RESERVOIR SEDIMENTATION DATABASE AND SELECTING SUITABLE SEDIMENT MANAGEMENT OPTIONS IN JAPAN

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ABSTRACT

Approximately 3,000 dams over 15 meters in height have been constructed so far in Japan, but the total reservoir storage capacity is only 23 billion m^3. Following the widespread recognition of sedimentation problems, all dams having a storage capacity over one million m^3 have been obliged to report sedimentation progress to the authority every year since the 1980s. As of 2006, from 971 dams accounting for approximately 1/3 of all dams in Japan, annual changes in sedimentation volume and the shape of accumulated sediment were reported to the central government. It is probably only Japan that established such a nationwide survey system, and such accumulated considerably valuable records on a global basis. Based on these data, we can estimate regional or river basin scale reservoir sedimentation progress such as total storage loss and its annual speed. Classification of reservoirs both by reservoir sedimentation index and reservoir turnover index can be useful to understand the current situation and selecting suitable management options. In this paper, history of reservoir sedimentation survey in Japan is explained, and how we have established and how we are trying to effectively utilize the database is discussed.

INTRODUCTION

The sediment yields of the Japanese rivers are high due to the topographical, geological and hydrological conditions. This has consequently caused sedimentation problems to many reservoirs constructed for water resource development or flood control purposes. Under such circumstances, studies on estimation of sediment volume and countermeasures for sedimentation have been conducted for a long time.

Currently, the reservoir sedimentation management in Japan is embarking on new stages from two points of view. One is, in contrast to the emergent and local conventional countermeasures such as dredging and excavation, the active promotion of introduction of sediment flushing using sediment flushing outlets and sediment bypass systems, which aim at radically reducing the sediment inflowing and deposition. Unazuki dam and Dashidaira dam on the Kurobe River (e.g. Sumi and Kanazawa 2006, Sumi et al. 2009, Kantoush et al. 2010), and Miwa dam on the Tenryu River (e.g. Sumi and Kantoush 2011a, Sumi et al. 2012) and Asahi dam on the Shingu River (e.g. Fukuroi 2012) are advanced examples of using sediment flushing and sediment bypass techniques, which are placed as permanent measures for sedimentation at dams.

The other is, considering a sediment movement zone from mountains through coastal areas, the initiation of a comprehensive approach to recover a sound sediment transport in the sediment routing system. However, these advanced techniques for sediment

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management aiming at long life of dams have only been applied to a limited number, and therefore continuous study is required. It is also important to solve the social issues, such as consensus building on the need for sediment management throughout the basin people, establishment both of legal system and cost allocation system. In this paper, history of reservoir sedimentation survey in Japan is explained, and how we have established and how we are trying to effectively utilize the database is discussed.

PRESENT STATE OF RESERVOIR SEDIMENTATION GUIDELINE IN JAPAN

History of guidelines on reservoir sedimentation design can be summarized as follows.

1) Dam Design Guideline by the Ministry of Interior in 1936 did not describe any information on reservoir sedimentation.

2) Design and Research Conclusion of Gravity Dam in 1939-1943 by the Japan Energy Council, the Japan Electric Generation and Transmission Company and the Committee on Dam Design.

3) Design Standard of Agricultural Land Improvement Project in 1954 indicated design value for sedimentation depth base on the location in the river basin, reservoir water depth and storage volume.

4) Technical Criteria for River Works by the Ministry of Construction in 1958 indicated that necessary volume for reservoir sedimentation is 100 years and showed some examples of recorded specific sediment yield rate ranging from 25 to 600 $m^3/km^2/yr$.

5) Technical Criteria for River Works: Practical Guide for Planning by the Ministry of Construction in 1976 showed updated examples of recorded specific sediment yield rate ranging from 49 to 5,257 $m^3/km^2/yr$. 100 years sedimentation volumes has been also described but some exceptions in special case where sediment can be discharged through spillways or excavated periodically were also accepted.

6) Design Standard of Agricultural Land Improvement Project in 1981 indicated design sedimentation volume for designing allocation of reservoir storage volumes, calculating upstream flood water level and defining sedimentation depth for dam stability analysis. Tentative specific sediment yield potential map was introduced.

