Operation of the Selective Water Intake Facility of Sameura Dam, taking Account of Downstream Water Temperature and Turbidity

Morimasa Tsuda[1], Masashi Moriya[2]
1- Japan Water Agency (JWA), Saitama City, Japan
2- CTI Engineering Co, Ltd., Osaka City, Japan

Email: 1) morimasa_tsuda@water.go.jp
2) m-moriya@ctie.co.jp

Abstract

Release of low-temperature water during summer and prolongation of muddy-water discharge from the dam reservoir after extreme floods have been big challenges in the operation of the Sameura Dam in Japan since the beginning of its operations in 1975. Release of low-temperature and muddy-water has a negative impact on fisheries and downstream water use. To address these issues, the surface-water-intake facility was converted to a selective water-intake facility in 1999. Since the conversion, the level of water withdrawal has been changed according to the vertical profile of water temperature and turbidity in the dam reservoir as observed by a real-time monitoring system. The rules of operation were determined through discussions with academic experts, local people, and river managers. Water-intake elevation has been set to be relatively low, and water temperature is cooler than that in the surface layer while also meeting the target level to conserve warm water. High-turbidity water is selectively discharged during flooding for early release of suspended matter. In our research, we quantified the effect of the operation by using a two-dimensional vertical water-quality model that numerically simulates water temperature and turbidity in the dam reservoir and downstream.

Keywords: Selective water-intake facility, dam operation, saving of warm water, early release of high-turbidity water

1. INTRODUCTION

Release of low-temperature water from a stratified reservoir and prolongation of muddy-water discharge after flood events cause several problems. Low-temperature water release causes health problems in fish (in particular sweetfish in Japan), especially during their migration period. Prolonged muddy-water discharge has negative impacts on the downstream ecosystem and water use.

Release of low-temperature water and prolonged muddy-water discharge from the dam reservoir after a flood were big challenges from early stage in the operation of the Sameura Dam in Japan. To address these issues, a selective water-intake facility was installed and operated at the Sameura Dam. Such facilities are widely used, usually for single purposes, in the operation of stratified dam reservoirs to control various problems, such as released-water temperature [1, 2], downstream turbidity [3], and reservoir water-quality issues (e.g., anoxia [4, 5] and sedimentation [6]). The Sameura Dam's case is very challenging because the facility is used for two purposes, requiring detailed rules of operation and their continuous updating through regular evaluation.

Thermal and turbidity profiles of the dam reservoir, key factors in managing discharge temperature and turbidity of a stratified reservoir, are the results of reservoir operations and of physical processes involving heat distribution and mass conservation. Various numerical studies have been conducted to investigate thermal dynamics and turbidity profiles in reservoirs [1–6]. In our research, we used a two-dimensional (2D) water-quality model to evaluate the operation of a selective water-intake facility for the management of low-temperature and high-turbidity water release.

2. STUDY AREA

The Sameura Dam is a multipurpose dam in the Yoshino River basin on Shikoku Island, Japan (Figure 1). The dam is operated and managed by the Japan Water Agency (JWA). The operation of the dam started in 1975. The reservoir is used for flood control, water supply, and power generation, while maintaining the normal function of the river. Its gross capacity is 316 million m^3 and effective capacity is 289 million m^3. Released water is distributed among all four prefectures on the island and supports the recreation, urban activities, and agriculture in the region.

The Sameura Dam is equipped with a selective water-intake facility and outlet pipe for water utilization (Figure 2). Crest gates are used for flood control, and the selective water-intake facility is normally used for controlling water supply. At the Sameura Dam, water-intake elevation is varied within the range of 327–285 m. The selective water-intake facility, which was constructed in 1999 by modification of an existing surface-water-intake facility, is connected to the downstream power-generation plant. The outlet pipe is arranged horizontally at 262 m elevation for complement water intake.

