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Development of multi-stage method for opportunity constraint in water supply and drainage system

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ABSTRACT

This paper introduces a multi-stage planning and chance constrained programming, develops a model of chance constrained multi-stage method, and applies them to the water supply and drainage system. And the chance constrained multi-stage model is constructed. The model takes the pre-judged and determined initial configuration scheme of water resources as the first phase variable, and sets the subsequent phase variable to conduct water resources allocation planning according to the practical situation of supply and demand. In this way, it can make an analysis on the water resources allocation scheme set in advance to make the allocation of water resources under the condition of uncertainty. This model can not only effectively handle the uncertainty problem of random numbers in water resources system but also solve the random problem that probability information is very difficult to obtain, to put forward the policy solution under different situations. Through the opportunity constraint planning, in-depth analysis of the balance between system stability and the risk of environmental default will provide suggestions for the decision-making of the integrated environment, economy and system reliability factors.

Keywords: Water supply and drainage system; Multi-stage; Uncertainty; Random

1. Introduction

In recent years, with the increasing demand for water due to the development of urbanization and industrialization, water shortage has become a key factor restricting economic and social development. In the water supply and drainage system, due to the unbalanced and seasonal variation of precipitation distribution, it is easy to face the risk of water shortage in the water supply department [1]. Therefore, it is highly anticipated for the water supply and drainage system in which various uncertainties and complexities can be effectively determined [2]. This paper develops an opportunity constraint multi-stage approach, introduces the opportunity constraint planning in the framework of multi-stage planning, and effectively processes the uncertainties in the model [3]. Application of the multi-stage method into the water supply and drainage management planning is to reflect and deal with the complexity of stochastic uncertainty and multi-user competition water in the distribution model [4]. Chance constrained multi-stage method can also generate multi-stage water resources allocation scene to form different water distribution options. At the same time, in view of the actual value of available water resources distribution, it can provide a quantitative interaction analysis between system economic returns and the risk of default for policy makers, obtain the characteristics of water resources shortage of different stages, and support the rational allocation of water supply and drainage system [5].

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2. Method construction

2.1. Opportunity constraint multi-stage model

In the water supply and drainage management system, the amount of water is a random variable in the form of probability distribution, and water distribution policy has multi-stage dynamic randomness [6]. Probability can be used to describe these random variables which will be equal to the specific value, or describe the possibility in a given range of a particular value [7]. Multi-stage stochastic programming method can reflect the system uncertainty through a screening process to effectively simulate the dynamic change of system conditions [8]. The main advantages of this method based on scenario analysis are that it has a lot of flexibility when the decision process is simulated and the scenario is defined, and the outputs of multiple sets of results can be made. Especially when the dimension is quite high, this method is more effective. In planning, the uncertainties caused by the random variables often characterized by dynamics, that is, the decision will change with the different level of random probability at different planning stages, and such a problem can be solved by multi-stage planning [9]. In multi-stage stochastic programming approach, uncertainty is generalized as a multi-layers scenario tree. At each stage of the tree, random variables and tree nodes at each stage (tree nodes represent a variety of cases) are one-to-one correspondence [10]. The chance probability constraint model can deal with the uncertainty expressed by the random variable and the probability in the probability constraint condition.

Because of the uncertainty of dynamic changes in the management of water supply and drainage, many different stages of decision and information need to be taken into consideration [11]. At the same time, under the condition of limited resources, meeting the resource requirements of multiple users leads to the existence of default risk [12]. These complexity and uncertainty are expressed as parameters with random probability characteristics [13]. Therefore, we construct chance constrained multi-stage stochastic programming method and introduce probability constraint into multi-stage planning framework. The build model is as follows:

$$\text{Max } f = \left(\sum_{i=1}^{I} \sum_{t=1}^{T} \left(\text{NB}_{it} - \text{EX}_{it} \right) W_{it} - \sum_{i=1}^{I} \sum_{t=1}^{T} \sum_{k=1}^{K_t} p_{tk} C_{it} D_{itk} \right) L \tag{1}$$