Technical Criteria for River Works: Practical Guide for Planning by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (hereafter MLIT) in 2005 is describing necessary storage capacity for sedimentation as follows.

Normally the sediment deposition estimated for the next 100 years is used as the storage capacity for sedimentation. However, the design sediment storage can be reduced in the case of a facility that flows sediment from a flood spillway, one that removes inflow sediment in the reservoir, or other facilities for which special measures have been implemented.

Regarding reservoir sedimentation database, the first guideline was released in 1966 and 1967 to collect necessary information on riverbed aggradation in order to prevent flooding risks upstream of reservoirs caused by sedimentation. In 1982, more detailed guideline was released which all dams having a storage capacity over 1 million m^3 are obliged to report sediment condition to the Ministry of Construction every year. Data includes measured sedimentation volume both in dead storage (B), lower than L.W.L., and active storage (A), between N.W.L. and L.W.L., volumes described in Figure 1.

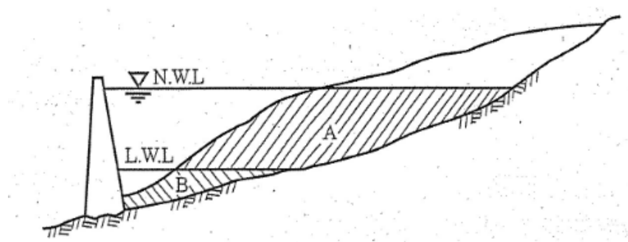

Figure 1. Definition of sedimentation in (B) dead and (A) active storage volumes.

As of 2006, from 971 dams accounting for approximately 1/3 of 3,000 dams over 15 meters in height, annual changes in sedimentation volume and the shape of accumulated sediment were reported. It is probably only Japan that established such a nationwide survey system, and such accumulated data is regarded as considerably valuable records on a global basis.

Figure 2 shows characteristics of those dams regarding years after completion, purposes of dams and total storage volumes. Many dams are listed after the 1950s and storage volumes are mainly less than 10 million m^3.

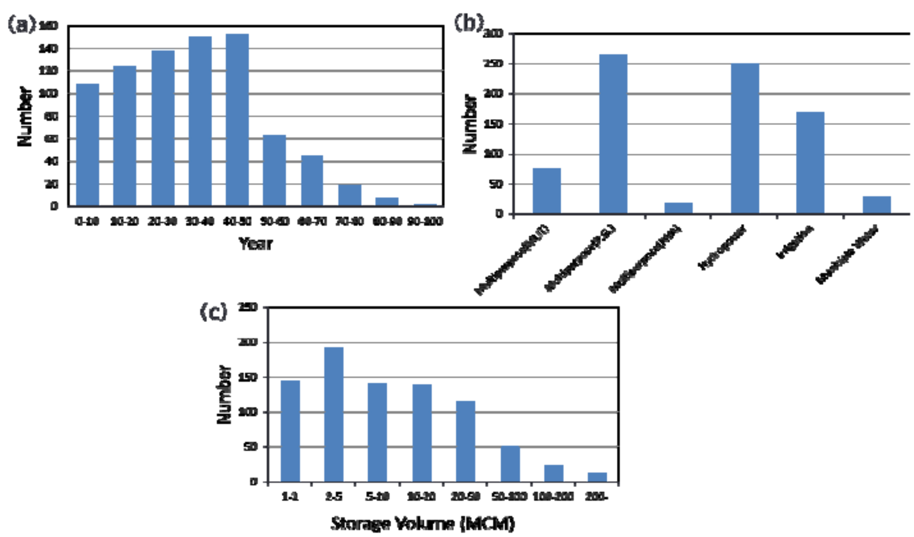

Figure 2. Dams of reservoir sedimentation database.
(a)Years after completion, (b)Purposes of dams and (c)Total storage volumes.

Figure 3 shows reservoir storage losses by sedimentation depend on regions and categories based on purposes. Regions are illustrated in Figure 4. Hydropower dams show higher ones because they were mainly constructed before the 1960s and have longer operation records. Dams in Chubu region is showing higher one because major tectonic lines are passing where a large amount of sediment is produced.

