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Flood control management system for reservoirs

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Abstract:

Flooding disaster is one of the most damaging natural disasters in China, with annual average losses costing more than 200 billion yuan in recent years. After the 1995 floods in Liaohe River and the 1998 floods in Yangtze River, both national and local governments realized that flood control operation of reservoirs could play a major role in alleviating flood losses and that some enhancements in flood control management for reservoirs would be required. Since the existing flood control management systems for most reservoirs are established for specific purposes and are lacking in data sharing and communication with governments, it is very difficult for individual decision-making department to acquire real-time information within a short period. As a result, a national programme on flood control management system for reservoirs is undertaken. The paper is a summary of the outcome of the national programme about the flood control management system for reservoirs in China. The background, objectives, challenges and contents of the programme are presented. The main focus is on the integration of flood control management system for reservoirs as well as on the design of the flowchart of the system and its core components. The current system can be applied to either a river control center or a single reservoir through the use of the national standard databases. Hence, it will be readily integrated into the national flood control system in the future. An application example is shown for easy understanding of the system.

KEY WORDS: flood control; integrated management; database; reservoir

1. Introduction

Flooding constitutes the most prevalent and costly natural disaster in the world. There are a large number strategies and methods today to address flood hazards and disasters (Simonovic, 2002). One of the most important aspects of mitigating the damaging impacts of floods is the real-time operation of flood control systems. Real-time operation of reservoirs system involves various hydrologic, hydraulic, operational, technical, and institutional considerations, requiring an integrated management framework (Shim et al., 2002). During the past three decades, decision support system (DSS), an important non-structural tool for analyzing alternative mitigation, has been developed to assist the flood control decision in the word. Ford and Killed (1995) developed a DSS for flood control operations in Trinity River Basin, Texas. The DSS includes the whole procedure from retrieving and processing data for rainfall and streamflow to estimating basin averaging rainfall, updating model parameters, forecasting runoff and simulating reservoir operation. It integrates a database management system with specialized versions of the HEC-1 and HEC-5 river basin models. Simonovic (1999, 2002) developed a Red River Basin Decision Support System that integrates hydrologic models, hydraulic models, economic models and virtual databases. It is envisaged as serving the needs of decision-makers and stakeholders in the Red River Basin. Recently, Shim et al. (2002) developed a spatial DSS for integrated river basin flood control. It integrates several modules, including a relational database management system for hydrometeorological data, a spatial

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analysis module using a GIS, a flood-forecasting module employing an artificial neural network, a fully dynamic optimization model incorporating hydrologic routing characteristics of the basin, a dialog interface module incorporating graphical user interfaces and graphical display systems supporting all other modules. It had been applied to the Han River Basin in Korea. While many reservoir operation software packages are currently available and some systems exist in many countries, deployed in many projects, an integrated system is still under significant research and development with rapid advances in remote sensing and satellite technology, geographic information systems, database management systems, hydrology modeling analysis and decision techniques.

Flood disaster is one of the most damaging natural disasters in China, with annual average losses more than 200 billion yuan (1 US$ equal to about 8.3 CNY$) in recent years. As major structural measures to defend against floods, more than total number of 86,000 reservoirs have been established in the past fifty years. These reservoirs have great role on mitigating flood losses together with other flood protection measures. A typical example is the flood control operation of Gezhouba Reservoir, Geheyan reservoir and Danjiangkou Reservoir for 1998 floods of the Yangtze River. The three large-scale reservoirs are at the main stem and tributaries of the upper and middle reaches of the Yangtze River. Their joint operation with other flood control projects have avoided the use of division flood regions and decreased the losses with up to more than tens of billion yuan for the 1998 floods. The flood control operation of the four large-scale reservoirs at the main stem of the Liaohe River for 1995 floods is another example. Dahuofang reservoir, Qinhe Reservoir, Chaihe Reservoir and Guanyinge Reservoir had reduced the losses by 14.3 billion yuan for 1995 floods with magnitude in more than 100 years return periods. After 1995 floods in the Liaohe River and 1998 floods in the Yangtze River, the governments from national to local have realized that the flood control operation of reservoirs can play a major role in alleviating flood losses but there are some problems in flood control management for reservoirs. Most of the existing flood control management systems for reservoir were established for special purposes and are lack of data share and communication with governments, it is very difficult for decision-making departments to get real-time information in short time. In order to make full use of the flood control capacity of existing reservoir projects and to improve the national level of the flood control operation for reservoirs, the National Flood Control and Drought Defying Chief Headquarters of China has commissioned Dalian University of Technology (DUT), Hohai University, and Wuhan Hydroelectric University to develop an integrated management system for flood control of reservoirs (IMSFCR) since 1998, with a duration of five years. The objectives are to establish a standardized flood control software system of multi-reservoir, integrated real-time data acquisition and processing, precipitation analysis, flood forecasting, reservoir system analysis, information query and some of the recent methodologies of flood control based on large scale database management system.

This paper is a summary of the outcome of IMSFCR project. The main focus is on the issues of the software integration of flood control management system for reservoirs. Emphasis is concentrated on the flowchart design of the system and its core components.

2.Main challenges

The main challenges in developing IMSFCR lie in dealing with the complexity of typical systems, the interface integration and standardization of software system. It is because China is a country with a vast territory and there exist substantial differences in flood conditions determined by variations such as physical geography, hydrological and meteorological characteristics at different locations. Owing to these variations, methods employed in the reservoir flood control system are determined to a large extent by the purposes and the scope of the project. In addition, the data available has an effect on the choice of models. Hence, extensive model libraries will be established, which may take a lot of time and effort. Advances in computer technology have made it possible to simulate the flood control management processes in an integrated and comprehensive framework.

The flood control management system for reservoirs involves directly with real-time data acquisition and processing, precipitation analysis, flood forecasting, reservoir system analysis and information query. Large-scale database management system (DBMS) is the basis of the integrated system. A distributed model requires the analyst to acquire, maintain, and extensively utilize a referenced database. It is greatly different from the traditional text files systems. Database sources including input, output, calculation, query and temporary procedure should be used in all operations. Another question, which arises here, is whether it is necessary to replace all the existing software. A lot of mathematical models, including professional models and general algorithms, are coded with a variety of programming languages such as Fortran, C++, Powerbuilder, and so on. The user interface of the old software may be under traditional database system or in previous versions. The choice in reusing or rewriting them under the new environment mainly depends on the quantity, complexity and quality of the existing software as well as on the availability of time and resources. Furthermore, the programs must meet a minimum standard of quality as far as reliability, efficiency and maintainability are concerned. We chose to reengineer and redevelop all existing systems in order to satisfy the common rules and to meet the requirements of reliability, efficiency and maintainability as far as possible. To speed up the development procedure, the functions of old systems are refereed and made some translation from one language to another.

3. Selection of prototype system

In China, there are more than 5,000 rivers with catchment area over 100km^2. There are about 86,000 reservoirs, and among them, more than 3,000 have storage capacity over 100 million cubic meters. These reservoirs are classified as medium to large types that are the essential objects of development for the national software project of reservoir flood control. 20 reservoirs were chosen as prototype systems in the first trial project from the whole country in 1998. 40 reservoirs were chosen in the second batch in 1999 while 60 reservoirs were selected in the third batch in 2000. From these prototype systems, we aim to find the common features and to distinguish the differences among them. Furthermore, we are planning to develop a general software system of reservoir flood control.

4. Flood control management system scheme for reservoirs

A flowchart representation of the flood control management system for reservoirs is given in Figure 1.The system consists of five components: (1)data collection, (2)observed data validation& processing, (3) reservoir forecasting, (4) flood control operation and (5) information inquiry. IMSFCR adopts client/server structure based on large-scale database. Databases include: (1) forecast database, (2) operation database, (3) real-time database, (4) history database and (5) results database.

