Development of Numerical Model for Flood Inundation Analysis in a River with GIS Application

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Abstract: FIAS(Flood Inundation Analysis System) using Arc/Info is developed and applied to the Namhan River basin. The DWOPER model is revised and expanded to handle simultaneous multiple overtopping and/or breaking, and to estimate the inundated depth and extents. The model is applied to an actual levee overtopping case, which occurred on August 23~27, 1995 in the Namhan River. Stage hydrographs inside and outside of the levee are compared, then inundated discharges from overbank spilling are computed. The Graphic User Interface is developed with AML. Two- and three-dimensional inundation map by Arc/Info are presented. The computed inundation extends agree with observations in terms of inundated depth and flooded area. The FIAS is useful for the analysis of flood hazards and preparation of inundation map for river basins.

1. Introduction

It is necessary and important to estimate an inundate depth and extents accurately due to recent unusual rainfall and heavy storm in order to measure and prevent flood damage. Existing studies for flood inundate analysis in a river were not based on hydraulic theory but based on empirical background such as inference from inundate situation and approximate estimation by mapping. Therefore, it is not able to predict the propagation of flood wave according to time and the distribution of inundate depth. In this study, numerical model for flood inundate analysis in a river is developed for analyzing the propagation phase of flood wave due to flood inundate. For a rational flood control, GIS is combined with the output of the developed model. The developed numerical model is applied to flood inundate event of yeojoo in Namhan River basin (August, 1995) for calibration and availability. As biographical studies, 有賀世治 (1977) investigated the cases of levee breaking and reviewed the behavior of flood inundate based on hydraulic model experiments. 西原 巧 (1981; 1982) analyzed the behavior by numerical model using levee breaking data in Japan. Evans and Lany (1983) used

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first order implicit FDM for analyzing inundate flood wave of Whitham in U.K., and Hromadka and DeVries (1985) used integral FDM for analyzing that of Orange Country reservoir. HEC (1992) developed flood analysis model using HEC-2 and GRASS. Syme and Paudyal (1994) used Mike-11 and Arc/Info for flood control model. Estrela and Quintas (1994) used GRASS for flood control of Jucar flood plain in Spain. Han (1987) and Lee et al. (1986) analyzed flood wave due to dam break. Lee and Han (1989) analyzed a phase of levee break of Mangwon Dong (1984) and inundate depth. Lee et al. (1995) and Han (1995) performed numerical simulation for levee break of Ilsan, and Han (1997a; 1997b) developed and combined risk evaluate model. Since GIS was introduced in 1980, there were several experienced cases such as hydrological analysis model, environmental information, and non-point source pollution analysis. However, there is not application and study of GIS for flood inundate

The first purpose of this research is a development of numerical model which can analyze inundate flood wave according to river levee breaking, and predict the range of inundate, depth, and damage magnitude. The second is making a flood map using the model and GIS.

In this study, DWOPER model is modified for flood and inundate analysis according to levee overtopping and breaking. And the developed model is applied to flood inundate in Namhan River basin for calibration. The output of the developed model is used for making a flood map according to time based on GIS. Therefore, flood control can be performed rationally.

2. Flood Inundate Model

2.1 Hydraulic Analysis of Flood Inundate

Full dynamic equation applied to analyze flood routing including overtopping and levee breaking consists of continuity equation and momentum equation such as Eqs. (1) and (2),

$$\frac{\partial Q}{\partial x} + \frac{\partial (A + A_0)}{\partial t} - q_L = 0 \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2/A)}{\partial x} + gA(\frac{\partial h}{\partial x} + S_f + S_e) + L = 0 \tag{2}$$

where x : streamwise distance, t : time, Q : discharge, A : cross section area, A_o : storage cross section area, h : water elevation, and q_L : inundation discharge through bank. $L(= -q_L V_L)$ is the effect of momentum based on inundation discharge, S_f and S_e present the friction slope and energy slope due to contraction and enlargement, respectively.

Eqs. (1) and (2) containing q_L and L reflect the effect of overtopping and levee breaking. For the numerical solution of Eqs. (1) and (2), Preissmann scheme is used. The nonlinear equation derived from Preissmann scheme is solved by Newton-Raphson method such as

$$J(x^k)\Delta x = -f(x^k) \tag{3}$$

where, x = unknown vector; k = the number of iteration; $J(x^k)$ = Jacobian matrix which consists of partial differential values of x^k; $f(x^k)$ = nonlinear equation of x^k; x^k = initial value; and $x^{k+1}(=x^k+\Delta x)$ = derivative of x^k.

DWOPER model is improved to the numerical model proposed herein to analyze overtopping spilling, inundation discharge and phenomena in protected lowland.

The improvements are as follows:

① Input data contains bank heights of main channel.

② To simulate detention storage of protected lowland, the states of protected lowland are presented as stage-area relationship or stage-inundation relationship.

③ It can solve the problem of the recent program that does not simulate the bank overflow or breakdown properly to carry out the simulation in complete algorithm.

