PREDICTION OF THE LARGEST EVER FLOOD: CASE STUDY ON TYPHOON RUSA IN 2002 AT THE GAMCHEON BASIN, KOREA

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This study focuses on a prediction of the largest ever flood, which caused by Typhoon Rusa in 2002 at the GamCheon Basin, Korea, with a distributed hydrologic model. Using hydrologic events data earlier than the typhoon flood, the model was calibrated with the SCE optimization algorithm under various conditions, such as different event size and duration, integrating evaporation information and adopting additional model parameters for distributed land use. As more hydrologic data (evaporation and land use) integrating, the model shows improved simulation behavior for long-term events. However, parameter sets calibrated with short term events provides stable and efficient prediction on the Rusa flood event.

Key Words: *Typhoon Rusa, distributed hydrologic model, model calibration, SCE algorithm*

1. INTRODUCTION

Typhoon Rusa (No. 0215) hit South Korea on 31st August 2002, which is the strongest typhoon to strike Korea since Typhoon Sarah (1959). More than 200 people were deceased or missing and up to 870 mm/d rainfall was reported in some areas. Damage, mostly by severe floods, was estimated to more than 750 million USD.

To predict this kind of heavy flood before it occurs is one of the main topics to hydrologists, and many models have developed to meet this demand. After a model is composed and calibrated for a certain basin using available hydrologic data, the model is possible to simulate any future flood with predicted rainfall input. At this moment, calibrated parameter sets are believed to represent inherent properties of the hydrologic system sufficiently.

However, since the representation is not perfect yet with any model and any parameter, calibrated parameters are also believed to represent a specific condition of the event that used for the calibration, such as event size and duration, seasonal or climate difference. If the model confront with very different type of events to the prior hydrologic records that were used for the model calibration, there will be considerable uncertainty on the model performance.

This study examines a prediction performance of a distributed hydrologic model, CDRMV3[1)], on the largest ever flood, which happened in a basin of Korea during Typhoon Rusa in 2002. Parameters were calibrated only with typical flood events data using the SCE algorithm[2)] under various conditions. The various conditions for the calibration were (1) variant flood sizes and durations, (2) integrating evaporation data for giving further hydrologic data into the model and (3) allowing more model parameters to consider spatially variant land use. Variant parameter sets that were calibrated under these conditions were tested to predict the largest flood event of the study basin.

The organization of this paper is as follow: Section 2 illustrates the scopes of this study including an introduction to the distributed model, optimization algorithm, the study basin and the hydrologic data for the model calibration. Section 3 shows the procedure and the results of the parameter optimization. Section 4 provides the application results of the calibrated parameter sets on the Rusa flood event and discuss with the results. Finally, Section 5 concludes the paper by summarizing this study.

2. METHODOLOGY

Due to the distinctive flood characteristics of Japan and Korea, which has very rapid change of discharge within a short time, it is still on-going research to develop a hydrologic model applicable to various conditions. So far, it has not been easy to figure out the general parameter set of a basin even only for short-term flood type events.

However, extensive model testing under various scenarios on a certain flood vulnerable basin can decrease the uncertainty on flood predictions. In this study, a distributed hydrologic model, CDRMV3 has tested on the GamCheon basin, Korea to figure out its performance adaptability and to search the best way to predict abnormal flood event during Typhoon Rusa in 2002.

The model performance test was started from model calibration with variant event and conditions, such as different event size and duration, additional hydrologic data and different model complexity. Firstly, hydrologic data of the GamCheon Basin from June to September of the year 2000, 2001 and 2002 was examined, and different size of six short-term flood events (events last for several days) were selected, and the model was calibrated with those events. Secondly, four long-term flood events (events last for 30 to 40 days), which include the short-term events within their event durations, were selected for the second case of model calibration. This case is for avoiding possible influences of variant soil wetness condition by any prior rainfall of the each short-term event. Thirdly, to give more hydrologic information for the long-term events calibration, evaporation data has given into the model, and the model was calibrated again. Lastly, two types of parameter set were allowed for spatially variant land uses of the basin, and more complex model than earlier cases was calibrated for another long-term events calibration.

