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T3 ________________	Problem Chosen	F3 ________________
T4 ________________	**E**	F4 ________________

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MCM/ICM

Summary Sheet

Application of System Dynamics to Regional Water Resources Carrying Capacity Evaluation

Summary

Lack of freshwater resources is a common problem in the world. Nearly one billion people around the globe lack access to clean, safe water. It's a common problem in many parts of the developing world, but its severity and human impact are not widely known.

Thus, firstly in Task 1, we collect a huge data sample around the world. Depending on the data, we can find the common system structures of water, analyzing the relationship between them and the flow direction of water. Then, we build **the system dynamics (SD) model** of water in a region, which contains **five subsystems**.

In Task 2, we choose **Beijing** from those countries with water heavily overloaded. To explore the reasons of its water shortages, we take climate, hydrology, economy and facilities factors into account. Then in Task 3, in order to predicate the water situation after 15 years, we calculate all of 75 Parameters first of all. But some parameters are so particular that we have to make assumptions according to the data.

However, we found that **WSI** is not appropriate for Beijing. The domestic water takes huge part of the total water, while the industrial and agricultural water isn't important. With little average water resource amount per capita, **domestic water consumption per capita (DWCPC)** can be large, which shows that the water shortages are not that serious. Therefore, we take domestic water consumption per capita as the new water stress index. **Sensitivity** is also discussed in this section.

After designing an intervention plan by the factors in Task 2, we calculate the situation in the future. The water shortages will be just released temporarily in 2030 with 345.37m^3/yr DWCPC. However, it's sad to know that only depending on limited interventions the water shortages will appear once again in 2049. To solve the long-term water shortage, we must continue to improve the technology. Only in this way can we live in a world without worrying about water.

Keywords: system dynamics model, water stress index, water shortages, sewage recycling

1 Introduction

1.1 Background

As we all know, water is one of the indispensable conditions to human survival. If there no water, there would be no life existence. Although about three-quarters of the global area is covered with water, only one percent can be used.

Lack of freshwater resources is a common problem in the world. Nearly one billion people around the globe lack access to clean, safe water. It's a common problem in many parts of the developing world, but its severity and human impact are not widely known.

There are two primary causes for water scarcity: physical scarcity and economic scarcity. Physical scarcity is where there is inadequate water in a region to meet demand. Economic scarcity is where water exists but poor management and lack of infrastructure limits the availability of clean water.

Therefore, it is extremely important to carry out an in-depth study of the regions where are suffering from water shortage, and make the corresponding intervention plans according to the research results to alleviate the water resources crisis.

1.2 Our Work

In order to address problems above and provide an Effective intervention program, we conclude five sub-problems to tackle in our paper.

1) Develop a system dynamics (SD) model that provides a measure of the ability of a region to provide clean water to meet the needs of its population.

2) Select a region and analyze the reason of water shortage from the natural environment and social economy factor by addressing physical and/or economic scarcity.

3) Prediction of the supply and demand of water in a period of fifteen years (2015-2030) based on the SD model we have built.

4) Model building of the Intervention plan, including regional water pollution treatment and the sea water desalination plants and discuss the impact and the overall strengths and weaknesses of the plan

5) Use the intervention we designed and SD model to predict water availability into the future.

In the whole modeling process, we give full consideration to validity and feasibility of our model.

2 Assumption

1) The change of total population has nothing to do with the water supply, and the domestic water consumption per capita can be calculated by the total water supply and the total population. The population of a region is related to many factors. There was no significant relationship between change of total population and total water without death.

2) Sewage can be recycled and reused in the system several times. In real life, the water is constantly flowing. We don't have to think about the storage of waste water or the amount of

surprise that the amount of wastewater is greater than the total amount of water.
3) Those parameters declared by the government have fixed value or are linear with time.

3 Models

3.1 Model Overview

SD Water Model is composed by subsystem of available water resources, industrial water, agricultural water, total domestic water and total domestic water.

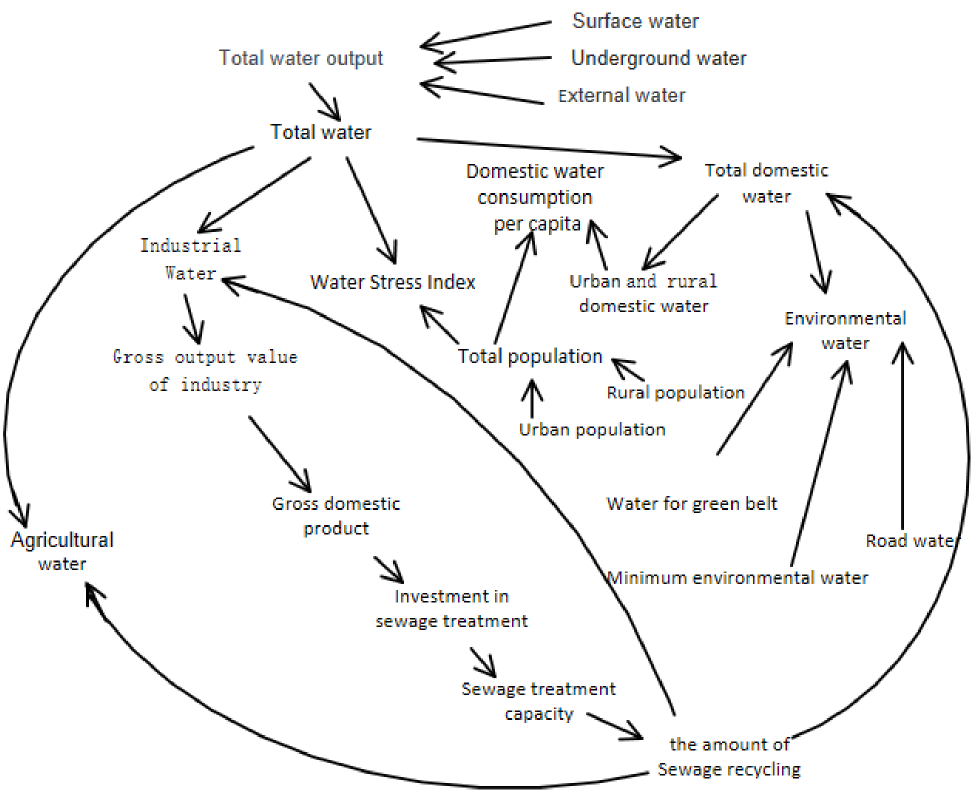

Figure 3-1 SD Water Model Overview

3.2 The subsystem of available water resources

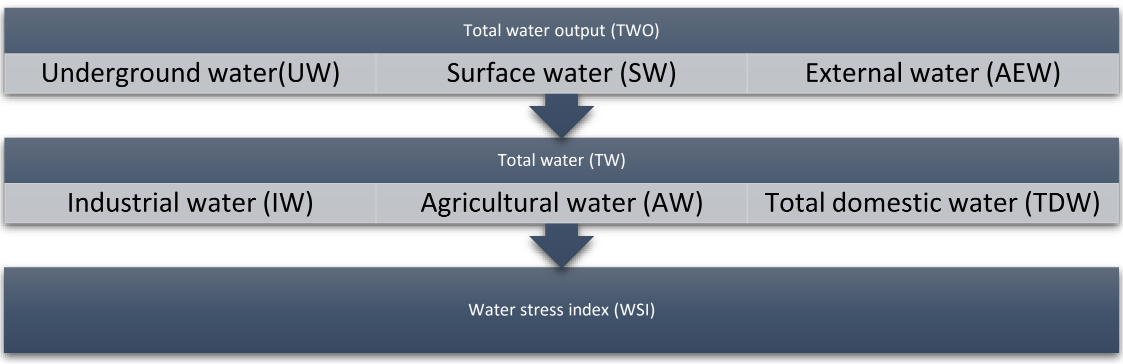

Figure 3-2 Subsystem of available water resources

In the subsystem of available water resources, total water output (TWO) consists of surface water (SW), underground water (UW) and the external water (AEW). Total available water (TAW) is selected as the state variables. It is calculated by total available water growth rate (TAWGR).Since it comes from total water output, total available water (TAW) should be less than total water output(TWO) .When considering water purification, purified sea water (PSW) is adjusted as the auxiliary variable input in to the model. The total available water quantity is multiplied by the industrial, agricultural and domestic water distribution coefficients (DCIW＆ DCAW ＆ DCTDW), and distributed in the industrial, agricultural and domestic water subsystems. The SD equations of the subsystem are as follows:

