〈論　文〉

하천유역의 홍수관리 시스템 모델

Flood-Flow Managenent System Model of River Basin

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Abstract A flood-flow management system model of river basin has been developed in this study. The system model consists of the observation and telemetering system, the rainfall forecasting and data-bank system, the flood runoff simulation system, the dam operation simulation system, the flood forecasting simulation system and the flood warning system. The Multivariate model(MV) and Meteorological-factor regression model(FR) for rainfall forecasting and the Streamflow synthesis and reservoir regulation(SSARR) model for flood runoff simulation have been adopted for the development of a new system model for flood-flow management. These models are calibrated to determine the optimal parameters on the basis of observed rainfall, streamflow and other hydrological data during the past flood periods. The flood-flow management system model with SSARR model (FFMM-SR, FFMM-SR(FR) and FFMM-SR(MV)), in which the integrated operation of dams and rainfall forecasting in the basin are considered, is then suggested and applied for flood-flow management and forecasting. The results of the simulations done at the base stations are analysed and were found to be more accurate and effective in the FFMM-SR and FFMM-SR(MV).

1. INTRODUCTION

The flood-flow management and control in the river basin is mainly carried out to reduce flood damages by accurately forecasting upstream and downstream flood runoff caused by storms in the area. The overall flood management in the basin during the flood period should be performed through accurate rainfall and flood forecasting as well as integrated operation of dams in the basin. In this respect, the flood forecasting system has been established to cope with severe flood conditions in the Nakdong river basin, Korea(Lee, et al, 1987). However, the existing system model in which the integrated operation of dams in the basin is not considered is not a very accurate forecasting tool (Lee, 1988-1990 and 1989).

Consequently this study attempts to develop a new flood-flow management system model with the application of newly developed techniques of integrated optimal operation of dams and rainfall forecasting in the basin(Lee, 1992).

2. THEORETICAL STRUCTURE OF SYSTEM MODEL

System Structure

The flood-flow management system is made up of 6 subsystems to perform the flood-flow forecasting and management in the river basin. Accordingly, in this study, the flood-flow management system consists, as in Fig. 1, of an ob-

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servation and telemetering system of data, a rainfall forecasting and data-bank system, a flood runoff simulation system, a dam operation simulation system, a flood forecasting simulation system and a flood warning system.

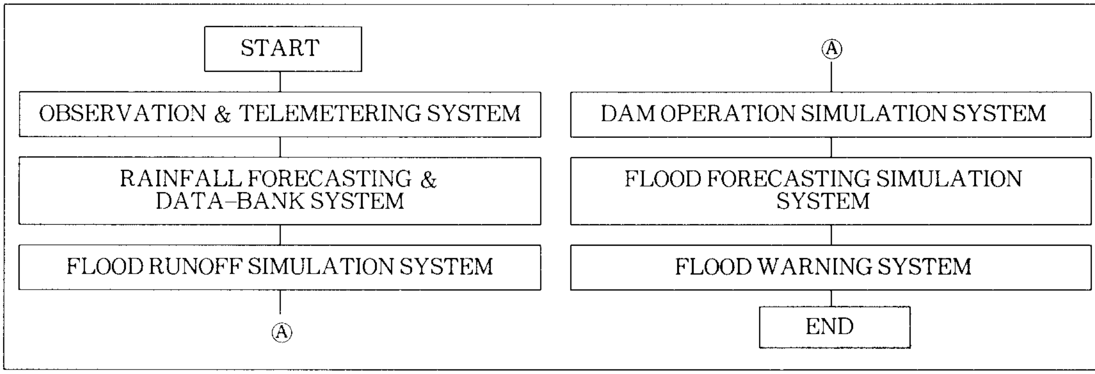

Fig. 1 Structure of Flood–Flow Management System.

In each subsystem, calibration of parameters or system simulation is carried out for the transmitted hydrologic data from T/M gauging stations, and the flood-flow forecasting and management are performed for the historical or predicted rainfall patterns according to these subsystems(Lee, 1989 and 1992).

