What is future of China's water needs?

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February 4, 2013

Contents

1 Summary

Aiming at the fresh water problem in China, our paper is organized in four models.

1. Grey Prediction Model
   Grey prediction is one of the methods that are good at forecasting data holding exponential growing tendency. In our model, we forecast industrial water, ecological water utilization and basic daily water utilization in 2025 basing on the historical data from 1995 to 2011 for these data are close to population, which is an obvious exponential growing model.

2. Non-linear programming model
   In this model, we apply graph theory to solve the problem of water transfer between cities. We attain our ideas via shortest path problem and we solve a problem of weighted shortest path. We set the weights for 31 provincial capitals from two side points–distance and height. With the help of Lingo, we resolve a non-linear programming model (after satisfying the cities' water demand, we have the lowest cost by our solution).

3. As the second model is quite idealized, we introduce some improvements to make it more specific. Firstly, this model concludes economics, environment and population factors; secondly, we change the objective function of our non-linear programming model by using Multi-objective linear weighting function method. Then, vividly, we get a feedback of corresponding relationship between fresh water resources and environment, economics, the yield of water, population and water quality.

4. Basing on the three models above, we find WEAP, a software describing and simulating water transferring. Via WEAP, we establish a simulation model to analysis annually of water strategy from 2013 to 2025 dynamically.

Generally, our results show water transmission and dispatching quantitatively and we overall considerate storage and movement of fresh water and economics, environmental factors in our model. Our results fit well with the South-to-north water transfer project and some other water strategies as well.

2 Introduction

As is known to all that fresh water is the limiting-constraint for development in much part of the world, people need fresh water for drinking. The total amount of water on the earth is 1.4 billion square kilometers. There is plenty of water on the earth while the fresh water only takes 2.53% of it among which the 68.7% is glacier and is hard to explore. Nowadays, there is only 0.26% of the total water amount on the earth. People have consumed 54% of the available fresh water over the world. Meanwhile, the problem concerning pollution of fresh water is not eliminated till now. Then it's obvious that fresh water problem is a widespread concern all over the world. As for China, the problem cannot be even slighter. China is a country with heavily shortened fresh water and the conflicts between provision and need can never be calmed down. According to the statistics data, there are 20 million people having heavy problem drinking water and over 400 cities in the situation of longing for fresh water. There can be droughts in either part of China. What's worse, the fresh water of most parts of China has been polluted more or less.

In 1972, UNHEC (United Nations Conference on the Human Environment) announced, "the next crisis after oil crisis is water". Then in 1977 The United Nations Conference of Water emphasized further that, "water will soon be a deep social crisis". As time goes by, the earth is suffering more and more by "water crisis", such as the loss of biodiversity and bad influence on people's health from water pollution. All in all, this is allowed of no delays to consider about the problem of fresh water in the world. In China the government has made some giant projects such as South-to-north water transfer project. Besides, China has made many reservoirs to balance the great difference in time in China, especially southern part of China.

People have done much work before about the corresponding questions. In allocation model for water right by Wang Xuefeng and his partners, they present a linear programming model discussing distribution problem of fresh water in China. Chen Kangning, Dong Zengchuan and Cui Zhiqing put forward an original idea to evaluate water system in their paper evaluation of vulnerability of regional water resources system based on the fractal theory. Yan Jun and his cooperators create their idea of the relationship between Water resources carrying capacity factor and the South-to-north water transfer project in the paper the influence of South-to North water transfer project on the water resources load capacity of the Yangtze River basin and the methods to optimize the allocation of water resources, which enlighten our road ahead.

In this paper we have two main theocratical models, the first one is based on grey prediction to forecast water needs in 2025 and the second is based on nonlinear programming algorithm. The results of grey prediction give us a whole view of China's future water needs and then based on the prediction, we build programming model to balance water resource distribution and water demand both of which present unbalanced geographically and seasonally. To check our original strategy coming from programming model, we build a regional simulation model to dynamically simulate changes and relationships of water supply and demand. In addition, considering the complexity and speciality of China, we look through information about both China's present water strategy and foreign countries' researches and experience. Based on these steps of analyzing and modeling, we get our final water strategy for 2013 to meet water needs in 2025 and submit one position paper recommending to governmental leadership.

3 Restatement of the Problem

As everyone knows, fresh water is a strong restriction towards development in most part of the world. How to present an effective, feasible efficient water strategy via producing a mathematical model to describe the very strategy in 2013 for China's water needs in 2025? Addressing storagemovement and conservation is vital to some degree while some economical, physical and environmental factors are better to be included.

4 Forecasting the Water Needs in 2025

4.1 Grey Theory Background

When considering many realistic problems whose internal structure, characteristics and parameters cannot be comprehended thoroughly, we can only find a solution to build models by rational assumptions and logic deductions instead of understanding the internal mechanism like white-box approach. This kind of system including unknown information inside is called Gray System.

Grey prediction refers to utilizing GM model to forecast the development regulation of systematic characteristics and as well the moment when anomalies occur. These applications indeed use *gray process* instead of *random process* and *gray variations* instead of *random variations* by applying GM(1,1) model in gray theory.

Grey prediction has been extensively applied in fields of industry, agriculture, business, environment, society and military, especially when forecasting trends of development in the future through available data at present.

4.2 GM(1,1) Model

Assume original data series as

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)) \tag{1}$$

and the 1-AGO formation of $x^{(0)}$ is defined as

$$x^{(1)} = (x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n)) \tag{2}$$

where

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1, 2, \ldots, n \tag{3}$$

The GM(1,1) model can be constructed as a *grey differential equation* as

$$x^{(0)}(k) + az^{(1)}(k) = b, k = 2, 3, \ldots, n \tag{4}$$

Corresponding *white differential equation* is

$$\frac{dx^(1)}{dt} + ax^{(1)}(t) = b \tag{5}$$

Using least square method, we can get the solution of differential equation as

$$x^1(k+1) = (x^0(1) - \frac{b}{a})e^{-ak} + \frac{b}{a}, k = 1, 2, \ldots, n-1 \tag{6}$$

in which the boundary condition is $x^1(0) = x^0(1)$.

The process of least square method is as follows:

The mean series is $z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1), k = 2, 3, \ldots, n$, given

$$u = (a, b)^T, Y = (x^0(2), x^0(3), \ldots, x^0(n))^T, B = \begin{bmatrix} -z^1(2) & 1 \\ -z^1(3) & 1 \\ \vdots & \vdots \\ -z^1(n) & 1 \end{bmatrix} \tag{7}$$

then $\hat{u} = (a, b)^T = (B^T B)^{-1} B^T Y$.

To check the accuracy of consequences of the GM(1,1) model, we calculate the *residual series* $\varepsilon^{(0)}$ of $x^{(0)}$ in order to get a better results than calculating $\varepsilon^{(1)}$ of $x^{(1)}$ which is generally used. Computing formula is defined as

$$\varepsilon^{(0)}(k) = \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)}, k = 1, 2, \ldots, n \tag{8}$$

4.3 Data Processing

To forecast the future water needs for 2025, we should get the real water supply in the past few years. In fact, the statistic data include a wide range of categories like surface water, underground water, waste, usage in agriculture, industry, residential assumption, etc. Considering the water assumption of agriculture will be dependent on climate change, changes of policies from government (when residential assumption or industrial needs cannot be satisfied, the amount of agriculture water supply will be reduced in some areas of China, we ignore this kind of water usage for water dispatching in the next section. On the one hand, ignoring agricultural water assumption is consistent with real situation and policies of China, even though this category occupies a big part of water usage according to statistics (above 50%). On the other, except agricultural consumption, most of water usage, like residential and industrial consumption, are relevant with the growth of population. In addition, the waste of water supply is minimal, which in most provinces occupies less than 1%, thus the water supply is approximately equal to the water assumption. To exclude the agricultural water assumption, we use GM(1,1) model to forecast water needs in only *urban area* including production water supply and daily water needs of 31 provinces in China at first. Then we find that the accuracy of these fitting curves is sometimes not good enough as expected previously. Then we search more information about circumstances of these provinces and also the precise implications of statistics like what dose water supply means and includes. Finally, we decide to use water assumption excluding agricultural supply of both urban area and other area to calculate fitting curves again. Comparing the two consequences using different data gives us some new understandings and encouragingly, the second results come to a better fitting effect in most provinces. To be clear, for the second fitting processing results, we only use data ranging from 2002 to 2011 instead of that from 1997 to 2011 when calculating first fitting, because we later consider that China had natural disasters like flood in during 1990s which may influence the water needs increasing regulation relevant to population increase. Total curve pictures are attached in the appendix and the original statistics come from *China Statistical Yearbook (1996-2012)* and the statistics consist only 31 provinces of China (exclude Hongkong, Macao and Taiwan). Blue circles are original statistics series, green stars are first fitting values and red triangles are secondary fitting ones. Secondary fitting is based on the results of first fitting results with the same GM(1,1) model.

