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Measures against the predicted degradations of water quality of Makio dam by the volcanic eruption

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ABSTRACT

Mt. Ontake erupted on September 27, 2014 and it was the second time in recorded history. The distribution and volume of products by the volcanic eruption were almost similar to those of the previous eruption in 1979. The catchment of Makio Dam is located at the foot of Mt. Ontake, therefore the influence of the eruption on the water quality of the dam reservoir was predicted to be continuing over a long period. In response to this situation, Japan Water Agency (JWA), the management body for Makio Dam, has collaborated with local governments/municipalities concerned and water users/stakeholders to implement not only efficient water quality monitoring but also appropriate measures for water quality conservation while making accurate forecast of discharged turbidity. As a result, the dam has kept supplying water to the downstream continuously without any particular trouble in water use at the moment.

1. GENERAL INSTRUCTIONS

Makio Dam in the Kiso River system has a catchment area of 304 km^2 (including the crater of Mt. Ontake) and total impoundment of 75,000,000 m^3. Makio Dam, a water resource for the Chukyo area, supplies domestic water, industrial water, and irrigation water, as well as the water used by the Kansai Electric Power to generate electric power of 35,000 kW.

Since there are few residential houses within the catchment of Makio Dam, an eutrophication problem has not been generated in the reservoir. But according to the reports (National Research Institute for Earth Science and Disaster Prevention 1980 & Meteorological Agency 1984) and papers (Shimada Y 1982) at that time, highly turbid water and acidic water flowed into it in the eruption of Mt. Ontake in 1979.

Mt. Ontake erupted on September 27, 2014 after 35 years' dormancy since 1979, and highly turbid water and acidic water, both of which contain significant amounts of volcanic products, entered into Makio Dam (Reported by Earthquake Research Institute of Tokyo University, National Research Institute for Earth Science and Disaster Prevention & National Institute of Advanced Industrial Science and Technology 2015).

To study measures against water pollution, the Ministry of Land, Infrastructure and Transport, Ministry of Economy, Trade and Industry, Ministry of Agriculture, Forestry and Fisheries, Nagano Prefecture, Aichi Prefecture, Gifu Prefecture, Mie Prefecture, Nagoya City, Kansai Electric Power, and JWA, all of which are concerned with water quality control of the Kiso River, established an organization called "Study Committee for the Conservation of Water Quality of Kiso River Catchment Upstream Area after the Eruption of Mt. Ontake" (hereinafter, "Study Committee"). Since the objective of this Study Committee is to implement effective and efficient water quality monitoring, it selected 26 points to strengthen water quality monitoring capabilities. The Study Committee not only distributed the monitoring data collected from these monitoring points to all committee members but also published it on the Internet whenever necessary.

The JWA, the management body for Makio Dam, implemented an appropriate water quality conservation program to protect water users in the downstream from water intake problems caused by water discharge from the dam while making an accurate forecast of the discharged turbidity.

This article reports on the water quality conservation measures taken after eruption of Mt. Ontake.

2. WATER UTILIZATION OF MAKIO DAM

Figure 1 shows the changes in water utilization of Makio Dam within the period from 2012 to 2015. The reservoir level decreased to almost its minimum level of EL. 832 m at the end of March since the stored water is mainly used to generate electric power during the period from December 1 to March 31 of the next year. Thereafter, the reservoir starts storing the snow-melted water to regain the specified level from April 1 so that the water can be used in the irrigation period from May. The water supply to the downstream is implemented by means of the power-generating water discharge facility installed at EL. 826 m (bottom of the reservoir). When the facility is not available, the water discharge facility installed at EL. 827 m is used. Therefore, either facility features bottom water discharge from the level at or below the minimum level of EL. 832 m.

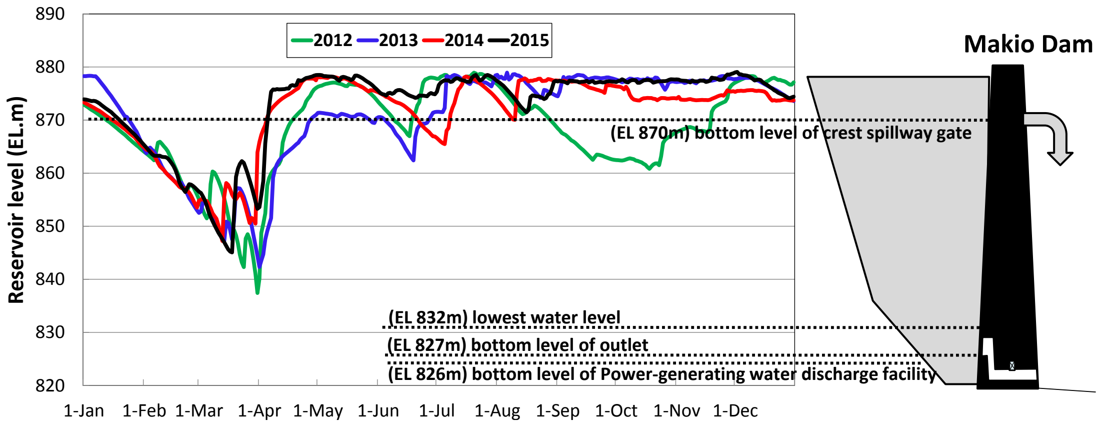

Figure 1. Result of water utilization of Makio Dam (2012 to 2015)

