathrm{C})}{\sqrt{\frac{4b}{a}-1}}\sin\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t) \tag{11}$$

The curve of plan for transfer water from other area can also be obtained as equation (12):

$$W_{r(t)} = e^{-\frac{1}{2b}t}((\mathrm{B}-\mathrm{C})\cos\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t + \frac{2\mathrm{A}+\mathrm{B}-\mathrm{C}}{\sqrt{\frac{4b}{a}-1}}\sin\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t) + \mathrm{C} \tag{12}$$

The curve of project building can also be obtained as equation (13):

$$W_{br(t)} = \frac{D_{f(t)}}{b} = e^{-\frac{1}{2b}t}(\frac{\mathrm{A}}{b}\cos\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t - \frac{\mathrm{A}+\frac{2b}{a}(\mathrm{B}-\mathrm{C})}{b\sqrt{\frac{4b}{a}-1}}\sin\frac{1}{2b}\sqrt{\frac{4b}{a}-1}t) \tag{13}$$

2. Condition 2

When $b = \frac{a}{4}$, $\frac{1}{b^2} - \frac{4}{ab} = 0$, Then: $\lambda_1 = \lambda_2 = -\frac{1}{2b}$

The general solution of equation (5) is shown as the follow:

$$W_{s(t)} = e^{-\frac{1}{2b}t}(C_1 + C_2 t) + \mathrm{C} \tag{14}$$

$W_{s(0)}$ =B will be into equation (14). Then,

$$\mathrm{B} = C_1 + \mathrm{C}\ ,\ C_1 = \mathrm{B} - \mathrm{C}$$

From,

$$W'_{s(t)} = -\frac{1}{2b}e^{-\frac{1}{2b}t}[(\mathrm{B}\text{-}\mathrm{C}) + C_2 t] + C_2 e^{-\frac{1}{2b}t} \tag{15}$$

$W'_{s(0)} = \frac{D_{f(0)}}{b} = \frac{\mathrm{A}}{b}$ will be into the equation (15). Then,

$$\frac{\mathrm{A}}{b} = -\frac{1}{2b}(\mathrm{B}-\mathrm{C}) + C_2\ ,\ C_2 = \frac{2\mathrm{A}+\mathrm{B}\text{-}\mathrm{C}}{2b}$$

According to the above, the special solution of equation (5) is shown as the follow:

$$W_{s(t)} = e^{-\frac{1}{2b}t}((\mathrm{B}-\mathrm{C}) + \frac{2\mathrm{A}+\mathrm{B}-\mathrm{C}}{2b}t) + \mathrm{C} \tag{16}$$

The equation (16) is the curve of the water supply capacity.

From $D_{f(t)} = bW'_{s(t)}$, then

$$D_{f(t)} = -\frac{1}{2}e^{-\frac{1}{2b}t}((B-C)+\frac{2A+B-C}{2b}t)+\frac{2A+B-C}{2b}e^{-\frac{1}{2b}t} \tag{17}$$

The equation (17) is the curve of the delay flow.
The curve of the water transfer rate can be obtained as (18) and the rate curve of Building water supply facilities can be obtained as (19).

$$W_{r(t)} = (C-W_{s(t)})/a = e^{-\frac{1}{2b}t}(\frac{C-B}{a}-\frac{2A+B-C}{2ab}t) \tag{18}$$

$$W_{br(t)} = \frac{D_{f(t)}}{b} = -\frac{1}{2b}e^{-\frac{1}{2b}t}((B-C)+\frac{2A+B-C}{2b}t)+\frac{2A+B-C}{2b^2}e^{-\frac{1}{2b}t} \tag{19}$$

3. Condition 3

when $b<\frac{a}{4}$, $\frac{1}{b^2}-\frac{4}{ab}>0$, Then, $\lambda_{1,2} = -\frac{1}{2b}\pm\frac{1}{2b}\sqrt{1-\frac{4b}{a}}$

$$W_{s(t)} = C_1 e^{(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t}+C_2 e^{(-\frac{1}{2b}-\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t}+C \tag{20}$$

$W_{s(0)}=B$ will be into the equation (20). Then

$$C_1+C_2+C=B,\ C_1 = B-C-C_2$$

From

$$W'_{s(t)} = (-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})C_1 e^{(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t}+(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})C_2 e^{(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} \tag{21}$$

