ABSTRACT

Construct a multi-source and multi-terminal network flow model and work out the minimum cost maximum flow from the source to the sink point so as to put forward an effective, feasible, low-cost water resource strategic optimization model. Finally, the lowest total cost of water resource supply is calculated as $M_{\text{min}} = 4806.918(100 \text{ million RMB})$ and the minimum cost maximum flow is shown. (unit: 100 million cu.m)

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KEYWORDS

Multi-source and multi-terminal network; Minimum cost maximum flow; Multi-objective linear programming.

INTRODUCTION

Fresh water is a limiting factor influencing the development of most regions in the world. Taking China’s vast land and uneven water resource distribution into account, we will divide it into seven regions of North China, Northeast China, East China, Central China, Southwest China, Northwest China and South China and then construct a water resource strategic optimization model. Taking China’s vast land and diverse land-form and climate into account, we will divide it into seven parts of North China, Northeast China, East China, Central China, Southern China, Southwest and Northwest China to discuss about the distribution of fresh water resources.

In order to minimize the cost of water resources utilization, we further optimize the water strategy in Model One and put forward a strategic model of water resources allocation. Considering the economic, social, environmental and other factors, based on Model Two,

<table>
<thead>
<tr>
<th>$y_i$ (i = 1, 2, 3...)</th>
<th>Water supply and demand of different regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_j$ (j = 1, 2, 3)</td>
<td>Factors influencing water supply and demand</td>
</tr>
<tr>
<td>$S$</td>
<td>Year</td>
</tr>
<tr>
<td>$P$</td>
<td>per kilometer freight per cubic meter of water</td>
</tr>
<tr>
<td>$Q$</td>
<td>Seawater desalination cost per cubic meter</td>
</tr>
<tr>
<td>$M$</td>
<td>water supply cost</td>
</tr>
<tr>
<td>$j$ (j = 1, 2 3)</td>
<td>Water supply direction (1=industry; 2=agriculture; 3=life)</td>
</tr>
</tbody>
</table>
construct a water resource application strategy with maximum benefits, minimum environmental pollution and being able to satisfy people’s needs. Then, give feasible suggestions based on the strategic plan. Finally, based on the established model, we provide a non-technical plan for the government, introducing the method, feasibility, and cost of the model. Make a detailed introduction of the strategy advantages.

Assume society, economy, policy and culture can maintain stable development. Glacier melting due to global warming is not taken into account. There is no war and natural disasters. Annual water consumption of residents in one area is the same. The unit cost of sea water desalination in different regions is the same. The unit cost of fresh water transfer in different regions is the same.

**OPTIMIZED WATER RESOURCE STRATEGIC MODEL CONSTRUCTION**

**Multi-source and multi-terminal network flow construction**

Taking the major reservoir of different regions as the study object, utilize satellite imagery to obtain the distances of major reservoirs shown in TABLE 2.

<table>
<thead>
<tr>
<th>Region</th>
<th>North</th>
<th>Northeast</th>
<th>East</th>
<th>Central</th>
<th>South</th>
<th>Northwest</th>
<th>Southwest</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>0</td>
<td>689.7</td>
<td>1037.6</td>
<td>1166.5</td>
<td>2148.2</td>
<td>751.6</td>
<td>1854.1</td>
</tr>
<tr>
<td>Northeast</td>
<td>689.7</td>
<td>0</td>
<td>1656.4</td>
<td>1749</td>
<td>2834</td>
<td>1422</td>
<td>2518</td>
</tr>
<tr>
<td>East</td>
<td>1037.6</td>
<td>1656.4</td>
<td>0</td>
<td>408</td>
<td>1239</td>
<td>1517</td>
<td>1514</td>
</tr>
<tr>
<td>Central</td>
<td>1166.5</td>
<td>1749</td>
<td>408</td>
<td>0</td>
<td>1013.5</td>
<td>1458.8</td>
<td>1151.6</td>
</tr>
<tr>
<td>South</td>
<td>2148.2</td>
<td>2834</td>
<td>1239</td>
<td>1013.5</td>
<td>0</td>
<td>2376</td>
<td>1985</td>
</tr>
<tr>
<td>Northwest</td>
<td>751.6</td>
<td>1422</td>
<td>1517</td>
<td>1458.9</td>
<td>2376</td>
<td>0</td>
<td>1431</td>
</tr>
<tr>
<td>Southwest</td>
<td>1854.1</td>
<td>2518</td>
<td>1151.6</td>
<td>1102</td>
<td>1985</td>
<td>1431</td>
<td>0</td>
</tr>
</tbody>
</table>

