PRESENT STATUS OF WATER QUALITY IN JAPANESE DAM LAKES AND WATER QUALITY PRESERVATION MEASURES

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Abstract

The water in the dam lake is laid still and motionless with a flat surface to stop it from flowing. Therefore, their existences change water environment and affect water quality. To avoid water quality problem, effective water quality management in dam lakes are important, and appropriate countermeasures should be applied based on understanding of features or mechanisms of water problem in dam lakes. In this paper, we assembled and analyzed water quality data of major 77 dam lakes in Japan. We also described and analyzed implementation status and efficiency of each countermeasure. As a result, (1) we obtained distribution and modal value of each water quality item, (2) we described general tendency of accumulation (e.g. T-P at high concentration range) and generation (e.g. T-N, COD and BOD) in major dam lakes in Japan, (3) we summarized implementation status and performance of countermeasures for eutrophication, cold water problem and long term persistence of turbid water.

Keywords: dam lake, water quality, countermeasure, eutrophication

1. Introduction

Dam lakes generally have a tendency to cause water quality problems, because dam lakes are dead water areas, which were created by damming natural river (Japan Commission on Large Dams, 2006). For example, water temperature characteristic is changed by storing. It may cause cold water problems to downstream environment or ecosystem, if proper water withdrawal was not conducted. Water storing also causes accumulation of organic materials and nutrients. This accelerates eutrophication, which appears to be unavoidable problem for most of dam lakes.

As of March 2007, there are 2702 dams all over Japan (Japan Dam Foundation, 2008). As constructed dams have been increased, quantity of water resource has been satisfied in most of places. On the other hand, people's interest or demand concerning water quality has been increased recently.

To solve or alleviate water quality problems, water quality management including some countermeasures in dam lakes are necessary. Appropriate selection, application and operation of countermeasures are primarily necessary, and these issues must be discussed based on understanding of not only general features and mechanism of water quality in dam lake but also specific feature and position of objective dam lake. This must be achieved by comparing many other dam lakes and examining the results.

In Japan, some sorts of water quality preservation measures have been developed and applied for the purpose of effective water quality management (Ushijima et al. 2007). Data or information, concerning status of implementation or efficiency of countermeasures, have been stored and analyzed at each dam lake. However, comparison with each other has not been carried out enough. It is important that these sets of data or information are assembled from all over Japan and analysed also.

In this paper, we described present status of water quality in Japanese major dam lakes based on the analysis of data collected from all over Japan. We collected and analyzed on implementation status of water preservation measures and their effect. Following to the results, we discussed on present methods or techniques, which need improvement.

2. Materials and method

We focused on dam lakes, which have relatively large capacity in Japan. Most of Japanese 2,702 dam lakes are small irrigation dams. On the other hand, only 106 dam lakes, which were constructed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) or Japan Water Agency (JWA), hereinafter collectively called as "major 106 dam lakes", are occupying 23% of total capacity of all dam lakes in Japan. Seventy seven of major 106 dam lakes have available data as a periodic report based on "Follow-up institution of dam lakes". We call these 77 dam lakes as "targeted 77 dam lakes" hereinafter.

According to follow up institution, which started full application at 2003, each dam management officer is required to make periodic report every 5 years. First 5 years, year of 2003 to 2007, 10 to 20 dams were applied every year, and now it has been 2nd cycle. In this study, we collected original data of periodic report, which were published from 2003 to 2007.

We selected and abstracted common data for every dam lake as possible. Fundamental data set was abstracted form results of monthly monitoring. This include water temperature, BOD, COD, SS, Coliform group count, Chlorophyll-a, Total Nitrogen and Total Phosphorus for each inflow river, downstream river and surface water in dam lake. Time-frame is set from 1998 to 2002, because most of report covers these 5 years. As additional to these, we read out the report and aggregated status of water quality problem, implementation status of water quality preservation measures, and efficiency of each countermeasure.

