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Study on Reduction of Non-point Sources in Storm-water Reservoirs

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Abstract
Although non-point sources significantly affect water quality in lakes, no definitive solutions have been developed for reducing non-point source pollution. As a measure for reducing non-point sources, we investigated a storm-water reservoir, which was originally constructed for flood control in urban areas by temporarily catching storm water to delay flood runoff. It is believed that a storm-water reservoir may trap particulate matter of non-point sources transported with storm water. To clarify the trap effect of the particulate matter, we conducted field measurements on the quality and dry weight of bottom sediments in reservoirs located within the watershed of Lake Inba-numa, a well-known eutrophic lake in Japan. The measured results reveal that the dry weight of the bottom sediment in the reservoirs increases with the bottom area of the reservoirs mainly because of the increase in retention time of storm water. The deposition rates of suspended solids (SS), total nitrogen (TN) and total phosphorus (TP) of bottom sediment in the reservoirs are comparable to unit effluent loads on SS, TN and TP measured in urban districts of the watershed. The reduction effects of TN and TP loads in all the reservoirs in the watershed of Lake Inba-numa are 1.0% and 8.4% of the non-point sources generated in the overall watershed, respectively. These facts indicate that the storm-water reservoirs function as traps for particulate matter from non-point sources.
Keywords: non-point source, storm-water reservoir, bottom sediment, trap effect, Lake Inba-numa

1. Introduction
Water pollution related to human activities has become increased in lakes, inner bays, and urban rivers. To improve water quality in these areas, the extension rate of sewerage networks has increased and industrial wastewater has been regulated. Thus, point sources such as domestic and industrial pollutant loads have decreased appreciably [1]. On the other hand, no definitive solutions have been developed for reducing non-point source pollution, such as deposits on roads and roofs, and hence these non-point pollutant sources remain largely uncontrolled with respect to the above-described aquatic areas [2], [3]. It is therefore desirable to develop an appropriate measure for effectively reducing non-point source pollutants.

Figure 1. Typical example of storm-water reservoirs in Japan, taken at reservoir 1.

A storm-water reservoir, shown in **Fig. 1**, originally constructed for flood control in urban areas, is believed to reduce non-point sources. These reservoirs temporarily retain storm water to delay flood runoff, and thus pollutants transported with the storm water are also retained in the reservoirs. As a result, a storm-water reservoir may trap the particulate components of non-point sources. However there is little quantitative information on how storm-water reservoirs can reduce non-point source pollution.
We examined the trap effect of particulate matter of non-point sources in storm-water reservoirs. We conducted field measurements of the quality and dry weight of bottom sediments in 28 storm-water reservoirs located within the watershed of Lake Inba-numa, a well-known eutrophic lake in Japan. We collected sediment deposited on the bottom of the reservoirs and then analyzed its dry weight and particle-size distribution. Total nitrogen (TN) and total phosphorus (TP) contained in the bottom sediment were also analyzed. From these data, we evaluated the trap effect of suspended solids (SS), TN and TP of non-point sources in the reservoirs. This study is partly done by “trial and error” actions for improving the water quality in Lake Inba-numa conducted by Chiba prefecture, Japan [4].

