River Flow Prediction for Low Flow Management Considering Power Plant Discharge

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Abstract

River administrators are currently carrying out “low flow management” to ensure the river flow necessary for maintaining normal river function by taking steps such as dam discharge. Low flow management establishes, as a target, the normal flow necessary for maintaining normal function of the river. From the standpoint of efficient utilization of water resources, it is also necessary to predict the amount of decline in flow in the future, and appropriately determine the amount of dam discharge. This paper discusses an approach to flow prediction for low flow management—more specifically, the unique features of low flow management in the Arakawa River upstream, the prediction algorithm of the prediction system, and the results of predicting flow using past track record data. The developed prediction algorithm has the following characteristics: (1) It predicts phenomena that can be dealt with such as changes in the amount of dam discharge, and (2) It removes the effects of power plant discharge which are difficult to accurately predict due to lack of data. Using this algorithm, it was confirmed that flow can be predicted with high precision while suppressing upward deviation of prediction, even in the complex water budget environment of the Arakawa River upstream.

1. Introduction

River administration includes both “high flow management” where flood control is performed during flooding, and “low flow management” which involves flowing water management performed in the normal environment or for the purpose of water utilization. In low flow management, the flow necessary for maintaining normal function of the river is stipulated, and that is called the normal flow. More specifically, this flow is made up of the maintenance flow—established in light of factors such as protection of plants and animals, fishing industry, scenic views, and ensuring the cleanliness of flowing water—and the water utilization flow. The flow is established as a target in the context of low flow management. A river administrator must perform management, through steps such as dam discharge, so that river flow does not drop below normal flow(1). From the standpoint of efficient utilization of water resources, it is also necessary to predict the amount of decline in flow in the future, and appropriately determine the amount of dam discharge(2)(3).

In the upstream part of a river, normal flow is set at a water use reference point, with the objective of maintaining normal functions of flowing water such as conserving the river environment—e.g., by preventing the river bed from drying up—and providing stable supply of municipal water, agricultural water, and so on(4). The water use reference point for the Arakawa River upstream is the Yorii point (Saitama Prefecture). Staff currently check flow at the Yorii point day and night, and predict the decline in flow. The amount of dam discharge is determined based on experience, and a discharge instruction is issued. More efficient integrated operation of dams and reduced burden on staff can likely be achieved by automatically calculating the appropriate discharge amount, taking into account information like rainfall and river flow predictions. Therefore, there is a need for a river flow prediction system which can estimate river flow, to serve as the basis for determining the amount of water supplied near the water use reference point.

This paper describes the development situation surrounding a river flow prediction system to support low flow management for the Arakawa River upstream. The purpose of this system is to automatically calculate the decline in flow at the water use reference point, where staff currently make experience-based predictions relying on observation data on dams and river flow, and thereby reduce the burden of low flow management, and improve its efficiency. In accordance with the purpose of low flow management, it was decided in this system to focus on prediction during flow decline, and to deemphasize prediction precision when flow is increasing.

2. Low Flow Management for the Arakawa River Upstream and the Flow Prediction Algorithm for Low Flow Management

This section describes the approach to flow prediction for low flow management, and the algorithm for that prediction. In low flow management, actions must be taken to ensure that that river flow at the water use reference point does not drop below normal flow. Therefore, the conditions where the predicted flow does not exceed the actual flow (i.e., where there is no upward deviation) are taken to be the goal of algorithm review.

Figure 1 shows the river system connections of the Arakawa River upstream. On the Arakawa River, the Arakawa Upstream River Office (the river administrator) determines discharge from the upstream dams so that flow at the Yorii point exceeds the normal flow. Directly above the Yorii point is the Tamayodo Dam. Since the Tamayodo Dam is a facility not subject to integrated management (authority to issue instructions), it was decided to make the Oyahana point (Saitama Prefecture) the flow prediction point. In low flow management, the first step is understanding the recovery situation of reservoir storage based on the influx situation for each dam. Then the flow decline is predicted at the flow prediction point. Efficient low flow management is performed through integrated management of amounts discharged from multiple dams—in Fig. 1, the Futase Dam, Takizawa Dam, and Urayama Dam—while taking into consideration the arrival time of water discharged from each dam at the flow prediction point. However, at present, a flow prediction system for low flow management has not been adopted, and thus operational decisions are dependent on the experience and know-how of skilled staff, and the burden is excessive. In the Arakawa River upstream, the propagation delay time of dam discharge water up to the flow prediction point is roughly 10 hours. Thus, for this prediction system, it was decided to predict flow at the flow prediction point (Oyahana point) up to 12 hours later.

