MATEC Web of Conferences 246, 01023 (2018) https://doi.org/10.1051/matecconf/201824601023
ISWSO 2018

Review and prospect about water resources operation research

Yu Wang[1,2], Bojun Liu[1,2,a], Shaoming Peng[2], Siyu Cai[3] and Dawei Zhang[3]

[1]Yellow River Engineering Consulting Co., Ltd Postdoctoral Programme, Zhengzhou 450003, Henan, China
[2]Yellow River Engineering Consulting Co., Ltd, Zhengzhou 450003, Henan, China
[3]China Institute of Water Resources and Hydropower Research, Beijing 100038, China

Abstract. The concept of water resources operation is expatiated and classified and the theories and methods with regard to water resources operation are also summarized. Research progress of water resources operation exists to analyse the problems and to take a look to the future of research directions in the field of water resources operation. In conclusion, the research on water resources operation needs a combination with the actual state of projects, climate change and increasing human activities, actually considering water resources demands and employing uniform control of water quantity and quality, which could ensure the sustainable utilization of water resources in China.

1 Introduction

As the basic resource, water resources are also a strategic resource for nations, which has become one of the main factors restricting the social and economic development in China [1-2]. It is well known that China is a country with water resources shortage, at the meantime, population growth and economic development is gradually deepening the contradiction between water supply and demand. In addition, a higher challenge has been arisen due to the uneven distribution of water resources and the frequent flood disasters [3-4]. How to alleviate the contradiction between incoming water and water consumption through keeping the coupling relationship among balance among water resource, society, economy and ecology deserves further research [5-6]. Water resources operation plays an important role in the sustainable of social economy, that is, the realization of uniform, cross-regional, multi-objective, intelligent operation for water resources based on the accurate inflow forecasting and scientific operation for water conservancy projects is an effective way to ensure flood control, water supply, water diversion and ecological security of basin or region.

2 Concept and characteristics of water resources operation

Water resources operation is composed of planning, allocation, pre-arranged operation response, that is, based on water resources planning and inflow forecasting, the water-supply strategy of water conservancy projects for users is developed and then, rationally and scientifically allocation according to river and lake water volume and water demands will be carried out[7-8]. Currently, there is not clear and unified concept of water resources operation. Generally understanding, on the premise of the safety of water conservancy projects operation, water resources operation is a control and application technology to make the water-supply strategy for meeting water demands as much as possible under the operation plans of water conservancy projects[9-11]. In addition, water resources operation is also be understood as a water volume allocation process by reservoir operation according the operation rules, in which, the operation rules are planned based on the operation demands and relevant information[12-13]. Thus, water resources operation can be divided into the conventional operation and emergency operation[14-16], that is, individually or simultaneously achieving the goals like flood control, irrigation, water supply, sand drainage, electricity generation and ecological protection based on the annual, monthly, period, week, day operation or real-time operation by water conservancy projects to guarantee the rational development and utilization for the limited water resources[17-18]. The conventional water resources operation is to complete the annual water allocation, projects operation and section release planning by the steps of water resources monitoring, water resources evaluation and distributed water in available forecasting. However, if exists drought, water pollution or flood, the emergency operation is needed to obtain the water intakes operation, reservoir or generating station, section release plans[19-20]. Water resources operation process is shown in Fig. 1.

[a]Corresponding author: Bojun Liu, bojun_l689@126.com

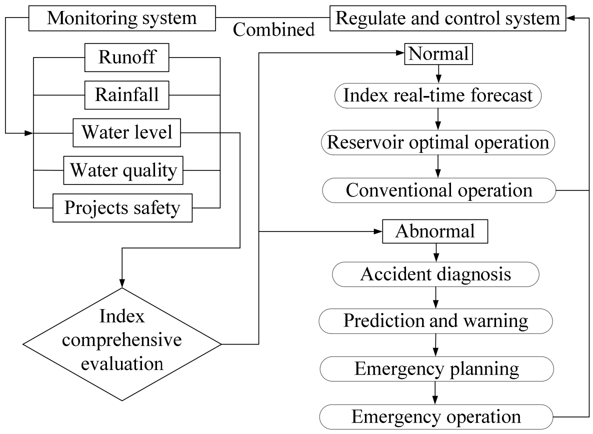

Figure 1. Procedure of water resources operation

2.1 Characteristics of water resources operation

The uneven distribution of water resources in China and the increasing of waste water discharge both make the problems of resource-type water shortage, project-type water shortage, water quality-type water shortage more and more prominent. Thus, water resources operation in the wet area and in the drying area respectively included in the water resources operation of rivers and lakes (reservoirs).