$W'_{s(0)} = \frac{D_{f(t)}}{b} = \frac{A}{b}$ will be into the equation (21). Then

$$\frac{A}{b} = (-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})C_1+(-\frac{1}{2b}-\frac{1}{2b}\sqrt{1-\frac{4b}{a}})C_2 \tag{23}$$

Because

$$C_1 = B-C-C_2$$

So, $C_1 = \frac{(\sqrt{1-\frac{4b}{a}}+1)(B-C)+2A}{2\sqrt{1-\frac{4b}{a}}}$, $C_2 = \frac{(\sqrt{1-\frac{4b}{a}}-1)(B-C)-2A}{2\sqrt{1-\frac{4b}{a}}}$

According to the above, the special solution of equation (5) is shown as the follow:

$$W_{s(t)} = \frac{(\sqrt{1-\frac{4b}{a}}+1)(B-C)+2A}{2\sqrt{1-\frac{4b}{a}}} e^{(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} + \frac{(\sqrt{1-\frac{4b}{a}}-1)(B-C)+2A}{2\sqrt{1-\frac{4b}{a}}} e^{(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} + C \quad (22)$$

The equation (22) is the curve of the Water supply capacity.
From $D_{f(t)} = bW'_{s(t)}$, then

$$D_{f(t)} = \frac{\frac{4b}{a}(C-B)+2A(-1+\sqrt{1-\frac{4b}{a}})}{4\sqrt{1-\frac{4b}{a}}} e^{(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} + \frac{\frac{4b}{a}(C-B)+2A(1+\sqrt{1-\frac{4b}{a}})}{4\sqrt{1-\frac{4b}{a}}} e^{(-\frac{1}{2b}-\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} \quad (23)$$

The equation (23) is the curve of the delay flow.
And the curve of the water transfer rate can be obtained as (24).

$$W_{r(t)} = \frac{(C-W_{s(t)})}{a} = \frac{(\sqrt{1-\frac{4b}{a}}+1)(C-B)-2A}{2a\sqrt{1-\frac{4b}{a}}} e^{(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} + \frac{(\sqrt{1-\frac{4b}{a}}-1)(C-B)+2A}{2a\sqrt{1-\frac{4b}{a}}} e^{(-\frac{1}{2b}-\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} \quad (24)$$

The rate curve of Building water supply facilities can be obtained as (25).

$$W_{br(t)} = \frac{D_{f(t)}}{b} = \frac{\frac{4b}{a}(C-B)+2A(-1+\sqrt{1-\frac{4b}{a}})}{4b\sqrt{1-\frac{4b}{a}}} e^{(-\frac{1}{2b}+\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} + \frac{\frac{4b}{a}(B-C)+2A(1+\sqrt{1-\frac{4b}{a}})}{4b\sqrt{1-\frac{4b}{a}}} e^{(-\frac{1}{2b}-\frac{1}{2b}\sqrt{1-\frac{4b}{a}})t} \quad (25)$$

From above deduction, we can know that although SD equations are linearity, they simulating in computer can describe nonlinear characteristics produced by multi-feedback when consider temporal dynamic affection.

4. Decision-making system based on SD-MOP integrated model for urban water resources demand forecasting and planning

From above analysis, we can know that urban water resources demand forecasting is the key procedure of urban water system management. In different scenarios, the forecasting

outcomes may be different, which result in different corresponding planning. From above deduction, we can also get the conclusion that SD model can be applying to simulate nonlinear and complex system behavior though the basic equations are linear and simple. Hence, we introduce a decision-making system which core in SD-MOP integrated model for urban water resources demand forecasting and planning. The procedure of applying SD-MOP integrated model as Fig.5.

