Rainfall-runoff Modeling of the Tokachi River Basin Using Integrated Flood Analysis System

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***Abstract*—In the context of global warming, the loss caused by the flood are increasing, therefore, flood calculation is very necessary. Hydrological station quantity shortage and unreasonable distribution have resulted in the lack of hydrological data, in many countries and regions around the world. Therefore, it is essential to carry out the study of flood calculation in the area without hydrological data. This work studied a flexible system called Integrated Flood Analysis System for flood calculation, flood information support. This paper took the flood process of the Tokachi River Basin in Hokkaido typhoon season in 2016 as the research object and the application of IFAS to flood calculation in areas without hydrological data was explored. The results show that the catchment boundaries created based on GIS-processed elevation data are more accurate. The estimation safe-side discharge and water level were possible by using Ground rainfall data. When IFAS used satellite rainfall data for flood calculations, the results obtained by the 3B42RT were more exact than Gsmap, but precision still needed to be improved. Changing the parameters is an important way to improve the accuracy of flood calculation results.**

***Index Terms*—Flood calculation, Tokachi river, IFAS**

I. INTRODUCTION

Floods represent one of the most serious natural disasters that humankind face, accounting for 55% of natural disasters and 31% of economic losses caused by natural disasters[1-2]. A warmer climate would increase the risk of floods[3-5]. Globally, 46 million people were affected by flooding in 1990 and this would rise to 60 million people/y in 2100[6]. Hirabayashi et al suggested that the risk of floods in wet areas of Asia and Africa had the potential to increase[7]. The distributed hydrological model is better than some other hydrological models and is a developing trend for future hydrological models[8-11]. Integrated Flood Analysis System (IFAS), a concise tool kit with a Graphic User Interface builds the Distributed Rainfall-Runoff analysis model[12-13]. Integrated Flood Analysis System (IFAS) model is a runoff analysis model converting rainfall into runoff for a given river basin. The simulation can be done using either ground or satellite-based rainfall to produce calculated discharge within the river[14-15]. The catchment area of the Tokachi River basin is ranked sixth in Japan and second in Hokkaido[16]. During the period from August to September in 2016, four typhoons affected Hokkaido area, especially the fourth typhoon had a huge impact. This study used IFAS to simulate runoff during the typhoon period from August to September in 2016 in the Tokachi Basin of Hokkaido. By comparing the results of simulating flood runoff with different rainfall data, the applicability of IFAS for flood calculation is studied, and the method to improve IFAS flood calculation accuracy is explored.

A. Study Area

Tokachi river originate from Tokachi mountain of the Taisetsu mountains (with altitude 2077m), flowing through Tokachi mountain valleys into the plain, and then it jion in Sahoro river, Memuro river, Bisei river, Shikaribetsu river and other tributaries into the Obihiro, then Department of Otofuke river, Satsunai river and Toshibetsu river into the pacific at toyokoro town. The climate features are that there is no Meiyu period and because of the rising temperature and rainfall in spring, it is easy to cause the melting of snow to lead to flood and due to the influence of the typhoon front in the late summer to autumn, it brings heavy rain. The largest precipitation in Hokkaido is from August to September, and the precipitation in November to February is greater than that in summer. The Tokachi river catchment was shown in Figure 1. [17-20]

