Decision support for preliminary release of reservoir for flood control using ECMWF medium-range ensemble rainfall forecast

Aide à la décision pour l'opération de libération préalable d'un barrage pour la gestion des crues utilisant la prévision d'ensemble des précipitations à moyenne échéance du CEPMMT

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Abstract. A method for integrated reservoir operation is developed by considering medium-range ensemble rainfall forecast provided by European Centre for Medium-Range Weather Forecasts (ECMWF) to enhance reservoir's flood storage capability while maintaining its function for water use. Preliminary release operation, in which storage water for water use is released just before a flood occurs, is considered here. The desired timing and amount of preliminary release are estimated from ensemble prediction, maximizing the flood control capacity while securing storage recovery after the flood event. The case study with Shin-Nariwagawa Reservoir in the Takahashi River basin, Japan, demonstrated the effectiveness of introducing long-range ensemble prediction in decision making for preliminary release.

Résumé. Une méthode d'aide à la décision pour l'exploitation intégrée des réservoirs est développée en tenant compte des prévisions de précipitations d'ensemble à moyen terme fournies par le Centre européen pour les prévisions météorologiques à moyen terme (CEPMMT) afin d'améliorer la capacité de stockage des crues du réservoir tout en maintenant sa fonction d'utilisation de l'eau. L'opération de rejet préalable, dans laquelle l'eau de stockage pour l'utilisation de l'eau est rejetée juste avant qu'une inondation ne se produise, est considérée ici. Le moment souhaité et la quantité de rejet

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préalable sont estimés à partir de la prévision d'ensemble, maximisant la capacité de contrôle des crues tout en assurant la récupération du stockage après l'événement de crue. L'étude de cas avec le réservoir Shin-Nariwagawa dans le bassin de la rivière Takahashi, au Japon, a démontré l'efficacité de l'introduction de la prédiction d'ensemble à longue distance dans la prise de décision pour la libération préliminaire.

1 Introduction

In recent years, Japan has suffered from large-scale floods, some of which were beyond the capability of a dam reservoir to control floods with the storage capacity currently allocated for flood control. In the flood event in July 2018, where recordable torrential rain hit broad regions across the western Japan, flood control capacity was used up in eight reservoirs during floods due to excessive water inflow. These reservoirs therefore had to carry out emergency gate spillway operation (EGSO), where water as much as inflow is released from the reservoir to prevent further increase in storage water, and lost their flood control functions in middle of flood. This EGSO was also conducted in six reservoirs in floods due to Typhoon Hagibis, which also brought heavy rainfall in wide areas in the eastern Japan in 2019. Severe damage was caused by flood inundation in the downstream areas of some of these reservoirs. It is therefore needed to enhance flood control capability of reservoirs so that they can effectively mitigate flood damage in the downstream also in extreme floods.

As a measure to enhance flood control capability of a reservoir, preliminary release operation has been introduced in reservoirs in Japan recently. In this operation, water stored in the reservoir is released just before a flood event based on real-time hydrological prediction in order to have more empty volume in the reservoir for flood control during the flood event. This operation allows a reservoir to have greater flood control capacity in flood conditions, while it can maintain storage water level as high as possible for water use purposes in non-flood conditions. It is therefore expected to provide an enlarged flood control capability of existing reservoirs without changing allocation of their storage capacity between flood control purpose and others. This operation can also be applied to reservoirs that are operated exclusively for power generation or water supply, so as to enhance flood control function by reservoirs in a target river basin.

Preliminary release operation, however, relies on real-time hydrological prediction, which essentially contains some uncertainty. This uncertainty of the prediction makes decision making for preliminary release operation difficult. If much preliminary release is conducted based on some overestimated rainfall prediction, reservoir storage may not be recovered in the end of the flood event, which can pose a problem for water supply or power generation after the flood event. On the other hand, the empty volume in the reservoir secured by preliminary release may not be enough to store flood waters if preliminary release is carried out based on some underestimated prediction. It has not yet been well established how to conduct reservoir preliminary release operation considering imperfect hydrological predictions in an effective manner.

Considering these circumstances, various studies have been reported in order to develop a robust way to conduct preliminary release operation considering hydrological predictions. Nohara et al. [1] proposed a method to make decision for preliminary release operation based on rainfall forecast for the coming 51 hours provided by Japan Meteorological Agency (JMA) considering forecast uncertainty by use of the fuzzy theory. On the other hand, Shimosaka et al. [2] studied a way for preliminary release based on observed rainfall where reservoir releases as much storage water as expected to receive during the coming flood event estimated from observed rainfall using rainfall-runoff analysis. Some studies employed other operational deterministic rainfall forecasts for the coming 33 to 84 hours calculated by JMA's Meso Scale Model (MSM) or Global Spectral Model (GSM) for decision making on reservoir preliminary release [3, 4].

