Team Control Number

20047

For office use only		For office use only
T1 ________________		F1 ________________
T2 ________________		F2 ________________
T3 ________________		F3 ________________
T4 ________________		F4 ________________

Problem Chosen

B

2013 Mathematical Contest in Modeling (MCM) Summary Sheet
(Attach a copy of this page to your solution paper.)

Worst Water Problem to Best Water Strategy

Summary

This paper concerns developing the water strategy for 2013 to meet the projected water needs of China in 2025, and discussing the implications of the model that may have on its economic, physical, and environment.

First, based on the gray prediction method, we get the population and the projected supply-demand of water resources of China in the period 2013-2025. The result shows that: in 2025, the distribution of water resources in China will not be balanced, 15 provinces (or municipalities) are in a shortage of water status.

Next, we set that: when it comes to the water shortage provinces (or municipalities), we give priority to use the sewage recycling method to make up of the shortage of water, the remaining amount of water are supplied by transferring water from other provinces (or municipalities). We build the linear programming model (model 1), after computing the model, we get the optimal solution of the water shortage transporting.

Then comprehensively consider both the method diversion from other provinces and desalinated water from the adjacent to supply water shortage, we establish the dynamic programming model (model 2), model 2 is the improvement of model 1, and its total the cost is lower than that of the model 1.

Model 3 takes a comprehensive consideration from three aspects: improving the utilization level of water, strengthening the management of both water supply and water demand, and maximizing the comprehensive benefits of water resources. As to maximize the comprehensive benefits of water resources, we establish the evaluation model based on AHP.

Model 3 can not only meet the water requirement of China in 2025, but also be in line with the requirements of the sustainable development of water resources. It’s feasible, and can make the overall efficiency of unit cost the largest, so it is a long-term implementation strategy.

Finally, we do sensitivity analysis of our model, discuss its strengths and weaknesses and test the rationality of it. According to the predictions of the model, we provide a report of recommendations for China's water resources to government.

Contents

1 Introduction

An adequate supply of affordable water of suitable quality makes a major contribution to economic and social development. Recent studies show that by the next 50 years water resources per capita will go down to around 1700 m^3, which is the threshold of severe water scarcity. This problem is serious especially in China: fresh water has become a critical constraint factor for socioeconomic development in the long run. So it's of great significance to come up with an effective, feasible, and cost-efficient water strategy to meet the projected needs in the future. In this paper, we mainly discuss the strategy for the present year to meet the water needs of China in 2025.

So our goal is pretty clear:

- Divide China into different regions according to its water status.
- Predict the supply-demand water of each region and determine the regions that are of water shortage.
- Develop method for 2013 to meet the projected needs of China in 2025.
- Give some suggestions to the governmental leader as reference.

Our approach is:

- Analyze the main factors that affect the water resources.
- Search the information about the background of those factors on internet and find the main problems of water resource in China.
- Divide China into different regions according to its provinces, search related data of those provinces.
- Predict the annual amount of supply-demand water and the population of China in the period 2013-2025.

- Analyze the differences between supply water and demand water in the various regions, and mark out the provinces of water shortage.
- Develop a simple method which only asks existing water conservancy facilities to solve the water shortage in some regions and compute its total costs.
- Analyze a developed method which considers another factor to supply the water, compare those two methods and determine what disadvantage they have.
- Establish a long-term planning model based on the above analysis, consider a number of factors, make up for the shortcomings of the above two models.
- Make a sensitivity analysis of the factors we consider above.
- Analyze the best strategy for our goal
- Evaluate our solutions, analyze the strength and weakness of our model.
- Provide a letter to governmental leadership to give suggestion

2 Background of Chinese Water Resources ([7][11])

The water resource problem of China is so complex, this is because China is facing the problems of fast growing population, rapid urbanization, rising costs of providing water and pollution of fresh water. So it’s necessary for us to know the background of this country and the status of its water resources.

Covering a total area of about 9.6 million square kilometers, which accounts for some 6.5% of the world total land area, China is the third largest country in the world. It is one of the world's top exporters and is attracting record amounts of foreign investment. In turn, it is investing billions of dollars abroad. The population of China approaches 1.3 billion at present [16].

However, China has less than half the water per person than the absolutely water-scarce Egypt. This simple comparison helps us to understand that China will face great water-related challenges in the coming decades. According to related literature data and information[16], we conclude that, those challenges are:

- Non-uniform and scarce of Chinese water resources

The water distribution gap between South-China and north China is so large. China possesses roughly 20% of the nation's water resources and 64% of land area. Parts of Northeast China and almost all of Northwest China have suffered from chronic severe water shortages in the face of rapidly rising demand. The water table has fallen rapidly over the last decades, in some cases over 2 m per year, raising pumping costs, resulting in land subsidence, saltwater intrusion, and causing farmers to abandon thousands of wells [ ].

- Population density is extreme

Through population control of China is well advanced, the population density is very high and growing in certain regions, which will lead to the uneven distribution of water resources.

- Serious water pollution

To enhance the economic development and attract foreign investment, the “first pollute—then clean” doctrine is often used in the utilization of water in China. China's emissions are huge in comparison to produced wealth [10].

- Lack awareness of water conservation

Water conservation refers to action taken to use water efficiently, and it has two parts: water resources conservation and water supply conservation. Water conservation awareness is an understanding of the need to use water efficiently at all stages from capture to consumption, in order to promote change in attitudes and behavior with regard to water management and use. Except in a few cities that are successfully promoting WCA, overall awareness in other regions of China is especially low [2].

- Low utilization rate of water

This is mainly because the recycling of water resources isn’t spread through all the regions. Since agricultural water consumption accounts for a large proportion of the total water consumption, some agricultural irrigation facilities and irrigation technology are backward which also lead to the low utilization rate of water [7].

In our paper, our first target is to predict each of the region's water supply and demand,next we come up with some methods to solve water shortage problems in the regions where the available supply water is less than the demand water, then we analysis the best water strategy for 2013 to meet the projected water needs in 2025.

3 Basic Assumptions

- The sum of domestic water, industrial water, agricultural water and ecological water can represent the region's total volume of water. The reason is that the proportion of the sum is large enough to account for the total amount of water.
- The data we used in this paper is real and can reflect the real situation of the region. As the data resources related to water in China is limited, we can’t have access to the accurate data.
- No significant impact on water resources in China in the 2013-2025 periods.
- The geographical distribution of the Chinese population is relatively stable, that means we ignore the impact on water demand-supply strategy of population migration and urbanization.
- No abnormal growth of each indicator in various regions in China. This is the basic of our forecast.

Other assumptions we will illustrate when it is mentioned in the corresponding part of the model.

4 Prediction Model

4.1 Conceptual Framework of Supply-demand Water *[21]*

In order to satisfy the projected water needs of China in 2025, we first should forecast the needs according to the data of previous years we have searched. [China Water Conservancy Bureau]. Next we will get the supply in 2025 through the same way, then compute the differences between supply and needs of China and the different regions of China, that is the problem we should come up with strategies for 2013 to solve.