A TWO=AEW+SW+UW+PSW

A TW=IF THEN ELSE (TAW>=TWO, TWO, TAW)

L TAW=INTEG (TAWG, TAW0)

R TAWG=TAW×TAWGR

C TAWGR=CONSTANT

Where

L: Equation of state

R: Equation of rate

A: Auxiliary equation

C: Constant

3.3 The subsystem of industrial water

In the subsystem of industrial water, industrial water consumption (IW) is the sum of total water (TW) and the amount of Sewage recycling (ASR) used in industry. The Gross output value of industry (GOVI) is the state variable of the system. It is influenced by the growth rate of industrial output (GOVIGR), and is also one of the indicators of water resources carrying capacity. The Gross output value of industrial growth (GOVIG) is influenced by the industrial water consumption (IW), the change of industrial water use (CIWU) and the efficiency of industrial water per cubic meter (EIWPC). The SD equations of the subsystem are as follows:

A IW=TW×DCIW+ASR×SRCI

A CIWU=TAWG×DCIW

A SRCI=CONSTANT

L GOVI=INTEG (GOVIG, GOVI0)

R (IW+CIWU) ×EIWPC

3.4 The subsystem of agricultural water

In the subsystem of agricultural water, agricultural water consumption (AW) is the sum of total water (TW) and the amount of Sewage recycling (ASR) used in agriculture. The gross output value of agriculture (GOVA) is the state variable of the system, which is influenced by the growth rate of agricultural output, and is one of the indicators of water resources carrying capacity. The gross output value of agriculture growth (GOVAG) is the rate variable, and it is influenced by the agricultural water consumption (AW), the change of agricultural water use (GOVA) and the efficiency of agricultural water per cubic meter (EAWPC). The SD equations of the subsystem are as follows:

A AWG=TAWG×DCAW

C DCAW=CONSTANT

C SRCA=CONSTANT

C WAWEG=CONSTANT

A AW=TW×DCAW+ASR×SRCA

L GOVA=INTEG (GOVAG, GOVA0)

R GOVAG=(AW+AWG)× EAWPC

3.5 The subsystem of total domestic water

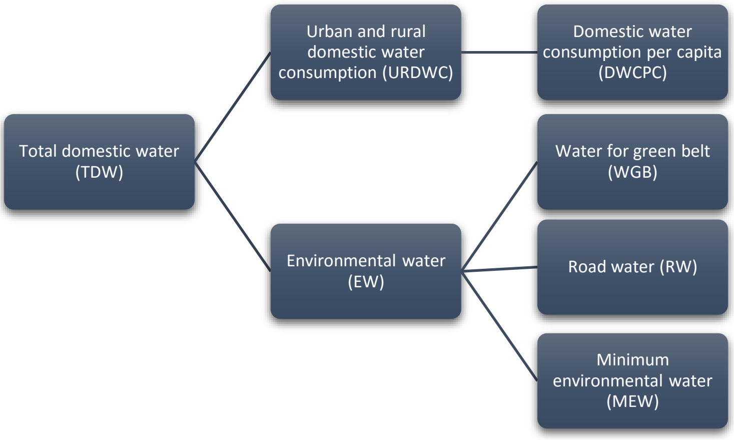

Figure 3-3 Subsystem of total domestic water

Total domestic water includes the environmental water (EW) and urban and rural domestic water consumption (URDWC). It comes from total water (TW) and Sewage recycling (ASR).The environmental water (EW) is the sum of water for green belt (WGB), road water (RW) and minimum environmental water (MEW). Water for green belt (WGB) and road water (RW) can be calculated by their area (GA＆RA) and water for unit area (WUAGB＆UARW). Minimum environmental water (MEW) is necessary to make rivers and lakes maintain normal. We can forecast the urban and rural population (UP＆RP).With the urban and rural domestic water consumption (URDWC), domestic water consumption per capita (DWCPC) can be calculated, which is an important indicator of water shortage in the region. The SD equations of the subsystem are as follows:

A TDW=TW×DCTDW+ASR×SRCE

C SRCE=CONSTANT

C UARW=CONSTANT

C RA=CONSTANT

A RW=RA×AARW

C GAGR=CONSTANT

R GAG=GA×GAGR

L GA=INTEG (GAG, GA0)

C WUAGB=CONSTANT

A WGB=GA×WAAGB

C MEW=CONSTANT
A EW=WGB+RW+MEW
L RP=INTEG (RPG, RP0)
R RPG=RP*RPGR
C RPGR=CONSTANT
A DWCPC= URDW/TP/365*10^11
A UDW= TDW-EW
A TP=RP+UP
A WSI= (TW+ASR)/TP*10^8

3.6 The subsystem of sewage treatment and recycling

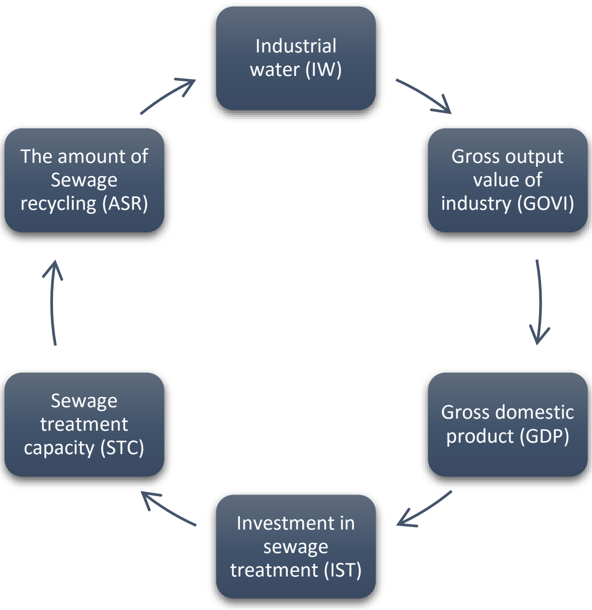

Figure 3-4 Subsystem of sewage treatment and recycling

Total discharge of sewage (TDS) comes from industrial water (IW) and total domestic water (TDW). It is determined by the coefficient of industrial sewage and domestic sewage (CIS & CDS). Sewage treatment cost will be deducted from the investment in sewage treatment (IST). The remains will be used to improve the sewage treatment capacity (STC).However, it should be less than the total discharge of sewage (TDS).Therefore we should restrict the sewage treatment capacity growth (STCG). Besides, according to the sewage recycling rate (SRR), only a part of sewage can be recycled (ASR). It will be distributed by the sewage recycling coefficient of industry, agriculture and environment (SRCI & SRCA & SRCE). The SD equations of the subsystem are as follows:

C CIST=CONSTANT
A IST=GDP×CIST
C STPUI=CONSTANT
A STR=STC/TDS
L STC=INTEG (STCG, STC0)
R STCG= IF THEN ELSE (STR<1, (IST-STC*Constant*10^ (-8))*STPUI, 0)

A ASR=SRR×STC
C CIS=CONSTANT
C CDS=CONSTANT
A TDS=IW×CIS+URDW×CDS

3.7 Nomenclatures

Table 3-1 Nomenclatures of all parameters

TWO	Total water output
AEW	The amount of external water
SW	Surface water
UW	Underground water
PSW	Purified sea water
TAW	Total available water
TAWG	Total available water growth
TAWGR	Total available water growth rate
TW	Total water
DCIW	Distribution coefficient of industrial water
CIWU	Change of industrial water use
IW	Industrial water
SRCI	Sewage recycling coefficient in industry
GOVI	Gross output value of industry
GOVIG	Gross output value of industry growth
GDP	Gross domestic product
GPDPPC	Gross domestic product per capita
EIWPC	the efficiency of Industrial water per cubic meter
AWG	Agricultural water growth
DCAW	Distribution coefficient of agricultural water
AW	Agricultural water
SRCA	Sewage recycling coefficient in agriculture
GOVA	Gross output value of agriculture
GOVAG	Gross output value of agriculture growth
EIWPC	the efficiency of industrial water per cubic meter
ASR	the amount of Sewage recycling
TAWG	Total available water growth
ISC	Industrial sewage coefficient
TDS	Total Discharge of Sewage
STR	Sewerage treatment rate
STC	Sewage treatment capacity
STPUI	Sewage treatment per unit investment
IST	Investment in sewage treatment
CIST	Coefficient of Investment in sewage treatment
GDP	Gross domestic product
CLS	Coefficient of life sewage

ASR	the amount of Sewage recycling
SRR	Sewage recycling rate
UDW	Urban domestic water
TW	Total water
TDW	Total domestic water
DCTDW	Distribution coefficient of total domestic water
SRCE	Sewage recycling coefficient in environment
UDW	Urban domestic water
UDWCPC	Urban domestic water consumption per capita
UP	Urban population
RP	Rural population
RPG	Rural population growth
RPGR	Rural population growth rate
TP	Total population
RDWC	Rural domestic water consumption
RDWCPC	Rural domestic water consumption per capita
GA	Green area
GAG	Green area growth
GAGR	Green area growth rate
WGB	Water for green belt
WAAGB	Water for average area green belt
EW	Environmental water
MEW	Minimum environmental water
RW	Road water
AARW	Average area road water
RA	Road area

4 The situation of water resources in Beijing

The problem of water shortage in Beijing is caused by both geographic and social factors.

4.1 Climate factors

Precipitation is the main replenishment of water resources in Beijing. However, Beijing is located in the warm temperate zone and annual precipitation is about 595 mm, 60%~70% of that is loss from evaporation but just only a few becomes runoff or sinks into the ground. What's worse, the north and west of Beijing is higher than the other places, which is very bad for storage of natural precipitation and more likely to cause drought.

Besides, as precipitation reduces temperature rises and evaporation increases, it causes much drought. At the same time, the annual precipitation change greatly and irregularly.

In the nearly hundred years, precipitation varies widely, as the maximum and minimum rainfall is 23.62 billion and 4.07 billion respectively. Furthermore, it often appears continuously rough periods and there exists two long drought periods: 1940-1945, 1980-1985.In addition to the uneven distribution of precipitation per year, rainfall is not evenly distributed within a year. The precipitation in summer (June - August) accounted for over 76% of the annual precipitation, while the precipitation in water peak period, spring (March-May), is less than 60mm, and that in winter is only 10mm.

Table 4-1 Changes of temperature and precipitation in Beijing Observatory

Time	1950	1960	1970	1980	1990	2000
Annual precipitation/mm	781.9	627.9	598.8	581.8	572.4	437.7
Annual temperature/℃	11.6	11.6	11.4	12.1	13	13

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Moreover, the precipitation was 1318.9mm from June to September in 1959, accounting for 93.8% of annual precipitation, whereas, the precipitation accounted for only 6.2% of other months.

4.2 Hydrology factors

90% effective surface water in Beijing comes from Guanting Reservoir and Miyun Reservoir. However, the amount of water is significantly reduced in the two reservoirs, which is related to overusing of water and the precipitation decreasing.

Table 4-2 available water in Guanting and Miyun Reservoir($\times 10^8 m^3$)

Time	1994	1995	1996	1997	1998	1999	2000	2001	2002
Miyun Reservoir	15.94	5.72	11.23	4.66	10.05	1.33	0.97	3.48	0.78
Guanting Reservoir	3.08	7.32	8.35	4.01	4.56	2.57	2.47	1.15	0.95
Summation	19.02	13.04	19.57	8.67	14.61	3.9	3.44	4.63	1.73

As for underground water, it also has the problem of excessive using in order to meet to the need. Besides, the large amount of polluted water sink into the underground, causing underground water pollution in the plain zone.

4.3 Economy factors

Building water conservancy works and expanding farmlands in upstream of Guanting Reservoir and Miyun Reservoir, even water-intensive industries, such as metallurgy， electric power, chemical industries, they cause the water in the two reservoirs decrease.

Water-using structure is irrational in the past 30 years. During the past 30 years, water for industrial and agricultural production is about 70% of the city. Especially, agricultural use accounted for half of the whole using of this city. It shows a problem that effectiveness of water using is not so high. In the nearly years, water for industrial and agricultural production have decreased a lot, and at the same time, tertiary industry's water using percent have increased.

Besides, as one of the largest cities of China, Beijing appeals to more and more people from other regions for its quantities of advantages and resources, which causes some urban diseases, the booming of population, water shortage, etc. We can conclude the amount of people who is participating in part time job from the following chart.

Table 4-3 population Statistics in Beijing (×10^8)

Time	2008	2009	2010	2011	2012	2013	2014
water-use population	1439.1	1491.8	1685.9	1740.7	1783.7	1825.1	1859
Year-end total population	1232.28	1247.52	1258	1277.92	1297.45	1316.34	1333.4

4.4 Facilities factors

According to the *National Statistical Office*, there are 700 km pipelines existing potential hazards and 900 km pipelines working overload of which the water leakage rate is 15.9%. 35 million cubic meters of water is wasted every year. Because of the rapid development of Beijing, the urban pipe network system has been out of date and need to be transformed. And some of the water conservancy facilities have also not worked well. It is necessary to pay attention to the design of water saving when the pipelines are reformed.

5 Model for Beijing

5.1 Water stress index

When describing water availability in a country, the Falkenmark Water Stress Indicator, which was developed by the Swedish water expert Falkenmark in 1989, is one of the most commonly used indicators. Originally, the indicator based on the estimation that a flow unit of one million cubic meters of water can support 2,000 people in a society with a high level of development, using Israel as a reference by calculating the total annual renewable water resources per capita. Water availability of more than 1,700m^3/yr is defined as the threshold above which water shortage occurs only irregularly or locally. Below this level, water scarcity arises in different levels of severity. Below 1,700m³/yr water stress appears regularly, below 1,000m³/yr water scarcity is a limitation to economic development and human health and well-being, and below 500m³/yr water availability is a main constraint to life.

But for Beijing, this indicator is not appropriate. As the capital of China, Beijing has a large population density and scarce water resources.

According to the model, when the WSI reaches 1751.08 m^3/yr, domestic water consumption per capita (DWCPC) increases to 2271.22 m^3/yr, which is 4 times the national average. And total water (TW) reaches 415.541 m^3/yr, which is 10 times the total amount of water in Beijing city in 2014.