On the other hand, operational ensemble hydrological predictions have been provided by meteorological agencies in many regions in recent years. It is considered to be able to reduce the effect of prediction uncertainty by considering multiple prediction scenarios (called ensemble prediction members) contained in an ensemble hydrological prediction. Recognizing these potential advantages of ensemble predictions, some studies investigated effectiveness of introducing these ensemble predictions into decision making on preliminary release of reservoirs to consider prediction uncertainty. Some of them applied operational weekly ensemble rainfall forecast [5, 6] while others considered hydrological predictions with shorter prediction lead time varied from 48 hours to 84 hours [7, 8].

In the meantime, the temporal range of some operational ensemble hydrological predictions is longer than a week, which can cover the whole duration of a flash flood event before it occurs. Long prediction range gives reservoirs a chance to secure a greater empty volume for flood control by allowing to start preliminary release earlier. Consideration of long-range prediction is also essential for successful preliminary release operation by reservoirs mainly operated for water use such as water supply or power generation, because it often takes long time for those reservoirs to decrease storage water level due to their limited capacity of water release outlets that can be used for preliminary release.

In light of the potential advantages of considering long-range ensemble hydrological predictions to support decision making for preliminary release operation of reservoirs, the authors have proposed a method to effectively conduct preliminary release from a multi-purpose reservoir based on ensemble rainfall prediction derived from 15-day forecast provided by European Centre for Medium-Range Weather Forecasts (ECMWF) [9]. However, the number of studies or practices where long-range ensemble hydrological predictions were introduced for preliminary release operation of reservoirs is still limited [10, 11]. One of the reasons why long-range ensemble hydrological predictions has not yet been widely used in this operation can be considered because it has not yet been clarified how preliminary release of reservoirs can be improved by introducing those predictions.

In order to overcome the circumstance described above, this study aims at clarifying the effectiveness of preliminary release operation of a hydropower dam reservoir considering long-range operational ensemble hydrological prediction. In this study, ECMWF medium range rainfall forecast for the coming 15 days is considered to estimate ensemble prediction of reservoir inflow. The timing and amount of preliminary release are then decided based on the estimated ensemble inflow prediction (EIP) considering the expected scale of the coming floods and possibility of water recovery after the flood event.

2 Methodology

2.1 Operational ensemble rainfall prediction

For ensemble rainfall prediction, ECMWF medium range ensemble forecast for the coming 15 days is used. This consists of 51 ensemble members, providing predicted values with grid resolution of 0.25 degrees. The temporal resolution is three hours until 144 hours (6 days) ahead, and six hours from 144 to 360 hours (15 days) ahead (see also Table 1).

Although this forecast has a fine spatial resolution when considering it is generated by a global atmospheric model, it is still coarse to represent the spatial distribution of rainfall in the upstream of a reservoir in Japan, which usually has a small catchment (10-500 km2) in mountain areas where orographic rainfall is dominant.

Table 1. Specifications of ECMWF medium range ensemble rainfall forecast (original) and one employed in this study (after post-processing).

Items	Original Forecast	Employed Forecast
Temporal range	15 days	15 days
Spatial coverage	Global	Target catchment
Temporal resolution	3 hours (until 144 hours ahead) 6 hours (from 144 to 360 hours ahead)	Same as original
Spatial resolution	0.25°	1 km
Number of ensemble members	51	51
Updating frequency	Twice a day (0:00 UTC and 12:00 UTC)	Once a day (12:00 UTC)

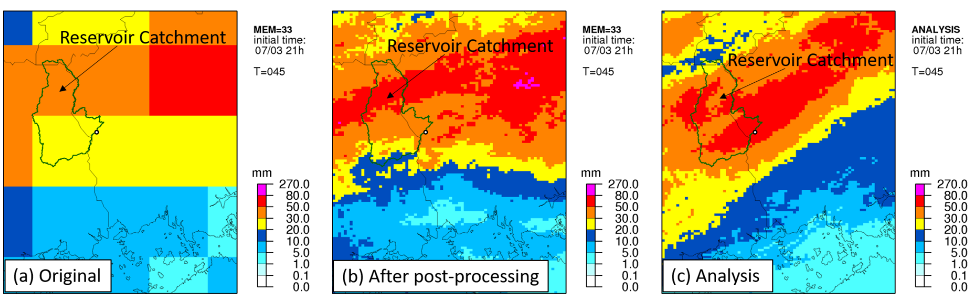


Fig. 1. Comparison in rainfall distribution: (a) forecast before post-processing (original), (b) forecast after post-processing, and (c) observed rainfall (analysis).