As we know that the consumption of water resources is closely related to human population and human activities, first we must know the population of a region if we want to know its supply-demand of water. So the first task for us is to predict the population of various regions in 2025 of China, in addition we also need to predict the total population of China since we want to have an overall understanding of the whole water supply-demand conditions of China in 2025.

The total amount of water resources $W_t = W_s + W_g - W_r$

Where : W_t is the total amount of water resources.

W_s is the amount of surface water resources.

W_g is the amount of groundwater resources.

W_r is the repeated amount of surface water resources and groundwater.

According to the requirements of sustainable development of water resources and the technical limitations in China, there are about 50% of W_t could be used every year ([11][14]). That means :

$$W_{\sup ply} = 50\% \times W_t = 50\%\left(W_s + W_g - W_r\right)$$

Where: $W_{\sup ply}$ is the net available water resource the region can supply.

The demand of water resources of a region include: domestic water, industrial water, agricultural water and ecological water and we have assumed that they can represent the region's total volume of water.

$$W_{demand} = W_d + W_i + W_a + W_e$$

Where: W_{demand} is the total demand of water resources.

W_d is the demand of domestic water.

W_i is the demand of industrial water.

W_a is the demand of agricultural water.

W_e is the demand of ecological water.

So the difference between supply and needs of each region $W_\vartriangle$ is:

$$W_\vartriangle = W_{demand} - W_{\sup ply}$$

After we collect the related data (Like population, the amount of total water resources ect),

4.2 Prediction of the Supply-demand Water in 2025

There are a variety of forecasting methods, in this section, we use **grey forecasting model** to calculate the index we need. First we will introduce the steps of grey forecasting model[28]:

Theory of GM(1,1)

The GM(1,1) is one of the most frequently used grey forecasting model. This model is a time series forecasting model, encompassing a group of differential equations adapted for parameter variance, rather than a first order differential equation. Its difference equations have structures that vary with time rather than being general difference equations. Although it is not necessary to employ all the data from the original series to construct the GM(1,1), the potency of the series must be more than four. In addition, the data must be taken at equal intervals and in consecutive order without bypassing any data [ ]. The GM(1,1) model constructing process is described below:

Step1: Denote the original data sequence by

$$X^0 = \left(X^0(1), X^0(2), X^0(3), L, X^0(n)\right)$$

Where n is the number of years observed.

The AGO formation of X^0 is defined as:

$$X^1 = \left(X^1(1), X^1(2), X^1(3), L, X^1(n)\right)$$

Where $X^1 = X^0(1),\ and\ X^1(k) = \sum_{m=1}^{k} X^0(m), \quad k = 2,3,4,L,n.$

Step2: The GM(1,1) model can be constructed by establishing a first order differential equation for $X^1(k)$ as:

$$\frac{dX^1(k)}{dk} + aX^1(k) = b \qquad (1)$$

$$B = \begin{bmatrix} -0.5\left(X^{(1)}(1) + X^{(1)}(2)\right) & 1 \\ -0.5\left(X^{(1)}(2) + X^{(1)}(3)\right) & 1 \\ \vdots & \vdots \\ -0.5\left(X^{(1)}(n-1) + X^{(1)}(n)\right) & 1 \end{bmatrix}$$

$$X_n = \left[X^{(0)}(2), X^{(0)}(3), X^{(0)}(4), \cdots, X^{(0)}(\mathrm{n}) \right]^T$$

Therefore, the solution of Eq. (2) can be obtained by using the least square method. That is,

$$\hat{a} = [a,u]^T = \left(B^T B\right)^{-1} B^T X_n \qquad (2)$$

Where $\hat{a}$ put into $\frac{dX^1}{dt} + aX^1 = u$, then solve

$$\hat{X}^1(t+1) = \left(X^0(1) - \frac{u}{a} \right) e^{\text{-at}} + \frac{u}{a} \qquad (3)$$

$$\hat{X}^0(t+1) = \hat{X}^1(t+1) - \hat{X}^1(t) \qquad (4)`$$

Step3: We obtained $\hat{X}^{(1)}$ from Eq. (3) .Let $\hat{X}^{(0)}$ be the fitted and predicted series,

$$\hat{X}^{(0)} = \left(\hat{X}^{(0)}(1), \hat{X}^{(0)}(2), \hat{X}^{(0)}(3), L, \hat{X}^{(0)}(n), \cdots \right)$$

Where $\hat{X}^{(0)}(1) = X^{(0)}(1)$

Step4: Using the inverse AGO, we then have:

Where $\hat{X}^{(0)}(1)$, $\hat{X}^{(0)}(2)$, L, $\hat{X}^{(0)}(n)$, are called the GM(1,1) fitted sequence.

$\hat{X}^{(0)}(n+1), \hat{X}^{(0)}(n+2), L,$ are the GM(1,1) forecast values.

4.3 Result of Prediction

Based on the GM(1,1) model above, by using MATLAB, we can get the prediction values of the all the indexes (like W_t, W_{demand}, and the population, Ect.) of each regions of China in 2025. Since the results are so many we just show a few part of it. The total prediction results and the check of population in 2025 are presented in Figure1 below:

Figure1: Result and check of population prediction

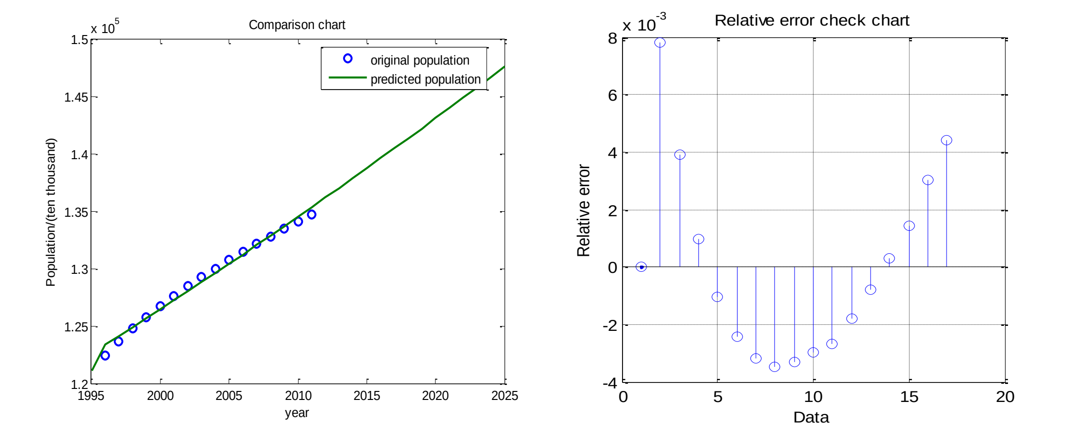


Figure 1 shows the number of the total population of China in 2025 will reach 14.75 hundred million, this is mainly because China's family planning policy so the population growth of China is not fast.