(1) Water resources operation in the wet area

The watercourse runoff of this area in dry season is less causing the water quality worse, so water resources operation in dry season deserves more attention. It is effective to guarantee the water-supply safety and the water quality up to the standard of rivers and lakes by operating reservoir release. While, the watercourse runoff of this area in flood season is larger making the water quality better, so the benefits among flood control, water supply, electricity generation and ecology can be maximized through the dynamic control of flood limitation water level of backbone reservoirs based on the two operation principles of “Joint Control of Water Quality and Volume” and “Impounding in wet season and supplying for dry season”. Meanwhile, it is important in the annual operation that the deviation of operation plans should be analysed in real-time and then adjusting timely the operation plans so as to the dynamic management for water resources operation[21-22].

(2) Water resources operation in the drying area

Water resources in this area is small throughout the year, in order to ensure the efficient utilization, not only should water rights distribution and transfer be completed, but also the real-time and unified operation for water resources is proceeding based on the rolling process of forecasting, decision made, implementation, new forecasting, new decision made and plan revision. Four parts can be summarized in the real-time and unified operation for water resources: Macroeconomic regulation and control, Long and short nesting, Real-time decision making, Rolling revision. In which, macroeconomic regulation and control means that according to the long-term operation plan, ensuring the rationality of annual, monthly and ten-day water resources operation, respectively. Long and short nesting is defined as the long-time operation plan can be made from long-term meteorological and inflow forecasting information, in the following, based on the long-time plan has been made, the short-time operation is planning in accordance with real-time forecasting information, that is, the short-time operation is nested by the long-time operation plan. Real-time decision making means that forecasting rainfall and runoff, meteorological and soil moisture information at each period, and then, to make the current operation decision combined with the current water resources situation. Rolling revision is to rectify operation deviations according to the real-time information and historical operation decision until one operation period ends[23-25].

3 Theory and methods of water resources operation

On the international, the theory of water resources operation started from the reservoir optimal operation method proposed by Masse in the 1940s [26], and in the mid-1950s, a number of scholars carried out the extensive researches on reservoir optimal operation[27-28]. While, the researches on water resources operation in China stared from 1960s, the optimal allocation of water resources based on reservoir operation was studied, and a large number of flood control operation researches emerged in the 1980s. In general, domestic and foreign researches on water resource operation mainly focus on operation modelling and its solution, water resources operation under uncertainty[29].

3.1 Operation modelling and technique solution

There are about 11 kinds of models involved in water resources operation, such as runoff simulation and forecast model, hydrological forecast model, reservoir operating model, hydrodynamic and water-quality model, water balance model, the Muskingum model, Multi-source precipitation fusion model, numerical weather prediction model, groundwater model etc. Thus, a whole set of water resources operation model system is made up by the above-mentioned models which can provide a strong support for water resources operation (seen in Fig. 2).

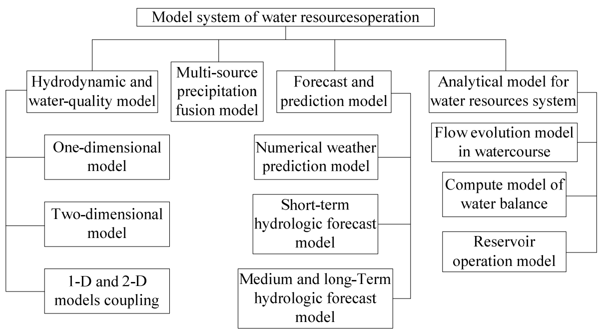

Figure 2. Model system of water resources operation

Water resources operation model should be used cooperating with solution methods. The conventional solution methods are the Chronological Series Method and the Statistical Method, that is, small and medium-sized reservoirs are operating by runoff regulation and

