SYSTEM DYNAMICS MODEL OF URBAN WATER RESOURCES USE AND IT's APPLICATION

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ABSTRACT

A new urban water resources use and forecasting model constructed by comprehensive considering the balance between the supply and demand of the water resources system to an industry city and the feedback relationship of the water resources control policy, and by applying DYNAMO language is presented in this paper.It can give more rational data of urban water resources simulation and planning than that given by the growth rate trend forecasting method.

key words:urban water resources,System Dynamics,forecasting model

Introduction

Urban water resources system is a natural system, being influenced by the human activities and reformed by humanity.The demand and the pollution of all kinds of political, economical, cultural, productional, living and enviroumental activities will act on the urban water resources system,and will make it become a complex system having all kinds of characteristic of social and natural system.

Complicated link has existed between each subsystem inside the urban water resources system. The macroscopic characteristics outside system has been displayed next property including finitility, dynamicality, regeneratability, nonreplacability,multiobjectivity, multipurposity,nonlinearity,and stochasticality [3].Due to the influence of the urbanization and industrialization, the acute contradiction in the unbalance between the supply and demand of the water resources appears in many urban regions.

Water resources has become an important restrictive factor of urban development.It's necessary to reasonably assess the present situation and to predict the future condition of development trend of urban water resources for supply and demand,to formulate an apporpriate policy of exploitation and management,if effective development and using of water resources are expected.As a result of the outside factors of politics, economics, technique, construction investment, policy, management and etc, which can give the effect to the supply and demand of water resources,but the forecasting result of present statistical method is always difficult to accord with the actual situation [4]. Because the complex system has both social and natural system characteristics, it can be essentially said that which can not be reasonably described with a simple mathematical formula

In this paper,for studying complex system,a computer simulation method has been adopted and the system dynamics simulation model has been constructed. These can be used to comprehensively and deeply simulate the past and present situation of the urban water use, and can further forecast the future water resources supply and demand development trend, and can provide data for the planning and management decision as well. Hence,this method can give rather satisfatory result in the practical application.

Construction of The System Dynamics Model of Urban Water Resources

The system dynamics [1] considers that system is a dynamic system consisting by a series of the information feedback hoop and having the complex feedback relationships.

According to actual construction analysis of a urban water resources system, by considering the balance between the supply and demand of system, the control of water quality,the re-use of sewege,the development of economy,the rational distribution of investment, the policy of exploitation and management, and the feedback relation of water policy, the model has then been established.

The model contains eight parts as follows:

<1>Water source,including surface reservoir,underground reservoir, surface run-off, diversion water from another watershed, and sewege re-use ;

<2>Water supply, including surface and underground water quantity used by industry,agriculture,daily life,and vegetable fields,etc;

<3>Water use, including various water uses and losses;

<4>Water demand, including various demand of water planning in the year 1995, 2000, and 2025;

<5>The balance between the supply and demand, considering the balance of water quantity of all urban region and each subregion;

<6>Water saving and sewege treatment, considering the feasible measurement of saving, the costs in industry, agriculture, daily life, and the sewege treatment.

<7>Water quality and sewege re-use, considering various target of water use quality and environment standard;

<8>The requirement of regional economic development and the capability of investment, etc.

The construction of model is shown in fig.1:

It can be seen that in urban water resources system the water-use subsystem is important constitutive part, which closly connected with the subsystems of water supply, water demand, water saving, water reuse and management control, and can also divided into subsubsystems of industrial water use, agricultural water use, daily life water use,public water use and environmental water use.

If isolatedly analyzing the water use system and only considering physical link, then it can't reflect the characteristic of this subsystems perfectly, of course. In Fig.1 , the solid lines express physical link of water quantity, and the dotted lines express informational link of feedback.Since system dynamics method has been used comprehensively to study this system and to analyze developing tendency of the urban water use system under the action of dynamic constrain and the mutual influence between the external environment and the internal facters,therefore, the prediction of the future water use situation has been given in this paper as well.

Due to the fact that this structure adds factor reflecting management policy into water resources model, and uses mutual relation between supply-demand balance of water resources and investment cost to simulate, hence which can reveal the moving process and the result of certain policy and certain scheme,and can help us to know and to grasp the developing regularity of urban water resources system. Therefore these models has become a laboratory of water resources planning.