④ The progressive analysis for the connecting part was carried out to get the flow from the overflow or breakdown of bank to the protected lowland.

⑤ The process of calculation is constituted enough to consider the flood inundation flow at several points of the main stream in each time step simultaneously.

⑥ Using the initial elevation of given bank, the flow from the overflow or breakdown was analyzed in terms of the shape-considered elevation. Where it was regarded the flow from the stream to the protected lowland of positive quantity and the alternative of negative.

2.2 Development of Flood Inundation Analysis System

To develope the flood inundation analysis system, Fig. 1 showed the basic relationship between the developed models and added or modified sub-program for this relationship. Fig. 2 showed the construction process with the time step combined with flood inundation simulation model with Arc/Info model. As shown in Fig. 2, data for digital map of the region using Arc/Info model was constructed in step 1, and the flood inundation was simulated in step 2. In step 3 and 4, model calibration was carried out and the calculation results ware plotted on Arc/Info, respectively. Finally, maintenance process for the flood inundation analysis system was constructed in step 5.

This flood inundation analysis system was constructed by AML in Arc/Info. The organization of MENU and the simulation using AML could recompose the model for user's demand and were convenient of the maintenance. Especially, this process could compensate for the disadvantage of trivial commands in composition of the output for Arc/Info, be easy to show the results graphically, and be applicable to the database of input/output of the model and interface between simulated model and Arc/Info system automatically.

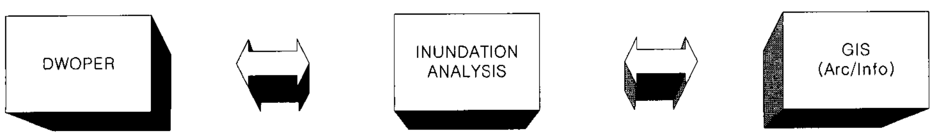

Fig. 1. Schematic Diagram of the Model

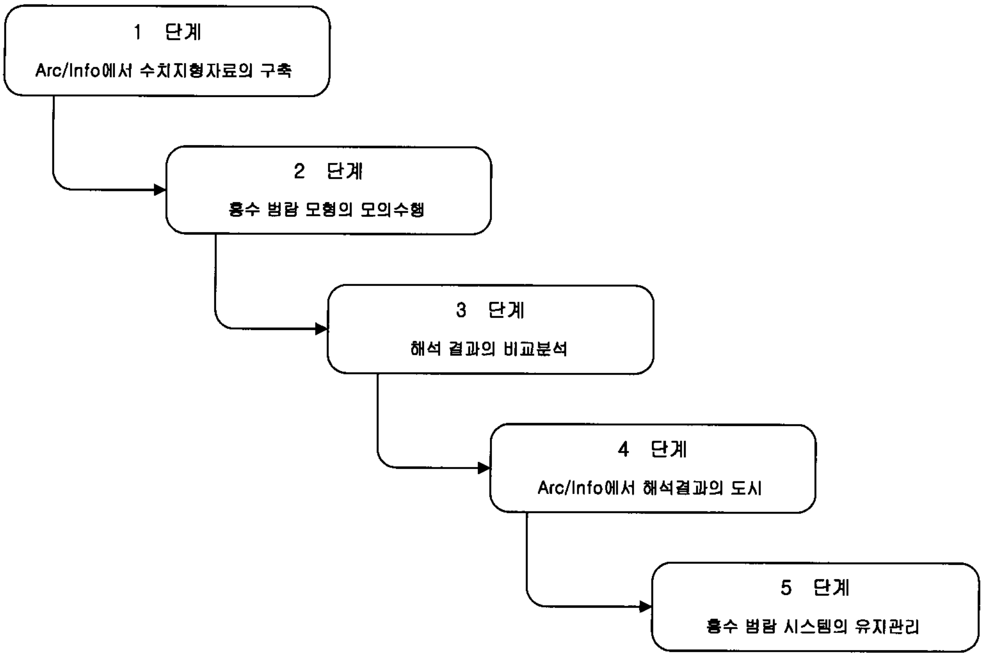

Fig. 2. Construction Process of the Flood Inundation Analysis System

3. Application on Basin of the Namhan River

3.1 '95 Yojoo Flood Event

The Daesin-myon, the Booknae-myon, the Yojoo-eup, the Kangcheon-myon were inundated by overflow of levee in tributaries of the Nam-han river and a part of the existing levee in the Yangseo river was washed out. The rainfall event at Yeojoo water mark on August, 1995 showed that the area-averaged rainfall was 122.2mm during the 19th-24th, August, 286.3mm during the 23th-27th, August, and especially 214.9mm during the 23th-24th, August. The flood event at Yeojoo caused the heaviest damage since the flood event had happened during the 19th-24th, September, 1990 in the Middle province.

