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The Model of Lake Operation in Water Transfer Projects Based on the Theory of Water-right

YAN Bi-peng  LIU Chao  TANG Fang-ping

Yangzhou university,Yangzhou china 225001

Abstract

The lake operation is a very important content in Water Transfer Projects. The previous studies have not any related to water-right and water-price previous. In this paper, water right is divided into three parts, one is initialization water-right, another is by investment, and the third is government’s water-right re-distribution. The water-right distribution model is also build. After analyzing the cost in water transfer project, a model and computation method for the capacity price as well as quantity price is proposed. The model of lake operation in water transfer projects base on the theory of water-right is also build. The simulation regulation for the lake was carried out by using historical data and Genetic Algorithms. Water supply and impoundment control line of the lake was proposed. The result can be used by south to north water transfer projects.

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Keywords: Water transfer project; The model of lake operation; Water right; Water supply pricec

1. Introduction

Pumping-lake regulation is the key content of optimal operation in water transfer project with regulation and storage capacity. At the present time the objective function for optimal operation is basically either maximum water supply volume or the minimum abandoned water volume, which has failed to take users’ water rights or different price for regulating water between different places. into condition The mode of interbrain water transfer management will gradually adopt new system construction and management with state macro-control, corporation market operation, the uses’ participation; implementation of charging water fees with two-party water price: capacity water price and measurement water price. In this way it will no doubt brings up changes in relationships of supply and demand for water. Optimal regulation and management for water transfer project has to accommodate to this change, namely, the users’ water rights have to be guaranteed to ensure a certain guarantee rate for their water rights. Besides, the interbrain water transfer projects are usually gradation pumping. There are lakes for regulation and storage. Since we have considered lake water, use of water, abandon of water and regulation of water, cost calculation would be a rather complicated and important project. Systematic optimal regulation should take cost (water price) fees
of transferring water between places into consideration so that a highest comprehensive system regulation benefit could be achieved. Obviously, the original optimal regulation model could not accommodate to the demand of reality, it is thus necessary to raise an optimal regulation model from water right theory to provide theoretical foundation for the optimal regulation and management of water transfer project on the basis of doing a research on water price in water transfer project and water price calculation.


2. Calculation Model of Users’ Water Regulation Rights

The user’s water transfer rights refer to his right to obtain a certain amount of water (water quality) at a specific time at a specific place with an agreed price. The user’s water transfer right is composed of three parts: firstly, user’s initial water right of the river before water transfer project construction; secondly, user’s water transfer right obtained according to the user’s investment share; thirdly, water transfer right obtained by the redistribution of state’s water rights. As for water transfer projects which have employed or partly employed the ready-made water transfer channel, distribution of the rivers’ initial water power should be conducted to make certain water rights of original users could be guaranteed when carrying on the calculation of water right distribution or else a compensation should be made. As for the water transfer project with totally newly-built channel, users’ water rights should be calculated according to the principle that those who have invested benefit. The calculation of water right distribution should be carried out respectively according to the initial water rights of the water channel, investment allocation of water rights, water rights of state’s investment, and thus this total amount is the user’s water transfer right.

\[
SQ = SQ_1 + SQ_2 + SQ_3
\]  

\( SQ \): total amount of user’s water rights;  
\( SQ_1 \): the initial water rights of the water channel;  
\( SQ_2 \): investment allocation of water rights;  
\( SQ_3 \): water rights of state’s investment.

2.1. Initial water rights of the water channel

Inasmuch as factors influencing the distribution of initial water rights of the water channel are hardly quantitative, Analytic Hierarchy Process is employed here to ascertain weights of varied indexes, seen in inference [5] and water right at a certain period of time of each user is calculated thanks to historic average data.

Suppose that the water channel provide water to m users and the evaluation is made up of n evaluation factors, then, \( p_{ij} \) is the water right percentage of the j factor of the ith user:

\[
p_{ij} = b_{ij} / \sum_{i=1}^{m} b_{ij}
\]

And \( \sum_{i=1}^{m} p_{ij} = 1 \; \; \; \; i=1\ldots m \; \; \; j=1\ldots n \)

b\(_{ij} \) is the value of j factor of ith user.