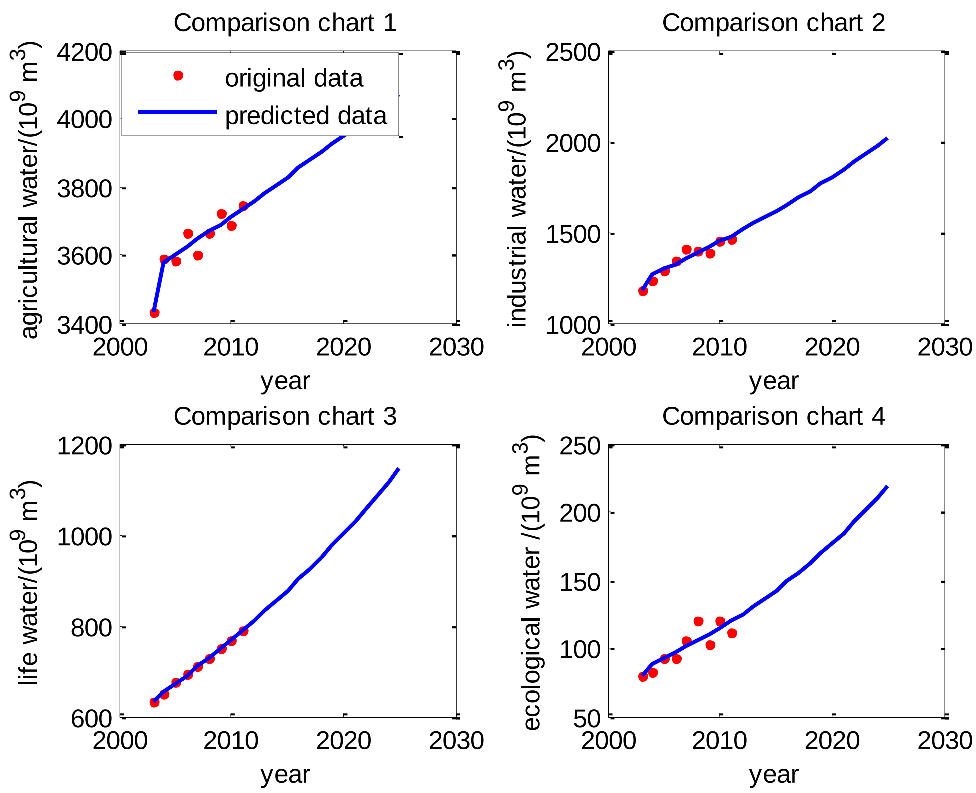
Then we get the amount of different types water in the period (2013-2025), next we compute the $W_\vartriangle$ in each region every year, in this section, due to the limitation of paper we just show a part of the prediction result(Table1 and Figure2) to show the credibility of our forecast.:

Table1: Part results of prediction

	W_a	W_i	W_d	W_e	W_t	$W_{\sup ply}$	$W_\vartriangle$

China	4072	2015	1144	219	7450	15035	7585.0
Beijing	7	2	24	47	80	24	-56
Tianjin	9	5	8	12	34	11	-23
He bei	125	21	31	14	191	103	-88
Shanxi	71	12	25	17	125	83	-42
Liaoning	98	35	29	78	240	170	-70
Jilin	110	70	27	201	408	213	-195

Figure2: Charts of our prediction result



In order to make all our forecasting results more intuitive and all-sided, we draw a map which we mark the shortage provinces ($W_{\Delta} < 0$) with symbols on the map of China, the result is shown below(map1):

Map1: 1

While in the map: the red triangle represents the provinces that $W_\Delta < 0$, that is the regions where the water supply for needs is sufficient. The red five-pointed star represents the regions that $W_\Delta > 0$, that is the regions where the water supply for needs is shortage.

Figure 3

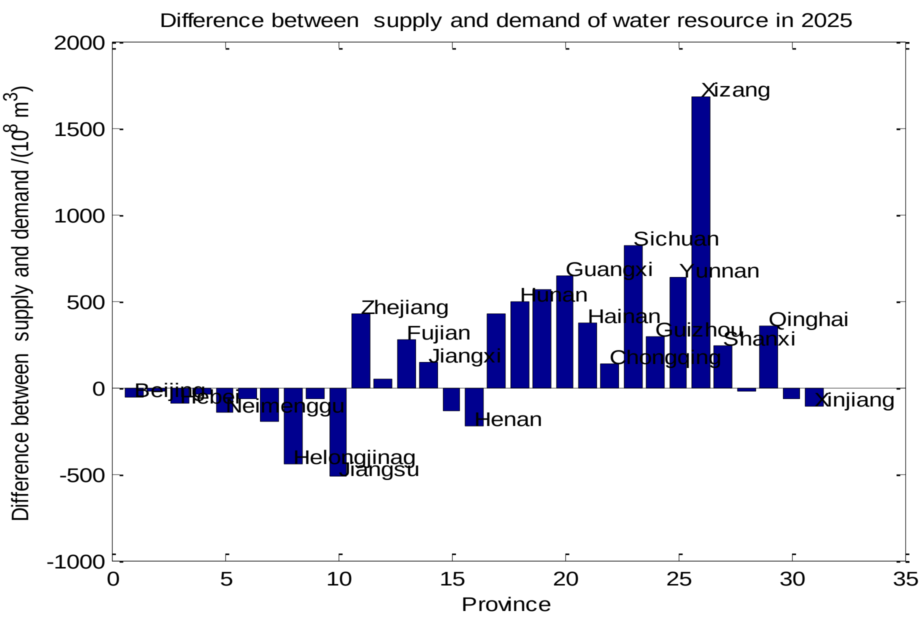


Figure 3 1

From the histogram(Figure 3) of the difference between supply and demand of water resource in 2025 above ,We can see that: there are fifteen regions are in water shortage condition, and the distribution of these areas are mostly in northern China, and the water of southern China regions are generally adequate, this is consistent with the actual water situation of China.

5 Analysis of Water Plan

From the results we have predicted in the section above, we know that: the distribution of the water resources in various regions of China are imbalances. Due to the fact that some areas are of serious water shortages, so we order some strategies to improve water resources in China. The goal of those strategies is to improve and optimize water resources supply-demand.

What we should add is: according to the policy of developing environment-friendly country, the government will first consider the method which is good to their environment ([10][12]). According to Chinese related environment department [10], they consider wastewater treatment as water use because it is so interconnected with the other uses of water. Much of the water used by homes, industries, and businesses must be treated before it is released back to the environment. The wastewater after the treatment can be used again, and from the information we have looked, the Sewage utilization is different in different regions. In this paper, we assume the sewage utilization is 25%, and this amount of water can be used in all ways ([10][12]).

So we assume that every water shortage region in China will first chose the sewage after treatment to make up the lack of water. By this way, after the supply of treatment water, the remaining water shortage regions and its amount of shortage water are:

Table2: the amount of shortage

Beijing	Tianjin	Hebei	Shanxi	Henan	Liaoning	Ningxia
56	23	88	42	225	70	68
Jilin	Shanghai	Jiangsu	Shandong	Heilongjiang	Neimenggu	
195	68	515	137	444	148	

6 Model 1: Water Transfer Model [8]

Since the total water supplies is larger than the total water needs in China, that is:

$$W_{\sup ply} = 50\%\left(W_s + W_g - W_r\right) > W_d + W_i + W_a + W_e$$

In this section, we will use a short-term strategy to meet the projected water needs of all the regions of China in 2025.