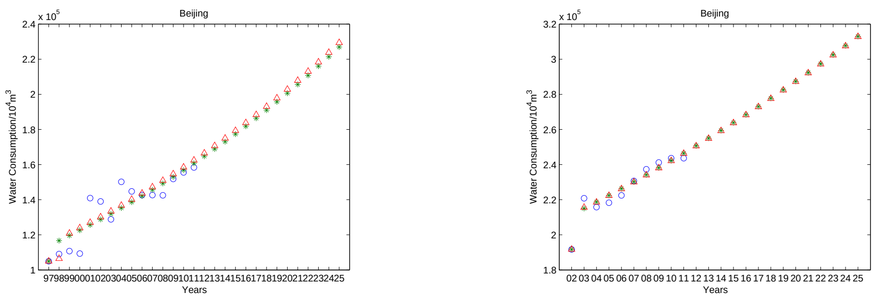
4.4 Data Analysis and Interpretation

We calculate the residual series and find that the second processing results are better than first fitting in most provinces. The residual series represent the relative errors when fitting which can to some degree reflect the accuracy of results. The little the values are, the more credible the forecasting differential equations are. To be clear, the residual series results are based on the secondary fitting curves.

Table 1: Residual Series List 1

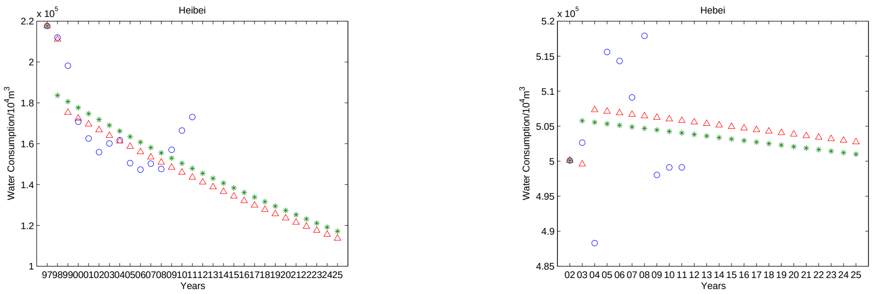
PROVINCES	Beijing	Hebei	Jilin	Heilongjiang	Anhui	Guizhou
FIRST	4.87%	5.16%	9.93%	6.76%	5.79%	9.35%
SECOND	1.18%	1.46%	5.25%	1.99%	2.56%	2.04%
PROVINCES	Jiangxi	Hunan	Guangdong	Hainan	Sichuan	Xizang
FIRST	13.30%	4.82%	10.72%	9.15%	5.34%	10.18%
SECOND	2.50%	1.73%	0.90%	5.86%	0.84%	5.66%

The reasons of two different results are the real circumstances of certain provinces. For example, observing pictures directly we can find that data of certain provinces are in accordance with GM(1,1) model and has the same trend both in urban area and reginal area, such as Beijing, Hunan, Guangdong, Xizang, but some others are not. The probable reason is that in these provinces, the urbanization is increasing rapidly and water assumption from urban area occupy