3. WATER QUALITY MONITORING

3.1 Monitoring points and items

In the reservoir of Makio Dam, we have implemented water quality monitoring twelve times a year. Since many volcanic products entered into and accumulated in the dam after the eruption as shown in Figures 2, we determined to increase the number of monitoring points, frequencies, and items from the day following the eruption.

High turbidity water flowing into the reservoir through "Nigorisawa River".

Volcanic products accumulated at the flow-in point of the reservoir.

Figure 2. View of the inflow river and flow-in point of the reservoir on September 29, 2014

To examine the turbidity and pH that may be most affected by the eruption, we selected three monitoring points (A, B, C) as shown in Figure 3.: the point where the contaminated water flows into the dam (at the surface layer); a point 200 m upstream from the dam site in the reservoir (at the surface layer); and the point where the water is discharged from the reservoir (at the surface layer). We also determined to monitor the water quality twice a day during the period from September 28, 2014 to October 31, 2014, once a day during the period from November 1, 2014 to December 19, 2014, and once a week after December 20, 2014.

To make an accurate forecast of water quality, we measured the vertical distributions of turbidity and pH in the reservoir at three points (B, a, b) in Figure 3., respectively, 200 m, 1,500 m, and 3,000 m away from the dam site in the upstream, once a week or once in two weeks. At each point, the data was continuously collected from the surface to the bottom of the reservoir at an interval of 1 to 5 m of water depth. In addition, we measured the particle size distribution of the turbid material at A point (at the surface layer) and B point (at the position 1 m above the lake bottom) four times.

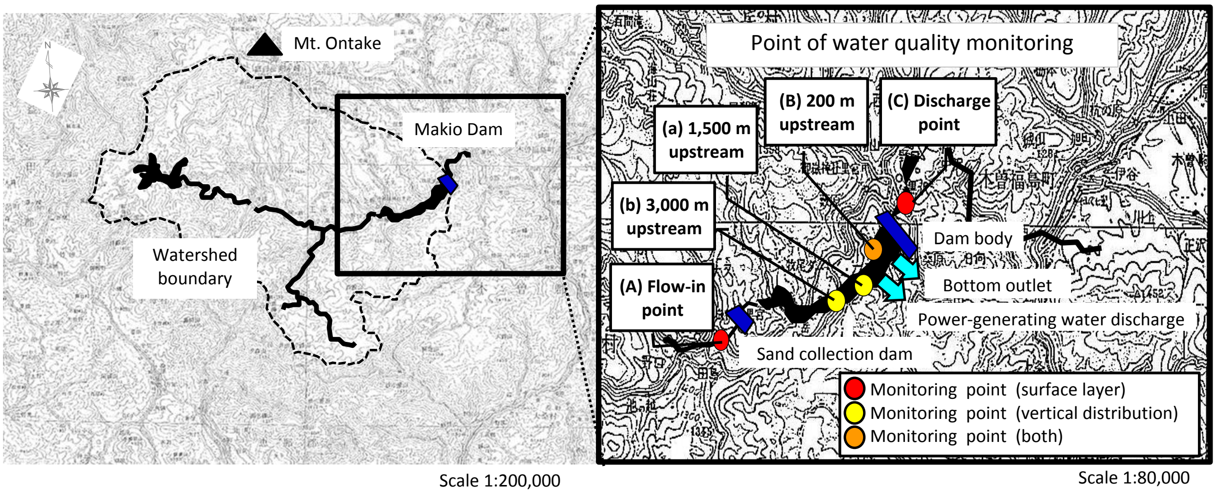

Figure 3. Point of water quality monitoring in the reservoir

Based on existing documents (Kosugi Y et al. 2006), we determined cadmium, lead, hexavalent chromium, arsenic, total mercury, selenium, boron, and fluorine as eight substances that would affect human health in the form of volcanic products released from the eruption and measured these substances at A point (at the surface layer), B point (at the surface layer), and C point (at the surface layer) one a month.

