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2016
MCM/ICM
Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)

Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

A System Dynastic Model For Water Resources Analysis

With the rigorous and detailed consideration of the cause of scarcity, this paper presents a considerate analysis from the aspects of water supply and water demand. A mass of potential factors is taken into account to provide a comprehensive reflection to the ability of a region to provide clean water. Furthermore, the paper proposes one model to assess the water scarcity and one method to discriminate the type of causes of water scarcity.

For task 1, this paper introduces a variable to define the ability of a region to provide clean water and proposes a model based on **system dynamics**. The model comprehensively illustrates the potential factors that could possibly affect the ability and carefully describes the connections between each factor by a mass of equations. In addition, the authors employ methods such as **history check** and **sensitivity check** to examine the validation and reasonability of the model.

For task 2, the method is introduced in this section to judge the type of causes of water scarcity. The authors select Shandong Province to evaluate water situation. In accordance with the dates simulated by the model, the authors deeply analyze the cause of water scarcity from the aspects of physics cause and economic cause. Both social and environmental factors are under consideration. In the process, the method shows objectivity and effectivity when analyzing the specific cause of water scarcity.

For task 3, the main difficulty is to confirm several constants value determined in the model. To address this issue, the authors make efforts in **statistical regression** and **plausible reasoning** to produce a convictive result. Moreover, this paper uses a graph to illustrate the trend of the water situation.

For task 4, this paper designs an intervention plan to mitigate water scarcity in Shandong Province. There are two main methods to mitigate water scarcity: broadening source and reducing expenditure. The authors propose a number of techniques to support the intervention plan. Meanwhile, the possible influences on surrounding areas are taken into careful consideration.

For task 5, the authors modify the constant value in the model according to the intervention plan. The result clearly reveals the significant effectiveness of the intervention plan. Water will not become a critical issue because of the efficient management of water. The living quality of residents would be improved because of the benign ecological environment and prudent economic situation.

Finally, this paper discusses the strengths and the weaknesses of the model, which would be useful for further study.

Contents

1 Introduction

1.1 Background

Water is an indispensable resource for human well-being and other life-support systems. According to the anticipation, the water source tend to decrease rapidly. Various factors lead to the scarcity, including the climate change of the climate, population increase, the increasing rate of personal consumption, industrial consumption and increasing pollution and so on. Facing the serious situation, it is necessary for us to analyze the detailed and specific cause of the ever-serious water scarcity and propose an effective way to access more clean water.

1.2 Introduction to team's work

Based on SD(system dynamics) method, we develop a model to analyze the relationship between the water supply and demand of a region. Considering the comprehensive factors, the region's water demand and the ability of providing clean water are both well evaluated in our model. In this paper, Shangdong Province, China is chosen as the analyzed region. The reasons for its scarcity and the type of water scarcity are explained in detail. And then we anticipate Shangdong's water situation by using the proposed SD model. A mass of potential factors is taken into account to enable the validation and effectiveness of the model. Through the model checks, the model shows good performance in simulating the rain water situation in a region. In the task 2, we introduce a method to discriminate the type of cause of water scarcity, And the cases in task 2 indicates the validity of the method. Connected with the realistic situation, an intervention plan is proposed and the corresponding impacts brought up are discussed. Using our model, the future situation with our intervention is analyzed and anticipated. Finally, the strengths and weaknesses of our model are discussed.

2 Task 1

2.1 Preliminaries

There are many methods proposed in a number of studies to measure the ability of a region to provide clean water. However, these approaches could hardly reflect the dynamic nature of the factors affecting both supply and demand in the model process. Inspired by the work of Babader *et.al*[1], this paper develops an effective model based on the system dynamics which possesses a good dynamic nature reflection.

2.1.1 System dynamic

System dynamics(SD) proposed by JWForrester in 1956 is an approach to understanding the nonlinear behaviour of complex systems over time using stocks and flows, internal feedback loops and time delays It has found application in a wide range of areas, for example population, ecological and economic like[2, 3].

2.1.2 Water shortage degree

Definition 1. *Water Shortage Degree(WSD) is the main parameter to measure the ability of a region to provide clean water defined as follows,*

$$WSD = \frac{W_S - W_D}{W_S} \tag{1}$$

where W_S represents the total supply of water in the region and W_D represents the total demand of water in the region.

2.2 Basic assumption

- **Assumption 1** Assume that the region is independent from others. Therefore, the factors influencing the water situation is internal.
- **Assumption 2** Assume that no extreme weather or natural disasters will happen in the future.
- **Assumption 3** Assume that no related government policies will be issued in the future.

2.3 Model developing

2.3.1 Parameters and equations determination

The parameters and the equations between relevant factors are determined as Table 5,6.