Figure 1. Location of the Sameura Dam

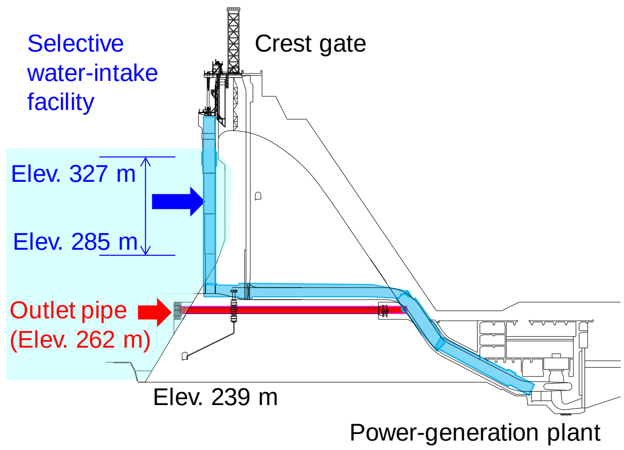

Figure 2. Cross section of the Sameura Dam

Normally, from April to December in any given year, the Sameura Dam reservoir is stratified. In summer, the water level of the reservoir tends to continuously decline because of increased water demand, mainly for agricultural purposes downstream. The Yoshinogawa River basin frequently suffers from a water shortage. Almost every other year, regulators impose a water-use restriction downstream from the Sameura Dam because of reduction in the impound volume behind the dam. This causes a reduction of warmer water in the epilimnion, the upper layer of the thermocline, and the release of colder water.

After a heavy flood, incoming high-turbidity currents stir up in the dam-reservoir water (Figure 3), which leads to prolonged high-turbidity water release. High turbidity at greater than 10 degrees for more than seven days is defined as prolongation of high turbidity downstream from the dam. For example, in 1976, the dam suffered record flooding, and high-turbidity water release continued for about 90 days. Release of muddy water has a negative impact on the migration and growth of fish. Once dam reservoir water is circulated by extreme flooding, a long period is necessary before suspended solids (SS) settle and a clean layer is regenerated near the water surface. Early release of high-turbidity water is considered to be an effective countermeasure to avoid the circulation of the reservoir water behind the dam.

Figure 3. Photo of dam reservoir after the July 2018 flood

To address the two environmental issues, a surface-water-intake facility was converted to a selective water-intake facility in 1999, as mentioned above. After the conversion, the level of water withdrawal was changed to take into account the vertical profiles of water temperature and turbidity. The information is observed through a real-time monitoring system at four sites, involving the automatic ascending/descending water quality profiler arranged vertically at 0.5 m intervals. The monitoring started at three sites in 1997, and another monitoring site was added in 1999.

3. Operation of the Selective Water-Intake Facility

Two types of rules of operation were determined for the selective water-intake facility in 2013 after more than 10 years' discussions and collaboration with academic experts, local people, and river managers. The first type aims to preferentially save warm water, and the second type concerns the early release of high-turbidity water (Figure 4).

Low-temperature water discharge was the agreed-upon countermeasure to conserve warm water. The target water temperature was determined over time in partnership with concerned organizations taking into account the effect on sweetfish and by balancing irrigation requirements. Water is taken from a middle layer where water temperature is lower than in the surface layer but still satisfies the target level. Warmer surface water is preserved for the possible deficit after drawdown by continuous water supply. This operation (referred to as the saving-warm-water operation) was officially started in 2013 and has been implemented since that time as the basic option every year. It makes the epilimnion extend because thermal release from dam-reservoir is decreased. It is also expected to mitigate muddy-water discharge; after a flood, high-turbidity water will be diluted in the extended epilimnion, thereby decreasing turbidity.

The other operation rule, that is, early release of high-turbidity water, aims to mitigate the prolongation of muddy-water discharge after a flood. High-turbidity water currents during a flood penetrate specific elevations restricted by the reservoir density stratification. Highly turbid-water currents over 25 degrees in turbidity is selectively discharged to accommodate the early release of SS before they get thoroughly mixed in with the reservoir water. Two situations have been defined: (1) floods exceeding 2,000 m^3/s at peak discharge at a water level above 300 m and (2) floods exceeding 200 m^3/s at peak discharge at a water level below 300 m. In the first situation, friable soil surrounding the reservoir is the reason for high turbidity; in the second situation, exposed sediment on the riverbed upstream is flushed by the subsequent flood. Maximum term to implement the planned countermeasure is limited to two or three days depending on the magnitude of the flood peak. The term for a given flood event is determined through discussion with concerned groups considering the effect on fish and water treatment on purification plants. This operation has been experimentally implemented twice in September 2013 and July 2018.