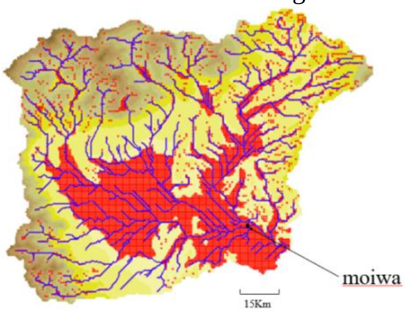

Fig.1. Study area depicts Tokachi River Catchment

B. Study Method

IFAS stands for "Integrated Flood Analysis System". IFAS, a concise tool kit with a Graphic User Interface builds the Distributed Rainfall-Runoff analysis model. The hydrological analysis model is regarded as the Public Works Research Institute Distributed Hydrological model (PWRI-DHM). The model consists of a distributed hydrological model based on the tank model and a routing model based on a kinematic wave hydraulic model. The PWRI-DHM model was developed in the 1990th after which it has been mainly applied in large-scale river basin in Japan as a rainfall-flood runoff analysis model for river administrators. After developing IFAS ver1.0, ICHARM has been continuing upgrading IFAS with feedback received at IFAS training for several years. On June 2014, ICHARM released IFAS second generation as an upgraded IFAS. The software is useful for the following activities, Firstly, to study the geospatial and hydrological feature of the target basin; Secondly, to study rainfall distribution; Thirdly, to study water resources management; Fourthly, to forecast magnitude and timing of flood. In this study, flow calculation was performed at the Moiwa Flow Observation Station.

C. Data

1. Geographical data

In this examination, two types of elevation data were used. One was elevation data downloaded by using the standard function of IFAS (hereinafter: IFAS standard elevation data), and Global Map was used in this study. The other was input data that was processed by using ArcGIS software (hereinafter: GIS-processed elevation data). The two types of data were outlined in Tables I and II, respectively [21-22]. The land-use data, which was downloaded by using IFAS, was shown in Table III. Global Map (Land Cover) was used in this study.

TABLE I.
ELEVATION DATA (IFAS STANDARD ELEVATION DATA)

Name	Provider	Spatial resolution	Coordinate System	Range
Global Map	ISCGM	30s(1km)	WGS84	Global
GTOPO30	USGS	30s(1km)	WGS84	Global

TABLE II.
ELEVATION DATA (GIS PROCESSED ELEVATION DATA)

Name	Provider	Spatial resolution	Coordinate System	Range
ASTERGDEM	ISCGM	30m	WGS84	Global
Base Map Information Number Value High	Territorial Institute of Geography	10m	WGS84	Japan

Table III.
LAND USE DATA

Name	Provider	Spatial resolution	Coordinate System	Range

Global Map (Land Cover)	ISCGM	30s(1km)	WGS84	Global
Global Map (Land Use)	ISCGM	30s(1km)	WGS84	Global
GLCC	USGS EDC	1km	ITRF94 GRS80	Global

2. Rainfall data

Satellite rainfall data and ground rainfall data were used in this study. There are eighty-three rainfall observation stations in the Tokachi River basin and its surrounding. Therefore, the Tokachi River Basin provides sufficient ground rainfall data. In this study, satellite rainfall data used the GSMaP_NRT and 3B42RT systems, in which the data for the period of analysis was available. The 3B42RT system is a product of the Tropical Rainfall Measuring Mission (TRMM), which is a satellite launched in a corporative mission of the Japan Aerospace eXploration Agency (JAXA) and the US National Aeronautics and Space Administration (NASA). The dataset GSMaP_NRT is a GSMaP product processed and provided by JAXA, and is part of Global Precipitation Measurement, a collaborative mission of JAXA, NASA and other organizations, and the successor to the TRMM. GSMaP_NRT uses sensor data from a highly accurate GPM main satellite, as well as using TRMM data; therefore, GSMaP_NRT is capable of sensing rainfall in wider areas and in smaller amounts than TRMM is capable of sensing. IFAS has a function for assigning rainfall of each observed point to each cell of the computational grid for the Thiessen polygon for that point [23]. The user inputs a set of discrete rainfalls for the observed point and the coordinates of that point into IFAS. The specifications of satellite data were shown in Table IV.

TABLE IV.
SPECIFICATIONS OF THE SATELLITE DATA

Product name	GSMAP_NRT	3B42RT
Resolution	0.10(L=11km, A=120km^2)	0.250(L=25km, A=600km^2)
Resolution Time	1(hour)	3(hours)
Coverage	60^0N-60^0S	60^0N-60^0S
Time lag	4(hours)	10(hours)
Coordinate System	WGS	WGS
Historical Data	Dec 2007	Dec 1997
Developer and Provider	JAXA/EORC	NASA/GSFC
Sensors	TRMM/TMIAqua/AMSR-EADE OSII/AMSRSSM/IIRAMSU-B	TRMM/TMIAqua/AMSR-EAMSU-BDMSP/SSM/IIR

3. River channel data

IFAS is able to automatically generate the river channel network from IFAS standard elevation data. In addition to the river channel network creation function, IFAS has a function for correcting the shape of generated the river channel network inputted in a shape file format that is prepared separately. The way that IFAS automatically generated network of rivers was used in this study.

