INFLOW PREDICTION FOR DECISION SUPPORT SYSTEM OF RESERVOIR OPERATION

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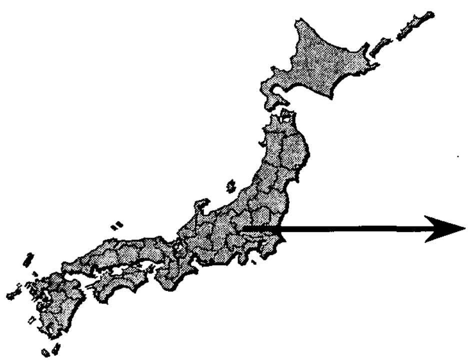
ABSTRACT : An expert system, to assist dam managers for five dams along the Saikawa River, has been developed with a primary objective of achieving swift and accurate reservoir operation decision-makings during floods. The expert system is capable of supporting on decision–makings upon establishment of flood management procedure and release/storage planning. Furthermore, an attempt was made to improve reservoir inflow prediction models for better supporting capability. As a result, accuracy on prediction of inflow up to 7 hours ahead was improved, which is important for flood management of the five dams, using neural network. The neural network inflow prediction models were developed for each types of floods caused by frontal rainfalls, snowmelt and typhoons, after extracting relevant meteorological factors for each.

1 1.INTRODUCTION

This paper outlines an expert system developed to support operation of the five-dams system (Ikusaka, Taira, Minochi, Sasadaira and Odagiri) for hydroelectric power generation plants located along the Saikawa River, which is a tributary of the Shinano River (Figure 1). All five dams are owned and operated by the Tokyo Electric Power Company, Inc. The paper reports results of the models used for long-term prediction of inflow, which plays an important role to provide appropriate support functions.



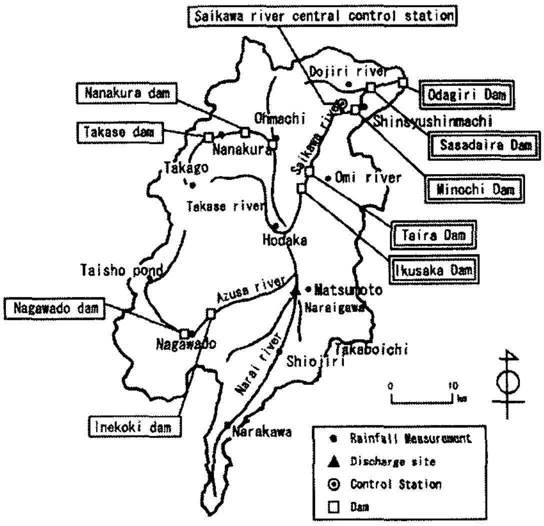


Figure 1 Location of the Saikawa River basin

2 DECISION SUPPORT EXPERT SYSTEM FOR RESERVOIR OPERATION

For proper operation of reservoirs during floods, dam managers are required to make precise and timely judgment on establishment/cancellation of flood control procedures, preparation of release/storage plans and many others, based on available hydrological and meteorological data. The Decision Support Expert System was designed to perform supporting functions for status monitoring, decision-making on establishment/cancellation of flood control procedure and release/storage planning, as shown in Table 1.

Results of inflow prediction greatly affects particularly on functions for supporting decision-making on establishment/cancellation of flood control procedure and release/storage planning among the three major functions of the System.

Table1 Functions of Decision Support System for Reservoir Operation

Function	Support	Description
Status monitoring	* Providing hydrological and meteorological information and dam reservoir data	* Monitoring of wide-area rainfall zone position, its speed of movement, and rainfall strength * Monitoring of weather alarm and warning * Monitoring of position and predicted path of typhoon * Monitoring of rainfall, river flow and increase tendency in upstream area * Monitoring of dam reservoir level and inflow, their increase tendency, and release from reservoir
Establishment/ cancellation of flood control procedure	* Suggesting the need to establish/cancel flood control procedure based on the hydrological and meteorological data according to dam operation rules	* Calculation of confidence to express possibility of flooding and judgment of flood control procedure based on it * Judgment of establishment/cancellation flood warning stage based on hydrological and meteorological information * Suggestion of the need to establish/cancel flood warning procedure (indication of reasons why)
Release / storage planning	* Predicting time for flow to reach flood flow based on inflow prediction, inflow tendency and meteorological and hydrological phenomena in upstream area * Making Release/storage planning of each dams * Making of based on circle representing position in case of typhoon	* Prediction of inflow into dam reservoir (using fuzzy inference, neural network, etc.) * Prediction of time to reach flood flow * Calculation of time to reach target flow level * Calculation of additional release