Rainfall Forecasting Model

Two mathematical models are selected and used to predict rainfall in the river basin namely : the Meteorological-factor regression model (FR Model) and the Multivariate rainfall forecasting model(MV Model).

(1) FR Model

The FR model(Lee, 1992) is a regression model of meteorological factors which are believed to be the most effective components in rainfall phenomena under the assuption of their accurate prediction. The rainfall can be predicted by using the following multiple linear regression equation in the relation between meteorological characteristic factor $Z_j (j=1, 2, 3, \cdots\cdots, k)$ and rainfall Y:

$$Y=\beta_0+\beta_1 Z_1+\beta_2 Z_2+\beta_3 Z_3+\cdots\cdots+\beta_k Z_k+e \quad (1)$$

where, e is an error in the estimation of dependent variable Y, β_0 is a constant and $\beta_j (j=1, 2, \cdots\cdots, k)$ is the coefficient of variable Z_j. These parameters are determined from the occurrence characteristics of storms by using the past meteorological data series, and AR(1), AR(2), ARMA(1, 1) and ARMA(2, 1) models are used on the basis of Box-Jenkins time series as the prediction model of meteorological factors

(2) MV Model

The MV model(Lee, 1992 and Johnson and Bras, 1978) is a nonstationary multivariate model for short-term rainfall prediction at multiple locations and at multiple values of time lead. In the model, vector of rainfall rates at time step t at N locations(x_N, y_N), **i**(t), is described as follows:

$$\mathbf{i}(t)=\mathbf{m}(t)+\mathbf{r}(t) \quad (2)$$

where, **m**(t) is vector of mean values at time step t, and **r**(t) is vector of residuals at time step t and can be defined as the following form of a diagonal standard deviation matrix $\Sigma(t)$ and a zero mean, unit variance, random vector process $\varepsilon(t)$.

$$r(t)=\Sigma(t)\cdot\varepsilon(t) \tag{3}$$

At issue in this model is the dynamics of the residual term $r(t)$. The residual is assumed to evolve in time according to a nonstationary Markov model of the form,

$$r(t+\tau)=A(t,\tau)\cdot r(t)+B(t,\tau)\cdot W(t,\tau) \tag{4}$$

where, $A(t, \tau)$ is N × N state transition matrix at time step t for a transition τ steps into the future, $W(t, \tau)$ is N × 1 vector of disturbances with zero mean value, and $B(t, \tau)$ is N × N matrix giving the effect of the noise terms at time step t on the residuals at time step $t+\tau$.

For the prediction points a measurement equation is written,

$$Z(t)=q(t)-m(t)=r(t)+v(t) \tag{5}$$

where, $q(t)$ is N × 1 vector of observed rainfall, $m(t)$ is N × 1 vector of mean values, $r(t)$ is N × 1 vector of true values of residual, $v(t)$ is N × 1 measurement errors, $z(t)$ is N × 1 vector of measured residuals and N is number of points predicted. Above equations (4) and (5) form the classic framework for the discrete Kalman filter and the filter equations can be written for a one-step lead.

The rainfall prediction at any future time $t+\tau$ is given by

$$i(t+\tau \mid t)=m(t+\tau)+r(t+\tau \mid t) \tag{6}$$

In order to implement the rainfall prediction method described above it is necessary to perform the sequence of operations which are divided into three phases : estimation of necessary statistics, estimation of system dynamics parameters and predictions, where estimations of mean and variance, covarince of normalized residuals, and storm velocity are included as the most important parameters.

Flood Runoff Simulation Model

The Streamflow synthesis and reservoir regulation(SSARR) model is selected for the flood runoff simulation in the river basin from the comprehensive studies on the applicability(Lee, 1988-90, 1989 and 1992). This model (Rockwood, 1968 and USAED, 1972) is a mathematical model by which streamflow can be synthesized from the evaluation of rainfall data. The model is comprised of three basic components : a watershed model, a river channel model and a reservoir regulation model. The watershed model can be explained by using the simple analogy as shown in Fig. 2. Before routing is made, the runoff components namely : surface, subsurface and baseflows are determined from the established empirical relationships of the basin characteristics in the model. These parameters are (a) Soil moisture index (SMI) and runoff percent(ROP), (b) Effectiveness of evapotranspiration(KE) and rainfall intensity(RI), (c) Baseflow infiltration index (BII) and baseflow percent(BFP) and (d) Surface(S) and subsurface(SS) separation.