In order to improve the reproducibility of rainfall distribution in the reservoir catchments with finer spatial resolution (1km), frequency bias correction based on quantile mapping and statistical downscaling using the constructed analogues method [12] are conducted as a post-processing by using a method developed by Japan Weather Association [9]. An example of forecasted rainfall distribution after bias correction and downscaling is shown in Figure. 1. Three-hour rainfall until 45 hours ahead predicted by an ensemble member in the forecast provided at 12:00 UTC on 3 July 2018 for the Shin-Nariwagawa Reservoir catchment, the target reservoir catchment in the case study described in Chapter 3, is shown in this figure (see also Figure 3 for detailed information on the catchment). It can be seen in this figure that the spatial resolution of forecasted rainfall distribution becomes much finer after bias correction and downscaling (Figure 1 (b)) than that of original forecast (Figure 1 (a)). Clear rainfall distribution can also be seen in the reservoir catchment surrounded by a green curve line in the post-processed forecast shown in Figure 1 (b), which is much closer to the observed (analysed) rainfall distribution (Figure 1 (c)) than original forecast (Figure 1(a)).

While ECMWF medium range ensemble forecast is updated twice a day (0:00 UTC and 12:00 UTC), only the forecasts updated at 12:00 UTC are considered as the first trial in this study to decrease computation load for data processing and post-processing. Therefore, estimation of EIP is also conducted once a day (12:00 UTC), and decision for preliminary release is made once a day considering updating EIP.

2.2 Estimation of ensemble inflow prediction

Ensemble prediction of reservoir inflow for the coming 15 days is then calculated from the post-processed ensemble rainfall prediction described in the previous section by use of a rainfall-runoff model. The Hydrological River Basin Environment Assessment Model (Hydro-BEAM), a cell-grid type distributed rainfall-runoff model developed by Kojiri [13], is used for estimation of EIP. The outline of the model structure is as follows.

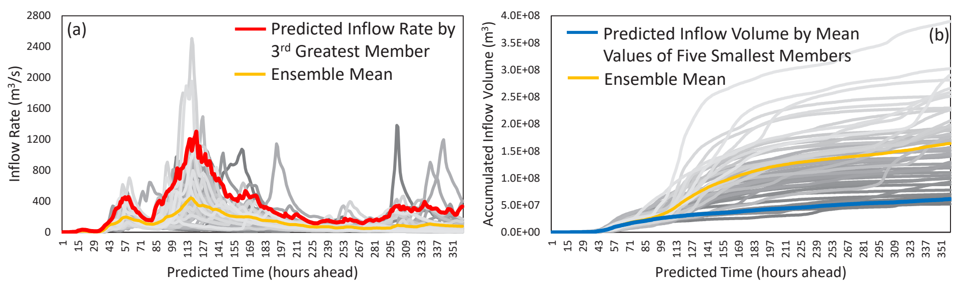


Fig. 2. Example of ensemble inflow prediction: (a) for hourly rate (highlighting the third-greatest values), and (b) for cumulative volume (higlighting mean values of the smallest five members).

The Hydro-BEAM divides each square-shaped grid cell into a pair of rectangular hill slopes and one river channel. The soil condition of each grid cell is represented as three layers that consist of the upper and two lower soil layers. Runoff flow is assumed to be surface and subsurface flows in the upper layer, and those flows are calculated by a kinematic wave model. On the other hand, a multi-layer linear storage function model is assumed to calculate base flows in the lower layers. Five land uses (field, forest, urban area, paddy field and water body) are considered for land surface and the upper layer of a non-river grid cell, and different parameters for soil and flow are respectively employed based on the land use. For a river grid cell, river flow is calculated by a kinematic wave model. Flow directions are estimated based on elevations within a grid cell as well as between adjacent grid cells so that water flows from the higher grid cell to the lower.

The grid size of Hydro-BEAM is set to be 1km in this study. Although ensemble rainfall prediction is given in a form of 3-hour or 6-hour rainfall as described above, EIP is estimated in hourly time resolution for the coming 15 days (360 hours) by use of Hydro-BEAM from prediction values of hourly rainfall that are estimated by averaging predicted values of 3-hour or 6-hour rainfall for the coming 15 days.

2.3 Decision making method for preliminary release considering EIP

When it is decided how to conduct preliminary release operation of the reservoir for the coming flood event, one needs to determine the timing and amount of preliminary release. In order to mitigate a rise in downstream river water level due to preliminary release before the flood event, the mean water release rate in preliminary release operation needs to be decreased, which requires to start preliminary release well in advance of the flood event. Earlier preliminary release is initiated, more empty volume can be secured in the reservoir in a safe manner for the downstream. On the other hand, from the viewpoint of water use after the flood event, it is desired to release storage water to the extent where storage water surely recovers in the end of the flood event without conducting unnecessary preliminary release. Later preliminary release is started, more accurate estimation of reservoir inflow during the coming flood event can be obtained for decision making for preliminary release.