Insert Figure 1 Here

4.1 Data collection

Data collection module will automatically collect the data from precipitation gages, streamflow gages distributed in a specific basin. Data can be transmitted from a remote site to a central base station through the microwave, VHF telemetric, meteorburst and satellite.

4.2 Observed data validation & processing

When a flood event happens, user can invoke the system. All raw data must be validated and processed before data will be stored into a database. The system will automatically or manually process the raw data into hourly precipitation, elevation and discharge after data have been validated. Two manners are interfaced to data transmission system and user can finish the validated and processed works at each hour time.

4.3 Reservoir forecasting

Based on observed rainfall data, hydrologic models are then used to estimate the quantity and timing of local flow into reservoirs for 3 days or more forecast period. Figure 2 is the flowchart of flood forecast module.

Insert Figure 2 Here

Flood forecast includes the choice of hydrologic models, initial condition set and modification on antecedent soil moisture, real-time forecast, simulation forecast, revised forecast. The system has integrated most of the commonly used flood forecasting models in China, such as the famous Xinanjiang model developed by Zhao (1992), Dahuofeng rainfall-runoff model(Liu, 1985), as well as typical rainfall-runoff models, unit hydrograph model(Linsley et al., 1975; Hoggan, 1997).When a model is chosen, the system will set it as the default in the next time. Flood forecast is classified into "real-time" and "simulation" depending on the situation when real-time and simulation data are used respectively. Inflow estimates are primarily based on observed rainfall(we mean "real-time" forecast); however, if additional rainfall is expected, the incremental impact of predicted rainfall is also determined(we mean "simulated forecast). During periods of flood reasons, inflow forecast are repeated at each interval times based on the available observed data or simulated rainfalls. Forecast results are dynamically analyzed and shown with tables and graphics, as shown in Figure 3. Some characteristic values of the flood, including total rainfall, total runoff, pure precipitation rate, peak inflow, peak time, the largest flood inflow volume, occurrence time and corresponding frequency during the given time interval, are displayed, as shown in Figure 4. When there is a large discrepancy between the predicted stream inflow and observed, user can click the mouse to modify the hydrograph such that the predicted data matches observed data as closely as possible through using an interactive interface.

Insert Figure 3 Here

Insert Figure 4 Here

4.4 Flood control operation

Figure 5 is the flowchart of the flood control operation module. During the development of a modeling system for flood control operation, the core aspects of the implementation are appropriate user interfaces and the corresponding evaluation method. It is because they determine the interactions between the computer system and the user, and affect the acquisition of a quick decision. Reservoir flood control operation is operated in real time, which often differs very much from other operations for planning purposes. The crucial difference between them is that decision making of flood control is usually effective only for the current period or for the following periods. Constrained by the updated results on flood forecasting at each current period, decisions need to be made on a daily or even hourly basis during flood events. It is very important how to quickly and easily generate the feasible flood control alternatives. One of main tasks of this module is to design the interactive interfaces to generate the flood control operation alternatives. A procedure for generating a flood control operation alternative by an interactive manner is represented in Figure 6.

Insert Figure 5 Here

Insert Figure 6 Here

Reservoir releases of a simulation operation can be a constant (e.g., 2000m^3/s) or a gate regulation (e.g., 1× 1.5, which means that one gate has an opening height of 1.5m and reservoir releases will be regulated with the gate regulation curve procedure). The system will automatically check the limiting capacity of the reservoir at each interval when user inputs a fixed outflow. A simulation alternative is constituted of a series of constant or gate regulation or their mixtures (refer to Figure 9). The mass balance equation or reservoir routing (Fenton, 1992) will be used to determine the changes of flood control storage at the reservoir.

When the outflow is represented with a constant outflow, the mass balance equation is

$$S_{t+1} = S_t + (I_t - R_t - EL_t)\Delta t \quad (1)$$

where S_t, I_t, R_t, EL_t are respectively the reservoir storage, inflow, outflow and evaporation at time t, with unit of S_t in m^3, and units of I_t, R_t, EL_t in m^3/s. EL_t is usually neglected and is only considered for runoff calculation procedure during flooding events. Δt is the time interval between time t and t+1, with unit in s.

When outflow is represented with opening status of the gates, reservoir routing (Fenton, 1992) is needed. Equation 2 is a simplified formulation developed here.

$$S_{t+1} = S_t + \frac{1}{6}[k_1 + 2(k_2 + k_3) + k_4)] \quad (2)$$

It is noted that the resulting equation is obtained from Taylor's expansion with fourth order (refers to Fenton, 1992). The coefficients are

$$\begin{aligned} k_1 &= h_{t+1}[I_{t+1} - R(Z(S_t))] \\ k_2 &= h_{t+1}[I_{t+1} - R(Z(S_t + k_1/2))] \\ k_3 &= h_{t+1}[I_{t+1} - R(Z(S_t + k_2/2))] \\ k_4 &= h_{t+1}[I_{t+1} - R(Z(S_t + k_3))] \end{aligned} \quad (3)$$

where k_1, k_2, k_3, k_4 = coefficients, with units in m^3. h_{t+1} = time interval between time $t+1$ and t. Z() is the functional relationship between storage S_t and level Z_t. When S_t is given, Z_t is obtained by using interpolation methods. R() is the functional relationship between level Z_t and outflow R_t. When Z_t is given, R_t is obtained by using interpolation methods.

For each alternative, equation (1) or equation (3) will be used and repeated at each time interval within the decision interval. Therefore, the flood control objective values, including the maximum release, maximum level and final level, will be determined (refer to the right bottom in Figures 9 and 10). This system unitizes the fuzzy iteration method of reservoir flood operation developed by Cheng and Chau (2001) to evaluate the alternatives. Two key equations are

$$w_i = \left[\sum_{k=1}^{m} \frac{\sum_{j=1}^{n} \left\{ [u_j(g_i - r_{ij})]^2 + [(1-u_j)(r_{ij} - b_i)]^2 \right\}}{\sum_{j=1}^{n} \left\{ [u_j(g_k - r_{kj})]^2 + [(1-u_j)(r_{kj} - b_k)]^2 \right\}} \right]^{-1} \quad (4)$$

and

$$u_j = \left[1 + \frac{\sum_{i=1}^{m} [w_i(g_i - r_{ij})]^2}{\sum_{i=1}^{m} [w_i(r_{ij} - b_i)]^2} \right]^{-1} \quad (5)$$

where *m* and *n* are the total number of objectives and the total number of alternatives. *i=1,2,...,m; j=1,2,...,n.* w_i and u_j denote the weight of *i*th objective and the membership degree of alternative j. g_i and b_i are the *i*th objective values corresponding to the ideal alternative *G* and the non-ideal alternative *B*. Only the fundamental principles of the methodology have been mentioned here. For more details, the reader may refer to Cheng and Chau (2001).

User can view the flood control process of a new alternative, as shown in Figure 7.

By repeating the process mention above, the real-time flood control decision will be updated for each time interval.

Insert Figure 7 Here

4.5 Information query

"Information query" provides several basic information inquiry for brief introduction of reservoirs, dynamic real-time flood situation, flood forecasting results, flood operation alternative results, historical records, operation rules, law and policy related to flood control operation, and so on. Query can be activated through access to the databases via internet/intranet. The query results may be shown in various formats such as tables, graphic, maps, videos, and text. The part of contents are general and simple, no details will be given further.

4.6 Database

The databases are divided into network databases and special databases. Network databases consist of real-time data library, historical records library and results library. Special databases include flood forecast library and flood operation library. Network databases are shared resources involving original records and public information. On the other hand, special databases are kept private to facilitate simulation and analysis of flood forecasting and flood control operation by both technical and non-technical personnel before formal or official results have been generated. Most data are temporary in nature and are only valid in user's machines. For non-technical users, it is especially important that they can operate and learn from the system, without the threat that their inadvertent action may erase some important and raw data. For technical users, they can simulate any alternatives in an efficient way. This layout of databases enhances data security as well as improves flexibility of the system application.

