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Keep Water Crisis Away from Us

Summary

Limited fresh water resource has become a restrictive factor for development in most regions across the world, thus how to handle water shortage in light of the cost is an ever pressing issue. Premised on the real situations in China, this paper analyzes the issue from three perspectives and comes up with sound coping strategies.

First of all, based on China's status, we create a risk assessment model of water shortage nationwide. Risk is defined as the product of risk occurrence probability (P) and level of loss (C). Here, the probability of risk occurrence is quantified by weight model while the level of loss is quantified by GDP and population density. By means of cluster analysis, the grade of risk is divided into five levels and the risk level prognostic map concerning all the provinces of China in 2025 is proposed. The map demonstrates a severe risk of water shortage that might confront China. Therefore, we come up with corresponding strategies from different perspectives so as to reduce the risk of water shortage.

The first strategy focuses on North China, a place that experiences the most severe water shortage, and manages to address the distribution of water resources. We create a multi-target dynamic optimization model that takes into account various restrictions like storage, transportation, supply and demand. Through the genetic algorithm, the optimal water distribution plan in each sub-region is produced.

The second strategy facilitates the site selection of desalination plants in coastal cities of North China, as well as the evaluation of economic benefits for desalination plants. Based on a comprehensive analysis of the impact of all the factors, the analytic hierarchy process is adopted to formulate the order of priority for building plants in the five cities in Bohai coastal region. The result shows that Tianjin is the optimal location for building plants. Matter-element assessment model is established in consistent with the principle of maximizing the benefits and is compared with the economic benefits of South-to-North water diversion project in Tianjin. The conclusion is that desalination is a better choice.

The third strategy analyzes the influencing factors of water price and water demand, as well as the mathematic relation between the two. By introducing elasticity coefficient, a progressive explanation of how to save water by means of adjusting the water price is made, which may provide guidance for local pricing of water. Finally, a regression analysis is conducted on water price and the use of water in Nanjing over the recent decade, the result of which is explained and verified.

Further, we discuss strengths and weaknesses of our models. Conclusion is rendered in the non-technical position paper.

Contents

1.Background

Significant threats to water resources exist across China. Climate change is an emerging challenge in all parts of the country, but numerous long term problems also exist, with serious implications for China's environment, economy and society [Rob de Loe, PhD, 2008].

Fortunately, China currently have an overarching national water strategy that facilitates more effective response to current and emerging challenges and threats. The benefits of having such a strategy are numerous. Examples include the following:

- More consistent and effective responses to concerns with national dimensions, such as water exports and climate change
- Increased accountability due to broader stakeholder participation in governance
- Enhanced environmental protection and a stronger foundation for economic productivity
- Stronger national capacity to respond to threats and crises
- Better positioning to meeting growing international expectations and obligations.

Of course, the existing problems are obvious:

- The distribution of water resource is far uneven in China. Though South-to-North water diversion project has already been under construction, its effectiveness is still invisible at the present.
- The period of rainfall focuses mainly on summer, and therefore, it is not uncommon to confront with dry seasons.
- The pollution of water is increasingly severe but no effective supervision measures have been taken and work.

2. Terminology and Definitions

2.1 Terminology

Desalinization: the removal of salt (especially from sea water).
Elastic coefficient: growth rate of two economic indicators in a certain period. It is a measurement of relationship between two economic indicators' growth.

2.2 Symbol Definition

Table 1.

Main parameters.

Parameter	Meaning
P	Probability of risk
C	Level of loss
$S(x)$	Social objective
$J(x)$	Economic objective
$H(x)$	Environmental objective
$E(x)$	Ecological objective
β_1	Price elastic coefficient
β_2	Income elastic coefficient

3. General Assumptions

- No great climate changes will take place in the years to come.
- The influence of new technologies which may affect the cost of desalination plants can be neglected.
- Population of China increases normally, such as without great amount of immigration, nationwide disease and so on.
- We do not take into account the construction time for desalination plants, divert project and so on. That is to say, all strategies we come up with can be put into effect immediately.

4.A Risk Assessment Model of Water Shortage Nationwide

4.1 Introduction

Given the current situation of China's water resource, people will confront with various problems in their daily living if no proper measures will be taken. Thus, it's essential to give an evaluation to every province's situation of water shortage in China. Therefore, we combine the level of water shortage with risk assessment concept in economics to formulate a risk assessment model of water shortage.

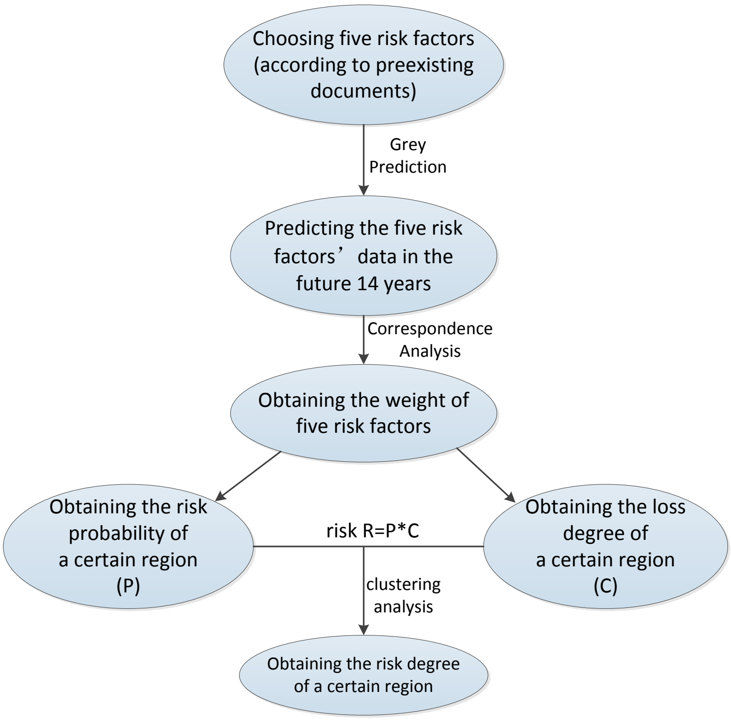

Figure 1. The flow chart of the risk assessment model.

Many scholars have made a multitude of researches to choose risk factors while the results are similar to each other. Hence, we pick out 5 risk factors from related documents [written by Wei Xin et al.2011] and they're annual precipitation, GDP, population, forest coverage, and the amount of wastewater treatment.