In order to meet these conflicting needs for preliminary release operation, a method to conduct preliminary release from the reservoir is developed in this study by taking advantage of introducing ensemble hydrological prediction (see also Figure 2 for the following discussions). Firstly, the third greatest value at each predicted time step of EIP for the coming 15 days is used to estimate flood occurrence possibility, and considered to decide whether or not preliminary release to be conducted. In our previous work [9], the average of ensemble prediction members with the top five values at each predicted time step was considered for this purpose. However, it was identified that the greatest value of EIP was often too much overestimated—sometimes to such an extent as to unlikely occur—in the target reservoir catchment. The third greatest value is, therefore, employed in this study as an equivalent index to five greatest values (but eliminating the effect of the greatest value) to determine whether or not preliminary release to be conducted. The criteria to conduct preliminary release operation can be defined by the following equation:

$$\max_{1\le l\le L}\left\{ i\text{-th}\underset{m=1,\ldots,M}{\text{greatest}}\left(q^{*}_{m,l}\right)\right\} > Q_{\mathrm{F}} \quad (i=3) \tag{1}$$

where, q*m, l is inflow rate predicted by ensemble member m for l hours ahead (m3/s), L is the number of predicted time steps (hours) (L=360 in this study), M is the number of ensemble members (M=51 in this study), and QF is the criteria to determine whether preliminary release must be conducted based on EIP (m3/s), which is identical to the criteria to start flood control operation in the target reservoir when observed inflow exceeds this rate in this study (called flood inflow rate hereafter).

If preliminary release from a multi-purpose reservoir which is operated for flood control and water use purposes is considered, it might be more important to know whether storage capacity for flood control is enough or not for the coming flood event. In that case, one can consider the predicted total inflow volume during the flood event instead of the predicted inflow rate at each time step in EIP. See Kido et al. [14] for more detailed discussions for an effective way to determine the amount of prelimnary release for multi-purpose reservoirs with flood control capacity. However, the maximum value among the third greatest value at each time step in EIP is considered here because this study focuses on preliminary release from a hydropower dam reservoir, which does not have a permanent flood control capacity.

On the other hand, the amount of water to be released by preliminary release is determined considering five smallest values of total inflow volume in EIP for the coming 15 days. Storage recovery can be more ensured by considering the smaller values of predicted total inflow volumes. The equation to estimate the amount of preliminary release can be defined by the following equation:

$$v_{\mathrm{PR}} = \frac{1}{K}\sum_{k=1}^{K}\left[k\text{-th}\underset{m=1,\,\ldots,M}{\text{smallest}}\left\{ \alpha\sum_{l=1}^{L}\left(q^{*}_{m,l}-d_{l}\right)\cdot\delta_{\mathrm{s}}\right\}\right] \tag{2}$$

where, vPR is the total amount of preliminary release (m3), dl is the target release for water use at l hours ahead (m3/s), δs is seconds in a time step (δs = 3600 in this study), K is the upper limit of the order how many smallest values to be considered when the probable inflow volume received by the reservoir during the coming flood event is estimated (K=5 in this study), respectively. The variable α is a parameter which represents how much of the total inflow volume can be stored for water recovery during a flood event, and is set to be 0.5

in this study assuming that at least the half of the total inflow water can be stored by storing all water flowing into the reservoir after the inflow peak.

The rate of preliminary release is subsequently calculated by dividing the total volume of preliminary release v_{PR} by available time for preliminary release before the flood event:

$$r_{PR} = \frac{v_{PR}}{t_F - t_L} \tag{3}$$

where, r_{PR} is preliminary release rate at each time step (m³/s), t_F is the number of hours from the current time to the time when reservoir inflow is expected to exceed the flood inflow rate (by the third greatest values), and t_L is lead time in hour to be secured before the flood occurrence after preliminary release is completed.

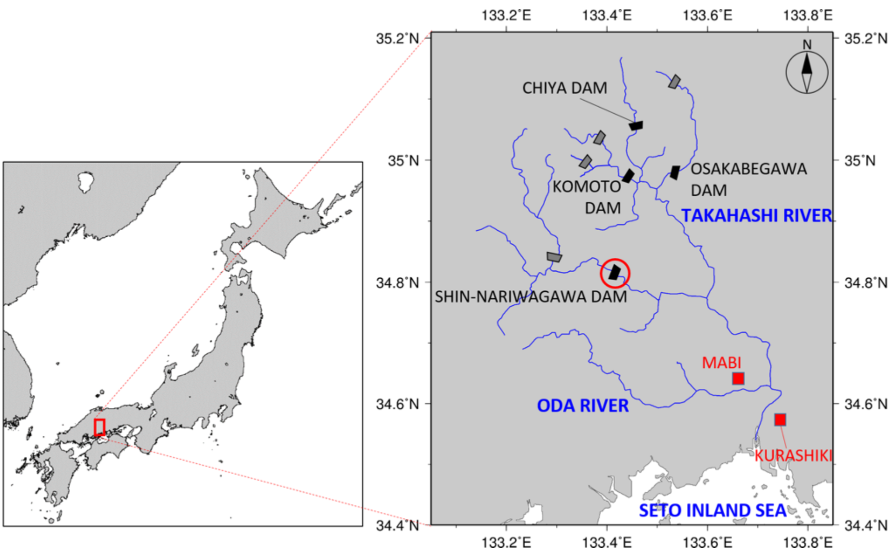


Fig. 3. Location of the Shin-Nariwagawa Reservoir and Takahashi River basin.