 https://doi.org/10.1051/matecconf/201824601023

water energy calculation based on reservoir operation chart and operating rules[30]. In China, Tan studied the optimization method for reservoir operation chart and the graphic method for reservoir flood control was improved by Jiang, which all promoted the domestic development of reservoir operation calculation[31-33]. Furthermore, in order to optimize water resources operating plans, a large number of optimization algorithm have been proposed, such as the Linear Programming Method, the Dynamic Programming Method, the Nonlinear Programming Method, the Decomposition and Coordination of Large System Method, the Heuristic Intelligent Algorithm.

(1) Linear Programming Algorithm (LPA)

The (LPA) proposed by Fourier in 1939 can solve hundreds of model variables, and some nonlinear programming problem can be simplified as a linear programming problem to solve. The LPA is often used in the calculation of reservoir operation model, that is, listing decision variables, constraint condition and objective functions, and after the determining of the feasible region described by constraint condition, the optimal results and values of objective functions can be obtained in the feasible region. In 1967, Hall proposed the coupling model of the LPA and the Dynamic Programming to study the optimal operation of reservoirs[34]. Windsor first used the LPA to calculate the joint operation of reservoir group for flood control[35]. In China, the linear programming model built by Wang etc. was successfully applied in the reservoir operation optimization for flood control[36]. And the LPA was employed to calculate the joint operation of multi-reservoir in parallel by Xu and Du[37-38]. Also, Yu built a linear programming model based on the mutual feed-back relation between the weight of reservoir flood control and the net rainfall to compute the flood control operation of the reservoir group in the Xiao Qinghe Basin[39]. However, it can be seen that the LPA needs the linear processing for the problems of objective functions and constraint condition with the nonlinear characteristics, which limits the application scope of the LPA.

(2) The Dynamic Programming Algorithm (DPA)

The DPA can transform the complex high-dimensional original problem into a series of simple low-dimensional sub problems by sectional dimension reduction, and solving each sub-problem thus computing the original problem. In 1955, J.D.C.Little is the first researcher using the DPA to calculate reservoir optimal operation[40]. Following the Dynamic Programming and Markov Process Theory was proposed by R.A.Howard in 1962[41]. In addition, many researchers all used the DPA for the dimension reduction to study reservoir operation[42-44]. In China, the most representative research is from Li and Mei, who built the dynamic programming model of joint operation of reservoir group for flood control based on the two conditions: lower reaches exceed the flood control standard and flood peak clipping is minimum, respectively[45-46]. But, it will encounter the dimension disaster in real problem solution processes. Especially, the rapid development of computer technology has alleviated the dimension disaster problem with the improved DPA, such as the Incremental Dynamic Programming Method, the Progressive Optimization Algorithm, the Discretely Differential Dynamic Programming Method and the Successive Approximation Algorithm for Dynamic Programming, etc.

(3) The Nonlinear Program Algorithm (NPA)

In the actual issues, multiple objectives, nonlinear constraints and other problems need to use the NPA to transform the problems into linearization, and then through the introduction of penalty terms, the constraint is added into the objective function to form an unconstrained problem, which can be calculated by the Lagrangian Multiplier, the Penalty Function, the Obstacle Function, the Feasible Direction and the Approximate Algorithm, respectively. Especially, Chinese researcher proposed an Adversity - successive Linear Method to solve the nonlinear problem of joint operation for reservoir group. However, the disadvantage of the NPA is that needs to analyse complex objective functions and constraints thereby causing low solution efficiency[47].