Figure 4 shows storage loss by sedimentation of each multipurpose dam belongs to MLIT, prefectural government and Japan Water Agency (JWA). Expected reservoir life (CAP/MAS) of almost dams is ranging more than 200 years but some dams are very short. Several countermeasures such as sediment flushing, sluicing or bypassing have been already taken in these dams.

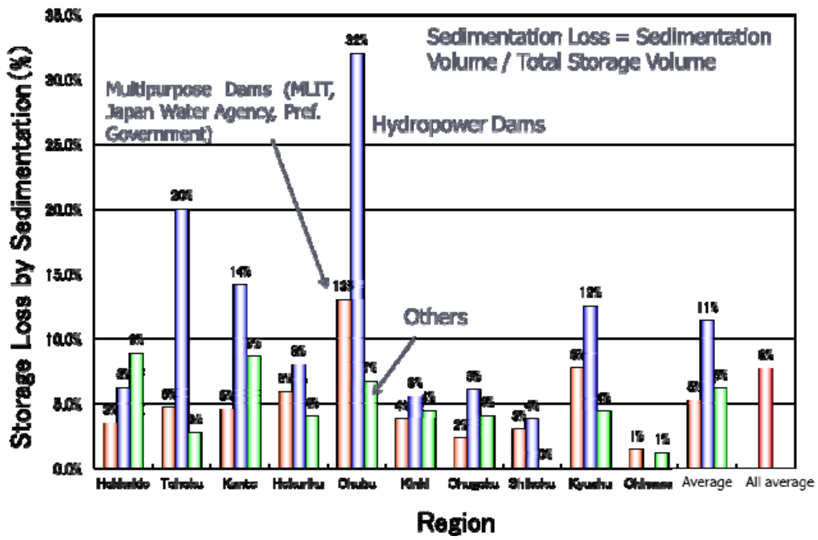

Figure 3. Reservoir storage loss by sedimentation in all regions in Japan.

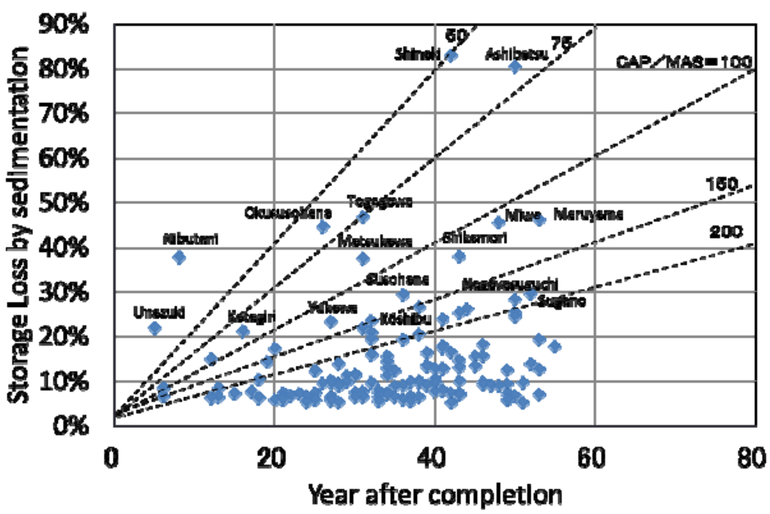

Figure 4. Reservoir storage loss by sedimentation in multipurpose dams.
(MLIT, Pref. Government and Japan Water Agency)
(CAP: Reservoir Total Storage Capacity, MAS: Mean Annual Sediment Inflow)

Figure 5(a) shows actual specific sediment yield of dams belong to MLIT. Some dams in Chubu region are more than 2,000 $m^3/km^2/yr$. Using these actual sedimentation records and, geologic and topographic conditions, sediment yield potential map have been prepared by the committee in the Water Resources Environment Technology Center (WEC) as shown in Figure 5(b). This map is currently used to check sedimentation planning for newly constructed dams and to estimate future sedimentation predictions for existing dams.