A part of levee in the tributaries of the Nam-han river was overflowed and washed away for lack of freeboard at Yeojoo district. Also, lowland and farm land were inundated by the increase of flood level in the Nam-han river. This leaded to the significant damage of properties such as the 377 flood victims of 90 households, the inundated area of 1,380.7ha. The total damage properties amounted to eight billion and two hundred seven five million won during the 19th-27th, Aug (Department of home affair, 1996).

The works of recovery of flood damage and adjustment of cultivated land (bank protection works) were carried out from 1973 to 1991 in the tributaries of the Nam-han river - the Hoopo river, the Han river, the Okeum river, the Soyang river, the Keumdang river, the Kalmae, the Kuleun river -, at Daesin, Booknae, Yojoo, Kangcheon districts. However, overflow, breakdown, and washing away of existing levee caused a significant damage of farm lands due to the backwater effect of the Nam-han river on Aug, 1995. The farm lands were inundated and buried by backwater effect in the Yangseo river (Neungseo-myon, Hongcheon-myon) district and by the levee-breaking due to piping effect in the Yanghwa river and other tributaries. The Yojoo rainfall observation stage of the Nam-han river recorded the data (T/M) of successive(or continuous) rainfall of 563mm during the 19th-27th, August, 1995, the maximum hourly rainfall of 31mm at 2 o'clock on the 20th, August. Flood level at Yeojoo water level stage rose up to 10.6m (El. 43.429m) and therefore, exceeded the flood level of danger by 1.1m.

Under the influence of flood level of the Nam-han river, farm lands and residences were flooded in the Yeojoo-eup, the Neungseo-myon, the Hongcheon -myon, the Daesin-myon, the Booknae-myon, and each tributary. At 18:30 on the 25th, August, the levee was washed away by rising water level and so the residents evacuated their houses. At 23:00, the safety examination surveying of the Yeojoo bridge was carried out and the Yeojoo bridge's traffic was controled and the storm alarm changed to the storm warning at 07:00 on the 27th, August. At 12:00 on the 27th, August, the storm warning was removed and restoration of damaged facilities in inundated area were proceeded by residents and government and people of Yeojoo (Yeojoo kun, 1996).

3.2 Flood Analysis

Flood wave analysis by DWOPER model was carried out for investigating flood phase of Yeojoo. The analysis was carried out for interest region which bounded upstream as Yeojoo watermark point, and downstream as Yangpyoung watermark point. Fig. 3 shows a plot of discharge hydrograph for Yeojoo watermark point, and Fig. 4 shows a plot of stage hydrograph for Yangpyoung watermark point. Table 1 shows rating curve at Yeojoo watermark point. As shown in Figs. 1 and 2, maximum stage at Yeojoo watermark point is 10.6m when the peak discharge is 17,145m^3/sec and occurrence time is 89hr, and maximum stage at Yangpyoung

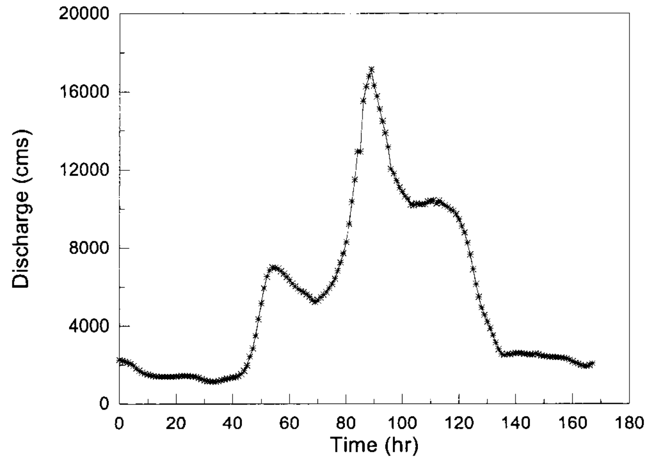

Fig. 3. Discharge Hydrograph of Yeojoo Watermark Point

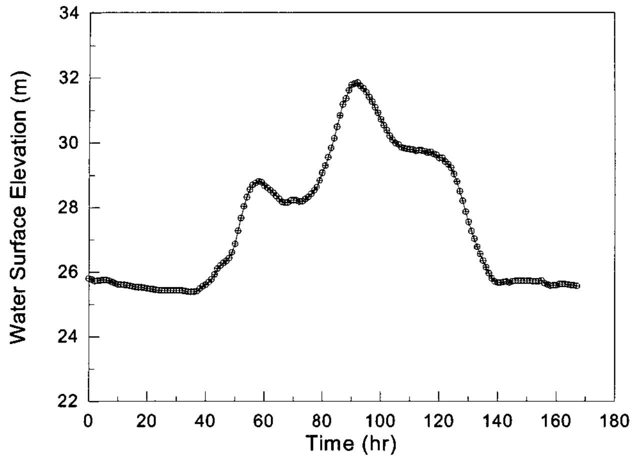

Fig. 4. Stage Hydrograph of Yangpyoung Watermark Point

Table 1. Rating Curve at Yeojoo Watermark Point

Site	Development year	Range	Rating curve
Yeojoo	1995	1.3<h<4.0	$Q=48.38032(h-0.257)^3$
		4.1<h<9.5	$Q=117.740(h+0.58)^2$
		h>9.6	$Q=7.6713(h+0.56)^{3.1969}$

watermark point is 31.86m when occurrence time is 89hr, respectively.