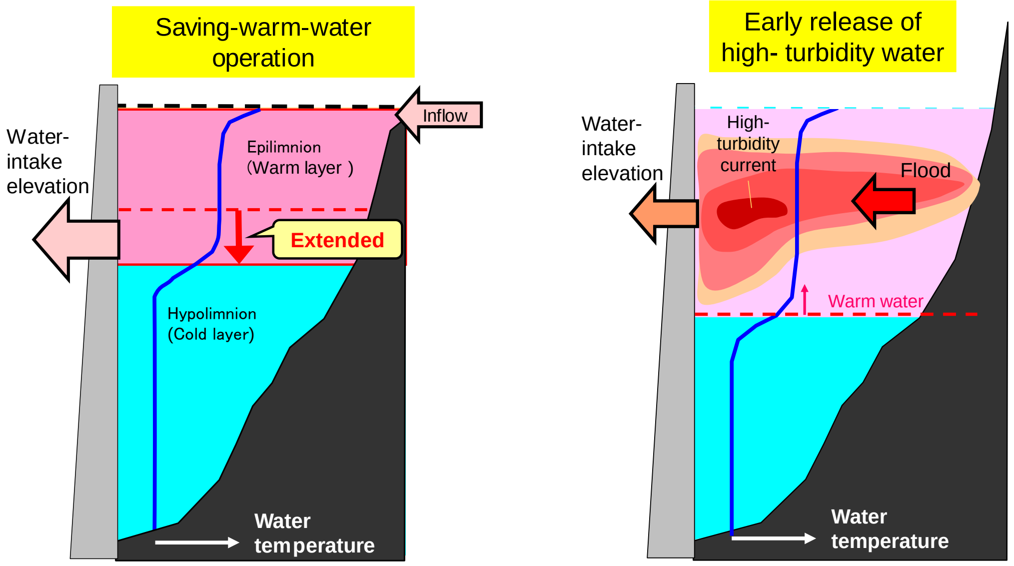

Figure 4. Operation of selective water-intake facility

Detailed operating procedures and decisions about issuing information were also determined through discussions between stakeholders and managers. Information about the operation plan for the selective water-intake facility was released by the JWA dam manager to all concerned parties every time before the water-intake elevation was to be changed. When the early release of high-turbidity water is to be executed, the approval of all concerned parties is required beforehand.

4. SIMULATION MODEL

The operation of the selective water-intake facility is evaluated using a 2D vertical water-quality model. The model numerically simulates hydraulic (diffusion, advection, velocity distribution etc.), thermal (diffusion, advection, radiation, evaporation etc.), and SS (diffusion, advection, sedimentation, entrainment etc.) dynamics in the dam reservoir using reservoir geometry, inflows, release, and meteorological data (Figure 5). The model, based on a width-averaged 2D water-quality model, considers heat exchange and SS conservation. SS concentration is bilaterally converted to turbidity based on assumed relationships obtained from field observation.

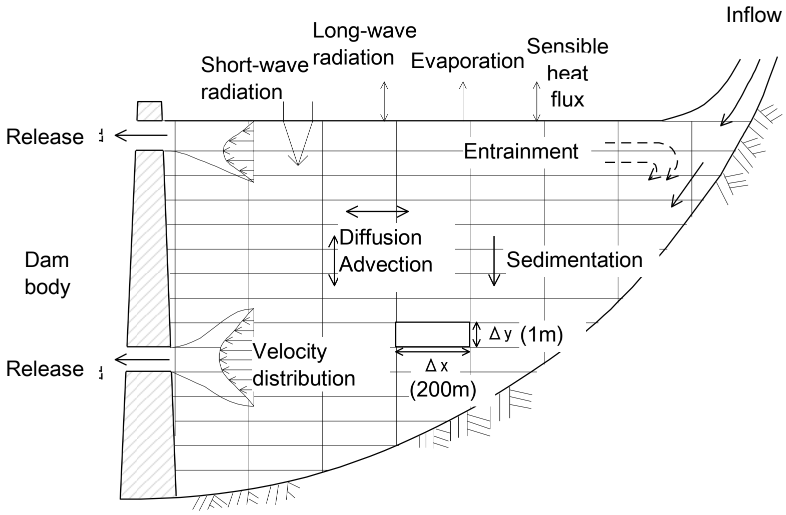

Figure 5. 2D vertical water-quality modeling scheme

Modeling domain includes 20 km upstream from the damsite and two major tributaries, Seto-gawa and Ohkita-gawa (Figures 6 and 7). The horizontal grid size is 200 m, and the vertical grid size is 1 m (Figure 7).