Based on the illustrated four types of calibration cases, automatic calibration using Shuffled Complex Evolution (SCE) algorithm has carried out. The calibrated parameter sets were applied on the Rusa flood event to check and compare its adaptability.

(1) Distributed Hydrologic Model, CDRMV3

A distributed hydrologic model adopted for this study is CDRMV3[1)], (http://flood.dpri.kyoto-u.ac.jp /product/cellModel/cellModel.html). The Model solves one-dimensional kinematic wave equations for both sub-surface flow and surface flow using the Lax-Wendroff scheme. Discharges and water depths diffuse to the steepest downward adjacent cell according to a flow direction map generated from DEM data. The CDRMV3 adopts specific stage-discharge relationship incorporating saturated and unsaturated subsurface as well as surface flow[3)].

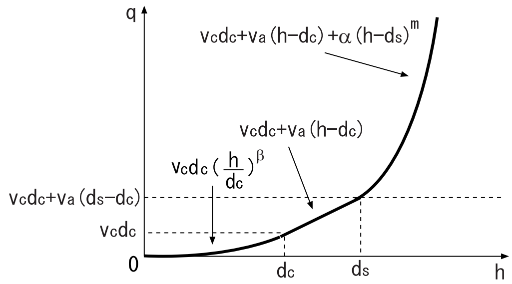

Fig. 1 Relationship between unit width discharge and water depth in the CDRMV3.

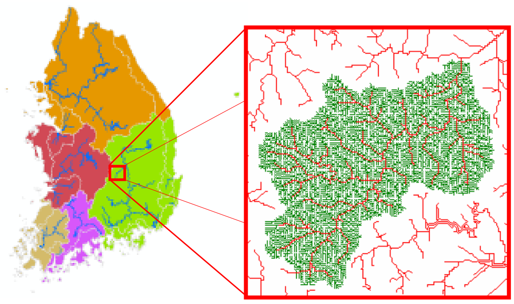

Fig. 2 Location of the GamCheon upper basin (413.3km^2) and the flow direction map for CDRMV3 model. Korean basin map (left) source: WAMIS website.[4)]

This relationship is expressed by three equations as shown in **Fig. 1**. Parameters to be optimized are roughness coefficient n, soil depths d_s-d_c and d_c, and hydraulic conductivities k_a and k_c, which determine the velocity of saturated subsurface flow, v_a and unsaturated subsurface flow v_c, respectively. The initial condition of CDRMV3 was determined using an observed discharge at the basin outlet under the steady-state assumption. More details for the CDRMV3, refer to Kim *et al.*[5) 6)]

(2) GamCheon Basin, Korea

GamCheon is a tributary of the NakDong River, and there are two water-stage stations along the River; KimCheon and SunSan. The KimCheon station is located in the middle reach of GamCheon, and upper basin of the station has 413.3km^2 of catchments area (see **Fig. 2**). The SunSan station is located at the confluence of GamCheon and NakDong River, and backwater effect makes it difficult to adopt the point as a model simulation outlet. In this study, upstream of the KimCheon station was modeled for the Rusa flood event simulation. During Typhoon Rusa, the middle reach of GamCheon was severely damaged by historic heavy flood with much debris from the mountain.

Several rating-curves are available at KimCheon station, and the rating-curve developed in 2002 was adopted to convert water stage into discharge data. Six rain gauge stations are around the GamCheon upper basin; KimCheon, YoungDong, DaeGa, MuPung, WungYang and HwnagGan. Spatially distributed rainfall was calculated from the stations' data using inverse distance weighting factor.