(1, 2...7), consider the transit among these regions as the side boundary, and set the maximum traffic capacity of transit (unit: ton) as weight. Then, construct the multi-source and multi-sink network flow chart of different regions (Figure 1):

Formulate an optimal water resource strategic plan, namely, work out the maximum flow $f$ and the total transport cost of the maximum flow is as follows:

$$r(f_{\text{max}}) = \sum f(u, v, w).$$

**Arithmetic principle**

The process of seeking the maximum flow starts from a feasible flow $f$, and find out the augmentation road $p$. Adjust $f$ along the road $p$; finding the augmentation path for new feasible flow; the process is repeated all the time until there is no augmenting path.

When it is required to find the minimum cost maximum flow, we first need to consider adjusting $f$ with the improving quantity $\alpha = 1$ along the augmenting
path $p$ towards $f$; as for the new feasible flow $f'$, obviously $f = f' + 1$, than how much quantity has been added from $r(f)$ to $r(f')$ It is not difficult to see that:

$$r'(f') - r(f) = \sum_{e \in p^+} r(e)'(f'(e) - f(e)) - \sum_{e \in p^-} r(e)'(f'(e) - f(e))$$

$$= \sum_{p^+} r(e) - \sum_{p^-} r(e)$$

Take $\sum_{p^+} r(e) - \sum_{p^-} r(e)$ as the cost of this augmentation road $p$.

**Arithmetic procedure**

Based on the above analysis the minimum cost maximum flow can be calculated in the following way:

1. Take $f_0 = \{0\}$;
2. Generally speaking, if we get minimum cost flow $f(k-1)$ in the step of $k-1$, then construct the adjoint network $W(f(k-1))$;
3. seek the shortest path from $V_s$ to $V_t$ in $W(f(k-1))$. If there is no shortest path(namely weight of the shortest path is $+\infty$), then choose $\mathbb{3}$; if the shortest path exists, then choose $\mathbb{5}$;
4. in the original network $G$, we can get corresponding augmentation path $p$, where we can make adjustment about $f(k-1)$:

$$\alpha = \min \{\min_{p^+} (c_{uw} - f_{uw}(k-1)), \min_{p^-} f_{uw}(k-1)\}$$

$$f_{uw}(k) = \begin{cases} f_{uw}(k-1) + \alpha & (u, v) \in p^+ \\ f_{uw}(k-1) - \alpha & (u, v) \in p^- \\ f_{uw}(k-1) & (u, v) \notin p \end{cases}$$

The new feasible flow after adjustment is $f(k)$; then choose $\mathbb{2}$;
5. $f(k-1)$ is the minimum cost maximum flow, then the execution is finished.

**Rithmetic solution**

The following Figure 2 hows the arithmetic solution of the minimum cost maximum flow illustrated in capacity network demonstration.