On the other hand, storage volume after preliminary release is completed S_G (denoted by the target storage volume hereafter) can be calculated by the following equation:

$$s_G = s_C - v_{PR} \tag{4}$$

where, s_c is the current storage volume. Reservoir storage volume is therefore designed to gradually be decreased to the target storage volume before expected time of flood occurrence by releasing as much water as r_{PR} at each time step as preliminary release.

3 Case study

3.1 Target reservoir and hydrological data

The proposed method of preliminary release was applied to the Shin-Nariwagawa Reservoir, which is located in the tributary of the Takahashi River basin in Japan (Figure 3). The Shin-

Nariwagawa Reservoir is a hydropower reservoir operated by the Chugoku Electric Power Company. The reservoir is mainly operated for hydropower generation and water supply, and does not have a permanent flood control capacity. Downstream areas in the Takahashi River basin were suffered from severe inundation in the flood event that occurred in July 2018 [15]. Although the reservoir is not operated for flood control, the Chugoku Electric Power Company has decided to allow the Shin-Nariwagawa Reservoir to take part in flood control by conducting preliminary release when heavy rain is predicted.

Table 2. Specifications of the target reservoir.

Items	Values
Effective storage capacity	80.5 MCM
Storage capacity below the spillways	55.62 MCM
Maximum amount of preliminary release	43.0 MCM
Minimum storage volume after preliminary release	37.5 MCM
Catchment area	616 km^2
Flood inflow rate	800 m^3/s
Maximum rate of preliminary release	400 m^3/s
Minimum target release for water use	30 m^3/s

In order to make the simulation settings simpler, assumed operation rules were considered in this case study by simplifying original operation rules of the Shin-Nariwagawa Reservoir. Settings of the target reservoir for this case study can be summarized as shown in Table 2. Values of effective storage capacity, catchment area, flood inflow rate, maximum rate for preliminary release were identical to those of the actual Shin-Nariwagawa Reservoir. The maximum total amount of preliminary release was assumed to be 43.0 million cubic meters (MCM), which means reservoir storage can be decreased to 37.5 MCM by preliminary release. Maximum rate of preliminary release is 400 m^3/s, which is identical to the maximum release rate from outlets for power generation. In other words, the reservoir can conduct preliminary release while generating electric power to this release rate. Flood control was assumed to be conducted by using empty volume in the reservoir secured by preliminary release if inflow more than the flood inflow rate (800 m^3/s) is observed. Initial water storage volume was set to be 72.45 MCM, which is 90% of the effective storage capacity, in all simulations in this case study.

3.2 Simulation cases

In order to understand the effectiveness to consider long-range ensemble hydrological prediction in decision making for preliminary release, four simulation cases were considered changing the way to consider EIPs (denoted by Cases 1 to 4). In Case 1, preliminary release of the reservoir was conducted based on the proposed method with consideration of both greater and smaller values in updating EIPs for the coming 15 days as described in Chapter 2. Preliminary release was conducted if inflow more than the flood inflow rate (800 m^3/s)

was predicted by the third greatest member, while the amount of preliminary release was determined to be a half of the total inflow volume estimated by the mean value of the five smallest members for the coming 15 days. On the other hand, preliminary release was conducted based on ensemble mean values of EIP for the coming 15 days without considering each ensemble prediction member in Case 2. Ensemble mean prediction was used to determine the amount of preliminary release as well as whether or not preliminary release should be conducted in this case. Case 3 simulated preliminary release operation considering an ensemble member that is called the control forecast instead of greater and smaller ensemble members of EIP for the coming 15 days. This corresponds to reservoir operation considering conventional deterministic prediction instead of ensemble prediction. Finally, in Case 4, preliminary release was carried out based on the proposed method considering EIPs, but EIP for only the first three days was considered. This corresponds to preliminary release operation when only short-range ensemble predictions are available.

Simulation of preliminary release operation of the target reservoir was carried out for the flood event in July 2018 described above, for all the four simulation cases.