3.2 Results and consideration

3.2.1 Turbidity and turbid material particle size distribution

The turbidity of the river water increased at the flood time and decreased with a decrease in flow rate. As shown in Figure 4, however, the turbidity increased to 1,800 Formazin Turbidity Unit (FTU) (result of measurement/analysis of sampled water) even at the flow rate of 5 m^3/s when measured at the flow-in point of Makio Dam immediately after the eruption and ranged between several hundred FTU to not less than thousand FTU regardless of flow rate during the two months after the eruption. After December, the turbidity was increased to several hundred FTU at the flood time but decreased to a value between several FTU and several ten FTU in normal flow conditions.

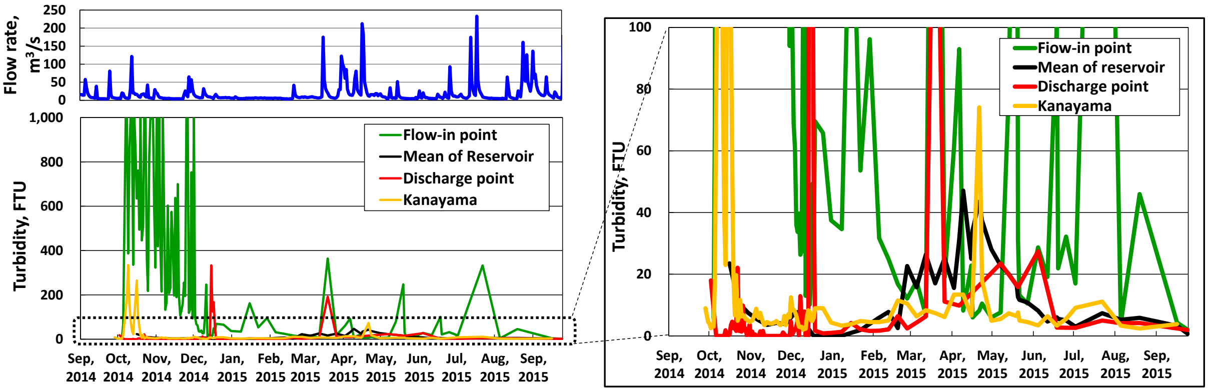

Figure 4. Change of turbidity (September 2014 to September 2015)

When the water with turbidity from several hundred FTU to not less than thousand FTU enters into the reservoir over a prolonged period, the turbid water usually diffuses and as a result, the reservoir remains highly polluted over a long period. When we examined the vertical distribution of the turbidity measured at the monitoring points in the dam site immediately after the eruption, as shown in Figure 5, a value of 500 or higher FTU was recorded (maximum of 380,000 FTU was recorded for the water sampled on October 16, 2014) only at the lower elevation from EL. 825 m to 829 m while smaller values were recorded at higher elevations. Since the high turbidity water flowing into the reservoir at the flood time contains particles of various sizes, coarse particles are deposited in the upstream and fine particles are deposited near the downstream dam site. Since the turbid water at the flow-in point contained high volumes of volcanic products, more than 90% of which were fine-particle silt and clay (particle size: 74 µm or under) as shown in Figure 6, the turbid material particle size distribution of the flow-in water was similar to that of the high turbidity water stagnating in the lower layer of the dam site. From the annual measurement of the sand deposited in the reservoir, we found that most of volcanic products were deposited in the sediment trap dam at the upstream end and at the bottom of the dam site. Based on this data, we judged that the flow-in water containing lots of volcanic products slid on the reservoir bottom as an underflow density current and resultantly reached the dam site.

Due to the effect of discharge water from the crest spillway gate (located at EL. 870 m) as a part of water quality conservation measures (see Section 4.1), the discharged turbidity from the time immediately after the volcanic eruption to December 14, 2014 is almost same as the average year, except for a low-water-level period in March and a water storage period in April.

