



EFFECT OF SUPPLY OF HIGH DO CONCENTRATION WATER ON WATER QUALITY IMPROVEMENT AND BEHAVIOR OF HEAVY METAL IN DAM RESERVOIR

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ABSTRACT

Shimaji-gawa River dam reservoir is in Shunan City, Yamaguchi Prefecture, Japan. This reservoir had also suffered from the elution of heavy metals with anaerobic states. To prevent the water quality in this reservoir from pollutions, a device to supply high DO concentration water into the bottom layer has worked in Shimaji-gawa River dam reservoir since April 2010. This device didn't work from February to July in 2013 because of mechanical trouble of this device. The monitoring of the water quality at the fixed observation point has conducted by Yamaguchi Office of River and Road from 2006 to present. We have investigated the effect of the supply of the high DO concentration water of the improvement of the water quality and the long-term behavior of the heavy metals using the long-term period monitoring data and the longitudinal observation data conducted recently. It is found that DO have spread over the region where the water quality must be improved. The concentrations of Arsenic and Iron decreased greatly in a few months. On the contrary, it took almost 1 year for Manganese to completely decrease, and manganese started to re-liquate out when the device stopped. Moreover, the concentration of Manganese didn't decrease satisfactory.

Keywords: High DO concentration water, Shimaji-Gawa River Reservoir, Arsenic, Iron, Manganese

1. INTRODUCTION

The concentration of the dissolved oxygen (DO) in the lower layer of lakes or dam reservoirs is quite low because DO is consumed when the organic matter is decomposed by bacteria. The water volume of the low DO concentration can lead to many water quality problems. One of the problems is the elution of the heavy metals from the lake or reservoir bed (Michioku et al., 1996). Shimaji-gawa river dam reservoir is in Shunan City, Yamaguchi prefecture, Japan. In this reservoir, the heavy metals, such as Arsenic (Aresenicum), Iron (Ferrum) and Manganese (Manganum) had flowed out with anaerobic states and the water volume of the high concentration of these heavy metals was in the lower layer (Matsumoto et al., 1993).

Yamaguchi office of river and road, ministry of land, infrastructure, transport and tourism, installed an equipment to supply high DO concentration water into the bottom layer to Shimaji-gawa fam reservoir to oxidize Arsenic, Iron and Manganese and make them settled down. This device has worked since April 2010. The vertical circulation in winter season doesn't reach the bottom layer in Shimaji-gawa dam reservoir. In addition, there is no mixing in the bottom layer even if the huge flood occurs. In other words, there is no natural vertical exchange mechanism in the low layer. The high DO concentration water is supplied calmly not to mix the upper layer water with the lower layer water. Thus, the water quality is improved with the chemical reaction due to only the supply of the high DO concentration water.

The monitoring of the water quality at the fixed observation point has conducted by Yamaguchi office of river and road from 2006 to present. We have investigated the effect of the supply of the high DO concentration water of the improvement of the water quality and the long-term behavior of the heavy metals using the long-term

period monitoring data and the longitudinal observation data conducted recently. This paper will discuss the results of this investigation.

2. SUMMARY OF STUDY FILED AND DO SUPPLY DEVICE

Shimaji-gawa dam is located in the upper stream part of Shimaji-gawa river. Shimaji-gawa river is a branch river of Saba-gawa river which is a class A river. Shimaji-gawa dam is a multi-purpose dam and was completed in 1981. The total water storage capacity is $20.6 \times 10^6 \text{ m}^3$. Figure 1 shows the location of Shimaji-gawa dam. The water area in which the water quality improvement is required is under the elevation level (EL) 250m and this area is hatched in the right-hand side of Figure 1. Figure 2 shows the longitudinal cross-section of the water quality improvement area. M0-M7 stand for the observation points. M0 is at the dam site and the distance between each observation point is 200m.