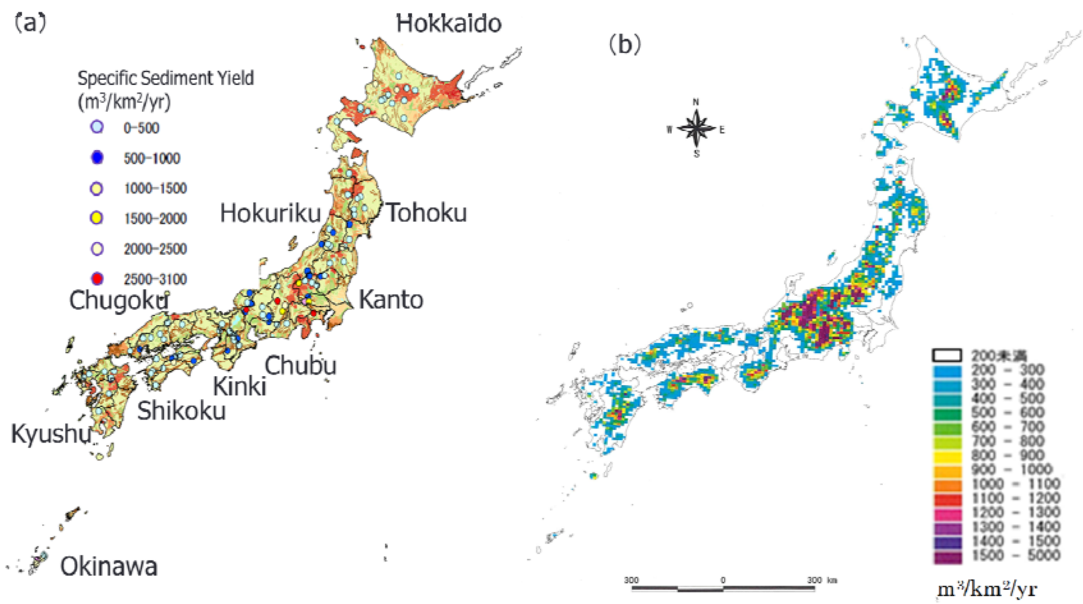

Figure 5. Specific sediment yield; (a) Actual record and (b) Sediment yield potential map.

More detailed information has been reported such as sedimentation volumes in each elevation. Figure 6 shows vertical profile of sedimentation and reservoir storage volume changes in every 10 years at Koshibu dam in the Chubu region. We can easily understand sedimentation progress depend on reservoir operation. At Koshibu dam, in Baiu, Japanese rainy season in June – July, and in Typhoon season in August – September, reservoir water level is slightly drawn down at EL. 592 m and 604.8 m respectively. These periodical partial draw down have been effectively transport sediment into more deep area. Furthermore, in Koshibu dam, two check dams have been installed after dam completion to trap and excavate mainly coarse sediment periodically as in Figure 7. These check dams have effectively minimized sediment deposition. On the contrary, just below L.W.L. at EL. 588.7 m, sedimentation delta is still progressing by sandy materials and finer materials are accumulated at density current bed below EL. 570 m.