The basin runoff is computed from given rainfall through the relationships in (a) and (b). The runoff is then decomposed into surface, subsurface and baseflow components through the relationship in (c) and (d).

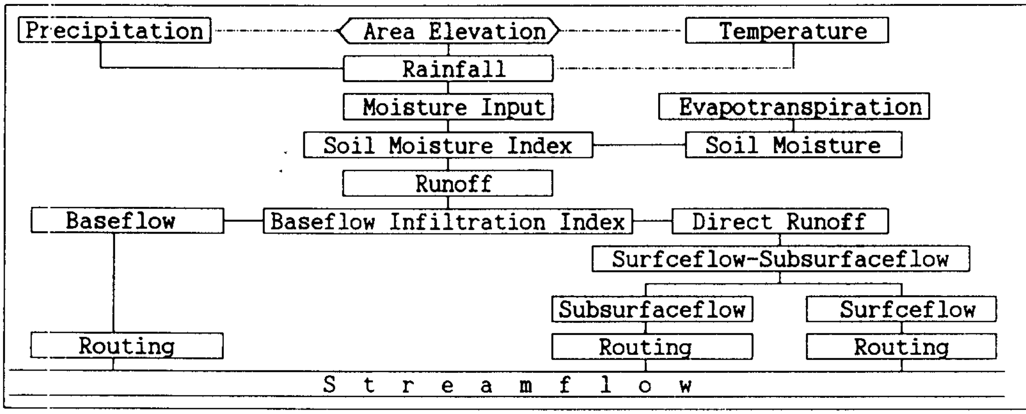

Fig. 2 Conceptual Diagram of SSARR Model.

The three components of the runoff are then routed using the basic routing equation as follows:

$$O_2 = t \cdot (I_m - O_1)/(T_s + 0.5 \cdot t) + O_1 \qquad (7)$$

where, O_1 and O_2 are the outflows from the subreach at time t_1 and t_2, respectively, I_m is the mean inflow which is equal to $(I_1 + I_2)/2$, t is the time interval, and T_s is the time of storage. The number of subreach N and time of storage T_s are assumed for each mode of flow and they are to be determined by trial and error during calibration. The routed surface, subsurface and baseflows are then added as the outflow of a river basin.

3. APPLICATION OF FLOOD-FLOW MANAGEMENT SYSTEM MODEL AND DISCUSSIONS

Study Basin Characteristics

The Nakdong river basin, which is located in the southeastern part of Korea as shown in Fig. 3, is selected as the study basin. In this basin, there are four existing multi-purpose dams and one estuary barrage. Plus 56 T/M rainfall gauging ststions, 44 T/M water-stage gauging stations and 4 dam water-stage gauging stations are in operation for the flood-flow management and forecasting at the moment. This basin and channel reach, for the sake of operating the flood-flow management system, are subdivided in consideration of the topographic conditions of the basin, the channel conditions, the land use and the water management as shown in Fig. 3. In the division into sub-basin, the location and distribution of T/M gauging stations are also considered in tributaries and mainstream. Thus, the basin is subdivided into six sub-basins in the mainstream and eighteen sub-basins in the tributary area.

Next, the division of channel reach is performed on the reaches necessary for channel routing, which are similar in channel runoff conditions. Therefore, the channel reach of this basin is divided into nine reaches in the mainstream and six reaches in the tributaries.