4.2 Definition of Risk

Risk (R) is not only a function of the probability of risk, but also the function of the consequence triggered by the risk. So it is easy to understand the point that the probability of the risk may be high while its damage may not so huge. On contrary, there might be a risk with little probability but a huge loss. We obtain the following formula after analysis:

$$\text{Risk (R)= probability of risk (P)} \times \text{level of loss(C)} \qquad (4\text{-}1)$$

The level of loss means the loss degree of objects which will suffer from water shortage when water shortage is taking place at a certain probability. Next, we take Heibei Province as an example to explain our calculate procedure and get its risk level. Other provinces' risk level comes with the same way at the end.

4.3 Quantification of the Probability of Risk (P)

We obtain the assessed value of P by the weight model which is shown by the following formula:

$$P = w_1 x_1 + w_2 x_2 + w_3 x_3 + w_4 x_4 + \iota \qquad (4\text{-}2)$$

Each factor's weight can be calculated by normalizing factors' degree of association

$$w_i = \frac{Z_{0i}}{\sum_{i=1}^{k} |Z_{0i}|} \qquad (k = 1, 2, . \tag{4-3}$$

Because the probability of risk correlates positively with water shortage, we consider water shortage as a reference sequence, five other risk factors as the comparative sequence. With the help of SPSS17.0, we carry the correlation analysis, and then obtain the correlation coefficient between water shortage and other risk factors to find the weight of risk factors.

In order to calculate the risk in 2025, we should use present data to predict the data in following 14 years. Next we use grey forecasting model to predict the reference sequence and the comparative sequence. Each sequence's tendency chart is showed in the picture below:

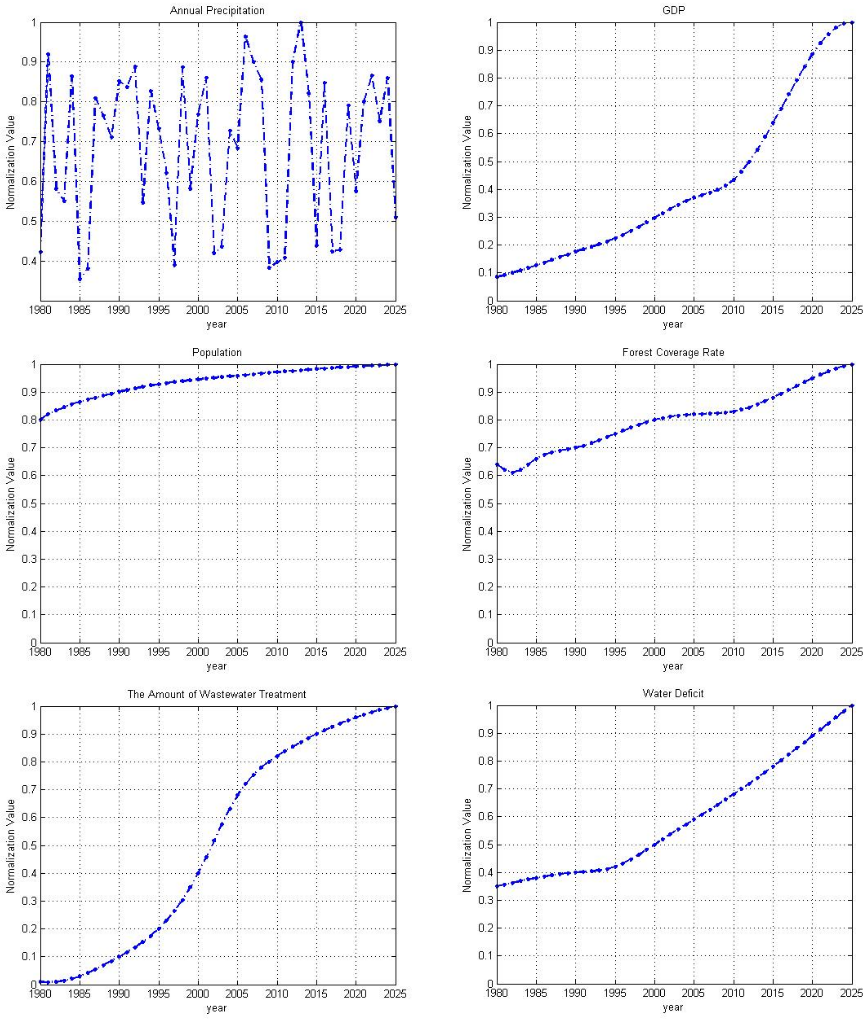

Figure 2. The tendency of annual precipitation, GDP, population, forest coverage, the amount of wastewater treatment and the amount of water shortage in the span of 46 years

We get the weight of each risk factor via correlation analysis with the help of SPSS17.0 by using the data after 2000. The result is listed in Table 1.

Table 1.

Weights of five risk factors.

GDP	0.233
Population	0.176
Forest coverage	0.206
Annual precipitation	0.209
The amount of wastewater treatment	0.176

The probabilities of risk in Heibei province from 2012 to 2025 can be calculated and shown in the following table.

Table 2.

Statistical chart of the probabilities of risk in Heibei province from 2012 to 2025.

Year	2012	2013	2014	2015	2016
Risk Probability	0.613	0.759	0.844	0.665	0.724
Year	2017	2018	2019	2020	2021
Risk Probability	0.646	0.700	0.619	0.818	0.799
Year	2022	2023	2024	2025	
Risk Probability	0.713	0.799	0.844	0.885	

4.4 Quantification of the Level of Loss(C)

The level of loss is quantified by GDP and population density. We take the method of range transformation to normalize the two factors and obtain G_0 and D_0. The formulas are shown as follows:

$$\begin{cases} D_0 = \dfrac{D_i - D_{min}}{D_{max} - D_{m}} \\ G_0 = \dfrac{G_i - G_{min}}{G_{max} - G_{mi}} \end{cases} \tag{4-4}$$

On the basis of calculation method for the level of loss in the evaluation of nature disaster level:

$$C = \sqrt{\frac{G_0 + D_0}{2}} \tag{4-5}$$

We obtain the level of loss of Heibei province from 2012 to 2025.

Table 3.

Statistical chart of the level of loss of Heibei province from 2012 to 2025.

Year	2012	2013	2014	2015	2016
Loss Degree	0.381	0.396	0.405	0.413	0.429
Year	2017	2018	2019	2020	2021
Loss Degree	0.437	0.440	0.453	0.463	0.478
Year	2022	2023	2024	2025	
Loss Degree	0.494	0.518	0.535	0.551	

4.5 The Division for the Level of Water Shortage

We make cluster analysis for the data of the risk of water shortage to obtain the division for the level of the risk.