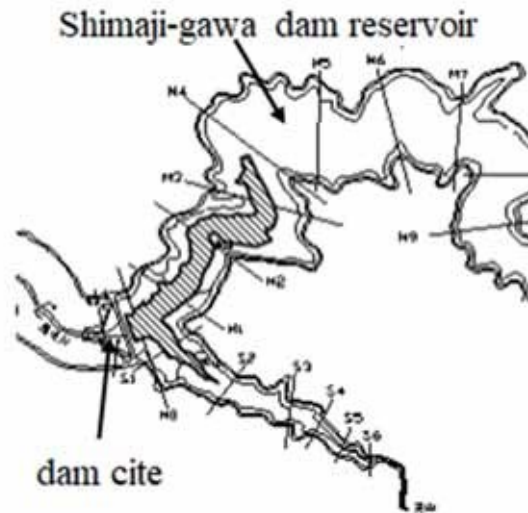


Figure 1. Shimaji-gawa dam reservoir

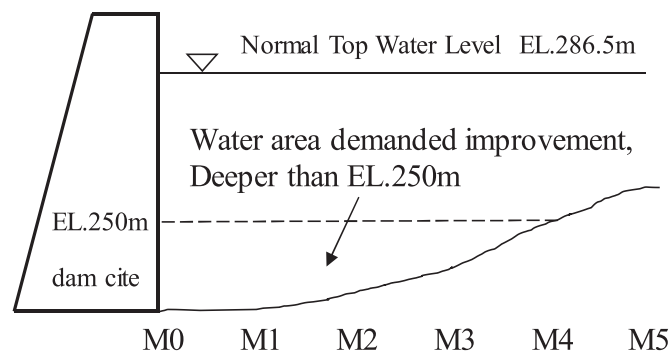


Figure 2. Shimaji-gawa dam reservoir

The device to supply the high DO concentration water is summarized in Figure 3. This device consists two parts. One is the generator of high concentration oxygen and is set on the land. This device is called the oxygen generator. The other is the device to dissolve high concentration oxygen in water and is set in the dam reservoir. This device is called the dissolving device. The dissolving device is in the lower layer so that the water pressure in this device is so high. The high DO concentration water can be generated by utilizing the high-pressure state. The high DO concentration water is spewed out in the horizontal direction and in the centric circle. This device doesn't spew out air bubbles. Therefore, this device has an advantage that the vertical mixing never occurs. The dissolving device is suspended by the wire rope and can be moved in the vatical direction.

This device has been worked since April 2010. In the first one year DO had been supplied in the middle layer (EL. 242m~250m) in which the concentration of the heavy metals is relatively low in order that the vertical mixing of the high concentration water in the bottom layer does not affect the intake gate. We call this operation

the middle layer operation. It was confirmed that Arsenic and Iron settled down smoothly. Therefore, the middle layer operation was terminated and another operation has started for the deep water which is under EL.250m since April 2011. We call it the low layer operation. The flow rate of air supplying to the low layer is 120m³/h and the concentration of oxygen in the supplied air is 90%. The elevation of the dissolving device is changed regularly from EL.231m to EL.250m. The device trouble stopped the operation from February to July in 2013.

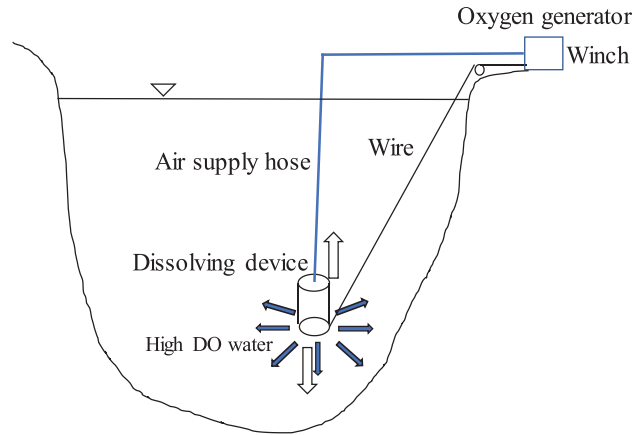


Figure 3. Schematic sketch of DO supply device

3. RESULTS OF WATER QUALITY INVESTIGATION

3.1 Time series and vertical profile of DO

Figure 4 shows the time series of DO at the observed point M1. The DO data at the low layer (EL.227m), the middle layer (EL.256m) and the surface layer (0.3m deep from the water surface) and the environmental reference value 7.5mg/l are shown.