We analyze the geographic distribution of the water-shortage regions and the amount of their water shortage. Since the total amount of supply water is larger than the total amount of demand water in China:

That means:

$$\sum W_{\sup ply} > \sum W_{demand}$$

Where: $W_{\sup ply}$ is the amount of supply water of a province.

W_{demand} is the amount demand water of a province.

Our first model to solve the problem is to transfer water, which means: in order to meet the projected needs of every region in China, we can transport water from the sufficient water regions to the shortage water regions, the costs of this method varies according to the total transport distance, this is a main factor for us to chose how to determine the transport line, because we want to make the cost to a minimum.

So we build our model based on Single-objective planning theory, the Mathematical equation the model is:

$$\min = \sum_{i=1}^{16} \sum_{j=1}^{13} x_{ij} d_{ij} y_{ij} c$$

$$st: \begin{cases} \sum_{i=1}^{17} x_{ij} y_{ij} \geq lack(j) & j = 1, \cdots 13 \\ \sum_{j=1}^{13} x_{ij} y_{ij} \leq plus(i) & i = 1, \cdots 16 \\ y_{ij}(y_{ij} - 1) = 0 & i = 1, \cdots 16 \quad j = 1, \cdots 13 \end{cases}$$

Where: x_{ij} is the amount of water transported from region i to region j.

d_{ij} is the transport distance from region i to region j.

C is the costs of per unit amount of water per unit transport distance .

Table3:the water transfer plan

Shortage province	Sufficient province	Numbers of water	Shortage province	Sufficient province	Numbers of water
Bei jing	Shanxi	56	Tianjin	Hubei	23
He bei	Shanxi	88	Shanxi	Shanxi	42
Neimeng gu	Qinghai	148	Liaoning	Hunan	70
Jilin	Anhui	48	Heilong jiang	Hubei	90
	Hunan	147		Hunan	214
Shanghai	Zhejiang	68	Jiangsu	Zhejiang	358
				Fujian	143
				Hunan	14
Shandong	Hubei	137	Henan	Hubei	173
				Shanxi	52
Ningxia	Qinghai	68			

$lack(j)$ is the amount of shortage water of region j.

$plus(i)$ is the amount of surplus water of region i.

The best transfer plan for 2025 is under the condition that the total costs of water transfer is the minimum ,then we will show some parts of the best transfer method: the amount of shortage water in Beijing can be supplied by Shanxi ,the cost is 23; He-bei can be supplied by Shanxi for its costs 88.

To have a more intuitive understanding of the result of our model, we plot a map (map 2) to show the direction and our transfer plan:

Map 2

Then we can compute the total of the best water transfer plan:

$$Q_{m1} = \sum \sum Q_{it}$$

Where: Q_{m1} is the total cost of our best water transfer plan.

Q_{it} is the cost of the water shortage province i.

The cost of desalination Per ton is 5 RMB.

The cost of transport unit ton Per km is 0.006 RMB.

Substituting the data we get the total cost of our best water transfer plan of model 1:

$$Q_{m1} = 13275 \times 10^8 \, yuan$$

7 Model 2: Combine of Water Transfer and Desalination Model [13]

In the water transfer model, we only consider one method to balance the available water resources. Such a method is not comprehensive, this is because there are some regions which are near the sea, as we know the sea water resources in the world is very rich and it's also the same in China. What's more, China puts more emphasis on this issue recent years. As far as we know, in China, desalination and membrane technologies are increasingly used to augment municipal water supply, to produce high quality industrial water supplies, and to reclaim contaminated supplies.

When it comes to the problem we are to discuss, we see that there are some water shortage regions near seas, so those regions can take advantage of the desalination of sea water to supply their water shortage. In this model, we assume that, the price of the water after desalination includes the cost of all the basic desalination infrastructures (like Pipelines, human, plant, Ect.); The price of desalination water from different sea is the same.

Then if we consider the supply of desalination water to reduce the pressure of water shortages of a region, the costs include two parts:

First part is Q_1, it is the desalination costs, while

$$Q_1 = z_j \times p$$

Second part is Q_2, it is the transportation cost of desalinated water, while

$$Q_2 = z_j \times \hat{d}_j c$$

So the total cost of it is:

$$Q = Q_1 + Q_2$$

Then in this section, we come up with a new improved model to meet the projected water needs of China in 2025, this model concerns both the water transfer and the desalinization of water. It really makes sense in terms of the reduction of the costs.

The Mathematical equation the model is:

$$\min = \sum_{i=1}^{16} \sum_{j=1}^{13} \left(x_{ij} d_{ij} y_{ij} c + z_j \left(p + \hat{d}_j c \right) \right)$$

$$st: \quad \begin{cases} \sum_{i=1}^{16} x_{ij} y_{ij} + z_j \geq lack(j) & j = 1, \cdots 13 \\ \sum_{j=1}^{13} x_{ij} y_{ij} \leq plus(\mathrm{i}) & i = 1, \cdots 16 \\ y_{ij}\left(1\text{-}y_{ij}\right) = 0 & i = 1, \cdots 16 \quad j = 1, \cdots 13 \end{cases}$$

Where: z_j is the amount of desalinated water transport to region i .

P is the costs for de-salinization of per unit seawater.

$\hat{d}_j$ is the distance of region j to sea.

Other symbols are as the same as they are above.

7.1 Result of Model 2:

The solution of our second (model2) are shown in[Table4] and [Table5],while [Table4] shows the water shortage provinces make up the shortage by desalination, and the amount of it, [Table5] shows the water shortage provinces make up the shortage by water transfer and the amount of it.

Table4:the amount of desalinization

Beijing	56	Liaoning	70
Tianjin	23	Jilin	195
Heilongjiang	444		

Table5:the amount of transfer water

shortage province	sufficient province	Amount of water	shortage province	sufficient province	Amount of water
Hebei	Shanxi	88	Shanxi	Shanxi	42
Neimenggu	Qinghai	148	Shanghai	Zhejiang	68
Jiangsu	Zhejiang	358	Shandong	Hubei	137
	Anhui	48			
	Hubei	109			
Henan	Hubei	117	Ningxia	Qinghai	68
	Shanxi	108			

To have a more intuitive understanding of the result of our model, we also plot a map to show our plan:

Map3

Then we calculate the cost of the optimal solution of model 2:

The cost of desalination Per ton is 5 RMB. So total cost of this solution is:

$$Q_{m2} = \sum Q_{it} + \sum Q_{id}$$

Where Q_{m2} is the total cost of the solution of model 2. Q_{it} is the cost of waer transfer of province i ,and Q_{id} is the cost of desalination of province i .

Then we get $Q_{m2} = 9260 \times 10^8 \, yuan$

Compared to the cost of model 1, the cost of model 2 decrease by:

$$\Delta = Q_{m1} - Q_{m2} = 4015 \times 10^8 \, yuan$$

8 Model 3: Medium-and long-term Strategic Model [14]

Both the two models above (model 1 and model 2) care short-term water plans to meet the projected water needs of China in 2025, but it can't fundamentally solve the water problems China faced, Because both the two models just consider from the perspective of supply, not the demand, water conservation, or the protection of water sources Ect. Besides there are many practical ways to help to reduce the pressure of water shortage, so we establish a medium-and long-term water plan.