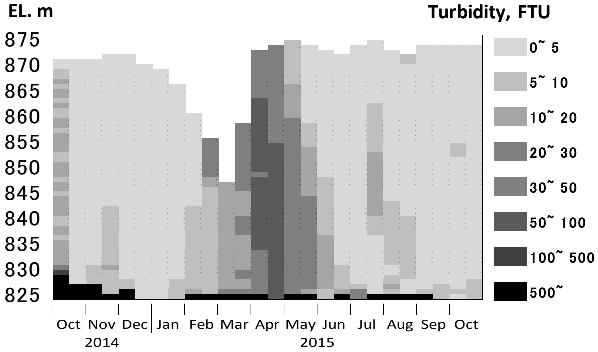

Figure 5. Change of vertical distribution of turbidity at 200 m dam site point

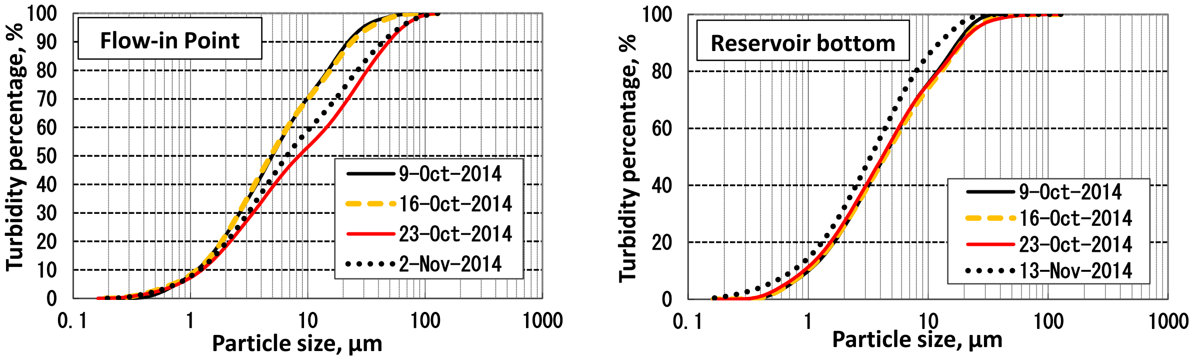

Figure 6. Turbid material particle size distribution at flow-in point and reservoir bottom

The turbidity at the Kanayama point (domestic water intake point 120 km downstream of Makio Dam), which is located in the main stream of Kiso River, increased to several hundred FTU for about two weeks from the end of September 2014 (the time immediately after the eruption) regardless of flow rate but maintained almost the same level as usual thereafter.

3.2.2 pH

The pH at the flow-in point before the eruption stayed at a level of about 7.0, but decreased at least 4.0 during the period from October to December 2014 after the eruption as shown in Figure. 7. After December 2014, the pH recovered to a level between 6.0 and 7.0 in the normal flow conditions but decreased to 4.5 at the flood time depending on the situation. It is estimated that much amount of volcanic products entered into the reservoir at the flood time and caused decreasing of pH value by their acidity. Same trend were applied for average pH of the reservoir (weighted average for all layers) and the pH of the discharged water.

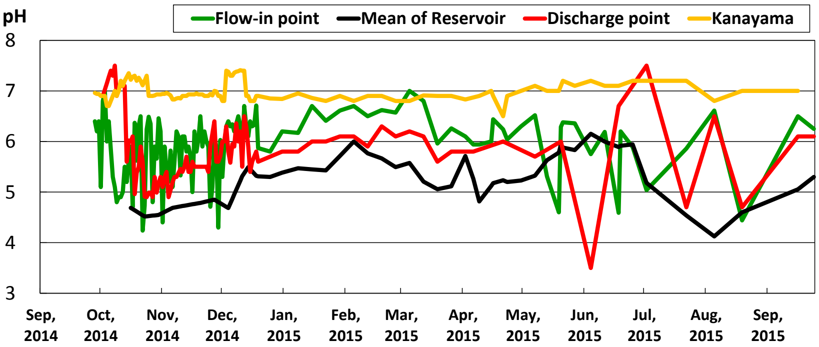

Figure 7. Change of pH (September 2014 to September 2015)

Although the pH at the Kanayama point, which is located in the main stream of Kiso River, showed about 7.0 immediately after the eruption, including the flood time, we found no drastic change at this point due to sufficient dilution by another tributaries.

3.2.3 Substances affecting human health

Substances whose concentrations exceeded the environmental standards as of October 2, 2014 immediately after the eruption were lead, arsenic, and total mercury as shown in Figure 8. The lead and total mercury exceeded the standards when the turbidity was higher than 1,000 FTU, while the arsenic exceeded the standards when the turbidity was higher than several ten FTU. All of them did not exceed the standards after the turbidity became lower than the normal level. Since these substances exceeding the environmental standards did not violate the standards with respect to soluble components (excluding the arsenic measured on October 9 (turbidity: 1,760 FTU)), it is estimated that most of these heavy metal adhered to the volcanic products. Cadmium, selenium, hexavalent chromium, fluorine, and boron did not exceed the standards.

