Water Scarcity Identification and Calculation based of Water Resources Entire Elements Option Allocation

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Abstract

Using the water supply and demand analysis, water deficit was recognized on based of water resources entire elements option allocation. After analyzing the character of different types of water scarcity, a model was established according to the reason that caused the shortage of water. Shortage recognition and calculation theory, as well as method was discussed in this paper. At last, the practical application was carried out in the basin of Song Liao.

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Keywords: Water resources; Entire Elements; Option Allocation; Water Scarcity Identification; Water Deficit Calculation; Song Liao Basin; China.

Water scarcity based of water quantity, water scarcity based of water quality and water scarcity based of engineering were main reasons that caused water deficit in China[1]. Identifying and calculating different kinds of water scarcity guarantee supply. After stating the situation of water resources entire elements option allocation, it raised one way to identify and compute the water scarcity type and water deficit. At last, water scarcity identification and calculation carried out for 2006s in Song Liao basin. Diagnosing the problem for exploiting in Long Liao basin, it put forwards the basic strategy of water development and usage.

Water Resources Allocation about Entire Elements

Water resources entire elements optimized allocation was a kind of brand-new distribution mode for water resources. Based on the binary water cycle simulation, coupling water quantity and quality, it studied satisfaction extent of different demand subjects under the situations of different water quality and different water types on discharge of stream; it studied water quality fulfillment degree of target water...
function zone, and standard conditions of pollutant carrying capacity from the starting-point of water quantity and quality of double attributes. Satisfying the target of the requirements of society and the nature, harmonizing the relationship among social economic, ecological environment and water resources system. it developed the case of water allocation scheme and pollutants reduction program from total control of water resources and pollutants. As a result, the model of water resources entire elements could realize water usage for social economic reasonable, meet the water requirement in rivers aquatic ecological, and control the total amount of pollutant going into water function zone as well as reach the water quality standard. In all, by it, achieving the harmonious coexistence of human and nature, getting to the sustainability of water resources development and utilization, were the fundamental targets[2].

Water resources entire elements optimization allocation model consisted of water resources optimization allocation model[3,4,5], water quality simulation model of river system[6,7] and numerical simulation model of groundwater. The river system water quality simulation could identify various sections or node water quality types. Based of water quality requirement for different users, however it could achieves effective water resources allocation according to water quality types. Finally it could realize two kinds of water resources allocation which was based on the traditional mode of water supply and water supply subject to water quality. In the configuration process, the three model worked and restricted between each other by data transmission as well as times iteration to finish operation. Figure 1 shown specific conditions.

![Figure 1 Chart of water resources entire elements option allocation](image)

**Water Scarcity Identification and Analysis**

Water scarcity identification and analysis was based on the results of water supply of quality equilibrium analysis and of water supply of un-quality equilibrium analysis which did in the process of water resources entire elements optimization allocation. With the river basin/ regional utilizable water resources for water resources development and utilization upper limit, it analyzed the relationship between the supplying water under different configuration result and utilizable water resources, identified water scarcity types, and calculated water scarcity of different water shortage types.

Recognition and calculation of water resources scarcity was determined by the relationship of water
resources development availability, groundwater available yield, water supply of un-quality, water supply of quality and water demand. According to the relationship of water availability for exploitation, water supply and demand, it could be divided into three kinds of situations.

**Water availability for exploitation was less than water supply.** When basin/regional water availability for exploitation was less than water supply, it could be considered that the regional water resources development and utilization was exorbitant and it was exploited exceedingly. It was that the water resources development and utilization was beyond the local water resources carrying capacity range. It existed the situation that ecological water was used as national economy water. Do the further analysis of water supply structure and demand. When the groundwater supply was more than groundwater availability for exploitation, it manifested the excavation of groundwater, and groundwater level continued to decline. Their subtraction determined the overexploitation. Then, it could calculated the river ecological water which was occupied. Contrast the relationship between the water supply and the water demand, it could be considered as water scarcity resources based. If according to the local social and economic development as well as the water use level to do the water use efficiency evaluation, it occurred the following situation: When the water use efficiency was low, it was considered water wasting phenomenon existed, and it should be improve the local water use efficiency to reduce the resource-based water scarcity. Contrast the water supply of un-quality and water supply of quality, it could determine the water scarcity quality based. So the water scarcity quality based and occupying ecological water as well as water scarcity resources based had been identified and calculated. Figure 2 shown Specific conditions.

**Water availability for exploitation was more than water supply, but less than water demand.** When water availability for exploitation was more than water supply, but less than water demand, it considered that the water supply capacity of the current water supply project was insufficient. Water scarcity engineer based existed. Do further analysis the water scarcity structure of engineer based. If need process and water inflow did not match, which led to process shortage engineering based, well it could adopt by constructed the storage reservoir to increase water supply. Presumably, if water supply projects was not enough largest and water supply capacity was insufficient, water scarcity produced, which solved by expanding water supply project scale give the solution. At present time, the water scarcity engineer based was found. Figure 3 shown Specific conditions.
Water availability for exploitation was more than the supplied water as well as the water demand. When the available water resources for exploitation was more than the required water in an area, there was no water scarcity resources based, and exploitation potentiality existed in future. At this situation, the amount of water was in rich, and the ecological water could be ensured, well it can meet to the requirement of the local social and economic development. Water scarcity could identify and calculated by above way.