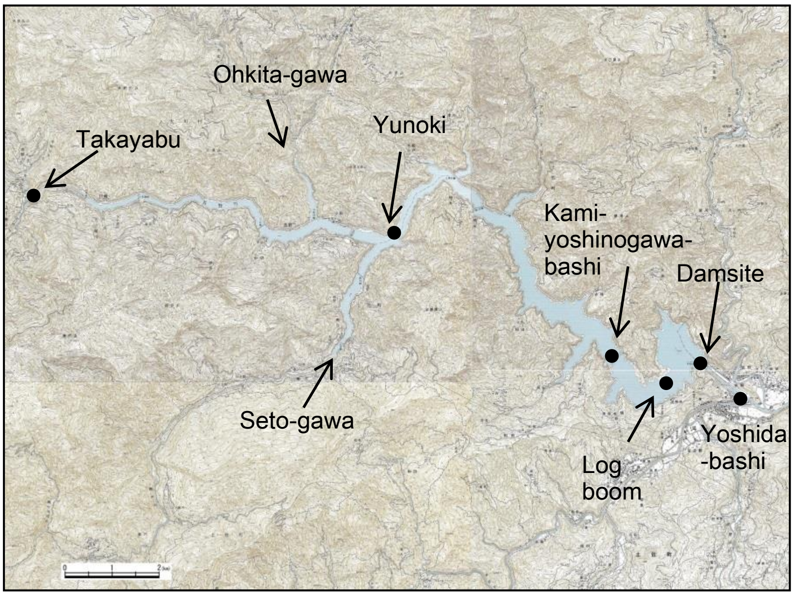

Figure 6. Model domain

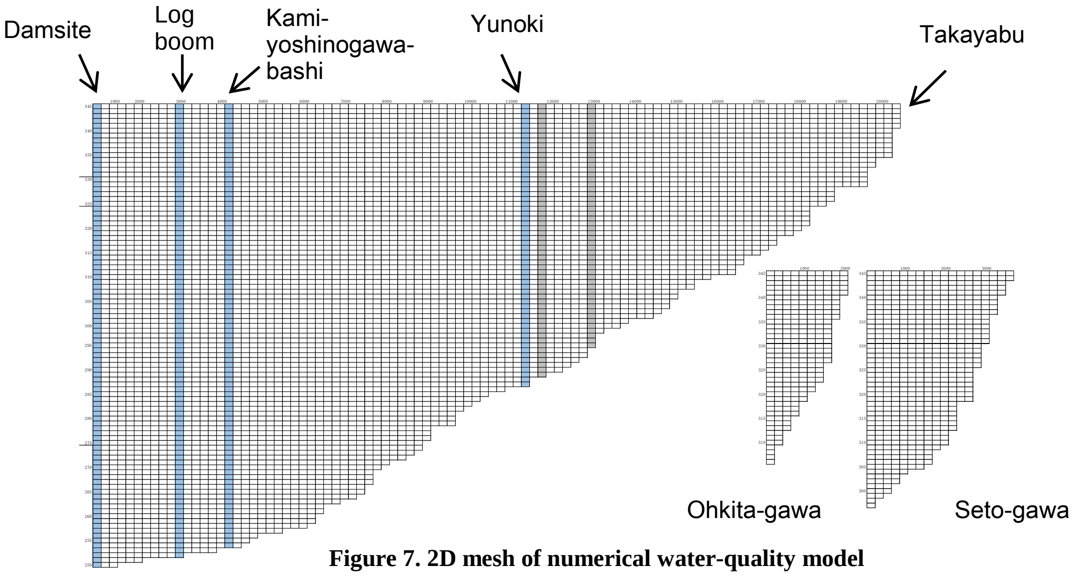

Figure 7. 2D mesh of numerical water-quality model

Water temperature and turbidity observed every 10 minutes at the Takayabu site were used for the boundary condition. Air temperature, humidity, wind speed, and solar radiation measured at the damsite and percentage of solar radiation obtained from the Japan Meteorological Agency were also inputted. Model parameters were calibrated using 3-hr- and 0.5-m-interval vertical profiles of temperature and turbidity at four sites: the damsite, log boom, Kami-yoshinogawa-bashi, and Yunoki. Downstream water temperature and turbidity observations taken every 10 min at Yoshida-bashi were also used for calibration.