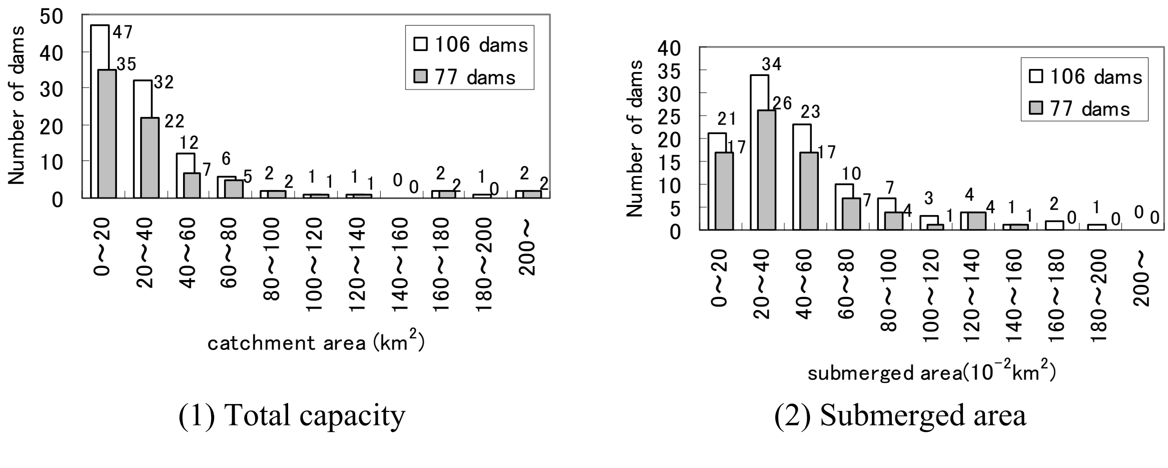
3. Water quality of Japanese dam lakes

3.1 Summary of targeted dam lakes

Figure-1 shows total capacity and submerged area of major 106 dam lakes and targeted 77 dam lakes. Distribution pattern is almost same between both groups. Followings are tendency of targeted 77 dam lakes. Sixty-five percent of them have a total capacity of less than 60million m^3 (Fig.1(1)). The largest one is Sameura dam lake, with total capacity of 316million m^3. Tokuyama dam lake has a largest capacity in Japan (as of July 2008, the total capacity is 660million m^3), however it is not included in targeted 77 dam lakes because it has been completed 2007 and they have few data. Seventy-four percent of targeted 77 dam lakes have submerged area of less than $3km^2$. The largest is $7.5km^2$ at Sameura dam lake.

3.2 Summary of water quality

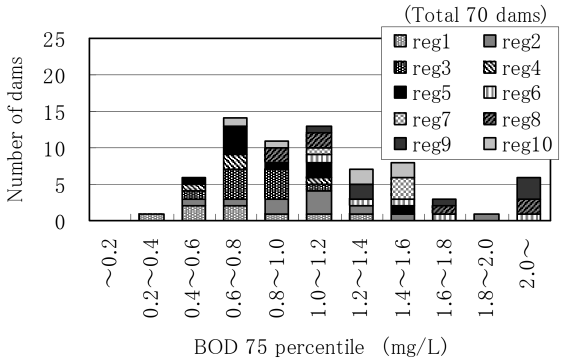
Figure-2 (1) to (8) show distribution of averaged water quality at surface of dam lake. These graphs include 67 to 70 of targeted 77 dam lakes, which have data of more than 3 years in the targeted 5 years, 1998 to 2002. Region1 to 10 are corresponding to regions shown on



