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A method of analysis of macro water environmental systems

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Abstract—— The phases of water environmental system (WES) and their emphatic intersections are analysed in this paper, and from the view point of system analysis, an analytical process of WES is provided. Based on the balance network of WES, a goal programming model for regional water environmental planning and the main computational result for a coastal city are provided, thus proving its usefulness and effectiveness.

Keywords: water environmental system; balance network of water environmental system; goal programming.

1 Introduction

Lack of water resources and water environment pollution are urgent environmental problems in the development of cities. With the development of economy, population increase and raising of people's living standard, demand for water resources, and the pressure created by all sorts of sewage toward environment will be both increasing. And all these increases will have, to some extent, effects on the development of economy and society the other way round.

The whole WES can be divided into an inside system and an outside system, which are interrelated. For the former part, the goal of planning is high efficiency and balance. The so-called high efficiency means to satisfy maximum demand and to obtain most benefits by minimum investment of resources and funds. The so-called balance means the balance among all intersections of water branches. However, the actual situation is usually not in balance, which is shown by the imbalance between water use (demand) and resources, discharge and treatment. Hence serious problems of over-development, earth subsidence and pollution of water environment of lower reaches are created.

The goal of planning for the relationship between water system and its outside system is coordination, which is manifested in the coordination among economic scale, structure and rate of water resources development and level of investment.

2 The build-up of macro-WES and analysis of balance of water flows

Water-system in cities is a complicated system. But it can be simplified to become a network form as shown in Fig. 1 after appropriate analysis and induction. Water systems can be divided into phases from the development of resources to the sewage discharging toward some accepting water body. They usually include development of water resources, use of water, production and discharge of waste water, discrete treatment, concentric treatment, discharge into accepting water body and recycling phases with self structural characters of each phase and balancing relationship of each other.

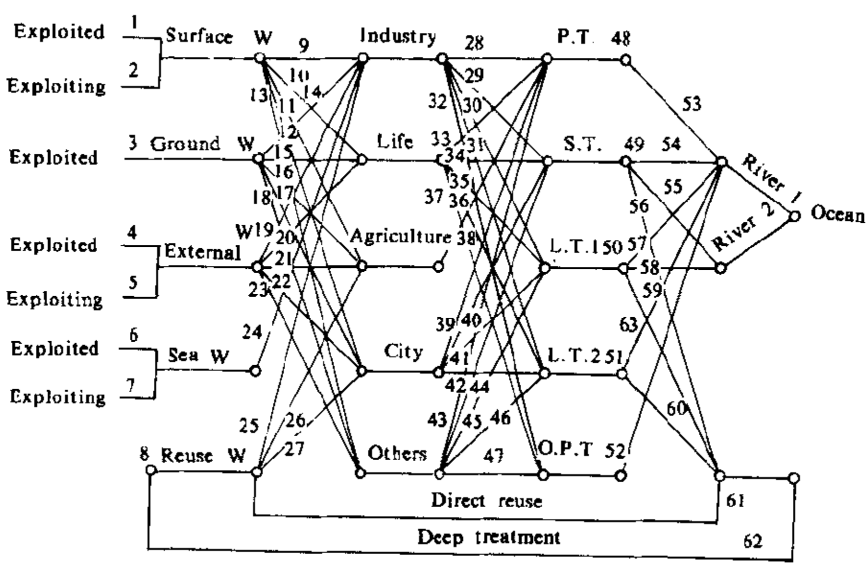

Fig. 1 Network of regional water environmental system
The numbers 1, 2, 3, …, 63 represent subscripts of water flow variables, W is water, P. T is primary treatment, S. T is secondary treatment, L. T. 1 is land treatment, L. T. 2 is high efficiency land treatment, O. P. T. is oxidation pond treatment

In the phase of development of water resources, the emphatic analysis is on environmental ecological problems caused by developing limit of water resources in planning years and development of water resources such as earth subsidence and fall of ground water level, decrease of surface water area, city and countryside gracing water, enlargement of sand land area, invasion of sea water, salinization of soil and nonrationality of distribution of water resources (including rationality of water quantity and economic feasibility); use of sea water and recycling of sewage which should be considered in the coastal cities lacking water resources seriously.