Model 3 include the consideration of three factors: improving the technology of water resources utilization, strengthening the management of both water supply and water demand, maximizing the comprehensive benefits of water resources.

8.1 Improving the technology of water resources utilization

We discuss this problem from three aspects:

- Improve the technology of water resources utilization

  Remote sensing technology [6]

  The advantage of remote sensing technology in the management of water resources is more and more obvious now days. Not only can it help to observe the characteristics and changes in water, but also provide comprehensive information of the surrounding geographic conditions and the impacts of human activities. It helps the government have an intuitive understanding of the changing characteristics of water in nature. According to some information, we know that remote sensing technique offers much more detailed and accurate information than is obtained by other measures of natural environment dynamic supervision which plays a vital role in water management and researches of global water cycle and water balance. Distribution, size, capacity and water quality of the surface water, along with those of ground water, can be measured by remote sensing technique. It can also show perfect water distribution map to control the total available sea water content to optimize water use structure. So it is of great significance to improve this technology to improve the allocation and management of water resources.

- Improve the technology of Agricultural irrigation technology([1][2])

  Among the total amount use of water, the agricultural water accounts for a large proportion. Our survey found that some parts of China Agricultural irrigation technologies and agricultural irrigation facilities are backward, which leads to a waste of a lot of water, and can't receive a good effect, what's more it is not conducive to the long-term development of agriculture. So we advise to improve the agricultural irrigation technology and to introduce advanced agricultural irrigation facilities. By this way, it can help to improve the utilization of agricultural water, as well as the development of the agricultural of China.

- Improvement of the technology of sewage[14]

In recent 20 years, the economy of China is developing at a high speed of 10% per annum. Because of the continued growth of the population, the emissions of water increase. However, many of its rivers, lakes suffer from serious pollution. According to statistics data we know, 80% of the country's waters and 40%groundwater has been polluted, over 90% water of the city is seriously polluted. In addition, in some of the southern mountain city, water lifting height is too large, resulting in the high cost of water and water shortage [ ].

High pollution levels are a serious concern in a densely populated country, although it seems that certain improvements in pollution abatement trends are already in place [ ].

Due to the fact that some countries like American did benefit a lot from the secondary treatment of urban wastewater by develop the technology of water treatment. This is because by this way they naturally reduce emissions to the waters and achieve the both the environmental and economic benefits at the same time,

So we point that, if China want to make full use of its water resources, it should consider the treatment of polluted water or the used water. To achieve that goal, we search some methods of water treatment for the government, they include traditional urban sewage reuse technology (such as : coagulation, sedimentation, conventional filtration) and biological filtration, biological treatment, activated carbon adsorption, membrane separation, disinfection, land treatment method.

8.2 Strengthen the management of water supply-demand *([5][15])*

Through relevant information, according to China's current situation, we found incentives are an effective way of encouraging water conservation. Incentives can be wide ranging from rebates and subsidies on water efficient saving appliances to rewarding urban developers for water conservation and use of different types of water in new developments.

In China, the incentives aimed at the whole country are not enough, so develop the incentives that are targeted to achieve an overall community benefit can help China reduce total water demand. We provide some methods which we think are suitable for China when develop the incentives:

The Water Smart Gardens and Homes rebate program[4] – Chinese government can provide rebates to householders for water conservation devices such as water efficient showerheads and rainwater tanks.

Home loan incentives[2] - There are a number of home loan products that provide interest rate discounts for homes that install water conservation measures

Information to drive behavior change([1][3])

Changing people's behavior is fundamental to saving water and adopting different sources of water. Studies show that many people are locked into their current habits because of a lack of information on how to save water, how to easily access water saving services and how to use different types of water such as rainwater and recycled water.

By providing information and assistance to help people make small changes to their lifestyle, China can make a big difference on the way how water is used. Successfully influencing people's behavior requires a combination of mass marketing campaigns and more personalised approaches. It is also important to influence people at an early age so that saving water and acceptance of different sources of water become part of daily life.

Example of a personalised approach to changing behavior

Improve the Interactive behavior change pilot programs that are being undertaken in China now to assist householders save water. To investigate in depth, the government can have an interview with local people, listening to their needs and assisting them to identify and implement ways to save water.

On average, according to our estimates, by this way the whole country can reduced their water consumption: like, it can reduce the water demand of Agriculture by 10% - 50%, industry water reduction is about 40% -90%. a decrease of 30% in urban water demand. This result is so considerable to some water shortage provinces in China.

8.3 Maximize the Comprehensive Model[9]

As to maximize the comprehensive benefits of water resources, we establish the evaluation model based on Analytic Hierarchy Process(AHP), regulate the provinces (or municipalities) of a low evaluation to draw the best allocation of water resources program under the condition that the benefits of economic, social and ecological are the largest.

Application of AHP Method[29]:

- Analysis of indicators

When determine guidelines layers judgment matrix I , to reach multi-win purpose of the economic, social and ecological benefits, we have reason to believe that the importance of these three factors are equal.

(1) Economic benefits:

$\left(\mathrm{D}_i\right)$ is the water consumption of ten thousand RMB agricultural GDP,

This value reflects the effective utilization of water resources in the economic from the negative directions. In the same output of agricultural production, the higher the value is, the higher the pay for the water resources of the province is.

$\left(E_i\right)$ is the water consumption of ten thousand RMB industry GDP,

This value reflects the effective utilization of water resources in the economic from the negative directions. In the same output of industrial production, the higher the value is, the higher the pay for the water resources of the province is.

$\left(GG_i\right)$ is the total GDP($10^4\,yuan$).

This value reflects the degree of optimization of the industrial structure from a positive direction. Because the maximum economic benefits is the goal for the optimization of the industrial structure, then the number of industrial-agricultural GDP per capita is one of the province's industrial structure optimization of the positive reflection.

(2) Social benefits:

$$DRG_i = \frac{DG_i * 10000}{C_\mathrm{i}}$$

The value reflects the province's agricultural self-sufficiency from the positive direction, which reflects positive social stability in the province;

$$ERG_i = \frac{EG_i * 10000}{C_i}$$

The value reflects the role of the industrial production in the province to support people living from the positive direction, which reflects the level of the province's social development.

$$P_i = \frac{D_i * DG_i + E_i * EG_i + H_i * C_i * 10000}{10^8 * A_i}$$

Where A_I is the total amount of water resources of province i ($10^8 m^3$);

H_i is the water consumption Per capita.(m^3).

Accounting for the ratio from the total water resources of social production and living to the total amount of water use within one year , this ratio reflect the region's water-saving efforts from negative direction, but also reflect the prospects for sustainable development from negative direction.

- Eco-efficiency:

  COD emissions

COD is the amount of oxidant consumed by using a strong oxidant to the deal organic matter under certain conditions in water samples, its value reflects the region's pollution control efforts from negative direction.