![Figure 4](image)

As to above mentioned three cases, it calculated the amount of being occupied total ecological water, the over-exploited of underground water, being occupied ecological water in river, quality water shortage, engineering water shortage, resources water shortage and the unreasonable water demand of the national economic.

Example Applications

The Song Liao river basin that covered the provinces of Hebei, Liaoning, Jilin, Neimenggu and Heilongjiang was chosen as the research area, it consisted of Liao river basin, Hun Tai river basin, Nen river basin and Songhua river basin. After sampling the research area according to necessary rule and research scale, a system net-chart was formed composition of dot, line and surface[8]. The model of water resources entire elements allocation was set up based of the system net-chart of Song Liao river basin. The 2006s supply amount worked for parameter checking, and adapted the long series 1956-2000s to calculate the supply water and to analyze the balance of supply and demand of the 2006s. Then the water scarcity was identified and computed.

Analysis of the balance of supply and demand. In present year, Song Liao basin needed 489.5 billion cubic meters. Without the water quality constrain, the amount of the supply water is 438.9 billion cubic meters, and the water shortage was 50.5 billion cubic meters. The rate of shortage was 10.3%. However, water supply based of different water quality, the amount of the supply water was 420.3 billion cubic meters and the water shortage was 68.5 billion cubic meters. The rate of shortage was 14.0%.

The specific results were followed by table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The year 2006 result of analysis for supply and demand [million m³, %]</th>
</tr>
</thead>
<tbody>
<tr>
<td>zone</td>
<td>Level2 zone</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Liao river basin</td>
<td></td>
</tr>
<tr>
<td>Xiao Liao river</td>
<td>5506.9</td>
</tr>
<tr>
<td>Dong Liao river</td>
<td>11089</td>
</tr>
<tr>
<td>Liao river</td>
<td>4566.1</td>
</tr>
<tr>
<td>Hun Tai river</td>
<td>6700.3</td>
</tr>
<tr>
<td>Total</td>
<td>17874.2</td>
</tr>
<tr>
<td>Songhua river basin</td>
<td></td>
</tr>
<tr>
<td>The second Songhua river</td>
<td>6669.9</td>
</tr>
<tr>
<td>Songhua river</td>
<td>13640.2</td>
</tr>
<tr>
<td>Total</td>
<td>31072.1</td>
</tr>
<tr>
<td>Total</td>
<td>48946.3</td>
</tr>
</tbody>
</table>
It can be seen through the table 1, in present year, there was a certain degree of water shortage in different areas, and the largest degree of water shortage was in Hun Tai river basin, well the rate of shortage is up to 27.0%. There was the smallest degree of water shortage in Songhua river basin, and the rate of shortage was up to 5.2%. However, the rate of shortage was up to 23.0% in Liao river basin, and the rate of shortage was up to 8.9% in Songhua river basin. The integrated rate of shortage was 14.0% in Song Liao basin.

**The identification and calculation of water shortage.** From the result of the analysis of the balance of the supply and demand, it can be seen that the amount of supply water was more than the available water resources for exploitation in present year, whether supplying water by water quality or not. And water scarcity quality based, water scarcity engineering based and water scarcity resources based existed, as well as occupying ecological water requirement. According to the model of water shortage identification and calculation, the types of water scarcity and quantity of water shortage in different areas was computed. The specific result was as followed by table 2.