2.3.2 Construction of causal diagram

For the sake of ensuring the accuracy and objectivity of the model, the factors as well as their dynamic nature related to the two variables Eq.(1) should be considered. A causal diagram describes the process of consideration as Fig. 1,

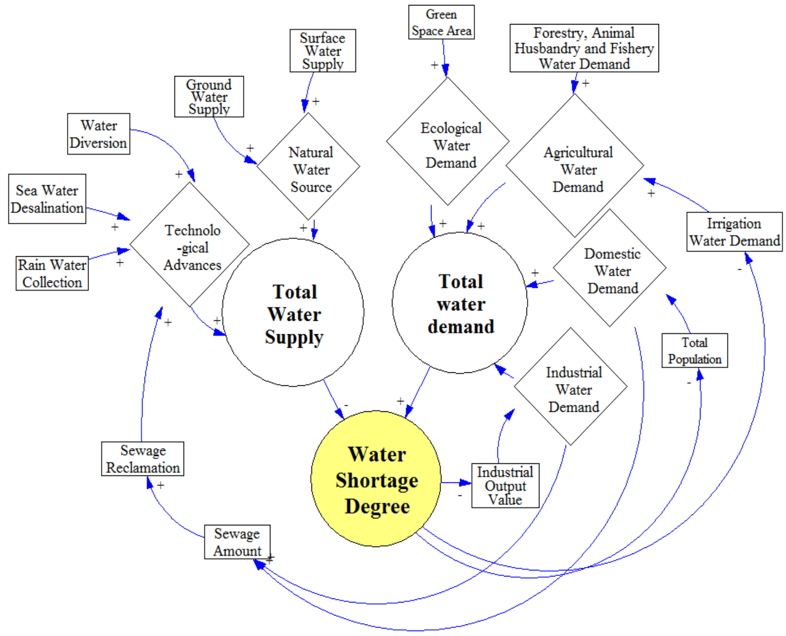

Fig 1: Causal Diagram

The "+" denotes the influence is positive, while "-" means the influence is negtive.

2.3.3 Construction of flow graph

The model is divided into five subsystems, including economy, population, ecology, water environment and water resources subsystems with the assistance of the causal diagram. The interaction among the subsystems are complex. To clarify it, a flow gragh is constructed as Fig. 2.
According to the flow graph nine feedback loop related to the water shortage degree are listed in the following. Virtually, the whole circulation circuits of the model are included.

- Loop Number 1 of length 4: Water Shortage Degree→ Industrial Output Growth Speed→ Industrial Output Value→ Industrial Water Demand→ Total Water Demand→ Water Shortage Degree

- Loop Number 2 of length 5: Water Shortage Degree→ Irrigation Area Growth Speed→ Farmland Irrigation Area→ Farmland Irrigation Water Demand→ Agricultural Water Demand→ Total Water Demand→ Water Shortage Degree

- Loop Number 3 of length 6: Water Shortage Degree→ Population Growth Speed→ Total Population→ Urban Population→ Urban Domestic Water