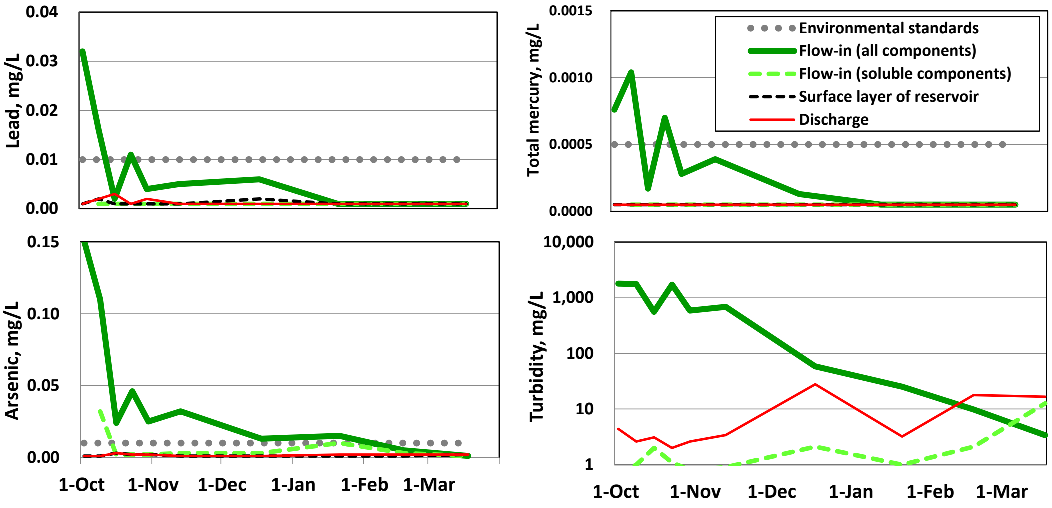

Figure 8. Change of major substances affecting human health (October 2014 to March 2015)

None of the eight substances exceeded the environmental standards at the in-reservoir monitoring points and discharge point. The supposed reason is that most of the volcanic products settled on the bottom of the reservoir.

4. WATER QUALITY CONSERVATION MEASURES

4.1 Discharge with crest spillway gate

Makio Dam is equipped with two discharge facilities: a power-generating water discharge facility (EL. 827 m) and a bottom outlet facility (EL. 826 m). Since both facilities use bottom water discharge, there was a concern that large volumes of high turbidity water stagnant in the bottom layer of the reservoir would flow out with the increase of discharge water volume. For this reason, we discharged the water through the crest spillway gate positioned in the upper section of the dam structure (EL. 870 m) immediately after the eruption.

In the period during which the reservoir level was higher than the gate, we attempted to implement combination discharge by means of the bottom outlet discharge facility, the power-generating water discharge facility, and the crest spillway gate to lower the discharged turbidity as far as possible.

4.2 Measures for mitigation of downstream influence due to discharge from dam

To reduce the discharge of high turbidity water stagnant in the bottom layer of the dam site, we installed a submersible water pollution prevention fence in the upstream point about 30 m away from the bottom outlet discharge facility (Figures 9). Since the power-generating water discharge facility was equipped with flash board rails, the Kansai Electric Power installed a flash board gate at the elevation between EL. 827 m and 829 m to reduce the flow-down of high turbidity water.

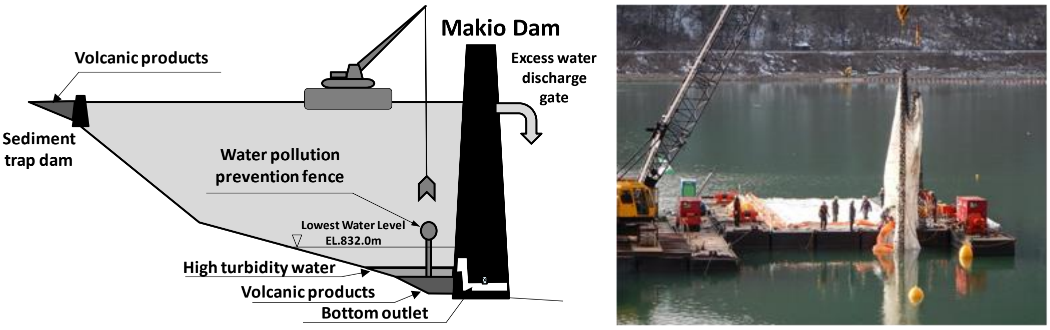

Figure 9. Submersible water pollution prevention fence (width: 140 m, height: 10 m)

4.3 Removal of volcanic products deposited in the sediment trap dam

When we surveyed the condition of deposited volcanic products in October 2014, we found that about 670,000 m^3 of volcanic products had been deposited in the sand collection dam located at the upstream end of the reservoir and on the bottom of the dam site. In particular, it was highly possible that the sediment at the upstream end of the reservoir would be scoured at the flood time and, therefore, we removed 15,000 m^3 of volcanic products deposited in the sediment trap dam during the period between October 2014 and March 2015 and implemented appropriate disposal (Figure 10).

Figure 10. Removal of volcanic products deposited in the sediment trap dam (February 4, 2015)

5. FORECAST OF WATER QUALITY

5.1 Forecast of water quality during test discharge

Water was discharged using the crest spillway gate for the interim period immediately after the eruption. After January 2015, however, the reservoir level became lower than the threshold for the crest spillway gate due to the start of power-generating water discharge and, therefore, the bottom water discharge would be the dominant discharge mode. Since such the discharge mode might cause a flow-down of large amounts of stagnant high turbidity water in the bottom layer of the reservoir, we implemented a test discharge during the period from December 15 to 18, 2014.

