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Network flow model of China's water resources

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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 $M_{\min} = 4806.918(100millionRMB)$ and the minimum cost maximum flow is shown. (unit:100 million cu.m)

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 landform 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 1 : Definition and explanation of symbols

y_i、$z_i (i = 1,2,3...7)$	**Water supply and demand of different regions**
$x_j (j = 1,2,3)$	Factors influencing water supply and demand
S	Year
p	per kilometer freight per cubic meter of water
q	Seawater desalination cost per cubic meter
M	water supply cost
$j(j = 1,2,3)$	Water supply direction (1=industry; 2=agriculture; 3=life)

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.

There are three aspects to consider in designing an optimized water resource strategic plan:

(1) Take the northeast region as the source and the six regions of East, Central, Southwest, Northwest, North and South China as the sink point. The water is transferred from northeast to other six regions. Then, work out six minimum cost maximum flow[3];

(2) The coastal areas of East, North and South China can make use of seawater desalination to provide self-sufficient fresh water. Therefore, take the three regions as the source and the rest three regions (excluding Northeast) as the sink point so as to formulate the minimum cost maximum flow of each area (with 15 minimum cost maximum flow in total);

(3) Splice all the above minimum cost maximum flow to form an optimal water resource strategic plan. Based on the above result, we construct multi-source and multi-terminal network flow model by mainly considering water resource movement and seawater desalination, and work out the minimum cost maximum flow from source to sink.

Take the seven regions of North, Northeast, East, Central, Northwest, Southwest and South China as the corner of the figure(represented by the number of

TABLE 2 : Distances of major reservoirs in different regions(km)

Region	North	Northeast	East	Central	South	Northwest	Southwest
North	0	689.7	1037.6	1166.5	2148.2	751.6	1854.1
Northeast	689.7	0	1656.4	1749	2834	1422	2518
East	1037.6	1656.4	0	408	1239	1517	1514
Central	1166.5	1749	408	0	1013.5	1458.8	1151.6
South	2148.2	2834	1239	1013.5	0	2376	1985
Northwest	751.6	1422	1517	1458.9	2376	0	1431
Southwest	1854.1	2518	1151.6	1102	1985	1431	0

$(1,2...7)$, 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:

$$r(f)_{\min} = \sum f(u,v,w).$$

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

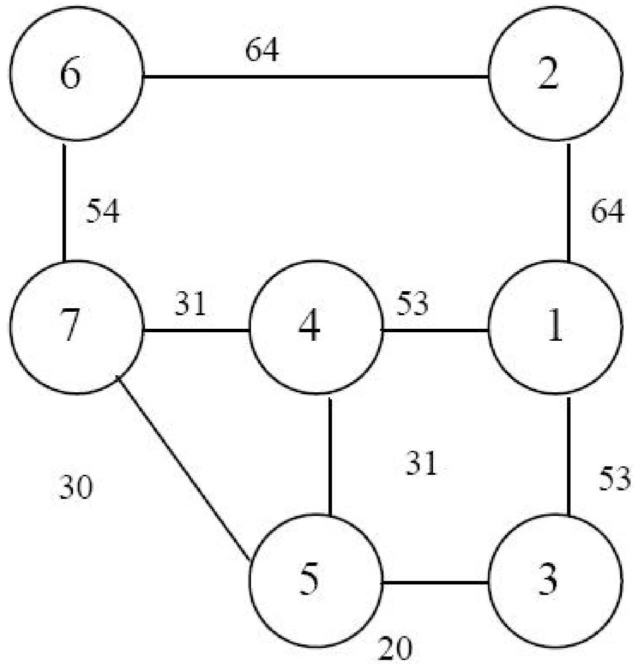

Figure 1: Network flow of different regions

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:

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

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

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

Arithmetic procedure

Based on the above analysisÿthe 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 ⑤; if the shortest path exists, then choose ④;

④ in the original network G, we can get corresponding augmentation path p, where we can make adjustment about $f(k-1)$:

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

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

The new feasible flow after adjustment is $f(k)$; then choose 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 obtainedÿwe can get improvable quantity $\alpha=20$, improve $f(0)$, and abtain $f(1)$;

