Development and Field Application of Optimal Operation Methods for Existing Dams Contributing to Flood Control

a) Background

At the 4th Asia–Pacific Water Summit held in Kumamoto City in April 2022, the Kumamoto Declaration was adopted, calling for a "transformation into quality-oriented societies that are resilient, sustainable, and inclusive." At the summit, Prime Minister KISHIDA Fumio announced the Kumamoto Water Initiative, which promotes the development of "high-quality dams." The initiative outlines the development and provision of dam-operation technologies that leverage rainfall observation and forecasting to achieve both climate-change adaptation and mitigation: reducing flood damage during the flood season through pre-release operations, and enhancing water-use and hydropower functions during the non-flood season and after flood events through high-water-level operation.

To establish flood-control functions in water-use dams while improving their water-use performance, it is essential to cultivate personnel capable of making sound operational decisions and to implement an integrated information system to support them. These personnel must be able to accurately interpret wide-area observation and forecast information and transition dam operations seamlessly from normal to emergency conditions.

ICHARM, in collaboration with the University of Tokyo's Earth Environmental Data Commons, has been conducting, on the DIAS platform, (1) real-time ensemble rainfall forecasting (short-term and seasonal), (2) system development and research, and (3) joint research with the private sector.

This report introduces examples of system development aimed at establishing flood-control functions and improving hydropower performance at hydropower dams, as well as case studies examining optimal dam operation based on short-term and seasonal rainfall forecasts.

b) Case study

To efficiently operate dams within a river basin, i.e., improving power-generation efficiency while also optimizing downstream flood control, it is essential to design a runoff model that can continuously and quantitatively estimate normal flow, peak flood discharge, and snowmelt runoff, as well as evaluate the effects of dam operations. To meet these needs, we developed and applied the Water and Energy Budget-based Distributed Hydrological Model with Snow (WEB-DHM-S).

This model enables highly accurate estimation of river discharge because it can calculate, at each time step, the spatial distribution of initial hydrological conditions (soil moisture, groundwater level, snow accumulation and melt, etc.) at the land surface, which strongly influence runoff prediction. Building on this capability, we examined optimal dam-operation methods that support both flood control and increased power generation, using inflow forecasts produced by Ushiyama et al.: short-term forecasts (3-km spatial resolution; 39-hour lead time, 1-hour temporal resolution; 32-member ensemble) and long-term forecasts (3-km spatial resolution; 3-month prediction horizon; 13-member ensemble).

The target basin for this study was the Hatanagi No. 1 Dam on the Ōi River in central Japan. Figure 1 shows the location map and a photograph of the dam.

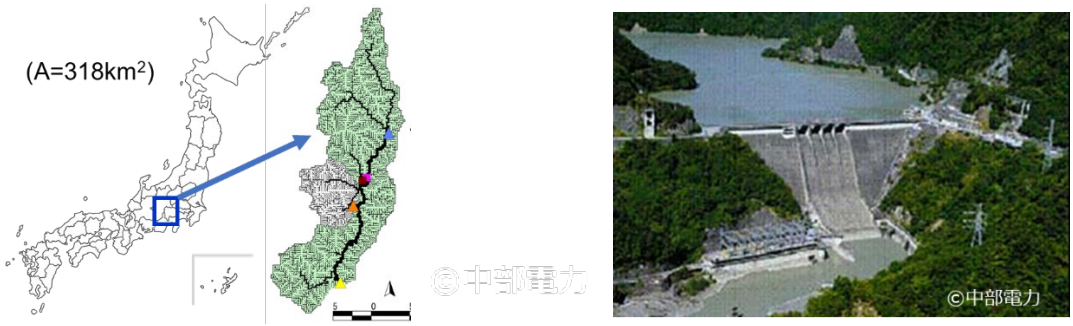


Figure 1, Photo 1　The location and a photo of the Hatanagi No.1 Dam

①Case study using short-term forecasts

Using ensemble rainfall-forecast data as input, we considered the range of 32 ensemble inflow predictions and set the following operational rules:

1. When prioritizing flood control, use the upper ~25% of the ensemble discharge time series; when prioritizing water retention for power generation, use the lower ~25%.
2. Check whether operating the dam according to existing regulations would result in releases exceeding the maximum safe discharge during the forecast period.
3. Check whether the cumulative inflow during the forecast period would exceed the available storage capacity at the start of forecasting.
4. If either threshold is exceeded, release the excess volume evenly over the forecast period while prioritizing water retention for power generation.
5. If not exceeded, calculate the average of the hourly inflow forecasts for the next 39 hours and use that as the power-generation release for the next hour.