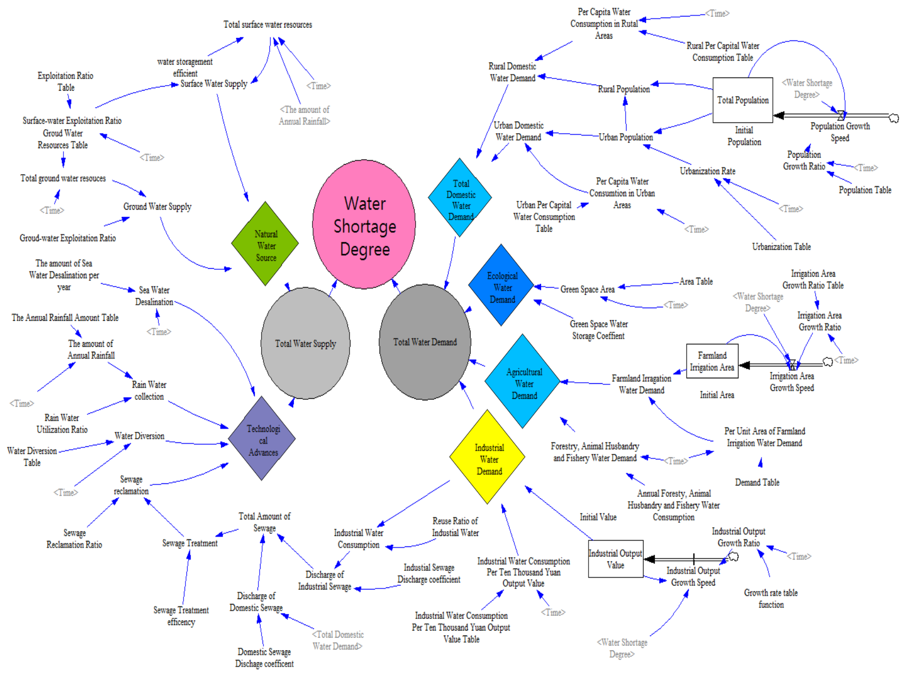

Fig 2: Flow Graph

Demand→ Total Domestic Water Demand→ Total Water Demand→ Water Shortage Degree

- Loop Number 4 of length 6: Water Shortage Degree→ Population Growth Speed→ Total Population→ Rural Population→ Rural Domestic Water Demand → Total Domestic Water Demand→ Total Water Demand→ Water Shortage Degree
- Loop Number 5 of length 7: Water Shortage Degree→ Population Growth Speed→ Total Population→ Urban Population→ Rural Population→ Rural Domestic Water Demand→ Total Domestic Water Demand→ Total Water Demand→ Water Shortage Degree
- Loop Number 6 of length 10: Water Shortage Degree→ Industrial Output Growth Speed→ Industrial Output Value→ Industrial Water Demand→ Industrial Water Consumption→ Discharge of Industrial Sewage→ Total Amount of Sewage→ Sewage Treatment→ Sewage reclamation→ Technological Advances→ Total Water Supply→ Water Shortage Degree
- Loop Number 7 of length 11: Water Shortage Degree→ Population Growth Speed→ Total Population→ Urban Population→ Urban Domestic Water Demand→ Total Domestic Water Demand→ Discharge of Domestic Sewage→

Total Amount of Sewage→ Sewage Treatment→ Sewage reclamation→ Technological Advances→ Total Water Supply→ Water Shortage Degree

- Loop Number 8 of length 11: Water Shortage Degree→ Population Growth Speed→ Total Population→ Rural Population→ Rural Domestic Water Demand→ Total Domestic Water Demand→ Discharge of Domestic Sewage→ Total Amount of Sewage→ Sewage Treatment→ Sewage reclamation→ Technological Advances→ Total Water Supply

- Loop Number 9 of length 12: Water Shortage Degree→ Population Growth Speed→ Total Population→ Urban Population→ Rural Population→ Rural Domestic Water Demand→ Total Domestic Water Demand→ Discharge of Domestic Sewage→ Total Amount of Sewage→ Sewage Treatment→ Sewage reclamation→ Technological Advances→ Total Water Supply→ Water Shortage Degree

2.3.4 Model validation

Model structure check The Vensim software offer the function to check the validity of the equations and the units of variables in the model. With the assistance of this function, we can conclude that both the equations and units are compatible and correct.

History check The history check can examine whether the model can produce good results by comparing with the existing data. In this test, we choose Total Population, Urban Population, Industry Output Value and Farmland Irrigation Water Demand to compare with the data produced by model from year 2008 to year 2014. The results are shown in the Table 1 .

From Table 1, the relative error of variables is lower than 1%, which indicates that the model is reasonable and valid.

Sensitivity analysis There are total 10 constants to be tested. For each constant, the floating range is from −10% to +10%, shown as Table 2.

10^6 When these constants change, the variable WSD would also change in a range. The range reflects the sensibility of WSD to every constant. The results are showed in Fig. 3 From the Fig.3, the constant *Initial Farmland Area* possesses the greatest influence on WSD. The constant *Ground Water Exploitation Ratioand* and *Initial Population* also have a obvious effect on WSD. The remaining 7 constants have little effect to the result. In another word, the model is insensitive to most constants.

Tab 1: History Check

		2008	2009	2010	2011	2012	2013	2014
Total Population(10^4 person)	Historical data	9367	9420	9470	9521	9568	9616	9665
	Model output	9367	9417	9470	9579	9637	9685	9789
	Relative error(%)	0	-0.27	0	0.61	0.72	0.72	1.27
Industrial Output Value(10^8 CNY)	Historical data	54428.27	62961.04	71136.06	83701.84	99242.10	114329.95	129401.63
	Model output	54428.27	62958.53	71209.42	83851.40	99504.98	114707.29	129906.01
	Relative error(%)	0	-0.04	0.10	0.18	0.26	0.33	0.39
Irrigation Water(10^8 m^3)	Historical data	164.45	160.65	159.19	153.64	151.63	149.00	146.66
	Model output	162.76	161.6	159.65	154.26	154.23	149.72	146.72
	Relative error(%)	-1.04	0.59	0.29	0.40	1.69	0.48	0.04