River channel mesh was constructed for finite difference method which was applied for flood wave analysis, with setting average distance Δx between each grid point as 0.77km and average channel slop as 1/2400. The numbers in the figure are numbers of channel sections upon the River Arrange Basic Plan. The roughness coefficient n was used from 0.0250 to 0.0904 as reach and discharge scale, referring to resultants of optimal roughness coefficient calculating at

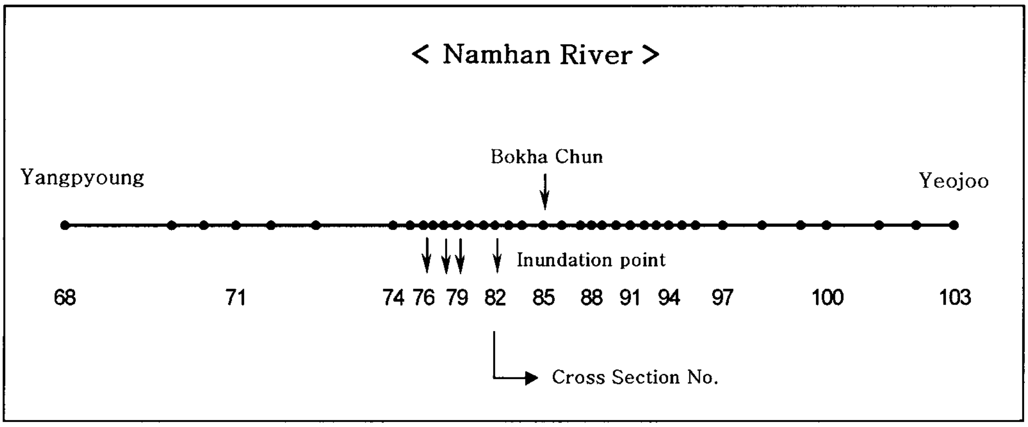

Fig. 5. Chart of Object River Channel Reach

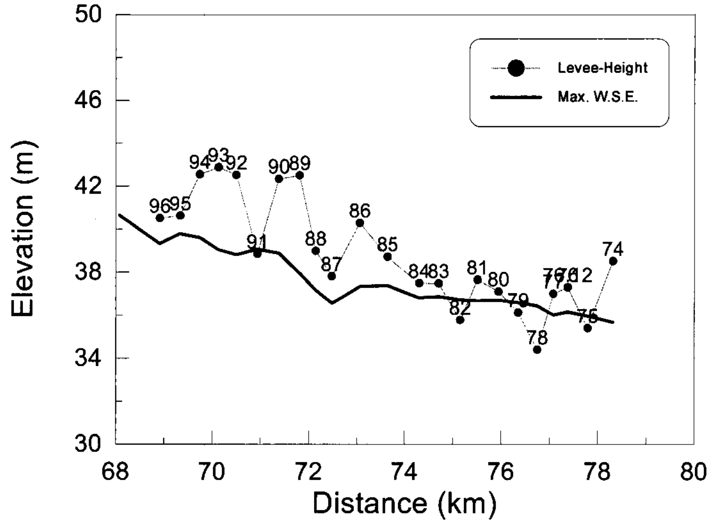

Fig. 6. Comparison Between Maximum Flood Stage and Bank Height

the reach from Choongjoo to Paldang, and 0.1hr is applied for calculating time interval Δt.

Fig. 6 presents comparisons between the compared calculated maximum stage and height of right side bank for understanding overflow pattern of bank after carrying out flood wave analysis. As shown in Fig. 6, calculated maximum stages at station number 82, 79, 78, and 75 are higher than height of right side bank amount of 0.937m, 0.458m, 2.040m, and 0.578m, respectively. This shows that overflow of river bank was high at these stations at that time.

3.3 Analysis of Flood Inundate in Protected Lowland

For the overflow points (No. 82, 79, 78, and 75 in Fig. 6), analysis of flood inundate in protected lowland was performed. Figs. 7 ~ 10 show an overflow discharge through bank. At No. 82, the overflow started at 86.2 hour, reached peak overflow discharge (404m^3/sec) at 91.1 hour and completed at 96.7 hour. At No. 79, the overflow started at 88.9 hour, reached peak overflow discharge (80m^3/sec) at 91.2 hour and completed at 93.7 hour.

At another point No. 78 in Fig. 6, which has the lowest bank height (34.4m), the overflow started at 83.6 hour, reached peak overflow discharge (1003m^3/sec) at 89.6 hour. After 91.8 hour the flow reversed from protected lowland to mainstream, at 96.4 hour reached peak value -306m^3/sec. At 167 hour, the interaction between mainstream and protected lowland finished. The point No. 75 has 35.4m bank height and the overflow from mainstream to protected lowland was relatively small value, 35.4m^3/sec. But the peak discharge of reversal overflow was -524m^3/sec at 91.0 hour and the overflow was completed at 96.4 hour.