Before the test discharge, we forecasted the discharged turbidity based on a water quality prediction model. In this forecast, taking into consideration the flowing layer thickness as well as the vertical distribution of the turbidity in the reservoir, we calculated the discharged turbidity under the assumption of the existence of two different layers (i.e., high turbidity water layer and low turbidity water layer was an initial condition as shown in Figure 11.). This study proved that the discharged turbidity of 1,200 FTU lasted for a long period in the case where the water pollution prevention fence was not used but the discharged turbidity decreased within one to two hours when the fence was used, as shown in Figure 12. Therefore, we implemented the test discharge after getting approval from the Study Committee.

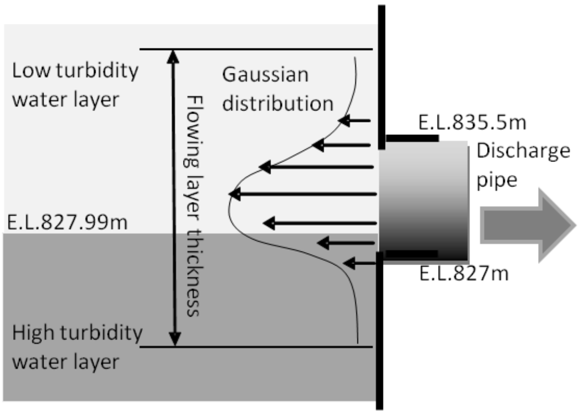

Figure 11. Water quality prediction model - Schematic view

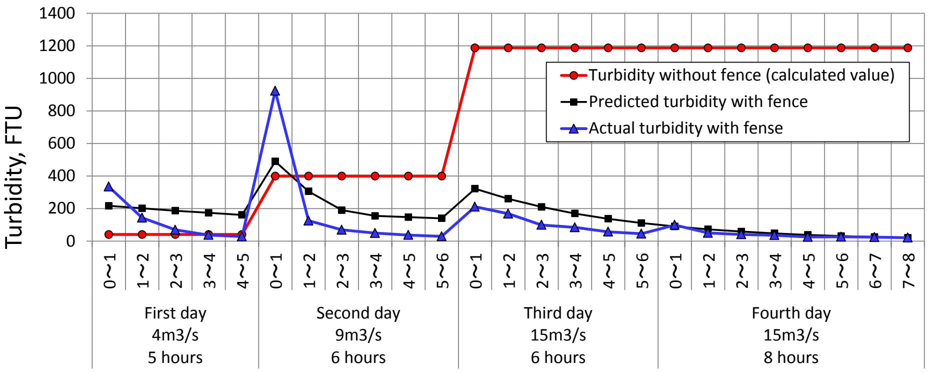

Figure 12. Turbidity at discharge point during test discharge (predicted and actual values)

The test discharge flow was gradually increased from 4 to 15 m^3/s while monitoring the influence to the downstream rivers. Since it was forecasted that high turbidity would be observed in the initial stage of the discharge, we implemented a combination discharge by using the crest spillway gate.

As shown in Figure 12, the turbidity increased to the maximum of 900 FTU at the discharge point in the initial stage of the test discharge but showed a rapid reduction tendency over time and became almost the same level as the forecast.

5.2 Forecast of water quality at low reservoir level

When the reservoir level decreased to the minimum according to the water utilization rule shown in Figure 1, most of effluent would be stored in April and thus there was a concern that the turbid water containing lots of volcanic products would be discharged over a period during which the water utilization would increase after May. For this reason, we implemented a study to comprehend the water utilization that would minimize the influence of prolonged supply of turbid water.

5.2.1 Study of flow-in load calculation (L-Q equation)

We observed that the turbidity in the reservoir maintained several tens FTU (Figure 5) while the high turbidity water entered into it as shown in Figure 4. For this reason, we implemented the present condition reproduction calculation to comprehend to what extent the turbid water reached the dam site as an underflow density current in the reservoir.

Then, we created the relationship equation of Suspended Substance (SS) ratio load (L) and specific flow (Q) (Figure 13). This equation (L-Q equation) was based on the actual measurement of water quality survey result. When we implemented the present condition reproduction calculation with L-Q equation, the vertical distribution of the turbidity in the reservoir indicated several thousand FTU and substantially differed from the measurements shown in Figure 5. Therefore, we modified the L-Q equation and corrected the turbidity to 1/10 of measurements, the turbidity condition in the reservoir at the flood time and the increase of and later reduction of turbidity in the low-level condition could be reproduced accurately (Figure 14). Therefore, it is estimated that 90% of the high turbidity water entering into the reservoir reached the dam site in the form of underflow density current and 10% of the water dispersed in the reservoir.