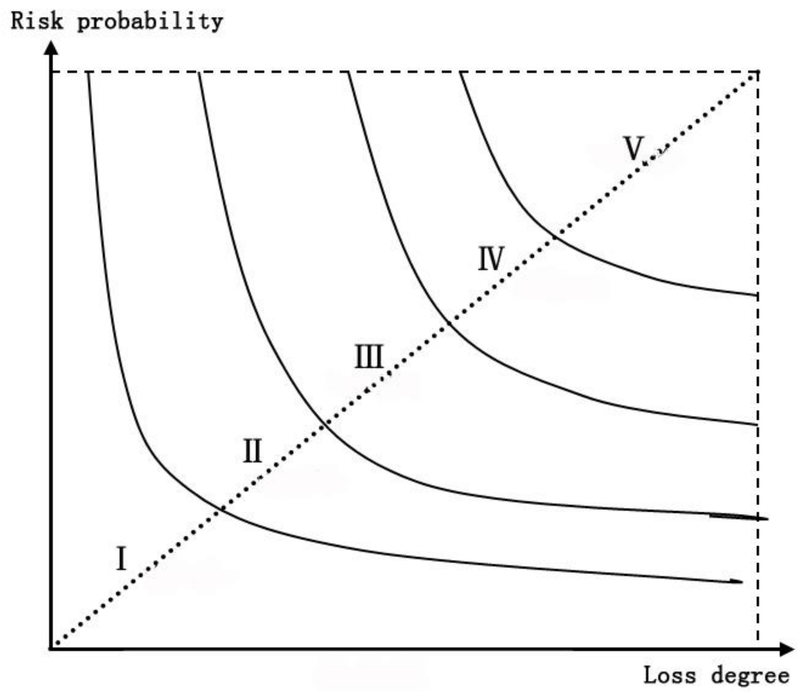

Figure 3. The division for the level of water shortage with respect to risk probability and loss degree

With the division upper, we obtain grade interval classification. To get the criterion of classification, we take the maximum and minimum of each level's data and its adjoining maximum and minimum's average as the boundary of the risk level. Finally, we make the criterion of classification as follows: (the following standard level divide):

Table 4.
The criterion of classification.

Level	Value of Assessment	Interpretation
I	0~0.069	Very Low
II	0.069~0.165	Low
III	0.165~0.237	Moderate
IV	0.237~0.340	High
V	0.340~1	Very High

From the results above, we can easily find that the value of assessment for Heibei province in 2025 is 0.487, designated in level V, which means it has a very high probability of suffering water shortage.

By applying the same method to other provinces, we obtain the level of the risk of water shortage nationwide, as shown in the map bellow:

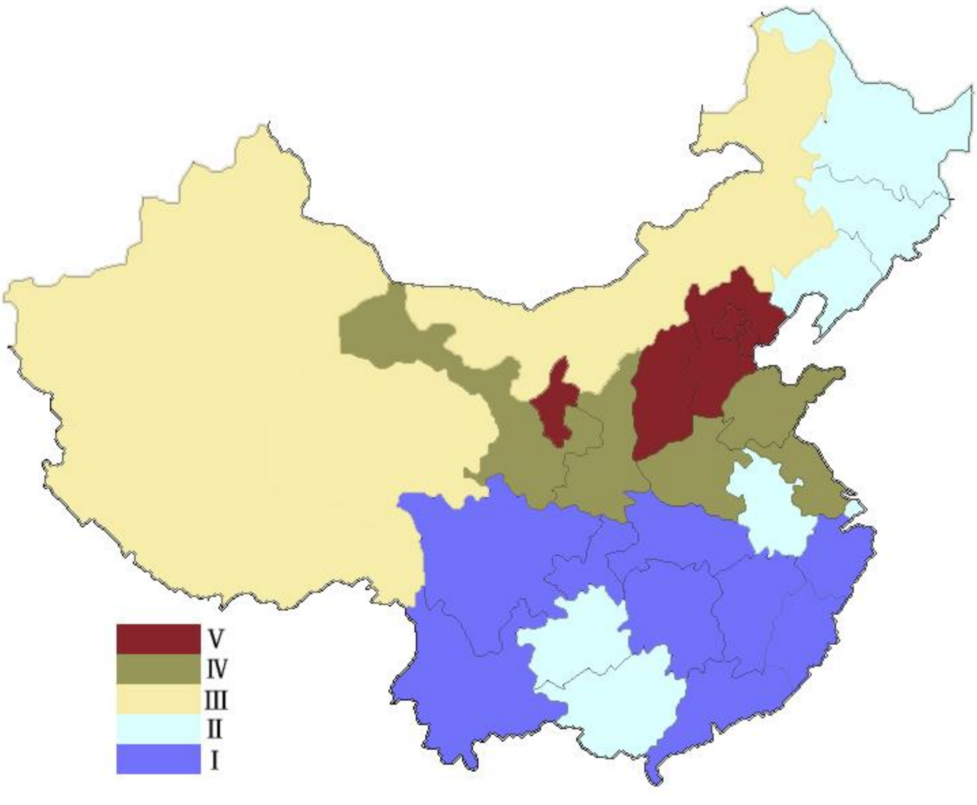

Figure 4. The map of assessment result, each color represents a level of risk of water shortage, and the specification is shown in the left bottom of the figure.

4.6 Conclusion

From the figure above, it is easily seen that the distribution of water resource is far uneven in China. However, the China government has been aware of the seriousness of the problem and already took some appropriate measures, such as South-to-North water diversion project. In the following part, we will build models to analyze a certain region which locates in North China and has the most severe situation.

5.Strategy I-a Multi-Target Dynamic Optimization Model

5.1 Multi-Objective Optimization in Optimal Problems

The objective of the use of water resource should be focused on four aspects: social, economic, environmental and ecological. Overall optimal is what the optimal allocation pursue.

$$F = optimize\{S(x), J(x), H(x), E(x)\} \tag{5-1}$$

Where, parameter Z is allocation vector; $S(x), J(x), H(x), E(x)$ represent social objective, economic objective, environmental objective and ecological objective, respectively.

