Real-time Forecast and Operation Model of Flood Control System in River Basin

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1 Introduction

China is located in the East Asian monsoon region, where southwest and southeast air currents prevail in summer, and flooding is prominent, with more than two-thirds of the country under the threat of flooding. China has built the world's largest water engineering system to ensure national water security and public safety, including 98,828 reservoirs, 413,679 kilometers of embankments, and 268,476 sluices. In the context of climate change and human activities, how to scientifically and rationally operate and control water engineering in real-time to maximize the flood control benefits of the engineering has become a key issue in the study of basin flood control systems.

2 Literature Review

Real-time flood forecasting is an important basis for real-time flood control operation of water engineering, and the accuracy and efficiency of real-time flood forecasting can cause risks and uncertainties in flood control operations due to the influence of model forecast error transmission(Beven and Binley, 2014; Xia et al., 2015). Therefore, the following is a review of the research on basin flood control systems from two aspects: real-time flood forecasting and flood control operation.

2.1 Multidimensional spatial-temporal wide-area integrated forecast modeling

The importance of models as a tool for water cycle research has been widely recognized, and a large number of models have been developed for each part of the water cycle process(Pandi et al., 2021). Basin flood forecasting models can be divided into hydrological and hydrodynamic models.

With the development of modern computer, GIS, remote sensing and other technologies, the hydrological model has experienced the development of the aggregate model, semi-distributed model and distributed model(Pandi et al., 2021). The representatives of the aggregate model include the Stanford model(Crawford and Burges, 2004) and Xin'anjiang model(Ren-Jun, 1992); semi-distributed models include the SWAT model(Arnold et al., 1998) and PRMS model(Markstrom et al., 2015); distributed models include the SHE model(Refsgaard, 1997), TOPMODEL(Beven et al., 2021), VIC model(Liang et al., 1994), etc. The development history of hydrological models marks the gradual maturation of basin runoff and convergence process simulation.

The hydrodynamic model is based on theoretical formulations such as St. Venant's equations, shallow water wave equation, and gate and pump overflow equation to simulate hydrological elements such as water level and flow velocity. Scholars have conducted in-depth research on the hydrodynamic theory and numerical discrete methods, resulting in commercial software such as MIKE(Symonds et al., 2017), HEC-RAS(Shrestha et al., 2020), Delft 3D, SWMM(Huber and Dickinson, 1988), etc., which are widely used in the fields of river flood propagation, flood inundation analysis, urban flooding simulation, and water resources management(Wang et al., 2022; Zhou et al., 2021).

The hydrological model and the hydrodynamic model have their scope of application. The hydrological model is suitable for simulating the rapid flow in the hilly area with stable water level and flow relationship, while the hydrodynamic model is suitable for simulating the slow flow in the plain area which is affected by the combination of upstream incoming water and downstream water level top support. To realize basin-wide real-time flood forecasting, it is necessary to closely couple the hydrological model and the hydrodynamic model to build a multi-dimensional spatial-temporal integrated forecasting model, which requires a general standard for the close coupling of the two(Jiang et al., 2021).

2.2 Real-time flood control system joint optimization operation

With the expansion of the scale of water conservancy projects, optimal flood control operation has gone through development stages such as single reservoir flood control operation, river and reservoir joint operation, reservoir group joint operation and basin flood control joint operation(Castelletti et al., 2008; Meng et al., 2019). At present, the optimal flood control operation has developed to the stage of joint operation of reservoirs, rivers and flood storage basins, which is a complex high-dimensional nonlinear hybrid optimization problem. The methods for solving such water resources system optimization problems include mathematical planning methods, group intelligence algorithms, fuzzy mathematical methods, large system decomposition-coordination methods, etc(Castelletti et al., 2010; Chang, 2008; Deb et al., 2002; Kumar and Reddy, 2006; Maier et al., 2014).

There are multiple conflicting objectives in the real-time operation of the basin flood control system, such as the contradiction between the safety of the dam itself and the safety of the downstream flood protection object, and the contradiction between the benefit of the flood period and the benefit of the post-flood benefit(Lu et al., 2022). The multi-objective optimal operation can not achieve optimal solutions for multiple types of objectives at the same time, and the optimal scheduling strategy exists in the form of Pareto optimal solutions. Most of the research on multi-objective optimal flood control operation has focused on the application and improvement of optimization algorithms, and preliminary results have been achieved, but in the face of real-time flood control scheduling problems， there is still a need to solve the problems of computational timeliness, solution space search efficiency, and search stability(Huang et al., 2022; Liu et al., 2019).

3 Methodology

To realize real-time forecasting and operation of the flood control system, it is necessary to first solve the problem of multi-model dynamic coupling for basin-wide flood simulation, then propose model acceleration calculation methods such as surrogate model and parallel computing for the respective characteristics of hydrological and hydrodynamic models, and finally build a robust multi-objective optimization framework to maximize the flood control benefits of water conservancy projects. The technology roadmap is shown in the following figure.