Constraints satisfy:

$$S_{1(t+1)k} = S_{1tk} + \tilde{Q}_{tk} - \left[A_{1a} e_{1t} \left(\frac{S_{1t} + S_{1(t+1)}}{2} \right) + A_{10} e_{1t} \right] - R_{1tk}, \quad \forall t; \; k = 1, 2, \ldots, K_t \tag{2}$$

$$S_{2(t+1)k} = S_{2tk} + R_{1tk} - \left[A_{2a} e_{2t} \left(\frac{S_{2t} + S_{2(t+1)}}{2} \right) + A_{20} e_{2t} \right] - R_{2tk}, \quad \forall t; \; k = 1, 2, \ldots, K_t \tag{3}$$

$$\sum_{i=1}^{I} (W_{it} - D_{itk}) \le R_{2tk}, \quad \forall i, \forall t, \; k = 1, 2, \ldots, K_t \tag{4}$$

$$S_{tk} \le \text{RSC}, \quad \forall t; \quad k = 1, 2, \ldots, K_t \tag{5}$$

$$S_{tk} \ge \text{RSV}, \quad \forall t; \; k = 1, 2, \ldots, K_t \tag{6}$$

$$W_{it\max} \ge W_{it} \ge D_{itk}, \quad \forall i, t, k \tag{7}$$

$$D_{itk} \ge 0, \quad \forall i, t, k \tag{8}$$

In the management distribution of water supply and drainage system, the developed model can directly deal with various forms of uncertainty (probability distribution and interval value) [14]. Based on the related management policy of water resources, decision makers first make a pre-judgement on the supply of water in different industries during the planning period according to the industry water demand and the available water resources, and then make initial water allocation plan [15].

Therefore, the pre-judged and determined initial configuration scheme of water resources were selected as the first phase variable, and the subsequent phase variable was set to conduct water resources allocation planning according to the practical situation of supply and demand [16]. It can not only maximize the utilization of water resources and minimize economic loss resulting from water shortage in the case of given initial water resources allocation scheme but also analyze the pre-established water resources allocation scheme [17]. In addition, a series of policy scenarios can be quantified by dealing with different probability levels, and the dynamic characteristics of the system can be described to make water supply and drainage distribution scheme under uncertain conditions (Fig. 1).

The physical meanings and corresponding definitions of the relevant economic parameters in model (1) are as follows:

NB_{it} is the economic gain ($/m^3) of the ith user in the t period when the water demand is met; C_{it} is the economic loss ($/m^3) when the ith user is not satisfied with the water resource requirements within the t period, ($\text{PE}_{it} > \text{NB}_{it}$); EX_{it} is the economic input value ($/m^3) in the process of obtaining water resources in the t period. f is the system benefit value ($). On the other hand, the specific physical meaning and corresponding definition of the related water resource parameters in model (1) are as follows: W_{it} is the water and drainage distribution target (m^3) in the t period; D_{itk} is the water resource shortage (m^3) in the situation k of the period t. W_{it} is the actual water resource allocation for the i user during the t period. $W_{it\max}$ is the largest water resource requirement (m^3) of the ith user during the t period; A_0 is the area coefficient; A_a is the effective amount of water of per unit area. In addition, the physical meanings of other parameters in the models (2)–(8) are defined as follows:

t is the time period, which is defined as $t = 1, 2,\ldots, T$; p_{tk} is the probability of occurrence of scenario k in the t time period and is defined as $p_{tk} > 0$ and $\sum_{k=1}^{K_t} p_{tk} = 1$; e_t is the average evaporation rate in the t time period; i is the different water resource user, $i = 1, 2,\ldots, I$; K_t is the number of scenarios in the t time period; Q_{tk} is the random value (m^3) of the amount of water (runoff) in the scenario k in the t time period; R_{tk} is the amount of runoff (m^3) from the situation k in the t time