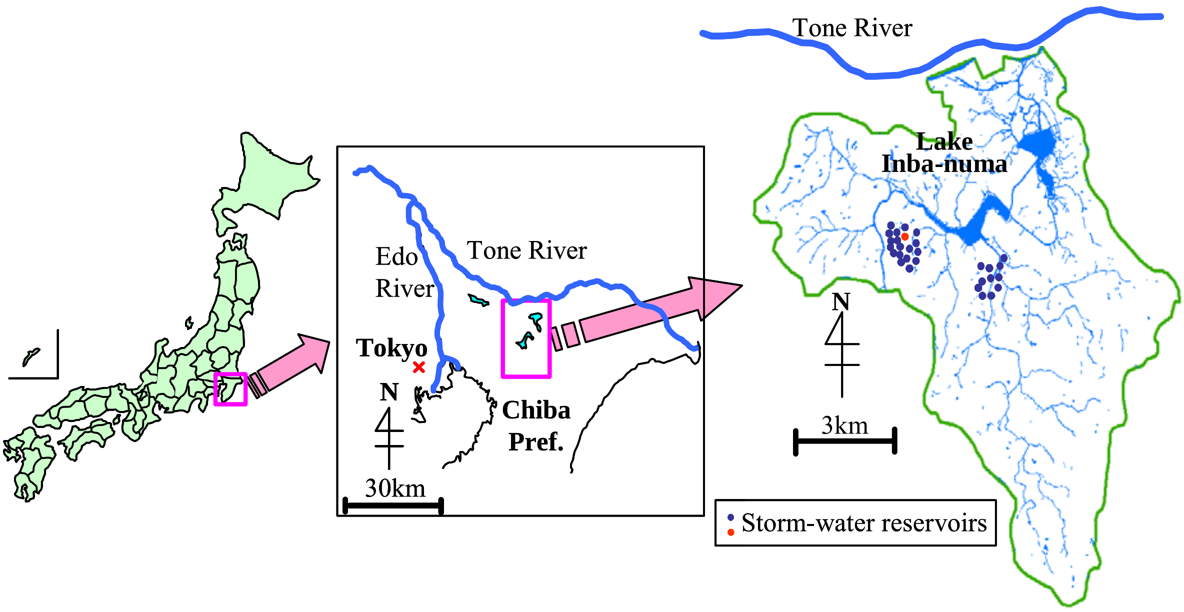

Figure 2. Location of Lake Inba-numa and field sites of 28 storm-water reservoirs. Red circle in the far right figure corresponds to the location of reservoir 1.

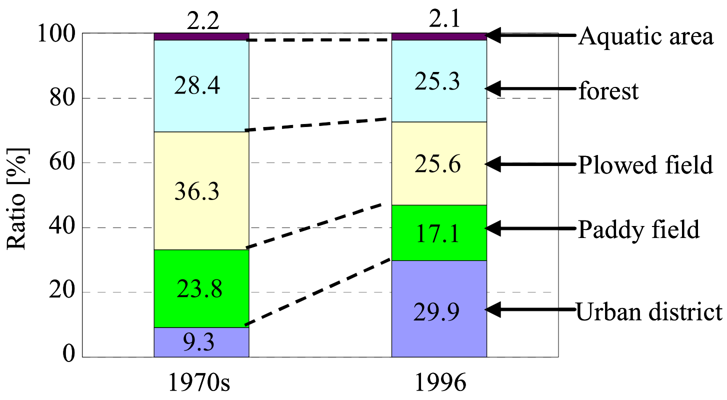

Figure 3. Trend of land use within watershed of Lake Inba-numa.

2. Outline of field measurement

2.1 Outline of Lake Inba-numa

The storm-water reservoirs chosen for the field sites are located in the watershed of Lake Inba-numa, which is located in northern Chiba Prefecture, Japan, as shown in **Fig. 2**. The surface area and average water depth of Lake Inba-numa are 11.6 km^2 and 1.7 m, respectively. The area and population within its watershed are 541 km^2 and 0.72 million, respectively. Water quality in Lake Inba-numa has become worse since the mid-1970s and hence Lake Inba-numa was recently ranked as the lake with the worst water quality among lakes which supplies water in Japan. **Figure 3** indicates the trend of land use within the watershed of Lake Inba-numa during the 1970s and in 1996. The main land use within the watershed has recently been for urban development, showing significant urban growth. Such urbanization in its watershed and the resultant increase in human activities have become the main causes for the eutrofication of Lake Inba-numa.

In urban areas, a storm-water reservoir must be constructed for flood control. Within the watershed of Lake Inba-numa, there are currently 299 storm-water reservoirs.

2.2 Method

To clarify the trap effect of the reservoirs on particulate matter of non-point sources, we collected bottom sediment deposited in 28 reservoirs and then analyzed their quality and dry weight. For field measurement, we first set a wooden square frame (1444 cm^2) on the bottom of a reservoir. Then we collected the sediment inside the frame using a shovel and brush. **Figure 4** depicts the actual procedure for collecting bottom sediment in a reservoir. After carrying the sediment samples back to our laboratory, we measured their dry weight and particle-size distribution. We also analyzed the TN and TP contained in the bottom sediment using an auto analyzer (swAAt, BL TEC K.K., Japan) based on a continuous flow analysis.

Figure 4. Actual procedure for collecting sediment deposited in a reservoir.