The database system is the basis of IMSFCR. Sybase and SQLServer are adopted as the DBMS of reservoir flood control system. The two DBMS can ensure high data integrity, recovery, and concurrency control. They support the high-level query language SQL and enable users to perform sophisticated data retrievals. Most of the structural definitions of Sybase about data properties is the same as those of SQLServer. One of the two DBMS can be chosen according to the scale of the application system and the economic condition of the user. It is not necessary to modify the programming source codes.

The design of the relational tables has a significant effect on the programming source codes and the operation efficiency of the flood control system. The software system based on the database is completely different from traditional files such as in HEC1-HEC5 packages (ASCE, 1996). All preprocessing, calculation, query and post-processing are based on database and necessitate the access to the data in the related tables. An optimized database design can render the system easier to expand and minimize adjustment to the programming source codes, as well as improve the efficiency.

The main works to achieve database optimization are to define the types of data queries and requests, and to normalize the database relationships. The optimization products are table structures where the table names, the name and data types of its fields, and the integrity constraints are defined. More than 400 tables have been designed for the reservoir flood control system. These tables form parts of the common rules for the national flood control system. The database can be utilized to generate all the standard reports required by the user. Another major objective is to provide the public with flood control information. The increasing use of the Internet makes the World Wide Web an attractive vehicle for the dissemination of such information. The flood control information about reservoirs can be accessed using Internet/Intranet. User can select the constant or two manners to interact the release at each time interval.

5. Applications

The software system has been installed into 69 reservoirs distributed among more than 15 provinces in China. The system has been used to flood control management for reservoirs in a single reservoir or river center. In order to understand how to use this software, the Biliuhe reservoir flood control management system is taken as an application example. The Biliuhe reservoir built up and operated in 1986, with a drainage area of 2,013 km^2 and a water holding capacity of up to 934 million cubic meters, is situated in Liaoning province of North–eastern China, 170 km away from Dalian City. Dalian is one of the cities which are most short in water resources in China. The long-term average annual precipitation for this region is 643mm and approximately 80 percent of precipitation is in the flood season from July to September. The main purposes of the reservoir are water supply and flood control. 70 percent of water supply in Dalian City is from the reservoir. The flood control management of the reservoir has important impact on the water supply of Dalian City. Thus, the balance between flood control and water supply is the main tasks of the reservoir operation management.

The early flood forecast system of the Bilihe reservoir is a command-line-oriented program in Basic version that needs to be ready for a text file in advance. The data input is often very labour intensive and time consuming. The outputs are several text files. The flood control operation is empirical and no flood control operation program is available before the current system. The need for improvement in user-friendliness, flexibility and entirety is definitely needed in order to facilitate the use of such systems.

The current system has been installed in the Biliuhe reservoir and the flood control management centre of Dalian region since the summer of 2000. The operation of the two systems is independent for each other. The two systems receive the same real-time data from the telemetry-based collection system through wireless connection. During recent years, Dalian has been in desert periods and no great floods happened. Here, a hypothetical flood event is given in order to demonstrate more results of this software.

The hypothetical flood event happened between 2002/8/2/8 and 2002/8/3/23, with duration of 39 hours. When flood happens, the system will automatically process the real-time rainfall and elevation data of each gauges transmitted. These data will be validated and processed into data with an hour interval and then stored in the real-time database after 3 minutes for each exact hour time.

The first step is to set up the beginning time and end time when a flood event happens. For this example, the beginning time is 2002/8/2/8 and the first end time is 2002/8/2/11. It should be noted that the lag between the two times is 3 hours which is the time interval of the hydrologic model for this reservoir. The inflow prediction and flood control decision will be updated at every three hours based on the most currently available observed data. It is supposed that the current end time is 2002/8/3/23, we will demonstrate how to operate the software system.

The second step is to enter flood forecasting module. The system will check whether there exist the values of the initial antecedent soil moisture at the beginning time. If not, then calculate their values based on the historical records data. Otherwise, translate an hour precipitation data into 3 hours precipitation in order to be ready for the real-time data of hydrologic model. Further processes refer to Figure 2. The parts of output results refer to Figure 3 and Figure 4.The input and output data in the process mentioned-above are both from databases.

The third step is to enter flood control operation module. Decision duration times, which depend on the flood routing time from the reservoir to downstream control points or the flood process times, are needed to be set up in advance before entering the interface for generating flood control alternatives. The decision duration times for this flood are 3 days. The initial alternative is first generated based on the operation rules of this reservoir and the releases of each period are shown in table. In general, the initial alternative is only a guide frame and seldom feasible because the operation rules are mainly determined from the design flood events and there exist great differences among the real-time floods and design ones. Therefore, additional alternatives are needed to interactively generate in order to deal with the real-time flood. User can select constant or gate regulation manner to interact the release of each time interval point though the flood control screen. When "constant" or "gate regulation" is clicked, the input screen will be available and user can set a continuous action for some operation such as 3 time intervals. Figure 8 is the interface of constant manner. Figure 9 is a new alternative using the methods mentioned above. Correspondingly, the objective values for this alternative are shown in the right bottom in the interface. The Figure 10 is another new alternative using the same methods and its graph results shown in Figure 7. Furthermore, the system will give the range of generated alternatives through the evaluation function module based on the objective values. The part of contents refer to the authors' another paper (Cheng and Chau, 2001). User can select one or more alternatives for decision.

Insert Figure 8 Here

Insert Figure 9 Here

Insert Figure 10 Here

6. Conclusion

The flood control management system for reservoirs has a significant role in alleviating flood losses. The establishment of IMSFCR will speed up the development of the national flood control system for reservoirs, make full use of the flood control capacity of existing reservoir projects and improve the national standard of the flood control operation for reservoirs.

IMSFCR defines the standard databases and their relational tables, which are the basis of IMSFCR. The databases are divided into network databases and special databases. This layout of databases enhances data security as well as improves flexibility of the system application. Furthermore, all preprocessing, calculation, query and post-processing are based on databases and necessitate the access to the data in the related tables, with wireless connection among modules and without the exchange data from one application to another. The pre-processing and post-processing are designed with an interactive GUI, which provide a convenient means for entering data and displaying results. The most important parts of flood control management are interactive. Users can easily interact with the databases or run various modules, with great improvement in user-friendliness and flexibility. The current system can be applied to a river control center or a single reservoir because of using the national standard databases and easily integrated into the national flood control system in the future.

Acknowledgments

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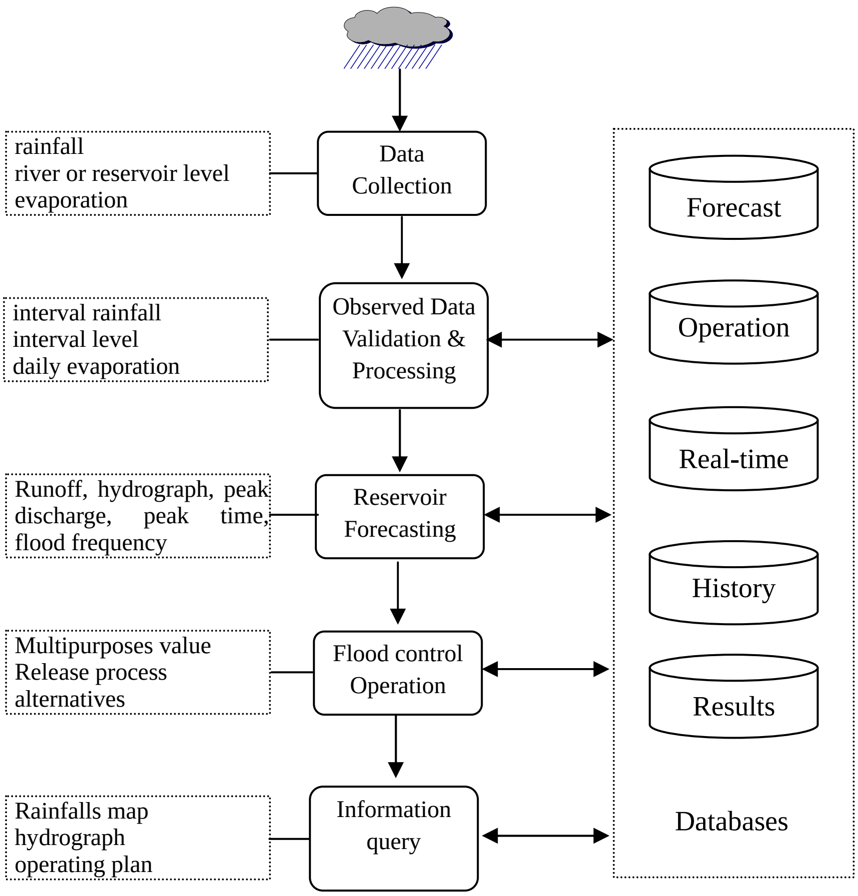