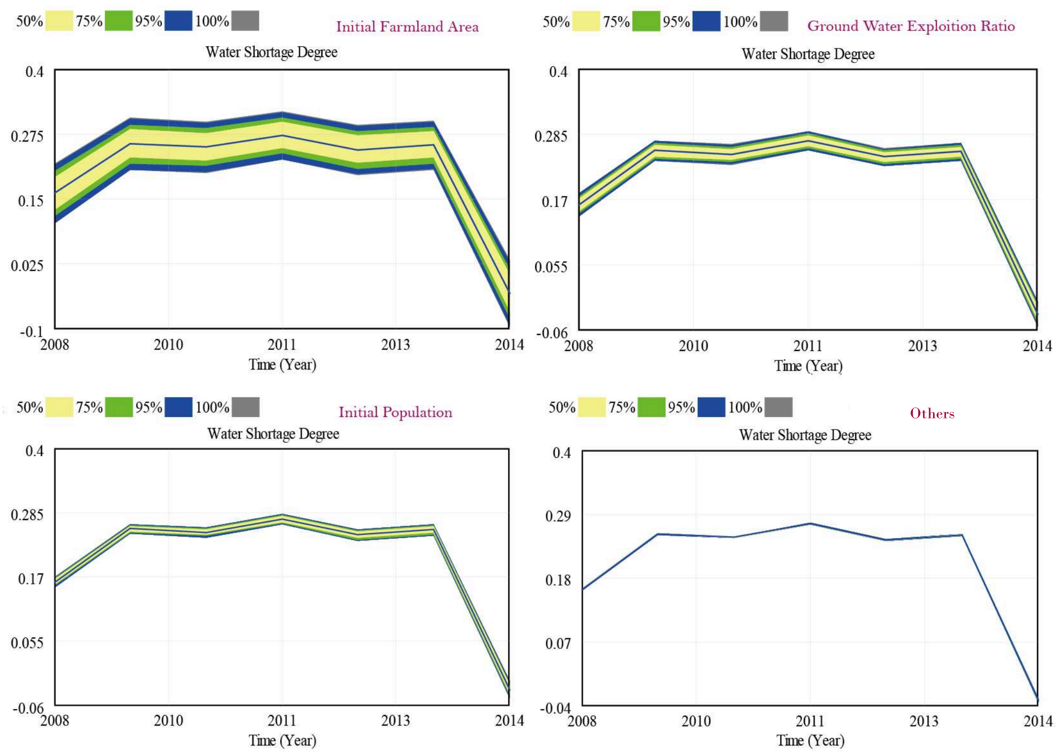

Fig 3: Sensity Analysis Results

Tab 2: Value Range of Constans

Constant	**Origin**	**Min**	**Max**
Domestic sewage dischage coefficient	0.74	0.666	0.814
Green Space Water Shortage Coeffient	0.22	0.198	0.242
Ground Water Exploition Ratio	0.7	0.63	0.77
Industial Sewage Discharge coefficient	0.8	0.72	0.88
Initial Are	4.836 10^6	4.353 10^6	5.320 10^6
Initial Population	9367	8430	10304
Rain Water Utilization Ratio	0	0	0.01
Reuse Ratio of Industial Water	0.8	0.72	0.88
Sewage Reclamation Ratio	0.3	0.27	0.33

3 Task 2

3.1 The region chosen

From the UN water scarcity map, we chose Shandong Province, China, where water is moderately overloaded to analyze.

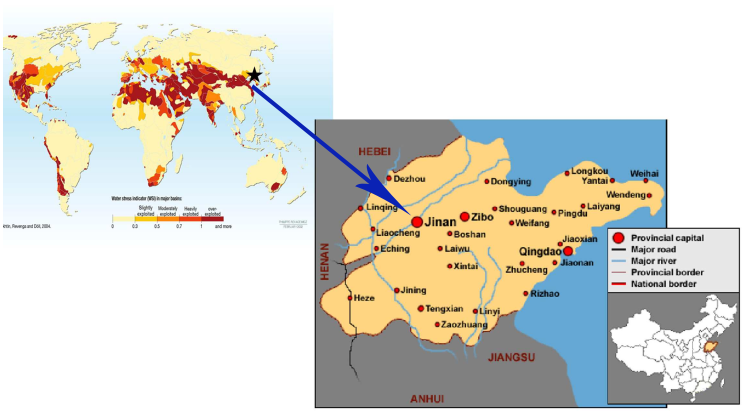

Fig 4: Shandong

There are many factors which influence the supply and the demand of water in one region, and environment and social are two major factors. For instance, the water supply W_s is determined by the amount of rivers, lakes and underground water, the annual average rainfall, the water diversion and so on. The water demand W_d is related to the population, the development degree of industry, the dependency level to local agriculture. However, limited by the robustness of the infrastructure, the geological, topographical, and ecological reasons, it is impossible to utilize all water resource in a region. In this case, we propose the concept of available water amount W_a and the coefficient of water use efficiency α. The water for living, the water for industry, and the water for agriculture are expressed as W_l, W_i and W_a. The relation among them is defined as follows:

$$
\begin{aligned}
W_d &= W_l + W_i + W_a \\
W_a &= \alpha \times W_s
\end{aligned}
\tag{2}
$$

3.2 Analysis water scarcity of Shandong Province

The next work is to judge whether water scarcity in the region or not. If so, how the water is scarce in that region. 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, and it is always caused by climate change and population increase. Economic scarcity is where water exists but poor management and lack of infrastructure limits the availability of clean water. Hence, we can get the following definition:

$$
\begin{aligned}
p &= W_s - W_d \\
q &= W_a - W_d
\end{aligned}
\tag{3}
$$

After we get the value of p and q, we can assess the water resources situation of the region.

- if $q \geq 0$, we can conclude that the water resources is enough in this region.
- if $p \leq 0$, we can conclude that it is physical scarcity in this region.
- if $P \geq 0$ and $q \leq 0$, we can conclude that it is economic scarcity in this region.

From the statistical yearbook of Shandong province, W_s and W_d of every year can be obtained. α always equal to 0.4.By using Eq.2 and Eq.3, p and q can be easily computed, the results are shown in Table 3.

