A Forecasting Model for the Flood Peak Stage and Flood Travel Time by Hydraulic Flood Routing

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Abstract/The peak flood discharge at a downstream station and the flood travel time between a pair of dams due to a specific flood release from the upper reservoir are computed using a hydraulic river channel routing method. The study covered the whole large reservoir system in the Han River, Korea. The computed flood discharges and the travel times between dams were correlated with the duration and the magnitude of flood release rate at the upstream reservoir, and hence a multiple regression model is proposed for each river reach between a pair of dams. The peak flood discharge at a downstream location can be converted to the peak flood stage by a rating curve. Hence, the proposed regression model could be used to forecast the peak flood stage at a downstream location and the flood travel time between dams using the information on the flood travel time, release rate and duration from the upper dam.

1. Introduction

The increase in peak flood stage at a downstream location and the flood travel time between a pair of dams due to flood release of various magnitudes from the upper dam are very important informations for the operation and management of flood forecasting system, urban interior drainage system, and the hydrometric network system. The flood travel time is, in general, inversely proportional to the flood velocity which depends on the magnitude of flood discharge as well as the river channel characteristics.

In the present study, the flood travel time due to a flood release from the upper dam to a downstream location and the subsequent flood stage variations downstream were computed by solving the St. Venant equations with appropriate initial and boundary conditions. The computed flood travel time and flood peak discharge were correlated with the flood release characteristics of the upper dam such as the rate and duration of the flood releases. Hence, simple forecasting models are established in the form of multiple regression equations among the variables involved.

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2. Hydraulic Flood Routing Model Employed

For the computation of the flood travel time and flood peak discharge at a downstream location due to a release hydrograph from upper dam river channel routing should be executed through the downstream reach of the dam. The general methodology of hydraulic flood routing is to solve numerically the continuity and momentum equations of unsteady flood flow, the St. Vennant equations. Among many numerical methods the most commonly accepted in recent studies is the weighted four-point implicit method first used by Preissmann (1961) and later by others (Quinn/Wylie, 1973 ; Chaudry/Contractor, 1975; Fread, 1973, 1974, 1978, 1988 ; Yoon/Chung, 1991). This method is accepted as the most advantageous of the various implicit schemes because it can readily be used with unequal distance steps and its stability-convergence properties can be controlled. Hence, the readily available computer model, DWOPER, has been used throughout the present study which was developed by the U.S. National Weather Service(Fread, 1978) according to the weighted four-point implicit scheme described previously.

3. Definition of Flood Travel Time Between Two Dams

The flood travel time is usually defined as the time required for the flood wave to travel from the upstream end to the downstream end of a river reach. It can be determined by estimating the time difference between the times of peak flows at the upstream and downstream ends of the reach(Chow/Maidment/Mays, 1988). However, in the case of flood releases from a reservoir the flood travel time has not yet been defined specifically, hence in the present study it is defined as shown in Fig. 1.