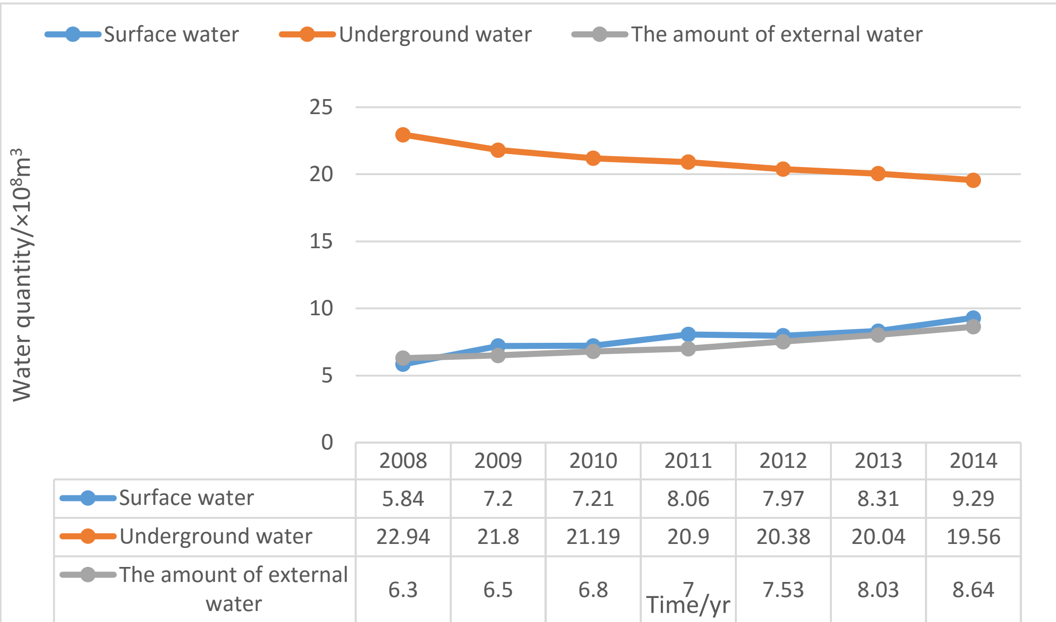
One way to solve the problem of water shortage in Beijing is the factory relocation to substantially reduce the IW and AW. The reason is that the tertiary industry in Beijing takes the lead all over the country, which becomes the main part of the GDP. The contribution of industry and agriculture to GDP is less than 20%. Reducing the scale of industry and agriculture will not have a great impact on the GDP. Besides, the tertiary industry takes little water. Therefore the government takes measures to increase the TDW, the proportion of TDW increased year by year.

In such a development model, WSI doesn't well reflect the situation of water resources. Normally the proportion of DWCPC is very small. However, the proportion of DWCPC in Beijing is very large. Taking external water (AEW) and Sewage recycling (ASR) into account, WSI is similar to DWCPC from 2008 to 2014. Therefore, WSI is not suitable for the evaluation standard of water shortage in Beijing. We should depend on DWCPC to evaluate the situation of water shortage in Beijing.

5.2 System Parameters

5.2.1 The subsystem of available water resources

Table 5-1 all kinds of Water quantity (×10^8m^3)



	2008	2009	2010	2011	2012	2013	2014
Surface water	5.84	7.2	7.21	8.06	7.97	8.31	9.29
Underground water	22.94	21.8	21.19	20.9	20.38	20.04	19.56
The amount of external water	6.3	6.5	6.8	7	7.53	8.03	8.64

The amount of external water (AEW) is

$$0.3861 \times (t-2007) + 5.7129\ (\times 10^8\ m^3)$$

Underground water (UW) is

$$-0.5168 \times (t-2007) + 23.04\ (\times 10^8\ m^3)$$

Surface water (SW) is

$$5.9314 \times (t-2007)0.2066\ (\times 10^8\ m^3)$$

Total available water (TAW) is

$$34.766 \times e^{0.0074 \times (year-2007)}\ (\times 10^8\ m^3)$$

Total available water growth rate (TAWGR) is

$$e^{0.0074} - 1 = 0.00743$$

5.2.2 The subsystem of industrial water

Sewage recycling coefficient of industry (SRCI) is 0.16

Distribution coefficient of industrial water (DCIW) is

$$-0.0038 \times (t-2007) + 0.178$$

Efficiency of industrial water per cubic meter (EIWPC) is

$$57.247 \times (t-2007) + 357.96\ (\times 10^{-8} yuan/\ m^3)$$

Therefore efficiency of industrial water per cubic meter growth (EIWPCG) is

$$57.247 (\times 10^{-8} yuan/\ m^3 \cdot yr)$$

Gross domestic product (GDP) is

$$GOVI \div [-0.0004 \times (t-2007)^2 + 0.0007 \times (t-2007) + 0.1908]$$

5.2.3 The subsystem of agricultural water

Sewage recycling coefficient of agriculture (SRCA) is 0.39

Distribution coefficient of agricultural water (DCAW) is

$$-0.0237 \times (t-2007) + 0.4177$$

Efficiency of agricultural water per cubic meter (EAWPC) is

$$4.4073 \times (t-2007) + 19.6\ (\times 10\text{-}^{8} yuan/\ m^3)$$

Therefore efficiency of agricultural water per cubic meter growth (EAWPCG) is

$$4.4073 (\times 10\text{-}^{8} yuan/\ m^3 \cdot yr)$$

5.2.4 The subsystem of total domestic water

Coefficient of Investment in sewage treatment (CIST) is 0.0108

Growth of sewage treatment per unit investment (GSTPUI) is 0.001 (m^3/yr·yuan)

Coefficient of domestic sewage (CDS) is 0.9

Coefficient of industrial sewage (CIS) is 0.8

Sewage treatment capacity growth (STCG) is

$$IST - 0.575 \times STC$$

Sewage recycling rate (SRR) is

$$0.1229 \times \ln (t-2002) + 0.2582$$

5.2.5 The subsystem of sewage treatment and recycling

Sewage recycling coefficient of environment (SRCE) is 0.45
Water for unit area green belt (WUAGB) is 0.958(m)
Unit area road water (UARW) is 1.141(m)
Road area (RA) is 1.3834 ($\times 10^8 m^2$)
Minimum environmental water (MEW) is 0.7041 ($\times 10^8$m3)
Distribution coefficient of total domestic water (DCTDW) is

$$0.0425\times\ln(t\text{-}2007) + 0.3701$$

Green area (GA) is

$$5.981\times e^{0.0235\times(t-2007)}\ (\times 10^8\text{m2})$$

Therefore green area growth rate (GAGR) is

$$e^{0.0235}=0.02378$$

Rural population growth (RPG) is

$$270.37\times e^{0.0172\,(t\text{-}2007)}$$

Therefore rural population growth rate (RPGR) is

$$e^{0.0172}=0.0173$$

Urban population (UP) is

$$188.07\times\ln(t-2007) + 1482.1\ (\times 10^4)$$

5.2.6 The initial value

In order to simulate the situation more accurately after fifteen years, we take the 2014 data as the initial value. The data are shown in the following table.