(4) The Decomposition-coordination Method of Large Scale Systems (DCMLSS)

As a large interconnected system, reservoir group has complex structure and large scale, also, the addition of an objective function would result in the exponential increasing of the system dimension, but the DCMLSS can solve this problem smartly[48]. The basic though of the DCMLSS is to decompose the large system into several independent and interrelated subsystems that is as the first level called the lower system. Each subsystem needs to be solved separately. Then, setting a co-ordinating body called the superior system as the second level for handling the correlations among subsystems. On the basis of obtained extremum results of each subsystem, the optimal solution of the whole system can be computed through repeated information exchange between superiors and subordinated. The DCMLSS is commonly used in the joint operation of reservoir group with multiple objectives and water resources optimization allocation in large-scale basin[49]. The DCMLSS was employed to optimize reservoir operation in the India River Basin and the Grande Basin by Chaudnr and Jamshidi, respectively. Especially, Huang from China studied a targeted DCMLSS considering the difference of real-time flood control operation between series and parallel reservoirs, which can make the dimension disaster in the real-time operation of hybrid reservoir group effectively overcome[50-51].

(5) The Heuristic Intelligence Algorithm (HIA)

Also, the system engineering theory has intensified combination with the rapid development of computer technology, thus the HIA has been unprecedented development. Various HIAs, such as the Genetic Algorithm, the Fuzzy Method, the Game Theory, the Storage Theory, the Queuing Theory, the Neural Network Algorithm, the Grey Theory Algorithm, the Ant Colony Algorithm, the Annealing Algorithm, the Particle Swarm Algorithm, the Bee Colony Algorithm, the combined technique of the Bee Colony Algorithm and the Back-Propagation Neural Network, etc. all greatly enriches the studies of joint operation for reservoir group[52-57].

3.2 Water resources operation technique under uncertainty

Uneven distribution of water resources, climate change, water demands and urbanization all have uncertainty that makes risks of water resources operation rising. Thus, how to operate water resources considering the effect of uncertainty is a hot and challenging research. In order to reduce the losses induced by the uncertainty in water resources operation, a lot of studies and works have been done by the foreign and Chinese researchers. The Two-stage Stochastic Programming Method (TSPM) was employed to control the uncertainty factors with the rule of probability distribution by Bosch and Huang. The TSPM firstly supplies the one-stage variables and initial decision, after the beginning of water resources operation event, the two-stage variables and optimal strategy can be obtained through operation object function, in which the economic punishment of water resources operation risk is considered to minimize the losses of water resources operation induced by uncertainty[58-59]. However, The TSPM has its disadvantage that the probability distribution of uncertainty is closely related to the amount of information, and in fact, the amount of information is always slightly deficient that leads the probability distribution of uncertainty difficult to compute. Similarly, the developed TSPM based on the interval mathematics is rarely used because the confused artificial determination of the upper and lower bounds of the interval.

The real revolution came in 2009 that the Interaction Fuzzy Method was coupled with the TSPM based on the interval mathematics and thus a Two-stage Interactive Stochastic Fuzzy Programming Method was proposed. This new method can eliminate the double risks from fuzzy bounds of the interval and artificial subjective consciousness, and effectively describe the uncertainty in an event[60]. In addition, the uncertainty in water-supply operation system was described by the probability distribution and its mathematical interval, and then a joint water supply operation model based on the multiple water sources was built[61]. Also, Liu etc. studied the uncertainty among water supply, water demand, water delivery and economic benefits under water resources operation so as to build a Two-stage Stochastic Fuzzy Water Resources Operation and Programming Model for the computation of the water resources operation plans under multiple rainfall patterns in the Shanxi province[62].

4 Problems of uniform water resources operation in China

China begun the research on water resources allocation based on reservoir operation in the 1960s, and the later studies mainly focused on the power generation or water supply operation for one basin. The comprehensive operation system for flood control and drought relief, ecological prevention, water supply has been put into practice in The Yellow River, the Yangtze River, the Black River, the Pearl River and the other main rivers. However, it has failed to achieve the goal of the uniform water resources operation in the national scale and the multiple basins. Therefore, the problems of uniform water resources operation in China have been summarized as follows.

(1) Rivers water resources allocation planning. In addition to the main rivers, the water resources allocation plans of the most rivers in China have not been completed which makes the development of uniform water resources operation delayed.