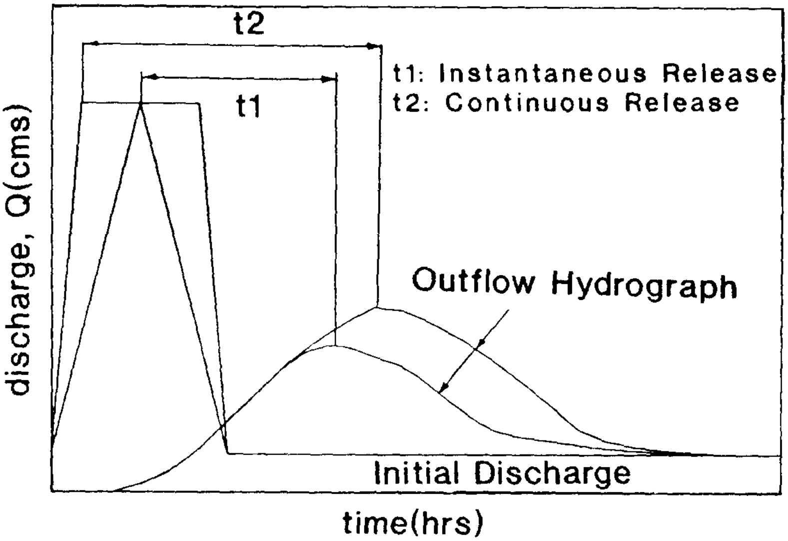

Fig. 1. Definition Sketch for Flood Travel Time

As indicated in Fig.1, two cases of flood releases are assumed from the upstream reservoir. The flood travel time t1 stands for the case when flood release is made by linear opening of spillway gates up to a certain maximum with a subsequent linear closing. Whereas, the flood travel time tc stands for the more usual case of a continuous opening of the gates for a certain time period with a subsequent closing, which reduces the reach flow to the initial discharge.

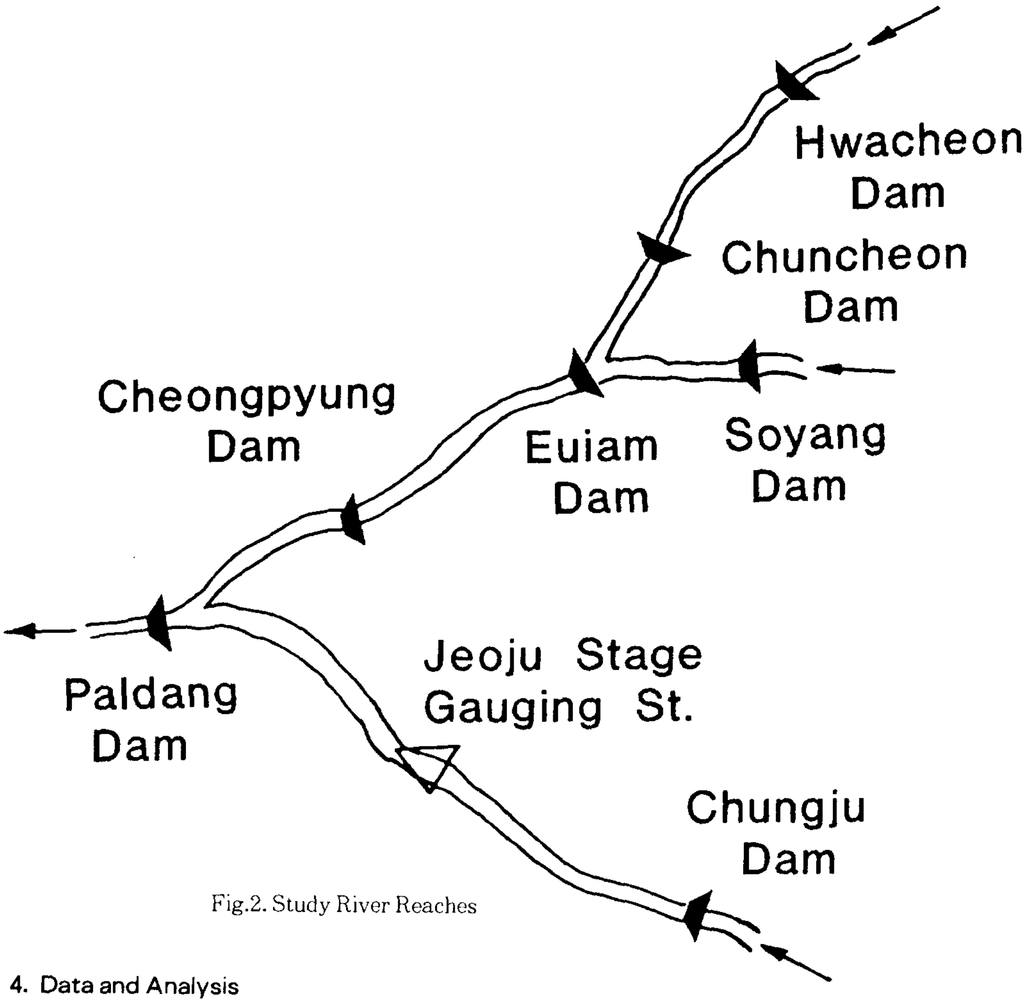

Fig.2. Study River Reaches

4. Data and Analysis

4.1 River Reach Studied

The river reaches dealt with in the present study are seven reaches on the Han River, each connecting the upstream and downstream dam, as shown in Fig.2. The main characteristics of each reach were obtained in the previous study (MOC, 1991). For the case of Hwacheon – Chuncheon reach the reach length is 33.2 Km, the elevation difference, 33.9 m, and the reach slope, 0.00102.