Table 5-2 initial value of system parameters

Parameter	TAW	GOVI	GOVA	RP	GA	STC
Initial value	36.38 $\times 10^8$ m^3	3748.8 $\times 10^8$yuan	420.07 $\times 10^8$yuan	2.94 $\times 10^6$	6.84 $\times 10^8$m2	8.468 $\times 10^8$ m^3

5.3 Sensitivity analysis

Sensitivity analysis is the study of the influence of model changes on the system results. There mainly are two kinds of influences on systems, one of which is the change of the system parameter; the other is the change of the system structure. In this study, the sensitivity analysis of the model is realized by changing the parameters or adding other parameters. By selecting a parameter that has a similar or greater impact on the system, each parameter can be increased or reduced by 10% as a variable. Due to the prediction time is 2015-2035, for each variable, each system parameter can be obtained corresponding to the 20 sensitivities. The mean values of these sensitivities are calculated as the sensitivity of the system parameters to the variable. Then the average value of the sensitivity of each parameter is obtained. So we can get the sensitivity of this variable to the whole system. The results of sensitivity analysis are shown in the table.

Table 5-3 the consequence of Sensitivity analysis

Parameter	GOVI	ASR	WSI	DWCPC	average
SRR	0.009194	0.119321	0.02028	0.037701	0.046624
CIST	0.001789	0.029124	0.004888	0.009088	0.011223
EIWPC	0.046739	0.009702	0.001619	0	0.014515
GAGR	0	0	0.001619	0	0.000405
TWO	0.013445	0.043757	0.056243	0	0.028361

The results show that the sensitivity of each parameter to system is less than 5%, and the behavior of the model is not sensitive to the reasonable variation of parameters. Thus the model has strong stability and can be simulated.

5.4 Simulation results

5.4.1 Impact of water

The total water supply is influenced by environmental factors. In the next 15 years, due to the excessive exploitation of groundwater in Beijing in recent years, the amount of underground water decreased rapidly. Due to the establishment of the new reservoir, Surface water increases. However, the utilization of surface water in 2014 has reached 86%, the construction of the new reservoir for SW impact is very small. The external water rises, along with the completion of the planned water transfer project. Although TWO remains virtually unchanged, the growing total available water needs are not being met.

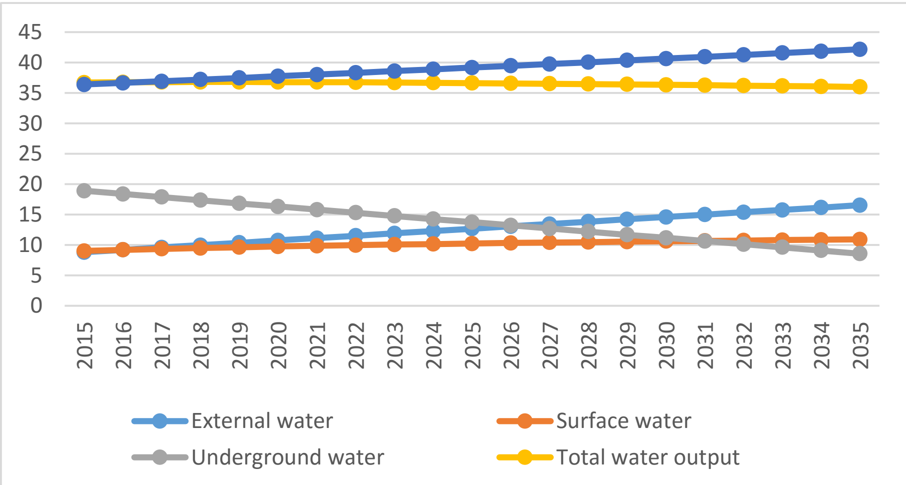


Figure 5-1 the changes of water in 15 years($\times 10^8$ m^3)

Beijing has serious water shortage. However, there is no serious social unrest, which shows that the model of social development in recent years has been adapted to the situation of water shortage. Because the data used in this model are nearly ten years, it is simulated that the water shortage type of development of Beijing. The government implements factory relocation and invests sewage treatment. However, under such a simulation, Beijing still appears such a phenomenon of water shortage that TWO is less than TAW. It shows that with the existing policy, only relying on the natural supply, Beijing's water shortage problem will be more serious.

5.4.2 Impact of economy

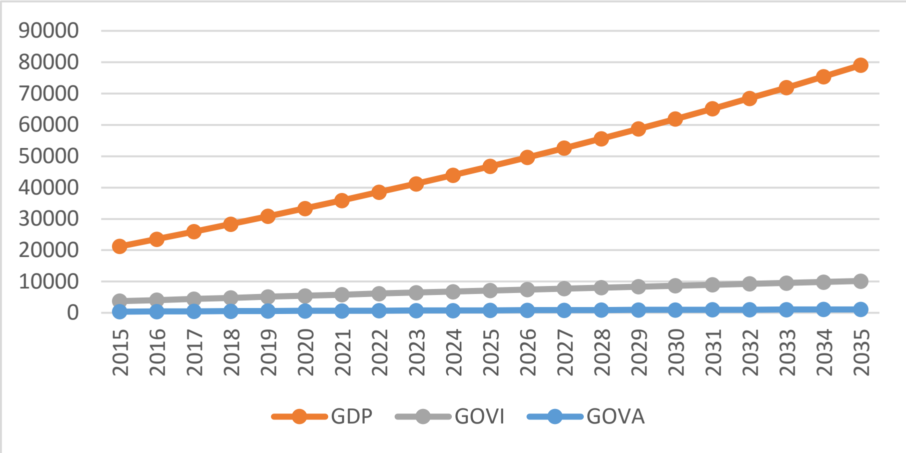


Figure 5-2 the changes of gross domestic product value (×10^8yuan)

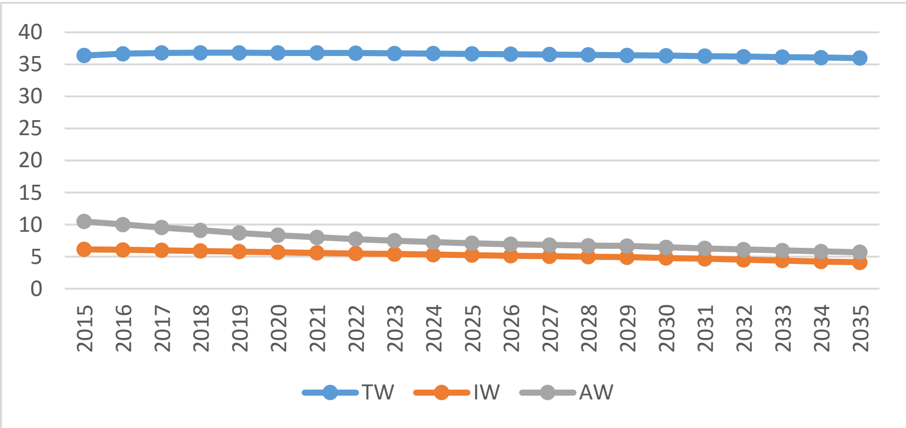


Figure 5-3 the changes of industrial and agricultural water (×10^8 m^3)

In this model of development, more and more factories are moving to the surrounding area. Because the scale of agricultural production is reduced, AW and IW are decreasing year by year However, due to scientific and technological progress, equipment improvement and other reasons, the rapid rise of EAWPC and EIWPC make the GOVI and GOVA rise. However, the growth rate continued to slow down.

But with the rise of the tertiary industry, the proportion of GDP which GOVI account for is lower and lower, while the GDP is rising and its speed is very fast.