According to the principle that sub-region division should be in accordance with administrative partition, we divide the North China region that we will investigate into four sub-regions: Hebei Province, Shanxi Province, Beijing and Tianjin. There are four water-consuming sectors: domestic, industrial, agricultural and ecological[FengYao-long et al.2003]. The mathematical descriptions of the models are as follows:

$$\begin{cases} S(x) = \min \sum_{k=1}^{K} \sum_{i=1}^{YS(k)} \left[a_i \sum_{j=1}^{HY(i)} (Q_{kij} - x_{kij}) \right] \\ J(x) = \min \sum_{k=1}^{K} \beta_k \sum_{i=1}^{YS(k)} \left[\sum_{j=1}^{HY(i)} (c_{ij} x_{kij}) \right] \\ H(x) = \min \sum_{k=1}^{K} \left[\sum_{i=1}^{YS(k)} \sum_{j=1}^{HY(i)} (0.01 d_{kij} p_{kij} x_{kij}) \right] \\ E(x) = \min \sum_{k=1}^{K} \sum_{i \in E(k)} \sum_{j=1}^{HY(i)} (x_{kij} / EX) \end{cases} \tag{5-2}$$

a_i:Stands for the weight coefficients reflecting the influences on social benefit triggered by water shortage in area *i*

Q_{kij}:Stands for forecast water demand of industry *j* in sector *i* of sub-region *k*

x_{kij}:Stands for water consumption allocated to industry *j* in sector *i* of sub-region *k*

β_k:Stands for weight coefficients in sub-region *k*

c_{ij} :Stands for benefit of unit water consumption of industry *j* in sector *i*

d_{kij} :Stands for unit discharge of wastewater of industry *j* in sector *i* of sub-region *k*

p_{kij} :Stands for coefficients of sewage discharge of industry *j* in sector *i* of sub-region *k*

$E(k)$:Stands for the set of eco-environment water-using sector in sub-region *k*

5.2 Constraints

(1)Constraint of Total Water Volume

$$\sum_{k=1}^{K}\sum_{i=1}^{YS(k)}\sum_{j=1}^{HY(i)} x_{kij} \le \sum_{g=1}^{G} Q_g + \sum_{k=1}^{K}\sum_{d=1}^{D(k)} Q_{kd} \tag{5-3}$$

Where, *g* is public water source; *d* is independent water source; Q_g is the amount of water available in public water source *g*; Q_{kd} is the amount of water available in independent water source *d*.

(2) Constraint of available water supply

$$\sum_{k=1}^{K}\sum_{g=1}^{G} D_g^k \le \sum_{g=1}^{G} Q_g \tag{5-4}$$

Where, D_g^k represents the amount of water allocated to sub-region *k* from public water source *g*.

(3)Constraint of water transportation capacity

Public resource:

$$D_g^k \le S_g^{k\max} \tag{5-5}$$

Where, $S_g^{k\max}$ represents the amount of water transported to sub-region *k* from public water resource *g*.

Independent water source

$$\sum_{i=1}^{YS(k)}\sum_{j=1}^{HY(i)} x_{kij} - \sum_{g=1}^{G} D_g^k \le \sum_{d=1}^{D(k)} S_d^{k\max} \tag{5-6}$$

Where, $S_d^{k\max}$ represents the water volume of independent water resource *d* in sub-region *k*

(4)Constraint of transported water volume

$$X_i^{k\min} \le \sum_{j=1}^{HY(i)} x_{kij} \le X_i^{k\max} \tag{5-7}$$

Where, $X_i^{k\min}, X_i^{k\max}$ represent the maximum and minimum water demand of sector *i* in sub-region *k*, respectively.

(5)Water allocation of sub-regions

$$\sum_{i=1}^{YS(k)} \sum_{j=1}^{HY(i)} x_{kij} \le \sum_{d=1}^{D(k)} Q_{kd} + \sum_{g=1}^{G} D_k \tag{5-8}$$

(6)Constraint of water quality

$$\frac{\sum_{i=1}^{YS(k)} \sum_{j=1}^{HY(i)} (0.01 d_{kij} p_{kij} x_{kij})}{Q_{k,h} + \sum_{i=1}^{YS(k)} \sum_{j=1}^{HY(i)} p_{kij} x_{kij}} \le W_k \tag{5-9}$$

where, $Q_{k,h}$ represents the amount of water in the river channel of sub-region k; W_k represents the maximum acceptable concentration of important pollutants in water [Yang Ai-min et al.2004].

5.3 Solving Steps Based on Genetic Algorithm

We build a two-level multi-objective optimal model, and apply GA for several times. At last, we achieved the best system comprehensive objective. Specified steps are as shown below:

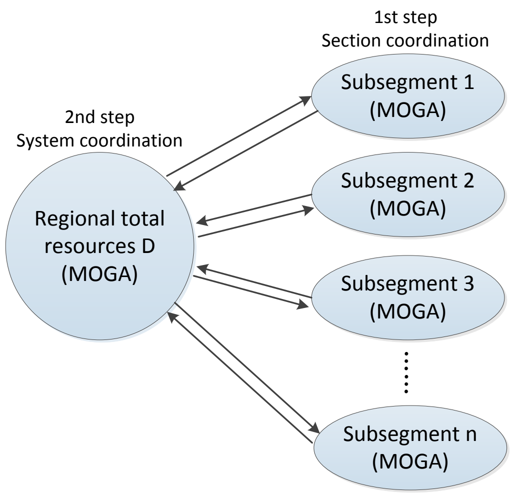

Figure 6. Specified steps of genetic algorithm

(1)Optimization of Subsegment in First Level

The procedures of solving the problem are as follow:

Step1:Firstly, decision variables in the first level are encoded;

Step2:Initial feasible solution can be obtained through genetic algorithm. Putting the solution into each the sub-functions and computing the functional value. Sub-Objection sort methods which mentioned above can be applied to work out fitness and optimize independently in the section of sub segment.

Although we can get optimum solution and the corresponding fitness in the section of subsegment through genetic algorithm, it may not be best equilibrium solution in the section. Hence, optimum solution and the corresponding fitness in the section of subsegment are fed back to the second level and coordination theory should be applied to the second level.

(2)The coordination of the second level system

The task of is the second level is to make optimum solution in the section of subsegment to be best equilibrium solution in the section. The coordination of the second level system also adopts genetic algorithm and the procedures are as follow:
Step1:Producing initial population, namely producing pre-allocated resources D and passing them to each subsegment in the first level.
Step2:Optimizing each subsegment, namely optimizing subsystems in the level, and optimum solution and the corresponding fitness of each subsegment are fed back to the second level.
Step3:The second level decodes information and calculates the fitness based on the feedback it gets， makes selection, crossover, mutation and gets the new group, that is new sorting program .
Step4:Judging the optimal individual in new population whether satisfies the terminating condition, or whether the generation number reaches the preset value. If satisfies, namely water resources has fulfilled optimum distribution, then stop computing of the evolution, output optimized calculation. Otherwise, passing new generation population/ new sorting program to the new level, namely turn to the step2 until satisfy the terminating condition or reach the generation number.

Table 5.

Specified solution of allocation

Sub-region	Agriculture	Industry	Living	Economy	Total
Beijing	10.82	5.14	15.43	4.02	35.41
Tianjin	11.03	4.85	5.55	1.24	22.67
Hebei	143.81	23.16	24.05	2.95	193.97
Shanxi	38.64	2.76	10.69	2.66	53.75

The unit of allocation is 10^9 m^3 /year.