Figure 1. Flowchart of the reservoir flood control operation system

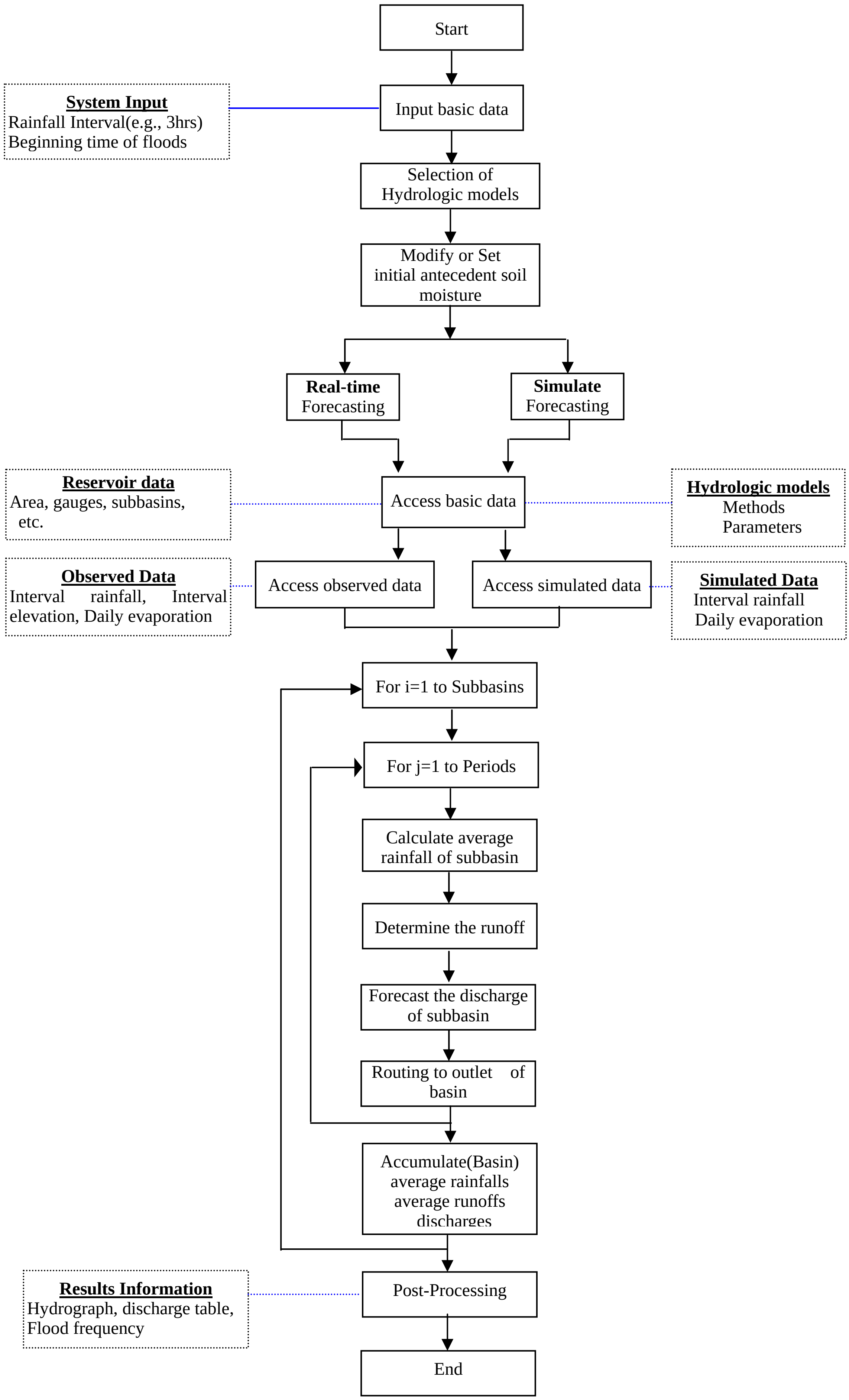


Figure 2 Flowchart of flood forecasting

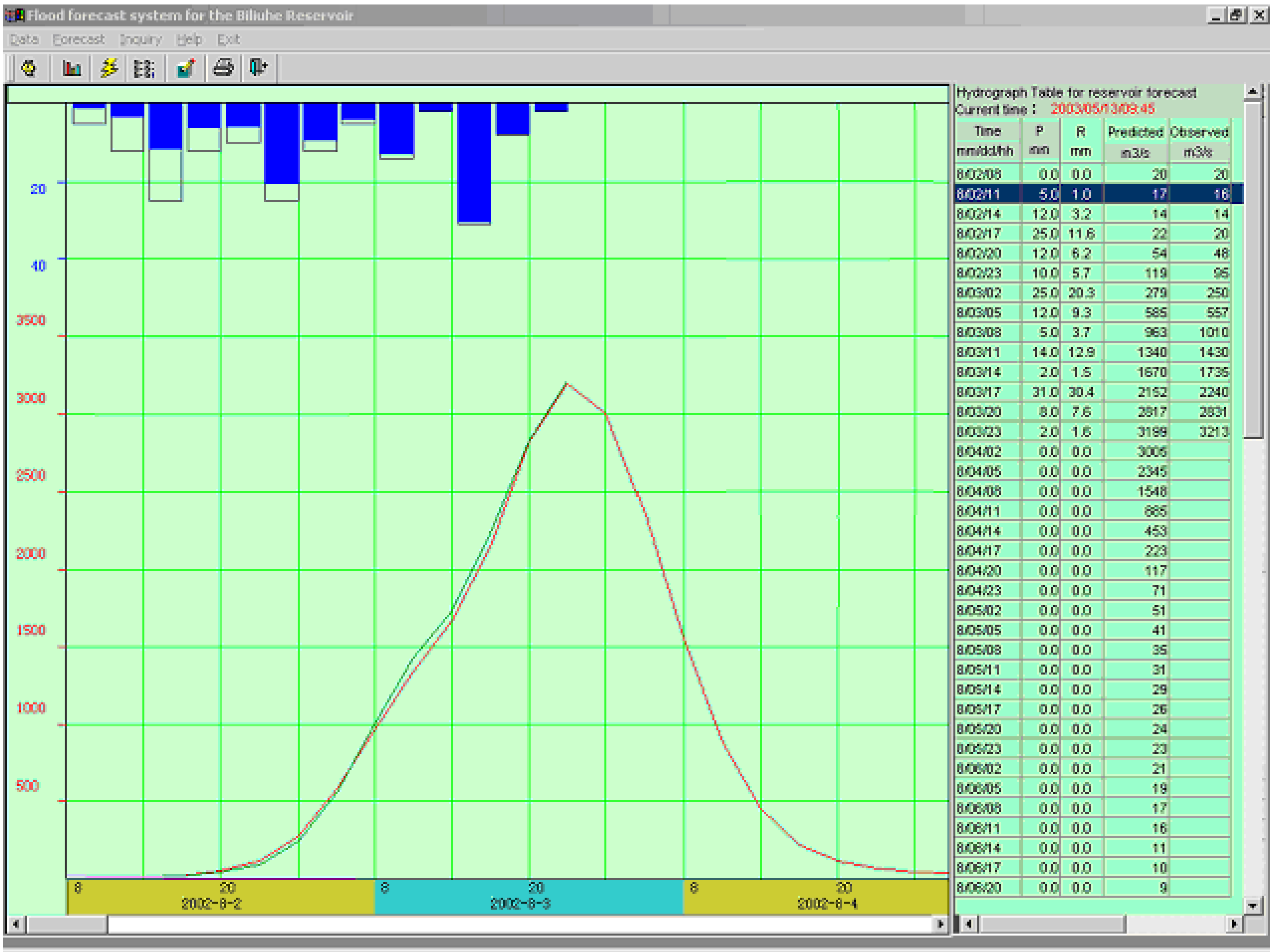


Figure 3 Forecast inflow hydrograph and table.