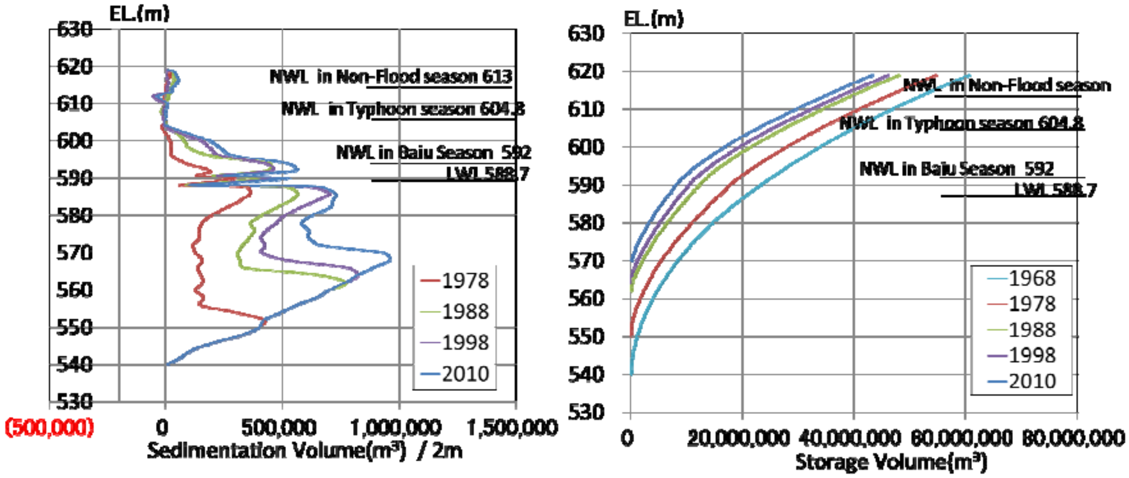

Figure 6. Sedimentation progress and storage volume changes at Koshibu dam.

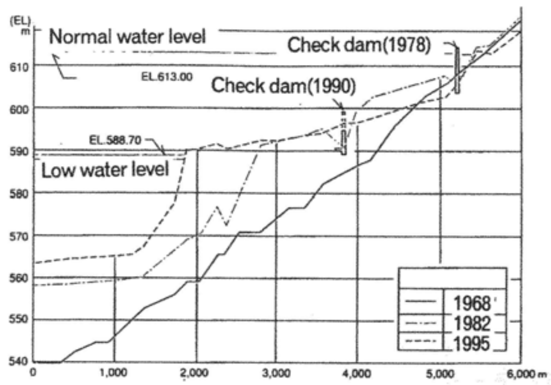

Figure 7. Sedimentation profile and two check dams at Koshibu dam.

In case of Koshibu dam, new sediment bypass tunnel system is now under construction in order to reduce all sediment loads to the reservoir. Dimensions of the tunnel are tunnel length: L=1982 m, diameter: R=3.95 m, A=49 m^2, Slope: s=0.02 %, design discharge =370 m^3/s. Inlet of the tunnel is installed upstream of the upstream check dam.

SELECTING SUITABLE SEDIMENT MANAGEMENT OPTIONS

Following a recommendation by River Council of Japan in 1997, comprehensive sediment management in order to recover a sound sediment transport regarding not only quantity but also quality point of view in the sediment routing system is now being advanced earnestly. Sediment management in reservoirs is largely classified into the three approaches: 1) to reduce sediment inflow to reservoirs, 2) to route sediment inflow so as not to accumulate in reservoirs and 3) to remove sediment accumulated in reservoirs. Sumi and Kantoush (2011b) has classified selected examples in Japan and Europ to these methodologies.

Reduction of Sediment Inflow into Reservoirs

There are two techniques to reduce the amount of transported sediment: 1) countermeasure to control sediment discharge which covers entire basin including the construction of erosion control dams; and 2) countermeasure to forcibly trap sediment by constructing check dams at the end of reservoirs. Although the catchment areas of dams have high forest cover rates, a remarkable amount of sediment is produced in the watershed where landslides frequently occur due to the topographical and geological conditions.

Since an attempt to trap sediment using check dams is found effective for the reservoirs where bed load of relatively coarse grain size accounts for a large percentage of sediment inflow, many dams have proceeded in constructing them recently. In this technique, a low dam is constructed at the end of reservoir to trap transported sediment, and then the deposited sediment is regularly removed. The accumulated sediment can be excavated on land except for flood time, and the removed sediment is utilized effectively as concrete aggregate. As of 2006, the check dams have been constructed at 57 out of the dams under jurisdiction of MLIT.

Recently, sediment augmentation, or replenishment, has been carried out in some dams in Japan (Kantoush et al. 2010, Kantoush and Sumi 2011). Trapped sediments in the sediment check dam upstream of the reservoir are excavated and transported to the downstream of the dam. These sediments are put on the downstream river channel temporarily and washed out by the natural flood flows.

Routing of Sediment Inflow into Reservoirs

Another possible approach to sediment management, next to the reduction of sediment inflow itself, is to route sediment inflow so as not to allow it to accumulate in reservoirs. In Japan, the following techniques are adopted: 1) sediment bypass by directly diverting sediment transport flow, and 2) density current venting by using a nature of high-concentration sediment transport flow.