Table 6.

The result of allocation

Sub-region	Balance	Agriculture	Industry	Living	Economy	Total
Beijing	Short A	0	0	0.611	0	0
Tianjin	Short A	0	0	0.126	0	0
Hebei	Short A	3.1	0	0.776	0	0
Shanxi	Short A	0	0	0.254	0	0
North China	Need A	204.3	35.91	55.72	10.87	306.8
	Supply A	201.2	35.91	53.953	10.87	301.933
	Short A	3.1	0	1.767	0	4.867
	Short R	0.015	0	0.0317	0	0.0467

A and R represent amount and rate, respectively. The unit of allocation is 10^9 m^3 /year.

5.4 Conclusion

From Table 6 above, it can be easily seen that the shortage of water in North China has been alleviated greatly. So, we can implement this method to other regions which suffer the same problem of water shortage.

6.Strategy II-a Assessment Model of Desalination Plant

6.1 Selecting the Site for Desalination Plant

(1)Pick Up the Correlation Index

Developing seawater desalination technology is an important approach of solving the problem of scarcity of water for coastal cities in northern China. Selecting the appropriate site for desalination plant is a big challenge when financial support from the government is limited.

In order to decide the location of desalination plant, we must set a number of parameters and establish a database for comparison (The data comes from www.stats.gov.cn). After carefully and thoroughly analyzing the condition of each city, we develop six most significant parameters as shown below:

- The urban economy (M_1)

Since constructing desalination plant is a high, long-term investment, a great amount of money is needed to sustain the running of desalination plant, which requires that the city must have adequate fund. GDP of a city reflects the developmental level of its economy and is easy to be found via the Internet.

- Land price of the city (M_2)

The building cost of projects is mainly determined by the price of the land. Hence, this factor must be considered carefully when selecting the site.

- Energy cost (M_3)

Desalination is an energy-consuming project, making energy cost an indispensable factor. Desalination plant utilizes the electrical energy directly or indirectly at the present. Under the condition of same productivity, electricity price is proportional to energy cost of desalination.

- Human capital(M_4)

Human resource is an irreplaceable role through the operation of the project. Apparently, it is not desirable that the labor cost is very high, so it is important to take into account the average wage of local residents.

- The degree of water shortage(M_5)

Solving the problem of water shortage is the main purpose of the desalination project. The degree of water shortage will have a huge impact on government’s decision-making period. The index can be described by the amount of annual water deficit, which has been mentioned above.

- Environmental protection cost(M_6)

Desalination plant will produce strong brine containing high level minerals which is harmful to the seawater around if dumped into the sea without treatment. A good environmental protection facilities service will benefit reducing the adverse impact of seawater desalination project to the minimum, and the emphasis of environmental protection in a region is measured by the cost of environment protection.

In summary, the relationship of each index can been shown clearly as hierarchical structure. Hierarchical structure of selecting the site is listed in the following:

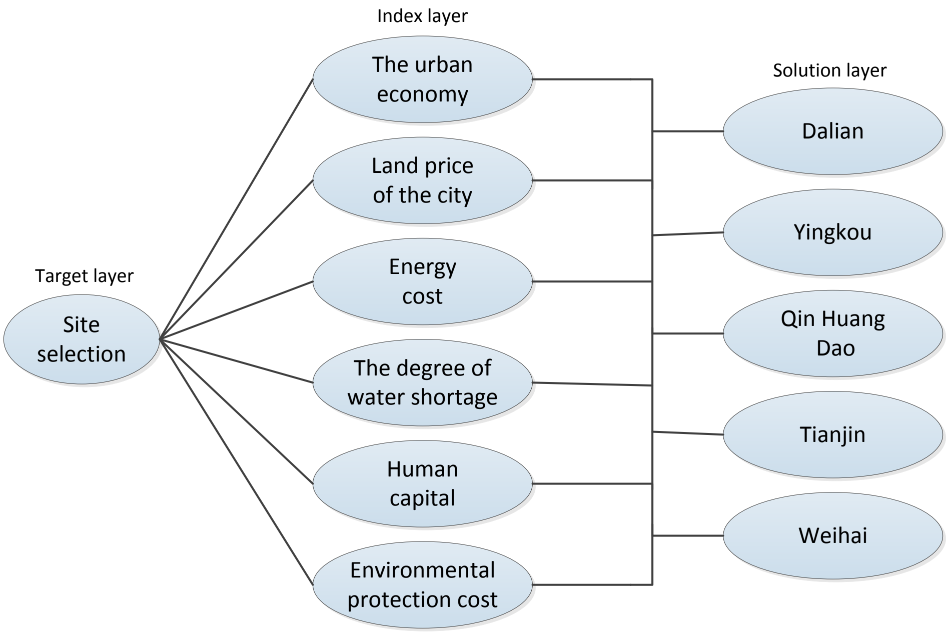

Figure 7. Hierarchical structure of selecting the site

$\mathrm{m}_{ij}\ (i=1,2,\cdots,6;\ j=1,2,\cdots,5)$ from the each data should be normalized at first. Procedures are shown as follow:

$$\mathrm{m}_{\mathrm{ij}}^{'}=\frac{\mathrm{m}_{ij}-\mathrm{n}_j}{N_j-n_j} \tag{6-1}$$

Where $N_j=\max\limits_{1\le i\le 5}\{\mathrm{m}_{ij}\}$

$$n_j=\min_{1\le i\le 5}\{\mathrm{m}_{ij}\}$$

$$\mathrm{m}_{\mathrm{ij}}^{'}\in[0,1]\ (i=1,2,\cdots,6;\ j=1,2,\cdots,5)$$

Table 7.

A database of five cities containing six parameters

The different parameters in the table are made dimensionless.

	M_1	M_2	M_3	M_4	M_5	M_6
Dalian	0.833	1.000	0.800	0.810	0.121	1.000
Yingkou	0.346	0.234	0.779	0.898	0.512	0.433
Qin Huang Dao	0.874	0.841	0.866	0.865	0.956	0.766
Tianjin	1.000	0.866	0.899	0.881	1.000	0.855
Weihai	0.653	0.857	1.000	1.000	0.789	0.713

(2)Comparison

We realize that some of the parameters are somehow more important than others. So in an effort to make our model more accurate and reliable, we introduce a weighted index w_i, with

$$I = M_1 w_1 + M_5 w_5 + M_6 w_6 - M_2 w_2 - M_3 w_3 \tag{6-2}$$

The value of I is bigger, the more likely for the relevant city to catch the chance.