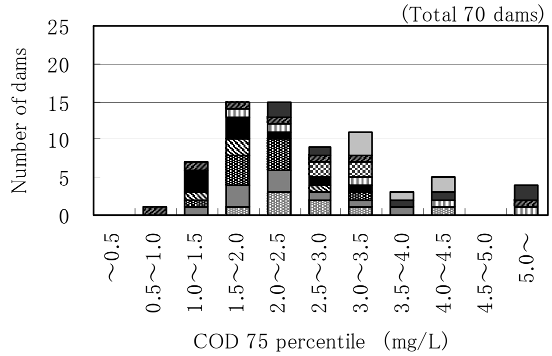
(1) Total capacity

(2) Submerged area

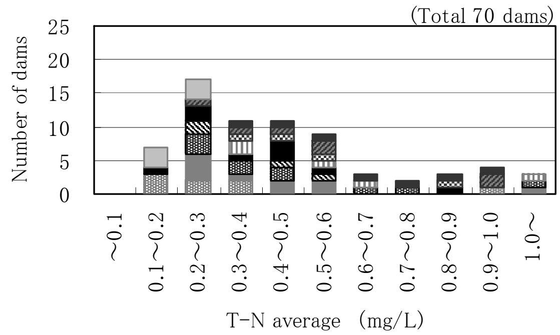
Figure-1 Features of targeted dam lakes



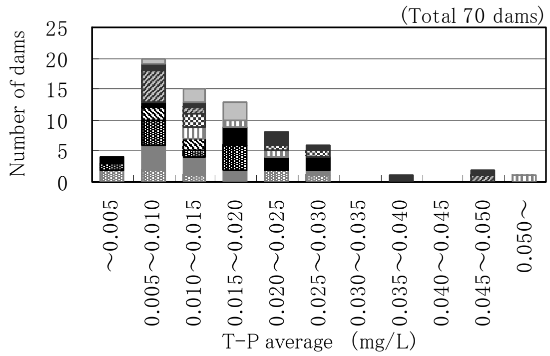
(1) BOD



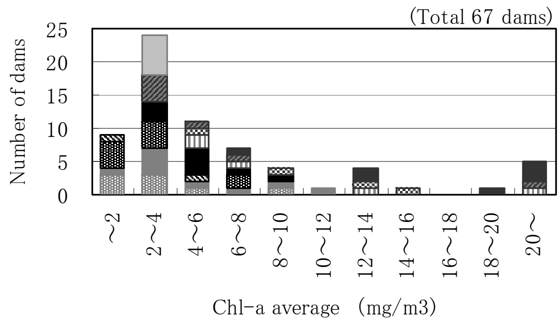
(2) COD



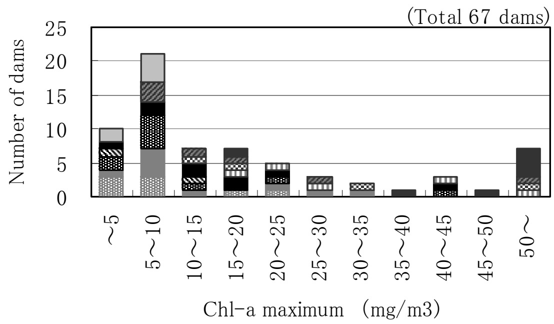
(3) Total Nitrogen



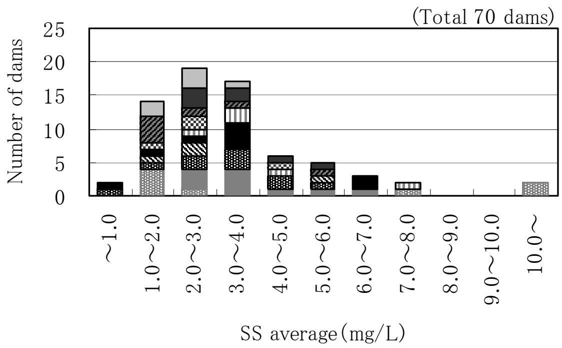
(4) Total Phosphorus



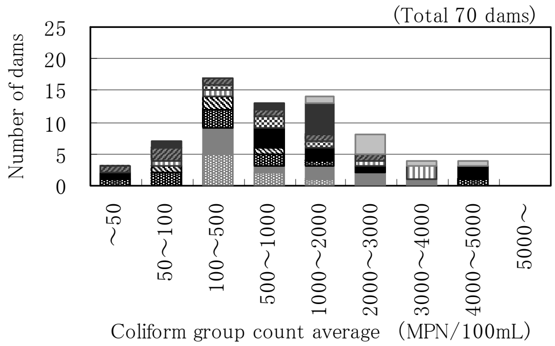
(5) Chlorophyll-a



(6) Chlorophyll-a (max)