From the Table 3, the p of the six years is greater than 0 and the q of the six yearsis smaller than 0, so, Shandong Province belongs to the type of economic

Tab 3: Water index of Shandong Province from the year 2008 to 2013

Water index ($10^8\ m^3$)	2008	2009	2010	2011	2012	2013
W_s	29.17	27.41	34.76	30.91	28.50	32.87
W_a	11.67	10.96	13.90	12.37	11.40	13.15
W_d	21.79	22.18	22.41	22.25	22.00	21.99
p	7.98	5.90	13.10	9.13	6.89	11.26
q	-9.52	-10.60	-7.78	-9.43	-10.21	-8.47

scarcity. When it comes to the reasons which lead to the condition: first, because the environment pollution and the climate change, the total amount of water is decreasing every year, however, the population of Shandong province is increasing every year. Second, the lack of infrastructure led to the low availability of water and the water resource is not efficiently managed. Last but not least, the industry is fleet development, but it consumed too much water in recent years. Also, the Green Land Nature of Garden is damaged by extensive economy. The conclusion is that the total amount of water is enough, but the available water is lacked in this region.

4 Task 3

4.1 Constants determination

Some constants should be set to predict the future situation. The value of them could be obtained through ways like statistical regression and plausible reasoning. All the constants are shown in Table 7.

4.1.1 Statistical regression

We obtained some constants through the planning report of Shandong Province. They are *Population Growth Ration, Industrial Output Growth Ration and Urbanization Ration*. By statistical regression, we get the value of these constants that are *Irrigation Area Growth Ratio, Per Capita Water Consumption in Rural Areas, Industrial Water Consumption Per Ten Thousand Yuan Output Value, Foresty, Animal Husbandry and Fishery Water Demand, Surface-Water Exploitation Ratio, Water Diversion, per unit Area of Farmland Irrigation Water Demand*.

4.1.2 Plausible reasoning

In order to ensure the reasonability of future data, we assume that the constant *The Amount of Annual Rainfall* in next 15 years is equal to the average value of past 5 years. The constants *Sea Water Desalination, Reuse Ratio of Industrial Water and Green Space Water Storage Coeffient* will not change in next 15 years.

4.2 Results and analysis

With all the constants determined, the result can be obtained as Fig. 5. From

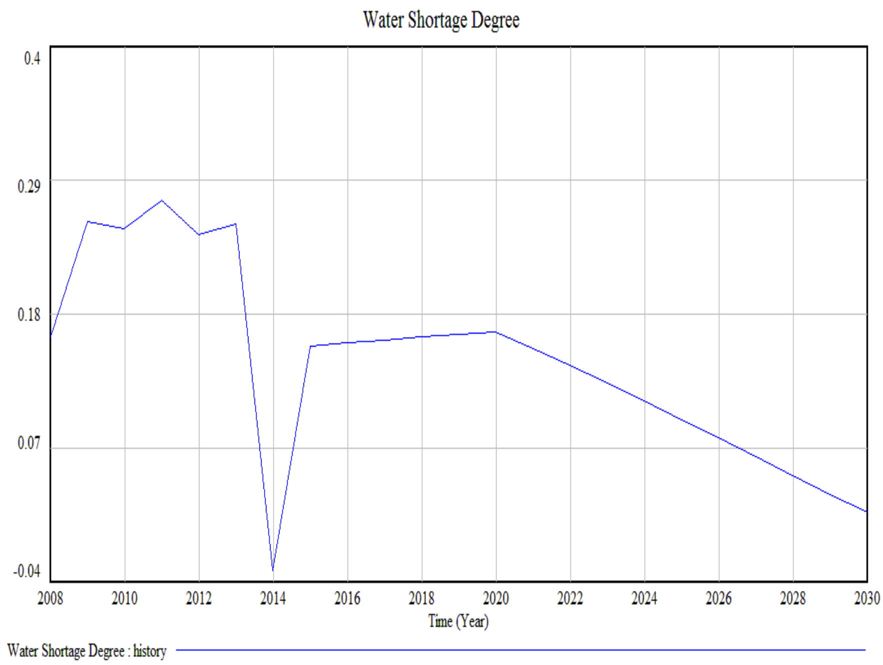

Fig 5: Water Situation in 15 years

the result of our model, the *WSD* in 2030 is nearly equal to 0 which indicates that the ability of Shandong Province to provide clean water is limited. With population and economic growing, the water demand of industry, agriculture and living will increase. If the technology is not improved, the sewage and exhaust gas of industry will destroy the ecological balance. As a result, the pollution of environment will decrease the water supply. In general, the situation of water is negative in 15 years. Some measures should be taken to change this situation.

5 Task 4

5.1 Intervention plan

In this section, the intervention plan is designed to mitigate water scarcity in Shandong Province. Hereinafter, we will introduce our intervention plan in detail.

First, broadening source is an efficient method to increase water supply. We propose three methods in our model to broaden the water source in Shandong Province.