We determine the weights via the Analytical Hierarchy Process (AHP) [Saaty 1982]. We build a 6×6 matrix reciprocal matrix by pair comparison:

$$\begin{array}{c} \\ M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \\ M_6 \end{array} \begin{array}{c} \begin{array}{cccccc} M_1 & M_2 & M_3 & M_4 & M_5 & M_6 \end{array} \\ \begin{pmatrix} 1 & 1/3 & 1 & 1/4 & 1/2 & 1/2 \\ 3 & 1 & 3 & 1 & 2 & 2 \\ 1 & 1/3 & 1 & 1/4 & 1/2 & 1/2 \\ 4 & 1 & 4 & 1 & 3 & 3 \\ 2 & 1/2 & 2 & 1/3 & 1 & 1 \\ 2 & 1/2 & 2 & 1/3 & 1 & 1 \end{pmatrix} \end{array}$$

The meaning of the number in each cell is explained in **Table 8** The numbers themselves are based on our own subjective decisions.

Table 8.

The multiplication table of D_{10}.

Intensity of Value	Interpretation
1	Requirements *i* and *j* have equal value.
3	Requirement *i* has a slightly higher value than *j*.
5	Requirement *i* has a strongly higher value than *j*.
7	Requirement *i* has a very strongly higher value than *j*.
9	Requirement *i* has an absolutely higher value than *j*.
2, 4, 6, 8	Intermediate scales between two adjacent judgments.
Reciprocals	Requirement *i* has a lower value than *j*.

We then input the matrix into a Matlab program that calculates the weight w_i of each factor, as given in **Table 9.**

Table 9.

AHP-derived weights.

Factor	M_1	M_2	M_3	M_4	M_5	M_6
Weight	0.211	0.294	0.190	0.103	0.112	0.09

We test the consistency of the preferences for this instance of the AHP. For good consistency [Alonso and Lamata 2006, 446–447]:

- The principal eigenvalue $\lambda_{\max}$ of the matrix should be close to the number n of alternatives, here 6; we get $\lambda_{\max} = 6.0427$.
- The consistency index CI = $(\lambda_{\max} - n)/(n-1)$ should be close to 0; we get CI = 0.0086.
- The consistency ratio CR = CI/RI (where RI is the average value of CI for random matrices) should be less than 0.01; we get CR = 0.005.

Hence, our decision method displays perfectly acceptable consistency and the weights are reasonable.

We calculate the value of I for each city via calculator, as given in Table 10.

Table 10.

The value of I for each city.

City	Dalian	Yingkou	Qin Huang Dao	Tianjin	Weihai
I	0.131	0.494	0.560	0.664	0.512

(3)Conclusion

According to the value of I from largest to smallest, we obtain the result that First, Tianjin; Second, Qin Huang Dao; Third, Weihai; Forth, Yingkou; Finally, Dalian.

Our suggestion is that when the condition is allowed, Tianjin is the the top candidates for the site of desalination plant. Then, Qin Huang Dao should be considered and so on.

6.2Matter-element Assessment Model of Economic Efficiency

(1)Selection of Indexes

In general, cost displays an inverse correlation with economic efficiency, while output and economic efficiency have positive correlation. Hence, total investment, average cost, energy consumption, supply and output value are chosen as indexes to estimate economic efficiency. The first three indexes come from the aspect of cost while the latter two stands for output. We analysis economic efficiency of both South-to-North Water Transfer and desalination in Tianjin. The former is regarded as the standard object. The latter one is considered as the comparison object.

(2)Data Pre-Processing

Firstly, we transform negative indicators into positive indicators:

$$y_i = \begin{cases} x_i & \text{for positiveind} \\ -x_i & \text{for negative i} \end{cases} \tag{6-3}$$

$$i=1,2,..p$$

we have $$Y=[y_1,y_2,\ldots y_p,]=[y_{ij}]. \tag{6-4}$$

Then, we standardizing original data so as to eliminate the difference on orders of magnitude or dimension among variables. Elements in the matrix are transformed as follow:

$$Z = \begin{bmatrix} Z_1^T \\ Z_2^T \\ \vdots \\ Z_n^T \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{p1} \\ Z_{21} & Z_{22} & \cdots & Z_{p2} \\ \vdots & \vdots & \vdots & \vdots \\ Z_{n1} & Z_{n1} & \cdots & Z_{np} \end{bmatrix} \tag{6-5}$$

(3)The Procedures of Building the Model

Step1: Confirm Matter Element[Cai Yuan 2006,55-60]

$$R(t) = \begin{bmatrix} N & C_1, & V_1 \\ & C_2, & V_2 \\ & \vdots & \\ & C_n, & V_n \end{bmatrix} = \begin{bmatrix} N(t), & C_1(t), & <a_1(t),b_1(t)> \\ & C_2(t), & <a_2(t),b_2(t)> \\ & \vdots & \vdots \\ & C_n(t), & <a_n(t),b_n(t)> \end{bmatrix} \tag{6-6}$$

Where, $N(t)$ *is* the water supply manner; $C_i(t)$ is the i economic index such as output which is mentioned above; $V_i=<a(t),b_i(t)>$, and it is quantitative field of $C_i(t)$ (i=1, 2, ⋯, n). We set m kinds of assessment Level such as $N_1, N_2,\cdots,N_m$ and build the corresponding matter element.

$$R_i = \begin{bmatrix} N & C_1, & X_{i1} \\ & C_2, & X_{i2} \\ & \vdots & \\ & C_n, & X_{in} \end{bmatrix} = \begin{bmatrix} N(t), & C_1, & <a_{i1},b_{i1}> \\ & C_2, & <a_{i2},b_{i2}> \\ & \vdots & \vdots \\ & C_n, & <a_{in},b_{in}> \end{bmatrix} \tag{6-7}$$

Where, X_{ij}(j=1,2,⋯, n) are the quantitative field of economic indexes $C_i(i=1,2,\cdots, n)$ in N_i level(i=1,2,⋯, m). And we define X_{ij} as the classical matter elements.

$$R_P = \begin{bmatrix} N & C_1, & X_{P1} \\ & C_2, & X_{P2} \\ & \vdots & \\ & C_n, & X_{Pn} \end{bmatrix} = \begin{bmatrix} N(t), & C_1, & <a_{P1},b_{P1}> \\ & C_2, & <a_{P2},b_{P2}> \\ & \vdots & \vdots \\ & C_n, & <a_{Pn},b_{Pn}> \end{bmatrix} \tag{6-8}$$

We construct the extensional matter elements based on t the classical matter elements. We build the matter elements *RP* and set $RP \supset Ri$. We define $X_{Pi}=<a_{Pi},b_{Pi}>(i=1,2,\ldots n)$ as the extensional matter elements of $C_i(i=1,2,\ldots,n)$ for *NP*.