5.4.3 Impact of sewage system

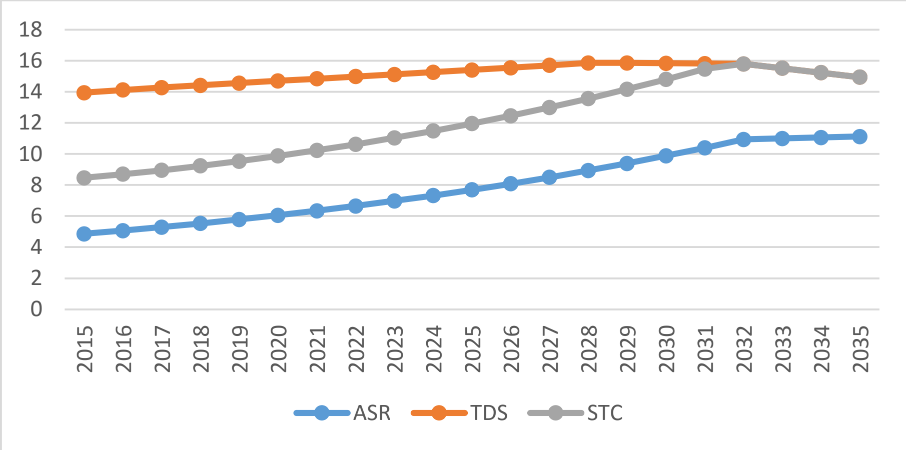


Figure 5-4 the changes of sewage recycling (×10^8 m^3)

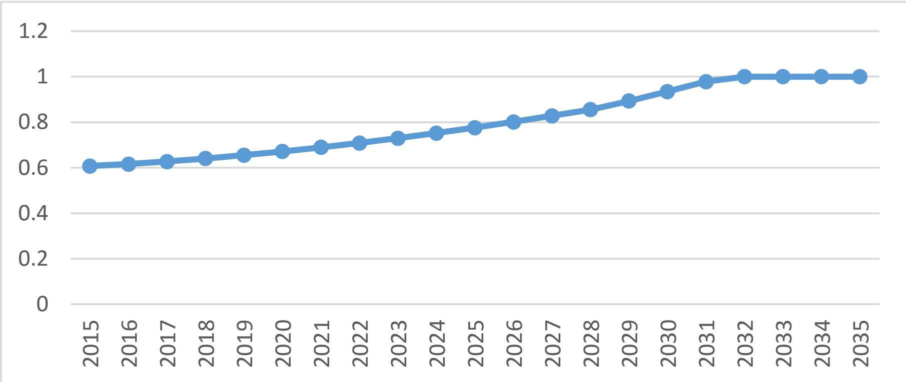


Figure 5-5 the changes of sewage treatment rate

In addition to the factory relocation and other water-saving methods, another measures taken by the government is to increase investment in sewage disposal. The figure indicates that maintaining the existing investment ratio, 93.5% of the TDS was purified in 2030. However, due to the impact of ASR, SRR is only 62.4% of TDS. At the same time, EW gradually increases. EW will not be turned into waste water. So it makes ASR increases slowly and eventually reach the limit. However even in this case, ASR is only 1/3 of TW. This shows that investment in sewage treatment project is an effective way to solve the problem of water shortage. However, since EW and Aw will not become waste water. With little TWO, even if a large number of sewage treatment investment makes STR reach 100%, it is still difficult to solve the problem of long-term water shortage.

5.4.4 Water stress index

When calculating DWCPC and WSI, we take the ASR into consideration. Because it is more consistent with the actual situation. According to data released by the government, the government does not take the ASR into account. As a result, the WSI and DWCPC which we calculated is higher than the government's data. The figure indicates that even if the sewage treatment have eased the water shortage, due to the increase in population, DWCPC and WSI continue to decrease. They are still far less than the national average. WSI is still less than 500 ×10^{8}m^3/yr. So we can see that Beijing's water is still heavily overloaded in 2030, which shows that water shortage problem has not been resolved. Instead, it becomes more serious.

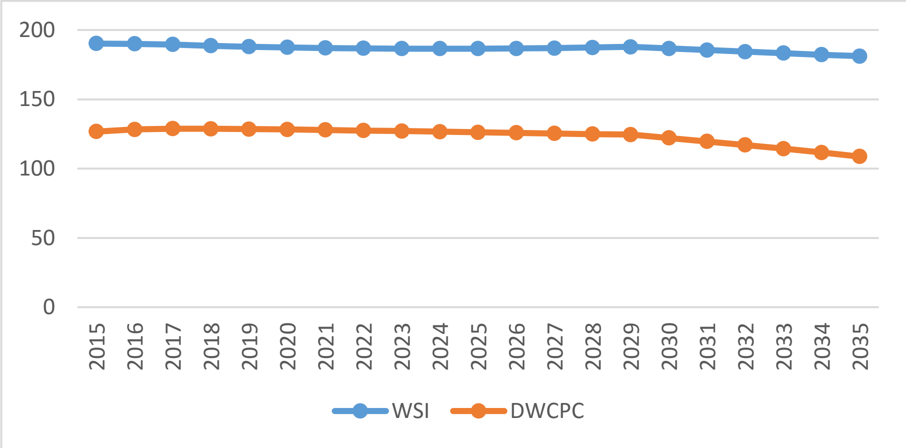


Figure 5-6 the changes of WSI and DWCPC (×10^8m^3/yr)

6 The Intervention plan

From the analysis of task2, the water shortage in Beijing is caused by geographical and social factors. Relevant data shows that Beijing's per capita water consumption is less than 200 tons, far below the international standard of extreme water shortage which is 500 tons per capita. In 2012, for example, the total amount of water in Beijing is about 36 tons. The amount of water shortage will be at approximately 1.1 billion tons. The following interventions can be developed to alleviate the water shortage in Beijing.

6.1 Cross-regional project of diverting water

Building the cross-regional project of diverting water to redistribute the water is able to ease water shortages in Beijing and other northern areas. However, south-to-north water diversion project costs huge money and, on the contrary, its consequence is terrible. So we don’t take it into account. But the project is building. When rest of the project is completed, about 1 billion cubic meters of water will be diverted to Beijing annually.

6.2 Adjust the industrial and agricultural structure of Beijing

For Beijing, industrial and agricultural water consumption is relatively large. As a national political and cultural center, industrial production and agricultural production is not important for Beijing. Therefore, the relocation to around areas of some factories is necessary.

6.3 Build rainwater collection system

Obviously, the development of the rural rainwater collection industry could improve the water supply capacity. The amount of average annual rainfall in Beijing is about 10 billion m^3.Assuming that 20% of the rain could be collected through the rain collection industry, there are 2 billion m^3 water. Therefore, under the conditions of water resources in Beijing City, it is an important direction to solve the water shortage. Beijing's total area is about 1 million and 680 thousand Hm2. if we can build a 200 thousand Hm2 rain collection industry, the average annual rainfall collected can reach more than 1 billion m^3, equivalent to the amount of water transferred by the south-to-north water diversion project. It can be believed that the cost of rainwater collection should be much lower than the south-to-north water diversion project. At present, there are a lot of researches about the rainwater harvesting technology in other countries, and it can be introduced to Beijing.

6.4 invest sea water desalinization

Caofeidian is about 200 km away from Beijing. Its geographical position is superior. Under the influence of ocean currents, the water in Caofeidian is clean, with a national class II water quality. Its Water quality is significantly better than other areas of the Bohai Bay so that the pretreatment is more convenient. The natural advantage from water quality is likely to unleash the growth potential of seawater desalination.

At present, the Government has approved the construction of desalination plants in caofeidian. From the perspective of operation, 1 ton of water costs about 5 Yuan. If diverting desalinated water to Beijing, we need to build 270 km long aqueduct, which will cost 10 billion yuan. Eventually it costs about 8 Yuan for each ton of water, but the cost is still lower than the cost of diverting water from the South. Considering we has built enough sea water desalination plants and the production finally reached 2.8 million tons, annual water supply to Beijing will exceed 1 billion tons.