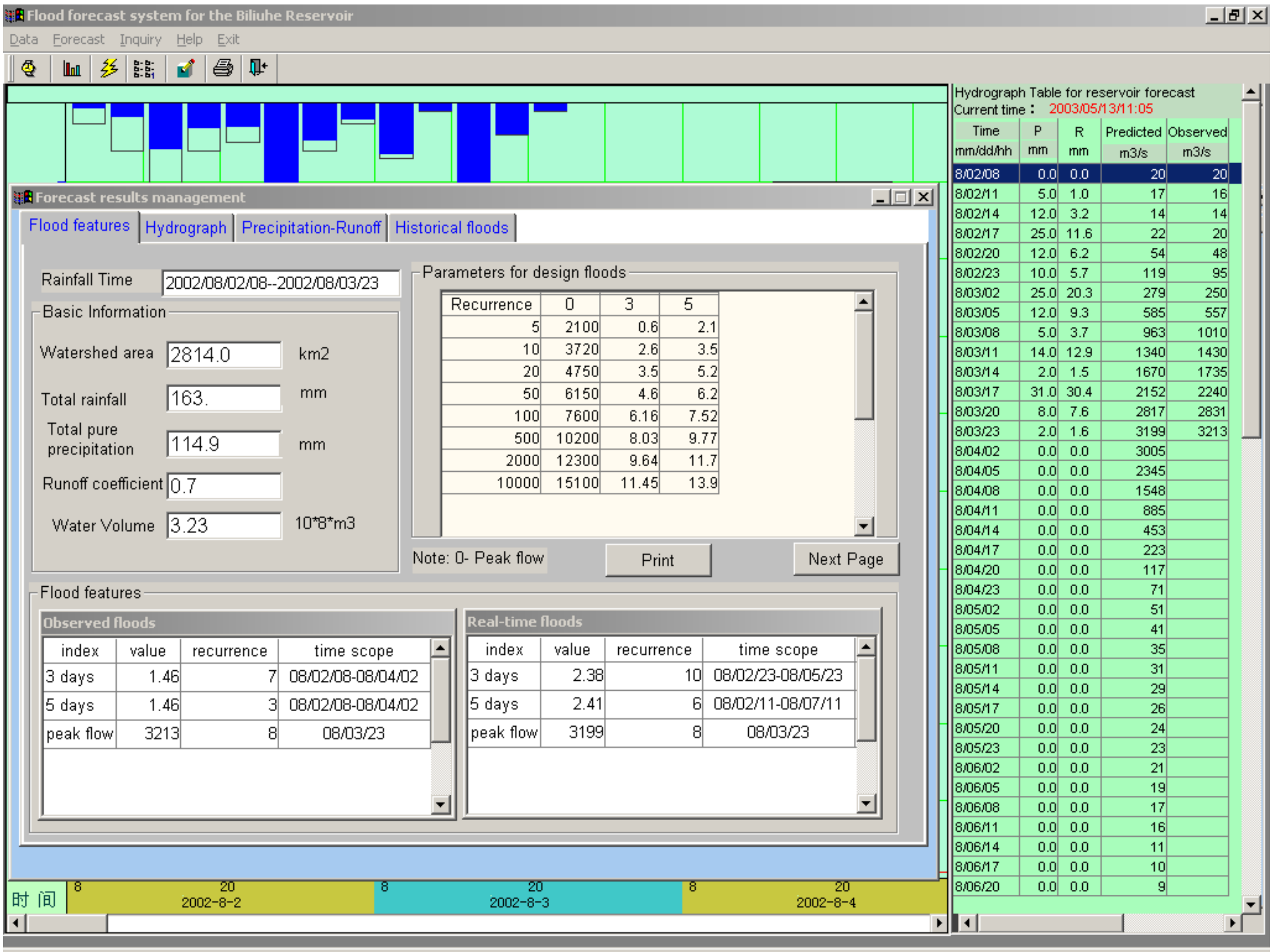


Figure 4 Characteristic values of the predicted flood

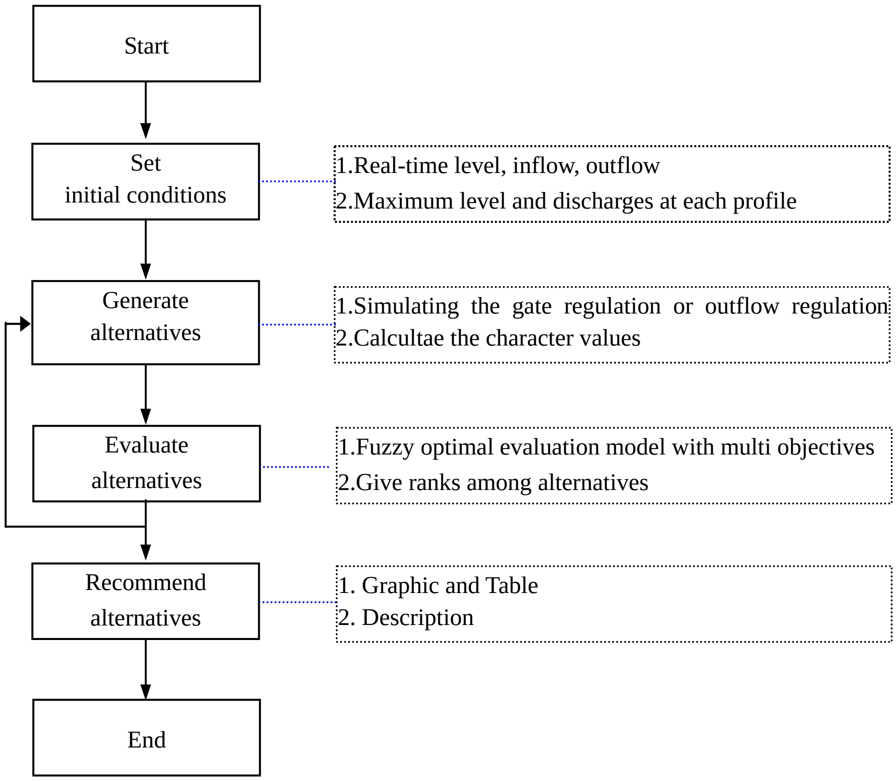


Figure 5 Flowchart of flood control operation

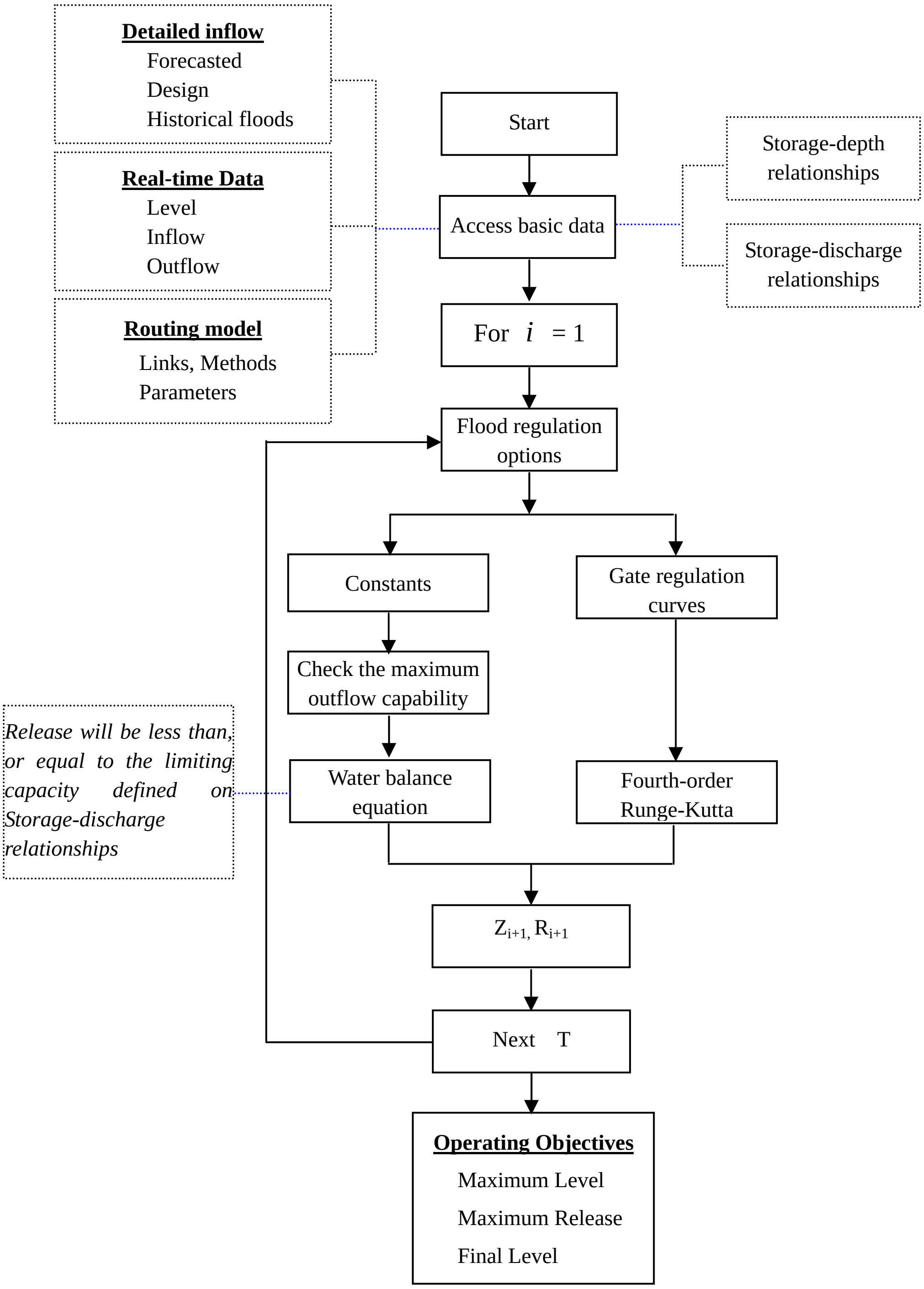


Fig 6. A procedure for generating a flood control operation alternative by interactive manner