3 PREDICTION OF INFLOW BY THE SYSTEM

3.1 A short-term prediction up to 3 hours ahead:

Prediction of inflow up to 3 hours ahead is performed in two stages by using three methods including the storage function method followed by correction of the mean values of prediction results through fuzzy inference.

Prediction was carried out using the three methods as shown in Table 2. The inflow into the reservoir located at the furthest upstream among the five dams along the Saikawa River could be predicted even when hydrological and meteorological data for the upstream region are not available, and certain degree of accuracy could be maintained for each prediction method. Prediction results of the three methods vary during the start-up period of flooding. In practice, however, experienced dam managers can make comprehensive prediction on inflow into reservoirs, referring to the prediction results, taking into consideration of rainfalls in the upstream region and data on inflow into the Ikusaka reservoir, relying on their empirical judgment. The inflow prediction method in the System is represented by rules according to fuzzy inference, so that the final results match well with predictions made by experienced managers. Thus, the System is capable of supporting comprehensive judgment on precise prediction of inflow.

To be specific, for judgment on the prediction results obtained by the three methods, four parameters are described in a fuzzy set and standardized in the if-then format. Control algorithm of fuzzy inference is expressed by (Kojiri & Sakakima, 1994):

If $R(t)$ is Ai and $QI(t)$ is Bj and $\Delta QY(t)$ is Ck then $\alpha(t)$ is Zijk (1)

where $R(t)$: average rainfall in the upstream catchments along the Saikawa River (mm/h); $QI(t)$: inflow into the Ikusaka reservoir (m^3/s); $\Delta QY(t)$: difference in prediction results for 3 hours ahead obtained from the three methods (maximum - minimum; m^3/s); $\alpha(t)$: corrective multiplication factor (0.7 to 1.3) for arithmetic mean of the prediction results for 3 hours ahead obtained by the three methods (excluding any values equivalent to or less than 50% of the maximum predicted value from mean calculation). Ai, Bj, Ck, Zijk are fuzzy sets for each parameter, expressed in terms of membership functions. Certainty of the "if" part is calculated using the membership function. Corrective multiplication factor for the mean values of prediction results in the "then" part is calculated by the min-max centroid method.

Table 2 Outline of the Three Prediction Methods

Method	Outline	Basic equation
Inflow tendency method	Predicts inflow assuming inflow change tendency at Ikusaka Dam 3 hours ago and at the current time continue for more 3 hours.	Q(t+3) = (Q(t) - Q(t-3)) + Q(t),Q(t): inflow to Ikusaka Dam, t : time
Simple prediction	Predicts inflow into Ikusaka Dam 3 hours ahead based on the inflow into upstream reservoirs.	QI(t+3)=α{QN(t)+QT(t)}+QR(t),α={QI(t)- QR(t-3)}/{QN(t-3)+QT(t-3)} QI(t): inflow into Ikusaka Dam, QN(t): inflow into Nagawado Dam QT(t): inflow into Takase Dam, QR(t): discharge of Narai River α : coefficient t : time
Storage function method	Predicts inflow up to 7 hours ahead using the following information: • Rainfall observatories • Average rainfall in catchment basin concerned based on Thiessen coefficient • Release from upstream dam (Inekoki Dam and Ohmachi Dam) • Predicted rainfall (3 hrs ahead): given by Meteorological Agency as average rainfall in catchment basin	$S = KQ^P$, dS/dt = Re - Q S: storage height in catchment area (mm), Q: run-off height (mm) Re : precipitation (mm), K and P: constant

3.2 Prediction of inflow into reservoirs by neural network:

Based on the past flood experiences, 6 to 7 hours are needed to lower reservoirs water levels up to specified level for preliminary release. Therefore, precise inflow prediction for approximately 7 hours ahead is necessary for accurate judgment on the time to start the preliminary release. The storage function method provides prediction results of inflow approximately 7 hours ahead based on the input of predicted rainfall values. However, precision of prediction for rainfall during recent floods has shown a tendency to decline as the prediction time-span increased. Thus, it is difficult to predict inflow accurately 7 hours ahead only through the storage function method.