Model Parameters Calibration

The meteorological and hydrologic data including main storm events are selected during the wet season from June to September between 1975 and 1991, and the calibration is car

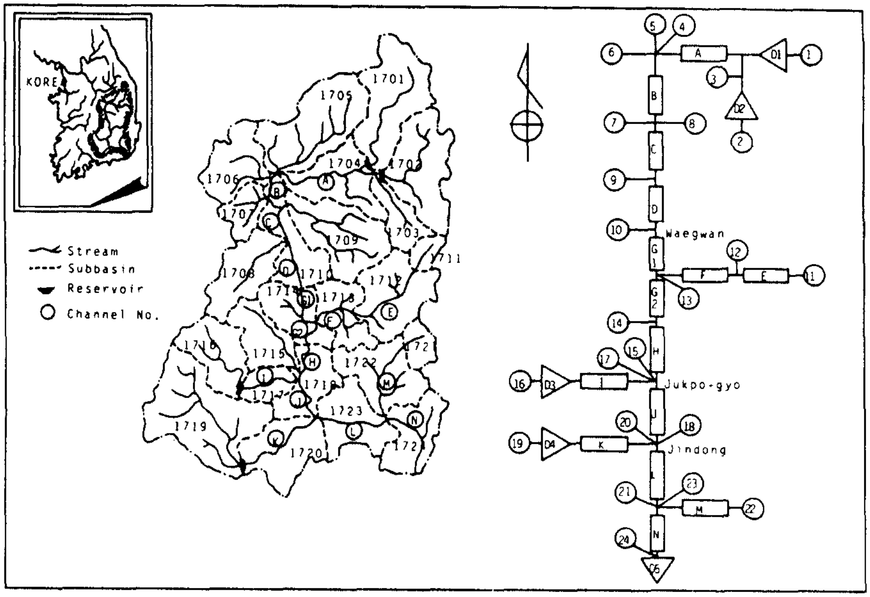

Fig. 3 System Diagram for Flood-Flow Management in Nakdong River Basin.

ried out on both model parameters of rainfall forecasting and flood runoff simulation.

(1) Calibration of Rainfall Forecasting Model

The multiple regression analysis between meteorological factors and rainfall is carried out for two types of storms, frontal-type storms and typhoon/low atmospheric pressure-type storms, to calibrate parameters in the FR model. The results of calibration show that the most effective components in rainfall phenomena among meteorological factors are 24hr-variation of atmospheric pressure, daily mean temperature, daily mean sea atmospheric pressure and cloud amount by which FR models are determined in the basin. The prediction models of these factors are also determined as ARMA(2, 1) model from the calibration.

Next, the calibration on the MV model is performed to determine model parameters from the analysis of necessary statistics, storm distributions, covariance estimates, storm velocity and direction by which the MV model is determined for real-time rainfall prediction.

(2) Calibration of Flood Runoff Simulation Model

In the SSARR model, it is difficult to decide the appropriate values of parameters to apply to actual situations. In particular, since the calibration of model parameters in each small basin is very difficult, three groups of sub-basins, upper, middle and lower zones, are divided to calibrate parameters such as SMI-ROP, KE-RI, BII-BFP and RGS-RS. By assuming the model parameters such as the empirical rainfall runoff relationships, the time of storage T_s and the number of routing increment N in the beginning of calibration, these parameters are fed as input to the model and the simulated hourly hydrographs are compared with the observed hydrographs at various base stations. The values of these parameters are adjusted by trial and error until an adequate agreement is obtained. Satisfactory results of model calibration are obtained as shown in Fig. 4.

