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Research on the Method of Substation Control Flood Forecasting Based on the GIS

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Abstract—**Some of the watersheds not only have rain stations and evaporation stations, but also have one or more than one hydrological stations within it, which can provide the corresponding sections' flow processes. Therefore, when a flood forecasting model is needed to be built, in order to use those flow process data to improve the precision of the real-time flood forecasting of the watershed's outlet section, the structure of the flood forecasting model should be changed. This paper takes the Ouyanghai watershed located in Hunan province in China as the object of the study, using the DEM data of this watershed to divide the whole watershed into three sub-catchments according to the two hydrological stations and the watershed's outlet control section within it. What's more, the three sub-catchments are further divided into smaller hydrologic response units according to the natural sub-basin. The established flood forecasting model calculates the runoff and the conflux of the three sub-catchments respectively according to the hydrologic response units. The model firstly uses the two hydrological stations' flow data to correct real-timely the sub-catchments' forecasting flow, and then uses the corrected flow to calculate the flow concentration of the river channels of the watershed as a whole. The research shows that the forecasting results of the substation control flood forecasting model is better than those of the traditional flood forecasting models based only on the data of the rain stations and evaporation stations.**

Keywords-flood forecasting, GIS, substation control, real-time flood correction, hydrologic response unit

I. INTRODUCTION

Flood forecasting is an indispensable method in rational use of water resources and in flood control. For some river basins with reservoirs, the flood forecasting results will directly affect the reservoirs' operation modes, the result of the flood control, and the economic benefits of the reservoir operation. With deeper studies on the hydrological models at home and abroad, many hydrological models have now received recognition [1]. Especially with the development of the conceptual hydrological models, certain reliability has been achieved in the real business applications.

With the development of the remote sensing technology and the GIS technology, the characteristics of the watershed underlying surface can be more detailedly described and more conveniently obtained. These features include the watershed DEM, the land use, the soil classification, the leaf index, etc., and they also include some basin characteristics obtained through the GIS technology transformation, such as the drainage network, the average slope, the catchment area, and the wetness index. The characteristics of the watershed underlying surface with a distributed structure provide a strong information support for a better study on the watershed runoff characteristics. The watershed runoff process of the studied river basin can be more objectively constructed in the model structure, which to some extent improves the model's simulation ability. Particularly for those medium-sized and large-sized river basins, the significance is more obvious.

From the start of precipitation to the end of flood at the cross section, the basin process generally experiences the interception, the infiltration, the evaporation, the runoff, the overland flow, the river convergence [2], etc.. For some smaller watersheds, those hydrological processes take shorter durations, while for the medium and large watersheds, due to the long river course and the long evolution time of the flood within the river channels, the time of the peak emergence in the watershed outlet lags several hours or even days. When abundant rainfall stations in the watershed are constructed and there exists the river flow data of the multiple hydrological stations, how to make good use of the hydrologic data of the internal hydrometric stations to improve the forecasting precision of the river export stations becomes very important. By using the GIS technology to divide the river basin into sub-basins, with a separate hydrological model being establish in each sub-basin and then all the hydrological models being synthesized to construct a distributed hydrological model with a distributed structure, an effective method of improving the flood forecasting precision can then be achieved. The flood forecasting under sub-station control uses the GIS technology and combines with the watershed DEM data aim-directly to divide the river basin into sub-basins according to the positions of the watershed hydrological stations, with flood forecasting models being respectively constructed in each sub-basin [3]. The flood forecast of the sub-basins is made in up-down turn, the results of which is calibrated in real time by using the flow data of the sub-basin control stations, then by application of the river routing model in flood evolution , a top-down flood forecasting model of series- parallel combination is finally established.

This paper selects Ouyanghai River Basin as an example, using the GIS technology in the sub-catchment division and in the internal units division within each sub-catchment. In up-down turn, the runoff models in the Jiahe River Basin, the

Feixian Sub-catchment, and the Ouyanghai Sub-catchment are respectively constructed. Each sub-catchment is subdivided into different units, which are taken as the minimal hydrological response units. The distributed flood forecasting model is constructed according to the principles of the Xin'anjiang Model. The two controller nodes within the basin adopt the correction model of residuals from the regression to correct in real time the flood forecasting results of the two controllers. With the river routing model being used in the flood evolution and the downstream flood process being superimposed until to the basin outlet, a flood forecasting model with sub-station control features is finally constructed.