(2) Monitoring system building of rivers water resources. The current measure installations of water intaking and utilization in China are deficient. The layout of some parts of the monitoring station network in the river tributaries is unreasonable and also the monitoring devices are backward, which makes it difficult to support the uniform water resources operation.

(3) The coordination between basin operation and regional operation. Basin operation involves the interests of different provinces and regions. Due to the lack of the consensual water resources allocation plans and the necessary monitoring data, the coordination is difficult.

(4) The coordination among water utilization departments. The interests of different water utilization industries, departments and units are involved in water resources operation, thus the coordination needs long time and also is difficult.

(5) Multiple water sources operation. The combined operation system of multiple water sources is large and complex, especially for the reasonable collocation of new and old projects has not yet the scientific and final conclusion.

(6) Incomplete law and compensation system. The incomplete law and compensation system of water resources operation would cause the interdepartmental responsibility unclear, the interests and contradictions prominent, and the coordination difficult. Thus, irregular operation happens all the time driven by the interests from the departments. Also, the incomplete law and compensation system would make the relationship between water diversion area and beneficial area disharmonious.

(7) Insufficient theory of uniform water resources operation. The universal water resources operation model is needed to build to develop the command system of uniform water resources operation at the national level.

5 Research prospect

Although the foreign and domestic researches have good development in electricity generation operation or flood control operation of reservoir group, water resources operation modelling, operation optimization algorithm, but these researches have not much practical application, and meanwhile, climate change, increased human activities and basin ecological deterioration all have changed the situation of water resources operation. It is necessary to form a scientific and mature uniform operation theory and method of water resources, which can provide a broader developing prospect for water resources operation. Thus, the studies on water resources operation can be focused on the following fields.

I. Study on inter-basin water diversion operation. That is, according to operating objects' order and operating rules of reservoirs (lakes) group in water supply area and water intake area, and making reservoirs (lakes) playing a full role in water resources regulation and storage, to improve the comprehensive benefits of water resources utilization and meet the demands of all departments. How to determine the starting standard, stopping condition and the corresponding water volume for water diversion or water supply, respectively, is the hot issue that needs to be focused.

II. Study on ecological operation of reservoirs group. Ecological priority has become the general plan for water resources operation. How to guarantee the ecological runoff or water volume of rivers and lakes by reservoir operation is the important basic work of water resources development and utilization, conservation, protection, allocation and operation. Based on the national conditions and water resources state, runoff conditions of rivers and lakes in different areas, ecological protection requirement, it is necessary to study joint operation rules of reservoirs group, which can provide the supports for strengthening basin water volume operation, ecological restoration and comprehensive management of a large-scale basin.

III. Study on joint operation between new and old reservoirs. With the new reservoirs coming into service, the capacity of water resources operation gets enhanced and thus the existing operation rules of reservoirs group may be no longer suitable for use. How to make full use of hydrological and storage capacity compensation function of new reservoirs and to ensure the existing operating capacities of old reservoirs simultaneously deserve further study. In addition, the researches on the joint operation between new and old reservoirs can be concentrated in the benefits distribution of joint operation, risk analysis of joint operation and joint operation with multiple objects considering new reservoirs.

IV. Study on water resources operation based on ecological compensation and hydro-meteorological forecast. Deterministic forecasting values and its error distribution are employed to describe the future runoffs, and also ecological factors are included into the current reservoir operation and regional water resources allocation plans for multi-objective comprehensive operation, so as to make the nearly practical storage and release plans, eventually realizing the goal of rivers flood control and ecological restoration and improving the comprehensive benefits of water resources utilization. In the main key issues, the analysis of reservoir rainfall-runoff forecast system and flood forecasting plans evaluation system, the available condition analysis of short-term rainfall forecast information in real-time forecast operation, the practical risk analysis of forecast operation, the criterion selection of forecast operation mode, the computation of ecological flow in river course, the determination of the total social and economic water consumption in basin, the selection of ecological-operation hierarchical goals and key control nodes, and the macro system decomposition and coordination of basin ecological operation are respectively included.