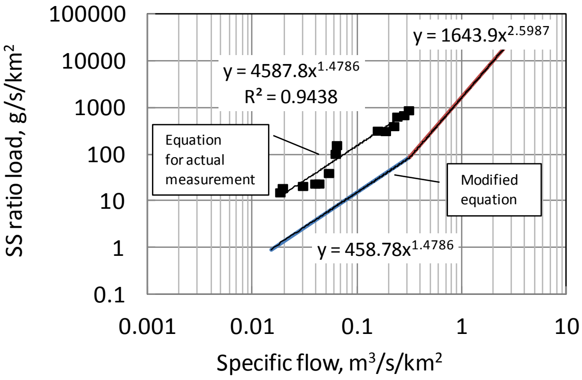

Figure 13. Actual measurement L-Q equation and modified L-Q equation

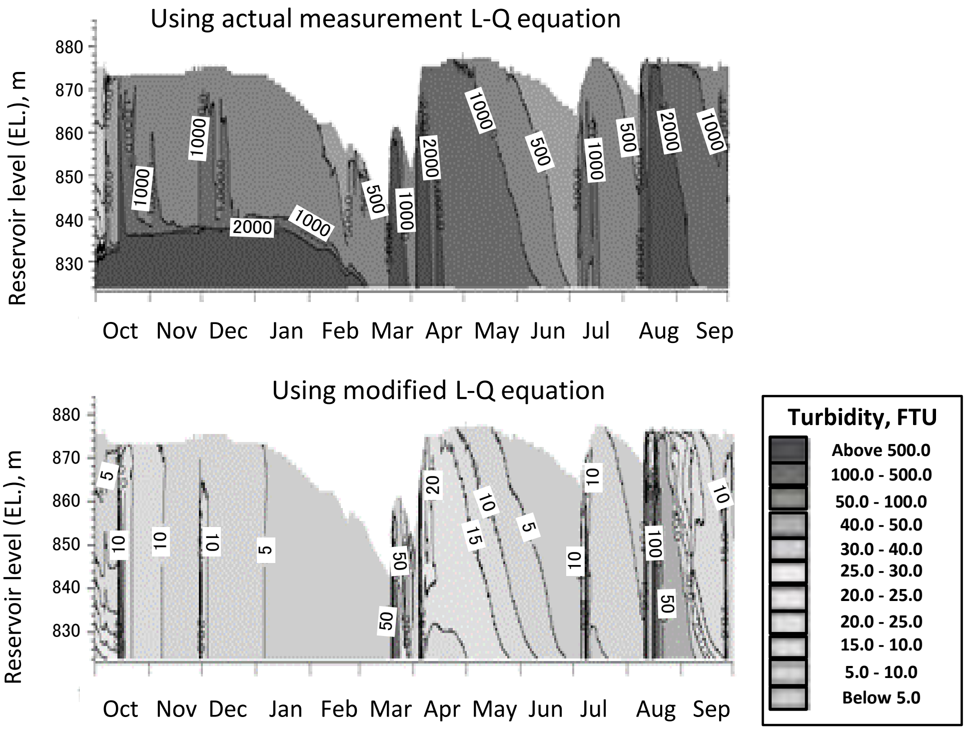

Figure 14. Result of forecast of vertical distribution of turbidity (October 2014 to September 2015)

5.2.2 Result of forecast

To find the reservoir level that would reduce the prolonged existence of turbid water during the low-level period in March and the water storage period in April, we implemented the water quality prediction calculation using the modified L-Q equation.

We determined three minimum reservoir levels, EL. 846 m, EL. 855 m, and EL. 863 m, in the early part of March and compared the discharged turbidity. As a result as shown in Figure 15, such the forecast was obtained that at the flood time lower reservoir level could provide higher peak value of discharge turbidity but the turbidity would be decreased rapidly thereafter while higher reservoir level could provide lower peak value of discharge turbidity but the turbidity would be decreased slowly thereafter. Since the influence of the discharged turbid water over the downstream rivers was similar in both cases, we determined not to limit the drawdown of the reservoir after the approval from the Study Committee.