In Japan, sediment bypass tunnels have been studied most exhaustively. Although this technique involves high cost caused by tunnel construction, there are several advantages such that it is also applicable to existing dams; it does not involve drawdown of reservoir level and therefore no storage capacity loss; and it has relatively small impact on environment because sediment is discharged not so rapidly as sediment flushing. Nunobiki dam is the first example of the bypass tunnel in Japan. The reservoir to which longevity is estimated to be only 25 years without bypass is prolonged to over 1,000 years. Recently, the bypassing effect is clarified after completion of Asahi and Miwa dams and the bypass tunnels in Matsukawa and Koshibu dams are under construction.

Density current venting, on the other hand, is a technique to use a nature of high-concentration sediment transport flow, which runs through relatively deep reservoir with original channel bed of steep slope as a density current with less diffusion, and to discharge it effectively through outlets in timing of reaching dam. In both techniques, the main target is fine-grained sediment such as suspended sediment and wash load. In multiple-purpose dams in Japan that usually have high-pressure bottom outlets for flood control, the effective operation of these facilities during flood season can increase a chance to actively discharge fine-grained sediment.

Removal of Sediment Accumulated in Reservoirs

This approach is regarded as the last measure in case sediment is accumulated in reservoirs in spite of various efforts being done: 1) mechanically excavating sediment accumulated in the upstream region of reservoirs, 2) dredging sediment accumulated at the middle and downstream regions, and 3) flushing out sediment with tractive force. As for excavation and dredging techniques, it is important that the removed sediment should be treated properly and reused.

On the other hand, sediment flushing is a technique to restore tractive force in a reservoir beyond its critical force by means of drawdown of reservoir level, and flush the deposits through bottom outlets in the dam body with inflow water, mainly in an open channel flow condition, to the downstream of dam. When the amount of sediment inflow is significantly large, man-powered techniques such as excavation and dredging are hard to be adopted because of problems involving transportation and dump site. In such a case, however, sediment flushing can be a permanent measure if conditions are met. Traditionally in Japan, sediment flushing facilities such as flushing sluices and outlets were installed at small-scale hydroelectric dams or weirs for the purpose of discharging sediment deposited in the vicinity of intake. In contrast, at Dashidaira-Unazuki dams in the Kurobe river, where a large amount of sediment is discharged, sediment flushing is implemented in coordination of upstream and downstream dams, e.g. coordinated sediment flushing.

Sediment flushing is performed at many dams all over the world. Sediment flushing is considered as an extremely effective technique for discharging sediment in terms of harnessing tractive force in natural river channel. However, when this technique is introduced, an extensive study is required in the planning stages, considering such conditions as inflow, sediment inflow, storage capacity, grain size distribution and reservoir operation. At the same time, it is also required to consider measures concerning environmental problems under sediment flushing process.

Moreover, HSRS (Hydro-suction Sediment Removal System) which can intake and discharge sediment using only the water level differences without the mechanical force is developed in some types in recent years. There are stationary and movable types in the system. In case of the stationary type, establishment of the measures to move sediment to the system neighborhood in the reservoir and, in case of the movable type, securing enough operation time corresponding to the target sediment volume to be discharged during a year and a safe work environment are problems to be solved.

Promotion Strategy of Reservoir Sedimentation Management

The problems to promote such reservoir sedimentation management in future are priority evaluation of reservoirs where sediment management should be introduced and appropriate selection of reservoir sediment management strategies. Especially, when several dams exist in a water system, it is realistically difficult to introduce the sediment management all together due to the limit of the budget under the present situation. Then, it is necessary to evaluate priority according to some indices.