II. Introduction of the OuyangHai River Basin

The Ouyanghai River Basin is located in the southeastern part of Hunan province in China, midstream of the tributary of the Xiangjiang River, with the reservoir watershed area being 5409km^2. Hills are dominant within the basin, with the hilly area being about 70% of the total area. The rainy season of the basin generally starts in March, with April, May and June being the main flood seasons. During that time, the Western Pacific subtropical high pressure starts moving north and the South warm air becomes increasingly active, so when the cold and warm air mass converge with each other, a cover rain band is formed. This rain band makes frequent activities in the midstream areas of the Yangtze River, which is the main reason for the storm and flood in that period. This basin is humid with the average annual rainfall being 1474mm. In the basin, a total number of 15 rainfall telemetry stations are evenly distributed to measure and provide in real time the rainfall in 1-hour period. One watershed outlet control station and two hydrological stations, respectively the Jiahe hydrological Station and the Feixian hydrological Station, are built within the basin. Each station can provide in real time the river runoff in 1-hour period. At the outlet of the basin, an evaporation station is built to measure the daily water surface evaporation of the basin.

III. The Construction of the Flood Forecasting Model

A. GIS based Watershed Division

According to the layout of the hydrological stations within the basin and the natural watershed boundaries, based on the DEM data, the basin is divided into three sub-catchments, namely, the Jiahe sub-catchment, the Jiahe–Feixian River Basin (Feixian sub-catchment for short), and the Feixian–outlet River Basin(Ouyanghai sub-catchment for short). According to the location of the basin rainfall stations, the Thiessen Polygon Principle, and the natural watershed boundaries, and by using the GIS software, each sub-basin is subdivided into several sub-units, namely, the hydrological response units. Among them, there are 4 HRUs in the Jiahe sub-catchment, with the total area being 1534 km^2; the Feixian sub-catchment has 7 HRUs, with the total area being 2165km^2; the Ouyanghai sub-catchment has 10 HRUs, with the total area being 1771.3 km^2. Fig 1 shows the division schematic diagram of the sub- catchments and the HRUs.