(7) Suspended solid



(8) Coliform group count

Figure-2 Water quality at surface water of dam lake

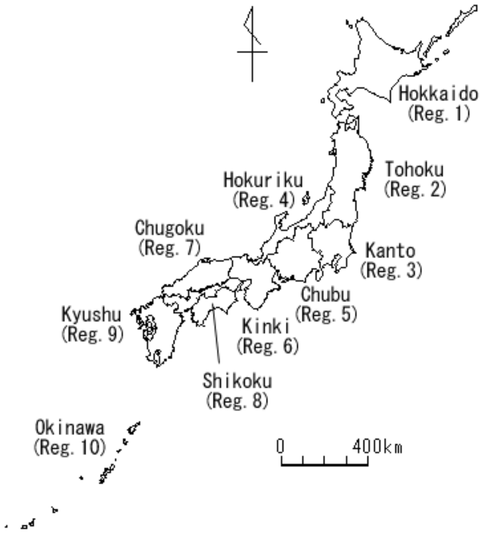


Figure-3 Regions in Japan

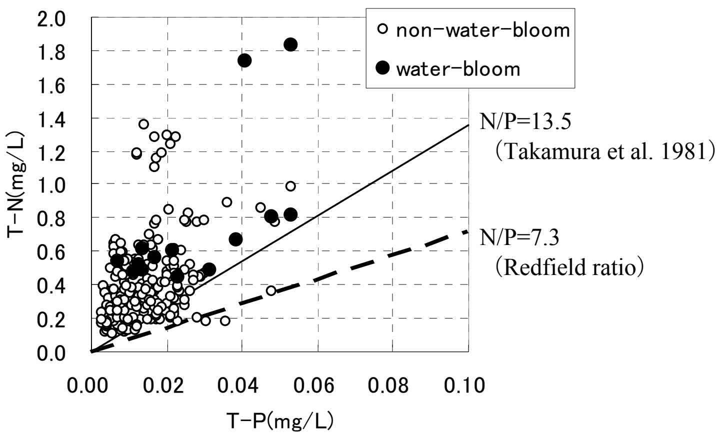


Figure-4 N/P ratios at surface water of dam lakes

Table-1 Modal level of water quality at dam lakes in Japan

	Modal level	Unit
BOD	0.6 – 1.2	mg/L
COD	1.5 – 2.5	mg/L
Total Nitrogen (T-N)	0.2 – 0.3	mg/L
Total Phosphorus (T-P)	0.005 – 0.010	mg/L
Chlorophyll-a	2 – 4	mg/m^3
Chlorophyll-a (max)	5 – 10	mg/m^3
Suspended solid (SS)	2.0 – 3.0	mg/L
Coliform group count	100 – 2,000	MPN/100mL

figure-3. All distributions on figure-2 show one or approximately one peak shape. Table-1 shows modal range of each item. In case it has 2 peaks, modal range on table-1 is covering 2 or 3 range groups, which include both peaks.

3.3 Evaluation with eutrophication indicators

(a) N/P ratio

Some favourable N/P ratios for phytoplankton have been reported. Sixteen (mol/mol), equivalent to 7.2 (kg/kg), is known as Redfield ratio led from marine phytoplankton (Water

Resources Environment Technology Center, 2006), and it is often used as rough indicator. Regarding to freshwater phytoplankton, Takamura et al.(1981) reported 13.5 (kg/kg) as an actual measured N/P ratio of *Microcystis* cells. Figure-4 shows N/P ratio distribution of surface water at 58 of targeted 77 dam lakes, which is not implementing countermeasure for eutrophication, from 1998 to 2002. Black dots show the cases which took place eutrophic phenomena, and white dots show the cases without eutrophication effect.

Comparing with reported N/P ratios and plotted data, most of dam lakes are possessed on higher range of N/P ratio. In these dam lakes, phosphorus appears to be restricting factor. On the other hand, we cannot find clear difference between distributions of eutrophication-experienced dam lake and non-experienced dam lake as long as in this figure.

(b) Evaluation with OECD's categorization

OECD (1982) shows some boundary values concerning eutrophication status for phosphorus, chlorophyll-a and so on (table-2). Following to this categorization, modal values (on table-1) of phosphorus, averaged-chlorophyll-a and maximum-chlorophyll-a are categorized as "oligotrophic", "oligotrophic or mesotrophic", and "oligotrophic or mesotrophic", respectively. Figure-5 shows distribution of averaged phosphorus concentration of each dam lakes and OECD's categorization boundaries. Only 4 dam lakes categorized as "eutrophic", and 43 as "mesotrophic", 24 as "oligotrophic". On the other hand, water-bloom is one of important problem caused by eutrophication, however, not a few dam lakes, which are categorized mesotrophic or oligotrophic, have experienced water-bloom (fig.-5).

c) Vollenweider's model

We evaluated eutrophication possibility of targeted 77 dam lakes with Vollenweider's model, which is often used for simple prediction on eutrophication (Arita et al.). Figure-6 shows the results. Record of water-bloom occurrence is also shown in this graph as a typical

Table-2 Boundary values for trophic categories by OECD (mg/L)

Trophic Category	Phosphorus (average)	Chlorophyll-a (average)	Chlorophyll-a (maximum)
Ultra-oligotrophic	< 0.004	< 0.0010	< 0.0025
Oligotrophic	< 0.010	< 0.0025	< 0.0080
Mesotrophic	0.010 – 0.035	0.0025 – 0.008	0.008 – 0.025
Eutrophication	0.035 – 0.100	0.008 – 0.025	0.025 – 0.075
Hypertrophic	> 0.100	> 0.025	> 0.075