For flood control, we evaluated whether the reservoir water level would remain below the normal water level when the target maximum gate-release discharge during floods was set at 600 m^3/s. For power generation, performance was assessed using a “power-generation index,” which incorporates effective head into the power-generation release.

During the warm seasons (July-October) of 2018 and 2019, two flood events exceeding the target maximum gate-release discharge of 600 m^3/s occurred: September 30 to October 1, 2018, and October 12 to 13, 2019. Figure 2 shows the results of the analysis.

The 2018 case represents a situation in which the reservoir water level was high at the start of forecasting. With the reservoir level already close to the preliminary release level, a pre-release based on the predicted inflow was carried out on the morning of September 29, the day before the flood (pink shading). This timely lowering of the reservoir level (yellow dashed line) enabled the gate-release discharge (pink shading) at the inflow peak (blue solid line) to be kept below the prescribed limit of 600 m^3/s. (If no pre-release had been conducted, the gate-release discharge would have exceeded 600 m^3/s, as indicated by the orange shading.)

The 2019 case represents a situation in which the reservoir water level was low at the start of forecasting. With sufficient storage capacity available, water was effectively stored in advance up to the normal water level (red dashed line), enabling the gate-release discharge to remain below 600 m^3/s.

Regarding power generation, the power-generation index showed an average increase of 12.8% in 2018

and 3.7% in 2019 during the warm season (July-October).

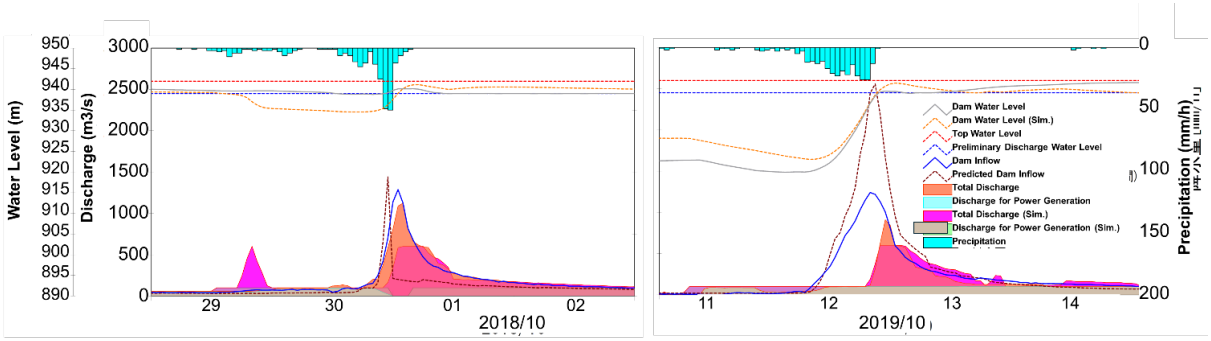


Figure 2 Results of the analysis for two flood events used to examine dam operations during floods exceeding the gate-release discharge of 600 m³/s (left: September 30–October 1, 2018; right: October 12–13, 2019).

②Case study using both short-term and long-term forecasts

In addition to the short-term forecasts examined in Section ①, we conducted simulations of long-term dam operations using ensemble three-month rainfall forecasts. Short-term forecasts (39-hour ensemble forecasts with 32 members) and long-term forecasts (three-month ensemble forecasts with 13 members) were executed simultaneously.

This case study focused on the one-year period from March 2020 to February 2021. For the short-term forecasts, when the reservoir water level at the time of forecasting was higher than Href (the threshold water level used to distinguish high and low levels), the upper 8 ensemble members (approximately the top 25%) were used. When the water level was lower than Href, the upper 24 ensemble members (approximately the top 75%) were used.

For the long-term forecasts, the analysis was based on the average inflow obtained by dividing the cumulative inflow from the start of forecasting to N days ahead by N. More specifically, the average inflow was examined using three averaging periods (N = 10, 30, and 86 days) in the warm season (May-October) and the cold season (November-April). When the reservoir storage at the time of forecasting exceeded the storage corresponding to Href, the highest inflow ensemble (rank 01) was used; when it was lower, the lowest inflow ensemble (rank 13) was used.

Both the short-term and long-term forecast procedures produced a release value for the next hour (the total of power-generation release and gate release). The larger of the two values was adopted. By varying the averaging period and the ensemble members used, three cases (Cases 1-3) were examined.