4.2 Input Data

1) Initial Reach Condition

The initial flow condition in each river reach between two dams was set up by steady uniform backwater computation with the assumed initial discharges and cross section data of the reach.

2) Boundary Condition

The flood release hydrograph from the upper dam spillway was taken as the upstream boundary condition for the routing of the flood wave through each reach. Whereas, the discharge rating curve at the downstream dam spillway was used as the downstream boundary condition.

3) Other Input Data

The input data required for the unsteady flow computation with flood release from the upper dam of each reach consist of the initial flow condition in the reach, upstream and downstream boundary conditions, cross section data, roughness coefficient, computation time and distance intervals, Δt and Δx. Appropriate data used in previous studies(MOC, 1988; MOC 1991) were taken as the input in the present study.

5. Analysis on the Factors Affecting Flood Travel Time

The flood travel time due to flood releases from a dam should be dependent on more factors than in the case of flood wave propagation in the natural river reach. The followings can be mentioned as the factors affecting flood travel time: initial flow condition in the reach, magnitude of maximum release, release duration, spillway gate opening at the downstream dam, lateral inflow to the river reach. Among these factors the effect of lateral inflow depends highly on the rainfall patterns, hence the effect can not be analyzed in general term. Therefore, the analysis is confined to the effect of the rest of the influencing factors.

1) Initial Flow Condition in the Reach

The initial flow before flood releases from upstream dam usually consists of hydropower releases and base flow of the reach, and its magnitude is relatively small compared with that of reservoir releases during flood period. This suggests that the effect of initial flow condition would not be significant with repect to the magnitude of flood travel time and flood peak at the downstream dam. Fig.3 illustrates the insignificant effect of initial flow conditions on the computed flood characteristics at the downstream dam section for the reach Hwacheon–Chuncheon. The initial flows of 500, 600, 700 cms were assumed with the maximum release of 5,000 cms for $t_o = 1$ hour duration. The routing results show no significant effect on the flood peak magnitude and time.

2) Spillway Gate Openings at the Downstream Dam

The spillway gate openings at the downstream end of the reach would critically affect the storage characteristics of the reach. Fig.4 shows the computed outflow hydrographs corresponding to the total gate openings of 12 m, 24 m, and full opening of Chuncheon spillway gate for the flood release of 4,500 cms during 2 hour period. As can be seen in Fig.4, when the gate opening becomes larger, the flood travel time gets shorter, but the peak outflow tends to be larger because of the diminishing effect of reach storages. Since the gate opening conditions vary to a great extent a full open condition was assumed throughout the following studies. For the case of the lowermost dam, Paldang, the reservoir surface elevation was set to El. 25.5 m in order to take the peculiar discharge characteristics of the low weirs as mentioned earlier.