6.5 Increase the investment of sewage treatment

After completing above plan, the total amount of water in the system will increase rapidly in a short time. With the sewage treatment capacity nowadays is difficult to deal with all the sewage. Therefore, we should improve the investment of sewage treatment, so that the sewage purification capacity will meet the increasing amount of water to increase the available water.

6.6 Evaluation of the Intervention plan

- Advantages: Intervention plan comprehensive open source, throttling, and pollution-governing to formulate related policies. At the same time, it combines short-term and long-term planning. For instance, in the short term by applying water-saving appliances, water consumption can be quickly reduced. Supplied by seawater desalination, interregional water transfer policy in the long term, this can supply 2 billion m^3 for Beijing in a year, which gives Beijing a reliable water resources strategic reserves.
- Shortcomings: it is badly limited by time, at the same time it needs more upfront investment. According to the data of the national bureau of statistics, it would be a difficult task for Beijing Municipal Government to undertake the reform works in the invention plan, considering it is facing financial deficit at the moment, which means it may need state fund. And the final effect remains to be inspected. Besides, the amount of water-exporting provided by water diverting project is only enough to temporarily alleviate the water shortage. In another word, it is not a long-term policy. Long-time

water-diverting may lead to insufficient water supply in water-exporting region.

7 Models after Intervention

7.1 Assumption

1) Extend the social development pattern for lack of water
2) When TWO is more than TAW, all of the remaining water will become TDW.
3)The GDP to invest the rainwater collection project is a certain proportion each year, except for collection fees, the remaining investments for scaleup. Within 15 years the cost of rainwa ter collection project is changeless, the cost of unilateral remains the same. Regardless of the evaporation, the collecting utilization rate is 100%.
4)The power to collect the rainwater is limit, the limitation is from the area of Beijing land an d the average rainfall.
5) Desalination projects are increasing year by year because of the investment from nation , and the desalination capacity is limited.
6) The facilities' building cost in the intervention programs are not included in the GDP.

7.2 Additional parameters

Table 7-1 Additional Nomenclatures

SWDC	Sea water desalinization capacity
IRC	Investment in rainwater collection
GRCCPUI	Growth of rainwater collection capacity per unit investment
RCC	Rainwater collection capacity
CIRC	Coefficient of Investment in rainwater collection
GRCC	Growth of rainwater collection capacity
TAWG	Total available water growth

Changed SD equations are as follows：

L RCC=INTEG(RCCG，0)
R RCCG=IRC*GRCCPUI
C GRCCPUI=0.005
A IRC=GDP*CIRC-0.2*RCC
A TWO=AEW+SW+UW+SWDC+RCC
A TDW= TW*DCTDW+ASR*SRCE+IF THEN ELSE ((TWO-TAW)>0, TWO-TAW, 0)
A WSI= (TWO+ASR)/TP*10^8
C CIST=0.324
C CIRC=0.0268

7.3 Simulation results

Because Sea water desalinization (SWDC) and Rainwater collection (RCC) appears, total water output (TWO) grows rapidly after intervention. However, after SWDC reaches the limit threshold, TWO growth slowed down significantly. With SWDC and RCC, recycling sewage (ASR) increased rapidly. Though social develops with the water shortage model, the growing ASR makes IW and AW increase on the contrary.

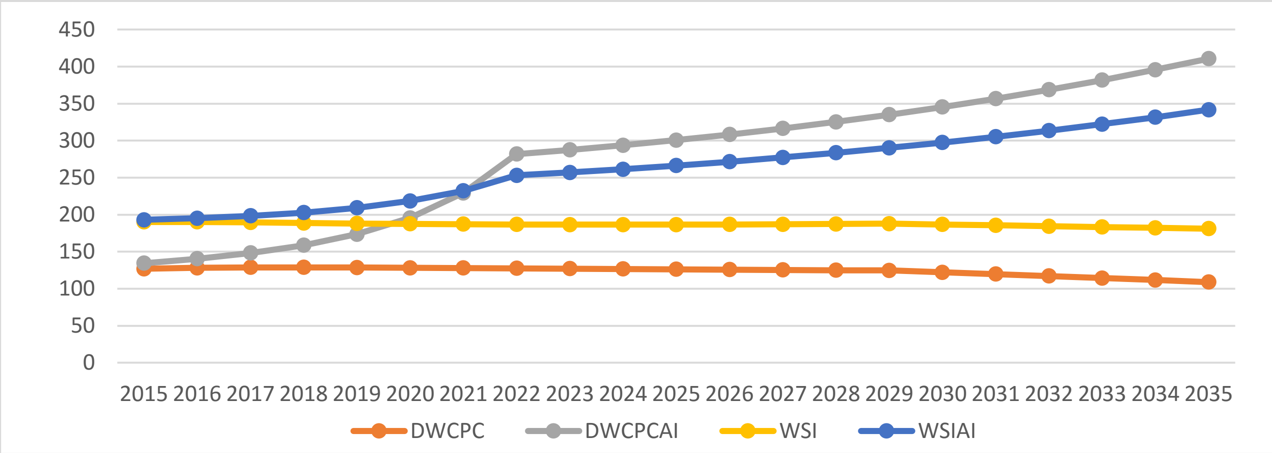


Figure 7-1 the changes of water after intervention (×10^8 m^3)

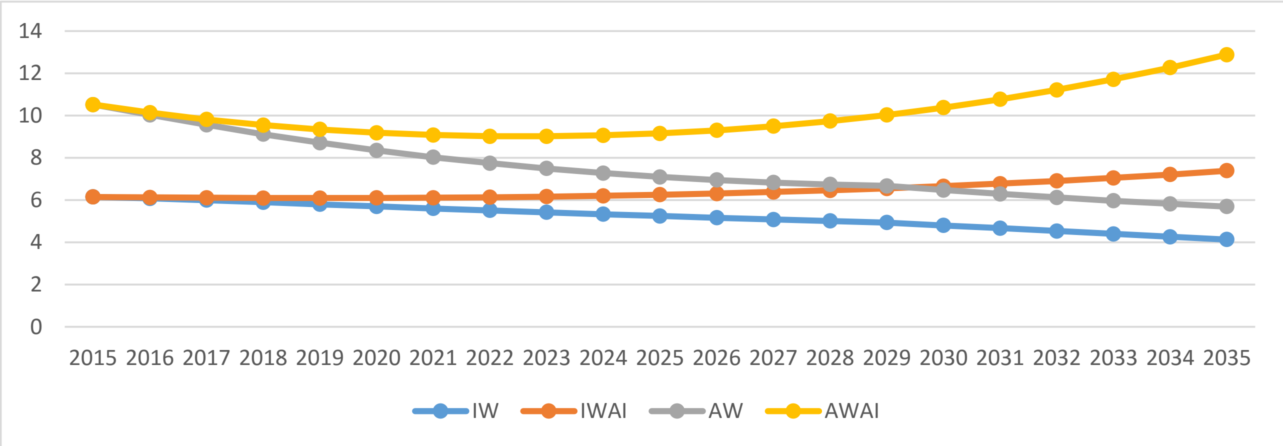


Figure 7-2 the changes of industrial and agricultural water after intervention (×10^8 m^3)