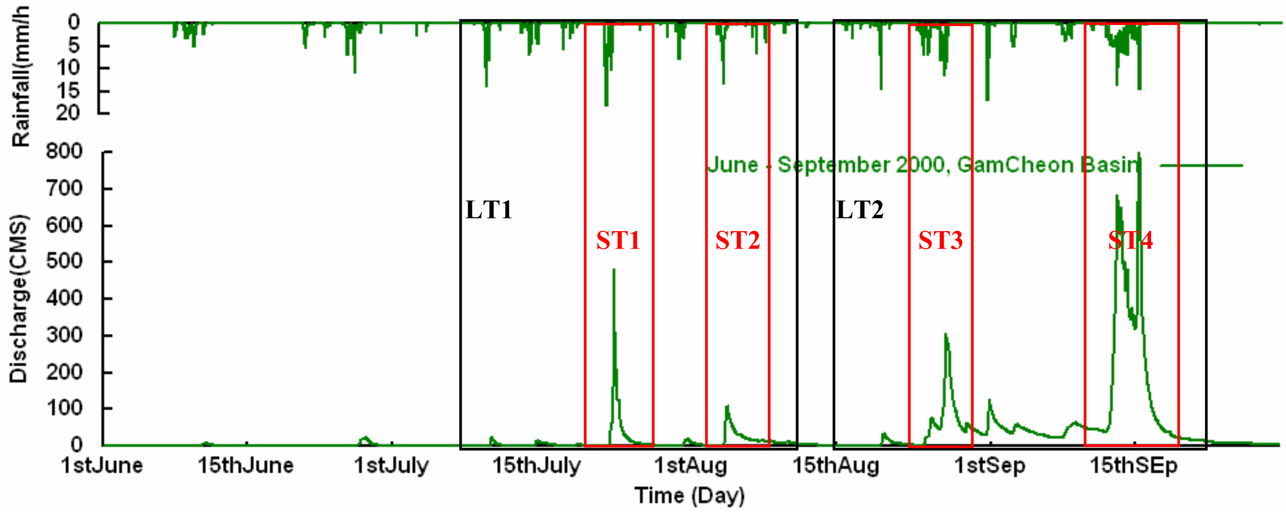

Fig. 3 Recorded rainfall (basin average) on the GamCheon upper basin and observed discharge at KimCheon gauge station from June to September, 2000, and the selected flood event, LT1, LT2, ST1, ST2, ST3 and ST4.

Table 1. Duration and peak discharges of selected flood events and the Rusa event

Short-Term Event				Long-Term Event			
Title	Duration	Rainfall (mm)	Peak Q (m^3/s)	Title	Duration	Rainfall (mm)	Peak Q (m^3/s)
ST1	2000 July 21 ~ July 26	140.8	483.0	LT1	2000 July 09 ~ Aug 11	434.2	483.0
ST2	2000 Aug 02 ~ Aug 10	92.4	108.3				
ST3	2000 Aug 23 ~ Aug 30	177.6	305.7	LT2	2000 Aug 15 ~ Sep 18	664.8	822.3
ST4	2000 Sep 10 ~ Sep 18	310.4	822.3				
ST5	2001 June 22 ~ June 28	110.2	179.4	LT3	2001 June 16 ~ July 22	359.4	179.4
ST6	2002 Aug 05 ~ Aug 19	466.4	518.8	LT4	2002 July 18 ~ Aug 22	517.4	518.8
RUSA	2002 Aug 29 ~ Sep 03	316.4	**2,572.5**	(303.6mm of rainfall was concentrated within 24hrs.)			

(3) Selected Flood Events

Table 1 presents the details of the selected flood events, and **Fig. 3** shows rainfall and discharge data of the events in 2000. Each event is numbered as ST for short-term event and LT for long-term event. LT1 includes ST1 and ST2, and LT2 includes ST3 and ST4; and so on for LT3 and LT4.

Observation data for rainfall and discharge has one-hour time resolution and the simulation output also has the same time resolution. Every event includes more than one-day of dry period before its rainfall started for model worming up.

(4) Automatic Optimization Algorithm, SCE-UA

The Shuffled Complex Evolution algorithm[2)] was utilized for searching the best fitted parameter set on each calibration event. The SCE algorithm is a single-objective global optimization method, and has been performed on a variety of models with outstanding positive results[2)]. The algorithm is synthesized by three concepts; combination of a simplex procedure with controlled random search approaches, competitive evolution and complex shuffling. Objective function adopted in this study for the optimization algorithm is to maximize the Nash-Sutcliffe Coefficient (NSC).