	N［日］		アンサンブル(長期)	発電量指標（落差と水量）	増減［%］	年間発電使用水量[㎥]	増減［%］
	暖候期	寒候期					
実績	－	－	－	218,294	－	871,517,952	－
ケース1	N=10	N=86	Rank1 or 13	214,335	-1.80%	900,618,347	3.30%
ケース2	N=10	N=30	Rank1 or 13	231,465	6.00%	897,865,266	3.00%
ケース3	N=10	N=30	Rank6	211,687	-3.00%	890,741,812	2.20%

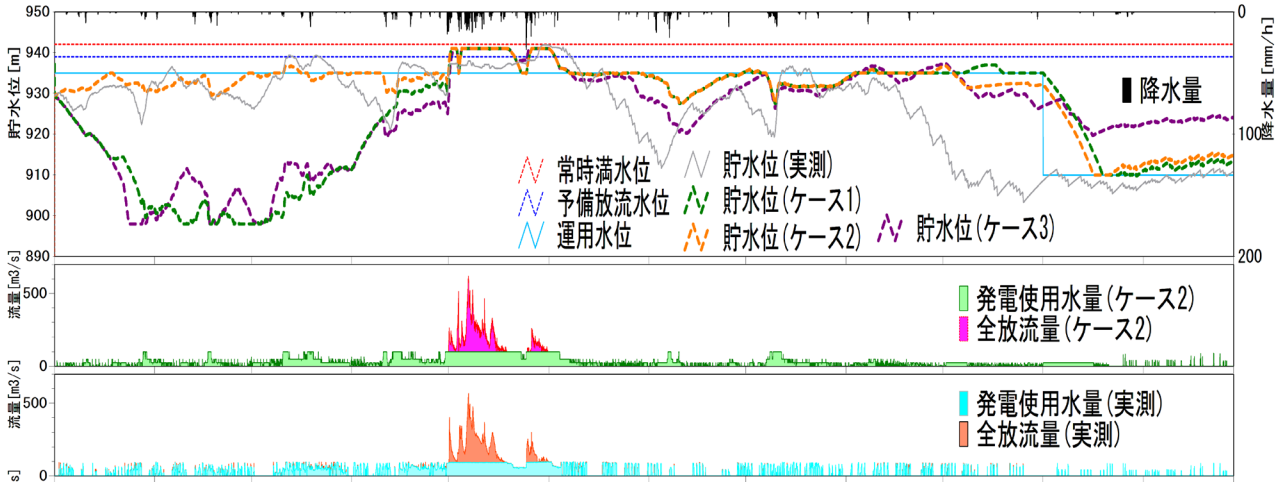


Figure 3 Annual operation simulation results for the Hatanagi No. 1 Dam on the Ōi River (March 2020-February 2021)

Table: Comparison of power-generation output for Cases 1-3

Charts: Annual operational water levels (upper chart), and power-generation water-use and release volumes for Case 2 (middle chart) and observations (lower chart).

As a result, we found that Case 2 (orange line), with N = 10 days in the warm season and N = 30 days in the cold season, achieved a 6.0% increase in power generation compared with conventional operations. In Case 1 (green line), although the annual volume of water used for power generation increased, power generation decreased by 1.8% due to a drop in the reservoir level in April. This drop occurred because using N = 86 days includes major rainfall events after the rainy season, leading the system to assume that abundant water would be available and therefore lowering the reservoir level. Case 3 (purple line) resulted in a 3.0% decrease, as it always used rank 6 and performed power-generation-oriented operations regardless of the operational water level, causing the reservoir to fall to its minimum level in late March.

These results demonstrate that running short-term (39-hour) and long-term (three-month) forecasting simultaneously, while appropriately adjusting the averaging period and ensemble ranks used in long-term forecasts according to the season, provides valuable information for increasing power generation. This approach also indicates a clear direction for establishing optimal dam-operation methods that can be applied more broadly.

c) Future Work

In this study, we examined two short-term cases (September 30-October 1, 2018, and October 12-13, 2019) and one long-term case covering the one-year period from March 2020 to February 2021. For wider application, we plan to conduct similar analyses for different periods and to extend the study from a single-dam setting to optimal operation methods that also account for cascade-dam systems.

<References>

1） Koike, T., Nakamura, S., Cho Thanda Nyunt, Ushiyama, T., Rasmy, M., Tamagawa, K., Ito, H., Ikeuchi, K., Ikoma, E., and Kirekawa, M.: AN OPERATION SUPPORTING SYSTEM FOR HYDROELTCTRIC DAMS TO IMPROVE FLOOD CONTROL AND POWER GENERATION, Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), Vol. 77, No. 2, pp. I_79-I_84, 2021.

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