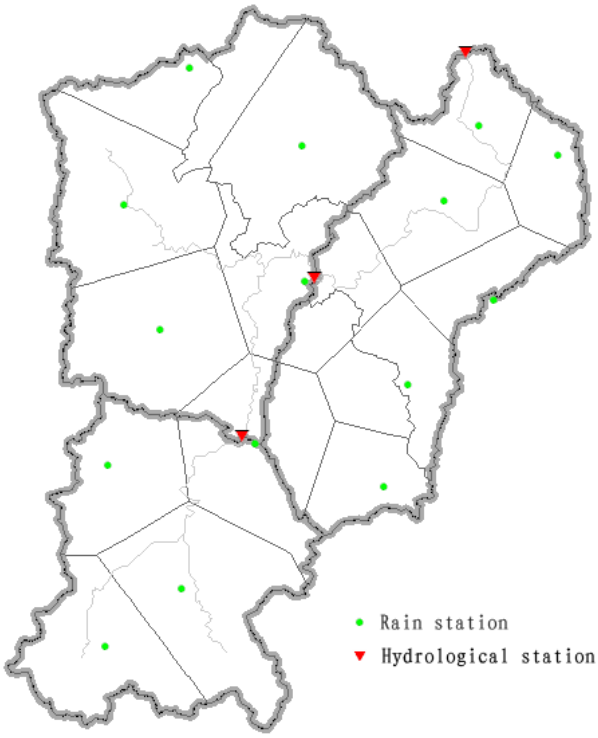

Figure 1. Sub-catchment and HRU distribution of the Ouyanghai watershed

B. The Flood Forecasting Model Structure

Based on the above divisions of the sub-basins and sub-units, the flood forecasting model of the Ouyanghai River Basin establishes independent sub-flood forecasting models in the three control stations of the sub-catchments, with the three sub-models being formed in series according to the mutual hydraulic connections. Considering the uneven rainfall of the sub-basins, the sub-units within the sub-basins are taken as the smallest hydrological corresponding units of the river basin, and the runoff model and the convergence model of each sub-unit in the Xin'anjiang River Basin are respectively constructed. In establishing the convergence models of the sub-units, the distance differences of each sub-unit from the sub-basin export are taken into account. When the sub-unit is far from the sub-basin export, the river concentration is further increased, and by using the Muskingum Piecewise