D. Configuration of PWRI Distributed Model

The PWRI Distributed Model (version 2) compromises the configuration of two tanks on vertical direction, one is the surface tank and the other is the underground water tank. Besides, the third one, the river channel tank was shown in the Figure 2 and 3.

E. Configuration of PWRI Distributed Model

1. Surface parameters

As shown in Table V, the surface parameters were used in this study.

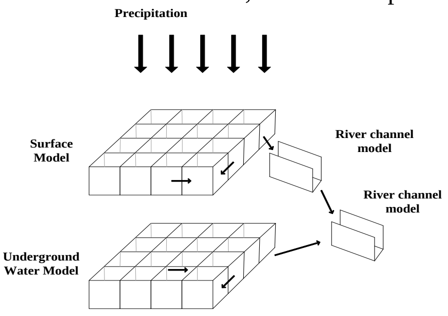

Fig. 2. Scheme image of the model

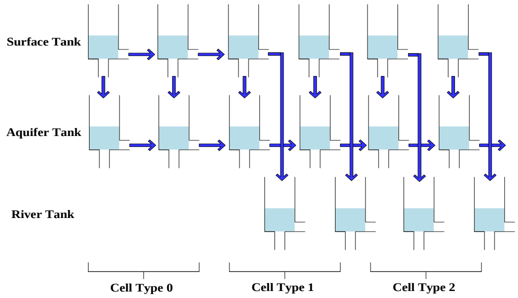

Fig. 3. Cell type outline chart

TABLE V.
SURFACE PARAMETERS USED FOR TOKACHI RIVER

Parameters	Final infiltration capacity fo(cm/s)	Maximum storage height S_{f2}(m)	Rapid intermediate flow S_{f1}(m)	Height here ground infiltration Occurs S_{fo}(m)	Surface roughness Coefficient N($m^{-1/3}$)	Rapid intermediate flow regulation coefficient α_n	Initial storage height (m)
1	0.0005	0.1	0.01	0.005	0.7	0.8	0
2	0.00002	0.05	0.01	0.005	2	0.6	0
3	0.00001	0.05	0.01	0.005	2	0.5	0
4	0.000001	0.001	0.005	0.0001	0.1	0.9	0
5	0.00001	0.05	0.01	0.005	2	0.5	0

2. Aquifer parameters

The aquifer parameters used in this study were shown in Table VI.

3. River tank parameters

Table VII showed the usage of the river tank parameters in this study.

TABLE VI.
AQUIFER PARAMETERS USED FOR TOKACHI RIVER

Parameters	AUD(1/mm/day)$^{1/2}$	AGD(1/day)	HCGD(m)	HIGD(m)
1	0.1	0.003	2	2

TABLE VII.
RIVER TANK PARAMETERS USED FOR TOKACHI RIVER

Parameters	1	2	3
Constant of the Resume law(c)	7	7	7
Constant of the Resume law(s)	0.5	0.5	0.5
Manning roughness coefficient	0.035	0.035	0.035
Initial water table of river channel(m)	0.2	0.2	0.2
Infiltration of Aquifer tank	0	0	0
Coefficient of cross shape (RHW)	9999	9999	9999
Coefficient of cross shape (RHS)	1	1	1
Coefficient of cross shape (RBH)	0.5	0.5	0.5
Coefficient of cross shape (RBET)	0.05	0.05	0.05
Coefficient of cross shape (RLCOF)	1.4	1.4	1.4

(n: number of cell)

F . Name Description

The naming conventions for using different boundary extraction techniques and rainfall data were shown in the Table VIII.

G . The Method of Operation of IFAS

The method of operation of IFAS was described in Figure 4.