- Inter-basin water transfer project. The total water resources in the south of China is lager, but most of areas in the north of China belong to semi-arid and arid climate. In this case, an appreciable measure is to develop the inter-basin water transfer project. Fortunately, there exists a massive of canal made by previous Chinese government. In the meantime, Chinese labour force is enough. Hence, it is low-cost for Shandong to renovate the old canal and build the water conveyance pipe.

- Seawater desalination and rainwater collection project. Shandong is a coastal province, so there is a geographical advantage in Shandong to develop the technology of seawater desalination. Due to the low-cost and high efficiency of reverse osmosis technology in treatment of brackish water with high fluorine content, we choose it as our main measure in seawater desalination. There are many strengthes of rainwater collection technique. First, it will enlarge the total amount of water supply. Second, this technique can mitigate the pressure of urban drainage system. last, it can solve the problem of acid rain.

- Sewage reclamation and reuse. In Shandong Province, a lager amount of sewage is produced every year and it is discharged into the sea. Therefore, we will develop the technology of sewage reclamation and reuse. Not only it can mitigate water scarcity, but also it is an environmental protection measure which can protect the marine environment of Shandong. The method also satisfy the strategy of sustainable development which is advocated by China government.

Second, reducing expenditure is also considered in our model to deal with the problem of water scarcity. The demand of water in living, industry and agriculture is mainly discussed.

- Develop the industrial water-saving technology. According the date of statistical yearbook of Shandong province, we can conclude that it consumed

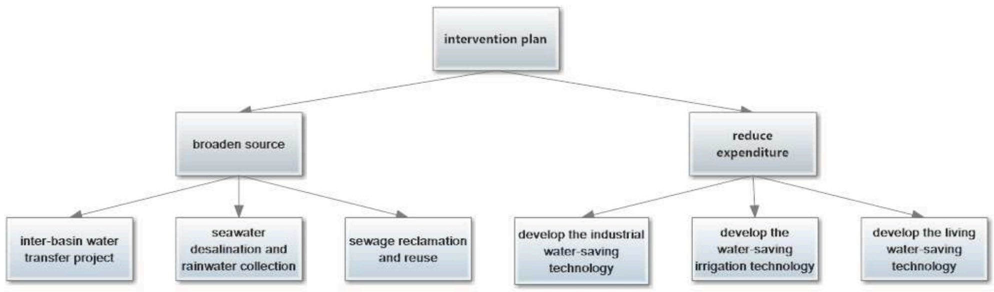

Fig 6: Intervention plan

too much water when producing per 10,000 dollars of GDP. It is essential to development the industrial water-saving technology to decrease the water demand of the industry.

- Develop the water-saving irrigation technology. The farmers take the form of broad irrigation which is a great waste of water to satisfied the demand of soil, which is a great waste of water. Hence, we plan to use sprinkler irrigation and drip irrigation instead of the traditional form, which can economize about 60% water demand of agriculture.

- Develop the living water-saving technology. According to statistical date from The National Statistical Offices Of China, the amount of living waste water takes up about 70% of the demand of living water. So, there is great space for us to develop the living water-saving technology to decrease the demand of living water. For example, Water-saving of washing technology, intelligent flushing system of toilet and automatic stopcock. It is estimated that these technologies can save about 60% of the demand of living water.

5.2 The effect of intervention plan

The proposed intervention plan will inevitably impact the surrounding areas, as well as the entire water ecosystem. In this subsection, we will discuss the overall strengths and limitations of the intervention plan.

Inter-basin water transfer project The inter-basin water transfer project will have negative effects in surrounding areas. On one hand, it will decrease the total amount of water in the water-exporting areas. As the result, the ecological environment of the water-exporting area will be changed or even destroyed. Especially, when the water-exporting areas are in low-water period, aridity will strike them. On the other hand, water conveyance pipe will take up a large amount of land in surrounding areas. Not only will it result in a shortage of available land, but also it will have bad influence of the forest, rive and soil in the surrounding areas.

Seawater desalination Seawater desalination has both advantage and disadvantage to the surrounding areas. In the process of seawater desalination, lots of byproductswill be brought about, such as salt, calcium, sodium, magnesium and so on. It can satisfy the need of industry and decrease the industrial cost of the surrounding areas. However, if consuming too much water in the process of seawater desalination, the level of rainfall in the surrounding areas may decrease and it will influence local ecological environment.

Sewage reclamation and reuse Apparently, the plan of sewage reclamation and reuse will have a lot of strengths to the surrounding areas. It decreases the amount of sewage discharge to river or sea. In this case, the ecological environment of the surrounding areas will benefit from the implement of sewage reclamation and reuse. Besides, the factory and technique of sewage reclamation and reuse will help to control the pollution of the surrounding areas.

6 Task 5

According to the intervention plan in Task 4, some constants value should be modified as Table 4. By running the simulation based on the new constants value, the result is shown in Fig. 7. From the Fig. 7, it can clearly be concluded that after implementing the intervention plan, the water scarcity has been alleviated and the ability of the region to provide clean water will be improved. The factory will consume less water when it produces ten thousand dollars GDP because of the industrial water-saving technology. Family will save more water due to the living water-saving technology. Most important of all, the ecological environment will be protected because of the sewage reclamation and reuse techniques. The living quality of residents will be improved because of the benign ecological environment and prudent economic situation.