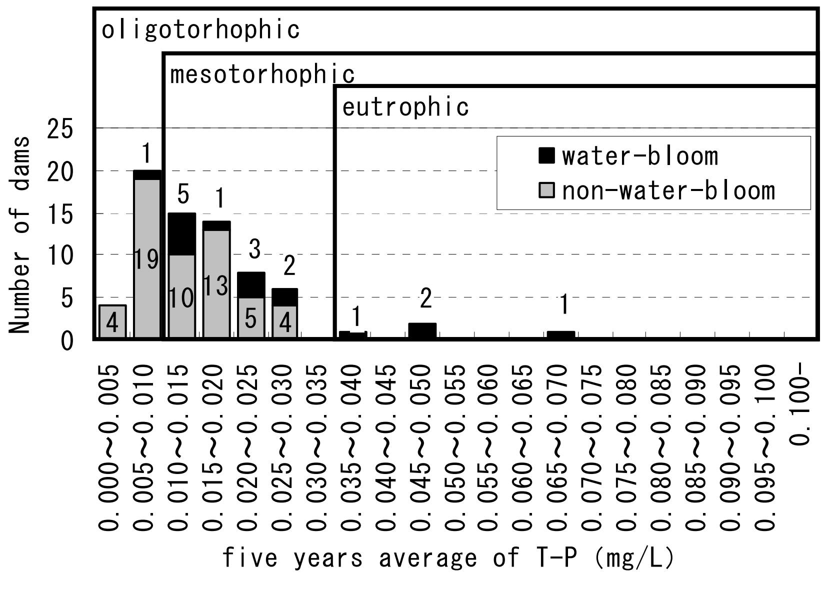


Figure-5 Eutrophic level evaluation with OECD standard and actual condition phenomenon caused by eutrophication. Black dots show cases of water-bloom experienced and circles show cases of non-experienced.

Many of water-bloom-experienced cases were plotted on the area of "high possibility to eutrophication" or near the boundary of eutrophic and mesotrophic. However, most data including water-bloom-non-experienced are possessed near the boundary, and it appears to be difficult to predict actual phenomenon caused by eutrophication, such as water-bloom, with high accuracy by vollenweider's simple model.

3.4 Changes of water quality by passing through dam lakes

We compared water quality of inflow river and downstream river to understand water quality change by passing through dam lakes. Figure-7 (1) to (8) show comparison of each water quality at inflow point and downstream. Total nitrogen (T-N) concentrations are almost the same between inflow and outflow (fig.-7 (3)). However, downstream exceeds inflow a little in low concentration range and they are scattering in high concentration range. T-N appears basically pass through dam lakes, but there are some phytoplankton species, which can utilize nitrogen in air and they may cause increase of nitrogen in dam lakes.

Total Phosphorus (T-P) concentrations are also almost the same in low-concentration range, but inflow is higher in high-concentration range (fig.-7(4)). Generally, high concentration of T-P is observed in flood term, with high turbidity. Phosphorus provided with turbid substances would be deposited with turbid substances in dam lakes. As a result, inflow is higher than downstream at high concentration range. On the other hand, suspended solid become high while flooding, however, figure-7(7) show scattering result and does not show clear tendency such as phosphorus.

BOD and COD show tendency that downstream is higher than inflow (fig.-7(1) and (2)). Chlorophyll-a also show same tendency even though comparatively scattering. These seem to be caused by primary production, such as growth of phytoplankton. Coliform group count of inflow river exceeds downstream (fig.-7(8)). Coliform group count sometimes show higher value in middle or bottom layer in dam lakes. Under low flow rate condition, such as inside of dam lake, coliforms may be deposited.

4. Water quality problems and countermeasures

We sorted data of targeted 77 dam lakes by kind of water quality problem, countermeasure implementation, and evaluation of its efficiency.

4.1 Eutrophication

Figure-8 shows summary of water quality problems based on periodic reports. Seventy one percent (55 dam lakes) experienced effect of eutrophication, such as water bloom. And, 84% of these dam lakes (46 dam lakes) reported some sort of suffering.

Forty five percent of 55 dam lakes, which took place eutrophic phenomena (25 dam lakes) apply some sort of measures. They