TABLE VIII.
NAME DESCRIPTION FOR DIFFERENT BOUNDARY CONDITIONS AND RAINFALL DATA

Name	Technology to extract watershed boundaries	Rainfall data
Ground--ArcGIS	ArcGIS	Ground-based rainfall
Ground--IFAS	IFAS	Ground-based rainfall
Gsmap-- ArcGIS	ArcGIS	Gsmap_NRT
3B42RT-- ArcGIS	ArcGIS	3B42RT(V7)

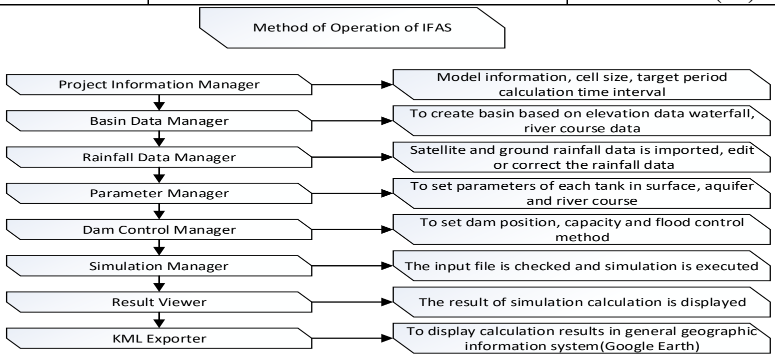

Fig. 4. Flow of runoff analysis using IFAS

H . Results and Discussion

1. The results of catchment boundary extraction for different types of elevation data

The paper studied two catchment boundary extraction methods and the runoff calculation results under different catchment boundary extraction methods [24]. First, the boundaries made using elevation data downloaded using the standard features of IFAS and the boundaries made using elevation data processed by ArcGIS software were compared. The results show that the elevation data processed using ArcGIS software makes the boundaries was more accurate. The result was shown in Figure 5. Next, in the same case of ground rainfall data, comparing runoff calculation results by Watershed with Boundary Extraction by IFAS and ArcGIS, few differences were found in runoff calculation results. The result was shown in Figure 6. Comparisons between different results mentioned above, the catchment boundaries created based on GIS-processed elevation data is better.

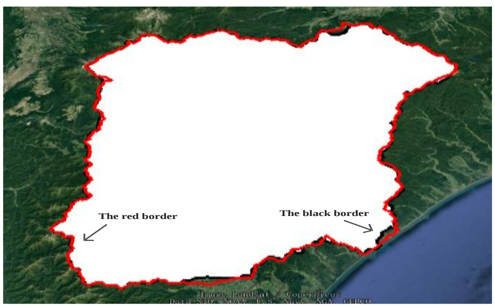

Fig. 5. Compare of the watershed boundaries created by ArcGIS and IFAS
(The red border is made with ArcGIS, Drainage area: 8997km2)

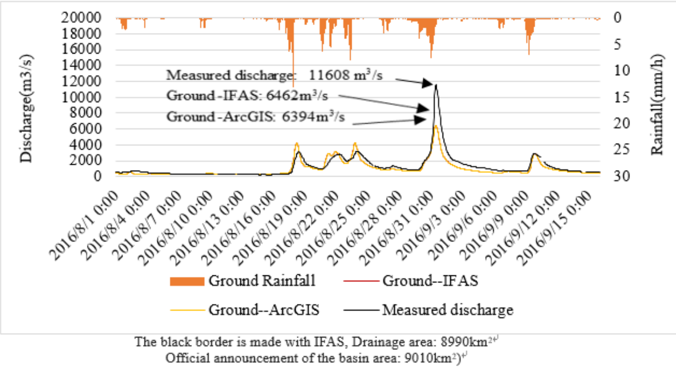

Fig. 6. Comparison of Runoff Calculation Results by Watershed Boundary Extraction by IFAS and ArcGIS (In Moiwa)

2. The results of runoff calculation done by using various rainfall data types

The result of the IFAS based on Ground rainfall shows the IFAS records the flood duration well in almost all the cases. The result of satellite GSmap and satellite 3B42RT shows calculation accuracy is not high, especially for the flood caused by Typhoon No. 10 that was not captured, explaining that satellite rainfall data used by IFAS are flawed in cases of long duration flood or a large flux flood in a short period of time. This part is in need of improvement. The result was shown in Figure 7.