Overall, the model showed good performance in reproducing the vertical temperature and turbidity profiles (Figure 8). Regarding temperature, the position of thermocline was effectively reproduced. The vertical profile of turbidity was almost represented, but peak turbidity tended to underestimate possibly because of the complexity of the hydraulic profile. This may be attributed to the limitation of applying the 2D model. However as illustrated below by Figure 13, simulated withdrawal turbidity effectively reproduced observation during the period early release of high-turbidity water operation was implemented. Then the model was considered acceptable for evaluating the effect of the operation.

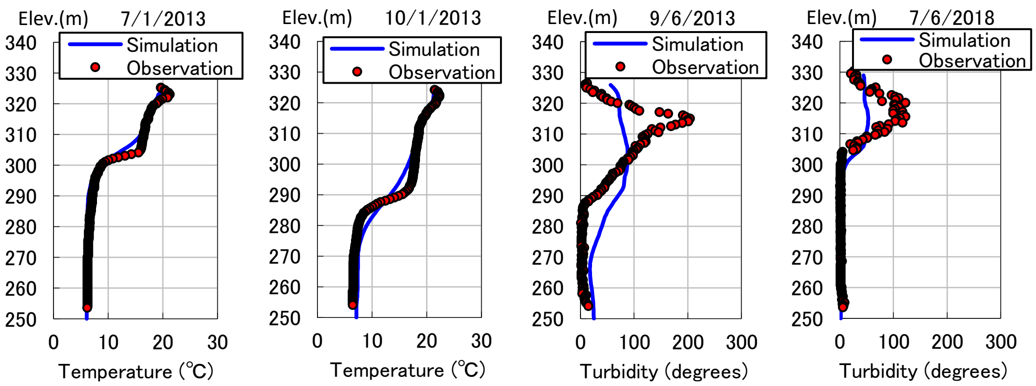

Figure 8. Comparison of temperature and turbidity. Representative examples for damsite, comparing model simulation and observation

5. RESULTS AND DISCUSSION

The saving-warm-water operation was implemented as the basic operation option after 2013. In August 2013 and 2016, water shortage during the summer period made the water level steeply decline and the volume of warmer water decreased. However, warmer water was preserved by the planned operation during this period. Before the installation of the selective water-intake facility, low-temperature water release tended to occur under similar circumstances.

From the simulated time series of the vertical profile of temperature at the damsite with and without the saving-warm-water operation (Figure 9), from July to the beginning of September 2013, water level continued to decline. The vertical temperature profile was similar at the beginning of September in both cases, but a larger amount of warm water is conserved during July and August when the saving-warm-water operation was implemented. Consequently, a considerable difference was observed in terms of days and severity of low-temperature water release. Figure 10 (a) shows the simulation results of the released-water temperatures. Days for which water temperature was lower than the target level were estimated to be 22 days when saving-warm-water operation was not implemented and 17 days with saving-warm-water operation. In other words, the number of days below the target was shortened by five. The lowering of the water temperature was as much as 5.3 °C below the target without the operation but was only 1.7 °C with the planned operation, so 3.6 °C was mitigated by the operation.

Similarly, for August 2016, the duration of released-water temperature being lower than the target level was shortened by 12 days, and the temperature was mitigated by 0.9 °C by the planned operation (figure 10 (b)). These results indicate that the saving-warm-water operation is effective to alleviate low-temperature water release.