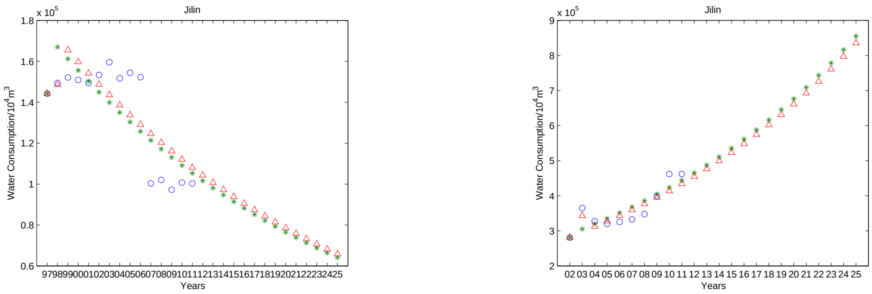
(a) First Fitting (b) Secondary Fitting

Figure 1: Beijing



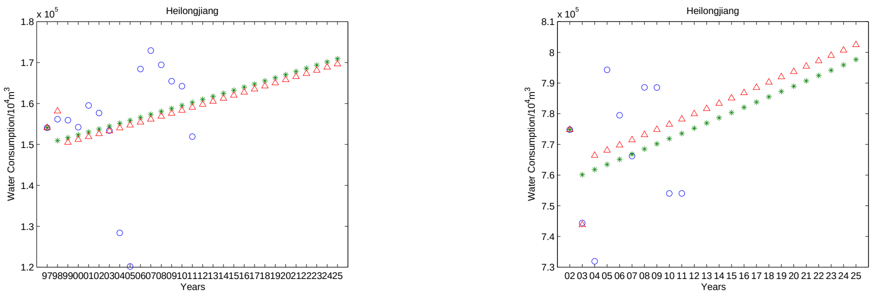
(a) First Fitting (b) Secondary Fitting

Figure 2: Hebei



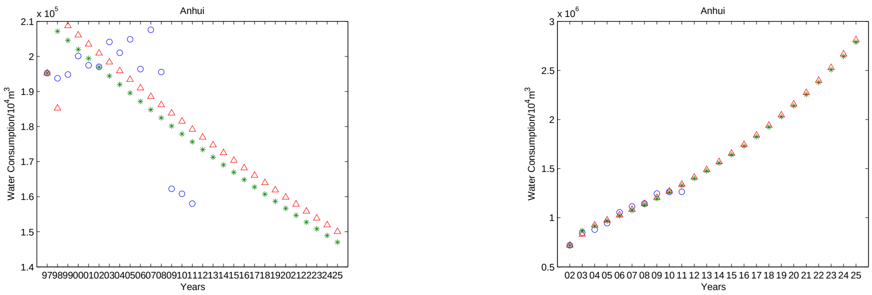
(a) First Fitting (b) Secondary Fitting

Figure 3: Jilin



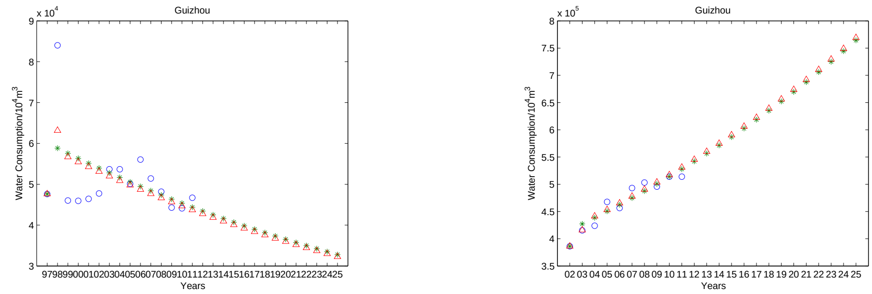
(a) First Fitting (b) Secondary Fitting

Figure 4: Heilongjiang



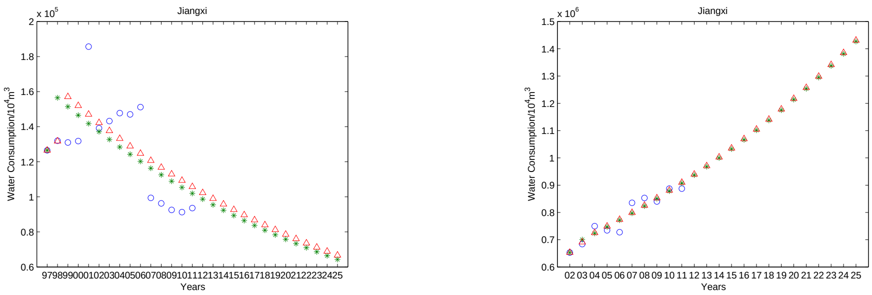
(a) First Fitting (b) Secondary Fitting

Figure 5: Anhui



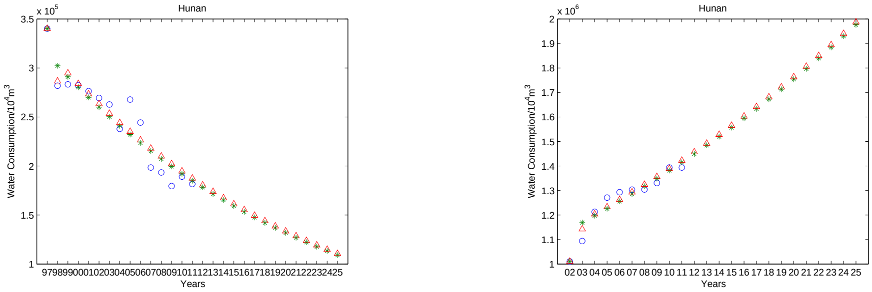
(a) First Fitting (b) Secondary Fitting

Figure 6: Guizhou



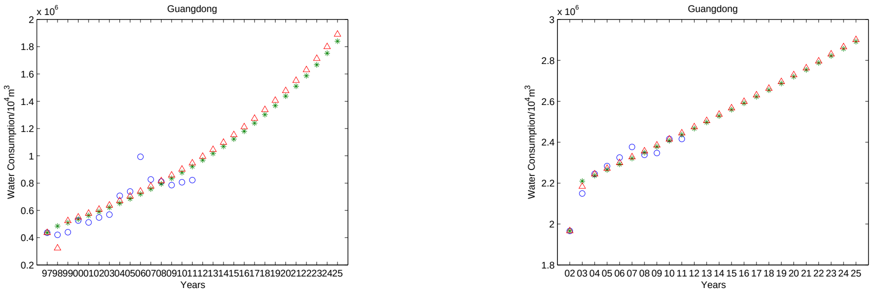
(a) First Fitting (b) Secondary Fitting

Figure 7: Jiangxi



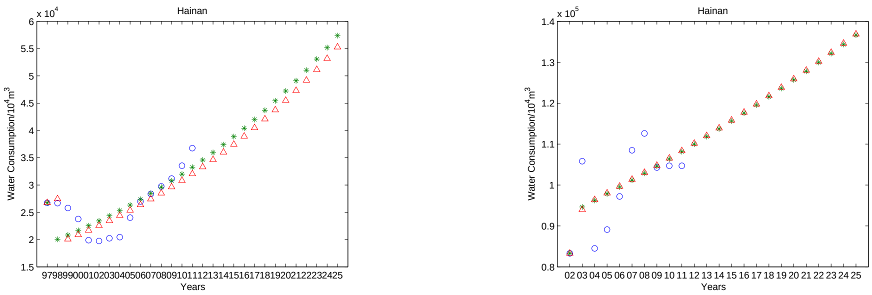
(a) First Fitting (b) Secondary Fitting

Figure 8: Hunan



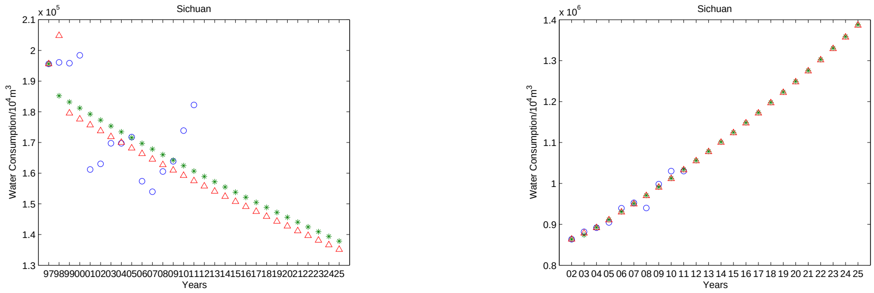
(a) First Fitting (b) Secondary Fitting

Figure 9: Guangdong



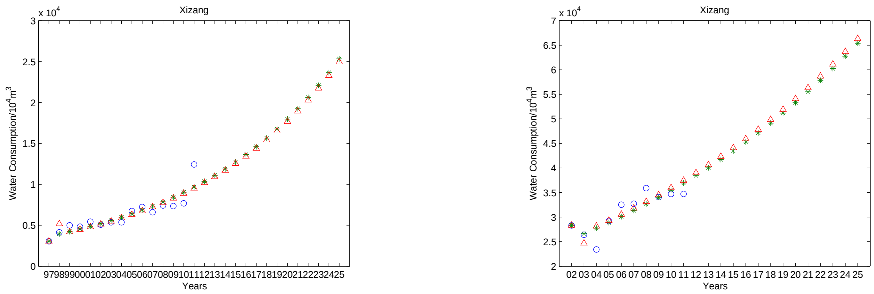
(a) First Fitting (b) Secondary Fitting

Figure 10: Hainan



(a) First Fitting (b) Secondary Fitting

Figure 11: Sichuan



(a) First Fitting (b) Secondary Fitting

Figure 12: Xizang

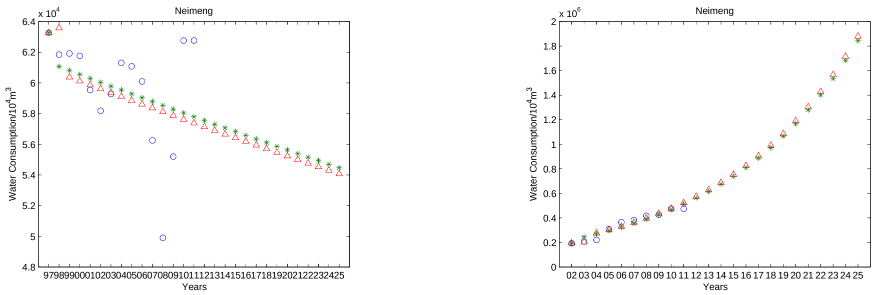
a huge part of total amount. However, provinces like Jilin, Anhui, Guizhou, Jiangxi, Hunan, Sichuan, most of which consist of major farmland of China show an opposite trend of two results. Data from Hebei and Heilongjiang show a turbulent regulation, possibly because of their vast area and population.

A few provinces, i.e. Neimeng, Jiangsu, Qinghai, illustrate that merely considering urban water needs will be more fitful to GM(1,1) model. Their residual series are showed in following table and pictures.

Table 2: Residual Series List 2

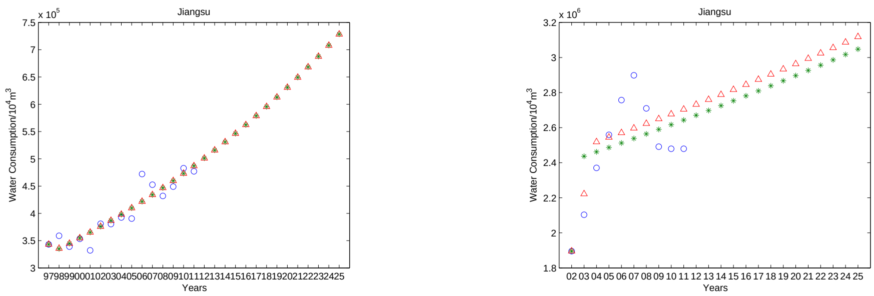
PROVINCES	Neimeng	Jiangsu	Qinghai
FIRST	4.17%	3.51%	4.35%
SECOND	6.20%	5.62%	13.71%

Neimeng and Qinghai provinces are vast in territory and major population concentrates in urban area. On the other hand, natural environment is worse in these area, possibly causing turbulent trend or statistic errors of data. Jiangsu may be just an exception.



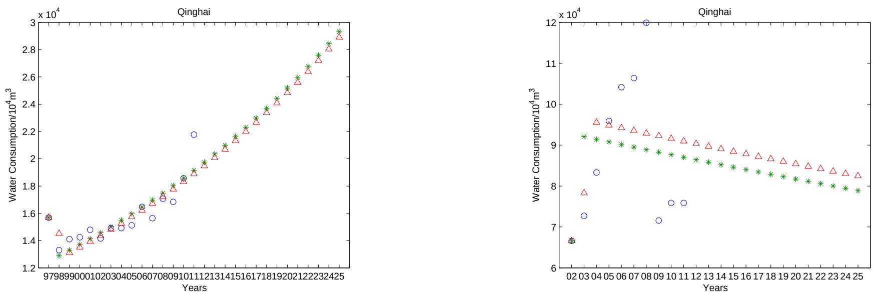
(a) First Fitting (b) Secondary Fitting

Figure 13: Neimeng



(a) First Fitting (b) Secondary Fitting

Figure 14: Jiangsu



(a) First Fitting (b) Secondary Fitting

Figure 15: Qinghai

Besides, we as well find that both first fitting and secondary fitting curves (i.e. green stars data and red triangle data) have a similar trend but the secondary fitting values have higher accuracy by checking residual series results. We do not give the whole results here and choose secondary fitting values to do the next model.

5 Nonlinear Programming

If the objective function or constraints include nonlinear function, this kind of programming problem is called nonlinear programming problem. In general, it is harder to solve nonlinear programming problems than linear ones. Unlike linear programming problems which have the simplex method as a universal method, each method for nonlinear programming has its own specific conditions and ranges for problems.

For a practical issue, we should consider following points before boiling problems down to nonlinear programming ones

- Determine alternative strategies

  First, get relevant information and data about issues and be familiar with the background. Then choose the alternative strategies and express them as sets;

- Provide objective

  After analyzing data and background of the problem, provide objective of minimizing or maximizing. Make mathematical model to represent objective;

- Make sure the standards of evaluation to the objective

  We should have standards to evaluate the advantages and disadvantages of the objective made in the second step. And express these standards as certain quantity forms;

- Find constrains

  For most problems, we have to find minimum or maximum under certain conditions and constrains. Find all of these constrains and express them as inequalities or equations of variables.

Difference between linear and nonlinear programming

- The optimal solution of linear programming problems merely exits on the boundary of the feasible region (especially on the vertex of the feasible region);
- For nonlinear problems, the optimal solution can exit on any points within the feasible region.

5.1 Original Model

Our model is developed from the non-linear programming principle. We focus our model on China. We consider the problem in 31 provinces of China and we use provincial capitals to represent the province as they are typically in need of fresh water rather than other cities in a province in most situations.

Firstly, draw a map showing the provincial capitals with their coordinates; Secondly, assign weights for the cities according to a Topographic map of China. There are eight essential principles for assigning the weights (denote vertical weight by and horizontal weight by and the weight of a city by P)

- $P_h = 0$;
- Every time when the height change (here, ”change” means to get the integral of the height) reaches 100 meters, we have $P_h = P_h + 1$;
- If the straight line between two cities cut through a river, we have $P_h = P_h + 2$;
- We say that $P_h = \infty$ if the terrain passed by the straight line between that two cities is quite complex especially a mountain area;
- If a city is on a plateauwe have $P_h = \infty$;
- If a third city is exactly on the line between two cities (city i and city j), we have $P_h(i, j) = \infty$;
- Set the coordinates of city i and j to be (x_i, y_i) and (x_j, y_j), then we have $P_l = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$;
- $P = k_1P_l + k_2P_h$, where $k_1 + k_2 = 1$; in our experiment, we take $k_1 = 0.05, k_2 = 0.95$.