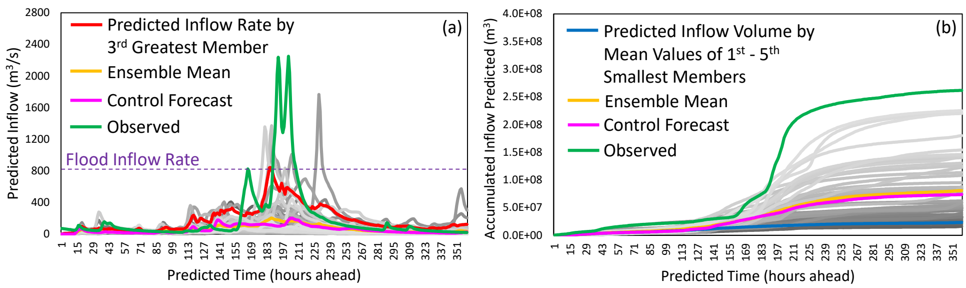


Fig. 4. Ensemble inflow prediction estimated on 28 June 2018 (a) for hourly rate and (b) for cumulative volume for the coming 15 days.

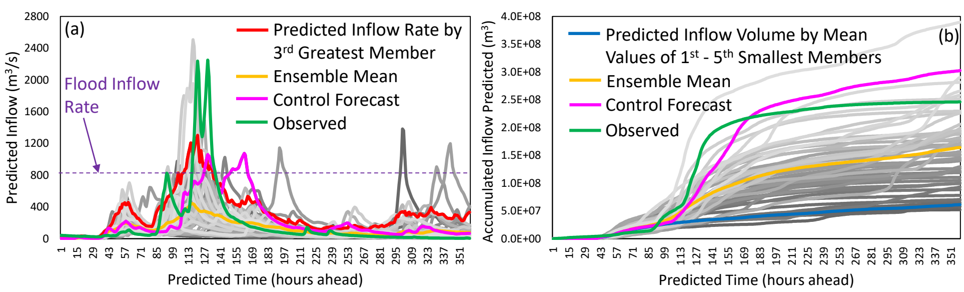


Fig. 5. Ensemble inflow prediction estimated on 1 July 2018 (a) for hourly rate and (b) for cumulative volume for the coming 15 days.

3.3 Results of EIP

Examples for results of EIP for the target reservoir are shown in Figs. 4 and 5. The result of EIP estimated on 28 June 2018 (eight days before the flood event) is shown in Figure 4. It can be seen in Figure 4 (a) that inflow more than flood inflow rate (800 m^3/s) was already predicted in the third greatest values of ensemble prediction (considered in Cases 1 and 4) eight days before the flood event. Although the peak value of observed inflow was much more than the maximal value of the third greatest member, the possibility of flood occurrence was somehow detected by this prediction in that early stage, which enabled to start preliminary release operation. On the other hand, no major increase in inflow was predicted by ensemble mean and control forecast, which are considered in Case 2 and Case 3, respectively. As for the total inflow volume shown in Figure 4 (b), all prediction members underestimated the total inflow volume received by the reservoir for the coming 15 days. Note that relationships between actual inflow and ensemble mean or control forecast depend on the scale of floods, and they can be overestimation if the scale of the target floods is small. However, reservoir storage water could be released up to 11.5 MCM (14% of the effective storage capacity) based on the mean prediction of the five smallest members at this moment, because it predicted total inflow volume more than 23.0 MCM for the coming 15 days.

The result of EIP estimated on 1 July 2018 (five days before the flood event) is shown in Figure 5. It can be seen in Figure 5 (a) that inflow more than the flood control rate was continuously predicted by the third greatest member on this day. Focusing on the prediction by the control forecast, it also predicted inflow more than 800 m^3/s, which had not been predicted on 28 June 2018 (Figure 4 (a)). Prediction by control forecast is often very variable like this way, which prevents consistent decision making for preliminary release from the early stage. On the other hand, ensemble mean values did not predict the occurrence of flood on 1 July 2018, which was also the case in predictions estimated on other days. Looking at the results of total inflow prediction shown in Figure 5 (b), the five smallest members and ensemble member still underestimated total inflow volume, while the control forecast overestimated it. This means that water storage recovery may not be accomplished if preliminary release is conducted to the amount predicted by the control forecast, which is considered to matter especially when the scale of the target flood event is small compared to the reservoir storage capacity. On the other hand, even though the mean values of five smallest members gave underestimated prediction, it predicted total inflow volume more than 60 MCM for the coming 15 days, which allowed around 30 MCM of preliminary release (equivalent to 37% of the effective storage capacity) five days before the flood event ensuring water storage recovery after the flood event.