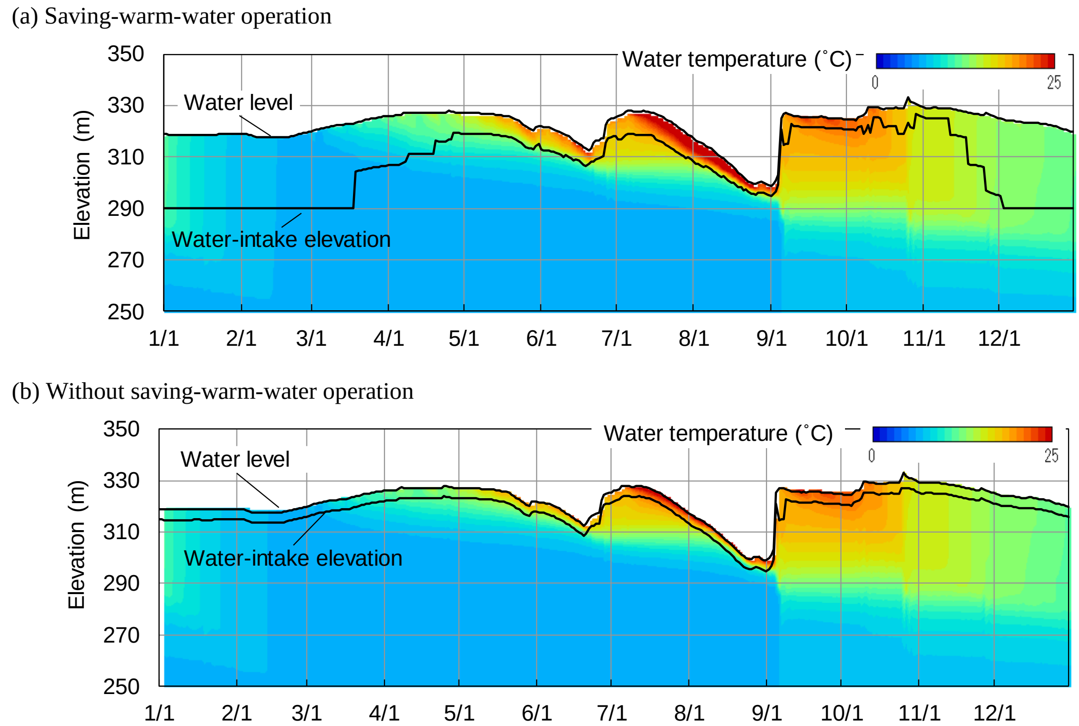

Figure 9. Simulation of water temperature in dam reservoir (2013)
(a) with saving-warm-water operation and (b) without saving-warm-water operation

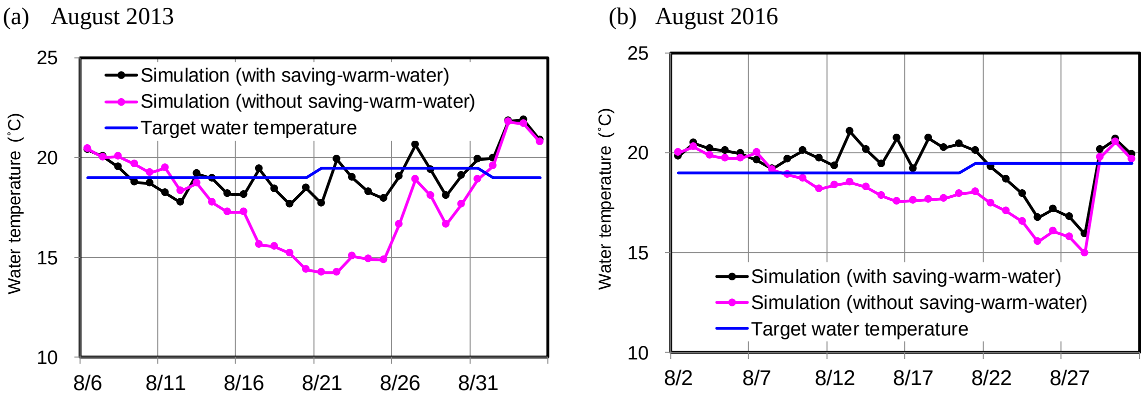

Figure 10. Simulation of water temperature downstream

The operation involving the early release of high-turbidity water was experimentally conducted twice, in September 2013 and July 2018. In the 2013 case, highly turbid water came after the drawdown at the beginning of September (Figure 11) when the water level was lower than 300 m and there was exposed sediment on the upstream riverbed. That was flushed by the subsequent flood, and a high-turbidity current was created. Unlike the 2013 case, highly turbid water came with flood when the water level was relatively high in the July 2018 case. Warm water layer had been preserved by previous saving-warm-water operation when the flood came.