Application of Model and The Result of Simulation

1) The determination of variants of water-use prediction model of Chang-Zhi city

Chang-zhi city is an industrial city of energy source & heavy

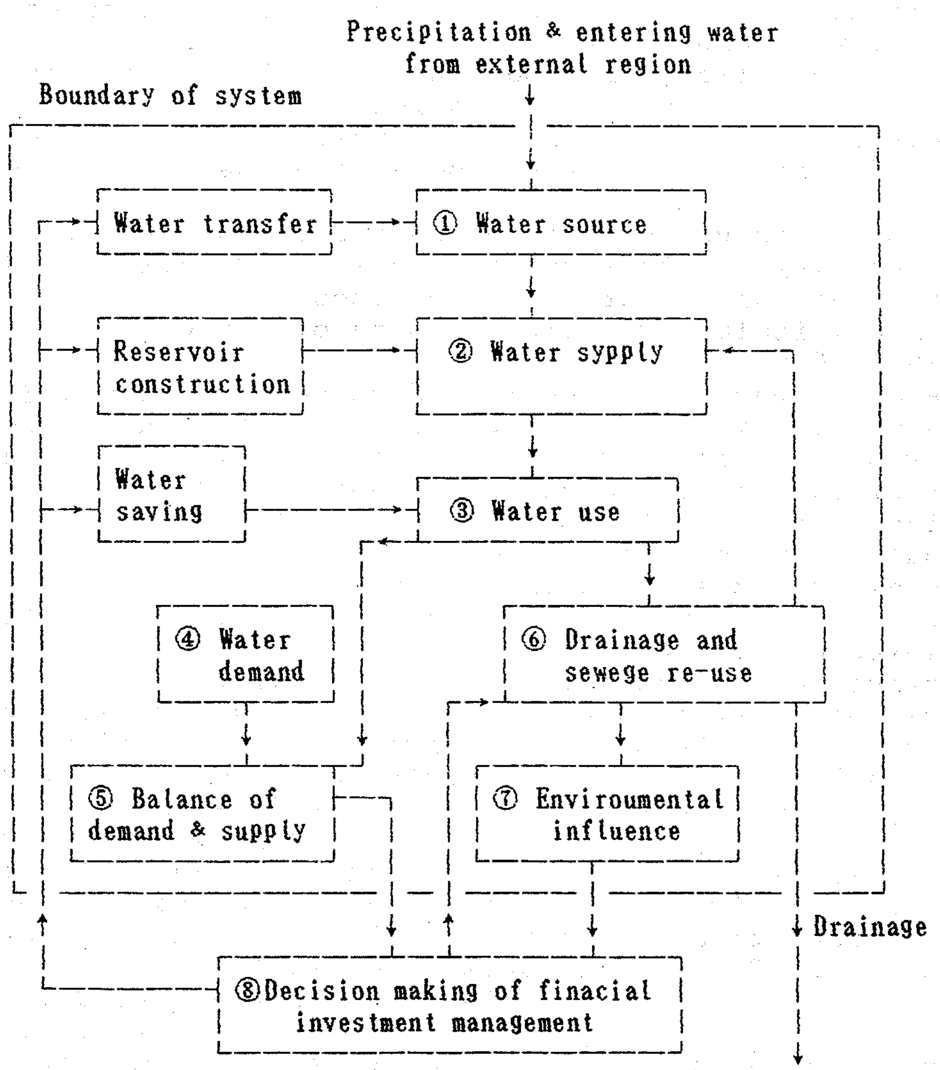

Fig.1 Structural Diagram of Urban Water Resources System

chemistry industry in Shan-xi province of north China. This city is having a total area of 13900 km2 & population of 2.56 million. The exploitation & utilization of water resources still has a suitable big potentiality. According to the actual situation of Chang-zhi city, the duty of model is to predict the water-use situation & its developing tendency of Changzhi city during 40 years from 1985 to 2025, and to provide a concept of development of water use quantity during comparatively long period with the economic development & the increasing of living standard. Then it will be able to adopt corresponding measure to regulate the layout of industry, to reform water use technology,and to work out a rational planning.

According to the planning requirements, there is a necessity to determine four main water-use variants which include water use quantity for general industry, for electric power industry, for agriculture and for daily life.