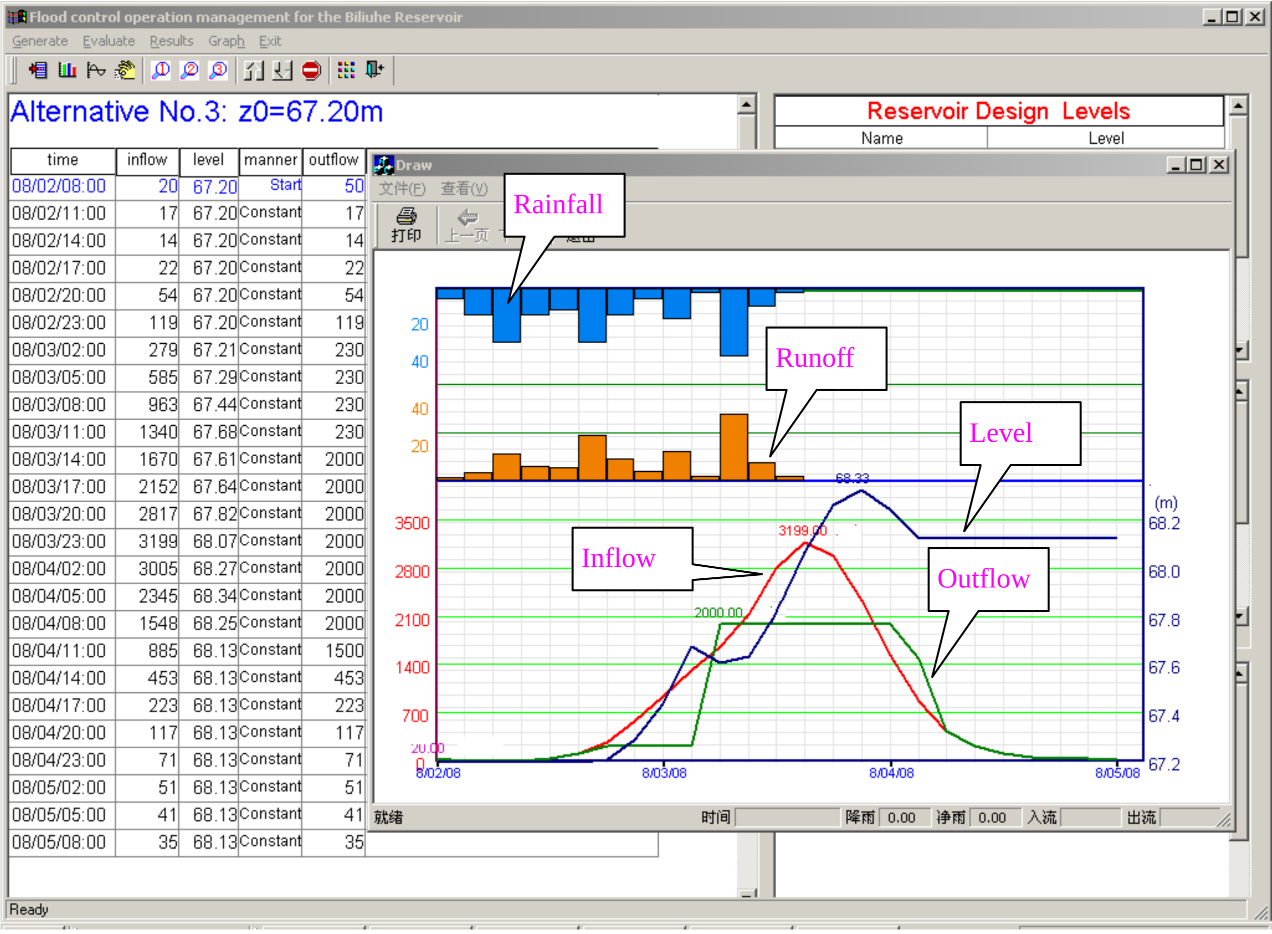


Figure 7 Flood control process of a new alternative