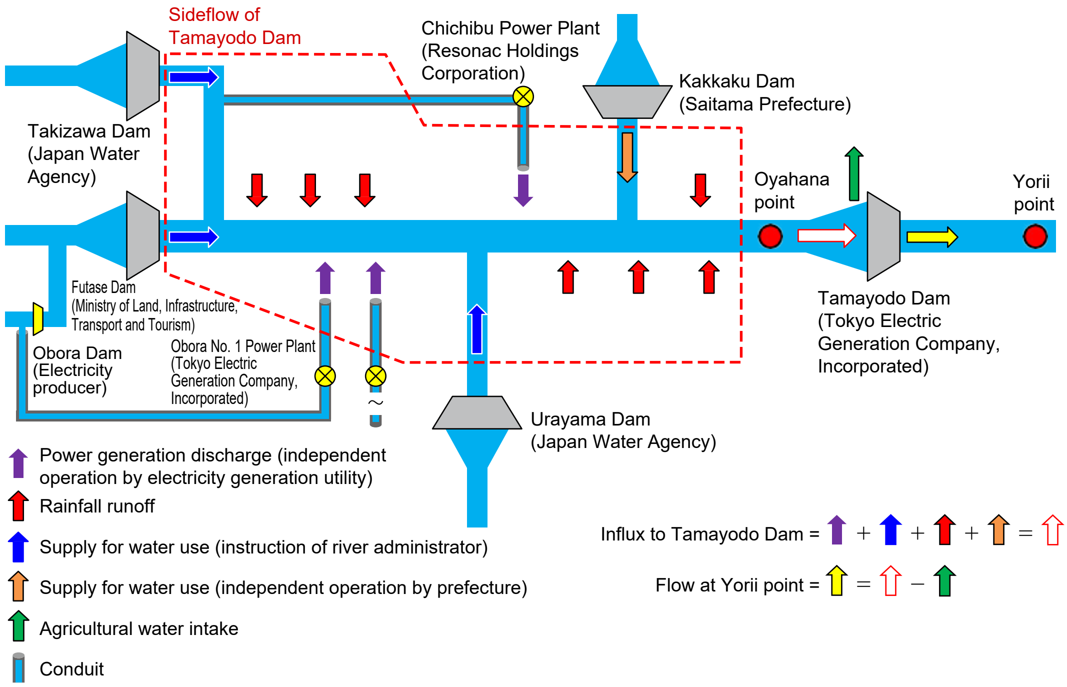

Fig. 1 River system connections of the Arakawa River upstream

Figure 2 shows a conceptual diagram of the effect of power plant discharge. As shown in Fig. 1, there are multiple power plants and conduits in the Arakawa River upstream. The power plant discharge that passes through those facilities is irregularly supplied (returned) to the Arakawa River main stream at intervals of a few hours to a few days, and thus flow at the Oyahana point (the flow prediction point) also varies irregularly. As shown in Fig. 2, what is predicted in this case is the natural flow of the Arakawa River, i.e., the original volume of water in the river without any human interventions, and thus there is a need to separate power plant discharge from the natural flow of the Arakawa River. However, the amount of power plant discharge is determined independently by electricity generation utilities, and data on that discharge is not available. Thus, an approach was considered where flow variation due to power plant discharge, which cannot be predicted, is left out of consideration, and flow variation due to dam discharge, for which data is available, is predicted. For flow variation due to power plant discharge, first the flow inflection points at the prediction point (Oyahana) are extracted, and then the start and end times of the temporary flow variation are estimated. Then the flow between the start and end times is removed by performing linear interpolation. This allows removal of flow variation due to power plant discharge by using only flow data for the flow prediction point.