Water use quantity for electric power industry is determined by the magnitude of installation capacity of thermal power station and the repeated utilization rate.

Water use quantity for general industry includes all other industrious water use quantity, but which doesn't include the water use quantity for electric power industry, and it should be calculated by the water use quantity which can produce 10000 yuan value of product and by the magnitude of the industrious production value.

Daily life water use quantity is referred to the sum of daily life water use,pablic facility water use and daily life water use of population of Chang-Zhi city & all rural area, which will be calculated by the water use quota per capita and number of population.

Agriculture water use quantity is referred to the water use of vegetable land, water use for cattles and water use of irrigated land. According to the area of vegetable land, number of cattles, area of irrigated land and its corresponding water use quota, amount of agriculture water use can be accounted.

For determing above four water-use quantity, these variants, that is the exploitation and utilization rate of water resources, the population, the area of irrigation, the level and standard of water use, the value of industry product, the level of management, the repeaed utilization rate, the sewege treatment, and the environmental protection , are to be used as inside variants in the design of model. Variants of the natural water resources, the requirment of economical development, the policy of developing investment etc,are taken as outside variants.The numder of variants totalled 241 in model,among which number of state variants is 39.

2) Models relation of main informational feedback

The main cause & effect feedback relation of this model has been shown as Fig.2. It can be seen that the main feedback loops are 5 positive loops & 5 negative feedback loops, and can be stated as follows:

<1>Increasing factor of exploitation and utilization rate of wa-

ter resources --- Exploitation and utilization rate of water resources--- Increasing factor of exploitation and utilization rate of water resources;
<2>Quantity of usable water resources---Difference between supply & demand --- Pressure of water shortage --- Increasing factor of exploitation and utilization rate of water resources --- Exploitation and utilization rate of water resources --- Quantity of usable water resources;
<3>Difference between supply & demand --- Pressure of water shortage --- Daily live water use level --- Daily life water use quantity--- Total water demand --- Difference between supply & demand;
<4> Difference between supply & demand---Pressure of water shorta-