In the phases of use of water, the using-water indexes should be emphasized to analyze. Usually the index of life and municipal use of water should be increasing year by year, while that of industrial and agricultural use of water decreasing.

The measures for saving and reusing water should be fully considered in the industrial use of water. The indexes of use of water in different industry department are quite different, and should be analyzed according to different department and industries. The quantity of industrial use of water should be counted according to the following formula:

$$TIW = \sum_{i=1}^{n} W_i \cdot IOV_i,$$

where TIW is total industrial demand of water, $W_i (i=1, 2, \cdots, n)$, is different indexes of use of water in different industrial department, IOV_i is output value of i-th industrial department.

The confirmation of indexes of use of water in different industrial departments should fully consider water saving, reforming technique, technical progress and enhancing of the using rate of recycling water. The total quantity of industrial use of water and industrial structure is connected with its scale. The suggestion of adjusting of industrial structure should be put up when the water resources can not satisfy the demand of industrial development, its analytical condition is

$$K_i = \frac{W_i \cdot \sum_{i=1}^{n} IOV_i}{TIW} = \frac{W_i}{\overline{W}}, \quad (i = 1, 2, \cdots, n),$$

where, K_i is evaluating indexes, W_i is indexes of using water of each department per 10000 RMB Yuan, $\overline{W}$ is indexes of average using water per 10000 RMB Yuan. When $K_i > 1$, the product value and rate of department of corresponding department should be decreased.

In the phase of the forming and discharge-up of waste water, the analytical emphases should be placed on the industrial waste water, we should analyze with emphases on the quantity of discharge-up water and total discharging waste water quantity of each department, including quantity of water and pollutants. There exists a converting coefficient between the use of water and the producing of waste water in the water system. The converting coefficient with weights should be identified after statistical analysis of different sorts of the basis of many years of observation. The discharge quantity of waste water and pollutants should be closely connected with the planning of each department and industries. The discrete disposal should usually put the emphases on the poisonous, harmful pollutants, taking notice on the big enterprises of discharging sewage. Meantime, a reasonalite argument and evaluation should be given toward sewage curing plans of each industry.

The analysis of concentric treatment should be aware of disposing method according to different places and effects. A compared analysis should be given toward investment, cost, disposal efficiency under different constraints.

The demand of control of total discharge quantity and reuse water quality should be satisfied. The macro measures in this phase should direct the plans of sub-sectors or the adjustment according to the feedback of plans of subsectors.

On the final phase of discharge, the controlling total quantity should be computed. The model of water quality should be selected according to the features of accepting water body and the situation of discharging places. The goal of control should be identified after computational analysis.

3 The analytical method of macro WES

As can be seen from Fig. 1, each intersection of the area water environment is connected, having the characteristics of hierarchy and intersection. For example, the water resource system determines the ability of water supply and the method and efficiency of water use system determine the demand toward water supply system and the size of discharging waste water quantity, while the efficiency and pattern of the using and discharging system directly influence the quality of WES.

It is obvious that the pattern of use of water resources and the pattern of disposing waste water create different environmental and economical benefits, hence determine the quality of water environment.

As to the feature of regional water environmental system, the water environmental system planning must fully consider the system as a whole, so that development of water environmental system should be well coordinated with that of socio-economic system. Furthermore, we can keep the sustainable development of socio-economic system. Here, a goal programming model of water environmental system planning has been established. The limited quantity of COD pollutant and the investment of water use and treatment of sewage are main objectives of the model. They are expressed with minimizing the deviations between aspiration level and realization level in the model. The following restraints are considered water demand of socio-economic industries, node balance of water environmental network, the limits of water resources, and some technical requirements.