If the dam whose priority is high is selected, it is necessary to select a concrete sediment management strategy. In Figure 8, dams in the Japanese whole country are plotted by the parameter of the turnover rate of water (CAP/MAR=Total capacity/Mean annual runoff) and sediment (CAP/MAS=Total capacity/Mean annual inflow sediment). It is thought that the selected sediment management measures are changed by these two parameters. It is understood that measures actually selected have changed in the order of the sediment flushing, the sediment bypass, sediment check dam and excavating, and dredging as CAP/MAR increases (decrease in the turnover rate). This is because of greatly depending on the volume of water to be able to use the sediment management measure that can be selected for the sediment transport. Figure 9 is focused on multipurpose dams which is described in Figure 4. This information is very much useful to detect suitable actions.

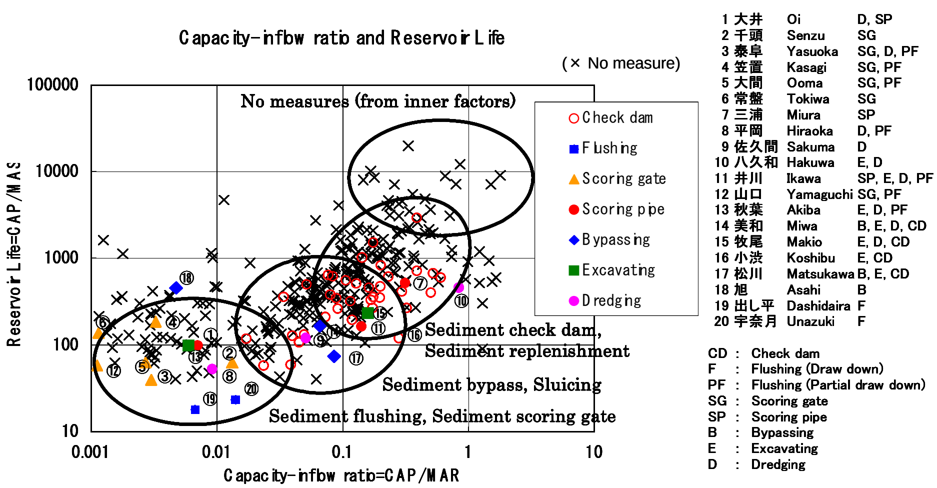

Figure 8. Representative sediment management dams in Japan.

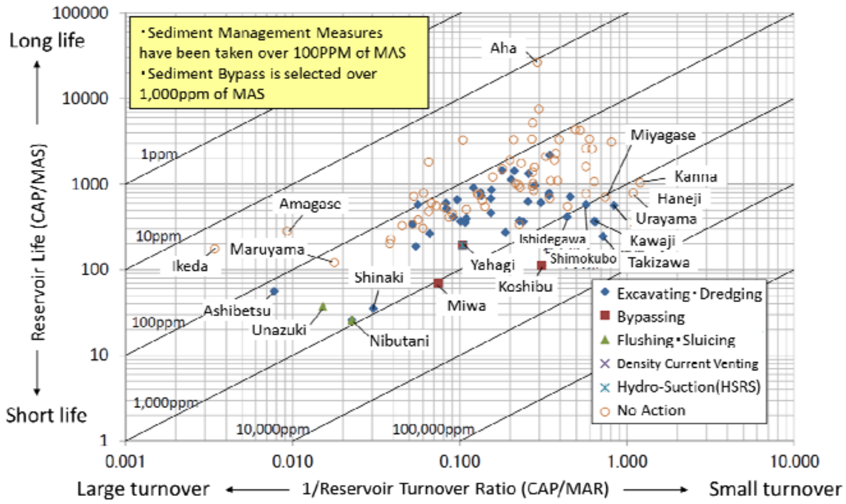

Figure 9. Representative sediment management dams in multipurpose dams.
(MLIT, Pref. Government and Japan Water Agency)

CONCLUSION

Reservoir sedimentation management in Japan is entering a new era. Although there are still technical problems to be solved, we believe that the importance of sediment management will increase. Assessing issues, depending on each case, of dam security, sustainable management of water resources and sediment management in a sediment routing system, an effective sediment management plan should be studied and materialized. Under such circumstances, collecting necessary data on reservoir sedimentation to provide database nationwide and releasing suitable guideline for sustainable reservoir management is one of important tasks. We should share lessons learned how to collect and how to utilize those data effectively worldwide through ICOLD mechanism.

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