The total amount of FF_i , $FF_i = F_i * C_i * 10000$,

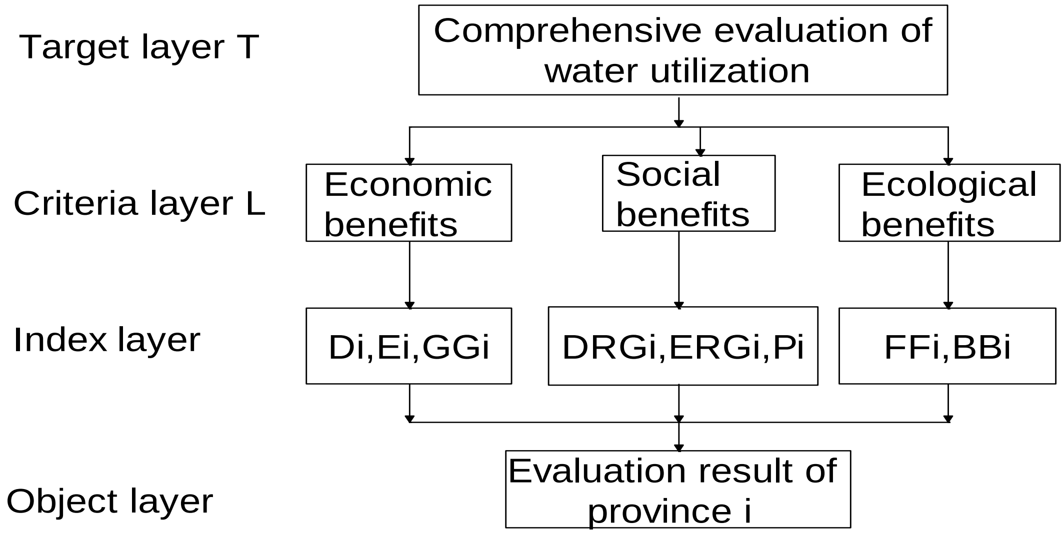
Define : BB_i is Annual precipitation (goblet).

C_i is the total population of province i (10^4).

In certain areas, the greater the annual precipitation is the more times of water exchange are. Due to the flow of water exchange, because of the degradation of some pollutants, the more the water exchange, the more capacity to deal with pollution of the environment. So, this amount reflected the level to prevent water pollution from positive direction.

Then we can get eight indicators and draw basic level [Figure 4].

Figure 4



- Analysis of Judgment matrix

After have determined the various indicators, according to AHP discrimination law, we need to determine the importance of judgment matrix between these variables. The specific values of the standard defined by Professor Saaty [ ]

When we determine the criteria level Judgment matrix, in order to take into account the economic, social and ecological benefits for a multi-win purpose, we have reason to believe that these three important extent equivalent.

Next, by using the same standard, we have to determine the importance of judgment matrix of the index layer I to the criteria layer L. In this process, due to China's specific national conditions and the actual situation of the fact, there are some points we should pay special attention to:

(1) Economic benefits judgment matrix

Because of the fact that the economic benefits is to maximize the gross domestic product (GDP),thus, in the evaluation of the index, we have reason to believe that: GG_i is little more important than E_i ; E_i is a little more important than D_i .

(2) Social benefits judgment matrix

The target of social benefits is to meet two goals at the same time: guarantee the production and living needs of contemporary people; guarantee production and life of the offspring. the main indicators related to the contemporary are the agriculture GDP per capita and the Industrial GDP per capita. Since that agriculture is the fundamental of life, we have reason to believe that: $\mathrm{DRG_i}$ is a little more important than $\mathrm{ERG_i}$; $\mathrm{ERG_i}$ is a little more important than P_i.

(3) Ecological benefits judgment matrix

Since the goal of ecological benefits is to minimize the pollution, and there is only one index of pollution, it is the emissions of COD, so we have reason to believe that $\mathrm{FF_i}$ is much more important than B_i.

- Determine the synthesis weights vector, test the consistency of the judgment matrix

Since we have determined the judgment matrix $I, I_1, I_{2,} I_3$, then we will determine the synthesis weights vector of the eight indicators of index layer, we define it is w. $Iw_0 = \lambda_{0\max} w_0$, the corresponding of the largest eigenvalue is 3

$$I = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Consistency test: $CR_0 = \dfrac{CI_0}{RI_0} = 0$.

Then we get the corresponding eigenvectors $w_0 = \left(\dfrac{1}{3}, \dfrac{1}{3}, \dfrac{1}{3} \right)$

Next we will do Consistency test of $I_1, I_{2,} I_3$ in order,

$$I_1 = \begin{bmatrix} 1 & \frac{7}{5} & \frac{7}{3} \\ \frac{5}{7} & 1 & \frac{5}{3} \\ \frac{3}{7} & \frac{3}{5} & 1 \end{bmatrix} \qquad I_2 = \begin{bmatrix} 1 & \frac{8}{6} & \frac{8}{3} \\ \frac{6}{8} & 1 & \frac{6}{3} \\ \frac{3}{8} & \frac{3}{6} & 1 \end{bmatrix} \qquad I_3 = \begin{bmatrix} 1 & \frac{7}{4} \\ \frac{4}{7} & 1 \end{bmatrix}$$

we know that they meet its tolerance(<0.1).Then determine the synthetic weights vector u of the indicator layer, and do consistency test of the total level

$$w_1 = (0.4667, 0.3333, 0.2000) \quad w_2 = (0.5000, 0.3125, 0.1875) \quad w_3 = (0.75, 0.25)$$

According to AHP method, we know that:

$$B_2 = w_0 * b$$
$$B_3 = diag(w_1, w_2, w_3)$$
$$w = B_3 * B_2$$
$$CI = [CI_1\, CI_1\, CI_1\, CI_2\, CI_2\, CI_2\, CI_3\, CI_3] * w + [CI_0\ CI_0\ CI_0] * w_0$$
$$RI = [RI_1\, RI_1\, RI_1\, RI_2\, RI_2\, RI_2\, RI_3\, RI_3] * w + [RI_0\ RI_0\ RI_0] * w_0$$
$$CR = \frac{CI}{RI}$$

Because CR<0.1, the eigenvectors of the Index layer to the target layer is:

$$w = (0.1556, 0.1111, 0.0667, 0.1667, 0.1042, 0.0625, 0.2500, 0.0833)$$

- Dimensionless indicators

Consider that the evaluation indicators are often non-homogeneous, we do this job follow the rules below:

The positive indicators:

the so-called positive indicators are that: the target values increase with the values of the indicators ,and it's developing in the right direction. For this type of indicators, we construct the following conversion function:

$$\eta_{ik} = \frac{x_{ik}}{x_{\max k}}$$

Where η_{ik} is the evaluation score value of Water resources utilization efficiency evaluation indicator k of the i-th province.

x_{ik} η_{ik} is the original value of Water resources utilization efficiency evaluation indicator k of the i-th province .

$x_{\max k}$ is the Maximum original value of Water resources utilization efficiency evaluation indicator k of the i-th province.

$$\eta_{ik} = \frac{x_{\min k}}{x_{ik}}$$

Where $x_{\min k}$ is the Minimum original value of Water resources utilization efficiency evaluation indicator k of the i-th province.