Acknowledge

The paper is jointly supported by the National Key R&D Program of China (2017YFC0404406), the National Natural Science Foundation of China (Gran No. 51509263), and the Yellow River Engineering Consulting Co., Ltd Postdoctoral Programme (YREC-2018-PD03).

References

1. Wang, Lizhong, and L. Fangb. "Basin-wide cooperative water resources allocation." *European Journal of Operational Research* **190**.3(2008):798-817.
2. Li, Y. P., et al. "A multistage fuzzy-stochastic programming model for supporting sustainable water-resources allocation and management." *Environmental Modelling & Software* **24**.7(2009):786-797.
3. Wang H, Wang J H, Qing D Y. Research advances and direction on the theory and practice of reasonable water resources allocation[J]. Advances in Water Science, 2004, 15(1):123-128.
4. Wang L Z, Fang L, Hipel K W. Water resources allocation: A cooperative game theoretic approach[J]. Journal of Environmental Informatics, 2003, 2(2):11-22.
5. Z. F. Yang, T. Sun, B. S. Cui, et al. Environmental flow requirements for integrated water resources allocation in the Yellow River Basin, China. Commun Nonlinear Sci Numer Simul, 14(5): 2469-2481[J]. Communications in Nonlinear Science and Numerical Simulation, 2009, 14(5):2469-2481.
6. Han Y, Huang Y F, Wang G Q, et al. A Multi-objective Linear Programming Model with Interval Parameters for Water Resources Allocation in Dalian City[J]. Water Resources Management, 2011, 25(2):449-463.
7. Windsor, James S. "Optimization model for the operation of flood control systems." *Water Resources Research* 9.5(1973):1219-1226.
8. Gregory J. Carbone, and Kirstin Dow. "WATER RESOURCE MANAGEMENT AND DROUGHT FORECASTS IN SOUTH CAROLINA." *JAWRA Journal of the American Water Resources Association*41.1(2010):145-155.
9. Pahlwostl, Claudia, et al. "Social Learning and Water Resources Management." *Ecology & Society* 12.2(2007):1-19.