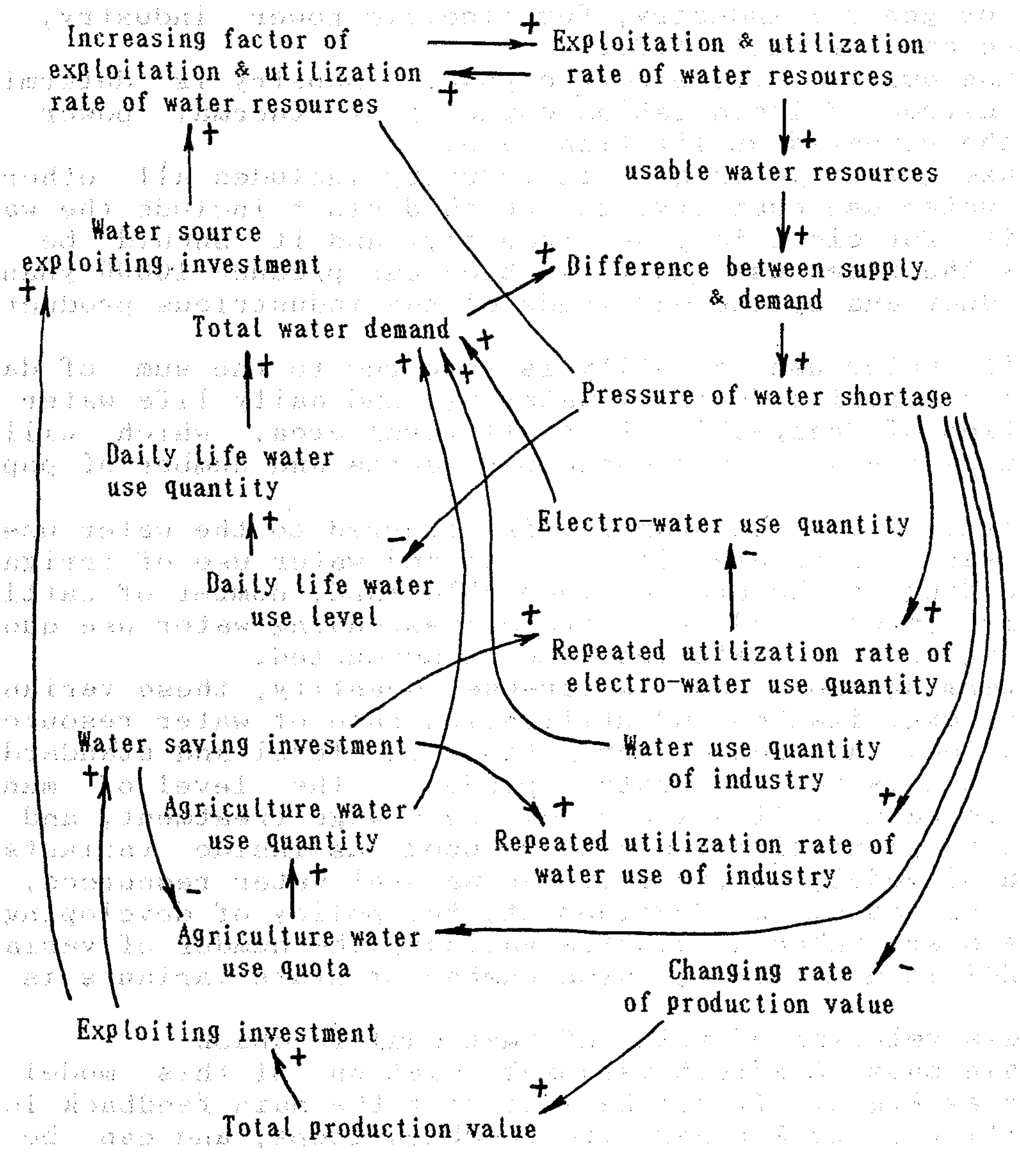

Fig.2 Simplified Diagram of Feedback Ralation of Water-use System

ge --- Repeated utilization rate of water use of industry --- Water use quantity of industry --- Total water demand--- Difference between supply & demand ;
<5>Difference between supply & demand--- Pressure of water shortage --- Repeated utilization rate of water use of electric power industry --- Water use quantity of electric power industry --- Total water demand --- Difference between supply & demand ;
<6>Difference between supply & demand--- Pressure of water shortage --- Agriculture water use quota --- Agriculture water use quantity --- Total water demand--- Difference between supply & demand;
<7>Water source exploiting investment --- increasing factor of exploitation and utilization rate of water resources --- Exploitation and utilization rate of water resources---Quantity of usable water resources--- Difference between supply & demand--- Pressure of water shortage --- Changing rate of production value --- Total production value --- Exploiting investment --- Water source exploiting investment;
<8>Water saving investment --- Repeated utilization rate of water use of industry--- Water use quantity of industry --- Total water demand --- Difference between supply & demand --- Pressure of water shortage --- Changing rate of production value--- Total production value --- Water saving investment;
<9>Water saving investment --- Repeated utilization rate of water use of electric power industry --- Water use quantity of electric power industry--- Total water demand--- Difference between supply & demand --- Pressure of water shortage --- Changing rate of production value---Total production value--- Water saving investment;
<10>Water saving investment --- Agriculture water use quota--- Agriculture water use quantity --- Total water demand ---Difference between supply & demand --- Pressure of water shortage --- Changing rate of production value --- Total production value --- Water saving investment.
The flow diagram of feedback relation can be illustrated as Fig.3.

3) Model operation & simulation result

Calculation data of model is by reference to the corresponding data from other cities and can be determined by the actual situation of Chang-Zhi city.Using actual measuring data of period 1980 to 1986 for verification with the result of simulation, the results demonstrate that the model is feasible & the parameter selected is suitable.

Data input to the model include years mean runoff values and its Cv, Cs of Chang-Zhi city, inflow water data and other parameters and initial value which were made up according to stochastic simulation method and obeyed distribution of Pearls-3rd type curve.

After transferring all these numerical values into model, the operated results and changing curve of water use can be shown as fig.4.