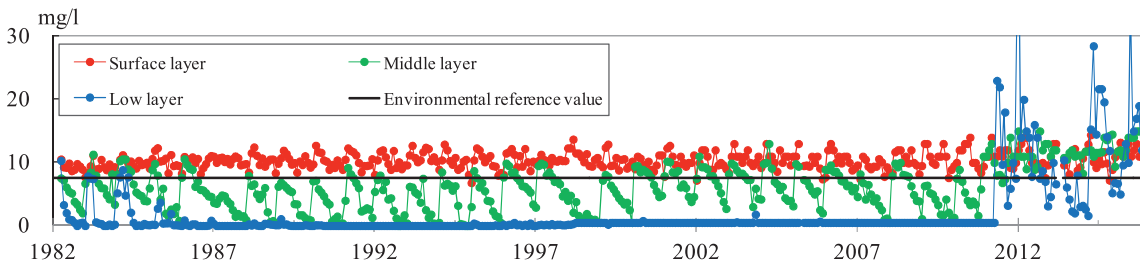
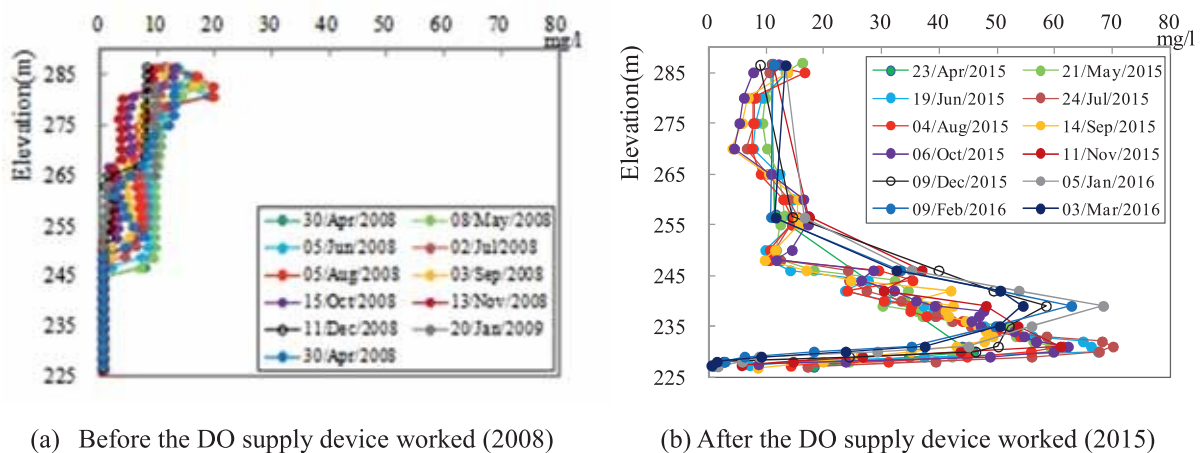


Figure 4. Time series of DO at M1



(a) Before the DO supply device worked (2008)

(b) After the DO supply device worked (2015)

Figure 5. Vertical profiles of DO at M1

DO concentration at the surface layer is around 10 mg/l and over the environmental reference value through all years. DO concentration at the middle layer indicates the cyclic pattern from 1982 to 2012 and is almost under the environmental reference value. This cyclic pattern is a seasonal change. The vertical circulation occurs in autumn-winter season and then DO concentration at this layer is recovered. From spring to summer DO concentration decreases. DO concentration is improved and over the environmental reference value after 2012 since the DO supply device is working.

The seasonal cyclic pattern of DO concentration at the lower layer can be seen from 1982 to 1987. However, DO concentration is quite low from 1987 until 2012. The elution of the heavy metals due to the low DO concentration makes the water density near the bottom heavier than the density of the upper water. As a result, the vertical circulation doesn't reach the low layer for 25 years. DO concentration is drastically improved after the DO supply device worked.