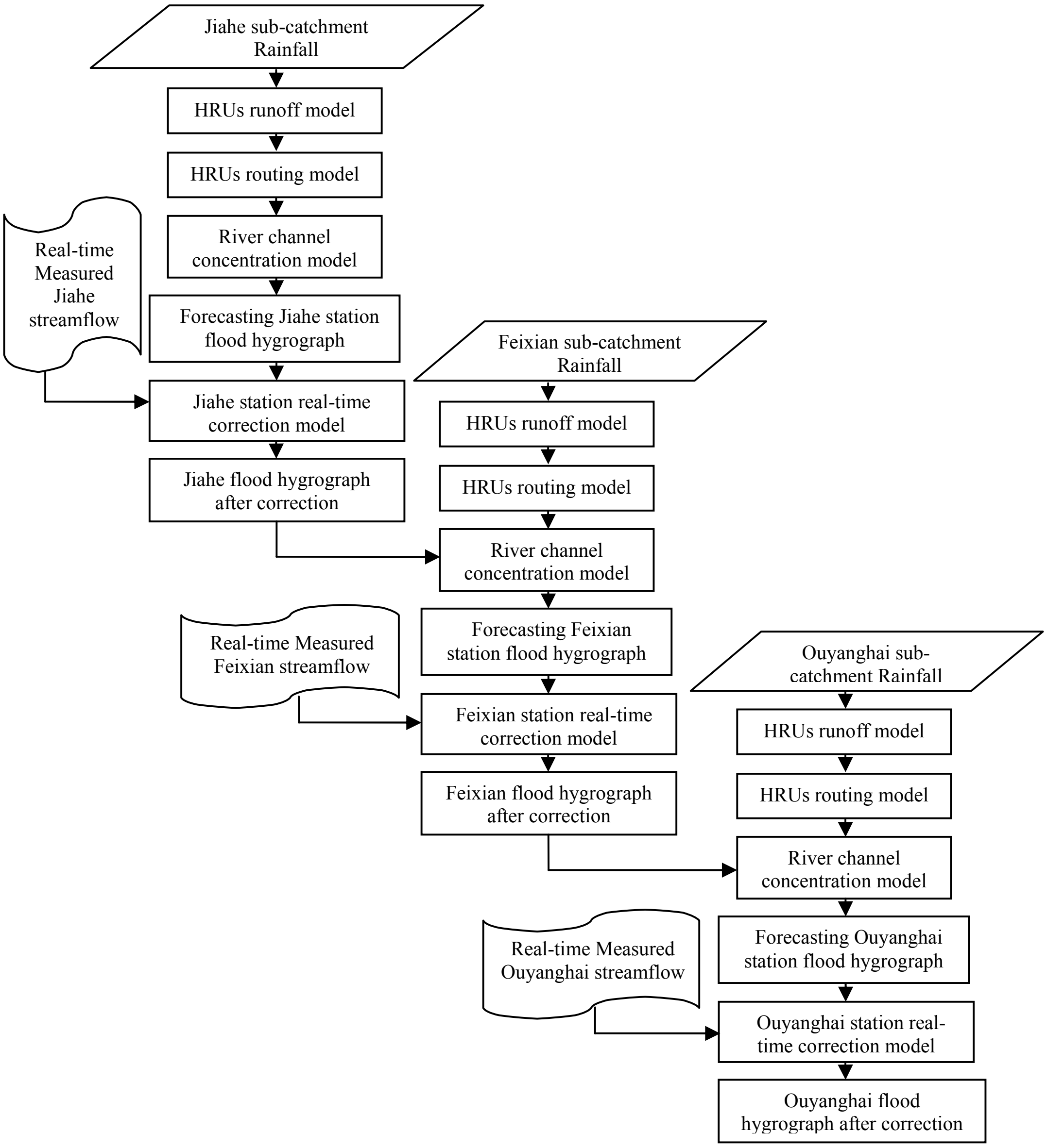

Figure 2. Flood forecasting model structure diagram of the Ouyanghai watershed

Continuous Algorithm, the flow process of the sub-unit is calculated to the sub-basin export. The sub-basins are linked up through the river concentration models of each control station and the calibration models of real-time flood residuals from regression [4]. The flood forecasting model being established is semi-distributed and has the control features of a sub-station. The general program structure of the model is shown in Fig 2.

C. The Optimization of the Model Parameters

In this study, the parameters of the forecasting models in each sub-basin are respectively optimized according to the measured historical flow data of the control stations within each sub-basin. To ensure that all the model parameters of each sub-basin are independent, in calibrating the model parameters of the Feixian Basin, the measured stream flow data of the Jiahe Station is taken as that of the Jiahe Station converging into the Feixian station; In calibrating the model parameters of the Ouyanghai Sub-catchment, the measured stream flow data of the Feixian Station is taken as that of the Feixian Staion converging into the Ouyanghai Station.

The hydrological data of the Ouyanghai River Basin from 1990 to 2007 are adopted in model parameter optimization, including the hourly rainfall of the 15 rainfall stations, the average daily evaporation of the evaporation stations of the basin, the hourly stream flow of the Jiahe Staion, the Feixian Station and the Ouyanghai Station, etc. . The hydrological data in all these years are divided into different flood screening, the floods from 1990 to 2002 being taken as the floods during the parameters calibration period, and the floods from 2003 to 2007 being taken as the validation period. Among which, the Jiahe Station has 65 flood events, the Feixian Station 48, and the Ouyanghai Station 47. The Genetic Algorithm Method is adopted in model parameters optimization, and the statistics of the simulation results of model parameters calibration is shown in Table 1.

TABLE I. SUMMARY OF THE STREAM FLOW SIMULATION RESULTS

	SN	TFN	RAR	ACE	PAR	PTAR
CP	Jiahe	51	0. 96	0. 86	0. 92	0. 82
	Feixian	27	0. 96	0. 90	0. 85	0. 89
	Ouyanghai	33	0. 88	0. 88	0. 91	0. 73
VP	Jiahe	14	0. 77	0. 84	0. 86	0. 86
	Feixian	21	0. 81	0. 88	0. 90	0. 81
	Ouyanghai	14	0. 79	0. 84	0. 86	0. 79

Note: SN=Hydrological station name; CP=Calibration Period; VP=Validation Period; TFN= Total Flood Number; RAR= Acceptance rate of runoff depth error(relative error≤0.2); ACE=Average Nash–Sutcliffe coefficient; PAR=Acceptance rate of Peak discharge error(relative error≤0.15); PTAR=Acceptance rate of Peak discharge time error(error≤3h)

As can be seen from Table 1, after the model being parameter optimized, the average Nash–Sutcliffe coefficients of the final flood forecast model are above 0.84 in both the calibration period and the validation period; the acceptance rates of peak discharge error of both period have achieved above 0.85; the acceptance rates of runoff depth error are both above 0.77, with the maximum up to 0.96; the acceptance rates of the peak time error of both period are above 0.73, with the maximum up to 0.89. The simulation results of the three stations in the constructed Ouyanghai flood forecasting model are all very high.

IV. CASE STUDY

After the model parameters being determined in the optimizing process, the sub-station control flood forecasting model of the Ouyanghai watershed is established. The application of this model in the three flood events, respectively the flood in January 15, 2010, the flood in April 12, 2010, and the flood in June 11, 2010, has been put into practice in the study.