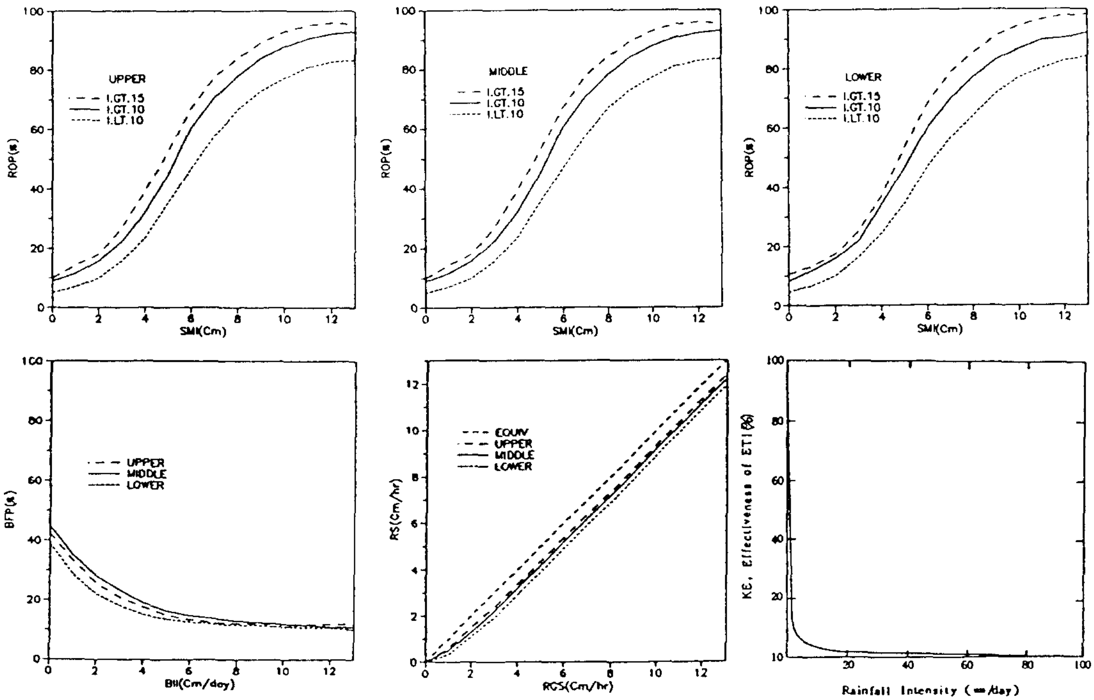

Fig. 4 Optimal SSARR Model Parameters.

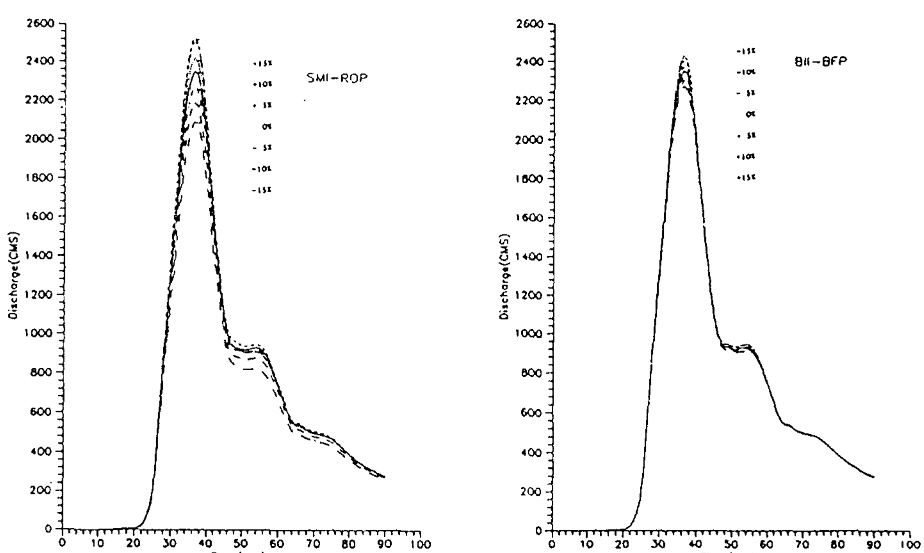

Fig. 5 Effect of Variation of Model Parameters on Runoff.

The effect of variation of these parameters is also examined by the sensitivity analysis(ME, MSE, Bias, VER and QER) from which sensitive variation of flood runoff is found according to the change of parameters as in Fig. 5.