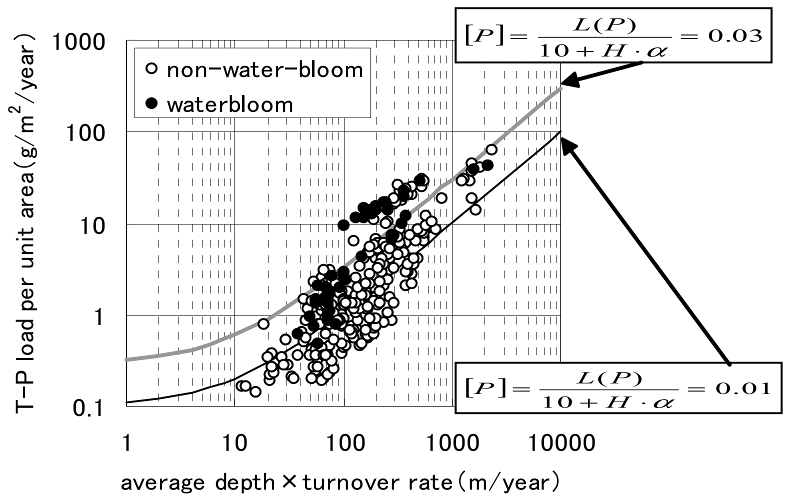


Figure-6 Estimation of eutrophication level by Vollenweider's model

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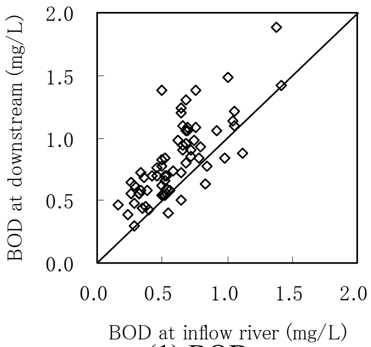
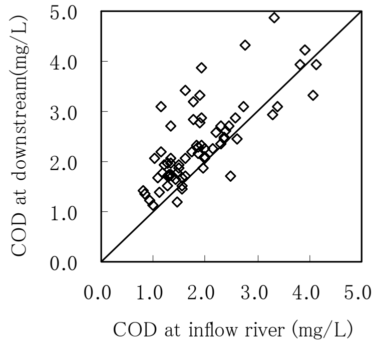
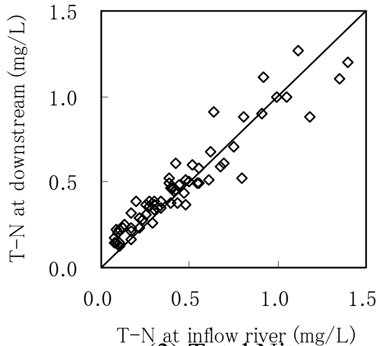


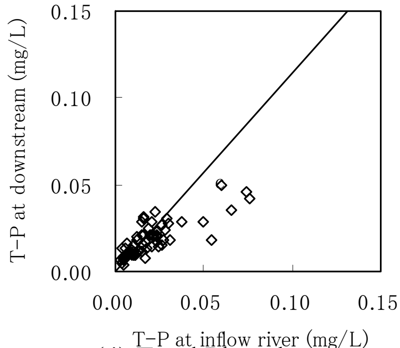
(1) BOD



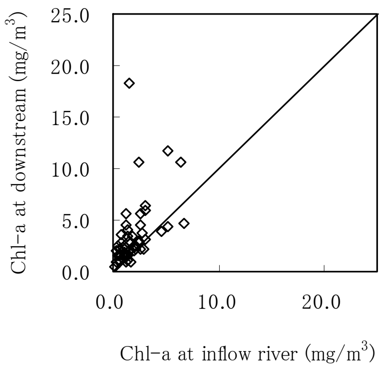
(2) COD



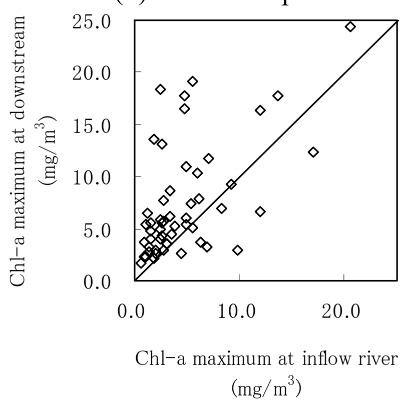
(3) Total Nitrogen



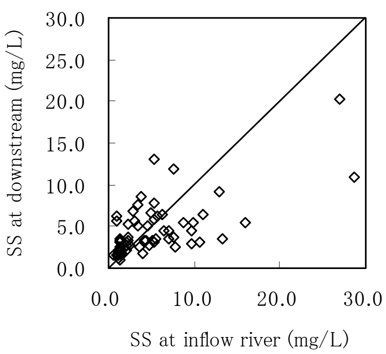
(4) Total Phosphorus



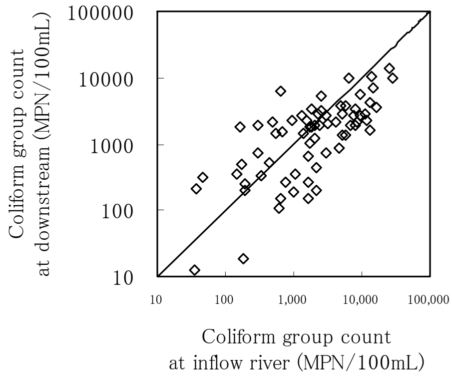
(5) Chlorophyll-a (average)



(6) Chlorophyll-a (max)



