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Optimal Allocation Model of Reclaimed Water Reuse

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Abstract

In order to utilize the reclaimed water resources reasonably and maximize energy-consuming green benefit, the optimal allocation model is established for reclaimed water resources, which is based on the marginal benefit equilibrium theory of water-consuming and marginal utility theory of the economics, and there are two levels including industries and consumers. It promotes consumers to improve the water-consuming green marginal benefit, accelerate the process of generalizing reclaimed water resource recovery.

Keywords: Reclaimed water resources; the Optimal Allocation Model; Marginal Benefit Equilibrium

1. Introduction

Sewage treatment will be one of the most potential measures of the all exploitation methods for the water resource. Now, in the world, the Israel's degree of utilization can be the first in the world [1].In China, until the 1980s, city sewage recycling technology was gradually developed and certain achievements were achieved. For example, Li Mei established the water supply price model from the angles of the market, cost and value theory[2]; Liu Zhiqiang improved the model of the network construction cost and operation cost[3]; Li Jiaguo simulated and analyzed the water utilization system according to the process of reclaimed water utilization status and actual condition, then the from macroscopic angle of the cost, distance and obtained quantity [4], they built the model of using optimally water with 5 sets linear programming. But they neglected or did not consider thoroughly some objective limitation reasons about sewage resource recovery which led to the application of study lagging behind

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the research level seriously. Therefore, the optimal utilization of the sewage after moderate treatment with lest investment which is in tolerable range of the current is the problem to be solved in the field of recycling reclaimed water in our country.

2. Theory analysis

2.1. Optimal allocation model of reclaimed water resources among industries

2.1.1 The optimal allocation model of reclaimed water resources among industries

At the assumption that at t moment, the amount of reclaimed water resources provided by a certain area under the existing conditions is R, and there are N industries which accept reclaimed water resources, the water resources (short for the conventional water) quantity provided for economic development of the industries is Q_{i0}, i = 1, 2, …N. The conventional water is assumed to be used firstly, and then the reclaimed water resources. Under the hypothesis that the marginal benefit of the industry consuming water resource is $f_i = f_i(Q_{i0})$, a quadratic function is used to fit the actual data of every industry. Based on the marginal benefit of the industries utilizing the water resources, the benefit is scheduled from big to small. Without loss of generality, we assume that $f_i > f_j$, $\forall$ i < j.

Now, The amount of reclaimed water resources obtained by each industries is R_i. The target is to get the maximum green benefit of reclaimed water resources after allocation. Assume that after each industry get relevant resource, the green benefit of total water resources is:

$$U_i = \int_{Q_{i0}}^{Q_i} f_i(Q_i)dQ_i = \int_0^{R_i} f_i(Q_{i0} + R_i)dR_i \tag{1}$$

Then the optimization problem is:

$$Max \;\; U = \sum_{i=1}^{N} U_i = \sum_{i=1}^{N} \int_{Q_{i0}}^{Q_i} f_i(Q_i)dQ_i = \sum_{i=1}^{N} \int_0^{R_i} f_i(Q_i + R_i)dR_i \qquad R = \sum_{i=1}^{N} R_i \tag{2}$$

S t

$$\frac{df_i(Q_i)}{dQ_i} = \frac{df_i(Q_i + R_i)}{dR_i} < 0 \tag{3}$$

where $Q_i = Q_{i0} + R_i$ is the consumption of the ith industry, the Eq.(3) is the decline constraints of marginal benefit of water consumption.

The above optimization problem is a conditional extremum problem. Therefore, the Lagrange multiplier function is constructed as follows:

$$L = U + \lambda\left(R - \sum_{i=1}^{N} R_i\right) \tag{4}$$

Then

$$f_i(Q_{i0} + R_i) = \lambda \;\; , \;\; \forall \;\; \text{i} = 1, 2, \cdots, \text{N} \tag{5}$$

It means that when the each marginal benefit of the industries consumption equals to λ, the total economic benefits is the biggest. From Eq.(5), here is:

$$R_i = g_i(\lambda) - Q_{i0} \tag{6}$$

In above formula, $g_i(\bullet)$ represents inverse function of $f(\bullet)$.

From the above analysis, λ can be interpreted as the marginal balance benefit of water consumption of each industry. The above result can be interpreted as the reference [5]. Therefore, the marginal benefit equilibrium principle of reclaimed resources allocation can be described as: when the industries of the water consumption marginal benefit is balanced, the total green benefit of water resources consumption of