Hence, application of neural network to reservoir inflow prediction was studied, in order to achieve precise prediction of inflow into reservoir over long hours ahead. The neural network is one of the most effective and powerful AI technology capable of simulating the relationship between the hydrological/meteorological conditions in catchment and inflow into the Ikusaka reservoir 7 hours ahead, after learning patterns pertaining to past floods.

(a) Issues on conventional prediction model

The actual and predicted rainfalls in upstream catchments (taking the mean values in the catchments for both), release from upstream dams, and inflow into the Ikusaka reservoir were considered as input parameters for the conventional neural network model. Connection weights of neurons Wji were calculated using past six flood events data for training the network, and the back-propagation method was employed to limit the error within 10 m^3/s.

For evaluation of accuracy of the prediction model, input data other than those past flood events used in the training of the model were considered, predicted results were compared with their actual values. Prediction error obtained by the following equation was used as an accuracy evaluation index:

$$E = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Q_c(i) - Q_0(i)}{Q_0(i)}\right)^2 \quad (2)$$

where E: prediction error; n: number of hours for prediction; Qo(i): actual flow at time i; and Qc(i): predicted flow at time i.

The results of prediction accuracy evaluation varies for each flood studied, as shown in Table 3. The reason for low accuracy could be attributed to the fact that the prediction model relies heavily on similarities with past rainfall and discharge patterns, without inputting of meteorological and hydrological factors of the catchments those affect inflow into dams 6 to 7 hours ahead. Another reason is the use of only one model to predict inflow occurring under various seasonal climatic conditions such as snowmelt, rainy seasons, typhoons, etc. In order to improve further accuracy of prediction, it would be necessary to introduce meteorological factors that enable prediction of rainfall several hours ahead, with developing models for various type of floods caused by different meteorological factors and adding/analyzing other flood events for training of the models.

Table 3 Prediction errors obtained at prediction accuracy evaluation

Floods studied	Prediction error	Floods studied	Prediction error
1995.05.16	0.242	1995.09.17	0.770
1995.07.03	0.155	1996.08.29	1.355

(b) Improved prediction models

With viewing of discharge characteristics observed in the catchment of the Ikusaka reservoir, information on predicted rainfall is indispensable for prediction of inflow at 4 or more hours ahead. However, it has known that use of information on predicted rainfall in the model varied prediction accuracy. Thus, it was decided to develop neural network models for various type of floods caused by different meteorological factors of rainfall, after extracting parameters which enable prediction of rainfall approximately 3 hours ahead, in order to improve accuracy of prediction up to 6 to 7 hours ahead. The meteorological factors which were considered include rainy seasons (fronts), snowmelt and typhoons.

(i) Input parameters common to all prediction models

The common input parameters include data on hydraulic and hydrological conditions that affect inflow into the Ikusaka reservoir. The past time period of data handling for each input parameters was decided with taking account of travelling time of water to reach the Ikusaka reservoir and other factors.

* Rainfall measurements taken at observation stations (up to 6 hours ago from the present time).
* Release from the Inekoki and Ohmachi reservoirs (up to 6 hours ago from the present time).
* Discharge in the Narai River (up to 3 hours ago from the present time).
* Inflow into the Ikusaka reservoir (up to 3 hours ago from the present time).

(ii) Input parameters for each prediction model

Frontal rainfalls are seems to be determined by the location and direction of movement of the rain front. Therefore, factors related to frontal rainfalls during rainy seasons include aerological data and location and direction of movement of rain fronts. However, aerological data are announced only twice a day and data on location and direction of movement of fronts are difficult to provide as on-line digital data. With considering these difficulties, it was decided to consider only the common input parameters in the model to predict inflow during floods caused by rain front development.

Air temperature, direction and speed of wind and insolation are potential meteorological factors related to snowmelt and snow accumulation as well. Thus, data on air temperature, direction and speed of wind, and sunshine hours were chosen as input parameters for inflow prediction during floods caused by snowmelt, which are available as on-line digital data from AMeDAS, etc.