	Beijing	Tianjin	Hebei	Shanxi	Neimeng	Liaoning	Jilin	Heilong	Shanghai	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi
Beijing	0	198.013	230.735	234.272	545.763	362.092	455.08	656.938	1886.93	1538.17	1936.98	1452.91	2510.24	1857.18
Tianjin	198.013	0	147.377	270.613	738.288	319.551	531.867	788.942	1689.6	1342.58	1740.78	1259.69	2316.52	1667.69
Hebei	230.735	147.377	0	150.362	703.82	464.645	650.788	881.788	1702.5	1345.39	1745.45	1252.85	2308.66	1647.83
Shanxi	234.272	270.613	150.362	0	583.404	559.699	689.313	877.778	1830.17	1469.03	1868.51	1371.45	2422.6	1755.77
Neimeng	545.763	738.288	703.82	583.404	0	839.266	734.934	696.792	2406.32	2048.34	2448.33	1953.26	3005.85	2339.04
Liaoning	362.092	319.551	464.645	559.699	839.266	0	293.529	595.441	1771.48	1454.61	1838.2	1393.04	2429.64	1813.97
Jilin	455.08	531.867	650.788	689.313	734.934	293.529	0	303.663	2060.88	1747.62	2129.44	1686.56	2721.74	2107.41
Heilong	656.938	788.942	881.788	877.778	696.792	595.441	303.663	0	2364.54	2050.01	2432.92	1986.91	3024.91	2406.95
Shanghai	1886.93	1689.6	1702.5	1830.17	2406.32	1771.48	2060.88	2364.54	0	367.374	107.063	481.814	677.121	374.8
Jiangsu	1538.17	1342.58	1345.39	1469.03	2048.34	1454.61	1747.62	2050.01	367.374	0	400.059	122.3	977.811	389.329
Zhejiang	1936.98	1740.78	1745.45	1868.51	2448.33	1838.2	2129.44	2432.92	107.063	400.059	0	500.972	594.894	295.96
Anhui	1452.91	1259.69	1252.85	1371.45	1953.26	1393.04	1686.56	1986.91	481.814	122.3	500.972	0	1057.37	421.9
Fujian	2510.24	2316.52	2308.66	2422.6	3005.85	2429.64	2721.74	3024.91	677.121	977.811	594.894	1057.37	0	674.566
Jiangxi	1857.18	1667.69	1647.83	1755.77	2339.04	1813.97	2107.41	2406.95	374.8	389.329	295.96	421.9	674.566	0
Shandong	623.112	428.949	438.5	576.275	1141	610.073	894.027	1182.77	1267.16	915.206	1314.44	830.74	1887.69	1240.26
Henan	729.454	557.348	508.303	611.643	1195.04	797.969	1068.16	1342.91	1234.1	868.149	1264.63	764.451	1811.3	1144.32
Hubei	1459.02	1273.97	1244.48	1348.01	1930.82	1447.39	1738.5	2032.75	607.143	298.676	594.623	194.878	1084.16	410.387
Hunan	1731.19	1550.01	1511.83	1606.74	2186.24	1731.45	2022.03	2315.07	584.527	443.378	523.266	405.871	874.971	238.627
Guangdong	2485.27	2303.21	2265.68	2357.88	2934.57	2472.78	2765.32	3061.74	896.557	1058.02	790.147	1089.28	469.368	670.769
Guangxi	2230.44	2065.26	2001.76	2071.32	2628.28	2282.21	2566.27	2849.16	1035.01	1027.36	936.145	1003.32	889.801	680.707
Hainan	2729	2555.58	2503.27	2581.9	3146.75	2749.41	3039.11	3329.83	1245.59	1377.42	1138.73	1392.51	776.553	988.546
Chongqing	1206.76	1078.13	977.868	1013.65	1543.05	1359.72	1609.32	1858.98	1263.18	934.808	1244.13	813.72	1659.74	1008.81
Sichuan	1028.76	953.684	821.784	804.086	1258.68	1267.78	1471.9	1681.63	1600.56	1252.81	1591.83	1130.63	2027.76	1370.98
Guizhou	1633.11	1484.53	1402.37	1455.6	1998.12	1736.74	2006.24	2273.35	1072.22	842.824	1017.5	748.45	1303.54	731.575
Yunnan	1706.5	1585.05	1479.98	1502.62	1997.34	1867.62	2116.69	2361.74	1384.87	1149.94	1327.73	1049.72	1569.71	1038.12
Tibet	1599.69	1677.47	1538.6	1408.74	1355.93	1958.54	2001.5	2044.31	2778.93	2430.5	2767.43	2308.51	3168.21	2533.14
Shannxi	633.298	549.163	418.379	422.087	954.089	864.676	1069.16	1290.02	1577.18	1210.09	1595.64	1096.99	2110.02	1435.46
Gansu	742.79	853.975	733.62	586.63	536.864	1104.88	1130.73	1189.8	2287.34	1920.02	2306.74	1807.88	2813.67	2139.78
Qinghai	923.681	1061.4	954.101	803.995	565.149	1280.63	1258.36	1260.72	2535.34	2168.01	2554.54	2055.83	3058.61	2385.21
Ningxia	698.874	860.618	776.811	629.509	298.123	1043.57	996.896	992.142	2437.29	2071.52	2467.01	1966.12	2998.44	2324.39
Xinjiang	2922.84	3111.85	3054.01	2912.12	2377.55	3194.49	3006.26	2793.62	4722.3	4355.41	4747.15	4246.65	5256.41	4583.21

	Shandong	Henan	Hubei	Hunan	Guangdong	Guangxi	Hainan	Chongqing	Sichuan	Guizhou	Yunnan	Tibet	Shannxi	Gansu	Qinghai	Ningxia	Xinjiang
Beijing	623.112	729.454	1459.02	1731.19	2485.27	2230.44	2729	1206.76	1028.76	1633.11	1706.5	1599.69	633.298	742.79	923.681	698.874	2922.84
Tianjin	428.949	557.348	1273.97	1550.01	2303.21	2065.26	2555.58	1078.13	953.684	1484.53	1585.05	1677.47	549.163	853.975	1061.4	860.618	3111.85
Hebei	438.5	508.303	1244.48	1511.83	2265.68	2001.76	2503.27	977.868	821.784	1402.37	1479.98	1538.6	418.379	733.62	954.101	776.811	3054.01
Shanxi	576.275	611.643	1348.01	1606.74	2357.88	2071.32	2581.9	1013.65	804.086	1455.6	1502.62	1408.74	422.087	586.63	803.995	629.509	2912.12
Neimeng	1141	1195.04	1930.82	2186.24	2934.57	2628.28	3146.75	1543.05	1258.68	1998.12	1997.34	1355.93	954.089	536.864	565.149	298.123	2377.55
Liaoning	610.073	797.969	1447.39	1731.45	2472.78	2282.21	2749.41	1359.72	1267.78	1736.74	1867.62	1958.54	864.676	1104.88	1280.63	1043.57	3194.49
Jilin	894.027	1068.16	1738.5	2022.03	2765.32	2566.27	3039.11	1609.32	1471.9	2006.24	2116.69	2001.5	1069.16	1130.73	1258.36	996.896	3006.26
Heilong	1182.77	1342.91	2032.75	2315.07	3061.74	2849.16	3329.83	1858.98	1681.63	2273.35	2361.74	2044.31	1290.02	1189.8	1260.72	992.142	2793.62
Shanghai	1267.16	1234.1	607.143	584.527	896.557	1035.01	1245.59	1263.18	1600.56	1072.22	1384.87	2778.93	1577.18	2287.34	2535.34	2437.29	4722.3
Jiangsu	915.206	868.149	298.676	443.378	1058.02	1027.36	1377.42	934.808	1252.81	842.824	1149.94	2430.5	1210.09	1920.02	2168.01	2071.52	4355.41
Zhejiang	1314.44	1264.63	594.623	523.266	790.147	936.145	1138.73	1244.13	1591.83	1017.5	1327.73	2767.43	1595.64	2306.74	2554.54	2467.01	4747.15
Anhui	830.74	764.451	194.878	405.871	1089.28	1003.32	1392.51	813.72	1130.63	748.45	1049.72	2308.51	1096.99	1807.88	2055.83	1966.12	4246.65
Fujian	1887.69	1811.3	1084.16	874.971	469.368	889.801	776.553	1659.74	2027.76	1303.54	1569.71	3168.21	2110.02	2813.67	3058.61	2998.44	5256.41
Jiangxi	1240.26	1144.32	410.387	238.627	670.769	680.707	988.546	1008.81	1370.98	731.575	1038.12	2533.14	1435.46	2139.78	2385.21	2324.39	4583.21
Shandong	0	217.385	852.455	1133.04	1882.97	1672.83	2147.11	796.739	823.226	1134.38	1293.99	1819.88	501.707	1112.01	1350.81	1203.19	3488.37
Henan	217.385	0	737.797	1003.56	1757.52	1507.96	2000.36	580.483	625.713	939.361	1081.31	1691.84	374.632	1063.71	1310.56	1203.38	3488.71
Hubei	852.455	737.797	0	284.755	1030.53	867.332	1303.34	656.177	997.396	553.722	855.319	2174.18	1026.65	1733.67	1980.07	1914.3	4177.69
Hunan	1133.04	1003.56	284.755	0	754.118	597.807	1018.62	786.016	1153.09	494.92	804.47	2304.56	1256.95	1949.39	2191.96	2148.76	4387.72
Guangdong	1882.97	1757.52	1030.53	754.118	0	475.991	352.305	1461.14	1825.71	1035.39	1244.18	2900.2	1993.39	2664.93	2900.88	2881.02	5081.65
Guangxi	1672.83	1507.96	867.332	597.807	475.991	0	530.279	1096.68	1441.51	641.055	790.635	2456.4	1674.2	2301.33	2526.83	2538.02	4680.51
Hainan	2147.11	2000.36	1303.34	1018.62	352.305	530.279	0	1624.34	1971.74	1170.6	1304.89	2966.61	2193.91	2830.87	3057.06	3065.06	5207.79
Chongqing	796.739	580.483	656.177	786.016	1461.14	1096.68	1624.34	0	369.348	457.559	508.186	1525.93	595.828	1208.77	1440.9	1441.34	3622.45
Sichuan	823.226	625.713	997.396	1153.09	1825.71	1441.51	1971.74	369.348	0	802.209	741.316	1178.64	404.641	863.293	1085.32	1115.01	3256.02
Guizhou	1134.38	939.361	553.722	494.92	1035.39	641.055	1170.6	457.559	802.209	0	313.26	1874.66	1046.06	1660.34	1887.1	1898.06	4051.87
Yunnan	1293.99	1081.31	855.319	804.47	1244.18	790.635	1304.89	508.186	741.316	313.26	0	1665.88	1080.53	1592.79	1798.53	1853.41	3909.91
Tibet	1819.88	1691.84	2174.18	2304.56	2900.2	2456.4	2966.61	1525.93	1178.64	1874.66	1665.88	0	1324.48	870.771	795.896	1057.96	2316.93
Shannxi	501.707	374.632	1026.65	1256.95	1993.39	1674.2	2193.91	595.828	404.641	1046.06	1080.53	1324.48	0	711.103	958.963	891.864	3153.31
Gansu	1112.01	1063.71	1733.67	1949.39	2664.93	2301.33	2830.87	1208.77	863.293	1660.34	1592.79	870.771	711.103	0	247.999	281.805	2444.02
Qinghai	1350.81	1310.56	1980.07	2191.96	2900.88	2526.83	3057.06	1440.9	1085.32	1887.1	1798.53	795.896	958.963	247.999	0	268.777	2198
Ningxia	1203.19	1203.38	1914.3	2148.76	2881.02	2538.02	3065.06	1441.34	1115.01	1898.06	1853.41	1057.96	891.864	281.805	268.777	0	2288.49
Xinjiang	3488.37	3488.71	4177.69	4387.72	5081.65	4680.51	5207.79	3622.45	3256.02	4051.87	3909.91	2316.93	3153.31	2444.02	2198	2288.49	0