Model Application and Discussions

The flood-flow management model with SSARR model(FFMM-SR model), in which the rigid ROM technique is adopted as the optimal integrated operation rule of dams in the river basin(Lee, 1988-90 and 1992), is applied in the flood management system in the Nakdong river basin. The forecasting or management decisions are generally done on the main storms during the flood period from June to September each year. The results of system management are compared with those of the existing flood-flow management models without the integrated operation of dams(FFMM model) and with the integrated operation of dams(FFMM-SF model) in both of which the Storage function model is used as the basic simulation model. The typical results of management at Jindong gauging station in the lower Nakdong river are presented as shown in Fig. 6 for the years 1990 and 1991. The management results by the FFMM-SR model show the most effective flood-flow management and integrated operation of dams in the basin.

Next, this FFMM-SR model associated with the rainfall forecasting models, the FFMM-SR (FR) model in the Meteorological factor regression model(FR model) and the FFMM-SR(MV) model in the Multivariate forecasting model (MV model), are then applied to the flood-flow management system in the basin according to the process of system simulation as shown in Fig. 7. The results of management at the same gauging station are presented in Fig. 8, where the results associated with the rainfall forecasting model show a bit less of the values of flood-flow and some differences in peak time than those of FFMM-SR model.

But the results show that the flood-flow management with the rainfall forecasting show good agreement with the corresponding values of the FFMM-SR model. The FFMM-SR(MV) model resulted in more effective management than could be obtained by just following the FFMM-SR(FR) model in general.

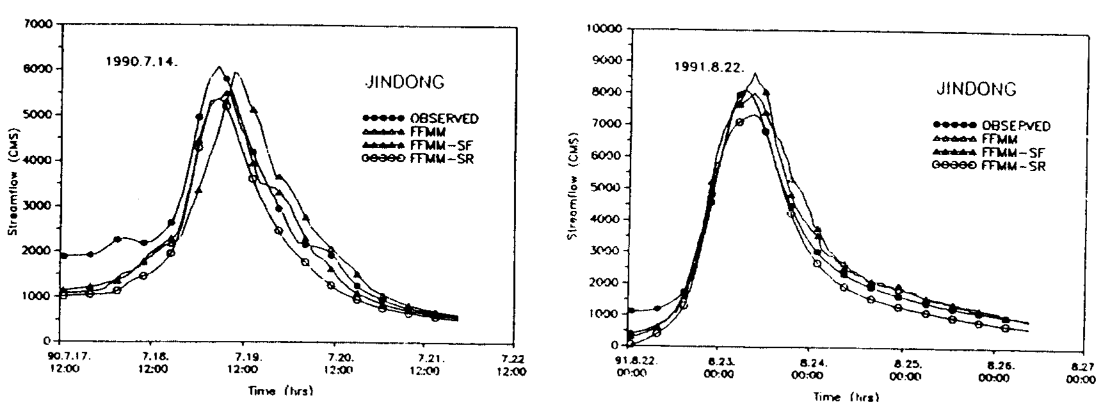

Fig. 6 Flood-Flow Management at Jindong Station in Nakdong River.