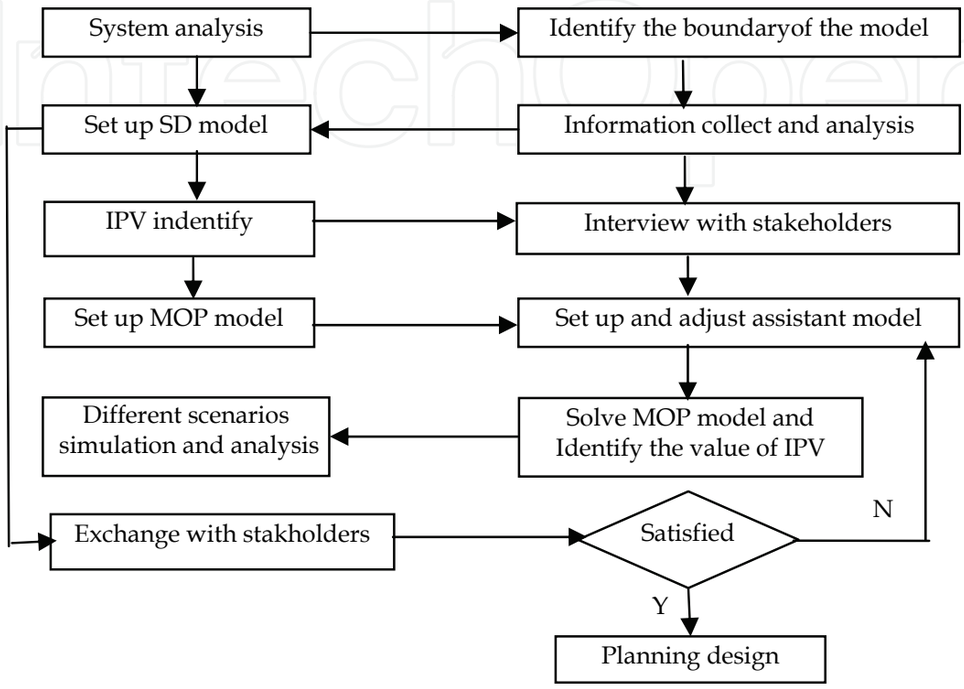

Fig. 5. The procedure of SD-MOP integrated model applying

In SD-MOP integrated model, SD is used for water resources system dynamics nonlinear behavior simulation, and MOP is used for optimal policy choice and optimal design forming.

4.1 Setting up SD model

The first step of SD-MOP applying is constructing SD model based on information collection system analysis. The procedures of constructing SD model are the follows:

1. identify the boundary of SD model;
2. classify sub-systems of urban water system;
3. determine the set of main level variables;
4. analysis the realtions of system parameters and variable;
5. design the flow diagram;
6. determine the basic value of parameters by mathmatic forecasting method both in statistical method and experience according to current and historical imformation of the target system;
7. set up basic mathmatic equations which consist of SD model;
8. test SD model validity and adjust it accoding testing results until it can be used in realistic system simulation.

4.2 Analyzing IPV

Analyzing the sensitivity by sensitivity test and original run (run in the condition which the system keep current behavior and tendency without any policy adjustment), the sensible parameters and the closed relating variables can be identified, which are named as IPV (Important Parameter and Variable).

IPV aggregation includes controllable factors and non-controllable two types. Non-control lable factors can become system development neck, while adapting controllable factors in suitable way could exploit urban development.

4.3 Setting up MOP model

Running the SD model based on the current situations (called original run). The gap between the original run results and ideal level of the system can be identified. In order to obtain optimal programme design and adjust the system function and behavior, MOP model cored in IPV is set up. In the MOP model the controllable factors of IPV become decison variables and non-controllable factors of IPV become constrains, while some level variable which closely related to IPV become maximum or minimum aim.

General format of MOP model as follow:

$$\max\left|f_k(x\ )/\forall_k\right| \tag{26}$$

$$\text{s.t. } g_i(x\ ) \le b_i, \forall_i \tag{27}$$

$$x_j \ge 0, x_j \in x \tag{28}$$

Where, x is decision variable (a set of real number in a closed boundary limit and is the value of IPV or value of variable that are related to IPV), equation (26) is objective function, (27) and (28) are the limiting conditions.

4.4 Setting up assistant model to solve MOP

Applying ODTL (Objective Deviation Tolerance Level) method (Zhou, 1998) to solve MOP model. Here, there is some different from Zhou in interview process. First, we determin each goal ODTL by interview with stakeholder based on giving them original run results and the ideal goals. Second, the decision is not finished in one time, but in several times based on showing them the former scenarios SD model simulation results which corresponding to their choice of each goals ODTL, and the stake holders can adjust there decision by comparing and discussing the former results. Finally, the optimal IPV can be determined by several adjust assistant model, solve MOP, simulation corresponding system tendency, and compare and selecte the desirable scenario.

4.5 Planning

Based on the optimum values of IPV, the proposals for running the model can be designed. Accordingly the final plan proposal can be formulated.