**Arithmetic process**

1. Figure 2(a): start from zero flow $f(0) = \{0\}$ to improve minimum cost maximum flow $f$;
2. Figure 2(b): construct adjoint network $W(f(0))$ based on the above method, calculate the shortest path from the source point $V_s$ to the sink point $V_t$, and use bold line to indicate the side boundary of the shortest path, which is taken as the augmentation route when the cost of $f(0)$ is minimum,
3. Figure 2(c): along the augmentation route with minimum cost obtained we can get improvable quantity $\alpha = 20$, improve $f(0)$, and obtain $f(1)$;
4. Figure 2(d) constructs adjoint network $W(f(1))$ and calculate the shortest path from the source point $V_s$ to the sink point $V_t$. This shortest route is taken as the augmentation road with the least cost for $f(1)$ and the improvable quantity $\alpha = 10$, improve $f(1)$, and then get $f(2)$;
5. Figure 2(e) constructs adjoint network $W(f(2))$, calculate the shortest path from the source point $V_s$ to the sink point $V_t$. This shortest route is taken as the augmentation road with the least cost for $f(2)$ and the improvable quantity $\alpha = 31$, improve $f(2)$, and then get $f(3)$;
6. Figure 2(f) constructs adjoint network $W(f(3))$, cal-
Calculate the shortest path from the source point $V_s$ to the sink point $V_t$. This shortest route is taken as the augmentation road with the least cost for $f(3)$ and the improvable quantity $\alpha = 3$, improve $f(3)$, and then get $f(4) = 31$, the cost is: $\sum f(u, v) \times r(u, v) = 683.64(100\text{millionRMB})$. 

Figure 2: Arithmetic demonstration of minimum cost maximum flow
Water resource strategy construction

If taking northeast as the source and southwest as the sink point, we can get a maximum flow of 31*(100 million cu.m). Other maximum flow can be worked out in the same way. See TABLE 3.

### TABLE 3: Minimum cost maximum flow list (100 million cu.m)

<table>
<thead>
<tr>
<th>Sink source point</th>
<th>North</th>
<th>South</th>
<th>Central</th>
<th>Northeast</th>
<th>Southwest</th>
<th>Northwest</th>
<th>East</th>
</tr>
</thead>
<tbody>
<tr>
<td>northeast</td>
<td>23</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>South</td>
<td>12</td>
<td>0</td>
<td>9</td>
<td>11</td>
<td>21</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>East</td>
<td>31</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>20</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>North</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>22</td>
<td>31</td>
<td>21</td>
</tr>
</tbody>
</table>

The total cost of water resource supply is: \( M_{\text{min}} = 4806.918 (100 \text{ million RMB}) \)

In addition, the water resources storage can increase the flow of surface water, improve regional climate and environment, as well as provide a new habitat and water source. It is also beneficial to increase and maintain the regional species diversity and ecosystem stability. In the meanwhile, it can increase the connectivity and mobility of water along the way and enhance the self-purification capacity of water environment.

### MODEL ANALYSIS AND PROMOTION

Based on the balance of supply and demand of water resources, economical, social and environmental factors, the water resources strategy optimization model aims at optimizing the comprehensive benefits of economy, resources and environment of the whole society. The prediction of supply and demand of water resources in 2025 guarantees the effects of the validity of the water resources strategy; the analysis of the present status of China’s water resources ensures the feasibility of the strategy; the program of minimum-cost maximum-flow make sure the low cost of the strategy planning. Furthermore, according to the results of the model, water for agriculture and industry plays a great role in China’s total water use, therefore it is crucial to take effective measures to save resources, such as, adjusting industrial structure, reducing or diverting high-water-consumption agricultural planting, resorting to drip-fed farming, transferring high-energy-consumption and high-water-consumption enterprises and turning to low-energy-consumption high-technology industry.

The model can be applied into and scheme water resources strategies in different periods. Besides, it can be put into the prediction and allocation of other resources, which provides a reference for the sustainable development of various resources.

### ACKNOWLEDGEMENTS

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### REFERENCES


[4] Aihua Li, Yuanyuan Li, Jianqiang Li; Primary investigation on coordinated development between water resources and economic and social and ecological environment system. Yangtze River, 42(18), Sep (2011).