10. Middelkoop, H., et al. "Impact of Climate Change on Hydrological Regimes and Water Resources Management in the Rhine Basin." *Climatic Change* 49.1-2(2001):105-128.
11. Y.P. Li, G.H. Huang, and S.L. Nie. "An interval-parameter multi-stage stochastic programming model for water resources management under uncertainty." *Advances in Water Resources* 29.5(2006):776-789.
12. Jain S K, Singh V P. Reservoir Operation[J]. Developments in Water Science, 2003, 51:615-679.
13. Neelakantan T R, Pundarikanthan N V. Neural Network-Based Simulation-Optimization Model for Reservoir Operation[J]. Journal of Water Resources Planning & Management, 2000, 126(2):57-64.
14. Shrestha B P, Duckstein L, Stakhiv E Z. Fuzzy Rule-Based Modeling of Reservoir Operation[J]. Journal of Water Resources Planning & Management, 1996, 122(4):262-269.
15. Jager H I, Smith B T. Sustainable reservoir operation: can we generate hydropower and preserve ecosystem values?[J]. River Research & Applications, 2008, 24(3):340-352.
16. Chang L, Chang F J. Intelligent control for modeling of real time reservoir operation. Hydrol Process[J]. Hydrological Processes, 2001, 15(9):1621-1634.
17. Zhao T, Cai X, Yang D. Effect of streamflow forecast uncertainty on real-time reservoir operation[J]. Advances in Water Resources, 2011, 34(4):495-504.
18. Smith B T, Jager Y, March P. Sustainable reservoir operation[J]. 2007.
19. Biswas A K. Integrated Water Resources Management: A Reassessment[J]. Water International, 2004, 29(2):248-256.
20. Seckler D, Seckler D. The new era of water resources management: from "dry" to "wet" water[J]. General Information, 1996, 1.
21. Petts G E. WATER ALLOCATION TO PROTECT RIVER ECOSYSTEMS[J]. Regulated Rivers Research & Management, 1996, 12(4-5):353-365.
22. Reca J, Roldán J, Alcaide M, et al. Optimisation model for water allocation in deficit irrigation systems : I. Description of the model[J]. Agricultural Water Management, 2001, 48(2):103-116.
23. ZHAO Yong; PEI Yuansheng; YU Fuliang. Real-time dispatch system for Heihe River basin water resources[J]. Journal of Hydraulic Engineering, 2006, 37 : 82-88,96.
24. Green G P, Hamilton J R, Gopalakrishnan C, et al. Water allocation, transfers and conservation: links between policy and hydrology[J]. International Journal of Water Resources Development, 2000, volume 16(16):197-208.
25. Yong Z, Pei Y S, Fu-Liang Y U. Real-time dispatch system for Heihe River basin water resources[J]. Journal of Hydraulic Engineering, 2006, 37(1):82-74.
26. LETTLE J D C. The use of storage water in a hydroelectric system[J]. Operational Research, 1955(3): 187-197.
27. UNDER O I, MAYS L W. Model for real-time optimal flood control operation of a reservoir system[J]. Water Resource Management, 1990(4): 24-45.
28. BECKOR G L. Multi-objective analysis of muti-reservoir operations[J]. Water Resources Research, 1982, 18(5): 1326-1336.
29. MOHAN S, RAIPURE D M. Multi-objective analysis of multi-reservoir system[J]. Water Resources Plan Management, 1992, 9(5): 356-370.
30. Cheng C T, Wang W C, Xu D M, et al. Optimizing Hydropower Reservoir Operation Using Hybrid Genetic Algorithm and Chaos[J]. Water Resources Management, 2008, 22(7):895-909.
31. Castelletti A, Galelli S, Restelli M, et al. Tree - based reinforcement learning for optimal water reservoir operation[J]. Water Resources Research, 2010, 46(9):4921-4921.
32. Reddy M J, Nagesh Kumar D. Multi - objective particle swarm optimization for generating optimal trade - offs in reservoir operation[J]. Hydrological Processes, 2010, 21(21):2897-2909.
33. Simonovi S P, Venemaa H D, Burna D H. Risk-based parameter selection for short-term reservoir operation[J]. Journal of Hydrology, 1992, 131(1-4):269-291.
34. HALL W A, SHEPHARD R W. Optimum operation for planning of a complex water resources system[C]//Technology rep: Water resources cent school of engineering and applied science. San Francisco: University of California, 1967.
35. JS Windsor. Optimization model for reservoir flood control[J]. Water Resources Research, 1973, 9(5): 1103-1114.
36. Wang Juegen. A brief introduction of the optimal flood control operation model for the Danjiangkou Rservoir[J]. Water Resources and Hydropower Engineering. 1985(8): 54-58.
37. Xu Zida. The introduction of a convenient method for optimal reservoir operation of flood control[J]. Yellow River. 1990(1) : 26-30.
38. Du Jinkang, Li Han, Wang Lachun, Yan Suning. A Linear Prigramming for Optimal Operation for Multireservoir Flood Control System[J]. Journal of Nanjing University (Natrual Sciences Edition). 1995, 32(2) : 301-309.
39. Yu Cuisong. Reserch on Flood Operation in Basins[D]. Jinan : The Shandong University of Technology, 2000.
40. LITTLE J D C. The use of storage water in a hydroelectric system[J]. Operational Research, 1955 (3): 187-197.