As shown in Fig. 9, No. 78 point (lowest bank height) was the first overflow location at 83.7 hour and No. 82 point started overflow at 86.2 hour. The reversal overflow from lowland to mainstream was occurred in No. 78 at 91.8 hour and in No. 75 at 89.6 hour. These results mean that the first reversal overflow appeared at downstream having the lowest water level.

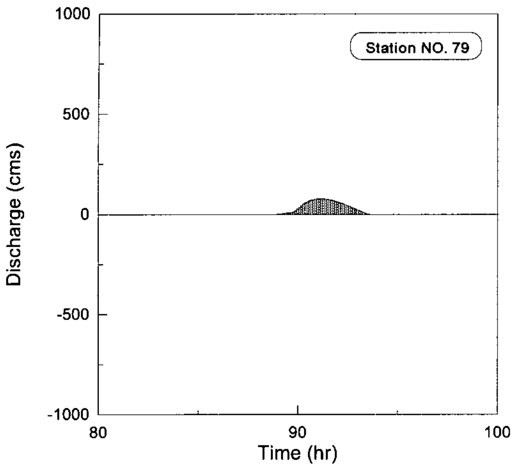

Fig. 7. Overflow Discharge at No. 82

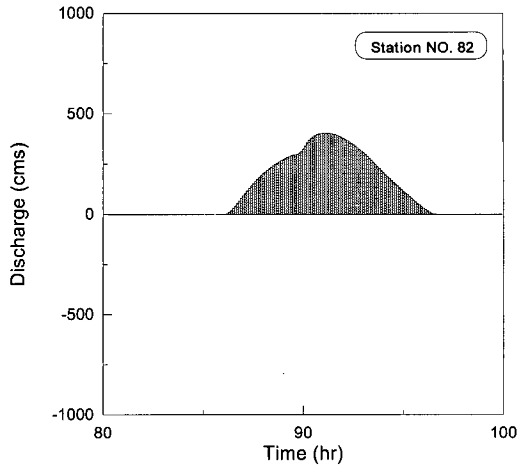

Fig. 8. Overflow Discharge at No. 79

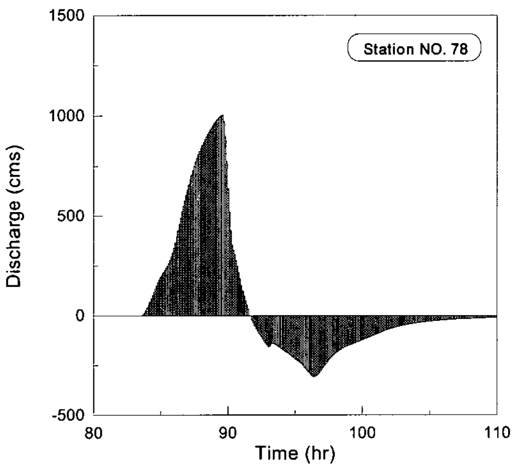

Fig. 9. Overflow Discharge at No. 78

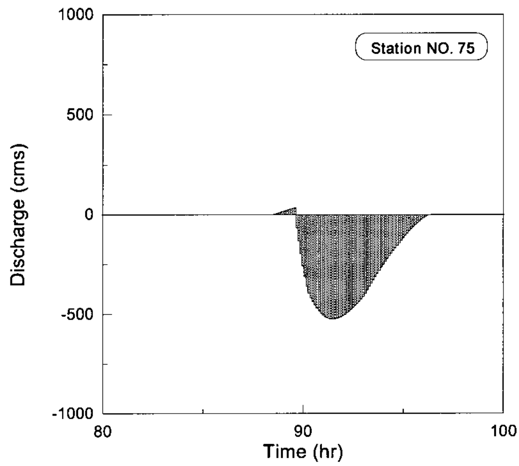

Fig. 10. Overflow Discharge at No. 75

The model developed in this study computed well a simultaneously overflow and the interaction between mainstream and protected lowland.

Table 2 show that the overflow quantity into protected lowland at each point as the water level of mainstream increasing and the reversal overflow quantity into mainstream because of a higher water level of lowland than mainstream. The computed storage in lowland was identical with the final storage by model. These results show that the developed model in this study calculated well a overflow discharge at multi-sites simultaneously and an interaction quantity between mainstream and protected lowland.