Figure 16: Pl of 31 Provinces

	Beijing	Tianjin	Hebei	Shanxi	Neimeng	Liaoning	Jilin	Heilong	Shanghai	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Shandong
Beijing	111	0	0	111	10	10	111	111	111	111	111	111	111	111	111
Tianjin	0	111	0	111	111	111	111	111	111	111	111	111	111	111	0
Hebei	0	0	111	10	10	111	111	111	111	111	111	0	111	6	0
Shanxi	111	111	10	111	5	111	111	111	111	111	111	111	111	111	10
Neimeng	10	111	10	5	111	10	111	111	111	111	111	111	111	111	111
Liaoning	10	111	111	111	10	111	2	111	111	111	111	111	111	111	111
Jilin	111	111	111	111	111	2	111	2	111	111	111	111	111	111	111
Heilong	111	111	111	111	111	111	2	111	111	111	111	111	111	111	111
Shanghai	111	111	111	111	111	111	111	111	111	0	0	111	111	111	111
Jiangsu	111	111	111	111	111	111	111	111	0	111	0	0	111	111	4
Zhejiang	111	111	111	111	111	111	111	111	0	0	111	4	111	10	111
Anhui	111	111	0	111	111	111	111	111	111	0	4	111	111	0	4
Fujian	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Jiangxi	111	111	6	111	111	111	111	111	111	111	10	0	111	111	111
Shandong	111	0	0	10	111	111	111	111	111	4	111	4	111	111	111
Henan	111	111	0	10	111	111	111	111	111	111	111	0	111	111	0
Hubei	111	111	111	111	111	111	111	111	111	111	111	10	111	0	111
Hunan	111	111	111	111	111	111	111	111	111	111	111	111	111	0	111
Guangdong	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Guangxi	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Hainan	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Chongqing	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Sichuan	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Guizhou	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Yunnan	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Tibet	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Shannxi	18	111	18	111	111	111	111	111	111	111	111	111	111	111	111
Gansu	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Qinghai	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Ningxia	111	111	111	19	12	111	111	111	111	111	111	111	111	111	111
Xinjiang	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111

	Henan	Hubei	Hunan	Guangdong	Guangxi	Hainan	Chongqing	Sichuan	Guizhou	Yunnan	Tibet	Shannxi	Gansu	Qinghai	Ningxia	Xinjiang
Beijing	111	111	111	111	111	111	111	111	111	111	111	18	111	111	111	111
Tianjin	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Hebei	0	111	111	111	111	111	111	111	111	111	111	18	111	111	111	111
Shanxi	10	111	111	111	111	111	111	111	111	111	111	111	111	111	19	111
Neimeng	111	111	111	111	111	111	111	111	111	111	111	111	111	111	12	111
Liaoning	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Jilin	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Heilong	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Shanghai	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Jiangsu	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Zhejiang	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Anhui	0	10	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Fujian	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Jiangxi	111	0	0	111	111	111	111	111	111	111	111	111	111	111	111	111
Shandong	0	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Henan	111	0	111	111	111	111	111	111	111	111	111	15	111	111	111	111
Hubei	0	111	0	111	111	111	111	111	111	111	111	111	111	111	111	111
Hunan	111	0	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Guangdong	111	111	111	111	8	111	111	111	111	111	111	111	111	111	111	111
Guangxi	111	111	111	8	111	111	111	111	111	111	111	111	111	111	111	111
Hainan	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Chongqing	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Sichuan	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Guizhou	111	111	111	111	111	111	111	111	111	30	111	111	111	111	111	111
Yunnan	111	111	111	111	111	111	111	111	30	111	111	111	111	111	111	111
Tibet	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Shannxi	15	111	111	111	111	111	111	111	111	111	111	111	111	111	13	111
Gansu	111	111	111	111	111	111	111	111	111	111	111	111	111	0	10	111
Qinghai	111	111	111	111	111	111	111	111	111	111	111	111	0	111	30	111
Ningxia	111	111	111	111	111	111	111	111	111	111	111	13	10	30	111	111
Xinjiang	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111

Figure 17: Ph between the 31 Provincial Capitals

Figure 18: China Graphical Map

	Beijing	Tianjin	Hebei	Shanxi	Neimeng	Liaonin	Jilin	Heilong	Shangha	Jiangsu	Zhejian	Anhui	Fujian	Jiangxi	Shandon	Henan	Hubei	Hunan	Guangdo	Guangxi	Hainan	Chongqi	Sichuan	Guizhou	Yunnan	Tibet	Shannxi	Gansu	Qinghai	Ningxia	Xinjiang
Beijing	65535	9.90067	11.5368	65535	977.288	968.105	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	1741.66	65535	65535	65535	65535
Tianjin	9.90067	65535	7.36886	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	21.4474	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Hebei	11.5368	7.36886	65535	957.518	985.191	65535	65535	65535	65535	65535	65535	62.6425	65535	652.392	21.925	25.4151	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	1730.92	65535	65535	65535	65535
Shanxi	65535	65535	957.518	65535	504.17	65535	65535	65535	65535	65535	65535	65535	65535	65535	978.814	980.582	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	1836.48	65535
Neimeng	977.288	65535	985.191	504.17	65535	991.963	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	1154.91	65535
Liaonin	968.105	65535	65535	65535	991.963	65535	204.676	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Jilin	65535	65535	65535	65535	65535	204.676	65535	205.183	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Heilong	65535	65535	65535	65535	65535	65535	205.183	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Shangha	65535	65535	65535	65535	65535	65535	65535	65535	65535	18.3687	5.35313	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Jiangsu	65535	65535	65535	65535	65535	65535	65535	65535	18.3687	65535	20.0029	6.11498	65535	65535	425.76	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Zhejian	65535	65535	65535	65535	65535	65535	65535	65535	5.35313	20.0029	65535	405.049	65535	964.798	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Anhui	65535	65535	62.6425	65535	65535	65535	65535	65535	65535	6.11498	405.049	65535	65535	21.095	421.537	38.2225	959.744	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Fujian	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Jiangxi	65535	65535	652.392	65535	65535	65535	65535	65535	65535	65535	964.798	21.095	65535	65535	65535	65535	20.5193	11.9313	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Shandon	65535	21.4474	21.925	978.814	65535	65535	65535	65535	65535	425.76	65535	421.537	65535	65535	65535	10.8692	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Henan	65535	65535	25.4151	980.582	65535	65535	65535	65535	65535	65535	65535	38.2225	65535	65535	10.8692	65535	36.8899	65535	65535	65535	65535	65535	65535	65535	65535	65535	1443.73	65535	65535	65535	65535
Hubei	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	959.744	65535	20.5193	65535	36.8899	65535	14.2377	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Hunan	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	11.9313	65535	65535	14.2377	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Guangdo	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	783.8	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Guangxi	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	783.8	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Hainan	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Chongqi	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Sichuan	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Guizhou	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	2865.66	65535	65535	65535	65535	65535	65535
Yunnan	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	2865.66	65535	65535	65535	65535	65535	65535	65535
Tibet	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535
Shannxi	1741.66	65535	1730.92	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	1443.73	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	1279.59	65535
Gansu	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	12.3999	964.09	65535
Qinghai	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	12.3999	65535	2863.44	65535
Ningxia	65535	65535	65535	1836.48	1154.91	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	1279.59	964.09	2863.44	65535	65535
Xinjian	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535	65535