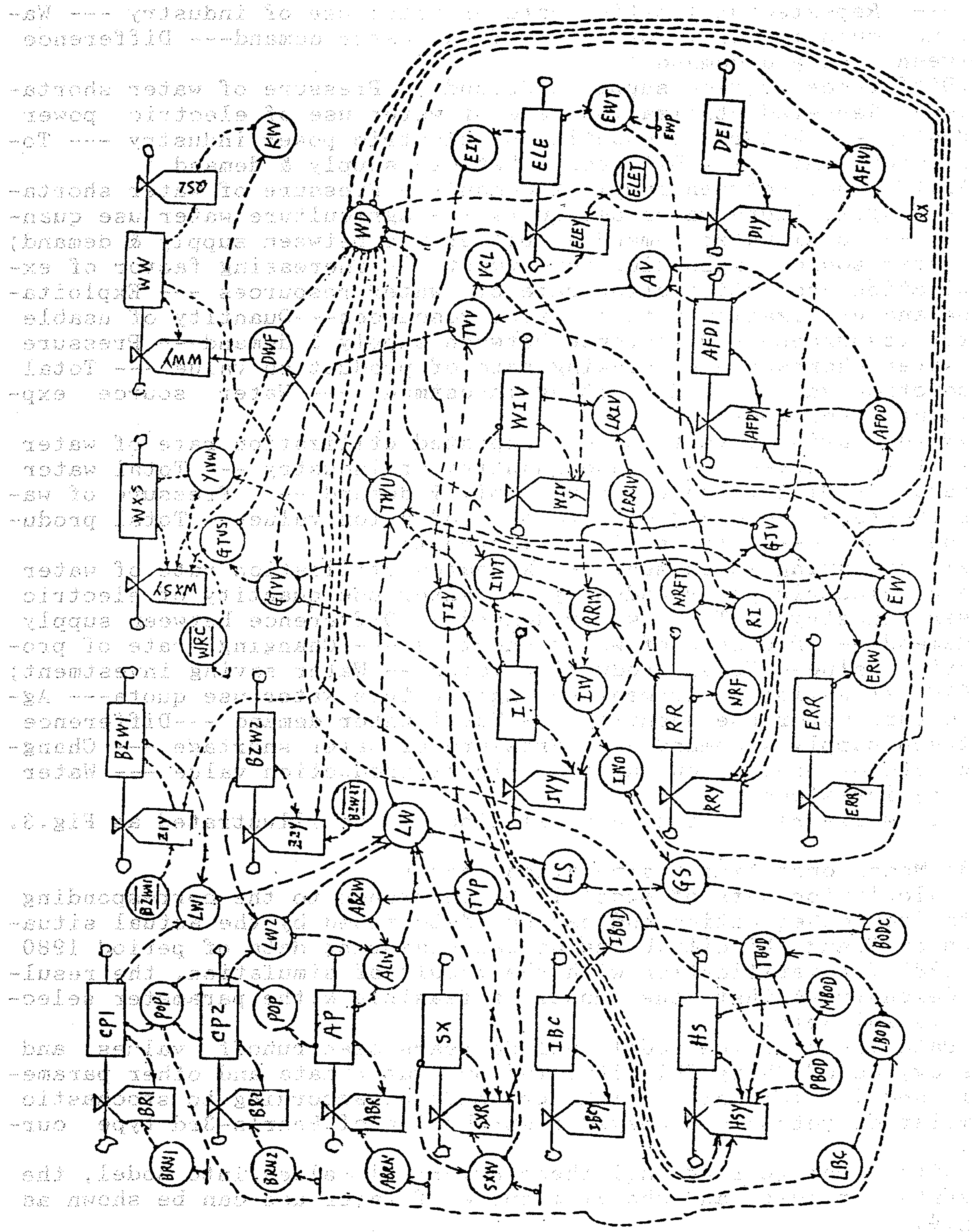

Fig.3 The Flow Diagram of Water-use SD-Model

Main Variants In Fig.3 (alphabetically arranged)

AFD1---Irrigated area of farmland;
AFW1---Water-use quantity of Irrigated agriculture;
AP-----Number of population of countryside;
AV-----Production value of agriculture;
CP1----Number of population of Chang-Zhi city ;
CP2----Number of population of towns;
DE1----Irrigated quota of rual area;
ELE----Installed capacity of thermal power station;
ERR----Repeated rate of water use of electric power industry;
EW-----Net demand water quantity of electric power industry;
GS-----Total quantity of sewege;
GTVV---Exploiting investment;
HS-----Capability of sewege treatment;
IBOD---Industry excreted BOD;
IV-----Production value of industry;
IW-----Net demand water quantity of industry;
RR-----Repeated water use rate of industry;
SX-----Number of cattles;
TWU----Total demand water quantity;
TVV----Total production value;
WD-----Target for pressure of water shortage;
WIV----Water-use quantity of 10000 yuan production value;
WRC----Natural coming water quantity;
WW-----Stored water quantity of reservoir;
WXS----Exploitation & utilization rate of water resources;
YWW----Usable water quantity;