3. MODEL CALIBRATION UNDER VARIOUS CONDITIONS

(1) Calibration with Short-Term Events

The five parameters of CDRMV3, n, d_s-d_c, d_c, k_a and k_c were optimized for each short-term flood event, and the results are presented in **Table 2**. Initial parameter ranges given to the optimization algorithm are presented at the top of the results with bold characters. Although there are several values that reach to the boundary of the given range, every optimization was successfully converged and shows high NSC value. As shown in **Fig. 4**, most of the calibrated parameters give awesome match of the simulated results to the observed hydrographs.

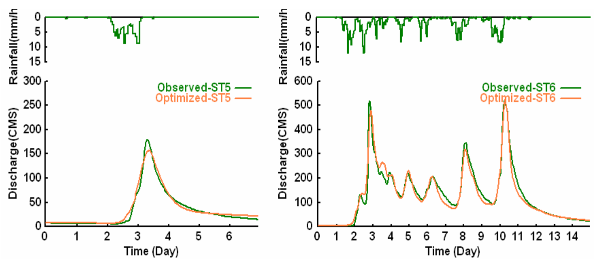

Fig. 4 Simulation results from the parameter optimization ST5 event (left) and ST6 event (right)

Table 2. Optimized parameter sets for each event and its Nash-Sutcliffe Coefficients (NSC)

Type	Condition.	Event Title	n	d_s-d_c	d_c	k_a	k_c	NSC
			Parameters Optimized					
Short Term Event	Single L.U. / No Evp		**(0.010~0.300)**	**(0.00~300.0)**	**(100.0~800.0)**	**(0.005~0.030)**	**(0.0001~0.003)**	
		ST1	0.0398	66.292	302.425	0.0050	0.0002	0.791
		ST2	0.0394	1.769	497.241	0.0121	0.0007	0.804
		ST3	0.1550	29.178	213.811	0.0076	0.0013	0.985
		ST4	0.0585	54.462	126.917	0.0203	0.0001	0.818
		ST5	0.1911	6.053	439.734	0.0065	0.0008	0.975
		ST6	0.1008	26.980	113.776	0.0130	0.0042	0.950
Long Term Event	Single L.U. / No Evp		**(0.010~0.300)**	**(0.00~300.0)**	**(100.0~1500.0)**	**(0.005~0.030)**	**(0.0001~0.003)**	
		LT1	0.0834	1.342	1499.682	0.0053	0.0002	0.470
		LT2	0.1014	0.044	1499.592	0.0152	0.0003	0.874
		LT3	0.1656	0.015	1499.811	0.0050	0.0005	0.629
		LT4	0.0525	21.813	1499.803	0.0300	0.0005	0.976
	Single L.U. / Evp		**(0.010~0.300)**	**(0.00~500.0)**	**(100.0~1500.0)**	**(0.005~0.030)**	**(0.0001~0.003)**	
		LT1	0.0518	3.653	1318.151	0.0300	0.0005	0.799
		LT2	0.0590	0.022	1296.715	0.0284	0.0004	0.818
		LT3	0.1282	1.000	909.810	0.0201	0.0010	0.774
		LT4	0.0113	42.460	501.497	0.0300	0.0001	0.897
	DoubleL.U. / Evp	**(forest/ non forest)**	**(0.01~0.300 / 0.01~0.300)**	**(0.00~300.0 / 0.00~300.0)**	**(1000~2000.0 /100.0~1000.0)**	**(0.005~0.030)**	**(0.0001~0.003)**	
		LT1	0.0145 / 0.0477	27.783 / 37.242	1186.014 / 999.943	0.0065	0.0001	0.825
		LT2	0.0100 / 0.0497	0.012 / 57.559	1998.662 / 103.508	0.0295	0.0003	0.821
		LT3	0.0111 / 0.0908	0.007 / 297.706	1002.531 / 997.184	0.0101	0.0004	0.809
		LT4	0.3000 / 0.0318	41.893 / 11.244	1000.475 / 102.402	0.0300	0.0001	0.909