Tab 4: The Constant Modified In Accordance With Intervention Plan

Constant	Origin Value	Intervention Value
Water Diversion	62	82
Rainfall Utilization Ratio	0	0.05
Sea Water Desalination	55.72	100
Sewage Reclamation Ratio	0.3	0.6
Sewage Treatment Efficiency	0.55	0.75
Domestic Sewage Discharge Coefficient	0.74	0.85
Industry Sewage Discharge Coeffcient	0.8	0.9
Reuse Ratio of Industrial Water	0.8	0.95
Industrial Water Consumption Per Ten Thousand Yuan Output Value	1	0.6
Farmland Irrigation Water Demand	0.25	0.16
Per Capital Water Consumption in Urban Area	143	133
Per Capital Water Consumption in Rural Are	130	*120*

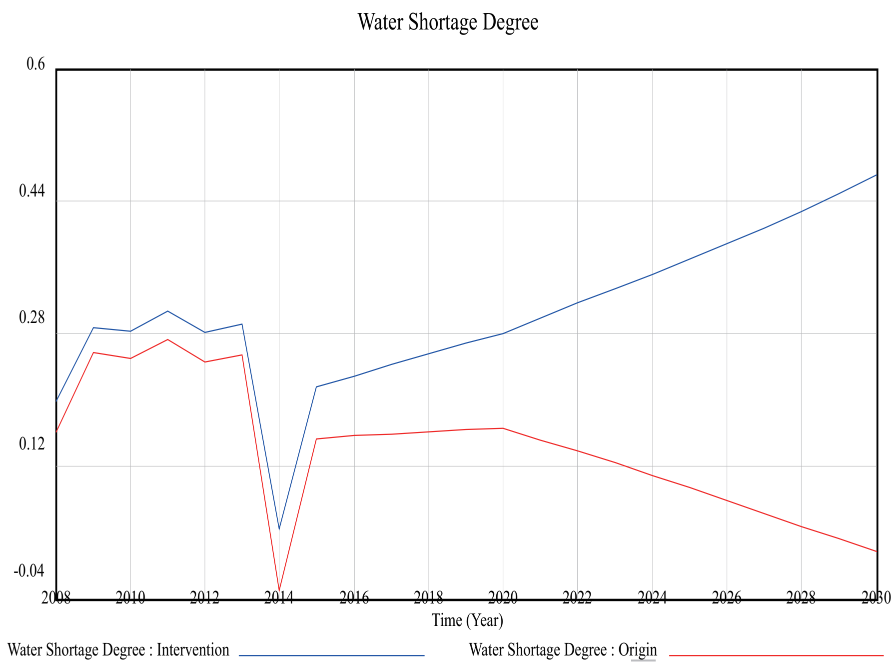

Fig 7: Water Situation After Intervention

7 Strengths and weaknesses

7.1 Strengths analysis

To analyze the intergrated water resource of a region is a considerable project. In this aspect, our model can effectively handle it.

- Facing the mutifold factors which are related to water resource, some methods only evaluate each aspect individually and make comparosons between them. However, our model is developed to deal with the interaction between the whole aspects and evaluate them. Five substystems(namely economy subsystem, population substystem, ecology subsystem, water environment subsystem and water resources subsystem) are inclued in our model. The interaction between these subsystems is comprehensively analyzed in our model, which help us study the knowledge of the real world.
- The parameters and graphical functions of the model are determined by various methods. For example, the sewage reclamation is related to both existing data(like the sewage reclamation ratio, sewage treatment effiency and domestic Sewage Dischage coefficent) and time-series data(like the industrial water consumption and total domestic water demand). It means that the value of our parameters and graphical functions are reasonable. Both qualitative varaibles(like the green space water storage coeffient) and quantitative varaibles(like total population) are allowed in our model, which is pratical in application. Moreover, even complex and nonlinear structures(like rainwater collection) can be handled in our model.
- The structral causes of the water resources system's behaviour are comprehensively analyzed. It provides insights into the effects of a wide range factors and increases the knowledge of each detailed element of the water resources system. Meanwhile it help us to settle an intervention plan targetedly.

7.2 Weaknesses analysis

Although relatively comprehensive factors are considered in our model, there are still some limitations inevitablely.

- Our model is only a simplified mathematical expression of the complex reality situation. Even though five subsystems are included, some problems still cannot be quantitatively described, such as the impacts of climate change on natural water resources, the change in the consumption of water supplies and so on. Ignoring the influences of these factors may lead to overly optimistic results.

- A considerable number of parameters and graphical functions need to be determined, but uncertainty of the simulation is inevitably increased. Although a variety of methods are adopted to determine and predict them, the accuracy is still insufficient.

- As the time line for the simulation is pretty long, the policy factor can be hardly predicted. And the policies like the population policies, environmental protection policies, water diversion policies will undoubtedly increase the difficulty of simulating the impacts of policy implementations.