In fig.4, electric power water use curve E will gradually increase with steps form. Until after year 2010, this curve will become stable and reduce stepdown. This is due to the fact that the development of electric power industry before year 2010, a great part of construction awaiting electric power plant will gradually commence to construct, following the increasing of total installation capacity of electric power, the water demand will increase as well.

But following the development of economy, water use from different departments will also increase, water resources can not satisfy the demand of water use, water shortage pressure will also increase, then this situation will compel the electric power industry to increase the repeated utilization rate of water,so as to cut down the using of fresh water.

But the increasing of the repeated utilization rate will be influenced by water saving investment. Only there is enough investment, repeated utilization rate can then be increased.

Daily life water use curve is a gradually escalating curve. Before year 2025,the population of Chang-Zhi city will continuously increase. According to the planning birth policy, the natural increasing rate of population will drop. Though the total sum is increasing , but the tendency of increasing rate is gradually becoming slow. Following the increasing level of economy,the water use per capita will gradually increase which will be expressed by the increasing of daily life water use year after year. But following the shortage of water resources, the water supply pressure will increase, the raising of the level of water use per capita will again be restricted .

Water use curve I of industry will increase with time.But until after year 2010,the increasing range will obviously become small. One reason is that the more increasing of the repeated rate of water use, the more difficult is the increasing. Another reason is that the development of industry will be restricted by the supply of water resources. At this time, if there is a need to continually develop industry, the only way is to adjust the production structure, to develop industry of less water use, then the amount of industry water use will approach to a stable value.

The change of agriculture water use curve A will change with the inflow of natural water.

The inflow process of natural water is a stochastical curve. It makes the agriculture water use curve fluctuated rigorously with the rich or poor exchange of the inflow water.

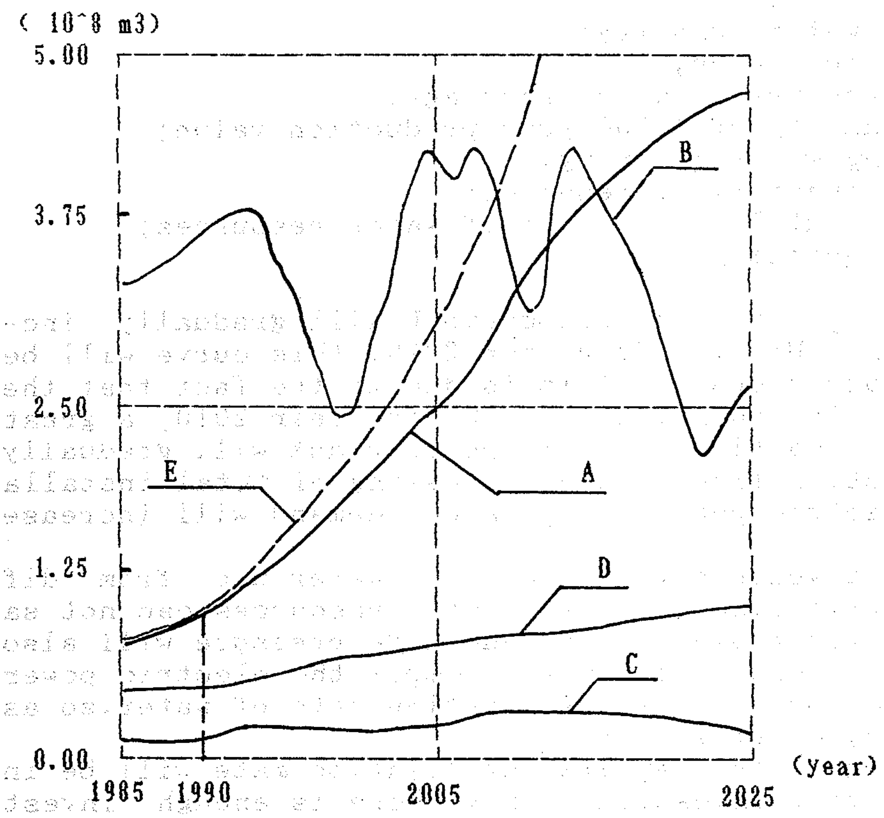

Fig.4 The Result Diagram of Water-use Simulation Curve
A -- Industry Water use quantity
B -- Agriculture Water use quantity
C -- Electro-industry Water use quantity
D -- Daily Life Water use quantity
E -- Industry Water use quantity (The Growth Rate Trend Method)