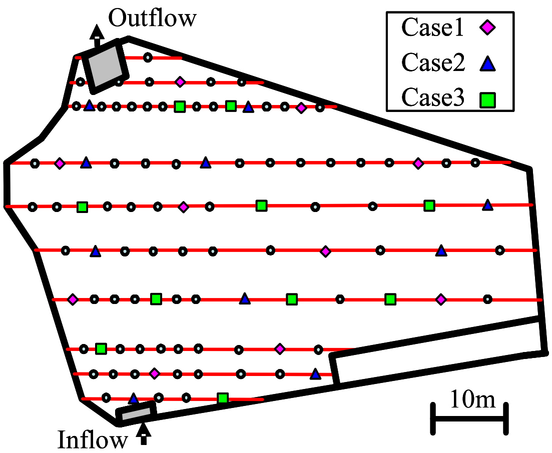

Figure 5. Locations of 100 measurement points for collecting sediment in reservoir 1.

2.3 Field sites

We conducted the above measurements in 28 reservoirs (about 10% of the reservoirs within the watershed of Lake Inba-numa), as depicted in **Fig. 2**. **Table 1** indicates the outline of each reservoir in which the period from the start of operation *T*, the bottom area A_r, and the watershed area A_w are displayed. The period and watershed area for reservoirs 17 and 18 are not listed.

Table 1. Outline of 28 reservoirs chosen for field measurement.

No.	Period T [year]	Bottom area A_r [m^2]	Watershed area A_w [km^2]
1	5	1,851	0.0296
2	27	501	0.0097
3	5	1,932	0.0287
4	17	1,375	0.4033
5	20	13,238	0.2040
6	9	2,150	0.2900
7	14	565	0.0044
8	13	935	0.0282
9	11	284	0.0125
10	11	105	0.0125
11	29	43,620	1.3480
12	8	1,314	0.0335
13	12	5,118	0.0176
14	6	1,502	0.0344
15	22	2,270	0.2290
16	24	197	0.0104
17	-	2,000	0.0773
18	4	166	–
19	15	1,205	0.0617
20	9	143	0.0076
21	12	62	0.0020
22	15	50	0.0042
23	15	91	0.0070
24	13	145	0.0275
25	13	74	0.0040
26	10	134	0.0072
27	10	110	0.0053
28	6	213	0.0422

For the measurement in reservoir 1, we collected bottom sediment at 100 points over the entire reservoir, as depicted in **Fig. 5**, to obtain detailed spatial distributions of the sediment in a reservoir. Since it would have been quite difficult to collect sediment at 100 points for all 28 reservoirs, we evaluated the total amount of sediment from the observed data at 10 points arbitrarily chosen from the 100 points. As shown later, the measurements at these 10 points are reasonably accurate. For the measurements in the other 27 reservoirs, therefore, we collected the bottom sediment at only 10 points. The measurements in reservoir 1 were conducted in 2006 and in the other were conducted in 2007.

To directly clarify the trap effect of non-point source pollutants in reservoirs, we also conducted field measurements for the inflow and outflow fluxes of pollutants under rainy conditions for reservoir 1. These results indicate that the reservoir functions as a trap for particulate matter of N, P and the chemical oxygen demand (COD). These results will be