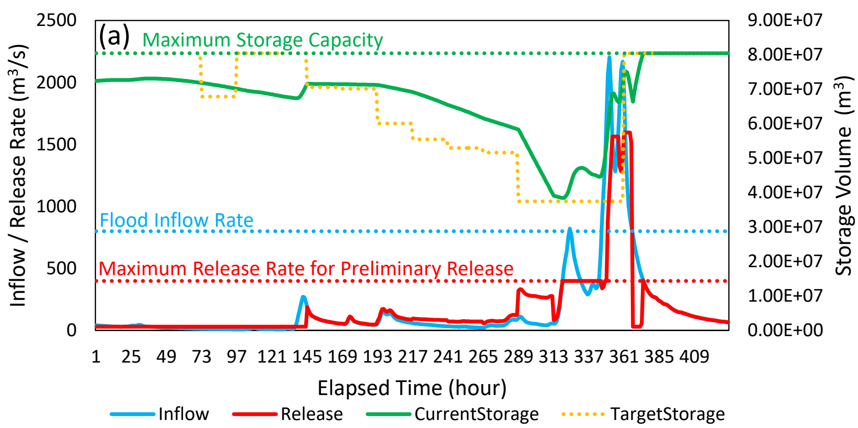
3.4 Simulation results and discussions

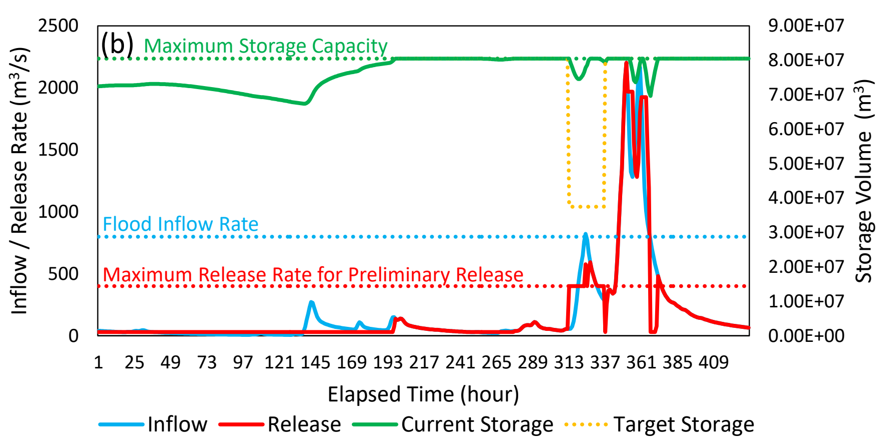
Results of reservoir operation simulation are shown in Figure 6. Reservoir operation was simulated from 15 days before the peak of inflow rate (flood peak) until two days after the peak in any simulation case. It can be seen in Figure 6 (a) that preliminary release was started about 11 days before the flood occurrence, which allowed to gradually decrease reservoir storage volume by preliminary release from an early stage. The target storage volume estimated from EIP based on the possibility of storage recovery gradually decreased reflecting updated predictions, which became more accurate as the flood event approached. Thanks to preliminary release from the early stage, reservoir storage was finally decreased to the minimum storage volume (37.5 MCM), which was the smallest among all four simulation cases. Maximum release rate during flood control was 1596 m^3/s for the peak inflow rate of 2203 m^3/s, mitigating the maximum amount of water release to the downstream by 607 m^3/s. In addition, averaged rate of preliminary release in Case 1 was 135 m^3/s, which was also smaller than other cases. This can be considered to be one of the advantages to use long-range ensemble hydrological predictions for reservoir preliminary release, because it is more likely that released water can be beneficially used for water use purposes such as hydropower generation if release rate is smaller.

On the contrary, little preliminary release was conducted in Case 2 as shown in Figure 6 (b). This is considered because ensemble mean prediction could not foresee the flood occurrence until just before the flood event. The target storage volume was decreased just before the flood event started corresponding to the last-minute prediction of flood occurrence, but it was too short to complete preliminary release operation to the desired storage volume.

Because almost no empty volume was secured in the reservoir, flood control was not successfully conducted in this case. Therefore, consideration of ensemble mean prediction is not considered very effective in decision making for preliminary release.

In Case 3 where the control forecast of EIP was considered (Figure 6 (c)), preliminary release was firstly conducted six days before the flood inflow peak. This decision was, however, cancelled when the prediction was updated next time (24 hours later), and preliminary release had not been conducted for two days after that. Flood occurrence was predicted again four days before the inflow peak, and preliminary release was restarted. However, preliminary release was not completed before the flood event started as only one day was available for preliminary release until the first flood peak after it was restarted. The maximum release rate from the reservoir during flood control was 1844 m³/s, which was higher than that in Case 1. In this way, effectiveness of preliminary release and flood control can be degraded if conventional deterministic predictions (including the control forecast of ensemble predictions) is employed because predicted values of those predictions tend to change significantly when predictions is updated.