5. Case study

Applying SD-MOP integrated model in a real urban system to test its validity [Zhang 2010].

The boundary of the target system is the urban area of Qinhuangdao, which is a city of Hebei province, located at latitude 39°22′-40°37′N and longitude 118°33′-119°51′E, and covers an area of 7,812 km². Qinhuangdao has jurisdiction over three districts (Shanhaiguan, Beidahe, and Haibin) and four countries (Lulong, Qinglong, Funing, and Changli). The annual rainfall in Qinhuangdao is about 670mm, with the water resource per capita in Qinhuangdao is 600m³/a, which is 1/4 the average level in China. The system is composed of population subsystem, industry subsystem, services subsystem, water supply subsystem and water environmental protection subsystem. The planned period is 15 years (2006 - 2020). It is divided into two phases, i.e., 2006-2010 and 2010 - 2020. The base year is 2000.

5.1. Constructing SD model

Based on the analysis of the target system, SD model of Qinhuangdao (QHDWSD) can be constructed, and thus the sensibility of the model can also be tested. There are more than 110 variables in SD model, in which there are more than 110 system dynamic equations. Fig. 6 is the flow chart of QHDWSD.

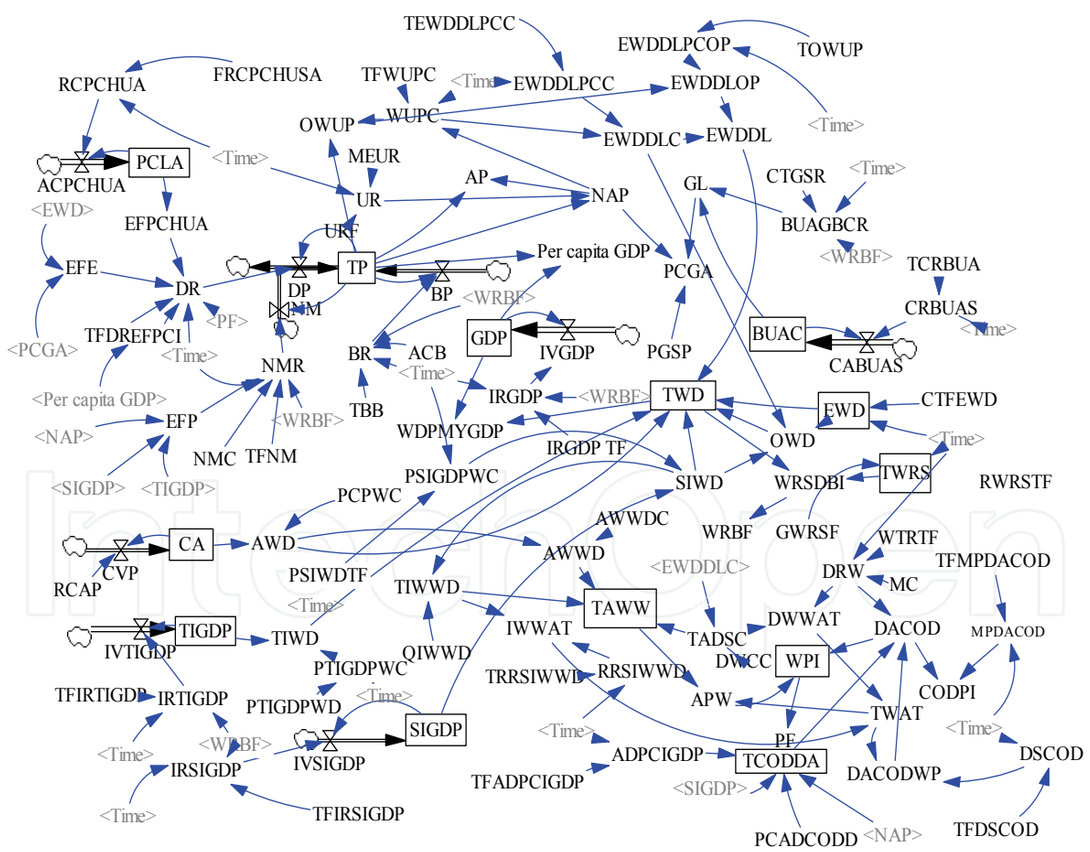

Fig. 6. QHDSD diagram

5.2 Identifying IPV

Based on original running and putting eight variables and fourteen parameters into sensitivity analysis, IPV were identified. Those are: Increase rate of second industrial GDP, per second industrial GDP water consumption, Per capita plow land water consumption.