- Determine the evaluation model

Suppose PZ_i represents the evaluation score of water resources utilization efficiency of province i ,it represents the evaluation score of $k-th$ index.

Then the evaluation scores of each indicator j of Provinces i constitute a vector:

$$\eta_i = (\eta_{i1}, \eta_{i2}, \cdots \eta_{i8})^T$$

According AHP Analytic Hierarchy Process, in our model, we established evaluation model based on, the evaluation score of comprehensive utilization of water resources of each province PZ_i, in essence, is the synthesis weights object layer (that is, we consider the 31 provinces).

$$PZ_i = \sum_{j=1}^{8} w(j)\eta_{ij}$$

The provinces with a low score will be considered to have a new allocation of industrial and agricultural water resources:

$$p(x,y)=\sum_{j=1}^{8} w(j)\eta_{ij}$$

$$st: \qquad x+y+l_i+h_i \le z_i$$

Then we get PZ_i, rank the provinces according to the values of PZ_i, and the ranking results are as follows:

Bei jing	Tian jin	He bei	Shan xi	Nei-meng-gu	Liao ning	Ji lin	Hei-long-jiang	Shang hai	Jiang su	Zhe jiang
0.354	0.335	0.310	0.223	0.244	0.288	0.243	0.218	0.288	0.374	0.356

Chong qing	Si chuan	Gui zhou	Yun nan	Xi zang	Shan xi	Gan su	Qing hai	Ning xia	Xin jiang
0.259	0.245	0.148	0.178	0.277	0.269	0.124	0.144	0.161	0.158

An hui	Fu jian	Jiang xi	Shan dong	He nan	Hu bei	Hu nan	Guang dong	Guang xi	Hai nan
0.221	0.302	0.168	0.426	0.278	0.263	0.253	0.390	0.255	0.314

Then optimize the industrial structure, take Hunan province for example, we assume that all those indexes below are unchanged.

Those indexes are: the total amount of water resources; Annual precipitation; the total population; water consumption of ten thousand RMB of agriculture GDP; water consumption of ten thousand RMB of industrial GDP ; COD per capita; and living water per capita.

x, y represent the distributions of Agricultural water and industrial water.

So we get: $$PZ_i = \sum_{j=1}^{8} w(j)\eta_{ij}$$

$$st: \begin{cases} x + y + l_i + h_i \le z_i \\ \eta_{i1} = \dfrac{x_{\min i}}{x} \\ \eta_{i2} = \dfrac{x_{\min i}}{y} \end{cases}$$

After the optimization of our model, the industrial structure has been changed, the new structure is to assigned to the agriculture of 4.6 billion cubic meters of water , the industrial water of 9.6 billion cubic meters, then the comprehensive evaluation value increase from 0.2513 to 0.5292. Other provinces can be tested in the same method.

9 Sensitivity Analyses [24]

In this section, we will take Hunan province for example to discuss the sensitivity of our model based on the key factors:

- According to our assumption that D_i is constant. To show the effect of how D_i affect our result, we change the value of D_i, and see that: The value of PZ_i will increase with D_i decrease, then we compute that: D_i decrease by5%, while PZ_i increase by0.2%. The specific changes are shown in [Figure4-1]

- To show the effect of how E_i affect our result, we change the value of E_i ,and see that: with E_i decrease. The specific changes are shown in [Figure4-2]
- By increasing the value of P_i, we see that it almost doesn't affect PZ_i The specific changes are shown in [Figure5]

  Through the figure above we can conclusion that: PZ_i depends little on D_i, E_i and P_i.

Figure4

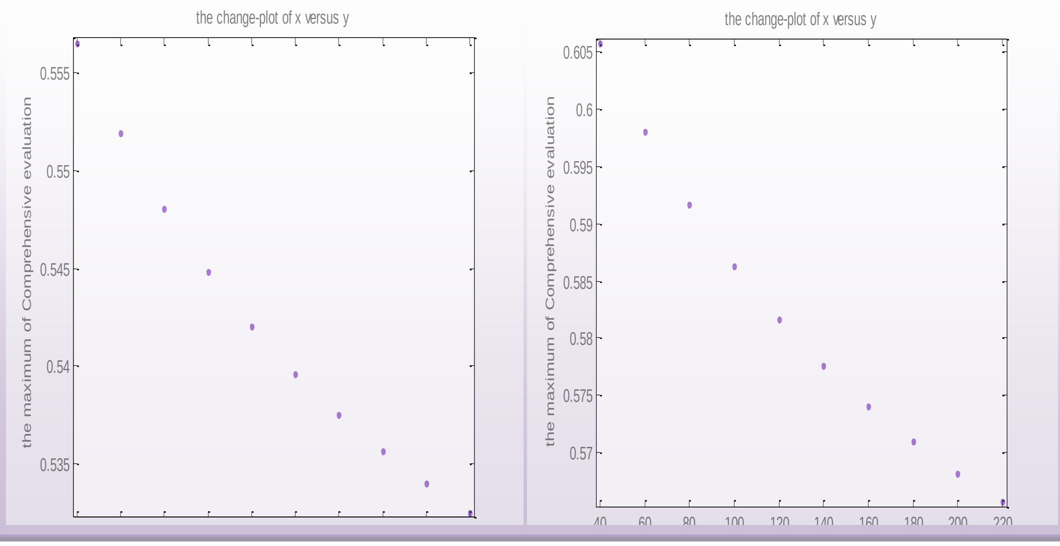
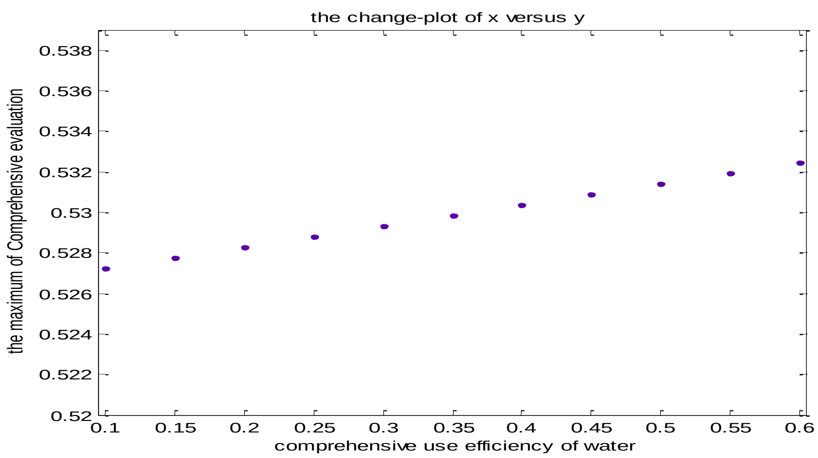


Figure5



10 Further Discussions [25]

In our model, we took account of the influence of environment, economy, society. From our results we can see that can see: the rational allocation of water resources can save economic cost, a good conservation and utilization of water resources will bring about good environmental and social benefits, what's more water resources and industrial structure influence each other.