Figs. 11 ~ 14 show the water level change at the station No. 82, 79, 78, and 75 between channel and protected lowland. The highest water level at channel is 36.55m at 90.8 hour for the station No. 82, 36.38 at 96.1 hour for No. 79, 36.12m at 90.9 hour for No. 78, and 35.72m

Table 2. Discharge Exchange Between Channel and Protected Lowland

	Overtopping discharge (m^3)	Inverse discharge (m^3)	Reserved discharge (m^3)
No. 82	8,429,598		
No. 79	702,320		
No. 78	13,792,241	7,233,516	
No. 75	80,251	7,312,680	
Sum	23,004,410	14,546,196	8,458,214

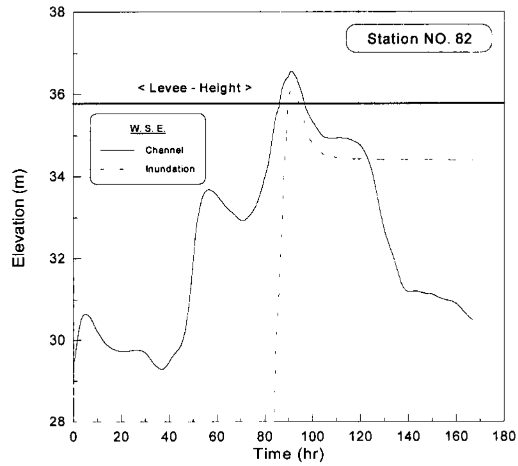

Fig. 11. Water Level Change Between Channel and Protected Lowland (No. 82)

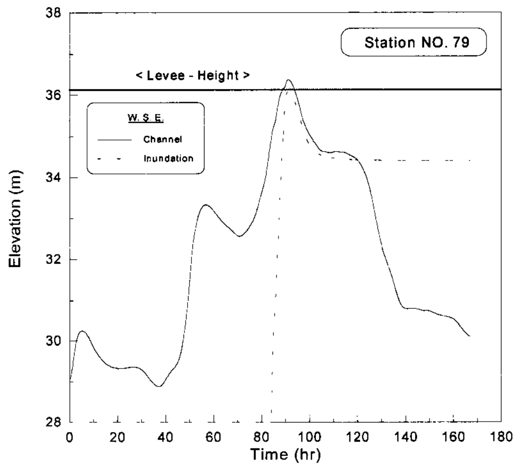

Fig. 12. Water Level Change Between Channel and Protected Lowland (No. 79)

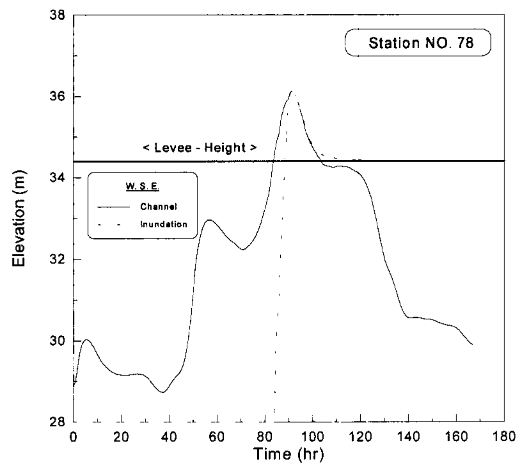

Fig. 13. Water Level Change Between Channel and Protected Lowland (No. 78)

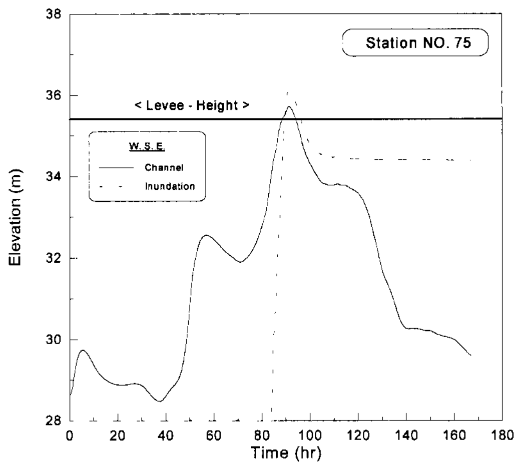

Fig. 14. Water Level Change Between Channel and Protected Lowland (No. 75)

at 91.0 hour for No. 75. The figures show that the overflow and flooding discharge calculation according to the water level at channel and protected lowland, and bank height reasonably reflect the situation of that time.

By the results obtained by the model in this study, It started at 83.7 hour to flood, and the flood damage occurred at the maximum area of 593.9ha at 91.0 hour with the maximum flood water level of 36.11m. Thus, we can see that the overflow and flooding discharge calculation according to the water level at channel and protected lowland, and bank height reasonably reflect the situation of that time.

4. Application of GIS

In case of being likely to flood overflow in the river, the flood overflow diagram should be make out with the analysis of the flood wave propagation characteristics, the deduction of the range and the water level of inundation, and with numerical analysis model that can predict damage scale. The numerical analysis model to make out the flood overflow diagram should be designed to be the basic data for the prediction diagram of the flood overflow zone in protected lowland, the flood-insurance, and the flood forecasting and warning by the temporal calculation of the flood wave propagation characteristics and the flood water level.

The more scientific flood management can be made by relating the results of the flood overflow analysis to GIS.