5.3 Setting up and solving MOP model

In the original simulation, when GDP getting in the aim scale' water resource supply and demand balance index (water available supply to human social and economic activities divided by water demand human social and economic activities) will be lower than 0.6 in 2020 (Fig. 2). The consequence will be that people active's water consumption invade and occupy eco-environmental share and lead to water ecosystem quality degradation and water resource sustainable supply capability decrease. According above analysis, the key issue is the structure of the economic, thus MOP model is setting up as follow.

$$\mathrm{Z}_1(X) = \max \sum_{i=1}^{3} X_i \tag{29}$$

$$\mathrm{Z}_2(X) = \min \sum_{i=1}^{3} \mathrm{q}_i \cdot X_i \tag{30}$$

$$\sum_{i=1}^{3} \mathrm{q}_i \cdot X_i \le \mathrm{Q} \tag{31}$$

$$\mathrm{Ymin}_i \le X_i / (\sum_{i=1}^{3} X_i) \le \mathrm{Ymax}_i \tag{32}$$

$$X_i \ge 0 \tag{33}$$

where: X_i=GDP of three industry (10^8￥); q_i=per GDP water consumption of three industry (t/10^8￥); Q=water resource amount could be supplied to human economic activities (t); Ymin_i= the lower bound of three industry proportion in total GDP; Ymax_i= the higher bound of three industry proportion in total GDP. Then set up assitant model and solved it based on interaction with stakeholders who consists of the staff of water resources bureau, the staff of the environmental protection agency, the staff of regional development and reform Commission the staff of related bureaus, the staff of water supply and wastewater treatment firms, delegates of the three industries, and representatives from the public.

5.4 Obtaining relative optimal programme

According IPV solution, the optimal design could be obtained and the corresponding water resources plan of Qinhuangdao city was formulated. Table 1 shows the comparison of different industry ratio in the total gross domestic production (GDP) respectively between optimal solutions and original tendency. The comparison results of the water supply-demand balance, GDP, population scale and water pollution index between the feasible programme simulations with the original simulation as Fig. 7.

year	item	Primary industry (%)	Secondary industry (%)	Tertiary industry (%)
2010	optimal designs	62	356	457.5
	original tendency	65	370	440.5
2020	optimal designs	102	1220	1397.2
	original tendency	107	1256	1357.2

Table 1. Industrial structure (different industry ratio in GDP)