Figure 19: P of 31 Provinces

5.2 Shortest Path Problem Model

5.2.1 The background

Shortest path problem is to find the shortest distance on a certain net between two points and the distance here is a joint name of arc (side) weights, it can be time or fees etc.

5.2.2 *Dijkstra* algorithm

Generally, problem of shortest path can be described as following: We are given a weighted directed graph $D = (V, E, W)$ (also known as the "net"). As for each arc (v_i, v_j), correspondingly we have weight w_ij. v_s, v_t are two fixed points in D, assuming that P is a path from v_s to v_t, now define the weight of path P as the sum of all the arcs on the path, we record this as $\omega(P)$. Shortest path problem is to find a path holding the minimum weight among the paths between v_s and v_t, which means to find a path P_0 from v_s to v_t so that we have

$$\omega(P_0) = \min_P \omega(P_0) \tag{9}$$

And the formula (9) fits the demand that P_0 is the minimum path from v_s to v_t.

When facing ordinary net problems, we can list all the possible paths and find the shortest one by the method of comparison. However, when it comes to some complex problems, the method above may not be feasible and then we need to find a new calculation method. Up till now the best way to find the shortest path in an all-positive-arc directed weighted network is the *Dijkstra* method.

Essential principle of *Dijkstra* is as follows: if $(v_1, v_2, \ldots, v_n)$ is the shortest path from v_s to $v_t$then $(v_1, v_2, \ldots, v_{n-1})$ is the shortest path from v_1 to v_{n-1}.

Assuming that in the network of $D = (V, E, W)(v_1, v_2, \ldots, v_n)$weight of arc $(v_i, v_j)w_{ij}$ represents the direct distance from v_i to $v_j$when there is no direct arc from v_i to $v_j w_{ij} = +\infty$we use $d(v_j)$ to represent the weight of the path passing those chosen points from only from v_1 to v_j. The specific steps of *Dijkstra* method finding the shortest path from v_1 towards other vertexes are as follows

- $d(v_1) = 0, d(v_j)\omega_{1j}(j = 2, 3, \ldots, n), S = 1, R = 2, 3, \ldots, n$, mark number from v_1, each mark consists of two parts, the former one shows its origin and the latter shows the shortest distance between the point and v_1.
- Search in R for vertex $v$so that

  $$d(v_k) = \min d(v_j) \tag{10}$$

  Make $S = S \cup kR = R/k$, and mark number for v_k. if $R = \emptyset$end her; otherwise, come to next step.
- Revise $d(v_j)$ so as to get

  $$d(v_j) = \min\{d(v_j), d(v_k) + \omega_{kj}\} \tag{11}$$

  Notice that remember the front point of v_j, return to the second step.

  Via the principle of shortest path method, we have a graph showing the minimum distances between each two provinces. Our objective function is $g(x) = \frac{1}{2}\sum_{i,j}|f_{ij}|d_{ij}$.

	1.98013	2.30735	99003.8	99005.5	99003.6	118807	138610	19.7326	16.0588	20.0594	14.8358		18.8722	6.26962	7.39038	14.7683	17.6159									148511	316811	316814	217808
1.98013		1.47377	99003	99007.4	99005.6	118809	138612	18.899	15.2253	19.2258	14.0023		17.9452	4.28949	6.46333	13.8413	16.6889									148510	316813	316816	217810
2.30735	1.47377		99001.5	99007	99005.9	118809	138612	17.4252	13.7515	17.7521	12.5285		16.5649	4.385	5.08303	12.461	15.3085									148509	316813	316815	217810
99003.8	99003	99001.5		49505.8	148514	168317	188120	99018.7	99015	99019	99013.8		99017.6	99005.8	99006.1	99013.5	99016.3									247510	267312	267314	168309
99005.5	99007.4	99007	49505.8		99008.4	118811	138614	99024.5	99020.8	99024.8	99019.6		99023.6	99011.4	99012.1	99019.5	99022.3									247512	217806	217808	118803
99003.6	99005.6	99005.9	148514	99008.4		19802.9	39606	99023.4	99019.7	99023.7	99018.5		99022.5	99009.9	99011	99018.4	99021.2									247515	316814	316817	217811
118807	118809	118809	168317	118811	19802.9		19803	118826	118823	118827	118821		118825	118813	118814	118821	118824									267318	336617	336620	237614
138610	138612	138612	188120	138614	39606	19803		138629	138626	138630	138624		138628	138616	138617	138624	138627									287121	356420	356423	257417
19.7326	18.899	17.4252	99018.7	99024.5	99023.4	118826	138629		3.67374	1.07063	4.89673		9.11573	14.7151	12.5412	13.2196	11.502									148516	316830	316833	217827
16.0588	15.2253	13.7515	99015	99020.8	99019.7	118823	138626	3.67374		4.00059	1.223		5.442	11.0413	8.8675	9.54586	7.82826									148513	316827	316829	217824
20.0594	19.2258	17.7521	99019	99024.8	99023.7	118827	138630	1.07063	4.00059		5.22358		9.44258	15.0419	12.8681	13.5465	11.8288									148517	316831	316833	217828
14.8358	14.0023	12.5285	99013.8	99019.6	99018.5	118821	138624	4.89673	1.223	5.22358			4.219	9.81835	7.64451	8.32287	6.60527									148511	316825	316828	217823
18.8722	17.9452	16.5649	99017.6	99023.6	99022.5	118825	138628	9.11573	5.442	9.44258	4.219			13.6557	11.4818	4.10387	2.38627									148515	316829	316832	217827
6.26962	4.28949	4.385	99005.8	99011.4	99009.9	118813	138616	14.7151	11.0413	15.0419	9.81835		13.6557		2.17385	9.55182	12.3994									148506	316817	316820	217814
7.39038	6.46333	5.08303	99006.1	99012.1	99011	118814	138617	12.5412	8.8675	12.8681	7.64451		11.4818	2.17385		7.37797	10.2255									148504	316818	316820	217815
14.7683	13.8413	12.461	99013.5	99019.5	99018.4	118821	138624	13.2196	9.54586	13.5465	8.32287		4.10387	9.55182	7.37797		2.84755									148511	316825	316828	217822
17.6159	16.6889	15.3085	99016.3	99022.3	99021.2	118824	138627	11.502	7.82826	11.8288	6.60527		2.38627	12.3994	10.2255	2.84755										148514	316828	316831	217825
																			79204.8										
																		79204.8											
																								297003					
																							297003						
148511	148510	148509	247510	247512	247515	267318	287121	148516	148513	148517	148511		148515	148506	148504	148511	148514										227712	227714	128709
316811	316813	316813	267312	217806	316814	336617	356420	316830	316827	316831	316825		316829	316817	316818	316825	316828									227712		2.47999	99002.8
316814	316816	316815	267314	217808	316817	336620	356423	316833	316829	316833	316828		316832	316820	316820	316828	316831									227714	2.47999		99005.3
217808	217810	217810	168309	118803	217811	237614	257417	217827	217824	217828	217823		217827	217814	217815	217822	217825									128709	99002.8	99005.3	

Figure 20: Final Result Showing Our Water Transfer Scheme

Our final water strategy has been showed in the table, and transferring links have been labeled on China regional map.

Figure 21: Our Water Transfer Scheme Showing on Map

Table 3: Water Strategy

Province	Resource	Water Demand	Inflow Transmission
Beijing	15.98	31.3	15.32
Tianjin	4.42	15.70	11.27
Hebei	13.38	50.30	36.91
Shanxi	86.35	86.35	0
Inner Mongolia	284.47	188.00	0
Liaoning	204.97	79.2	0
Jilin	242.05	83.60	0
Heilongjiang	379.88	80.2	0
Shanghai	3.95	142.90	138.94
Jiangsu	188.17	311.80	123.62
Zhejiang	650.31	133.00	-138.94
Anhui	435.54	281.10	-123.62
Fujian	677.65	181.10	0
Jiangxi	886.85	143.10	0.01
Shandong	192.86	85.00	-62.84
Henan	202.38	172.60	-0.66
Guangdong	1243.78	290.10	0
Guangxi	1155.45	218.80	0
Hainan	450.22	13.70	0
Chongqing	494.74	155.50	0
Sichuan	2112.23	138.6	0
Guizhou	575.97	76.90	0
Yunnan	1384.88	111.80	0
Tibet	4370.98	6.60	0
Shannxi	548.94	34.30	0
Gansu	147.92	30.60	-69.38
Qinghai	709.93	8.20	0
Ningxia	-56.28	13.10	69.38
Xinjiang	401.00	59.20	0

6 Optimization Model for Nonlinear Programming

6.1 AHP Background

AHP (Analytic Hierarchy Process) is a basic method resolving some complex or obscure problems. AHP fits well with those questions that are hard to make it quantitatively.