41. Howard R A. Dynamic Programming and Markov Process[J]. Mathematical Gazette, 1960, 3(358):120.
42. TURGEON A. Optimal short-term hydro scheduling from the principle of progressive optimality[J]. Water Resources Research, 1981, 17(3): 481-486.
43. Fu X, Li A Q, Wang H. Allocation of Flood Control Capacity for a Multireservoir System Located at the Yangtze River Basin[J]. Water Resources Management, 2014, 28(13):4823-4834.
44. Kumar D N, Baliarsingh F, Raju K S. Optimal reservoir operation for flood control using folded dynamic programming.[J]. Water Resources Management, 2010, 24(6):1045-1064.
45. Li Wenji, Xu Zida. Study on the optimal flood operation model considering Sanmenxia, Luhun and Guxian reservoirs for the lower reaches of the Yellow River[J]. Yellow River, 1990(4) : 21-25.
46. Mei Y, Feng S. Application of Network Flow Programming to Long-Term Optimal Operation of Multireservoir Systems[J]. Journal of Wuhan University of Hydraulic & Electric Engineering, 1989(5) :1231-1243.
47. Xia Q, Xiang N D, Wang S Y, et al. A new algorithm for nonlinear minimum cost network flow and its application.[J]. Journal of Tsinghua University, 1987(4):1-10.
48. Jia B, Zhong P, Wan X, et al. Decomposition–coordination model of reservoir group and flood storage basin for real-time flood control operation[J]. Hydrology Research, 2015, 46(1):11.
49. Wang D Z, Dong Z C, Ding S X. Research on aggregation-decomposition-coordination model of feeding reservoir group[J]. Journal of Hohai University, 2006, 34(6):622-626.
50. Li Ailing. A Study on the Large-scale System Decomposition—Coordination Method Used in Optimal Operation of a Hydroelectric System[J]. International Journal Hydroelectric Energy, 2004, 29(2):228-231.
51. LI Gui-xiang, WANG Ting, WEN Jin-hua. The Study on Decomposition and Coordination Model of Large-scale System in Optimal Allocation of Water Resources[J]. Computer Knowledge & Technology, 2010.
52. Huang W, Yuan L, Lee C. Linking genetic algorithms with stochastic dynamic programming to the long-term operation of a multireservoir system. Water Resour Res 38(12):1304[J]. Water Resources Research, 2002, 38(12):40-1-40-9.
53. Xue X J, Gao F, Wang H. Analysis on the Extension of Reservoir Compensation Benefits Based on Game Theory[J]. Arid Zone Research, 2010, 27(5):669-674.
54. Ahmadi M A, Ebadi M, Shokrollahi A, et al. Evolving artificial neural network and imperialist competitive algorithm for prediction oil flow rate of the reservoir[J]. Applied Soft Computing, 2013, 13(2):1085-1098.
55. Afshar A, Madadgar S. Ant Colony Optimization for Continuous Domains: Application to Reservoir Operation Problems[C]// Eighth International Conference on Hybrid Intelligent Systems. IEEE, 2008:13-18.
56. Kumar D N, Reddy M J. Multipurpose Reservoir Operation Using Particle Swarm Optimization[J]. Journal of Water Resources Planning & Management, 2007, 2006(3):192-201.
57. Hashemi M S, Barani G A, Ebrahimi H. Optimization of Reservoir Operation by Genetic Algorithm Considering Inflow Probabilities (Case Study: The Jiroft Dam Reservoir)[J]. Journal of Applied Sciences, 2008, 8(11):2173-2177.
58. Bosch P, Jofré A, Schultz R. Two-Stage Stochastic Programs with Mixed Probabilities[J]. Siam Journal on Optimization, 2007, 18(3):778-788.
59. G. H. HUANG, D. P. LOUCKS. AN INEXACT TWO-STAGE STOCHASTIC PROGRAMMING MODEL FOR WATER RESOURCES MANAGEMENT UNDER UNCERTAINTY[J]. Civil Engineering & Environmental Systems, 2000, 17(2):95-118.
60. H. W. Lu, G. H. Huang, L. He. A semi-infinite analysis-based inexact two-stage stochastic fuzzy linear programming approach for water resources management[J]. Engineering Optimization, 2009, 41(1):73-85.
61. Zhang Jing, Huang Guohe, Liu Ye, etc. Dispatch model for conbined water supply of multiple sources under the conditions of uncertianty[J]. Journal of Hydraulic Engineering, 2009, 40(2): 11-14.
62. Liu Zhonghua, Yu Hua, Yang Fangyan, etc. Study on water resources allocation in Shanxi in conditions of uncertainty[J]. Journal of Hydroelectric Engineering, 2016(3) : 36-46.