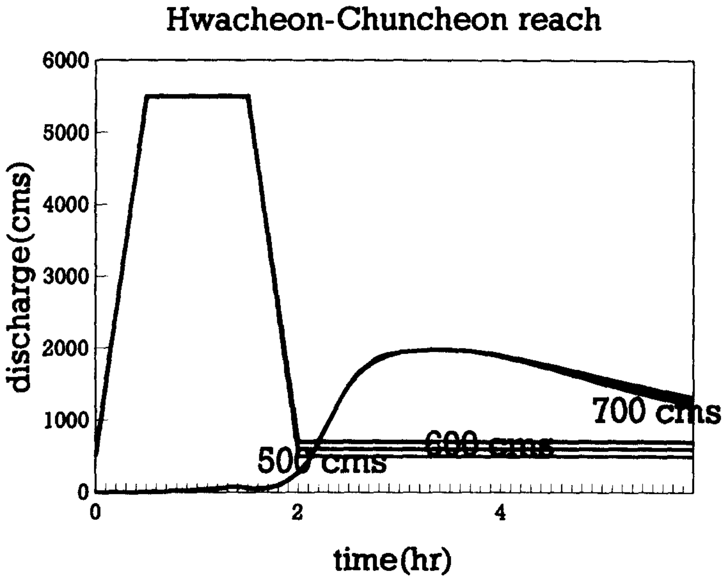

Fig.3. Effect of Initial Flow Condition

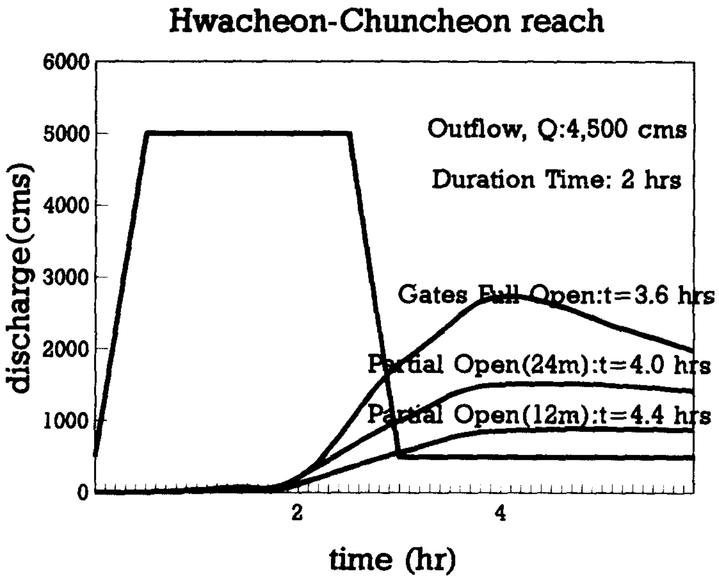

Fig.4. Effect of Downstream Spillway Gate Openings

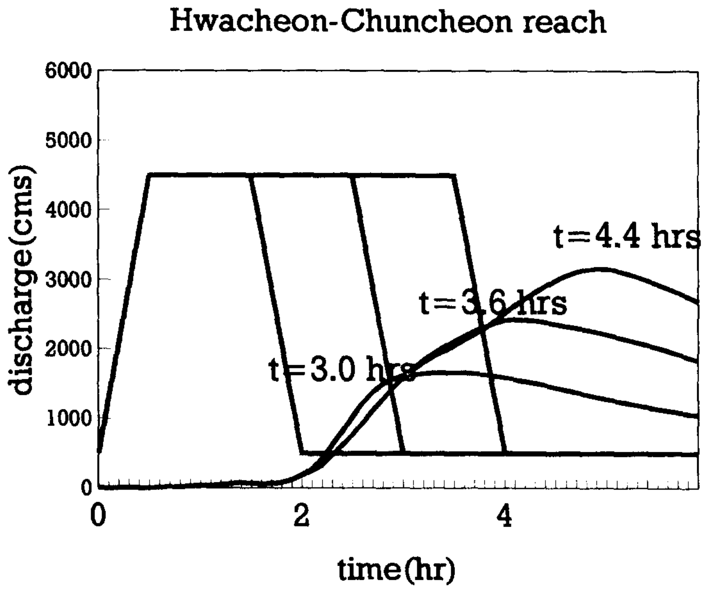

Fig.5. Effect of Flood Release Durations(Qo = 4,000 cms)