Apparently, $X_{Pi}=<a_{Pi} ,b_{Pi}>(i=1,2,\ldots n)$. We have obtained the result of the object P which should be distinguished.

$$R_o = \begin{bmatrix} P, & C_1, & x_1 \\ & C_2, & x_2 \\ & \vdots & \\ & C_n, & x_n \end{bmatrix} \tag{6-9}$$

Step2：The Calculation of Distance

$$D_{ij} = \begin{cases} \rho(x_j, X_{ij}) = \left| x_j - (a_{ij} + b_{ij})/2 \right| - (b_{ij} - a_{ij})/2 \\ \rho(x_j, X_{Pj}) = \left| x_j - (a_{pj} + b_{pj})/2 \right| - (b_{ij} - a_{ij})/2 \end{cases} \tag{6-10}$$

$$i = 1,2,\cdots,m; \quad j = 1,2,\cdots,n.$$

Step3：Build the Correlation Function of Various Indexes for the Comparison Object in Each Level

$$K_i(x_j) = \begin{cases} -\rho(x_j, X_{ij}) / \left| X_{ij} \right| & x_j \in x_{ij} \\ \rho(x_j, X_{ij}) / \left[P(x_j, X_{Pi}) - \rho(x_j, X_{ij}) \right] & x_j \notin x_{ij} \end{cases} \tag{6-11}$$

$$i = 1,2,\cdots,m; \quad j = 1,2,\cdots,n.$$

Step4：Compute Weight Coefficient

The function of calculating weight coefficient is as follow:

$$a_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \qquad i = 1,2,\cdots,m; \quad j = 1,2,\cdots,n \tag{6-12}$$

Step5：Work out the Degree of Association between the Comparison Object P_0 and the Level of j

We set $K_j(P) = \sum_{i=1}^{n} a_{ij} K_j(x_i)$, (6-13)

and define $K_j(P)$ as the degree of association between the comparison object P and the level of j

(4)Discussion

- If $K_j(P) \geq 1.0$, which means that of desalination is higher than that of South-to-North Water Transfer. The bigger the value is, the higher the economic efficiency is;
- If $K_j(P) \leq 0$,which means that of desalination is lower than that of South-to-North Water Transfer. The smaller the value is, the lower the economic efficiency is;
- If $0 \leq K_j(P) \leq 1.0$, which means that of desalination is lower than that of South-to-North Water Transfer. The changes of value in this section make little difference on the economic efficiency.

(5)The Case

We collect the data from www.stats-tj.gov.cn, and the results are listed as follow：

The amount of total investment of South-to-North Water Transfer in Tianjin is as much as 620 million yuan! Average water price produced by this method about 2.5yuan/m^3.Although annual value of production in South-to-North Water Transfer can reach almost 1,000 million yuan, 4000 hectares of land are occupied by the project! The amount of total investment of desalination plant with production capacity of 3000 m^3 per day is merely 24 million yuan. Energy cost of producing one ton water is 1.7kWh. Average water price produced by desalination is about 3.2yuan/m^3.What's more, annual value of production of is 57 million yuan.

(6)Conclusion

Putting the data into the matter element model, with the help of Matlab7.0, we get $K_j(P)$=1.6.Since the result is bigger than one, we may safely come to the conclusion that it is a smart strategy to construct desalination plant in Tianjin！

7.Strategy III- Sustainable Development of Water Price Model

7.1 Introduction

Water is not only a natural resource, but also a product in the market. Adjusting water price is a critical part for the strategy of water resources. Quite a lot of experience has proved that water price plays a significant impact on the demand for water. If the overall water resources are under certain conditions, the higher water price is, the smaller the demand is, and the higher the utilization efficiency is. This phenomenon is called the elasticity of supply and demand [Shen Da-jun et al.1999]. Therefore, we ought to establish reasonable water price so as to achieve the goal of saving water.

Due to the low water price of China, it is prevalent to waste domestic, agricultural and industrial water greatly. The direct consequence of low water price is that people pay little attention to water conservation and water price, thereby developing many water-consuming habits. In most regions of China, water irrigation is the only way for agriculture which has very low use efficiency, so do in industry. In this section, we build models to analyze the measures of setting the price of domestic water and agricultural water respectively.

7.2 Basic model

We suppose Q is per capita water consumption and P is water price. We call the ratio of two numbers-the decline of water demand and the increased on water price as elasticity coefficient E, namely

$$E = \frac{P}{Q} \cdot \frac{\partial Q}{\partial P}. \tag{7-1}$$

By integral, we can get:

$$Q = K \cdot P^{E_0}. \tag{7-2}$$

Where, K is a constant, E_0 is the price model of water demand.

According to the formula, we can roughly obtain the relationship between the water price and the per capita water as follow:

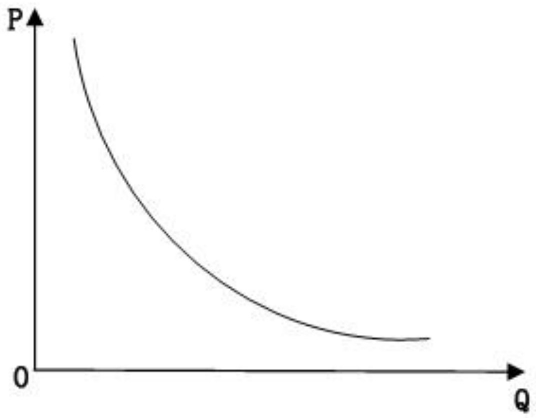

Figure 8. Demand curve between per capita water consumption and price of water

However, the water price elasticity coefficient is not a constant. It is kept on adjusting with the changes of water price. **Figure 9.** describes the correlation between water price and per capita water consumption perfectly.

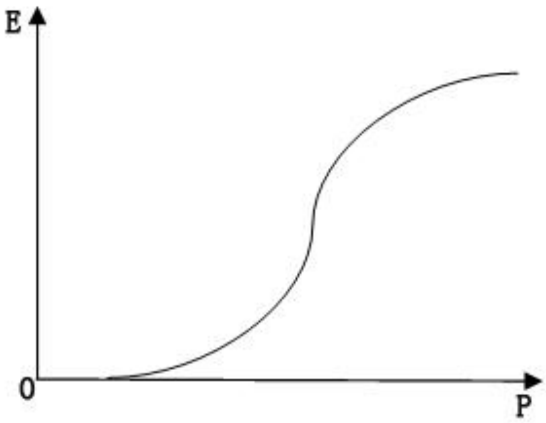

Figure 9. Diagram of water price elasticity coefficient

If we set:

$$E = \lambda In(P) + \alpha, \tag{7-3}$$

then, we can get:

$$E = \frac{P}{Q} \cdot \frac{\partial Q}{\partial P} = \lambda In(P) + \alpha. \tag{7-4}$$

Both sides are integrated, we have

$$\int_{Q_1}^{Q_2} \frac{\partial Q}{Q} = \int_{P_1}^{P_2} (\lambda In(P) + \alpha) d(InP), \tag{7-5}$$

$$InQ_2 - InQ_1 = \frac{\lambda}{2} \ln^2 P_2 + \alpha \cdot \ln P_2 - \frac{\lambda}{2} \ln^2 P_1 - \alpha \cdot \ln P_1. \tag{7-6}$$

Where the coefficients λ and α can be derived from the numerical analysis fitting.