Figure 5 shows the vertical DO profiles at M1. Figure 5(a) shows the profiles in 2008 before the DO supply device worked and Figure 5(b) shows the profiles in 2015 after the DO supply device worked. The DO concentration under LE. 245 in 2008 is almost 0, and the seasonal variation of the DO profiles above LE.245 can be seen. On the contrary, the DO profiles having the peak at around EL.240m are formed. These profiles are due to the oxygen supply. The DO concentration decreases drastically under EL.230. This elevation is the lower limit of the dissolving device.

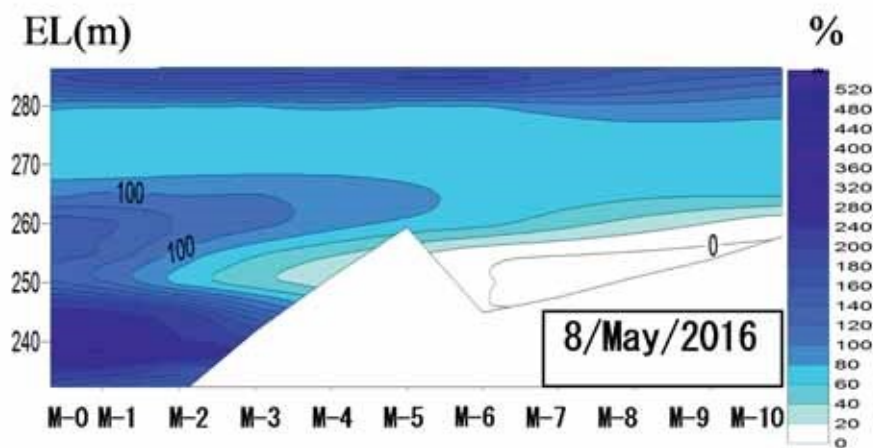


Figure 6. Longitudinal DO profile

Figure 6 shows the longitudinal DO saturation profile observed on 5 August 2016. The oversaturation of DO at around EL.240m can be seen. Although the distance between Mo and M3 is 700m water with the high DO concentrations spread over the water area that the improvement is needed. The high DO concentration area at around EL.260m also can be seen. The reason for this phenomenon might be thought that the high DO concentration water spewed out continuously from the device is upwelled by the dam site and spread out in the upstream direction along the thermocline at EL.265-270m. On the other hand, the low DO concentration water remains around M6-M10 because the high DO concentration water is blocked by the mound near M5.

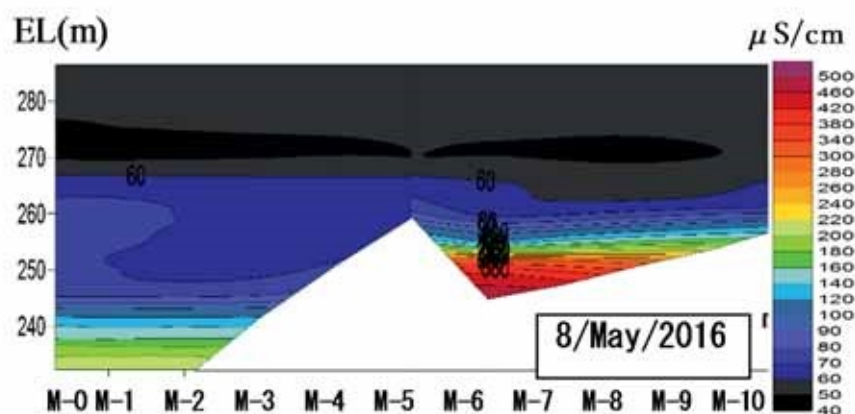


Figure 7. Longitudinal EC profile

Figure 7 shows the electrical conductivity (EC) observed on 5 August 2016. The high EC is indicated in a hollow near M6. It can be found that the heavy metals are eluted in the hollow because of the reduction condition. We can assume that the water quality in M0-M3 before 2012 is the same situation as M6, so it can be said that the water quality is quite improved.

3.2 Vertical profile of water temperature

Figure 8(a) and 8(b) show the vertical water temperature profiles at M1 in 2008 and 2015, respectively. Both figures show the thermocline at EL.280m in the summer season. From the thermocline to EL.270m there is a mixing layer and the water temperature is constant. A thermocline is also formed in EL.270m-260m and the water temperature is constant below EL.260m throughout the year.