The major factors related to prediction of rainfalls during typhoons include course of typhoons (present and predicted locations) and their severity (Kojiri & Ito, 1996). Hence, the available digital data on present and predicted courses of typhoon and atmospheric pressure at their centers were considered as input parameters to predict inflow during floods caused by typhoon.

(iii) Development of the Prediction Model

Figure2 shows a basic configuration of the improved prediction model. Input parameters into the prediction model are indicated as "input parameters common to all the models + input parameters for each model", and inflows are predicted up to 7 hours ahead through the System.

Furthermore, flood events to be used for training of neural network prediction models were determined. Major flood events between 1993 and 1996 were listed and classified them according to meteorological factors which caused floods.

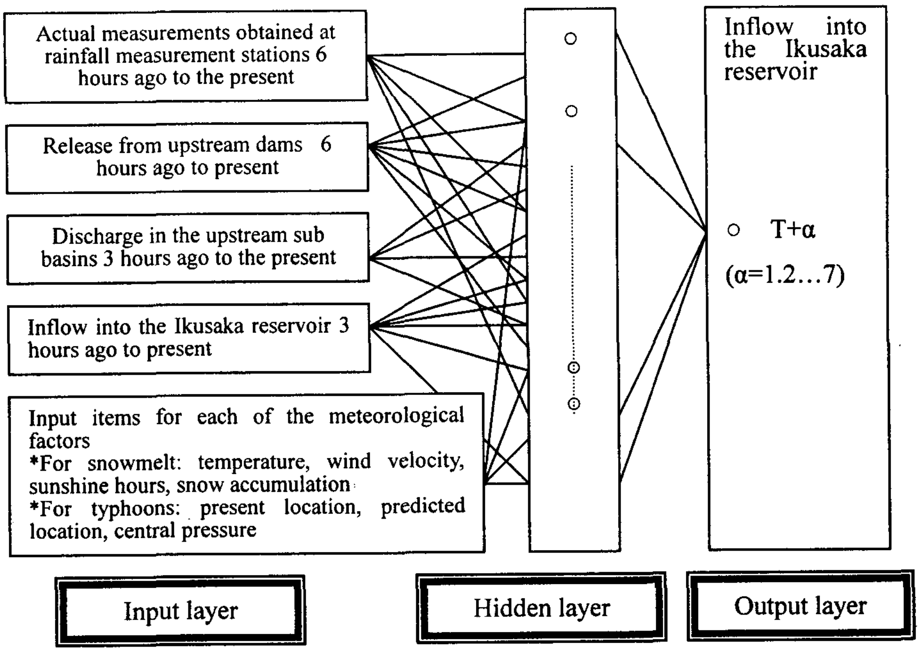


Figure 2 Improved prediction model applying neural network

(iv) Evaluation of Prediction Results

The predicted results by the models are presented in Table 4 and Figure 3. It has been clearly shown in the results that prediction error committed by the improved models have decreased in all the flood cases as compared to that in the conventional model. It indicates prediction accuracy in the improved models have enhanced. However, predicted values from the improved models tend to be lower than measured values. Thus, further studies are needed to improve prediction accuracy to some more extent.

Table 4 Comparison of prediction results (for 7 hours ahead)

Causes of rainfall	Date of the floods studied	Prediction results for the improved model	Prediction results for the conventional model
		Prediction error	Prediction error
Rain fronts	July 3, 1995	0.033	0.155
	August 29, 1996	0.047	1.355
Snowmelt	May 16, 1995	0.240	0.242
Typhoon	September 17, 1995	0.047	0.770

4 CONCLUSIONS

The study was aimed to improve accuracy of inflow prediction into reservoirs up to 7 hours ahead, which would play an important role for flood control of the five dams along the Saikawa River, using neural networks. The improved prediction models were developed based on the conventional model, after extracting meteorological factors responsible for occurring rainfalls during floods, so as to enable prediction of rainfall about 3 hours ahead. Neural network models were developed for various type of floods caused by different meteorological factors. The higher prediction accuracy was achieved using the improved model, as compared to the conventional model. Further verification of the prediction models are being planned with taking into consideration of other flood events. In addition, incorporation of aerological and rainfalls data collected by radars as input parameters into the prediction models are also being considered, to analyze the regional distribution of inflow based on radar data of rainfalls.