In the 2013 case, the withdrawal water level was set around the high-turbidity current during September 5–8 (Figures 11 and 12). After middle of September, surface clean layer was gradually created by the subsidence of SS. Figure 13 shows the observed turbidity at downstream (Yoshida-bashi) and simulation results of intake turbidity with and without the early release of high-turbidity water. Simulated peak turbidity overestimated on September 4, however simulated turbidity increased in the period of the early release of high-turbidity water operation from September 5 to 8 as observation. Then the model was considered to be acceptable to estimate the effect of the operation. The aggregate volume of the released suspended matter was estimated as 1.66 ton by early release. It was 1.49 ton in the case without early release. Approximately 11% increased by the operation.

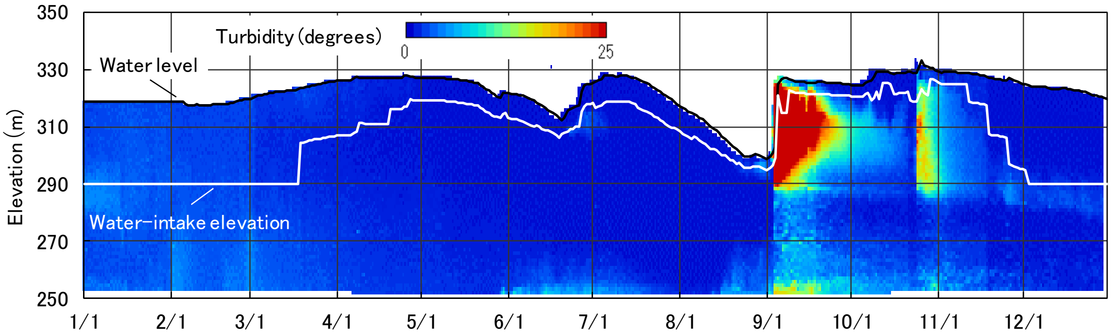

Figure 11. Vertical profile of observed turbidity at intake (2013)

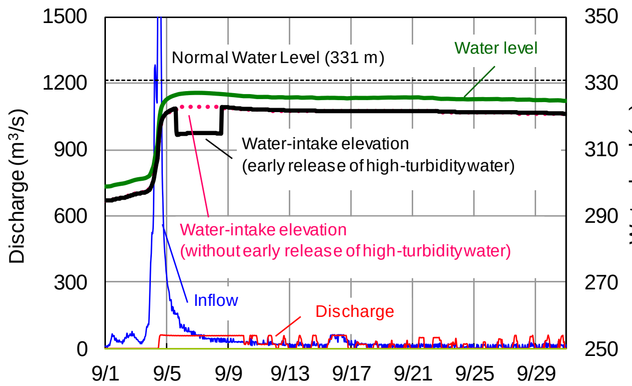

Figure 12. Simulation of operation (September 2013)

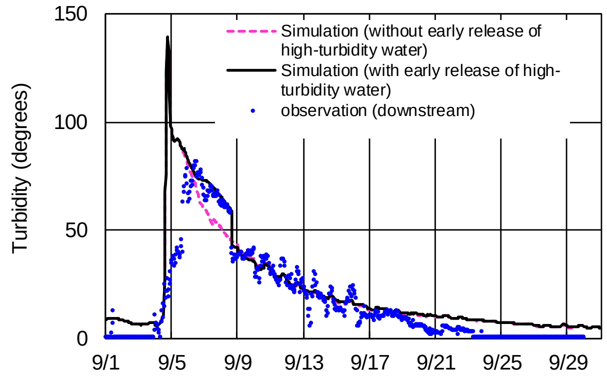

Figure 13. Simulation of turbidity of withdrawal water (September 2013)