The water temperature increases in the downward direction from EL.250m in 2008 and EL.240m in 2015, respectively. It is so called the reverse stratification and it is formed stably throughout the year without regard to the DO supply device. The density of water depends on the water temperature and the heavy metals eluted from the bottom. Therefore, the density profile is stable although the water temperature profile is reversed. The rate of the water temperature increases in 2015 is smaller than that in 2008. The mixing effect due to the supply of the high DO concentration water might be related to this phenomenon. The vertical circulation in winter season was expected to be expanded due to the supply of the high DO concentration water. However, the expansion of the vertical circulation cannot be seen up to the present.

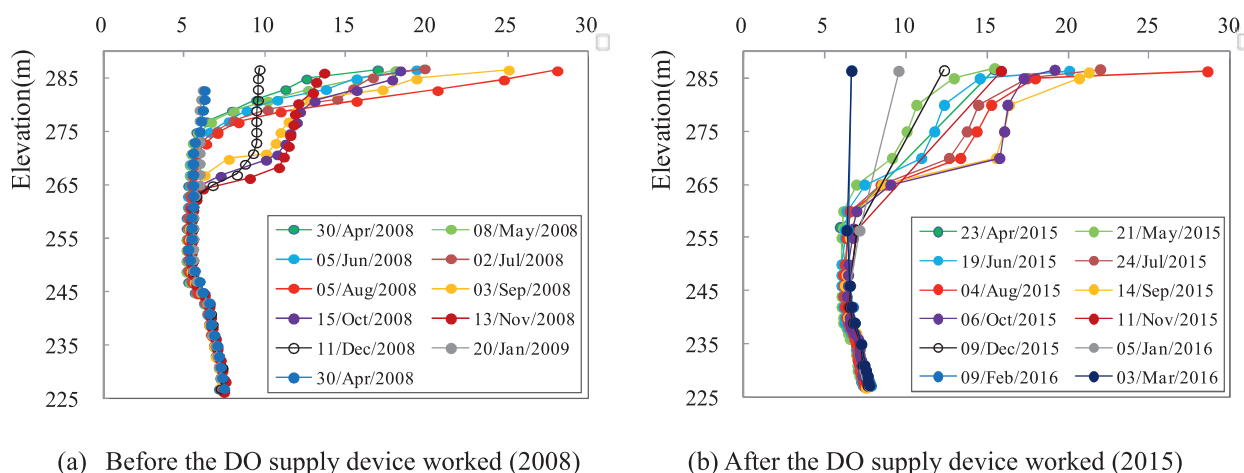


Figure 8. Vertical profiles of water temperature at M1

3.3 Time series of heavy metal

Figures 9, 10 and 11 show the time series of total arsenic, total iron, and total manganese for recently 10 years, respectively. The concentration of total arsenic in the surface layer and the middle layer is less than the environmental reference value 0.01mg/l from 2006. In the low layer, the concentration drastically has decreased since the DO supply device started to work in April 2010. The concentration decreased to 0.004mg/l in May 2010. The concentration increased after May in 2010, and it reached 0.06mg/l in November 2012. The concentration began to decrease after that, and it hasn't exceeded the environmental reference value since 2011.