Weight calculation of each factor based on Analytic Hierarchy Process

\[
\omega = ( \omega_1, \omega_2, \ldots, \omega_n )^T
\]

Water rights percentage of each user

\[
p_i = \sum_{j=1}^{n} \omega_j \times p_{ij}
\]
Pi: Water rights percentage of the ith user
ωj: Weight of the ith factor
pij: Water rights percentage of the jth factor

Initial water rights of the water channel of the ith user in a certain period of time:

\[ SQ_1 = Pi \times Q_1 \]  \tag{5}  

Q1: Amount of river flow in a certain period of time

\[ SQ_{2ij} = (E_i / E) \times QG_j \]  \tag{6}  

SQ2ij: investment allocation of water rights of the ith user in the j period of time;
Ei: investment amount of the ith user;
E: total investment of the water transfer projects;
QGj: New water supply capacity of water transfer project in j period of time.

2.3 mathematical model of redistribution of the national water rights

National water rights at last must be assigned to the user. Effectiveness, equity and sustainable development of water allocation must be taken into account in the process of the redistribution of the national water rights, which involves in indexes of water use efficiency, level of economic development, water shortage, ecological environment and social development. But some indexes would be out of considerations of recent development of water transfers project and hardly quantities calculated by means of Analytic Hierarchy Process and Fuzzy Decision. Therefore, optimization model in this part is utilized to study the allocation of water rights in different periods of time. The minimum economic loss of water is set as the objective function. Suppose that there are m users, the whole year is divided into n periods, the total investment of the water transfer project is E and E0 is national investment. And the optimization model is:

\[ z = \min \sum_{i=1}^{m} \sum_{j=1}^{n} \lambda_i (Q_{ij} - SQ_{ij} - SQ_{ij} - SQ_{ij}) \]  

Z: economic loss of water transfer system;
Q_{ij}: water requirement of the ith user in j period of time;
SQ1ij: initial water rights of the water channel of the ith user in j period of time;
SQ2ij: Water rights of investment allocation of the ith user in j period of time;
SQ3ij: variables to be seeking, water rights obtained from reallocation of national water rights of the ith user in j period of time:
\( \lambda_i \): Coefficient of economic loss of the \( i \)th user due to water shortage actually indicates the dependency of users’ economy development on water supply.

National water right in \( j \) period of time is:

\[
SQ^3_j = (E_0/E) QG_j
\]

(8)

Constraints: Allocation value of national water rights of each user in \( j \) period should be less than or equal to national water rights:

\[
\sum_{i=1}^{m} SQ^3_{ij} \leq SQ^3_j
\]

(9)

Total water rights obtained of each user in \( j \) period should be less than or equal to water requirement:

\[
SQ^1_{ij} + SQ^2_{ij} + SQ^3_{ij} \leq Qx_{ij}
\]

(10)

Optimization can be further explained as the optimal allocation of water supply capacity of water transfer project of each period.

3. Calculation model for users’ transferred water price

The general idea of calculating transferred water price is that it is constituted by capacity water price and measurement water price. The former is used as the dividends and capital repayment while the latter for the payment of the running of the project.

Based on the route of water transfer, node is set according to transfer unit, seen in the Fig. 1.

![Fig 1 node settings for water-price calculation](image)

Capacity water price could be shared according to the node settings between intervals, including the investment from water source to a node and the water rights proportion of the set of the total water rights. And measurement price should abide by cumulative calculation. One node is regarded as the transferred water source of the following node. The price of each node equals to the price of the former node plus total transferred water cost of the interval between the two nodes and water maintenance costs and environmental compensation cost price.

3.1. Users bear the water capacity price

Total water capacity price is closely connected with project repayment situation, capital dividend policy and users’ water rights. Suppose the total investment of the project is \( W \), \( K1 \) is the percentage of credit while \( K2 \) is the percentage of capital investment, loan rate is \( L2 \), term of the loan \( T \). During the period of repayment, according to the national investment policy, there is no capital dividend, which will be activated when loan is paired off, and dividend rate is \( L1 \), thus:
Total water capacity expenditure each year during repayment is:

$$CT = k_1 w l_2 (1 + l_2)^T / [(1 + l_2)^T - 1]$$  \hspace{1cm} (11)

CZ, Water capacity expenditure of the whole project after paying off repayment is:

$$CZ = k_2 \times W \times l_1$$  \hspace{1cm} (12)

Water capacity expenditure each user bore: suppose the total investment of the water transfer project is W, the whole is divided into m intervals, investments of which are specifically \(W_1, W_2\ldots W_m\), average water rights of users of each node are \(SQ_1, SQ_2\ldots SQ_m\), the general water rights of the water transfer project is \(SQ\). According to theory of water rights, Water capacity of the first node is the result of investment from water source to the first node multiplying water rights percentage of the first node, the remaining is transferred to the next node, and so on.