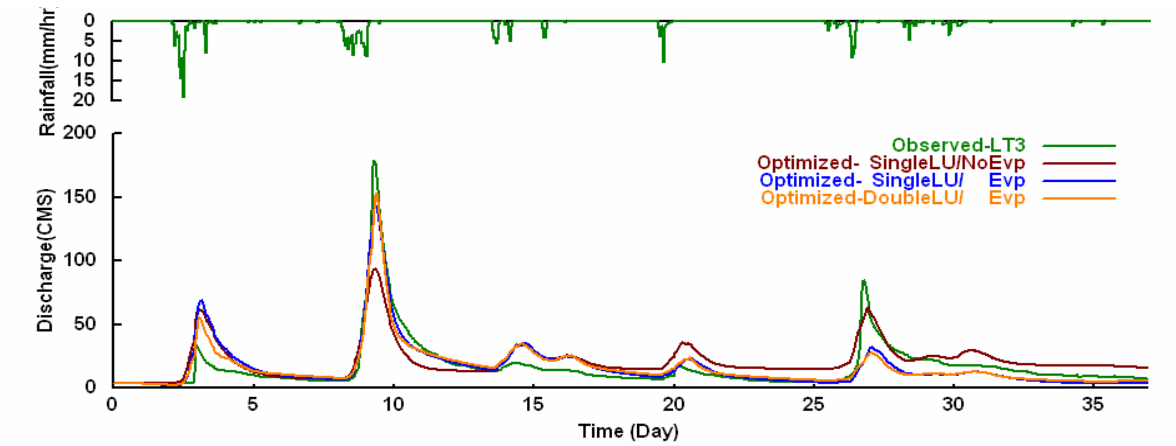

Fig. 5 Parameter optimization results of LT3 event. Consideration of evaporation loss improves the results well.

(2) Calibration with Long-Term Events

Four long-term events were also calibrated using the SCE algorithm, and the results as well as the given ranges are presented in **Table 2**. Even though some cases show good NSC values, every optimization result shows that the results of d_s-d_c and d_c have the boundary values. The ranges for d_s-d_c and d_c had modified and tried several times for a proper result, but every optimization in this case asks thicker soil layer. Thicker soil depth may give better match for the low flow duration, but it also gives dull responses on the peak.

Optimization results from the LT events show dependant behavior on the rainfall pattern, such as amount and its time distribution. In the case of LT2 event, as shown in **Fig 3**, it has large amount of rainfall which is distributed within and between the ST3 and ST4 events, and LT4 event also has concentrated rainfall within the duration of ST6. While LT2 and LT4 show very good optimization results with 0.874 and 0.976 of NSC values, the other events, LT1 and LT3, have more complex rainfall pattern, and the model failed to catch this dynamic behavior of the catchments. (See brown line in **Fig. 5**, which indicates the output with the optimized parameters of LT3).

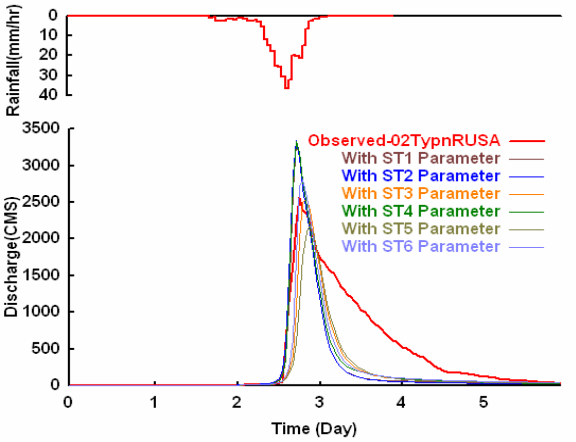

Fig. 6(a) Prediction of Rusa event with the parameters that were calibrated using the ST event series