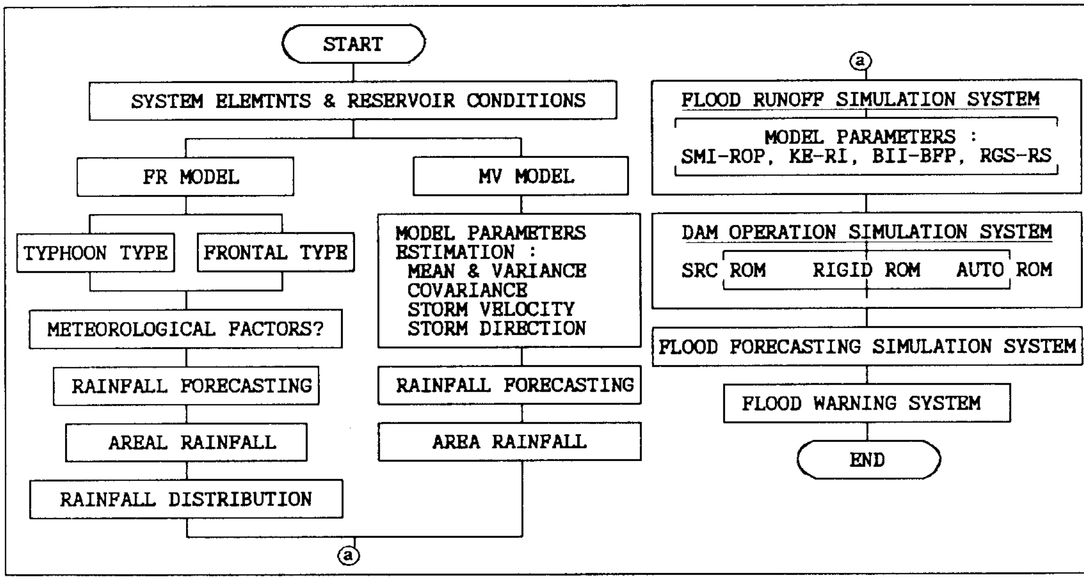

Fig. 7 Simulation Process of Flood—Flow Management System associated with Rainfall Forecasting Model.

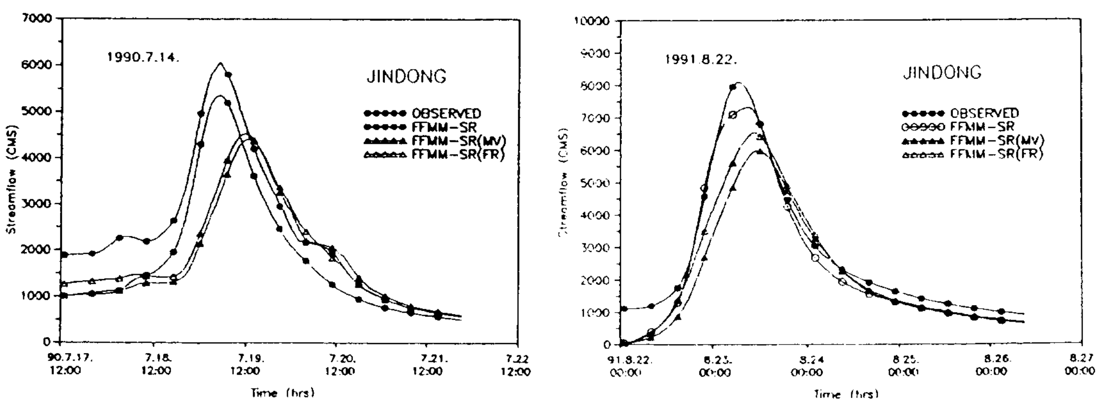

Fig. 8 Flood-Flow Management associated with Rainfall Forecasting Model.

4. CONCLUSIONS

A flood-flow management system model and its algorithm have been developed in this study for the Nakdong river basin and the system model consists of the observation and telemetering system, the rainfall forecasting and data-bank system, the flood runoff simulation system, the dam operation simulation system, the flood forecasting simulation system and the flood warning system. The Meteorological-factor regression model(FR model) and the Multivariate model(MV model) for rainfall forecasting and the Streamflow synthesis and reservoir regulation model (SSARR model) for flood runoff simulation are chosen as the mathematical models for flood-flow management and calibrated on the basis of observed rainfall, streamflow and other hydrological data during the past flood periods between 1975 and 1991. Good results are obtained in the calibration from which optimal model parameters are determined. After the calibration, the flood-flow management model with the SSARR model(FFMM-SR model) in which the rigid ROM technique is adopted as the optimal integrated operation rule of dams is applied in the flood-flow management system and compared with the existing flood-flow management models without the integrated operation of dams(FFMM model) and with the integrated operation of dams(FFMM-SF model) in both of which the Storage function model is used as the basic simulation model. The management results by the FFMM-SR model show the most effective use flood-flow management in the basin.

Next, the FFMM-SR models associated with the rainfall forecasting models, FFMM-SR(FR) model and FFMM-SR(MV) model, are applied in the flood-flow management system. From these management results, the flood-flow management with the rainfall forecasting show good agreement with the corresponding values of the FFMM-SR model using observed rainfall values, and the FFMM-SR (MV) model provides more effective flood-flow management in general.

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