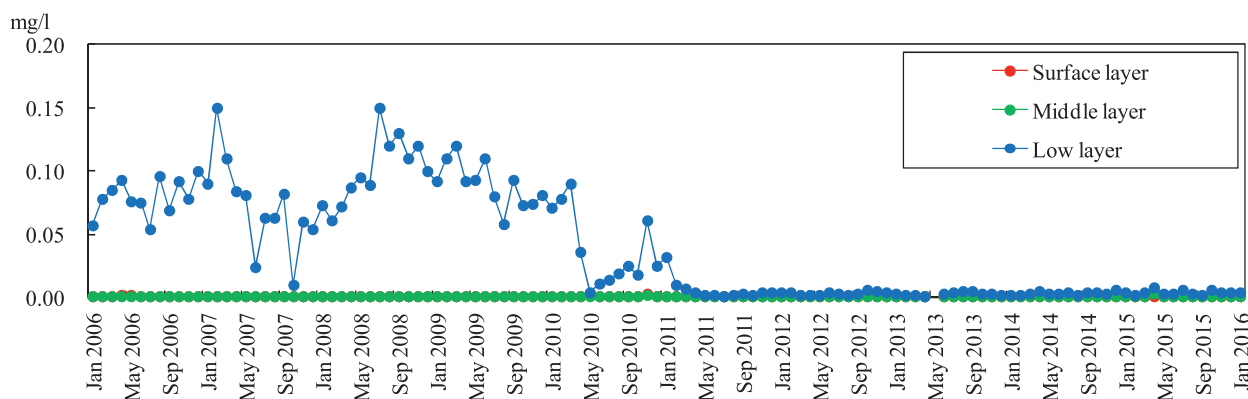


Figure 9. Time series of total arsenic at M1

The concentration of total iron in the surface layer is always smaller than the environmental reference value 0.3mg/l. The concentration in the middle layer is also smaller than the reference value except for January in 2008 and October-December in 2009. The concentration in the low layer started to decrease in April 2011 and reached 0.6mg/l in July 2011. The concentration is around 0.2-2.0mg/l after that.

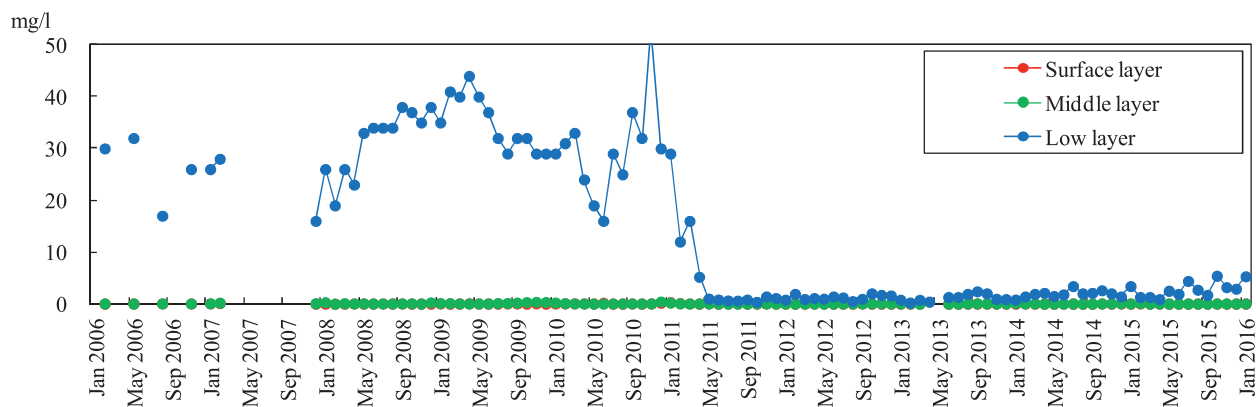


Figure 10. Time series of iron arsenic at M1

The concentration of total manganese in the surface layer is always smaller than the environmental reference value 0.01mg/l. The concentration in the middle layer is around 0.1-1.8mg/l and exceeds the environmental reference value until the DO supply device worked in 2010. The concentration is around 0.01-0.1mg/l after 2010. The concentration in the low layer is around 10.0mg/l until 2010. The concentration increased after 2010 and reached 23.0mg/l in September 2010. The concentration decreased after that, and it reached 1.0mg/l in July 2012. However, the concentration increased. The DO supply device stopped in April-May 2013, so the concentration highly increased after June in 2015. The concentration took a peak in March 2014, after that it started to decrease. The concentration is around 10.0-15.0mg/l after November 2014.