Roughlyit can be divided into five steps

- View the question as a hierarchy including the decision objective, the alternatives of reaching it, and the criteria for evaluating the alternatives;
- Set up priorities among the elements of the hierarchy by creating a series of judgments based on pairwise comparisons of the elements. For instance, when comparing potential real-estate purchases, the investors may say they prefer location over price and price over timing;
- Synthesize these judgments to control a set of overall priorities for the hierarchy. This may combine the investors' judgments about location, price and timing for properties A, B, C, and D into overall priorities for each property;
- Check the consistency of the judgments;
- (v) Get a final decision based on the results of this process.

6.2 Multi-objective Linear Weighting Function

The function of multi-objective linear weighting function method is

$$R = \sum_{i=1}^{2}(\sum_{j=1}^{n} x_i \frac{r_j}{z_j})w_i \tag{12}$$

R is the total score.
x_j is the actual value of a certain single index;
z_j is the standard value of a certain index;
r_j is the weight of a certain index in the jth level;
w_i is the weight of both ecological and social economy.

6.3 Optimal Model and Data Interpretation

In the original nonlinear programming model, one basic assumption is that most of water resource can be explored and utilized by local people. Considering more factors such as water quality, population and economic influence. Thus we adopt *Multi-objective linear weighted function method* to take these factors account by influencing available water. The modified objective function is

$$\max \sum_{i=1}^{31} [(a_i + \sum_{j=1}^{31} f_{ij})(w_1 s_{1i} + w_2 s_{2i} + w_3 s_{3i} + w_4 s_{4i})] \tag{13}$$

in which the evaluation function is

$$R = \sum_{i} (w_1 s_{1i} + w_2 s_{2i} + w_3 s_{3i} + w_4 s_{4i}) \tag{14}$$

w_1, w_2, w_3, w_4 are the weight of water quality, water supply, population and economy, respectively.

Considering the huge amount of data results of this model and limited time for writing, we state the main optimal results from this model.

- In North China area, most of provinces receive much water supply from south area where precipitation and runoff volume are abundant. For example, Tianjin receive $128.85 * 10^8 m^3$ more water. In addition, the results should that some regions like Tianjin, Shanghai, Jiangsu, Guangdong increase their disposable water. These regions are mostly developed ones who have prominent GDP and huge amount of population. Increasing water supply to these area will improve the development of industry and agriculture.

- In terms of origins of water, southeast provinces like Jiangxi, Hubei, Hunan transfer more water (74.3, 34.0, 74.2 billion m^3 respectively). These provinces have abundant water resource and flat terrain. Thus, the cost of transmission facilities will be relatively low.

- A few provinces (e.g. Inner Mongolia, Guangxi) have solve their own water shortage by increasing linking with other areas.

	Beijing	Tianjin	Hebei	Shanxi	Inner Mongoli	Liaoning	Jinin	Heilongjiang	Shanghai	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Shandong	Henan
京	0	76.5635	443.434	0	75.7412	375.741	0	0	0	0	0	0	0	0	0	0
天津	76.5635	0	56.3765	0	0	0	0	0	0	0	0	0	0	0	71.6965	0
河北	443.434	56.3765	0	0	1223.17	0	0	0	0	0	0	1176.36	0	0	266.655	443.701
山西	0	0	0	0	113.717	0	0	0	0	0	0	0	0	0	0	56.8583
内蒙古	75.7412	0	1223.17	113.717	0	208.161	0	0	0	0	0	0	0	0	0	0
辽宁	375.741	0	0	0	208.161	0	458.132	0	0	0	0	0	0	0	0	0
吉林	0	0	0	0	0	458.132	0	299.682	0	0	0	0	0	0	0	0
黑龙江	0	0	0	0	0	0	299.682	0	0	0	0	0	0	0	0	0
上海	0	0	0	0	0	0	0	0	0	1129.82	138.943	0	0	0	0	0
江苏	0	0	0	0	0	0	0	0	1129.82	0	378.372	2914.78	0	0	0	0
浙江	0	0	0	0	0	0	0	0	138.943	378.372	0	0	0	0	0	0
安徽	0	0	1176.36	0	0	0	0	0	0	2914.78	0	0	0	1018.14	0	810.463
福建	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
江西	0	0	0	0	0	0	0	0	0	0	0	1018.14	0	0	0	0
山东	0	71.6965	266.655	0	0	0	0	0	0	0	0	0	0	0	0	949.107
河南	0	0	443.701	56.8583	0	0	0	0	0	0	0	810.463	0	0	949.107	0
湖北	0	0	0	0	0	0	0	0	0	0	0	0	0	589.309	0	808.422
湖南	0	0	0	0	0	0	0	0	0	0	0	0	0	338.557	0	0
广东	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
广西	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
海南	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
重庆	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
四川	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
贵州	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
云南	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
西藏	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
陕西	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	445.26
甘肃	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
青海	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
宁夏	0	0	0	0	1663.08	0	0	0	0	0	0	0	0	0	0	0
新疆	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Hubei	Hunan	Guangdong	Guangxi	Hainan	Chongqing	Sichuan	Guizhou	Yunnan	Xizang	Shanxi	Gamsu	Qinghai	Ninxia	Sinkiang
京	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
天津	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
河北	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
山西	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
内蒙古	0	0	0	0	0	0	0	0	0	0	0	0	0	1663.08	0
辽宁	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
吉林	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
黑龙江	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
上海	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
江苏	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
浙江	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
安徽	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
福建	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
江西	589.309	338.557	0	0	0	0	0	0	0	0	0	0	0	0	0
山东	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
河南	808.422	0	0	0	0	0	0	0	0	0	445.26	0	0	0	0
湖北	0	403.895	0	0	0	0	0	0	0	0	0	0	0	0	0
湖南	403.895	0	0	0	0	0	0	0	0	0	0	0	0	0	0
广东	0	0	0	936.652	0	0	0	0	0	0	0	0	0	0	0
广西	0	0	936.652	0	0	0	0	0	0	0	0	0	0	0	0
海南	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
重庆	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
四川	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
贵州	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
云南	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
西藏	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
陕西	0	0	0	0	0	0	0	0	0	0	0	0	0	69.387	0
甘肃	0	0	0	0	0	0	0	0	0	0	0	0	701.732	819.061	0
青海	0	0	0	0	0	0	0	0	0	0	0	701.732	0	0	0
宁夏	0	0	0	0	0	0	0	0	0	0	69.387	819.061	0	0	0
新疆	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 22: Optimal Transmission Strategy

Table 4: Water Strategy

Province	Resource	Water Demand	Inflow Transmission
Beijing	15.98	31.30	31.30
Tianjin	4.42	15.70	133.32
Hebei	13.38	50.30	50.30
Shanxi	86.36	29.50	29.50
Inner Mongolia	284.47	188.00	188.00
Liaoning	204.97	79.20	79.20
Jilin	242.05	83.60	83.60
Heilongjiang	379.88	80.20	80.20
Shanghai	3.96	142.90	648.41
Jiangsu	188.17	311.80	123.62
Zhejiang	650.32	133.00	133.00
Anhui	435.55	281.10	281.10
Fujian	677.66	181.10	677.66
Jiangxi	886.86	143.10	143.10
Shandong	192.87	85.00	1013.06
Henan	202.38	172.60	172.60
Guangdong	1243.78	290.10	2180.44
Guangxi	1155.45	218.80	218.80
Hainan	450.22	13.70	450.22
Chongqing	494.74	155.50	494.74
Sichuan	2112.23	138.60	2112.23
Guizhou	575.98	76.90	575.98
Yunnan	1384.88	111.80	1384.88
Tibet	4370.99	6.60	4370.99
Shannxi	548.95	34.30	34.30
Gansu	147.93	30.60	30.60
Qinghai	709.93	8.20	8.20
Ningxia	-56.29	13.10	1134.67
Xinjiang	401.01	59.20	401.01

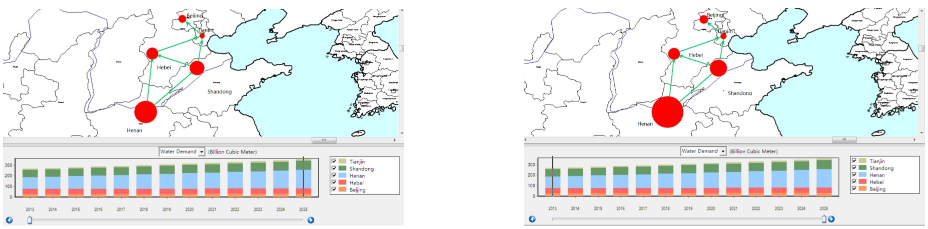
7 Simulation Model

The water strategy we get in the nonlinear programming is a steady-state one based on the prediction results in 2025. We do not give a precise model to describe the whole dispatching strategy between 2013 and 2025. Thus, we apply WEAP (Water Evaluation And Planning System) to build model for simulation in order to observe the dynamic process of dispatching water resource.