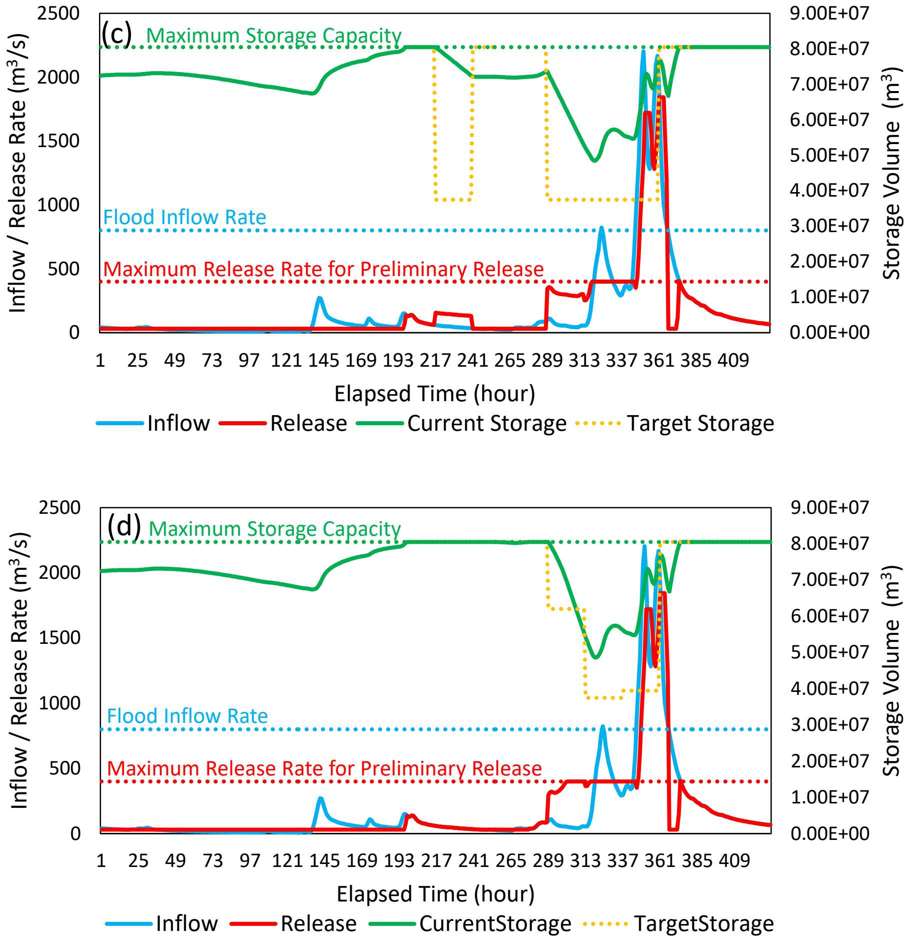


Fig. 6. Results of reservoir operation: (a) in Case 1, (b) in Case 2, (c) in Case 3, and (d) in Case 4.

As for simulation results of Case 4 shown in Figure 6 (d), preliminary release was not conducted just before the flood event started because only the short-range prediction was considered. Reservoir storage volume was not decreased to the desired volume by preliminary release as it was seen in the results in Case 3, while nearly maximum rate of preliminary release had been continued since preliminary release started. The effect of preliminary release on flood control was almost similar with that in Case 3 as the total volume of preliminary release was almost same in both cases.

Summarizing the results described above, the proposed method of preliminary release outperformed other ways considered in this case study. Storage volume of the reservoir can be decreased gradually from an early stage long before the flood event, which can be considered more acceptable for reservoir managers. On the other hand, reservoir storage was fully recovered after the flood event in any case of this case study, and no difference was seen in storage recovery among the cases. This point can be further investigated by increasing the number of flood events for the case study, which is the next step of this study.

4 Conclusions

A method to support decision making for preliminary release operation of a hydropower dam reservoir was developed by considering medium-range ensemble rainfall forecast provided by ECMWF. Ensemble prediction of reservoir inflow for the coming 15 days was estimated from ECMWF rainfall prediction by use of Hydro-BEAM. The timing and amount of preliminary release were then decided based on the estimated ensemble inflow prediction (EIP) considering the expected scale of the coming floods and possibility of water recovery after the flood event. As a result of the case study considering the simplified operation of the Shin-Nariwagawa Reservoir, it was demonstrated that the proposed method of preliminary release operation considering ensemble members with both greater and smaller values of long-range ensemble hydrological prediction (Case 1) outperformed the other ways of preliminary release applied in the case study (Cases 2-4). It was also shown that consideration of ensemble prediction members is important to estimate both the flood possibility and chance of water recovery more accurately, which is crucial for robust preliminary release operation. Advantage of the proposed method in water recovery was, however, not demonstrated in this case study because water was fully recovered after the flood event in any simulation cases. It is therefore the next step of this study to investigate this point by increasing the number of flood events for the case study.

On the other hand, short-range hydrological predictions, which generally have finer spatio-temporal resolution and more updating frequency, are available from several days before the flood occurrence. For example, short-range meteorological predictions with finer spatio-temporal resolution for the coming 39 days are provided by JMA Meso-scale Model (MSM) or Meso-scale Ensemble Prediction System (MEPS) in Japan. Therefore, it is desirable for better operation of preliminary release from reservoirs to use such short-range predictions for decision making from several days before floods while using long-range predictions for that until several days before the flood occurrence.

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