The calculation format of water capacity expenditure of users of the k internal is:

$$C_k = \left(\sum_{i=1}^{k} W_i - \sum_{i=1}^{k-1} C_i\right) \times \frac{SQ_i}{\sum_{i=k}^{m} SQ_i}$$  \hspace{1cm} (13)

3.2. Users’ measurement water expenditure

Suppose the price of the node I-1 is \(P_{i-1}\). \(P_{ci}\) is the unilateral costs from node I-1 to node I, including project cost, water source maintenance cost and environmental compensation cost. The transferred water price of node I is \(P_i\):

$$P_i = P_{i-1} + P_{ci}$$  \hspace{1cm} (14)

Based on cost analysis of water supply, suppose the annual gross transferred water from node I-1 to node I is \(Q_i\). Annual material power charges is \(E_1\) of intervals, depreciation \(E_2\), project maintains cost \(E_3\), running management expenditure \(E_4\), water source maintenance fee \(E_5\), environmental compensation \(E_6\), profit \(E_7\), taxes \(E_8\). Thus:

$$P_{ci} = \left(\frac{E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7 + E_8}{Qi}\right)$$  \hspace{1cm} (15)

To keep the stability of the water capacity price, water capacity expenditure should not undergo great changes. Water transferring companies should also bear the cost of provision. Water capacity only has theoretical meaning. Users, in accordance with water rights, subscript the investment in water supplanted design and project construction.

4. The Operation Model of Lake in Water Transfer Projects Based on the Theory of Water-right

4.1. Operation model of lake water

In the water transfer project, lake operation chart is quite different from that of general reservoir. The decision variables are the control process of pumping, storage and supplanted. In the operation chart, there are two main control lines, of pumping and storage. The functions of the control lines are to partly guarantee the water supply at present and future, which require the level of water should be controlled under the line, and to avoid over-pumping.

Determine the objective function of lake operation: Regulation-and-storage-lake is a complicated system in the water transfer system. Both pumping expenditure and users’ water rights must be taken into account when single lake simulation is conducted. Apparently, this is a pair of contradictory sub-objects. Weight factor \(\alpha\) of objective function is adapted to consort the contradiction.
Objective function:

- Pumping costs:
  \[ OB_1 = \sum_{j=1}^{n} Q_{dj}(k, j) \times P_k \]  
  (16)

- Economic loss due to water shortage:
  \[ OB_2 = \sum_{j=1}^{n} \sum_{i=1}^{m} \lambda_i (SQ(i, j) - Q_{ys}(i, j)) \]  
  (17)

- Comprehensive objective function:
  \[ OBJ = \min \{ \alpha \times OB_1 + (1 - \alpha) OB_2 \} \]  
  (18)

\( Q_{dj}(k, j) \): water quantity transferred from lake K at J period of time;
\( P_k \): transferred water price of lake K;
\( SQ(i, j) \): water right of the ith user at j period, water right is substituted by water quantity in calculation;
\( Q_{ys}(i, j) \): actual water quantity of the ith user at j period;
\( \lambda_i \): economic loss coefficient of the ith user due to water shortage.

Balance equation of lake water:
\[ V(k, j+1) = V(k, j) + Q_{d}(k, j) + Q_{s}(k, j) - Q_{w}(k, j) - Q_{s}(k, j) - Q_{w}(k, j) - Q_{k}(k, j) \]  
(19)

\( V(k, j+1) \): lake water quantity of j+1 period;
\( V(k, j) \): lake water quantity over period j;
\( Q_{dj}(k, j) \): water quantity pumped into lake over period j;
\( Q_{ls}(k, j) \): water quantity of natural runoff over period j;
\( Q_{ys}(k, j) \): total water usage of users over period j;
\( Q_{qs}(k, j) \): quantity of discarded water over period j;
\( Q_{dc}(k, j) \): quantity of transferred water over period j;
\( Q_{ss}(k, j) \): Water loss over period j.

Constraints:

1. Constraint of transferring and storage capacity of lake
   \[ V_i(k) \leq V(k, j) \leq V_m(k) \]  
   (20)

   \( V_i(k), V_m(k) \): Dead storage and maximal storage volume of Lake K

2. Constraint of capacity of pumping water into lake
   \[ Q_{dj}(k, j) \leq Q_{mdj}(k) \]  
   (21)

   \( Q_{mdj}(k) \): The maximum of pumping water of Lake K.