4.1 Basic Data

To analyze the flooding of Yeojoo in Nam-Han River basin, we performed the detail survey, and collected the solid body data which is composed of 1/5,000 topographic map, vertical and horizontal surveying data of bed section.

As shown in Fig. 15, we determined the sample site from upstream of Deashin -myun Dangsan-ri to downstream Deashin-myun Dangsan-ri Yipo bridge where it used to happen heavy flood and it had 7.2km long. To establish the digital map of basin of Namhan River, we used the data of 1/5,000 topographical map and surveyed in site. And we set the boundary of river channel and flood plain at the condition of flow condition in the topographical map.

The digital map of this objective land have not been made by now. For display with just one drawing about three type drawing of the field detail surveying which has each different scale, 1/5000 topographic map which already exist, and river longitudinal and horizontal map, we found major input data of flood model that will be applied by connecting topographic and numerical data.

In this study, above the rule that was set by The Development Rule of Numerical Map, we enforced transformation of vector of base map, and developed 3-dimensional topographic data of protected lowland. The 3-dimensional topographic form was builded with user's convenience above form of natural channel, and has merit of ability of accurate simulation. The base data, which was used in composition of geometrical form of protected lowland, was made by field detail surveying map, 1/5,000 topographic map which already exist and longitudinal and horizontal map in river arrange basic plan. Fig. 16 is flow chart about geometrical form of

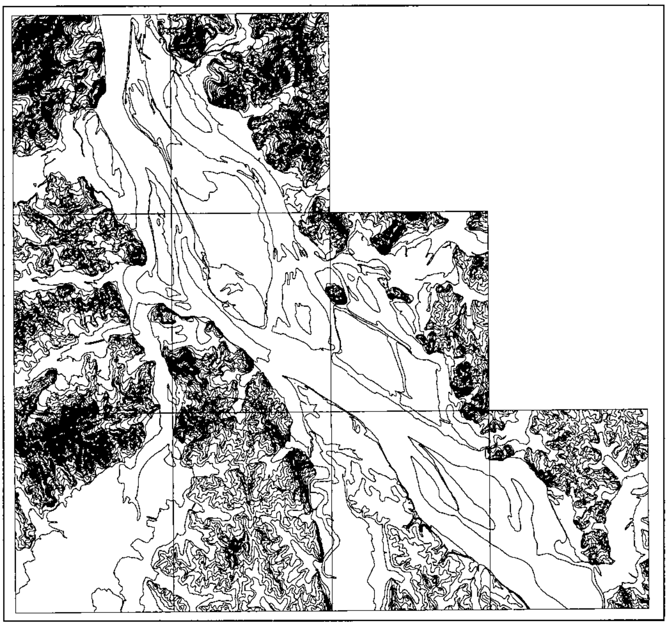

Fig. 15. Topographic Map of Objective Land

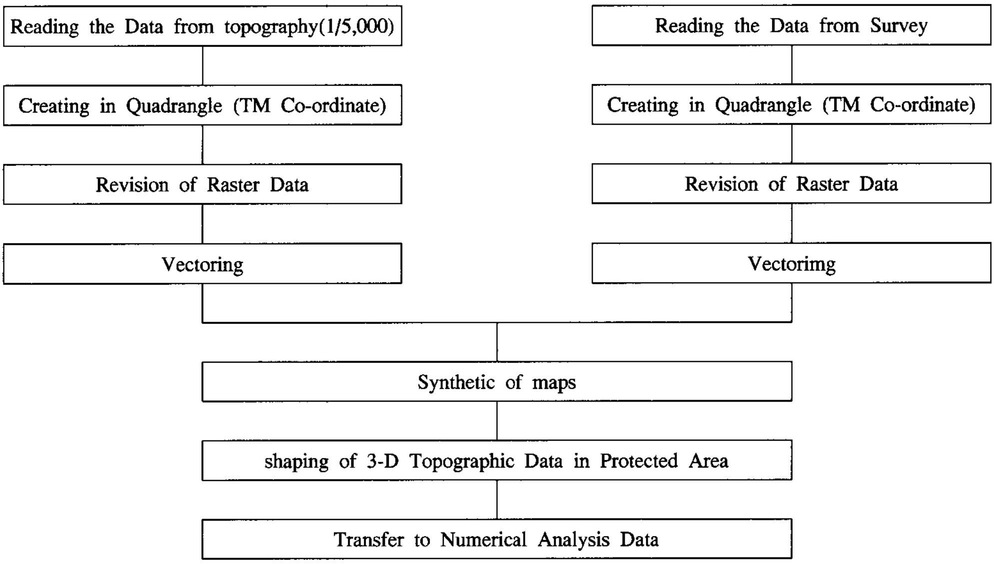

Fig. 16. Flow Chart about the Topographical Composition in the Protected Lowland

protected lowland.