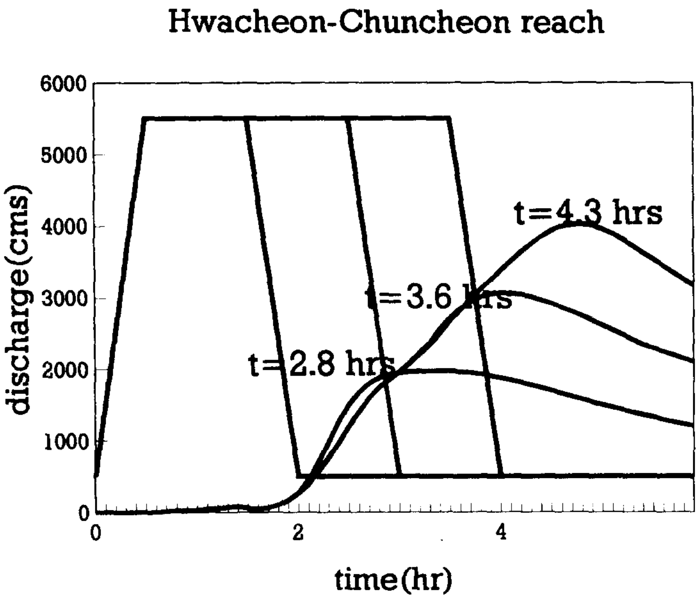

Fig.6. Effect of Flood Release Durations(Qo = 5,000 cms)

3) Peak Release Rate and Release Duration at the Upstream Dam

The peak release rate and release duration at the upstream dam showed a significant effect on both the flood travel time and the peak flood flow at the downstream dam as shown in Fig.5 and Fig.6. For a constant peak release rate from the upstream dam the peak flood and flood travel time at the downstream dam were increased with the increasing duration of flood releases from the upstream reservoir. Comparing Fig.5 and Fig.6, the effect of increasing peak release rate with keeping the release duration constant is shown as a decrease in the flood travel time, which appears to be due to the increased flood propagation velocity along the reach.

6. Correlation Analysis for a Forecasting Model

Taking the factors affecting flood travel time described so far into account unsteady flood flow computations were made by DWOPER for each of the seven river reaches under the varying conditions of the peak release rate, release duration, initial and boundary conditions, and the reach characteristics. From the result of this computations the flood travel time between a pair of dams and the peak flood flow at the downstream end of each reach were determined for the varying release conditions in order to establish a forecasting model by a correlation analysis.

6.1 Flood Travel Time(tp)-Peak Release Rate(Qo) -Release Duration(to)

A multiple regression of the following type was made for each of the seven reaches studied:

$$tp = a + b\,to + c \ln Qo \qquad (1)$$

where a, b, c are the regression constants. Fig. 7 shows a typical regression for the Hwacheon-Chuncheon reach. Similar regression analysis were made for each of the seven reaches considered, and the regression constants and correlation coefficients(r) determined. For the Hwacheon Chuncheon reach it was found that $a=5.611$, $b=0.860$, $c=-0.449$, $r=0.996$.

It can be seen from Fig.7 that the flood travel time decreases as the peak relesase rate increases when