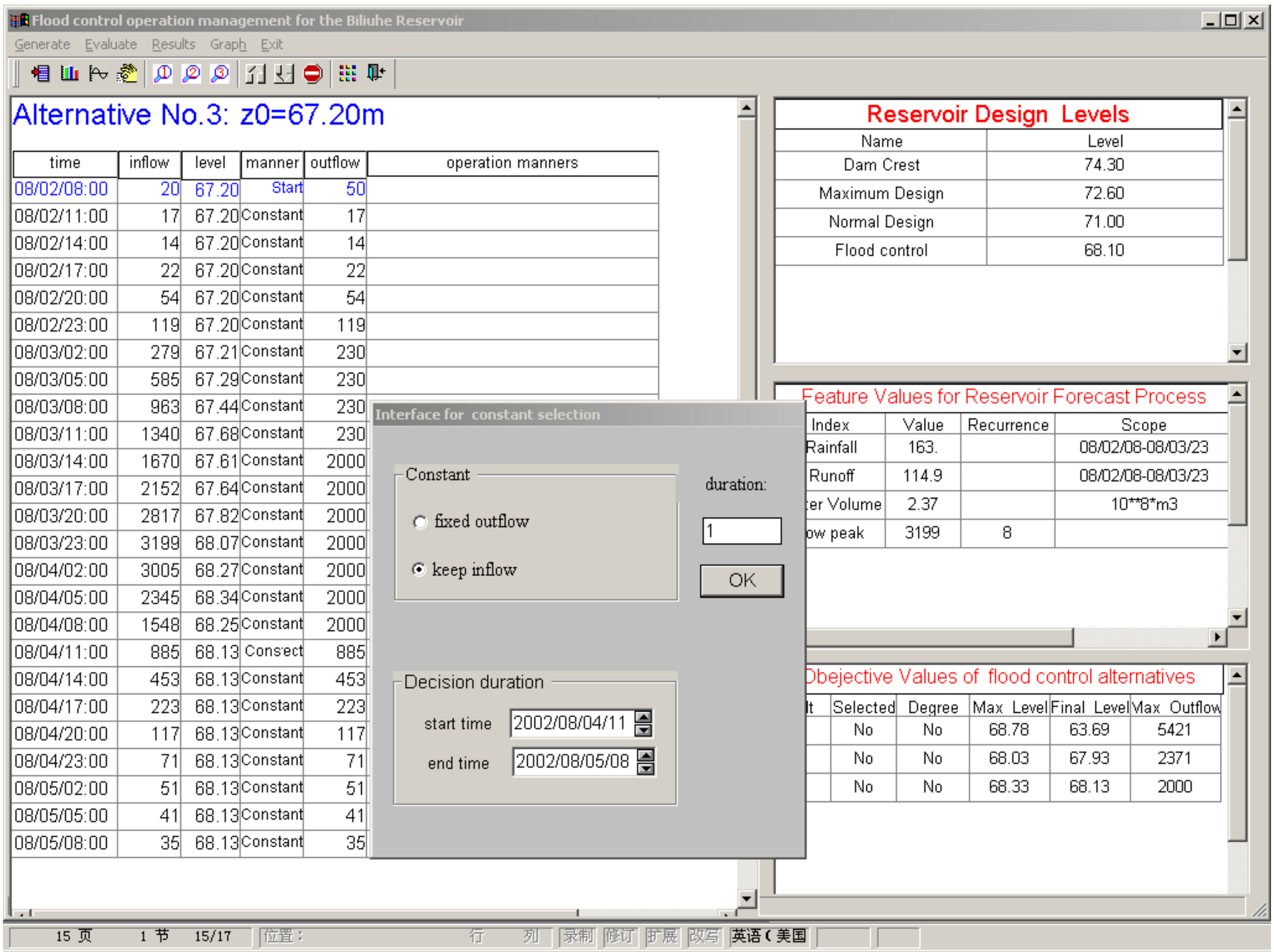
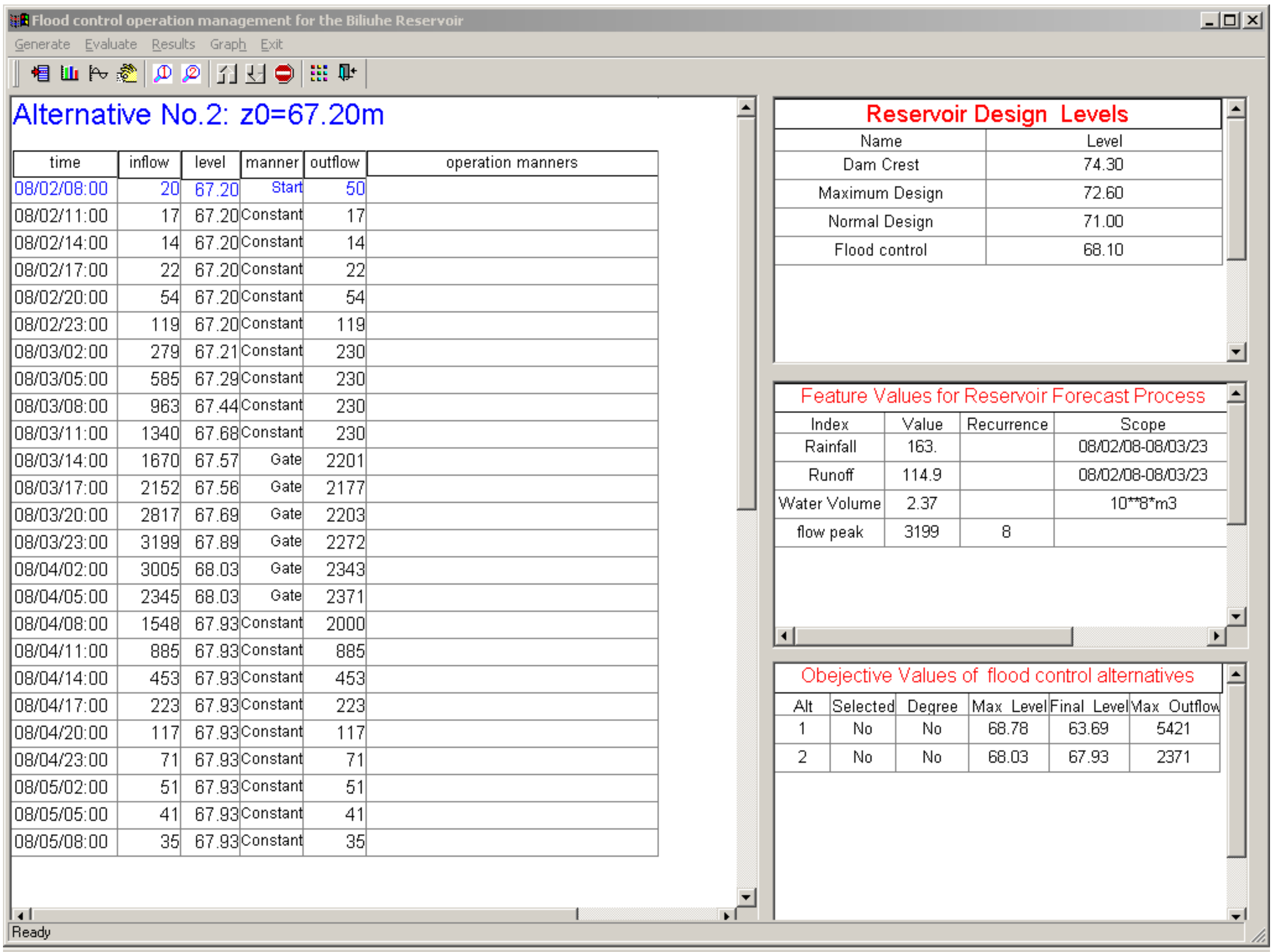