4.2 Relation with Arc/Info

It is considered a digital base map as a base map and organized TIN data for necessary section and converted x, y coordinate for each node of the organized finite element net to text file, so built the applicable form for this study model. It is determined digital model input data that contains the x, y coordinate of each spot and the elevation data be applicable to that and

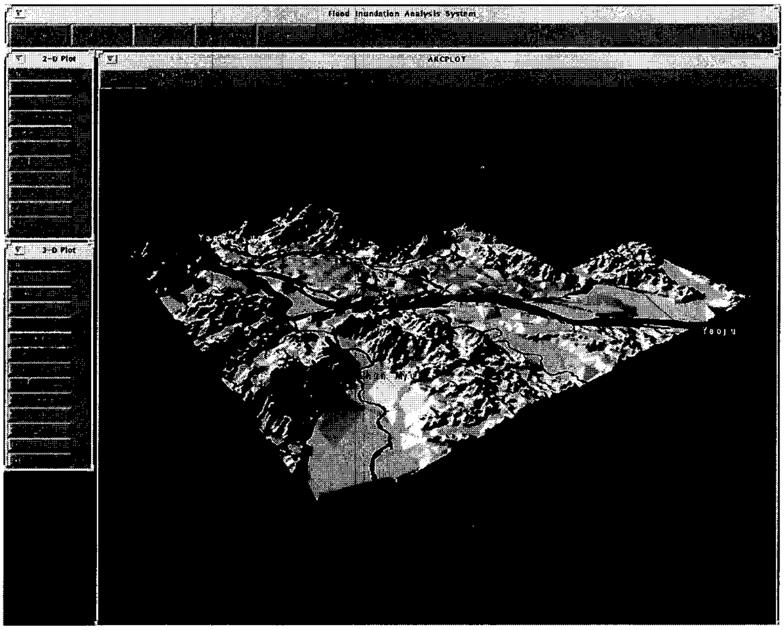

Fig. 17. Basin Map of reservoir by 3-dimensional grid (lattice)

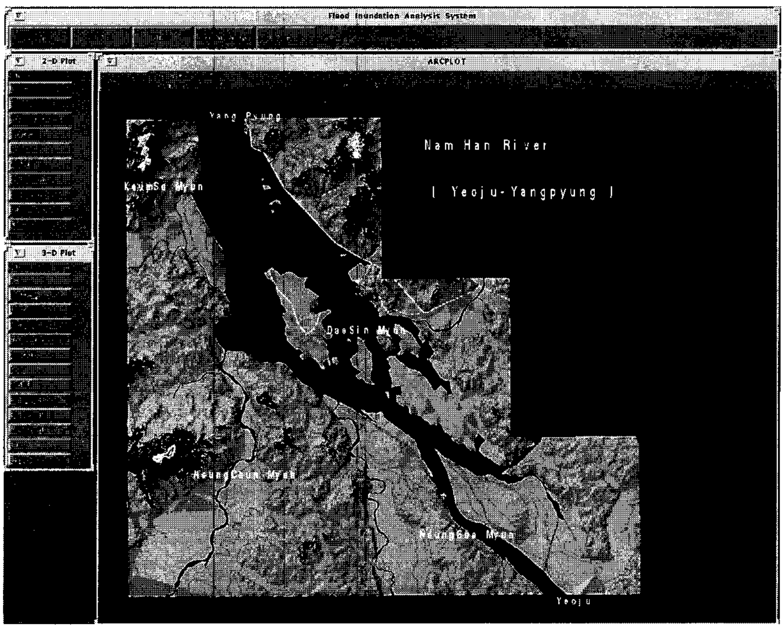

Fig. 18. 2-dimensional flood inundate map (1995 year flood event)

used topographic map auto-self-getting process for the terrain of main river of Nam-Han River, and selected a grid and a node of the section with the Micro Station. The geographical data of the interested region and the digital map of the channel are combined.

Figs. 17 and 18 present the results of simulation by Arc/Info and the basin map of the reservoir is made by 3-dimensional grid (lattice) as shown in Fig. 17. As shown in Fig. 18, 2-dimensional flood inundate map according to inundate depth 36.11m represents the measured data by "Prime Investigation for Protecting Inundation in Namhan River" and experienced data similarly.

5. Conclusions

In this study, the numerical model which can analyze inundate flood wave according to river levee breaking, and predict the range of inundate, depth, and damage magnitude was developed and the flood map was made by the developed model and GIS.

DWOPER model which can perform flood and inundate analysis according to levee overtopping and breaking was modified. And the developed model is applied to flood inundate event in Namhan River basin for calibration and analysis of flood inundate phase. The output of developed model was used for making a flood map according to time based on GIS.

The magnitude of overtopping at No. 82, 79, 78, and 75 sites turned out to be large based on the results of simulation. As results, inundate depth of inland was 36.11m and inundate area was about 593.9 ha. This results represents the measured data by "Prime Investigation for Protecting Inundation in Namhan River" and experienced data similarly.

FIAS using Arc/Info which can make an inland inundate map according to time was established and this model will make a contribution for predicting a flood inundate region.

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