4). Analysis of the calculation result

The water resources planning of Chang-Zhi city has been adopting tendency method to predict the amount of industry water use and urban daily life water use. It can be seen in Fig.4 that the increasing of amount of water use is approximately increased by exponential function. Following the increasing of the year, the increasing of amount of general industrial water use approaches to infinity. This is not coinciding with reality.

The operation result of this model demonstrates the future amount of water use will gradually stabilize on some finite value. It reflects composite state characteristic of the coupling of multilevel positive and negative feedback loops.This result by using feedback loop groups to discribe complicated system and by using actual measuring data to verificate is more close to the reality of the system.

Conclusion

Through the establishment and operation of the urban water resources system dynamics model, and through the calculation result obtained, the following points can be concluded:

1) The system dynamics method to be used for strategic prediction of water resources utilization is a method having better effect.This paper provides a new way for the link beteen the macroscopic planning and the microscopic calculation of water resources. The result of prediction is more rational than the traditional tendency prediction method.

2) System dynamics model reflects the structure of water resources. This method can reveal the changing process of water resources,will increase the perceptual cognition to the planner and decision maker, and will be benefit for finding the key of the issues, for making the decision of the alternative, for providing more reliable numerical data.

3) If water resources has a close relationship with the natural system of astronomy,meteorology, hydrology and so on, then after further studying the software link between this model and the aforesaid models,the application range of this model can be extended as well.

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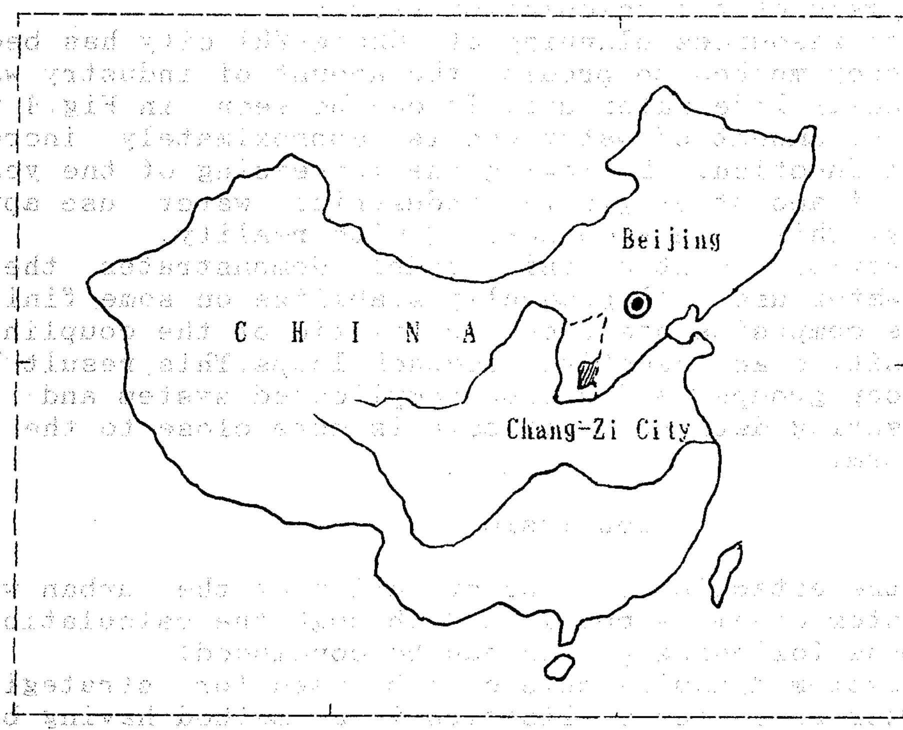

Fig.5 Position of Chang-zi City in CHINA