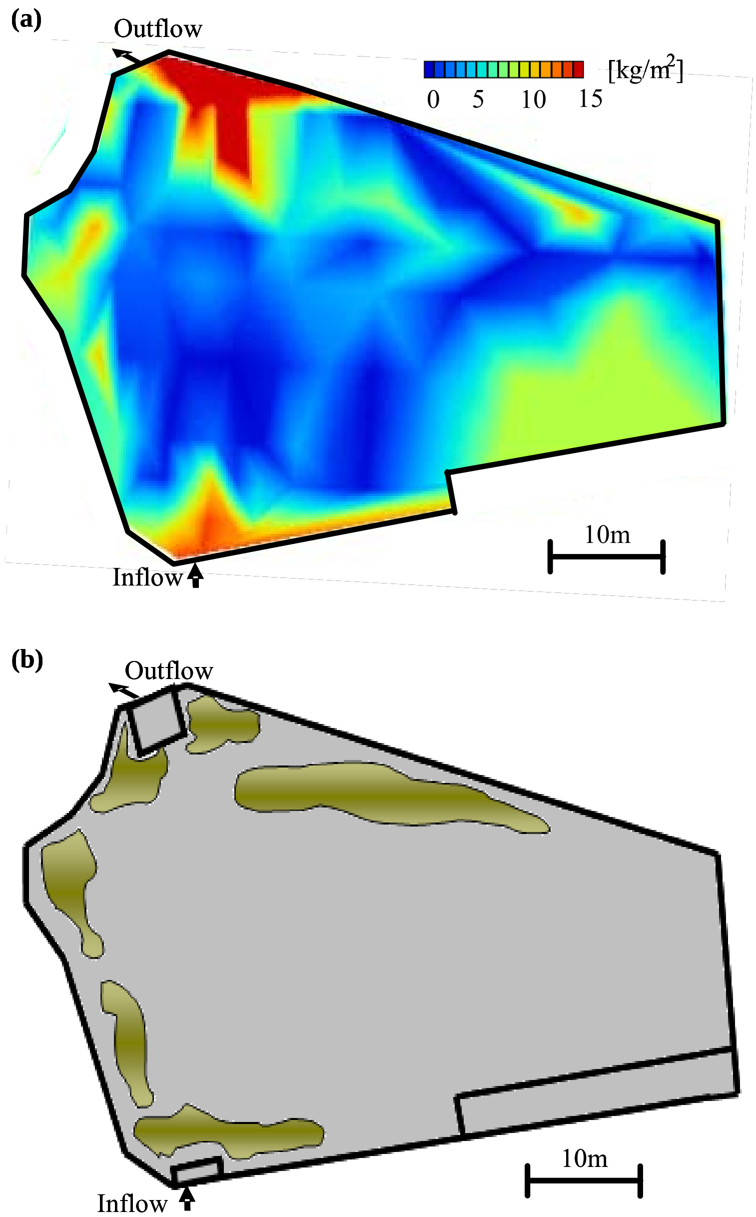

Figure 6. **(a)** Horizontal distribution of dry weight of sediment per unit area and **(b)** vegetation map in reservoir 1.

reported in the near future.

3. Measured results and discussion

3.1 Horizontal distribution of the dry weight of sediment per unit area

As for clarifying the fundamental properties of deposited sediment in the reservoir, **Fig. 6(a)** indicates the horizontal distribution for the dry weight of sediment per unit area in reservoir 1, in which there were 100 measuring points as stated above. The results show considerable spatial variations of the deposited sediment in the reservoir. Most of the sediment transported from the watershed was deposited near the inflow and outflow regions of the reservoir. In particular, the maximum dry weight of sediment appeared near the outflow exit. Also note that a relatively larger dry weight, excluding the inflow and outflow regions, was locally observed.

As for examining the cause of the spatial non-uniformity of the deposited sediment, a vegetation map in reservoir 1 is shown in **Fig. 6(b)**. The vegetation is located not only near the inflow and outflow regions, but also near the side-wall boundary. The comparison of **Figs. 6(a)** and **6(b)** shows that the dry weight of sediment per unit area is almost as large in the vegetation areas. Since vegetation has a significant role of fluid drag, the non-uniformity of sediment distribution is mainly related to the spatial profile of vegetation inside the reservoir.

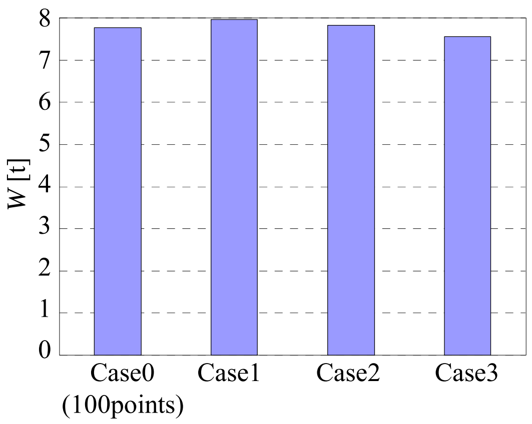

Figure 7. Total dry weight of sediment in reservoir 1, W_s, evaluated with Case 0 (100 points) and Cases 1-3 (10 points).

3.2 Effect of measurement points on evaluation of the total weight of sediment

To check the effect of the number of measurement points on evaluation for the total dry weight of sediment, W_s, in the reservoir, we calculated W_s using the observed data from the 100 points in reservoir 1. For this purpose, we selected samples from 10 out of the 100 points. As shown in **Fig. 5**, we set three cases each with 10 points selected from the total 100 points.