(7) Suspended solid



(8) Coliform group count

Figure-7 Water quality of inflow and downstream river

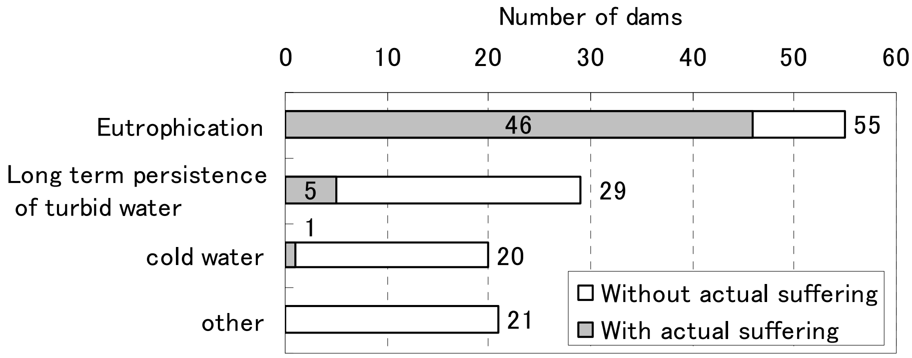


Figure-8 Type of water quality problems

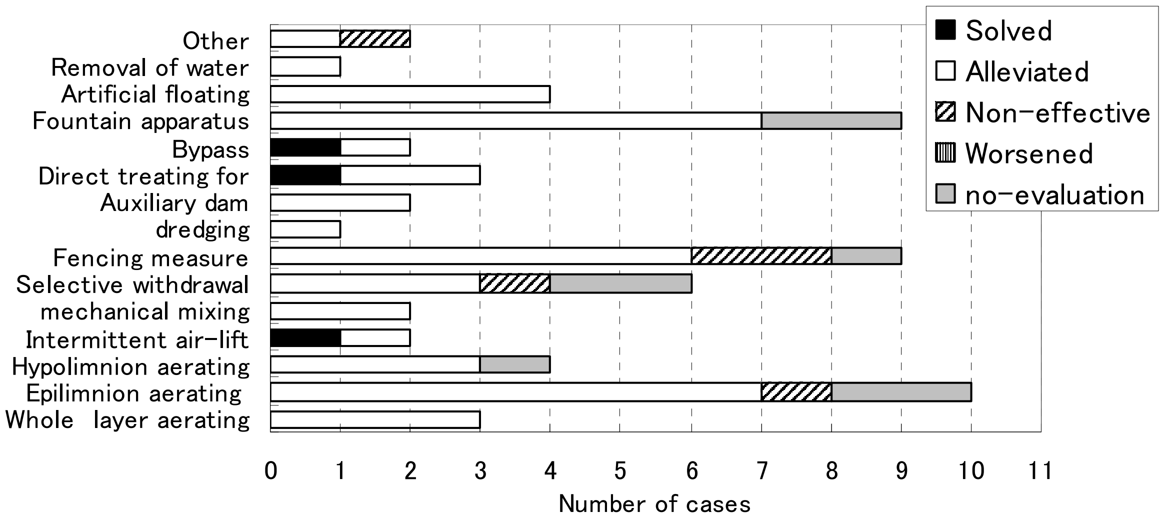


Figure-9 Countermeasures for eutrophication and their efficiency

perform as solution or alleviation for eutrophication problem at 68% (17 dam lakes). However in some cases, problems are not completely solved even though countermeasures are effective. Eutrophication is still issue to be solved in the future.

Figure-9 shows implementation status and efficiency of each countermeasure against eutrophic phenomena. "Non-effective" was reported in total 5 cases and these were reported from only 2 dam lakes, hereinafter called as A dam and B dam. A dam's countermeasure is fence facility only. B dam's counter measures include fence facility, and epilimnion aerating circulation system, selective withdrawal facility, and other. Periodic report described that these countermeasures did not show apparent effect against eutrophic phenomena in B dam lake.

Both A dam and B dam are concerning fence facility, which 9 of targeted 77 dam lakes equip. In A dam lake, they observed fence keep water bloom in the upstream side without diffusion to lake. However, regarding to the performance on all over the lake, they count that evaluation is difficult. In B dam lake, they reported that there achieved no clear difference of water bloom occurrence in dam lake before and after installing fence facility. In B dam lake, warm surface water show a tendency to stagnate at upstream side of the fence, and these stagnating water was appeared to be incubating spot of water bloom. Fence facility in B dam lake was broken by flood on August 2004, and it was removed. Fence facility is affordable because it costs not so much and does not need to operate, however it has few alternative improvement after installation if unsuspected stagnation occurred. Therefore, it is critically important to evaluate and consider on expectable effect before apply. Application manual should be prepared for appropriate assessment. Now MLIT is preparing it with collecting case studies and know-how.

4.2 Long term persistence of turbid water

With regard to this phenomenon, 38% (29 dam lakes) reported as “Experienced the effect”. However, only 17% (5 dam lakes) of these 29 dam lakes reports suffering caused by this phenomenon (fig.8).

Figure-10 shows implementation status and efficiency of countermeasures for long term persistence of turbid water. The countermeasures for this phenomenon were reported as effective in all cases except for 5 dam lakes, which carried out “no estimation”. Implementation of countermeasures in these dam lakes seems to perform for alleviating this phenomenon.