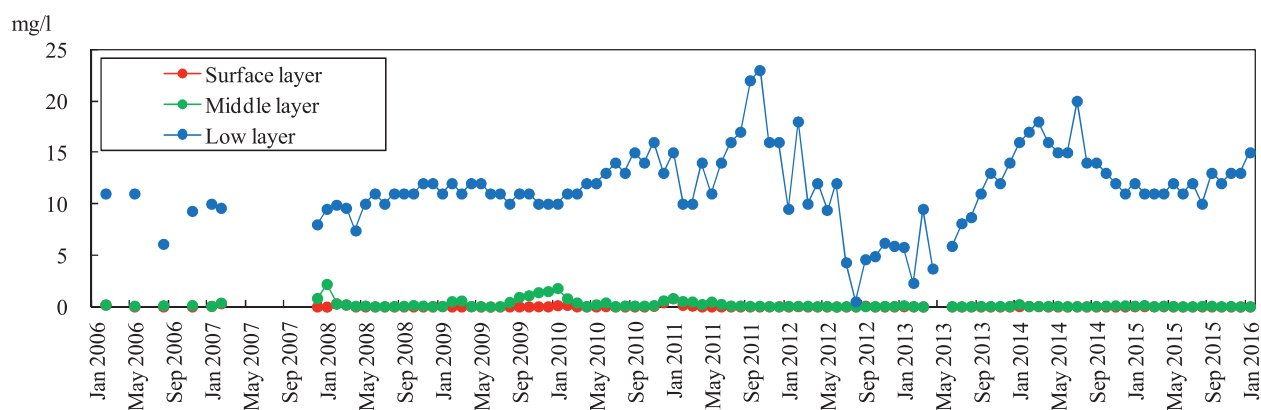


Figure 11. Time series of total manganese at M1

4. CONSIDERATION OF HEAVY METAL BEHAVIOR

When the high DO concentration water is supplied to the low layer water including arsenic, iron and manganese eluded from the bottom in the reduced state, these heavy metals are oxidized according to the following processes.

- 1) Iron ions of which the oxidation-reduction potential is low among them are oxidized and iron hydroxides (Fe^{3+}) is formed.
- 2) Arsenic is oxidized and pentavalent arsenic ($\text{As}^5\text{O}_4^{3-}$) ions are formed. Iron hydroxides absorb pentavalent arsenic ions and iron oxyhydroxides ($\text{Fe}^{3+}(\text{OH})_3 + \text{As}^5\text{O}_4^{3-}$) are formed.
- 3) Manganese ions are not easily oxidized if pH is low, but manganese ions are oxidized to be manganese dioxide if iron decrease and the oxidation-reduction potential in water increases.

On the reaction shown in 3), divalent manganese compounds and tetravalent manganese compounds are produced, and trivalent manganese is produced due to the intermolecular rearrangement. In fact, these phenomena are complicated.

According to the observations we have found that iron was oxidized and settled down because the oxidation-reduction potential of iron is relatively low. Iron hydroxides produced by oxidation capture arsenic, phosphorus etc., and settle down with them (coprecipitation). Therefore, the coprecipitation would be the reason why the concentration of arsenic decreased smoothly. In Figure 9, the concentration of arsenic in the low layer decreased

when the middle layer operation worked. This would be due to the absorption of arsenic in the low layer with iron hydroxide. However, re-elution of arsenic from May can be seen because there is no DO in the low layer during the middle layer operation. Eventually, the concentration of arsenic in the total layer had become smaller than the environmental reference value within one month since the low layer operation worked.

On the other hands, manganese, of which the oxidation-reduction potential is higher than that of arisen and iron, increased for 5 months after the low layer operation started. The following factors to explain this phenomenon could be listed. The settling velocity of manganese oxidized during the middle layer operation is very small so that it took 5 months to settle down from the middle layer to the low layer. The high DO concentration water doesn't reach the elevation below the dissolving device.

The re-elution of manganese can be seen after the DO supply device stopped on February-July 2013. The concentration didn't decrease after the DO supply device was restarted. In the present, we cannot reveal the mechanism of the phenomenon. We would like to leave this problem as a future task.

5. CONCLUDING REMARKS

The high DO concentration water supply device has worked since April 2010 to suppress low DO water in Shimaji-gawa dam reservoir. We have found from the monitoring data for 6 years that the high DO concentration water has supplied sufficiently to the water quality improvement area and the concentrations of iron and arisen are suppressed to the environmental reference levels.

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