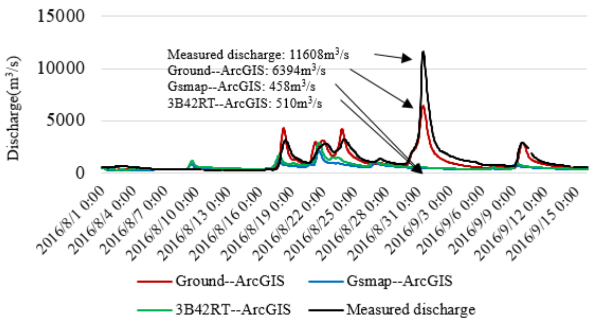

Fig. 7. Comparison of runoff calculation results using various types of rainfall data(In Moiwa)

3. Attempts to Improve the Precision of Runoff Calculation Results by Changing Parameters

For IFAS, users need to set parameters for surface, subsurface, aquifer and river courses to calculate runoff analysis in IFAS. The parameter set includes the surface of the river, the maximum storage height and runoff coefficient of the underground and aquifer, the roughness of the river and the runoff coefficient. The user can use preset / default values of parameters and manually change them during the calibration. This is an important function to improve the accuracy of the calculation results. In order to achieve this, this study attempted to change the parameters, and the tuned parameters were shown in Table IX. Under the same boundary conditions and rainfall data, it can be found by comparing the calculation results under different parameters that changing the parameters can improve the accuracy of the calculation results, especially for the flood caused by Typhoon No. 10. Moreover, the whole Typhoon No. 10 was the most important during the study because it has caused the largest-flux flood. Through the analysis of the results, it can be found that the change of parameters improves the calculation accuracy of the flood caused by Typhoon No. 10, while the calculation accuracy of the flood caused by Typhoon No.7, 11 and 9 decreases. In general, changing the parameters has the effect of improving the calculation accuracy. The result was shown in Figure 8.

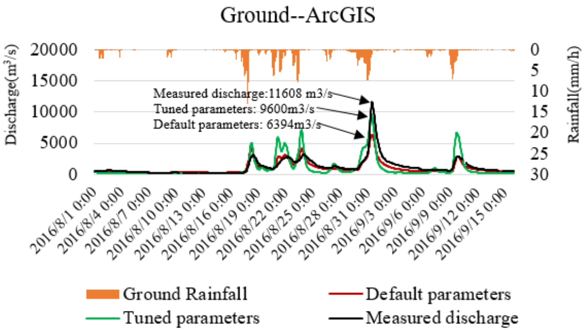

Fig. 8. Comparison of Runoff Calculation Results with Changed Parameters(In Moiwa)

TABLE IX.
TUNED SURFACE PARAMETERS

Tuned Parameters	Final infiltration capacity fo(cm/s)	Maximum storage height S_{f2}(m)	Rapid intermediate flow S_{f1}(m)	Height where ground infiltration Occurs S_{fo}(m)	Surface roughness Coefficient N($m^{-1/3}$)	Rapid intermediate flow regulation coefficient α_n	Initial storage height (m)
1	1×10^{-7}	0.1	0.01	0.005	0.7	0.8	0
2	4×10^{-9}	0.05	0.01	0.005	2	0.6	0
3	2×10^{-9}	0.05	0.01	0.005	2	0.5	0
4	2×10^{-10}	0.001	0.005	0.0001	0.1	0.9	0
5	2×10^{-9}	0.05	0.01	0.005	2	0.5	0

CONCLUSION

This paper studied the flood calculation of the Tokachi River during the Hokkaido typhoon from August to September in 2016. The results are as follows:

(1) It was found that the catchment boundaries created based on GIS-processed elevation data, which has high spatial resolution, made the catchment boundary more accurate and allow for more accurate emission calculation.

(2) It was found that estimation safe-side discharge and water level were possible by using Ground rainfall data.

(3) When IFAS used satellite rainfall data for flood calculations, the results obtained by the 3B42RT were more exact than Gsmap, while the accuracy needs to be further improved

(4) IFAS has low prediction accuracy for large floods and IFAS satellite rainfall data are ineffective for long duration flood or a large flux flood in a short period of time. Changing the parameters can improve the accuracy of flood calculation results.

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