Figure 8 Interface for constant means



Alternative No.2: z0=67.20m

time	inflow	level	manner	outflow	operation manners
08/02/08:00	20	67.20	Start	50	
08/02/11:00	17	67.20	Constant	17	
08/02/14:00	14	67.20	Constant	14	
08/02/17:00	22	67.20	Constant	22	
08/02/20:00	54	67.20	Constant	54	
08/02/23:00	119	67.20	Constant	119	
08/03/02:00	279	67.21	Constant	230	
08/03/05:00	585	67.29	Constant	230	
08/03/08:00	963	67.44	Constant	230	
08/03/11:00	1340	67.68	Constant	230	
08/03/14:00	1670	67.57	Gate	2201	
08/03/17:00	2152	67.56	Gate	2177	
08/03/20:00	2817	67.69	Gate	2203	
08/03/23:00	3199	67.89	Gate	2272	
08/04/02:00	3005	68.03	Gate	2343	
08/04/05:00	2345	68.03	Gate	2371	
08/04/08:00	1548	67.93	Constant	2000	
08/04/11:00	885	67.93	Constant	885	
08/04/14:00	453	67.93	Constant	453	
08/04/17:00	223	67.93	Constant	223	
08/04/20:00	117	67.93	Constant	117	
08/04/23:00	71	67.93	Constant	71	
08/05/02:00	51	67.93	Constant	51	
08/05/05:00	41	67.93	Constant	41	
08/05/08:00	35	67.93	Constant	35	

Reservoir Design Levels

Name	Level
Dam Crest	74.30
Maximum Design	72.60
Normal Design	71.00
Flood control	68.10

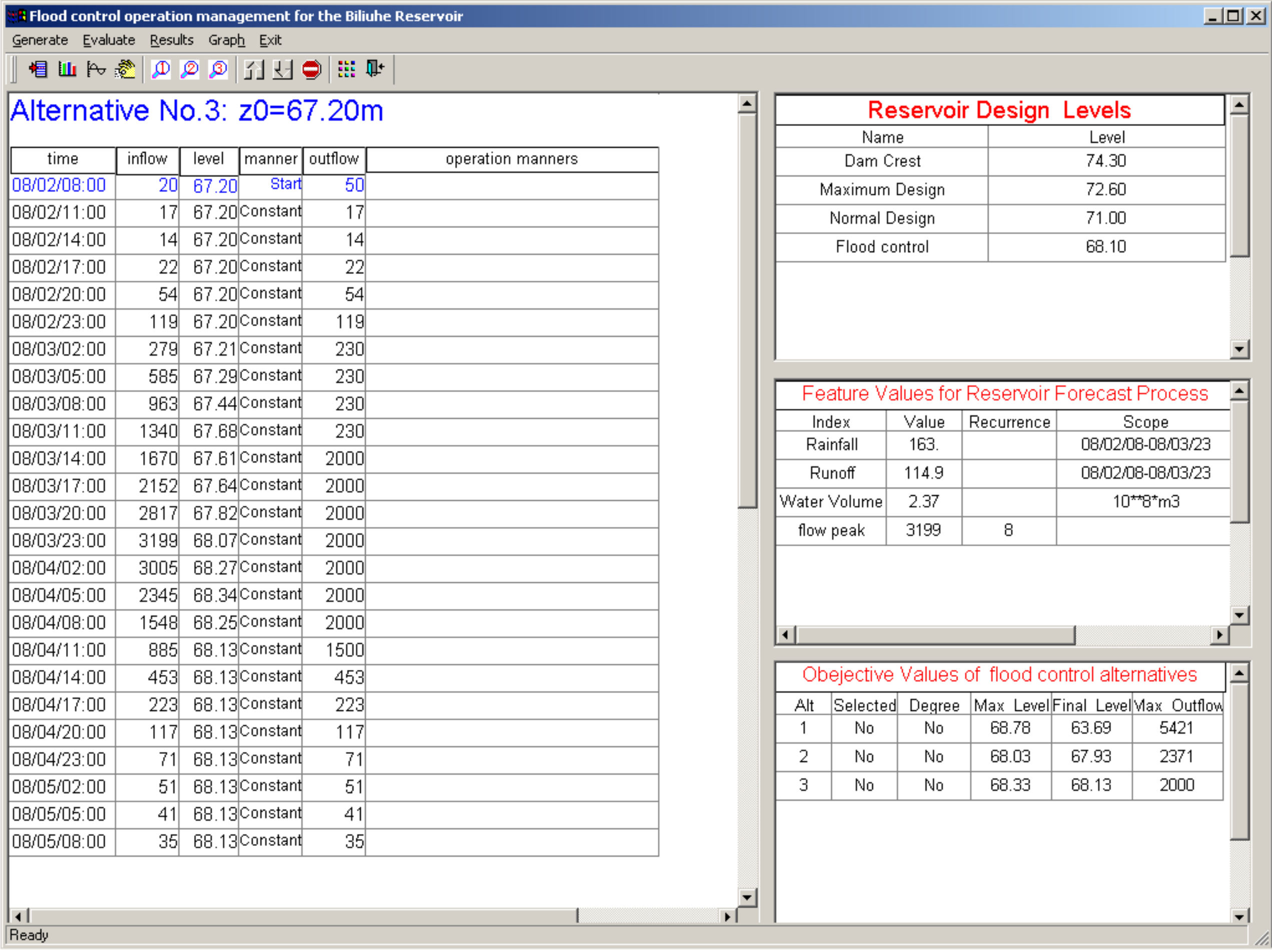
Feature Values for Reservoir Forecast Process

Index	Value	Recurrence	Scope
Rainfall	163.		08/02/08-08/03/23
Runoff	114.9		08/02/08-08/03/23
Water Volume	2.37		10**8*m3
flow peak	3199	8	

Obejective Values of flood control alternatives

Alt	Selected	Degree	Max Level	Final Level	Max Outflow
1	No	No	68.78	63.69	5421
2	No	No	68.03	67.93	2371

Figure 9 Reservoir flood control process of an interactive alternative-Alternative no.2



Flood control operation management for the Biliuhe Reservoir

Generate Evaluate Results Graph Exit

Alternative No.3: z0=67.20m

time	inflow	level	manner	outflow	operation manners
08/02/08:00	20	67.20	Start	50	
08/02/11:00	17	67.20	Constant	17	
08/02/14:00	14	67.20	Constant	14	
08/02/17:00	22	67.20	Constant	22	
08/02/20:00	54	67.20	Constant	54	
08/02/23:00	119	67.20	Constant	119	
08/03/02:00	279	67.21	Constant	230	
08/03/05:00	585	67.29	Constant	230	
08/03/08:00	963	67.44	Constant	230	
08/03/11:00	1340	67.68	Constant	230	
08/03/14:00	1670	67.61	Constant	2000	
08/03/17:00	2152	67.64	Constant	2000	
08/03/20:00	2817	67.82	Constant	2000	
08/03/23:00	3199	68.07	Constant	2000	
08/04/02:00	3005	68.27	Constant	2000	
08/04/05:00	2345	68.34	Constant	2000	
08/04/08:00	1548	68.25	Constant	2000	
08/04/11:00	885	68.13	Constant	1500	
08/04/14:00	453	68.13	Constant	453	
08/04/17:00	223	68.13	Constant	223	
08/04/20:00	117	68.13	Constant	117	
08/04/23:00	71	68.13	Constant	71	
08/05/02:00	51	68.13	Constant	51	
08/05/05:00	41	68.13	Constant	41	
08/05/08:00	35	68.13	Constant	35	

Reservoir Design Levels

Name	Level
Dam Crest	74.30
Maximum Design	72.60
Normal Design	71.00
Flood control	68.10

Feature Values for Reservoir Forecast Process

Index	Value	Recurrence	Scope
Rainfall	163.		08/02/08-08/03/23
Runoff	114.9		08/02/08-08/03/23
Water Volume	2.37		10**8*m3
flow peak	3199	8	

Obejective Values of flood control alternatives

Alt	Selected	Degree	Max Level	Final Level	Max Outflow
1	No	No	68.78	63.69	5421
2	No	No	68.03	67.93	2371
3	No	No	68.33	68.13	2000

Ready

Figure 10 Reservoir flood control process of an interactive alternative- Alternative no.3