We suppose the current water price P_1 and the current water demand Q_1 is given. Once the price after adjusting Q_2 is specific, we can easily calculate the water demand after adjusting the price Q_2.

7.3 Improved Model

Above basic model, we take income elasticity into account, because only when the water price's rise is proportional to the rise of income, can this have an effect on water conservation. In reality, there are many researches which show that when the water consumption accounts for 1 percent of family's total income, people trend to neglect it, and when it comes to 2 percent, people begin to pay little attention to it. Only when it comes to 5 percent, do people pay much attention to it. Thus,

$$Q = K \cdot P^{E_0} \cdot M^{E_1} \tag{7-7}$$

Where, M stands for the per capita disposable income, E_1 represents income elastic coefficient for water demand.

According to the characteristic of the equation, we transform it into the following equation in order to ensure statistical regression methods can be applied.

$$\ln(Q) = \beta_1 \ln(P) + \beta_2 \ln(M) + \xi \tag{7-8}$$

The meaning of the regression coefficients is listed as follow:

β_1—price elastic coefficient

If water price doubles, water consumption falls by β_1 percentage.

β_2—income elastic coefficient

If the per capita disposable income increases by one percentage, water consumption rises by β_1 percentage.

$$\begin{cases} \dfrac{\beta_1}{\beta_2} < 1 & \text{determined by the income} \\ \dfrac{\beta_1}{\beta_2} = 1 & \text{in equilibrium} \\ \dfrac{\beta_1}{\beta_2} > 1 & \text{determined by water price} \end{cases} \tag{7-9}$$

7.4 Model Promotion for Agricultural Water

The condition of agricultural water is similar with living water. But we should take annual precipitation into consideration when we discuss the function of agricultural water. Here, the parameter R is introduced to describe the function. So we obtain the function of agricultural water as follow:

$$\ln Q = \beta_1 \ln P + \beta_2 \ln M + \beta_3 \ln R \tag{7-10}$$

Where, Q represents water demand for agricultural water, P is the price for agricultural water.

7.5 Model testing

We take the data related with demand in households in Nanjing from 2001 to 2010 for the use of statistical analysis. (The data sources from www.njtj.gov.cn.). The data is listed in the **Table 11.**

Table 11.

Statistical chart of the data related with demand in households in Nanjing from 2001 to 2010.

Year	Water consumption per capita	Water price	The per capita disposable income
2001	55.51	1.45	8848
2002	55.67	1.63	9157
2003	56.23	1.99	10196
2004	56.66	2.14	11602
2005	56.99	2.23	14998
2006	56.20	2.30	17538
2007	56.45	2.40	20317
2008	56.47	2.70	23123
2009	56.67	2.90	25504
2010	55.41	3.10	28311

The unit of water consumption per capita is ton/year. The unit of water price is yuan. The unit of the per capita disposable income is yuan/year.

We make regression analysis for the data in the table via SPSS17.0 and obtain the regression equation as given in the following:

$$\ln(Q) = -0.318\ln(P) + 0.509\ln(M) \tag{7-11}$$

$$R^2{=}0.61 \qquad DW{=}0.92 \qquad F{=}13.151$$

Since $\frac{\beta_1}{\beta_2} < 1$,the equation shows that the increasing of income mainly contributes to the growing of water price. However, water consumption per capita undergoes little change in the ten years.

7.6 Conclusion

There is a negative correlativity between water demand and water price. The adjustment of water price has a very strong inhibition effect on water demand. Since water price still has much room to go up in China, the authorities can regulating water price properly to fulfill optimal allocation of water resources in the whole society. Therefore, under the circumstance of water shortage and low water price, we should give full play to the leverage of water price to adjust water price reasonably.

8.Strengths and Weaknesses

8.1 Strengths

•Our model is based on quantitative analysis/data, so the output is objective and reasonable.
•The results of our model conform to the data that we found.
•Our model is based on categories of leaf types that are the most typical and common
•The numerical computations in the research are precise.
•Our study has scientific value for the research on rational use of water resources in the future .

8.2 Weakness

•We take the North China as an example in particular when analyzing, which may not cover all the situations nationwide.
•Our analysis of adjusting water price is rather cursory, specific solutions for national significance are not explained.
•We have limited grades of risk , so the complexity of water risk cannot be described precisely.
•We ignore the influence of South-to-North Water Transfer Project when we make strategies.

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Position Paper for Governmental Leadership

Dear Leaders：

As we all know, China is faced with great challenges with respect to the strategy of water resource, for the fact that the distribution of water resource is far uneven and per capita water resource is well below the average level of the world. In order to minimize the probability of water crisis, we put forward the following remedies, on the basis our thorough analysis, which is helpful to policy-making.

As the development of new technology in recent years, the cost of seawater desalination has decreased to a large extent, especially in certain regions, it is even lower than the water diversion cost. Hence, it has huge market potential for the implementation of building desalination plants. Specifically, the construction site of desalination plants is supposed to converge around the coastal cities in north China, the best one of which is Tianjin and it is derived from the comprehensive consideration of economic factors.

Not only should we divert water resource well enough, but also we should make full use of it. So, it is crucial to reasonably allocate water resource locally. However, considering that China has a vast territory, it is impossible to take all regions into account. Therefore, we should make the most severe region a priority, such as regions in North China. Scheming by region and supplying by demand with various constraints are regarded as the most effective solution.

With limited water resource, it is a practical method to adjust the water price for the sake of saving water, giving the fact that water price has an effect on people’s water consumption. Most past policies failed to pay much attention to the rise of people’s income, thereby making the ratio of income to water price kept in a low level as well as failing to divert people’s attention to water conservation. Thus, it is high time that we should raise water price slightly in some regions, according to this paper.

In a word, only we spare no effort to insist on the strategy of water resource and make instant adjustment according to the current situation, can we keep water crisis away from us.

Sincerely yours
Team 22905
February 4th, 2013