3.1 Water resources and supply restraints

Water resources include surface water, ground water, water resource from upper reaches, sea water and reuse water. And two of existing part and developing part can be considered for each kind of water resources except ground water in the region. Because of the effect of earth subsidence, the development of ground water is limited. The planning requires that the total quantity of water demand does not exceed that of water resources. Where, water resource from upper reaches is a part of surface water, but it is a main part of water resources in the region, surface water is considered in two parts, respectively.

$$\sum_{i=9}^{13} x_i \leqslant x_1 + x_2, \quad \sum_{i=14}^{18} x_i \leqslant x_3, \quad \sum_{i=19}^{23} x_i \leqslant x_4 + x_5,$$
$$x_{24} \leqslant x_6 + x_7, \quad \sum_{i=25}^{27} x_i \leqslant x_8.$$

where x_i denotes water flow variables, the quantities of various water resources are decision variables, that is x_i, $i=1, 2 \cdots 8$, rater than constants.

3.2 Node balance restraints

The study takes the water environmental systems as a whole, so that keep the balance between input water flows and output water flows for each node. It mainly includes, use of water and drainage of sewage, drainage of sewage and treatment, treatment and draining to the river.

$$k_s \sum_{j_1 \in J_1} x_{j1} = \sum_{i_1 \in I_1} x_{i1} \qquad s = 1, 2, 3, 4, 5,$$
$$\sum_{j_2 \in J_2} x_{j2} = x_t \qquad t = 1, 2, 3, 4, 5,$$
$$x_i = \sum_{i_2 \in I_2} x_{i2},$$

where J_1 denotes water flow variables set of input nodes, I_1 denotes sewage flow variables set of output nodes, k_s denotes drainage coefficients, J_2 denotes sewage flow variables set of input nodes, I_2 denotes sewage treatment variables set of output.

3.3 The development restrains of water resources

In Part (1), the quantities of various water resources are decision variables, but they must be limited, according to the conditions, here, the total quantity of them can not exceed the limit.

$$\sum_{js} x_{js} \leq D_s, \qquad s = 1, 2, 3, 4, 5,$$

where, D_s denotes the developing limit for s-th kind of water resources, respectively.

3.4 Water demand restraints

$$\sum_{jt\in Jt} x_{jt} \leqslant D_t, \qquad t = 1, 2, 3, 4, 5$$

where D_t denotes the predicted value of water demand of the t-th industrial department in planning years, the sum of x_{jt} can not exceed the predicted one.

3.5 Technology requirements

Because of the technology requirements of water users and waste water treatment, the rates of sea water, reuse water used in industry and that of reuse water used in agriculture should be limited, that is, the rates can not exceed a_s, respectively. And, because of the requirement of waste water treatment, the sewage from domestic living should reach at least β_t.

$$x_s / \sum_{js} x_{js} \leq \alpha_s, \qquad s = 1, 2$$

$$x_t / \sum_{jt} x_{jt} \geq \beta_t. \qquad t = 1, 2, 3, 4, 5$$

3.6 Restraint of land used in waste water treatment

The total quantity of sewage treated by land treatment is limited by the resource of land, so the restraints for land treatment are given:

$$\sum_{ls} x_{ls} \leqslant L_s \qquad s = 1, 2.$$

3.7 Objective of investment limit

The investment limit can be considered in two parts-water resources and waste water treatment. It is determined by the financial budget.

$$\sum_{i=1}^{8} c_i x_i \leqslant Y_1 \quad , \quad \sum_{j=31}^{63} p_j x_j \leqslant Y_2,$$

where, Y_1, Y_2 denote the investment limits for water resources and treatment of sewage, respectively. c_i denotes the development coefficient, p_j denotes the price coefficient of treatment.

3.8 Quantity limit of COD pollutant drained to rivers or ocean

$$\sum_{is} b_{is} x_{is} \leq \mathrm{COD}_s \qquad \text{(quantity limit of COD pollutant per year)},$$

where the index of water pollutants COD is considered. CODs denotes the total quantity limit objective of COD pollutant under the expected water quality standard, b_{is} denotes the density coefficient of treated sewage.