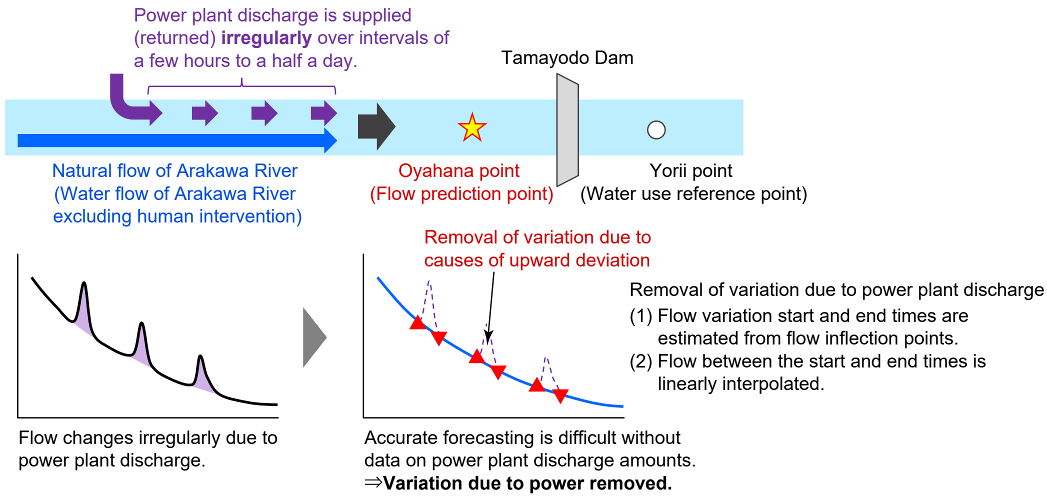

Fig. 2 Effect of power plant discharge

3. Results of Flow Prediction

The actual flow at the flow prediction point (Oyahana point) and the actual discharge of each dam for 2017 to 2022 were input, and flow at the flow prediction point was estimated and predicted using the flow prediction algorithm. Figure 3 shows estimation and prediction results for flow at the flow prediction point. The light blue line in the graph indicates the recorded flow at the flow prediction point, and the red line indicates the estimated/predicted value of the natural flow of the Arakawa river at the flow prediction point. The vertical red dotted line represents the most recent time of the input data. Before that are estimated values, and after that are predicted values. Short-term flow variation due to power plant discharge was removed from the graph, and it was confirmed that estimation and prediction were achieved without the predicted flow (red line) exceeding the recorded flow (blue line). It was also confirmed that flow variation during changes in dam discharge was correctly estimated.

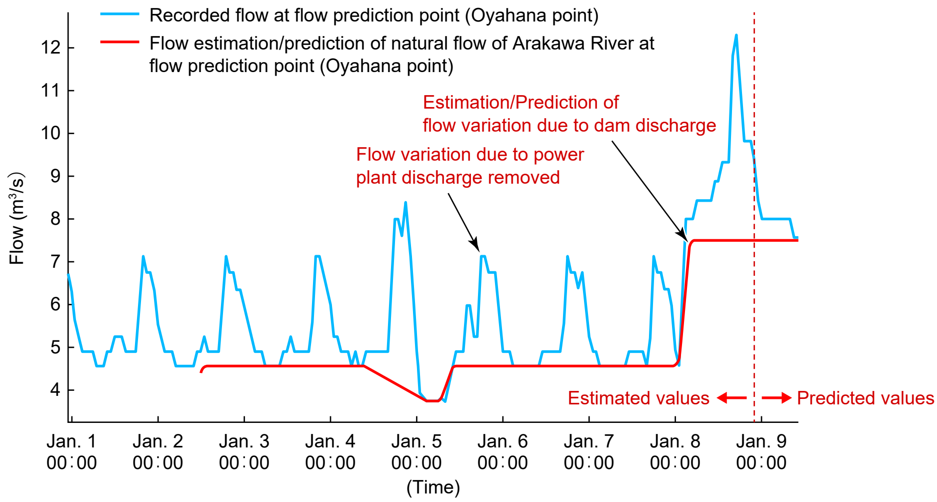

Fig. 3 An example of river flow estimation and prediction

Next, are the results of evaluating prediction error. Evaluation was carried out for an irrigation period (June 18 to July 1) and a non-irrigation period (December 1 to 31). Figure 4 and Fig. 5 show the flow prediction error 12-hours later. The red dotted lines in the graph indicate the range of error with respect to the recorded flow. Upper and lower bounds are +1m³/s and -2m³/s respectively. Positive error indicates an upward deviating prediction where the predicted flow exceeds the recorded flow, while negative error indicates a downward deviation. It is evident from the figures that prediction error is almost entirely in the range -2 to +1m³/s for both the irrigation and non-irrigation period, and flow can be predicted with high precision while suppressing upward deviation of predictions.