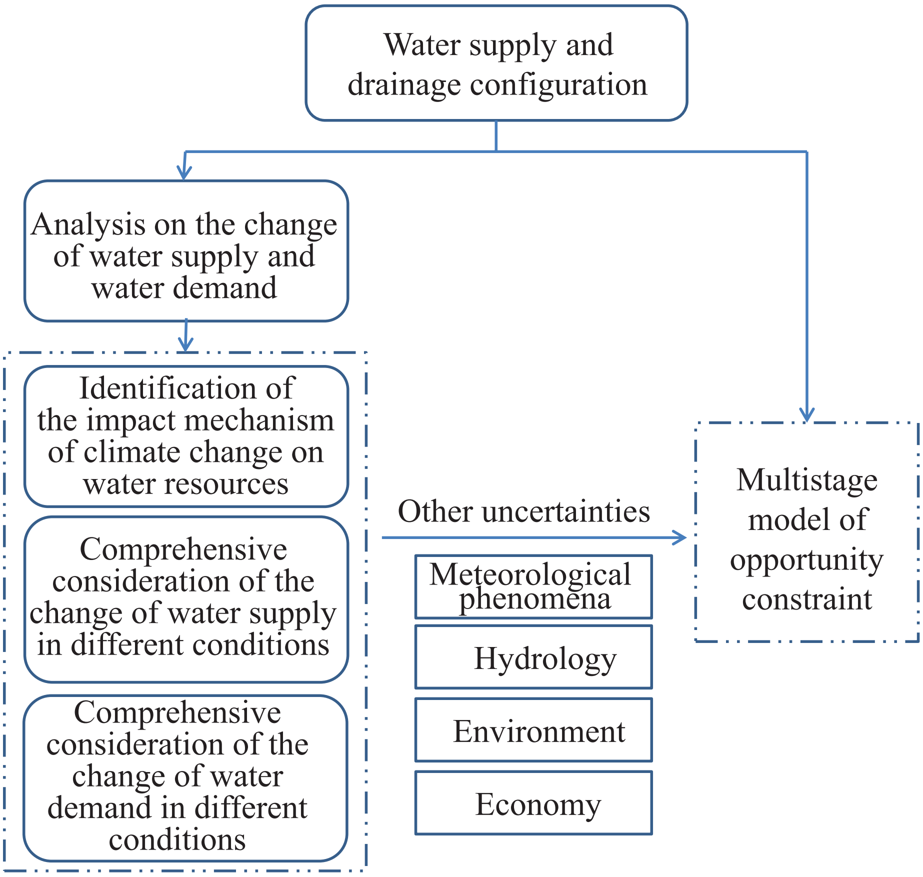

Fig. 1. Multi-stage model for establishing opportunity constraint for water supply and drainage system.

period; RSC is the capacity (m^3) of the river to store water resources; RSV is the lowest amount of water resources (m^3) in the river; S_{tk} is the value (m^3) of amount of water storage in scenario k in the t time period.

3. Results and discussion

The solutions of water shortage under the given targets are combinations of interval and probability information [18]. This reflects the variations of system conditions caused by uncertain inputs of economic data, storage capacities, reserve water requirements, and stream flow.

In general, under advantageous conditions (e.g., stream flow and storage capacities approach their upper bounds), the shortage levels may be low; however, under demanding conditions, the shortages may be raised. Moreover, the lower bound of water shortage (i.e., D_{itk}) corresponds to a higher system benefit, and vice versa [19,20].

At each level of joint probability, there were two sets of individual probabilities (i.e., scenarios A and B). In scenario A, increasing levels of individual probabilities were kept (e.g., 0.002, 0.003 and 0.005 in scenario 1A, which represented that violation levels for the chance constraints were increasing; In scenario B, individual probabilities were kept all the same as one-third of the joint probability (e.g., 0.0033, 0.0033 and 0.0033 in scenario 1B). It is indicated that the solutions for the objective function value and most of the non-zero decision variables are interval numbers. For example, in period 3, the result of $y_{31opt} = 1$ indicated that the optimized allocation target for the municipal sector would be $W_{31opt} = 231.4 \times 10^6$ m^3 (approaching its upper bound); in comparison, the results of $y_{32opt} = y_{33opt} = 0$ show that the optimized target for the industrial user and agricultural sector would reach its lower bound. The optimal targets for municipal sector would be 231.4×10^6 while the optimal targets for industrial and agricultural sectors would be 132.7×10^6 m^3 and 112.6×10^6 m^3.

4. Conclusion

Water resources optimization is an effective way of solving the shortage of water resources, improving the efficiency of water resources utilization, and promoting the coordinated development of society, economy and environment. For water resources system with multiple water sources and multiple water supply systems, we generally take the lowest system cost or maximum comprehensive benefit as the objective function to obtain the most reasonable water supply, combining with the constraint conditions. However, there is uncertainty in the relationship between supply and demand.

By introducing a multi-stage planning and chance constrained programming, this paper develops a model of chance constrained multi-stage method, and applies it into the water supply and drainage system. It provides scientific basis and technical support for the basin comprehensive decision. This model can not only effectively handle the uncertainty problem of random numbers in water resources system but also solve the random problem that probability information is very difficult to obtain, to put forward the policy solution under different situations. Through the test of water resource allocation scheme and complex tradeoffs relationship between the water shortage and default risk, this paper presents a series of policy options in different scenarios. At the same time, through the opportunity constraint planning, in-depth analysis of the balance between system stability and the risk of environmental default will provide suggestions for the decision making of the integrated environment, economy and system reliability factors.