Figure 7 illustrates the total dry weight of sediment W_s evaluated in the 3 cases and in Case 0, in which the all samples at 100 points were used. The total dry weight of sediment in reservoir 1 was 7.8 t in Case 0. In contrast, the results evaluated with samples at 10 points (Cases 1, 2, and 3) reveal that the values of W_s were 8.0, 7.8 and 7.6 t, respectively. The differences of W_s between Case 0 and the other cases were less than 10% of W_s. This fact indicates that the total dry weight of sediment W_s obtained from only 10 samples is similar to those from all 100 samples.

3.3 Deposition rate of sediment and particle-size distribution in all reservoirs

Figure 8 indicates the relationship between the deposition rate of sediment (=W_s/T) and the bottom area A_r in all reservoirs. The results show that the deposition rate of sediment roughly increases with the bottom area. The approximation between W_s/T and A_r is expressed as

$$\frac{W_s}{T} = 2.0 * 10^{-5} A_r^{\ 1.41}, \qquad (1)$$

where the units of W_s/T and A_r are t/year and m^2, respectively. The correlation coefficient between them is 0.840, showing that we can approximately evaluate the deposition rate of sediment in reservoirs from the bottom area of each reservoir. It should be also noted that the factor of the power function in Eq. 1 is larger than the unity, showing that reservoirs with larger bottom areas (or capacities) may trap a larger amount of sediment from non-point sources mainly because of the increase of the retention time of storm water.

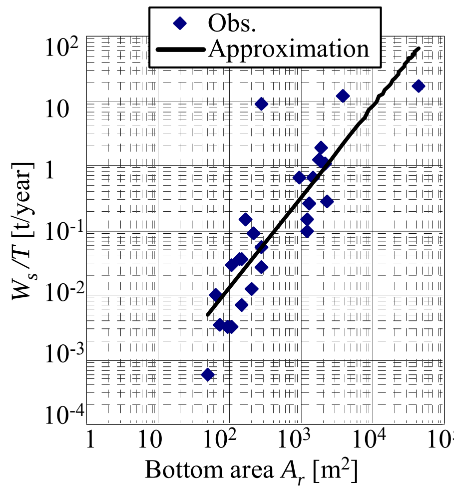

Figure 8. Relationship between deposition rate of sediment (=W_s/T) and bottom area A_r.

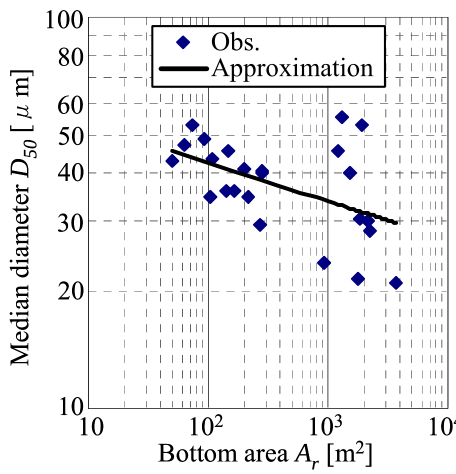

Figure 9. Relation between median diameter of sediment D_{50} and bottom area A_r.

As for the examination of the particle-size distribution of the bottom sediment in the reservoirs, **Fig. 9** reveals the relationship between the median diameter of particles D_{50} and the bottom area A_r. The median diameter of particles ranged from 20 to 60 μm. Note that the trend of the median diameter of particles decreases gradually with the bottom area. Since the retention time in reservoirs increases with the bottom area of reservoirs, the finer particles of non-point sources may be trapped in the reservoirs with a larger bottom area.

3.4 Trap effect of non-point sources in the reservoirs

As for the quantitative examination of the efficiency of the reservoirs on the reduction of non-point sources, **Fig. 10** shows the deposition rates of SS, TN and TP per unit watershed area vs. the bottom area. The deposition rates of SS, TN and TP are described as W_s, W_N and W_P, respectively. The solid lines in the figure depict the effluent unit loads for SS, TN and TP, directly measured in the urban area close to