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-

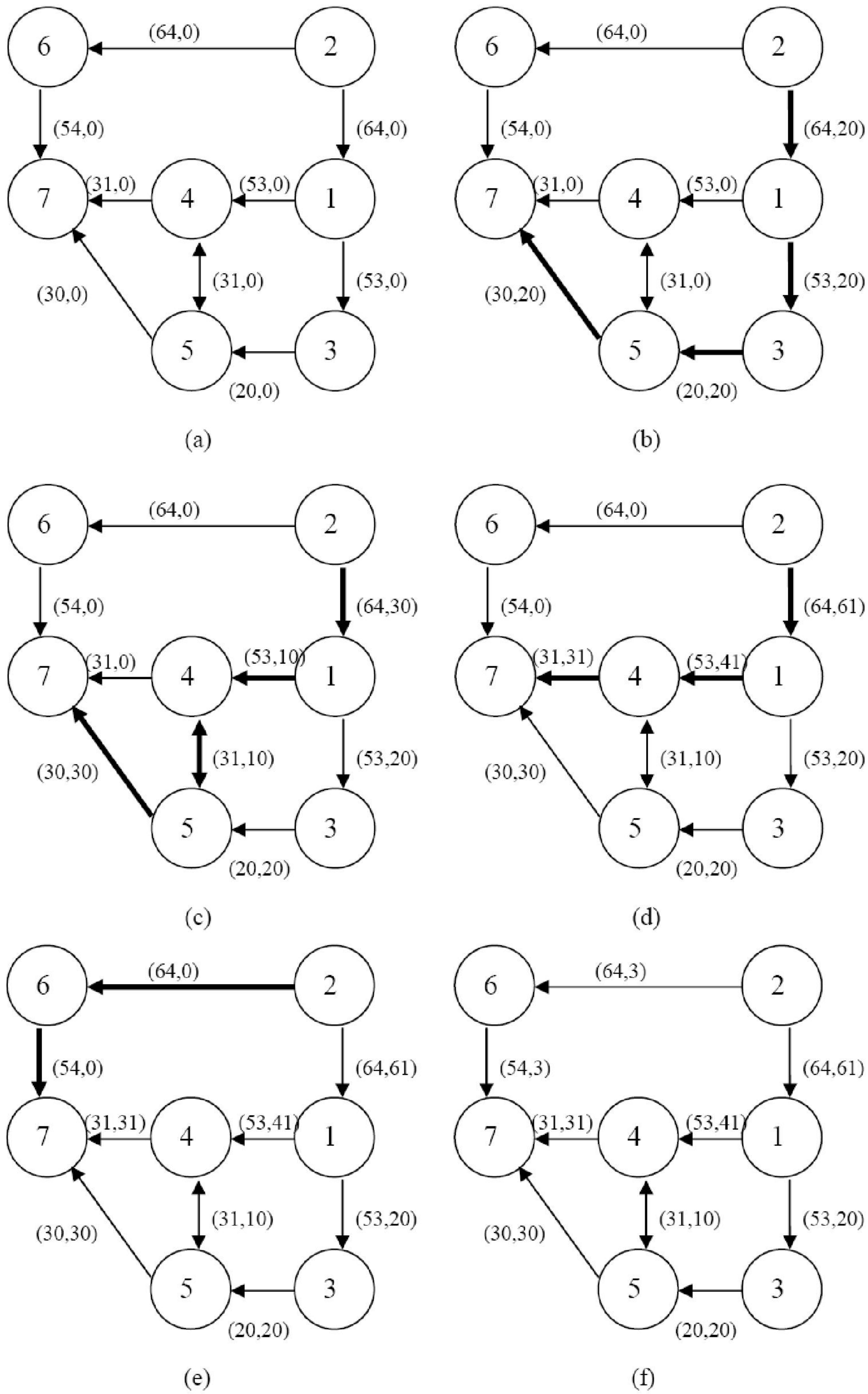

Figure 2 : Arithmetic demonstration of minimum cost maximum flow

culate 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*millionRMB*) .

Water resource strategy construction

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

The total cost of water resource supply is: $M_{\min} = 4806.918(100 millionRMB)$

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.

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

Sink source point	North	South	Central	Northeast	Southwest	Northwest	East
northeast	23	20	0	0	0	0	20
South	12	0	9	11	21	21	1
East	31	0	0	1	20	12	0
North	0	0	11	0	22	31	21

The total cost of water resource supply isÿ $M_{\min} = 4806.918(100 millionRMB)$

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.

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