3. Constraint of discharge capacity
   \[ Q_{qs}(k, j) \leq Q_{mqs}(k, j) \]  
   (22)

   \( Q_{mqs}(k, j) \): discharge capacity of lake k over j period.
(4) Constraint of capacity of transferring water to North

\[ Q_{dc}(k, j) \leq Q_{mde}(k) \]

\( Q_{mde}(k) \): The maximal capacity of transferring water to North of lake k.

(5) Constraint of water level of decision variable control line

\[ H_{\text{min}}(k) \leq H(k, j) \leq H_{\text{max}}(k) \]

\( H_{\text{min}}(k), H_{\text{max}}(k) \): Dead water level and optimum water level of lake k.

(6) Constraint of all non-negative decision variable.

A variety of methods confirm more objective function weight vector. This paper uses a fuzzy simple calculation method, with genetic algorithm to determine. Specific steps are omitted.

4.2 Model application research for regulation and storage property of Hongze lake

Hongze Lake is the most important regulation and storage lake for the optimization of South-to-North water transfer Easter route project. Its water level variation is mainly restricted by two factors: natural water flow and artificial regulation. The actual regulation is divided into two stages and irrigation is main stage. Every year from beginning of May to the end of July is the irrigation water peak, during this period Hongze Lake is merely used to supply water for irrigation district; during the storage period, in order to guarantee the water consumption next year, controlled water level should be raised and discharged water should be reduced from every August all the way to the end of next April to ensure that the water storage of April should be kept at 13.0m. The foundation principle for regulation is that the water flow should give preference to water use of this specific lake. The lake begins water storage when water use of this specific lake and pumping of the last-stage lake is satisfied; if storage capacity exceeds the water storage controlled level, pumping water to the lake should be stopped; abandoning water is allowed if storage capacity has still exceeded controlled water level after stopping pumping water; attempting to pump water to the controlled water level if storage capacity is between water controlled level and water supplying level after water flow and water use have gained a balance.

The hydrologic series adopted in this essay is derived from 42 years of hydrological data from July, 1956 to June, 1997. During calculation reservoir is regulated form hydrological year July the 1st to next June the 30th: the period form May to July is divided into nine stages; August and September is divided into six stages; All the other months are respective one stage, thus all together there are 22 stages. The regulation level is comprised of water supplying level and water storage level with different guarantee level. The 42 years of hydrological data is divided into this kinds of hydrological year, namely rainy year, average water year and dry years and controlled level should be calculated respectively. Set the initial value of optimization model and historical data according to different guarantee rate and restriction of capacity storage and conduct modeling through genetic algorithm using objective function and restrictive factors. Firstly, the value of objective function 1 and objective function 2 should be calculated to obtain a group of initial value of quadratic objective function and calculate weight factor \( \alpha \) employing vector-determination method of multi-functional function. The result demonstrate that \( \alpha=0.57 \) and then carry on optimization employing comprehensive objective function. See graph 2 for calculation diagram table 1 is the result.

5. Conclusion

Water transfer project with transfer and storage lake has always been the difficult and hot spot of the research. This paper firstly points out transferred water rights is made up of three parts: Firstly, user’s initial water right of the river before water transfer project construction; secondly, user’s water transfer
right obtained according to the user’s investment share; thirdly, water transfer right obtained by the redistribution of state’s water rights, and put forward the mathematical model of the calculation of the redistribution of water rights. On the basis of analysis of the formation of water price, calculation methods of water capacity price and measurement price is proposed. Based on the detailed analysis of transferred water rights and water price, the paper tries to, in view of theory of water-right, develop operation model of lake water in water transfer project. In the end, making use of historic data, by means of genetic algorithm, the paper probes into the optimal operation and controls lines of water storage and supply, which is positive to the optimal operation of water transfer project.

References


Input control parameter

Input data

Set initial control line

Input interval number=24

Balance calculation

Is there surplus water?

Pump water into lake

Lake operation regulation

Supply water to users

Calculate objective function

Does interval end?

Does traditional calculation method converge?

Not converge under determined parameter

Output optimal control line

Does control line end?

Ending

Fig. 2 calculating frame
Tab1. the operation control line  

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