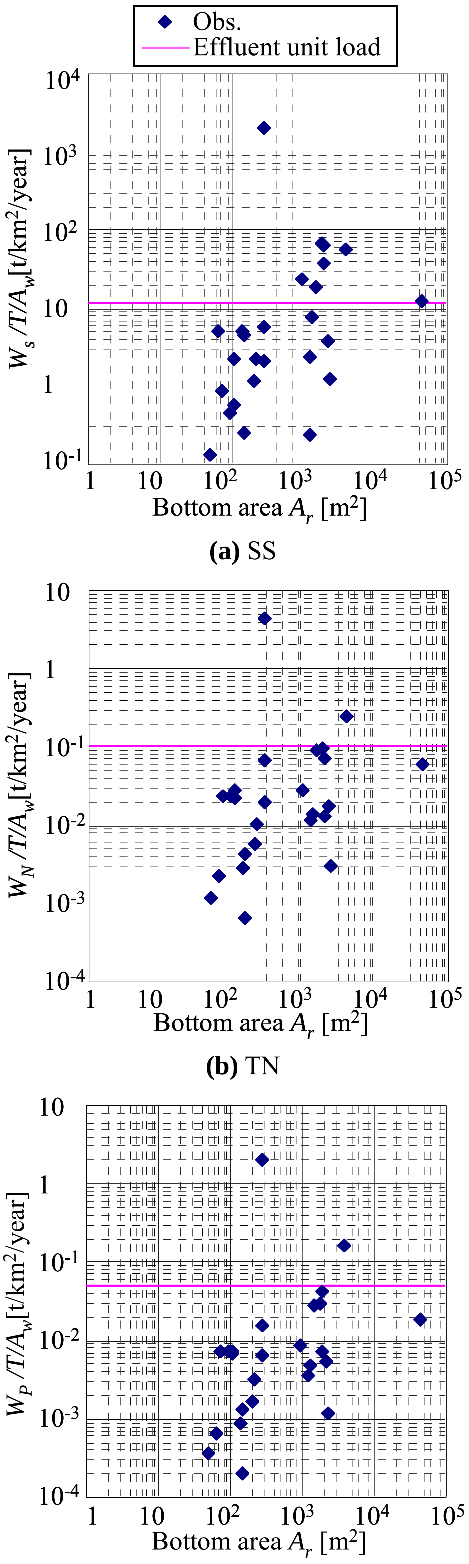

Figure 10. Deposition rates of sediment per unit watershed area vs. bottom area.

reservoir 1. The deposition rates of SS, TN and TP per unit watershed area increase roughly with the bottom area, which corresponds to the tendency of W_s/T shown in **Fig. 8**. The most important point in **Fig. 10** is that the deposition rates per unit watershed area are comparable to the corresponding effluent unit loads in most of the reservoirs. This fact demonstrates that the reservoirs have function for trapping the particulate matter of non-point sources.

Finally we evaluated the trap effect of the reservoirs in the overall watershed of Lake Inba-numa. **Table 2** indicates the effluent TN and TP loads of non-point sources in the overall watershed of Lake Inba-numa and the trap of the TN and TP loads in all reservoirs in the watershed. The effluent TN and TP loads were evaluated with a general approach of effluent unit load. The trap of TN and TP loads in the 28 reservoirs is given as the observed data. In the other reservoirs, the trap of TN and TP loads was evaluated using Eq. 1, the bottom area of each reservoir and the observed sediment qualities of TN and TP. The results indicate that the reduction effects of TN and TP loads with all reservoirs were 1.0% and 8.4% of the non-point source pollutants generated within the watershed of Lake Inba-numa, respectively. The total area of the all reservoirs within the watershed covers only 9% of the total watershed area. This fact demonstrates that storm-water reservoirs may significantly reduce non-point sources transported from urban areas.

Table 2. Ratio of reduction of the TN and TP loads in all reservoirs to effluent load in the total watershed of Lake Inba-numa (Unit: t/year).

	Effluent load of NPS ***A***	Trap in all reservoirs ***B***	Ratio [%] ***B/A***
TN	741.3	7.7	1.0
TP	27.7	2.3	8.4

4. Conclusions

We examined the function of a storm-water reservoir for reducing particulate matter of non-point sources through field measurements for quality and dry weight of bottom sediment in 28 reservoirs located within the watershed of Lake Inba-numa, a well-known eutrophic lake in Japan as field sites.

The results reveal that the dry weight of the bottom sediment in the reservoirs increases with the bottom area of the reservoirs mainly because of the increase in the retention time of storm water. The deposition rates of SS, TN and TP of bottom sediment in the reservoirs are comparable to unit effluent loads on SS, TN and TP measured in the urban districts close to the reservoir. The reduction effects of TN and TP of all the reservoirs within the watershed of Lake Inba-numa were 1.0% and 8.4% of the non-point source pollutants generated in the overall watershed, respectively. These facts indicate that storm-water reservoirs may reduce significantly non-point sources.

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