WEAP is a software designed for users to model the water supply construction and define relationship of dispatching. Based on the GIS graphical interface, users can rapidly make network model of water sources and demand sites, and then simulate to observe and analyze the results of model. Considering the complexity and accuracy of national water management model, we decide to build a small regional model of North China.

Our model consists of five major provinces: Beijing, Tianjin, Hebei, Shandong and Hunan because of our water dispatching strategy involving these five areas in North China area. North China area is the most water-deficient area of China and the government has been implementing a huge hydraulic engineering called *South-to-North Water Diversion Project* to solve the uneven graphical distribution of water resources. It is also noteworthy that our forecasting water demands of five provinces which cannot be supply from North China is approximate to the amount of water supply of the *South-to-North Water Diversion Project*. To base our model on this special area, we can check our water strategy for a dynamic process.

Water demand of the five provinces in 2013 and 2025 have been showed in the pictures relevant with area of red circle. Results of dynamic water transmission and outflow of every provinces have as well be presented as pictures.



(a) Present Water Demand(2013)

(b) Water Demand Prediction(2025)

Figure 23: Water Demand

The water demand trend is consistent with results from grey prediction. The simulation results has been shown in the picture.

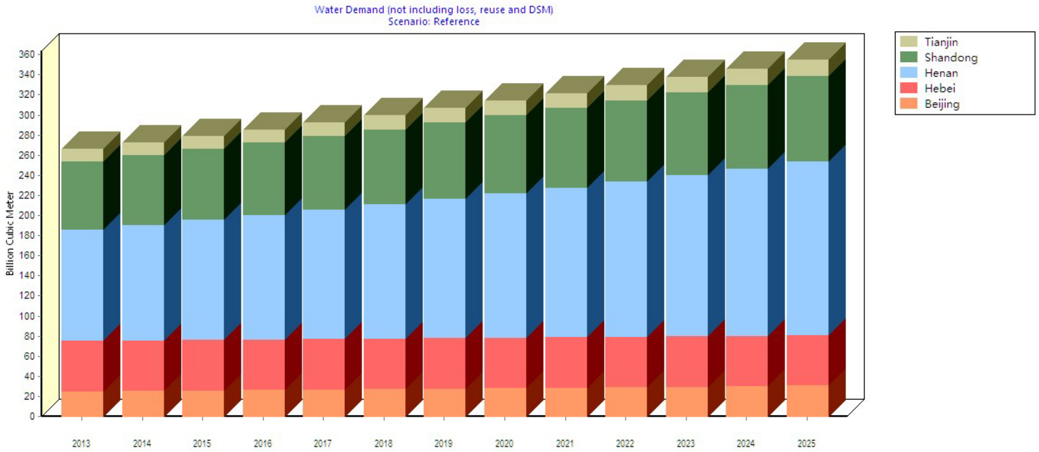


Figure 24: Water Demand Per Year in Simulation Model

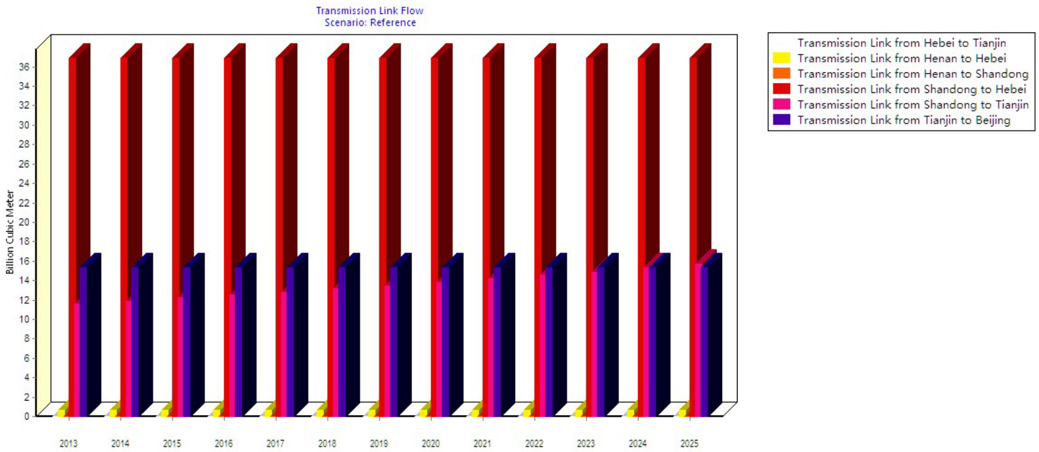


Figure 25: Water Transmission Links Flow

From the results, we find that transmission from Shandong to Tianjian presents an increasing trend which means that during 13 years, the water dispatching strategy should adjust amount of transferring instead of being constant. In further, this result tells us that our water strategy getting from programming based on forecasting values has been optimized.

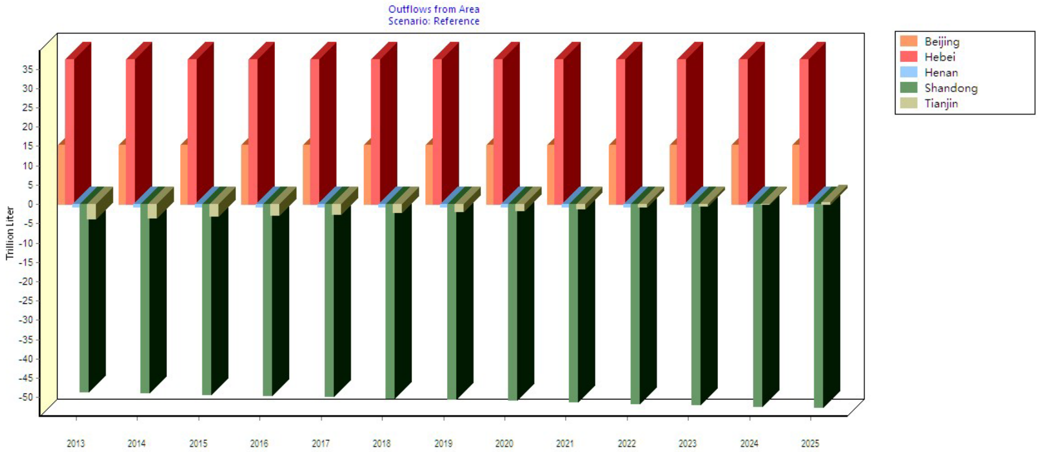


Figure 26: Dynamic Water Strategy

8 Defects of Our Models

- In the nonlinear programming model, we ignored the water used on agriculture for its difficulty to forecast;
- The objective function has a positive correlation with water transferring cost, but we ignored the real cost, which is much too idealistic;
- Strictly speaking, we choose provinces as elements instead of drainage which may be more fitful for forecasting;
- We ignored factors like price, environment, etc. These factors may be prominent in certain region or in certain time;
- In the nonlinear programming model, we consider only the straight lines between cities, which is not flexible. Plus, we concentrate all amount of water into provincial capitals, which may cause errors to some degree.

9 Conclusion

In this article, we build some theocratical models and one simulation model to find the best water dispatch and transfer strategy. Firstly, we use grey prediction to forecast the future water needs. Then based on results and other statistics, we build nonlinear programming model to make optimal strategy. Afterwards, we consider more factors and modify our original objective function. The final results of optimal model illustrate a more rational strategy relating to China's

South-to-North Water Diversion Project and show a better water managing scheme than previous one.

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10 Position Paper for China Government

To whom it may concern:

Based on our model of water resource management, we sincerely recommend you to implement some water strategies to meet water needs in 2025.

- According to our results of prediction, the trend of water needs of different provinces will be different before 2025. For Beijing, Heilongjiang, Guangdong, Hainan, Jiangsu,the water needs will increase and the major part may come from urban area. For Jilin, Anhui, Guizhou, Jiangxi, Hunan, Sichuan, Neimeng, these provinces will need to prepare more water for rural people and urban water demand may decrease.
- During next decade, building or encouraging desalination facilities is necessary for some southeast costal provinces such as Shanghai, Guangdong, Fujian, Hainan. This implementation will provide alternative demands for their own use.
- Keep on South-to-North Water Diversion Project which will solve most of water shortage in North China. In addition, pay attention to real-time demands changes from different provinces and build small-scale transmission to keep balance.
- Improve recovery efficiency of local water resource including both surface and underground water and it will make most of provinces keep their own balance of using water.

Most of these strategies are based on the present conditions and facilities, so you can adopt them as soon as possible. Plus, during making model, what we consider first is to make every area self-sufficient and the cost of other projects has been reduced. China has a huge population and water resource problems involve complex factors. Our model is based on major factors after carefully analyzing statistics. Not only China's present hydraulic project is taken into account, but also researches and experience from other countries are considered through analyzing review papers.

Best Regards,
Team 22862
Feb 4, 2013