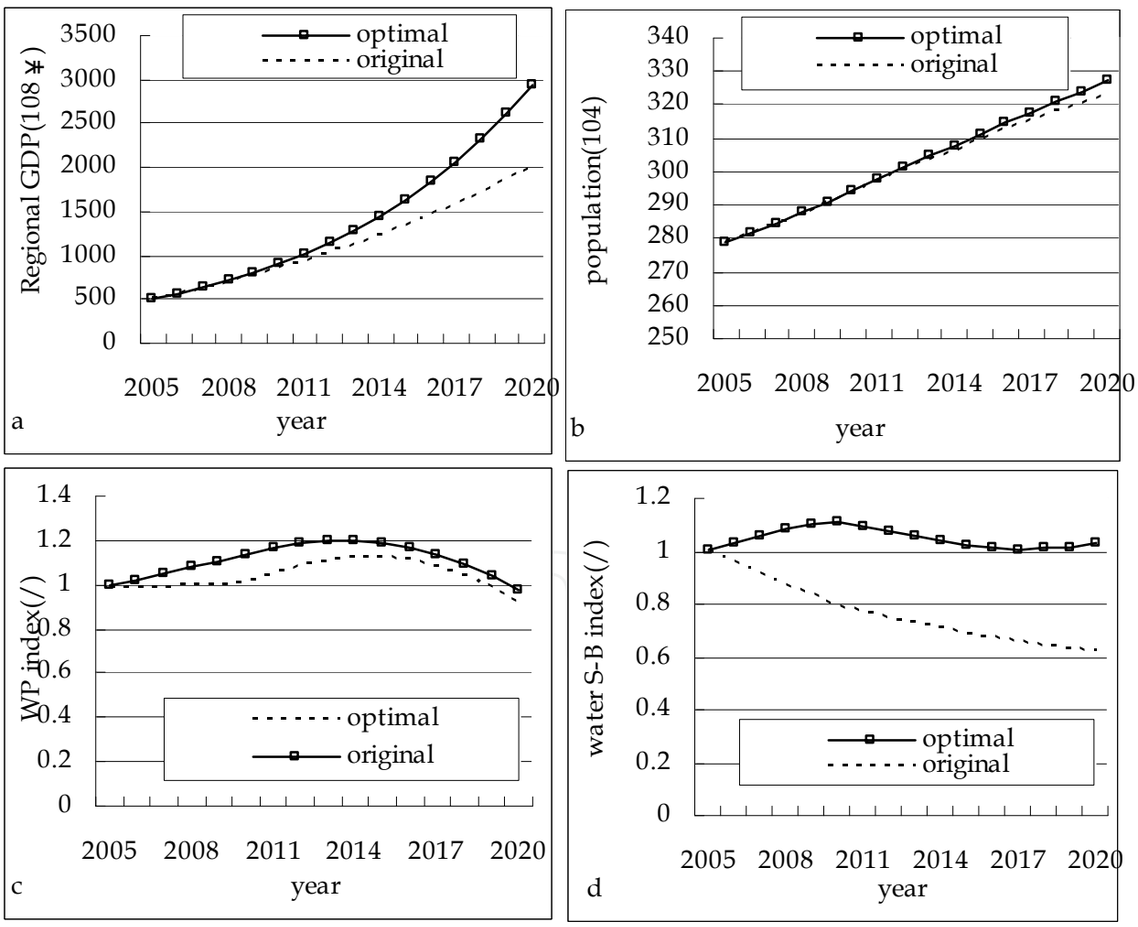

Fig. 7. Main level variable comparing between optimal design and original tendency

In Fig. 7, sub Fig-a is for gross domestic production, sub Fig-b is for total population scale, sub Fig-c is for water pollution index (WPI-the ratio of simulating year water contamination discharge to base year water contamination discharge) contamination, and sub Fig-d is for water resources supply-demand balance index (WRSDBI-the ratio of water supply quantity to water demand quantity).

Fig. 7 and table 1 indicate that through adjusting system structure can realize water sustainable utilization while not decreasing the speed of economic development. The water resource strategy plan is based on nonlinear dynamics forecasting approach for water resource demand.

5.5 Nonlinear dynamics approach validity test in practice

Follow is an example of Qinhuangdao water resource plan of 2000 to 2005. And it was researched by our group during 1998 to 2000. In the plan, we used two methods, nonlinear method and trend extending method, to forecast urban water resources demand. Fig. 8 shows the comparative errors for forecasting data and actual data between SD nonlinear method and trend extending method. From Fig. 8, we can know that nonlinear forecasting is more accurate with can give support to water resources plan.

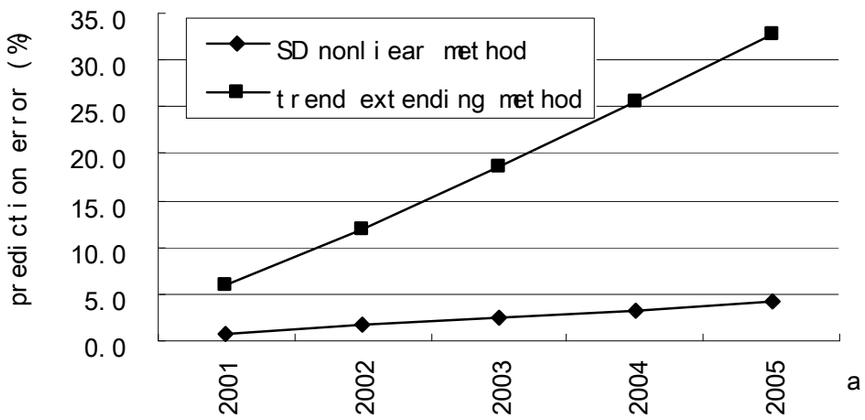

Fig. 8. The comparative analysis results

6. Conclusion

From above study, we can get the conclusion : (i) complex system analysis and nonlinear dynamics simulation are very useful for urban water resource demand forecasting and planning, (ii) the integrated model of SD-MOP can avoid the randomness of proposal designed by experiences of planners and decision-makers, which results in the generated planning proposal has high reliability.

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