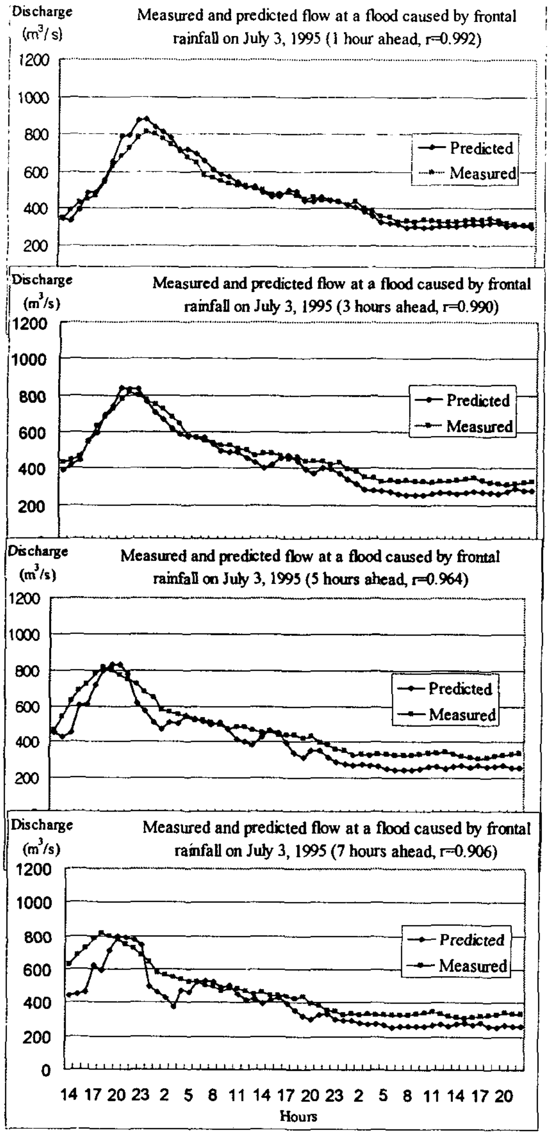


Figure 3(1) Prediction results for the flood caused by frontal rainfall (July 3, 1995)

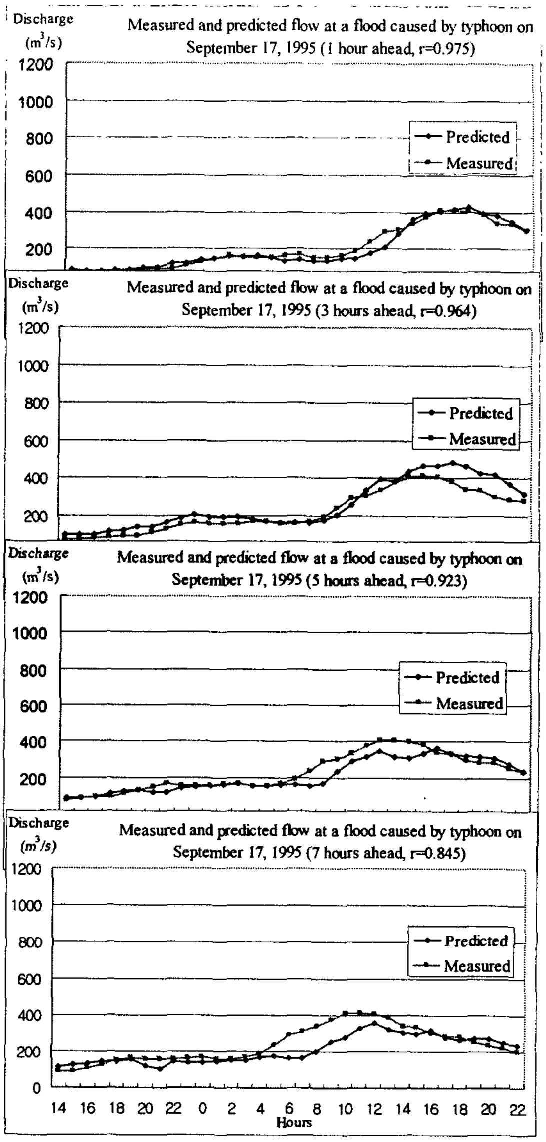


Figure 3(2) Prediction results for the flood caused by typhoon (September 17, 1995)

5 REFERENCES

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