Through our model 3, the result that: Shandong, Guangdong, Jiangsu and Zhejiang ranked top four for the highest comprehensive efficiency and effectiveness of water resources. It may for the reasons that these four provinces are more developed regions in terms of economic and social; its industrial structure is more reasonable ,most of the people in those regions with a good awareness of the efficient use of water resources ; more advanced water technology are introduced. They are consistent with the reality, so we think that this model is basically reasonable.

From the results of the sensitivity analysis, we have come to the conclusion that :in a region, when its natural and social conditions are certain, the key point to improve the efficiency and effectiveness of comprehensive utilization of water resources , is to improve the industrial structure, so as to achieve economic, social and ecological benefits.

On those basis if China can improve the water-saving technology and strengthen the people's awareness of water conservation and utilization, it can benefits more.

11 Evaluations of Solutions:

11.1 Strengths

- We developed two Short-term strategies which can be used every year for the emergency event of the water shortage. They are feasible, and it’s easy to operate the plan to balance the water in different regions.
- We come up with a Medium-and long-term strategy, which take full consideration of three factors from Effective, development and ecological. This is the best model for China because it’s feasible, and can make the overall efficiency of unit cost the largest.
- The result of our model is consistent with the actual situation of the water resources in China.

11.2 Weaknesses

- Some special data can’t be found, and it makes that we have to do some proper assumption before the solution of our models. A more abundant data resource can guarantee a better result in our models.
- Through the advantages of the Medium-and long-term strategy can’t be ignored, there are some factors that can’t be quantified by mathematical method.
- In this paper, in order to Simplify our model we ignore factors such as natural disasters and climate impact Ect., in fact these factors have a big influence on the water supply and demand which can’t be ignored when design the practical plan for real condition.

- The Price of water desalination and water transfer are not the exact value, this is because the calculation of the exact value is so complicated due to so many factors to consider.

12 A Letter to the Governmental Lead of China

Dear governments of China:

First of all, we are very sorry to tell you the message that: due to our forecasts and analysis ,the issue of water resources in the periods2013-2025 is still very serious, you need to take actively measures from now to cope with the pressure of those problems.

Based on the data of the previous years, by using the gray prediction model we predict the total population, water demand, the lack amount of water available water supply of China and various regions in China during the period 2013-2025. We found the main problems of water resources in China are: despite that the total supply water is greater than the total demand, the water consumption per capita is much larger compared to other countries, the economic benefits of unit water resources is very low; the other character is uneven distribution of water resources, through the result we got in our paper, there are 15regions in a water shortage status, almost all those regions are distributed in the noth of China.

Based on the characteristics of water resources problems in China, and according to the development of eco-friendly environmental country policy, we suggest that: every region firstly consider recycled sewage to make up for part of the water shortage. After that if the region is still insufficient, there are two ways to solve this problem: first is to transfer water from one place to another, this is the usual method China use now, since there are a few existing water conservancy project in China, such as the South-to-North Water Diversion Project, the Three Gorges. However, due to the development of desalination technology in recent years, and its advantages are more and more obvious, we think the method which combine water transfer and water desalination to meet the needs of water shortage regions. For example, Shanghai is close to Zhejiang, the amount of water in Zhejiang is sufficient, so we can transfer the water from Zhejiang to Shanghai. Heilongjiang, Liaoning, and Jilin provinces are near seas, so they can take advantage of water desalination to meet their needs. Compared to the usual plan, the costs of our new plan can reduce 401.492 billion RMB to achieve the same goal. So I think this program has certain significance for your job.

In fact, many factors that can help to improve the situation of water resources can't be specific and quantitative, but they can't be ignored, so we have established a long-term water strategy in our paper, the results of the model tells us three ways to reduce the pressure of water shortage: First is to improve water-saving technologies and water production technology. For example, we can make improvement by introducing advanced desalination equipment, and by improving irrigation methods or equipments.

Second, according to the information we have searched, the awareness of water conservation in China is not common enough, water-wasting phenomenon is very serious in some areas. We wonder if you can increase the intensity of water conservation and water recycling, which is beneficial to both the ecological and economic. To strengthen the management of water supply-demand is also a very important part. In order to cope with the implementation of the program, we also provide a water distribution plan as a reference for you. It can maximize the overall efficiency of the program of per unit of water, which we think can be a good guidance for China to cope with the water shortage problems.

The issue of water resources is a long-term problem, there is so much work we should do, we hope that you can get some information helpful from this letter.

Yours Sincerely

13 Reference

[1]. http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/2012/14-Israel-Water-Sector-Water-Saving.pdf

[2]. wwwmelbournewater.com.au/.../water.../water_supply_demand_strat

[3]. Eng. Sultan Mahmood. Promoting public awareness to conserve water resources for rational and sustainable use of water.

[4]. Zhang Junguo Gao Shigi. China Needs Comprehensive Water Resources Strategi and Effective Water Treatment Mechanism China Environmental Awareness Program.

[5]. Amelia Blanke Scott Rozelle Bryan Lohmar Jinxia WangJikun Huang Water saving technology and saving water in China ScienceDirect 16 June 2006.

[6]. Fu Guobin Liu Changming . Application and Research of remote sensing technology in hydrology ADVANCES IN WATER SCIENCE 11 2001.

[7]. Zhang Xiaoyu, Dou Shiqing. Current Situation and Countermeasures of China's waterresources management Journal of Natural Disasters 2006.

[8]. Zhang Yitao , Zhang Xiaobo . Study on Distribution and Management of South-North Water Transfer Environmental Management in China 10 2002:5.

[9]. Zhang Shuqian, Zhang Xi, Yu Lixi . Water use efficience and effective evaluation system MODERN SCIESE AND TECHNOLOGY 8 2009.

[10]. Zhang Zhi ,Yang Chun. Urban sewage reuse technology Journal of Chongqin Jianzhu University 8 22 2000.

[11]. Xia Jun, Zhu Yizhong. Measure of the safety of water resources:water resources carrying capacity and challenges JOURNAL OF NATURAL RESOUCES5 2002 :17.

[12]. Wu Junsheng Li Hengjun Urban sewage treatment and recyclingJournal of Shandong Normal University(Natural Science) 9 2005.

[13]. http://news.h2o-china.com/html/2010/07/671279501933_1.shtml.

[14]. Qian Zhengying, Zhang Xingdou. China's sustainable development of water resources strategy research report Engieering Science 8 2000:8.

[15]. http://www.npc.gov.cn/npc/xinwen/2012-04/27/content_1719961.htm.

[16]. http://219.235.129.58/welcome.do.

[17]. Department of Construction Engineering, National Taiwan University of Science and Technology, 43, Sec. 4, Keelung Rd., Taipei 106, Taiwan .2007.

[18]. C.K. Chen, T.L. Tien. The indirect measurement of tensile strength by the deterministic grey dynamic model DGDM(1, 1, 1), International Journal of Systems Science 28 (1997) 683–690.

[19]. http://wiki.mbalib.com/wiki/%E7%81%B0%E8%89%B2%E9%A2%84%E6%B5%8B%E6%B3%95.

[20]. http://baike.baidu.com/view/364279.htm.