According to the above restraints and objectives, we can establish the goal programming model of macro water environmental system. For each restraint or objective, the positive deviation d^+ and negative deviation d^- are given. In the achievement function, minimize d^+ for "$\leqslant$" restraint, and minimize d^- for "$\geqslant$" restraint, and minimize $d^+ + d^-$ for "$=$" restraint, then we can get the goal programming model. The achievement function is as follows:

$$min\Big[\sum_{l=1}^{6} P_l\Big(\sum_{j=1}^{m}(w_{lj}^- d_j^- + w_{lj}^+ d_j^+)\Big)\Big],$$

where, P_l denotes the l-th priority, w_{lj}^+, w_{lj}^- denote the weights for each restraint or objective.

Table 1 Programming results

COD (T)	8000	10000	11000	12000	13000	14000	15000	16000	17000
Water from upper reach, 10^4t	17716	19938	21049	22160	23272	24383	25366	25747	26128
Reuse water, 10^4t	11595	9373	8262	7151	6040	4929	3945	3564	3183
Primary treatment, 10^4t	469	469	469	469	469	469	469	469	469
Secondary treatment, 10^4t	10465	10465	10465	10465	10465	10465	10477	10545	10614
Land treatment, 10^4t	6289	6289	6289	6289	6289	6289	6223	5842	5461
Hi-effi. land treat, 10^4t	6667	6667	6667	6667	6667	6667	6667	6667	6667
Investment of treat, 10^4t	5177	4721	4494	4266	4030	3810	3609	3530	3452

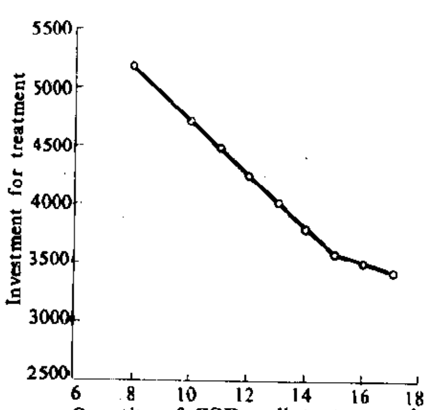

Fig. 2 The curve of COD — investment of treatment

The arrangement of priorities are determined according to the requirements of planning. Table 1 is the programming results when we take the total quantity of COD pollutant as the first priority. And the curve of treatment investment and total quantity of COD pollutant is given in Fig. 2.

From the results, we can find that the investment of treatment of sewage is 51. 77 million RMB Yuan when the limit of COD pollutant is 8000 tons; and the investment deduces to 35. 30 million RMB Yuan when the limit of COD pollutant is 16000 tons. The demand of investment for treatment of sewage is reducing with the lightening of the quantity limit of COD pollutant. The secondary treatment and land treatment and high efficient land treatment are all ideal ways for sewage treatment. From the model analysis, it is feasible to control the quantity of COD pollutant between 8000 tons to 16000 tons, and the method is to adjust the investment of sewage treatment, the main ways for sewage treatment are land treatment, secondary treatment, and changing the primary treatment into secondary treatment by constructing new plant of secondary treatment. And if the quantity of COD pollutant should be strictly controlled, the tertiary treatment for reuse must be done to the output of secondary treatment, and reuse the treated sewage.

4 Conclusion

In this paper, we have established the goal programming model for regional water environmental system, from the view point of system analysis and the balance of water flow network. In the model, the treatment quantity are variables rather than the limit for various ways of treatment, only the investment limit for treatment of sewage is given. Of course the structure of water environmental system can be optimized by calculating process, and then, we can decrease the pollution through optimizing the structure of water environmental system, and make the water environment system optimized and adjusted. From the results, we can find that the method of using goal programming model to analyze regional water environmental system is useful and effective, we can get the different optimized alternatives with corresponding total quantity control of COD pollutant.

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