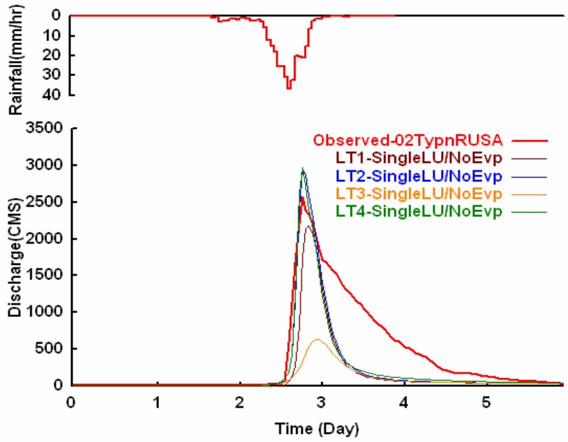

Fig. 6(b) Prediction of Rusa event with the parameters that were calibrated using the LT event series

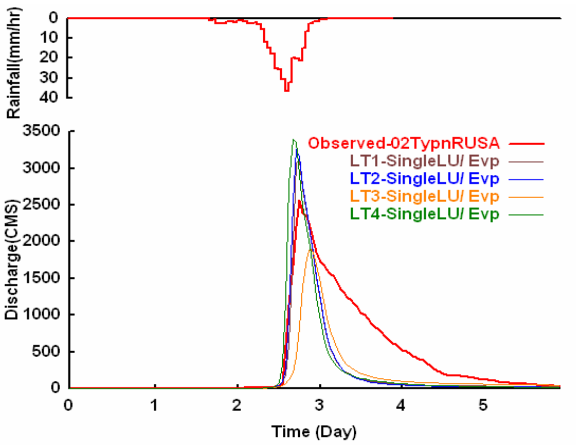

Fig. 6(c) Prediction of Rusa event with the parameters of LT (Evaporation loss considered) event series

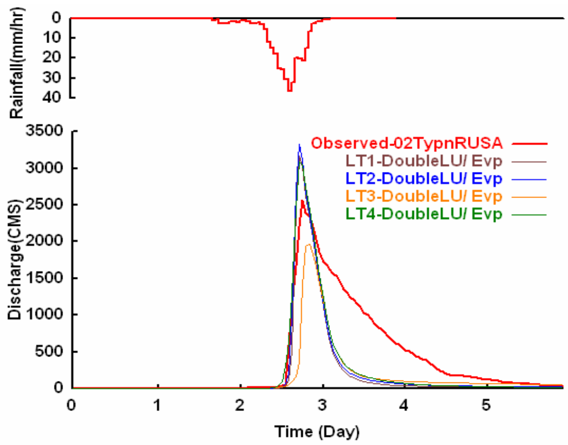

Fig. 6(d) Prediction with the parameters of LT (Evaporation loss and two types of land use considered)

The parameters n, k_a and k_c are within the given ranges and do not show very different behavior for both short-term and long-term events. Only the parameters d_s and d_c (especially d_c) show significant increase for the long-term events, and it might be because the model should keep much water in the soil to produce low flow discharge continuously, for a dry period of the long-term events.

(3) Calibration with Long-Term Events - with Evaporation and Land Use Data

To search for more stable and physical parameter sets for the long-term events, further hydrologic data and higher model complexity has given. Firstly, evaporation loss was considered into the model. According to the Korea Climate Table of KMA[7], average of daily evaporation loss from June to September at the GamCheon area is equivalent to 0.189 mm/hr. To consider this amount of the loss, 0.2 mm/hr was continuously extracted from the soil moisture for the long-term simulations.

Secondly, spatially distributed parameters were considered to reflect the variant land use type of the Basin. For forest area (62%) and non-forest area (38%), two types of soil depth and roughness coefficient were adopted so that eight parameters were optimized. With additional information on the catchments and more detailed model structure, the model may be able to properly describe low flow parts and peak flow parts as well.

Table 2 shows the optimized parameter sets from the additional data integrated long-term events. The NSC values show improved and more stable results as more information is available, especially in the case of LT1 and LT 3 (see **Fig. 5**), and most of the parameters were converged into the given ranges.