(a) Saving-warm-water **(b) Without saving-warm-water**

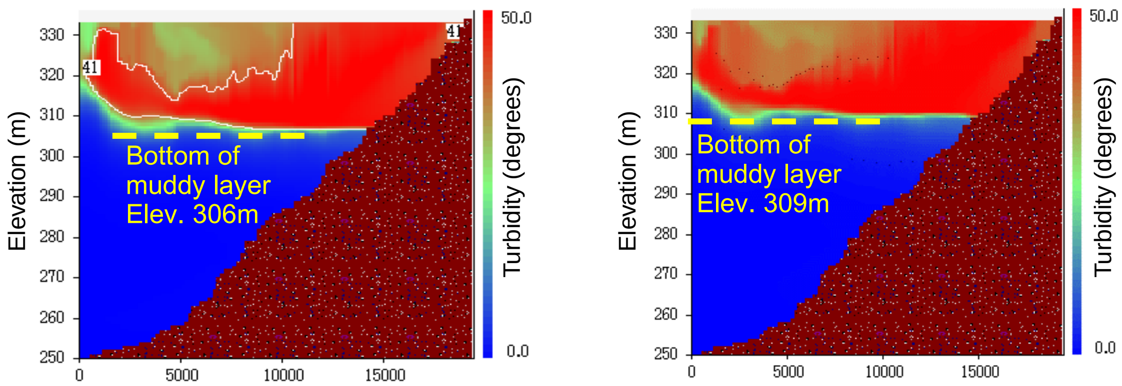

Figure 14. Turbidity distribution after the flood on July 4, 2018

In the 2018 case, the thickness of epilimnion was 3 m larger at the time of post-flood implementation of saving-warm-water operation (Figure 14). Average turbidity above 310 m at damsite was estimated 29.6 degrees when saving-warm-water operation was implemented. It was 31.2 degrees when saving-warm-water was not implemented. Concentration of turbidity is attenuated within the extended epilimnion. This phenomenon was not observed in the 2013 case because the warmer water layer was not preserved by the preceding drawdown, suggesting that saving-warm-water operation is also effective for the mitigation of high-turbidity-water release.

Based on the results of the 2013 and 2018 cases, the effect of early release of high-turbidity water to mitigate the prolongation of high-turbidity water is unclear. Additional analysis is required for more experimental operations in the future. However, saving-warm-water operation is also considered effective for the moderation of high-turbidity water release.

6. CONCLUSIONS

The operation of the Sameura Dam selective water-intake facility was evaluated using a 2D vertical water-quality model that numerically simulates turbidity and water-temperature stratification in the dam reservoir and downstream. The obtained major results are as follows:

1) The saving-warm-water operation is a planned countermeasure against low-temperature water release. Water-intake elevation was set at a relatively lower level in epilimnion, where water temperature was lower than in the surface layer but satisfied target water temperature. The elevation was determined with other concerned organizations, mainly taking account the effect on sweetfish and irrigation requirements. In August 2013 and 2016, released-water temperature became lower than the target level because of continuous water supply and water-level decline. However, the operation worked well in mitigating lower target water temperature in both cases. The saving-warm-water operation is considered also effective for moderating muddy-water release because the concentration of turbidity is attenuated within the extended epilimnion.

2) The early release of high-turbidity water operation is a countermeasure against the prolongation of muddy-water release. After the floods in September 2013 and July 2018, muddy water above 10 degrees in turbidity was released for more than two weeks after the end of the flood, but highly turbid water was selectively withdrawn during the flooding for the early release of suspended matter. Consequently, more SS were estimated to be released during the flood. Further analysis is necessary through additional experimental operations.

7. REFERENCES

1. Vermeyen, T. B. (2006), "Hungry horse selective withdrawal system evaluation 2000-2003", U.S. Department of the Interior Bureau of Reclamation Technical Service Center Hydraulic Investigation and Laboratory Group, Denver, Colorado.
2. Zheng, T., Sun, S., Liu, H., Xia, Q. and Zong, Q. (2017), "Optimal control of reservoir release temperature through selective withdrawal intake at hydropower dam", Water Science & Technology: Water Supply, 17 (1), pp. 279-299.
3. Park, H., Chung, S., Cho, E. and Lim, K. (2018), "Impact of climate change on the persistent turbidity issue of a large dam reservoir in the temperate monsoon region", Climatic Change, 151, pp. 365-378.
4. Ma, S., Kassinos, S. C., Fatta Kassinos, D. and Akylas, E. (2008), "Effects of selective water withdrawal schemes on thermal stratification in Kouris Dam in Cyprus", Lakes & Reservoirs: Research & Management, 13, pp. 51-61.
5. Çalışkan, A. and Elçi, Ş. (2009), "Effects of selective withdrawal on hydrodynamics of stratified reservoir", Water Resour Manage, 23, pp. 1257-1273.
6. Wang, S., Qian, X., Han, B., Luo, L., Ye, R. and Xiong, W. (2013), "Effects of different operational modes on the flood‐induced turbidity current of a canyon‐shaped reservoir: case study on Liuxihe Reservoir, South China", Hydrol Process, 27, pp. 4004-4016.