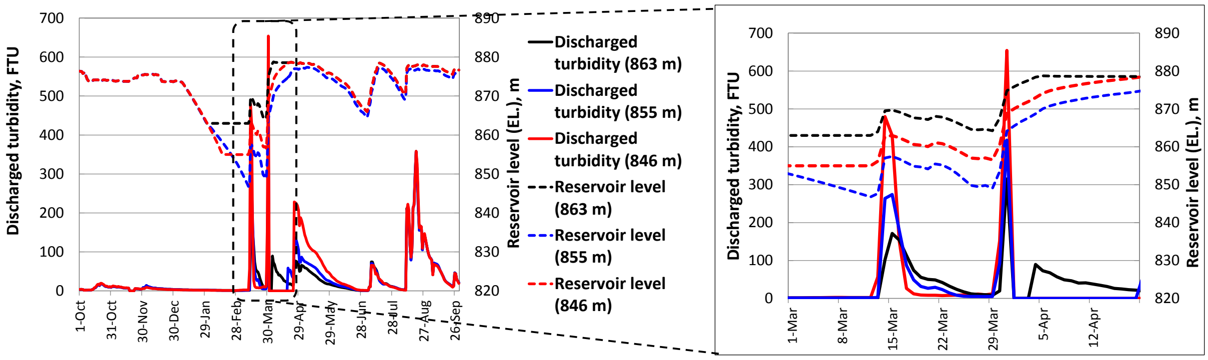

Figure 15. Result of forecast of discharged turbidity

6. FUTURE CHALLENGES

In the present time after the elapse of two years since the eruption, the turbidity of the reservoir has decreased in the normal flow condition although it has slightly increased at the flood time. Therefore, we judge the water in the reservoir will not seriously affect the ecological system in the area.

The post-flood pH value may decrease to 4.5 in the flow-in water, to 4.0 in the reservoir, and to 3.5 in the discharged water, although the influence over the surrounding ecological system has not been identified yet. Such low pH condition also lasted for a prolonged period after the eruption of 1979 as shown in Figure 16. When estimating from the fact that the low pH condition was eliminated after most volcanic products were buried by the Nagano Earthquake in 1984, it is forecasted that the low pH condition will be maintained into the future. For this reason, it is necessary to implement water quality monitoring from a long-term prospective.

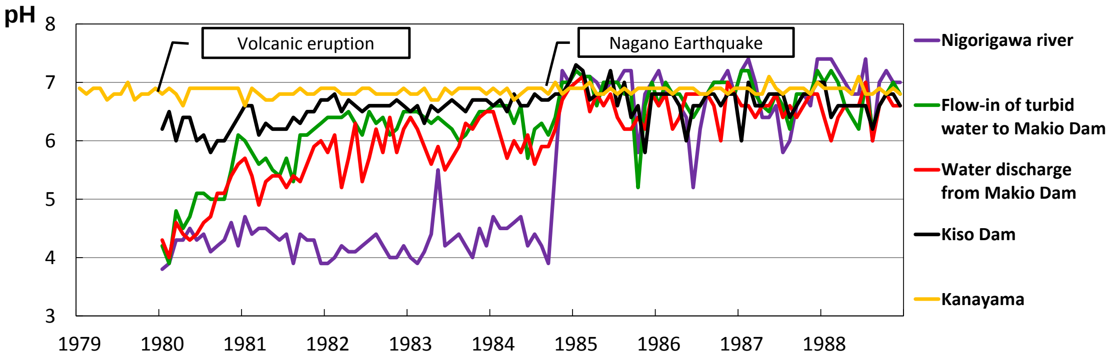

Figure 16. Secular change of pH at eruption of 1979

7. CONCLUSIONS

By the volcanic eruption of Mt. Ontake in 2014, highly turbid water and acidic water entered into Makio Dam immediately after the eruption. JWA collaborated with the local governments concerned and water users to implement not only efficient water quality monitoring but also appropriate measures for water quality conservation while making an accurate forecast of discharged turbidity. As a result, the dam has continued to supply water to the downstream without any particular problems in water use.

After two months of the eruption, the discharged turbidity decreased to almost the same level as an average year, except for the flood time, Therefore, we estimate that our prediction method based on the study of flow-in load calculation and the creation of water quality prediction model was almost appropriate, and our water quality conservation measures including the installation of submersible water pollution prevention fence was also highly effective. In the present time after the elapse of two years since the eruption, the turbidity of the reservoir has decreased in the normal flow condition except slightly increasing at the flood time.

Major substances affecting human health at the flow-in point of reservoir didn’t violate the standards estimated by soluble components. Also at the in-reservoir and discharge points, the concentrations of these substances were lower than the standards.

But the post-flood pH value has decreased to approximately 4.0 at flow-in point in the reservoir and discharged point. This deterioration also occurred at the low level period in March and the water storage period in April due to the erosion of volcanic products settle on the bottom of the reservoir. Such low pH condition also lasted for a prolonged period after the eruption of 1979, it is forecasted that the low pH condition will be maintained into the future. For this reason, it is necessary to implement water quality monitoring from a long-term prospective.

8. ACKNOWLEDGMENTS

In taking water quality conservation measures for Makio Dam, we received significant cooperation from the local governments and water users concerned Study Committee, and various persons concerned with the Kiso River basin. We would like to express our sincere gratitude to all these parties.

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