Adopting additional parameters for two types of land uses does not produce significant improvement after the evaporation loss consideration. When the model tested with opposite case (no evaporation loss but double land use considered), which is not described in this paper, the model shows quite similar behavior to the presented results; noticeable improvement with the additional parameters, but slight improvement after that.

The optimization with the SCE algorithm in this study has 800 ~ 1200 times of total searching combinations, and it takes about one day of running time for the short-term events and two and half day for long- term events on a Pentium desktop PC.

Table 3. Application results of the optimized parameter sets on the Rusa flood event

Type	Cond.	Event Title	Evaluation N.S.C	Q_P Diff. (Q_S-Q_O) m³/s	T_P Diff. (T_S-T_O) hr
Short Term Event	**Single** L.U./ **NoEvp.**	ST1	0.572	+748.0	-1
		ST2	0.554	+774.4	-1
		ST3	0.655	-19.5	+2
		ST4	0.627	+751.5	-1
		ST5	*0.604*	*-395.4*	*+3*
		ST6	0.668	+232.5	+1
Long Term Event	**Single** L.U./ **NoEvp.**	LT1	0.551	-393.6	+2
		LT2	0.662	+392.7	0
		LT3	*0.127*	*-1941.8*	*+4*
		LT4	0.661	+401.6	0
	Single L.U./ **Evp.**	LT1	0.609	+527.1	0
		LT2	0.591	+683.2	-1
		LT3	*0.525*	*-654.1*	*+3*
		LT4	0.461	+824.5	-2
	Double L.U./ **Evp.**	LT1	0.558	+595.1	-1
		LT2	0.580	+748.9	-1
		LT3	*0.510*	*-609.6*	*+2*
		LT4	0.637	+518.8	-1

4. PREDICTION OF THE RUSA FLOOD

The optimized parameter sets from the four cases were applied to the Rusa flood event. The Rusa event at GamCheon has 2,572.5 m^3/s of peak discharge, which is 4~25 times larger than the peak discharges of the calibrated flood events. The most interesting point is whether the calibrated model using a normal size or small size of event can successfully produce the largest ever flood event. The application results of each case are presented in **Fig. 6**. The ST events' parameter sets produce very reasonable simulation results as shown in **Fig. 6(a)**. For the peak discharge difference, it varies from -395.4 to +774.4 m^3/s (see **Table 3**), which is around 25% of peak discharge. For the peak time difference, four of six parameter sets of ST events show only one hour error; one hour is the minimum time step of the model output and observed data as well.

After the peak of the Rusa event, the observed discharge and every simulated result show very big discrepancy. It seems that the observed discharges include a certain level of observation error, since much debris flow was observed during the flood, and river bed had severely changed at that time.

In the case of LT events' parameters that were calibrated without considering evaporation loss, which is shown in **Fig. 6(b)**, also gives reasonable simulation results only except the parameter set from the LT3 event. However, with the other two cases of parameter sets from the evaporation loss and double land use consideration, parameters from the LT3 event also shows improved results as shown in **Fig. 6(c)** and **6(d)**. As more hydrologic information integrated, LT events' parameter shows a tendency toward overestimation.

5. CONCLUSION

This study examined a prediction performance of a distributed hydrologic model, CDRMV3, to the largest ever flood in the GamCheon Basin of Korea during Typhoon Rusa in 2002. Model parameters were calibrated with normal size flood data, and the calibrated parameter sets were applied for the flood prediction. The parameters were calibrated with the SCE algorithm under various conditions, such as different flood sizes and durations, integrating evaporation loss information and giving more parameters for two types of land use.

Results are summarized as follow:

1) For event based short-term flood simulations, calibration of CDRMV3 with a similar type of short-term event gives stable parameter set
2) Even the parameter set that was calibrated with a small size of event provides quite a good simulation for the largest ever flood event
3) Calibration for long-term events (30~40 days of duration) is dependant on the event type, such as rainfall amount and its time distribution
4) Consideration of evaporation loss for a runoff simulation more than one-month event duration improves the model performance significantly
5) Adopting additional model parameters after evaporation loss consideration provides only slight improvement on the model performance.

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