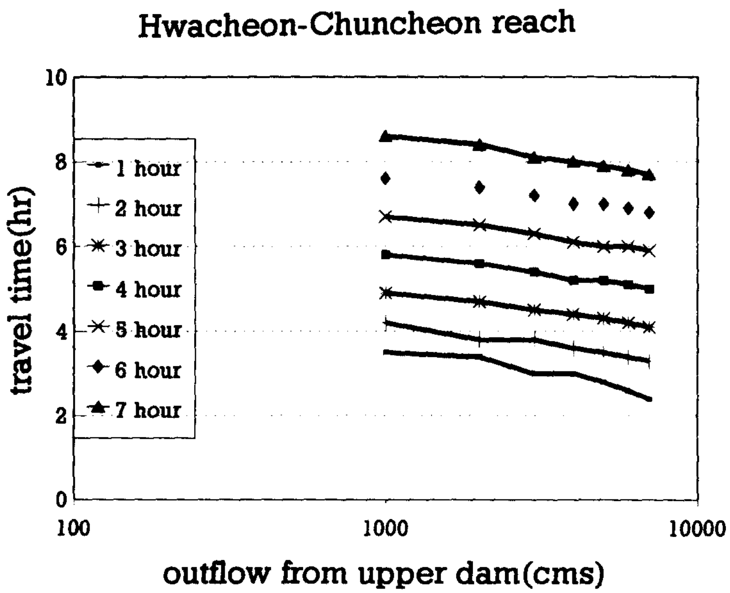

Fig.7. Flood Travel Time-Release Rate-Release Dura- tions

the release duration is held constant, and it increases with the increasing release duration for a constant peak release rate. It can also be seen that the regression of exponential type fits the computed data very well as indicated in Fig.7.

6.2 Peak Flood Discharge(Qp)-Peak Release Rate(Qo)-Release Duration(to)

From the outflow hydrographs computed at the downstream end of each routing reach by numerical solution of the unsteady flow under appropriate conditions the peak outflows were determined and those were related with the peak release rates and the duration of flood release from the upstream reservoir as shown in Fig.8. The relationship for the reach Hwacheon-Chuncheon shown in Fig. 8 can be expressed as

$$Qp = d + e\ to + f\ Qo \quad (2)$$

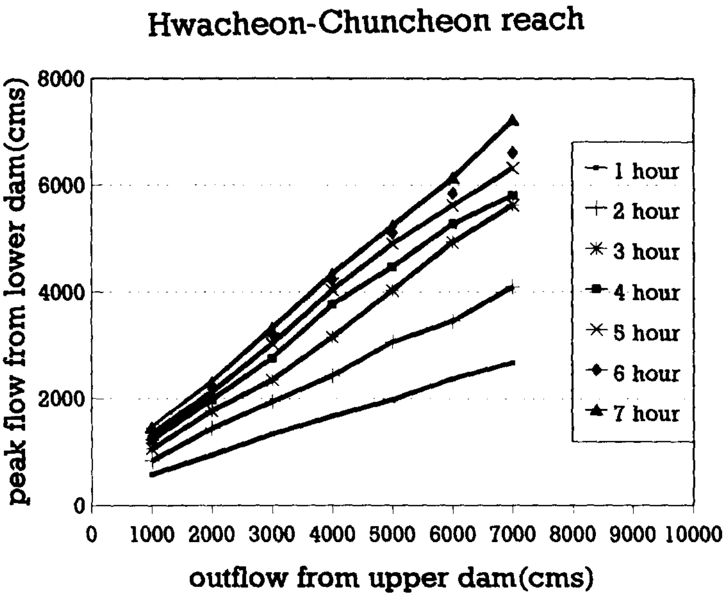

Fig. 8. Effect of Peak Discharge-Release Rate-Re- lease Durations

where d, e, f are the regression constants.

As can be seen in Fig. 8 and eq.(2), the peak outflow from downstream dam increases with the flood release rate for a given release duration, and it also increases with the flood release duration for a fixed flood release rate from the upstream reservoir. The regression anaysis of the type eq. (2) was made for each of the seven reaches considered herein. The regression constants and correlation coefficients for the Hwacheon-Chuncheon reach were found as $d = -1305.878$, $e = 422.250$, $f = 0.736$, $r = 0.924$.

7. Flood Peak Stage Prediction

The flood stages in the downstream reservoir of each reach are monitered by recording stage gauges near the intake structure of each reservoir, and the discharge rating curves between the reservoir outflows and the reservoir stages are well established for each dam.

Hence, the peak flood discharge which can be forecasted by eq.(2) for each reach can be converted into the flood peak stage using the discharge rating relation of each dam. Therefore, the flood peak stage can be forecasted for any possible combination of maximum upstream flood release rate and release duration.

8. Conclusion

Based on the hydraulic flood routing computations in river reaches a multiple regression model is proposed for forecasting the flood peak stage and flood travel time under the condition of various flood release rates and release durations. The effect of factors such as the initial reach flow condition, degree of downstream gate opening, peak release rate and duration which govern the magnitude of flood peak discharge(or stage) and travel time are also quantitatively analyzed.

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