Figure 3 shows the comparison of the simulation hydrograph results of the stream flow in the three flood events. It can be seen from Fig 3 that the sub-station control flood forecasting model can give much better flood simulation results than those of the general common forecasting models. Especially in the peak discharge simulation, the relative error is much smaller than that of the commonly-structured flood forecasting model.

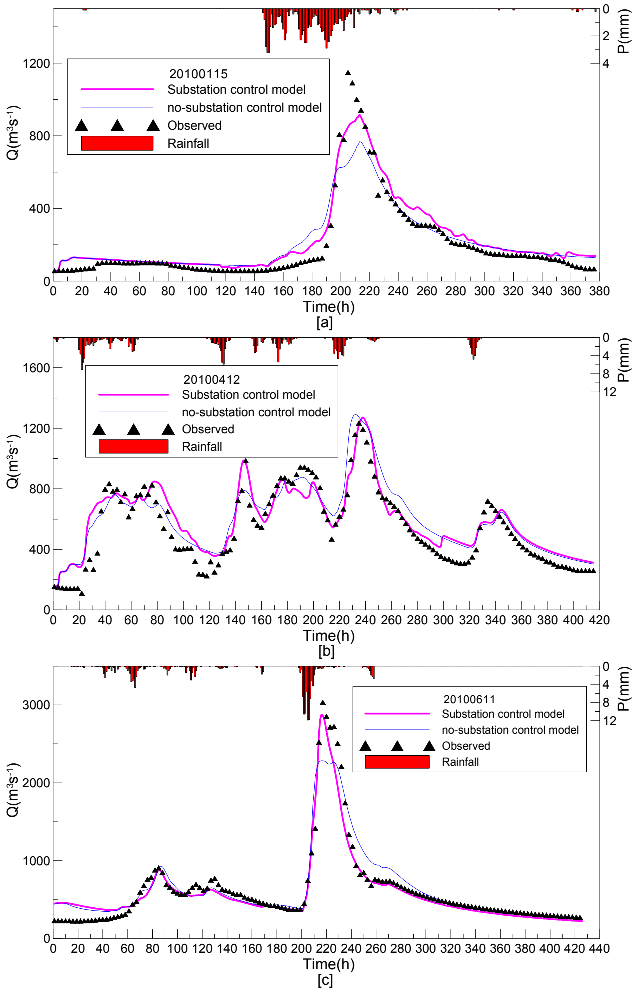

Figure 3. Comparison of the simulated hydrograph results for the streamflow of three flood events(a ~ c)

V. SUMMARY AND CONCLUSION

Based on the GIS technology, the distributed conceptual hydrological model, and the real-time flood correction model, a real-time flood forecasting model with sub-station control characteristics is constructed. The application of the model in the Ouyanghai River Basin indicates that the model can be well applied to the flood forecasting in those medium and large basins with complicated runoff and convergence characteristics, which has achieved high simulation accuracy. The flood forecasting method under sub-station control has the following advantages:

1） The basin can be divided into different sub-basins and sub-units, and the effects of the changes in the basin underlying surface to the flood forecasting model are fully accounted;

2） The flood processes of the control stations in the upstream are corrected in real time by the real-time correction model. As the measured flood peak of the upstream section appears some time later than that of the downstream section, inputting the flood forecasting results calibrated by the upstream data to the downstream flood forecasting model will then improve the flood forecasting accuracy of the downstream. Especially for the peak discharge, the forecast of the peak time in the upstream will help improve the forecast accuracy of the peak time in the downstream;

3）As far as the impacts of human activities are concerned within the watershed, such as the irrigation water in the watershed, with the effects of which to the runoff and convergence flow of the sub-basins being quantified, the corresponding flow processes of the sub-basins will be changed to simulate the effects of which to the runoff and convergence flow of the sub-basins, so that it can be more objective and accurate to forecast the flood processes in the downstream stations;

4）The flood forecasting results of the basin river sections can be provided to improve the ability of the flood warning and watershed management within the basin.

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