**Table 2** The year 2006 analysis of water scarcity For the valley of Song Liao [million m$^3$, %]

<table>
<thead>
<tr>
<th>Zone</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valley of Liao river</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xiao Liao river</td>
<td>3530</td>
<td>351</td>
<td>0</td>
<td>716</td>
<td>910</td>
<td>1977</td>
<td>35.9</td>
</tr>
<tr>
<td>Dong Liao river</td>
<td>647</td>
<td>0</td>
<td>0</td>
<td>303</td>
<td>151</td>
<td>454</td>
<td>41.2</td>
</tr>
<tr>
<td>Liao river</td>
<td>3490</td>
<td>284</td>
<td>0</td>
<td>189</td>
<td>603</td>
<td>1076</td>
<td>23.6</td>
</tr>
<tr>
<td>Hun Tai river</td>
<td>3837</td>
<td>893</td>
<td>0</td>
<td>1056</td>
<td>914</td>
<td>2863</td>
<td>42.7</td>
</tr>
<tr>
<td>Total</td>
<td>11504</td>
<td>1528</td>
<td>0</td>
<td>2265</td>
<td>2578</td>
<td>6370</td>
<td>35.6</td>
</tr>
<tr>
<td>Valley of Songhua</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nen river</td>
<td>15947</td>
<td>122</td>
<td>1542</td>
<td>0</td>
<td>0</td>
<td>1664</td>
<td>15.3</td>
</tr>
<tr>
<td>The second Songhua river</td>
<td>8144</td>
<td>29</td>
<td>359</td>
<td>0</td>
<td>0</td>
<td>388</td>
<td>5.8</td>
</tr>
<tr>
<td>Songhua river</td>
<td>18561</td>
<td>122</td>
<td>573</td>
<td>0</td>
<td>0</td>
<td>696</td>
<td>5.2</td>
</tr>
<tr>
<td>Total</td>
<td>42652</td>
<td>272</td>
<td>2475</td>
<td>0</td>
<td>0</td>
<td>2747</td>
<td>8.9</td>
</tr>
<tr>
<td>Total</td>
<td>54156</td>
<td>1801</td>
<td>2475</td>
<td>2265</td>
<td>2578</td>
<td>9117</td>
<td>18.6</td>
</tr>
</tbody>
</table>

*NOTE——A: Quantity of water availability; B: Water deficit quality based; C: Water deficit engineering based; D: Occupying ecology water; E: Water deficit resource based; F: Total scarcity; G: Scarcity ratio.* Date excerpted from water resources comprehensive planning for Song Liao river basin [9].

From the table 2, it could see that in present year, the available water resources for exploitation was 541.6 billion m$^3$ in Song Liao basin, yet the demand water was 489.5 billion m$^3$. The total water shortage was 91.1 billion m$^3$, and the integrated rate of water shortage was 28.3 billion m$^3$.

In 2006, the water scarcity quality based was 18.0 billion m$^3$, account for 19.7% of the whole water shortage; water scarcity engineering based was 24.7 billion m$^3$, account for 27.1% of the whole water shortage; occupying ecological water requirement was 22.6 billion m$^3$, account for 24.8% of the whole water shortage; water scarcity resources based was 25.8 billion m$^3$, account for 28.3% of the whole water shortage. There was no water scarcity resources based in the whole basin. In Songhua river basin, water scarcity engineering based was 24.75 billion m$^3$, account for 90.1% of the whole water shortage and the water scarcity quality based was 2.7 billion m$^3$, account for 9.9% of the whole water shortage. In Liao river basin, there was not water scarcity engineering based. And water scarcity quality based was 15.2 billion m$^3$, account for 24.0% of the whole water shortage; water scarcity resources based was 25.7 billion m$^3$, account for 40.5% of the whole water shortage. In Song Liao basin, in 2006s, occupying ecological water requirement was 22.6 billion m$^3$, which was gathered in Liao river basin, account for 16.4% of the whole supply water of Liao river basin. If water supplying except the amount of occupying ecological
water requirement, in Liao river basin, the water shortage would be up to 63.7 billion m³, and the rate of water shortage was up to 35.6%.

**The Strategy of water resources exploitation in Song Liao basin.** It is known that, the water scarcity based of water quantity, water scarcity based of water quality and water scarcity based of engineering together contributed to the water scarcity for Song Liao basin in base year. Engineer and non-engineer measure must be developed to work out the water scarcity problem.

1. Engineer measures: ① construct reservoir to improve scheduling and control for river; ② the engineer transferring water for other basin is necessary including transferring water into Xi Liao river reservoir from Nen river basin, transferring water for the middle city crowds of Jilin province from Fen Man reservoir, transferring water for the middle city crowds of Liaoning province from Da Huo Fang reservoir.

2. Non-engineer measures: ① control the total amounts of pollutants into river to purify water body, and reduce water scarcity quality based; ② implement the most strict water resources management regime, strengthen management and improve water usage efficiency and productivity.

**Summary**

It was important to exploit the water resources and protect environment in Song Liao river basin which ensure water supply safe for the whole area. According to the analysis above, we get several results below:

a. A new model of water scarcity identification and calculation was developed, which could recognized the water scarcity based of water quantity, water scarcity based of water quality and water scarcity based of engineering.

b. In 2006s, the water scarcity based of water quantity, water scarcity based of water quality and water scarcity based of engineering together contributed to the water scarcity for Song Liao basin. The water scarcity quality based was 18.0 billion m³; the water scarcity engineering based was 24.7 billion m³; the occupying ecological water requirement was 22.6 billion m³; water scarcity resources based was 25.8 billion m³, account for 28.3% of the whole water shortage.

c. In future, engineer and non-engineer measure must be developed to work out the water scarcity problem. In Songhua river basin, besides necessary measure for pollutants reduction to avoid water scarcity quality based, water reservoir must constructed to ease water scarcity based of engineering. In Liao river basin, first it had to eliminate water scarcity quality based by pollutants total amount controlling, and then the engineer transferring water from Songhua river basin and other basins was indispensable to substitute the occupying ecological water requirement and so on.

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