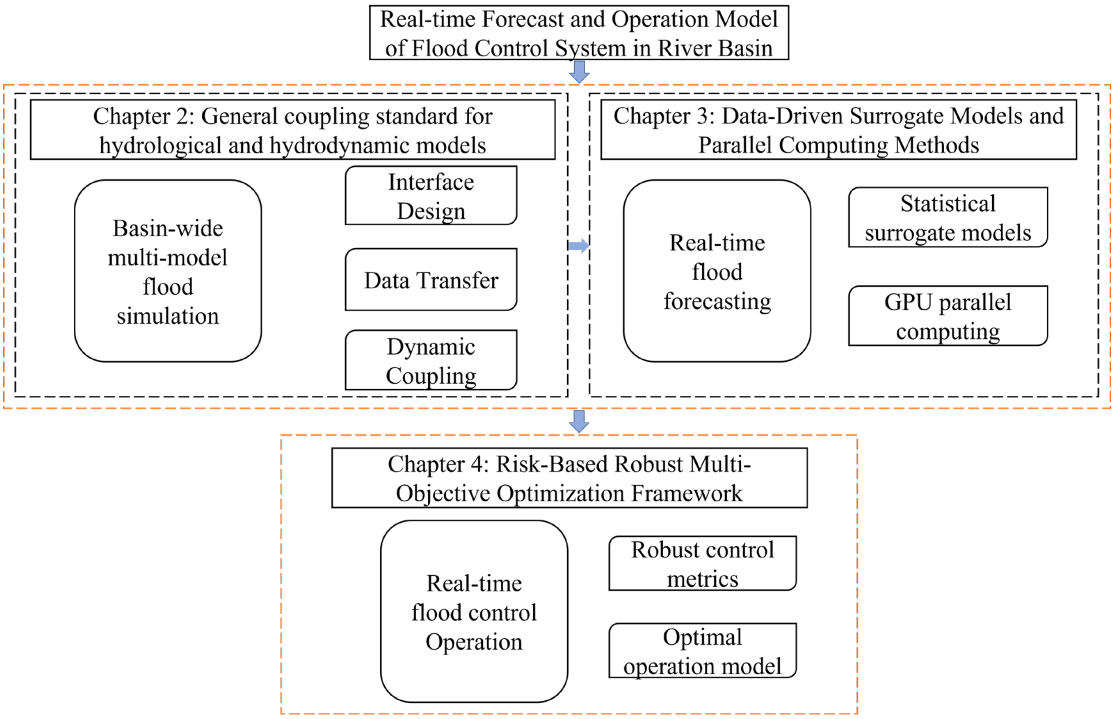

Figure 1 Technology roadmap of the paper

3.1 General coupling standard for hydrological and hydrodynamic models

The hydrological model and the hydrodynamic model are very different in timestep and spatial scale, and the implementation of forecasting operations will lead to problems such as unstable calculation and data mismatch(Jiang et al., 2021). To realize the close coupling between them, a set of general model coupling standards needs to be proposed to support the real-time data exchange during the model run. The proposed general coupling standard can not only improve the efficiency of model development but also support the rapid replacement and update of models in the future.

3.2 Data-driven surrogate models and parallel computing methods

To realize real-time flood forecasting, it is necessary to propose speedup computational methods for hydrological and hydrodynamic models(Chu et al., 2020; Fraehr et al., 2022). Currently, the two mainstream solutions to improve the efficiency of model solving are to use parallel computing(Liu et al., 2018; Owens et al., 2008) and to construct a surrogate model(Zhang et al., 2021). Parallel computing uses multiple computing resources to solve a full-order model computational problem without changing the computational complexity of the problem, while the surrogate model projects a high-dimensional nonlinear model to a low-dimensional space for approximate description, reducing the computational complexity while saving time(Liu et al., 2018; Xie et al., 2021; Yang et al., 2022).

3.3 Risk-based robust multi-objective optimization framework

Robust optimization refers to the search for a highly stable solution that satisfies the constraints of all possible water scenarios and optimizes the objective function under the worst-case scenario(Huang et al., 2022). Robust optimization is widely used in the real-time operation of power systems due to the pursuit of the stability characteristics of multiple types of energy output under variable and severe conditions, but it is less studied in the field of reservoir group optimal operation. How to ensure the safety of water projects themselves and flood protection objects in the flood control system is a typical multi-objective robust optimization problem, which needs to be studied in depth.

4 Expected Results

Apply the real-time forecast and operation model of the flood control system to the Hangzhou Dongtiaoxi watershed to realize real-time flood forecasting and protect people's lives and properties in Hangzhou city through real-time flood control and operation of reservoirs, river embankments and flood storage basins. The schematic diagram of Dongtiaoxi watershed water project is shown in Figure 2.

The paper will construct real-time flood forecasting and real-time flood operation models for flood control systems to support flood mitigation, emergency rescue and evacuation of people in the watershed.

Figure 2 Schematic diagram of water engineering in Dongtiaoxi watershed

5 Gantt Chart

Table 1 Work plan schedule

	Year 1		Year 2		Year 3		Year 4	
A review of research progress	■	■						
General coupling standard		■	■					
Speedup calculation method			■	■				
Multi-objective optimization framework				■	■			
Real-time forecast operation model application					■	■		
Writing a thesis							■	■
Thesis defense								■

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This is a very high standard research plan. I approve.

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