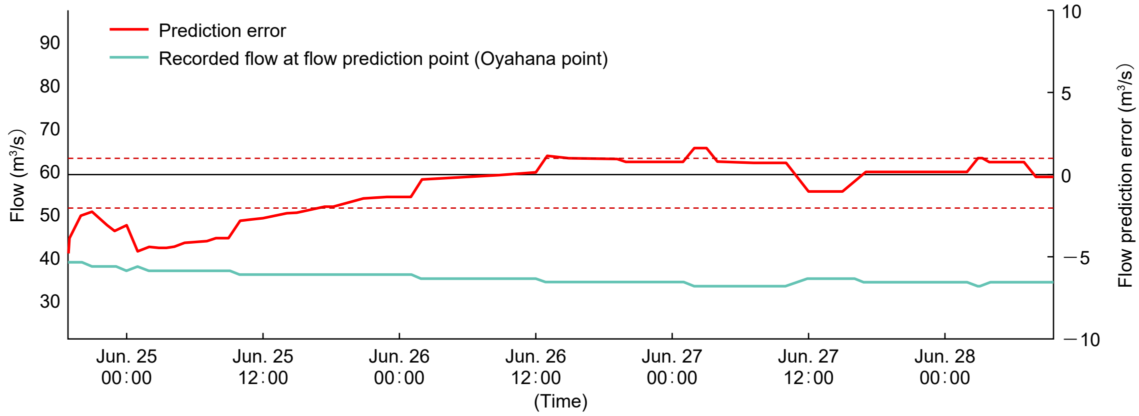

Fig. 4 Error of 12 hours river flow prediction (June 2021)

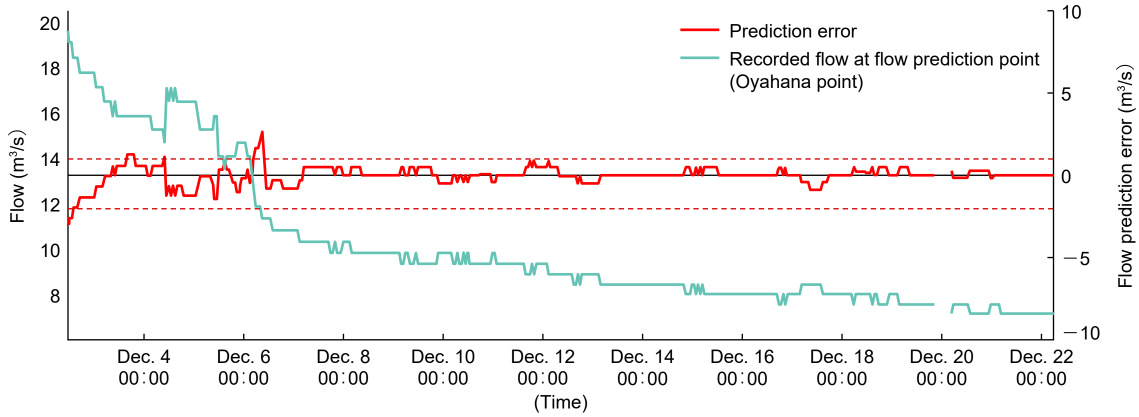

Fig. 5 Error of 12 hours river flow prediction (Dec. 2019)

4. Conclusion

This paper has discussed an approach to flow prediction for low flow management, the unique features of low flow management in the Arakawa River upstream, the prediction algorithm of the prediction system, and the results of predicting flow using past track record data. For low flow management, the predicted flow must not exceed the recorded flow (upward deviation) because the aim of management is to prevent flow at the reference point from dropping below the normal flow. However, in the Arakawa River upstream, a complex water budget is formed by multiple dams, power plants, and conduits, and thus flow at Oyahana (the point for prediction) also varies in a complex way. Therefore, an algorithm was developed to: (1) Predict phenomena that can be dealt with such as changes in the amount of dam discharge, and (2) Remove the effects of power plant discharge that are difficult to accurately predict due to lack of data. Using this algorithm, it was confirmed that flow can be predicted with high precision while minimizing upward deviation in prediction. By using this flow prediction system for low flow management, it will be possible to disperse the load concentrated on skilled staff, and improve the efficiency of low flow management.

References

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