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Tab 5: Parameters and Equations

	Parameter	Abbriviation	Unit	Type	Value/Equation
Economy subsection	Industrial output value	IOV	10^8 CNY	Variable	INTER(IOGS,IIOV)
	Industrial output growth speed	IOVS	10^8 CNY	Variable	IOV*IOGR*(1-2*WSD*0.01)
	Initial industrial output value (2008)	IIOV	10^8 CNY	Constant	54428.3
	Industrial output growth ratio	IOGR	-	Table function	-
Population subsystem	Total population	TP	10^8 person	Variable	INTER(GPS,IP)
	Urban population	UP	10^8 person	Variable	TP*UR
	Rural population	RP	10^8 person	Variable	TP-UP
	Initial population (2008)	IP	10^8 person	Constant	9367
	Population growth speed	PGS	-	Variable	TP*PGR*(1-1.5*WSD*0.01)
	Population growth ratio	PGR	-	Table function	-
	Urbanization rate	UR	-	Table function	-
	Per capita water consumption in rural areas	PCWCIRA	L	Table function	-
	Per capita water consumtion in urban areas	PCWCIUA	L	Table function	-
	Urban domestic water demand	UDWD	$10^8\ m^3$	Variable	UP*PCWCIUA*365*10^{-7}
	Rural domestic water demand	RDWD	$10^8\ m^3$	Variable	RP*PCWCIRA*36510^{-7}
	Total domestic water demand	TDWD	$10^8\ m^3$	Variable	RDWD+UDWD
Ecology subsystem	Green space area	GSA	*hectare*	Table function	-
	Green space water storage coeffient	GSWSC	-	Constant	0.22
	Ecological water demand	EWD	$10^8\ m^3$	Variable	GSA*GSWSC*10^{-4}
Water envirnment subsystem	Industrial water consumption	IWC	$10^8\ m^3$	Variable	IWD*RROIW
	Industrial water demand	IWD	$10^8\ m^3$	Variable	IOV*IWCPTTYOV*10^{-8}
	Discharge of industrial sewage	DOIS	$10^8\ m^3$	Variable	IWC*ISDC
	Discharge of domestic sewage	DODS	$10^8\ m^3$	Variable	TDWD*DSDC
	Total amount of sewage	TAOS	$10^8\ m^3$	Variable	DODS+DOIS
	Sewage treatment	ST	$10^8\ m^3$	Variable	TAOS*STE
	Sewage reclamation	SR	$10^8\ m^3$	Variable	SRR*ST
	Reuse Ratio of Industial Water	RROIW	-	Constant	0.8
	Industial sewage discharge coefficient	ISDC	-	Constant	0.8
	Sewage treatment efficency	STE	-	Constant	0.55
	Sewage reclamation ratio	SRR	-	Constant	0.3

Tab 6: Parameters and Equations

Water resources subsystem	Initial irrigation area (2008)	IIA	10^3 hectare	Constant	4.83678*10^6
	Farmland irrigation area	FIA	10^3 hectare	Variable	INTER(IAGS,IIA)
	Forestry, Animal Husbandry and Fishery Water Demand	FAHAFWD	10^8 m3	Table function	-
	Farmland irraga- -tion water demand	FIWD	10^8 m^3	Variable	FIA*PUAOFIWD*10^{-4}
	Agricultural water demand	AWD	10^8 m^3	Variable	FIWD+FAHAFWD
	Total water demand	TWD	10^8 m^3	Variable	AWD+EWD+IWD+TDWD
	Total water supply	TWS	10^8 m^3	Variable	NWS+TA
	Natural water source	NWS	10^8 m^3	Variable	GWS+SWS
	Technological advances	TA	10^8 m^3	Variable	RWC+SWD+SR+WD
	Rain water collection	RWC	10^8 m^3	Table function	-
	Sea water desali- -nation	SWD	10^8 m^3	Table function	-
	Rain water collection	RWC	10^8 m^3	Variable	TAOAR*RWUR
	Rain water utiliz- ation ratio	RWUR	-	Constant	0
	The amount of annual rainfall	TAOAR	10^8 m^3	Table function	-
	Water diversion	WD	10^8 m^3	Table function	-
	Ground water supply	GWS	10^8 m^3	Variable	TGWR*GER
	Total ground water resources	TGWR	10^8 m^3	Table function	-
	Surface water supply	SWS	10^8 m^3	Variable	TSWR*SER
	Total surface water resources	TSWR	10^8 m^3	Variable	TAOAR*(water storagement efficient(Time))
	Surface-water exploitation ratio	SER	-	Table function	-
	Ground-water exploitation ratio	GER	-	Table function	-
	Water shortage degree	WSD	-	Variable	(TWS-TWD)/TWS

1 $INTER$ means integration
2 $Tablefunction$ means the function is an array and the value for each input should be set by users.
3 The data is gathered from China Statistical Yearbook(2008-2014), China Resources Science Encyclopedia:Science of Water Resourcesd Bulletin(2008-2014) and Shangdong Province Water resources Bulltin(2008-2014).