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References

[1] O. Barron, R. Silberstein, R. Ali, R. Donohue, D.J. McFarlane, P. Davies, G. Hodgson, N. Smart, M. Donn, Climate change effects on water-dependent ecosystems in south-western Australia, J. Hydrol., 434 (2012) 95–109.
[2] W. Thissen, J. Kwakkel, M. Mens, J. Van der Sluijs, S. Stemberger, A. Wardekker, D. Wildschut, Dealing with uncertainties in fresh water supply: experiences in the Netherlands, Water Res. Manage., 31 (2017) 703–725.
[3] M. Qing, From the semantic explanation of material implication to the theoretical construction of the impossible world, J. Appl. Sci. Eng. Innov., 5 (2018) 13–17.
[4] M. Marquès, R.F. Bangash, V. Kumar, R. Sharp, M. Schuhmacher, The impact of climate change on water provision under a low flow regime: a case study of the ecosystems services in the Francoli river basin, J. Hazard. Mater., 263 (2013) 224–232.
[5] Z. Islam, T.Y. Gan, Effects of climate change on the surface-water management of the South Saskatchewan River Basin, J. Water Res. Plann. Manage., 140 (2014) 332–342.
[6] K. Jenkins, Indirect economic losses of drought under future projections of climate change: a case study for Spain, Nat. Hazards, 69 (2013) 1967–1986.
[7] Z.D. Zhang, Research on the strategy of existing residential quality improvement under the background of the supply-side reform, J. Appl. Sci. Eng. Innov., 4 (2017) 12–15.
[8] R. Wang, C. Yang, K. Fang, Removing the residual cellulase by graphene oxide to recycle the bio-polishing effluent for dyeing cotton fabrics, J. Environ. Manage., 207 (2018) 423–431.
[9] A. Sankarasubramanian, R.M. Vogel, J.F. Limbrunner, Climate elasticity of streamflow in the United States, Water Resour. Res., 37 (2001) 1771–1781.
[10] Z.R. Dong, J. Zhang, J.Y. Zhao, A review on the progress of environmental flow theory, J. Hydr. Eng., 48 (2017) 670–677.
[11] A.K. Sharma, D. Pezzaniti, B. Myers, Water sensitive urban design: an investigation of current systems, implementation drivers, community perceptions and potential to supplement urban water services, Water, 8 (2016) 272.
[12] D.R. Cayan, S.A. Kammerdiener, M.D. Dettinger, J.M. Caprio, D.H. Peterson, Changes in the onset of spring in the Western United States, Bull. Am. Meteorol. Soc., 82 (2001) 399–415.
[13] C.E. McMichael, A.S. Hope, H.A. Loaiciga, Distributed hydrological modeling in California semi-arid shrublands: MIKE SHE model calibration and uncertainty estimation, J. Hydrol., 317 (2006) 307–324.
[14] F. Hossain, Paradox of peak flows in a changing climate, J. Hydrol. Eng., 19 (2014) 0251–4001.
[15] F. Chebana, T.B.M.J. Ouarda, T.C. Duong, Testing for multivariate trends in hydrologic frequency analysis, J. Hydrol., 486 (2013) 519–530.
[16] S. Zhang, Y. Liu, M. Li, B. Liang, Distributed hydrological models for addressing effects of spatial variability of roughness on overland flow, Water Sci. Eng., 9 (2016) 249–255.
[17] M. Arabi, R.S. Govindaraju, M.M. Hantush, A probabilistic approach for analysis of uncertainty in the evaluation of watershed management practices, J. Hydrol., 333 (2007) 459–471.
[18] J. Seibert, K.J. Beven, Gauging the ungauged basin: how many discharge measurements are needed, Hydrol. Earth Syst. Sci., 13 (2009) 883–892.
[19] P. Zhang, Y. Wang, Effects of heat treatment on the nanoscale precipitation behavior of 7055 aluminum alloy under dynamic shock, Vacuum, 152 (2018) 150–155.
[20] P. Zhang, Y. Wang, Effects of shear strain and annealing on the nano-precipitate phase and crystal orientation of 7055 aluminum alloy during cutting process, Vacuum, 151 (2018) 247–253.