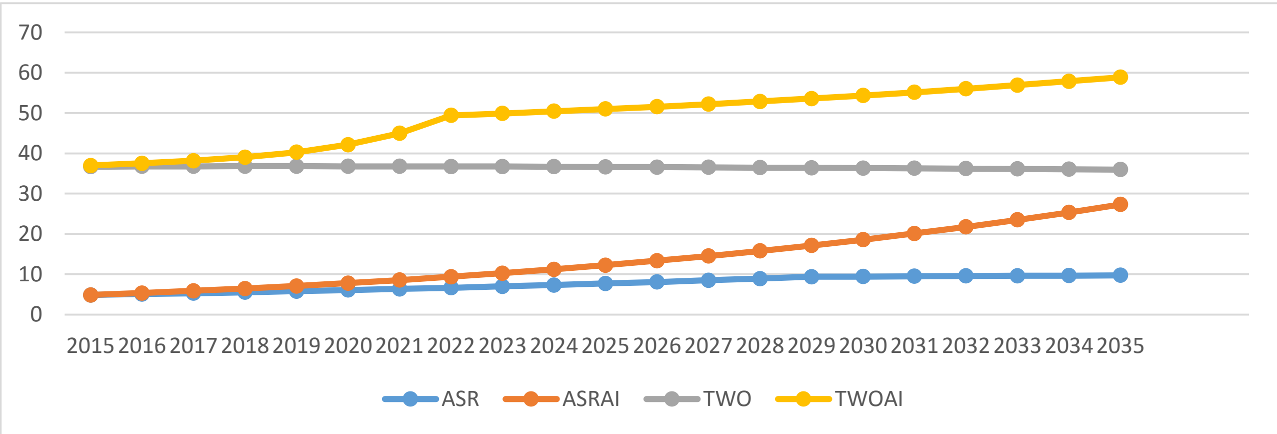


Figure 7-3 the changes of recycling sewage after intervention (×10^8 m^3)

In 2030, WSI is only 287.38 m^3/yr, but DWCPC reached 345.37 m^3/yr, which is similar to normal area. Therefore, after intervention, the water shortage situation has been improved significantly. Beijing is basically out of water shortages.

However, because SWDC and RCC reaching their limits, TWO grows slowly. With the growing total population, DWCPC and WSI decrease continuously. After the year 2047, DWCPC is less than 300 m^3/yr, Beijing gets into the water shortages once again.

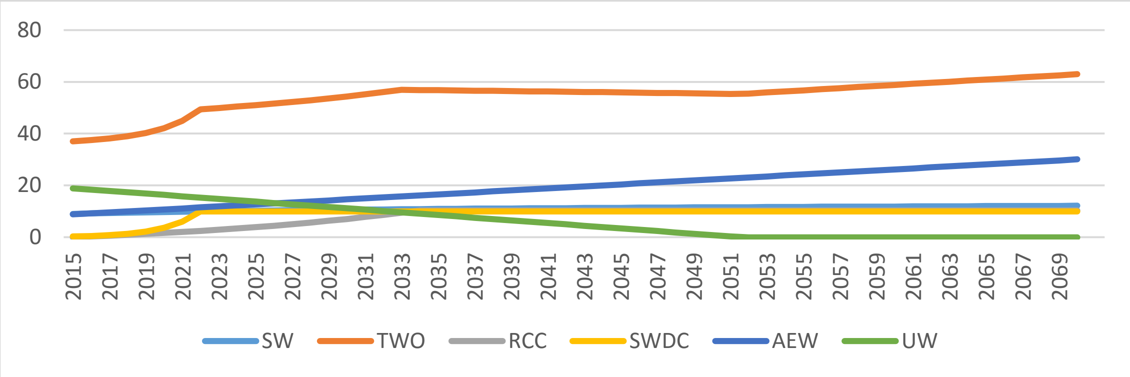


Figure 7-4 the changes of DWCPC and WSI after intervention (×10^8 m^3)

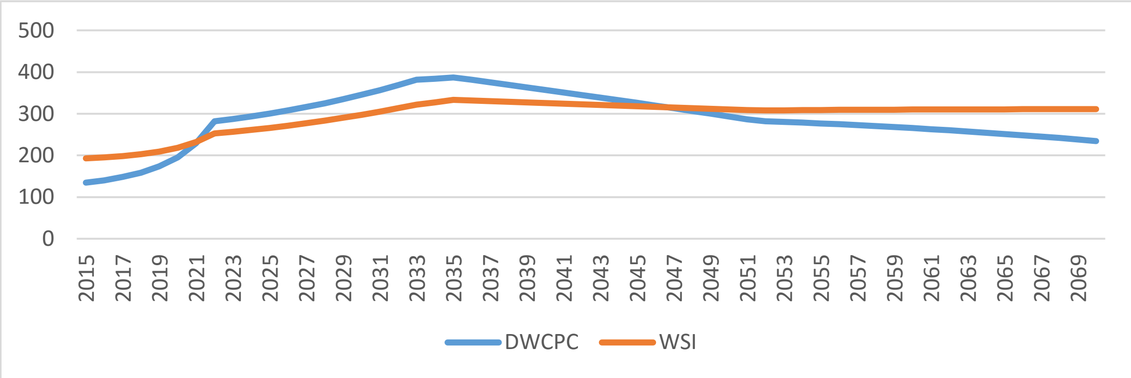


Figure 7-5 the changes of water and recycling sewage after intervention (×10^8 m^3)

We assume that Beijing always extends the social development pattern for lack of water in recent years, taking measures to increase TDW. In fact, however, after dry conditions improved, if the government changes the development pattern and begins to develop water-intensive industry, the water shortages will occur in advance. In short, without affecting the normal development of society, relying on the technology nowadays, there is about to appear a day when the water can't afford the increasing total population. Beijing can neither lay all the underground rainwater collection system, nor become a huge desalination plant. To solve the long-term water shortage, we must continue to improve the technology. Only in this way can we live in a world without worrying about water.

8 Evaluation

Advantages:

- **Good portability**. The model is constituted by several subsystems. Even if the water system in the two regions is very different, we can get a new model by adding or deleting each of the subsystems.

Disadvantages:

- **Too many parameters**. The calculation of the value of the parameter is very cumbersome. Besides it increases the uncertainty. Any parameter deviation will affect the future estimates.
- Based on the SD model, the model is only applicable to the **simple relationship** between parameters. If the relationship between parameters is very complex, it can't be simulated.

Reference

[1] Haiyan Feng (2006). *Prediction of water resources carrying capacity of Beijing city based on SD model* (dissertation Doctoral, China Agricultural University). 20-29.
[2] Xiaoqing Huang. The system dynamics model of coordinated development in Nanning City: Master thesis. Guangxi: Applied Mathematics of Guangxi University, 2003
[3] Hua Yan, Chunjiang Zhao, & Wengang Zheng. (2008). Research on agricultural water problems and Countermeasures in Beijing city. Water saving irrigation (12), 20-23.
[4] China science news. Can Caofeidian desalination solve Beijing's thirst? 2014.11.04 http://scitech.people.com.cn/n/2014/0506/c1007-24980347.html
[5] Changming Liu. (2002). The influence of the south to North Water Transfer Project on the ecological environment. Haihe River Water Conservancy (1), 1-5.
[6] Statistical Yearbook http://www.stats.gov.cn/tjsj/ndsj/ China
Beijing News. Beijing section of the south to North Water Transfer Project will be completed in Beijing per capita water resources can be increased by nearly 5
2014.10.08 http://news.xinhuanet.com/fortune/2014-10/08/c_127071138.html
[8] In the early twenty-first Century Beijing water resources sustainable utilization planning leading group.21 century Beijing water resources sustainable use planning thematic report compilation.2001
[9] Zhizhong Jiao. Building a water saving and pollution prevention society in the construction of circular water http://www.cas.ac.cn/index/0A/46/Index.htm 2005.10
[10] Shijun Hang, Jin Fang Xian, & Yunling Feng et al. (2001). Beijing urban sewage treatment and recycling and reuse. *The 21st century international urban sewage treatment and resource development strategy seminar*.