4.3 Cold water problem

With regard to this phenomenon, 26% of 77 dams (20 dam lakes) were reported as experienced. However, only 15% (3 dam lakes) of these 20 dam lakes reports suffering caused by this phenomenon (fig.8).

Figure-11 shows implementation status and efficiency of each countermeasure for cold water problems. Four of 25 cases, corresponds to 4 dam lakes (C – F dam) reported that its countermeasure “produced no effect”. All 4 dams equip selective water withdrawal facility as a countermeasure. At the C dam lake and D dam lake, selective water withdrawal facilities were equipped as countermeasures for long term persistence of turbid water also. In these cases, operation rule puts priority to long term persistence of turbid water, and sometimes they cannot avoid cold water discharge. At the E dam lake, epilimnion aerating circulation system was equipped with selective water withdrawal facility, and latter works enough but former does not have enough capacity. At the F dam lake, water is being withdrawn from surface. Warm water at surface is passed out and cold water comes on summer and autumn.

Selective water withdrawal facilities are effective measures for both long term persistence of turbid water and cold water phenomenon. There still are possibilities to improve operation with considering balance both purposes.

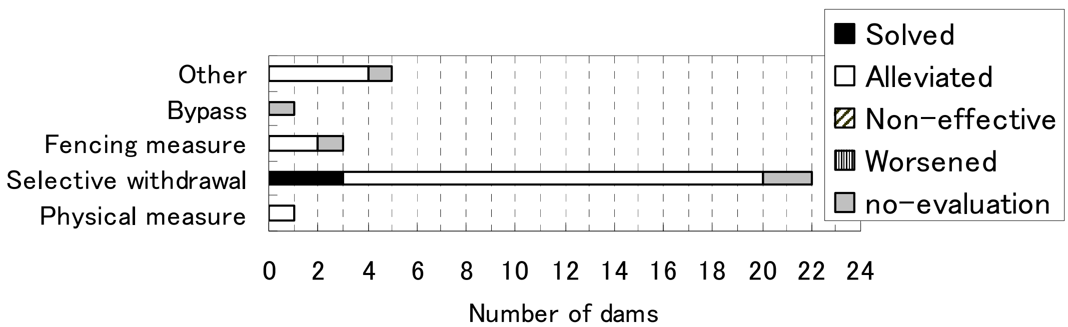


Figure-10 Countermeasures for long term persistence of turbid water and their efficiency

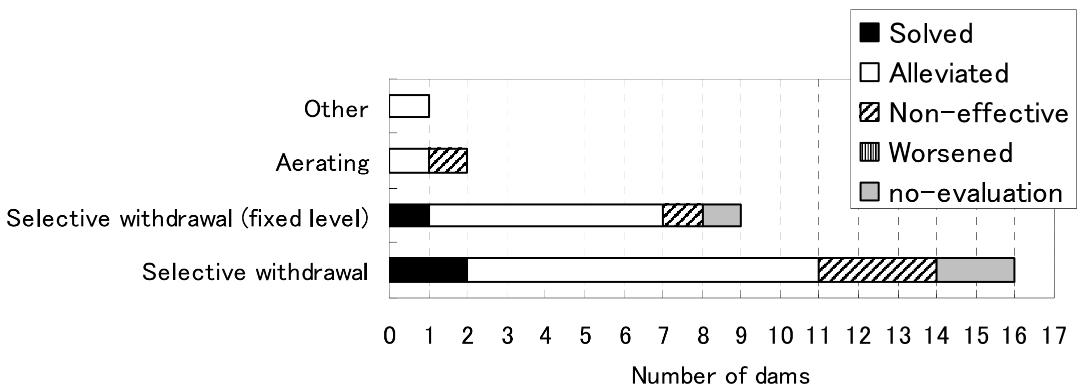


Figure-11 Countermeasures for cold water phenomenon and their efficiency

5. Conclusion

In this paper, we gathered and analysed water quality data of major dam lakes in Japan. And we also described and analyzed implementation status and efficiency of each countermeasure. Results are as follows.

- We obtained distribution and modal value of each water quality.
- In comparison of inflow with downstream, we described general tendency of accumulation (e.g. high concentration range of T-P) and increase (e.g. T-N, COD and BOD) in major dam lakes in Japan.
- As a major water quality problem, we collected and analyzed information about eutrophication, long term persistence of turbid water, and cold water. With regard to long term persistence of turbid water and cold water problem, efficiency of countermeasures were reported in many cases. On the other hand, eutrophication countermeasures are also regarded as effective in many cases, however, it still be issue to be solved in the future.

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