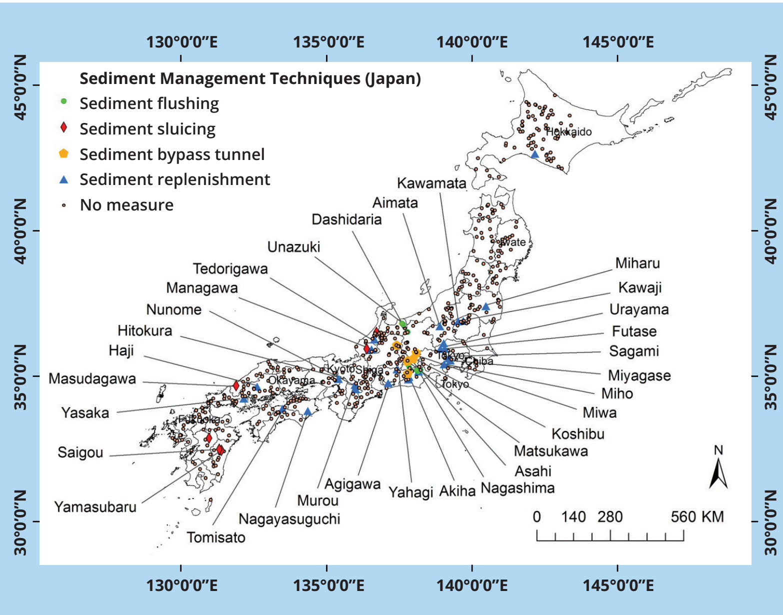
Paradigm shift for sediment management

Sameh A. Kantoush and **Tetsuya Sumi** from Kyoto University in Japan assess how sediment management can be improved basin wide



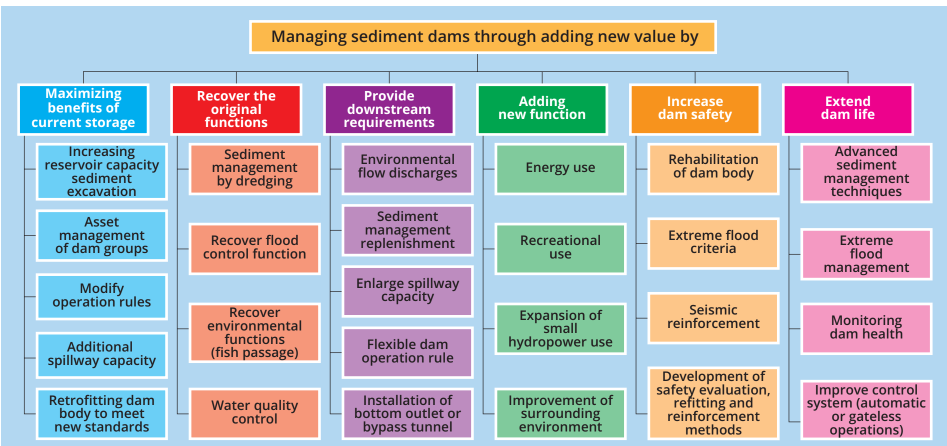
Above: **Figure 1 – Storage reservoirs in Japan with the most common implemented sediment management techniques** (Kantoush et al., 2018)

IN JAPANESE RESERVOIRS, sedimentation was originally handled by setting a 100-year capacity as the planned sedimentation storage. A traditional common design concept of a reservoir is to provide a dead storage space for sediment deposition. This concept is poor as delta formation and siltation is prevalent in the active storage from the early stage of the dam construction. Such dead storage space for sediments is actually a stagnant water storage with less deposition comparing to the active space deposition. It is necessary to account for such loss in active reservoir storage space early in the project design and recognise its impact on the reliability of water and power supply, and flood control. As the length of service life and priority of dam management activity varies between facilities, it is necessary to apply asset management according to these differences.

It is difficult to convince stakeholders to reinvest in recovering the original design or extending the reservoir life and so we should wisely include new values for sediment and dam management. Dam heightening secures new storage and a sediment bypass tunnel will help to increase the flood control functions by preliminary drawdown and increasing dam safety as the released discharge is increased. Another added value for sediment management is not only for the reservoir itself but also to recover downstream environment.

We need to propose upgrading the current sediment dam management not only to sustain the dam function, but also by adding new values. So how do we add new values? It is wise to include sediment management that combines hydro-sediment-eco systems in the basin scale. This will require viable sediment and flood management programmes, monitoring, and regular maintenance of the system.

Figure 1 presents 900 Japanese reservoirs and classifies the range of techniques that have been implemented. The map shows the extent of unsustainable nature of dam and sediment management. Among the implemented sediment management techniques, sediment replenishment is the most dominant technique to recover reservoir function and restore the river ecosystem in the Japanese rivers.



Right: **Figure 2 – Paradigm shifting diagram for necessity of adding new values for a sustainable dam development**

New Concept

By adding new value to existing dams, such as flood control and disaster risk reduction, rehabilitation, upgrading and retrofitting activities have to be implemented. There are various proposed methods to manage the dam and sediment as categorized in Figure 2. Some of these methods to support dam upgrading and retrofitting include:

1. Improving the hydropower functions and generating electricity from non-powered dams;
2. Increasing the capacity of the reservoirs by excavating/dredging the deposited sediments;
3. Increasing flood discharges by improving discharge facilities and adding new outlet;
4. Increasing dam height will add extra effective storage for flood control or other purposes;
5. Exchanging reservoir storage functions among groups of dams by linking several single adjacent dams in the basin so that the storage capacity can be effectively used;
6. Modifying reservoir operation rules by preliminary drawdown water level in the reservoir and keep it flexible during flood period. Thus, by increasing flow volumes, an additional reservoir storage capacity will be guaranteed;
7. Increasing dam safety and ability of the dam body to resist earthquakes and other disasters;
8. Improving the existing functions for recreation and amenities.

In Japan, there are various challenges with regards to dam management due to climate changes and increased number of flood peaks. As a common practice, a periodical monitoring for reservoir sedimentation is conducted before and after every flood event. In case of increased reservoir siltation, an immediate intervention for sediment management to recover the original dam functionality or upgrading the dam facility to ensure reservoir capacity is carried out. When a large-scale sediment removal technique is implemented, it is challenging to obtain storage for the removed sediments, and it is necessary to reduce costs by using sediment material effectively combined with flushing flow.

Regarding the environment, blocking the continuity of sediment by a dam impacts rivers, coastlines and the ocean, so it is necessary to restore sediment downstream from dams. The quantity that must be restored downstream to conserve the environment, and its benefits have not been evaluated. Sediment management techniques are implemented to restore the effective reservoir capacity needed to regulate flood events or water supply and to guarantee live storage.

The various structural and nonstructural methods as listed in Figure 2 which can be engaged are: (a) dry excavation, (b) permanent dredging facility, (c) redevelopment of old spillway by replacing gate and valves, (d) recovery environmental functions for river by constructing fish passage and sediment supply, (e) water quality conservation measures.

Japanese dams

Recently, the Japanese Government's Ministry of Land Infrastructure, Transport and Tourism (MLIT), has released the new policy initiative "Vision for upgrading under dam operation" which will enhance comprehensive upgrading of existing dams for sustainable development (Sumi and Kantoush, 2018). Based on limited water storage capacities, effective maintenance and new investment are needed not only to sustain the facility but also to upgrade existing functions from various aspects such as adaptation for future climate change effects by both optimising dam operation and increasing storage capacities, and rehabilitation of river environment. In that regard, reservoir sediment management plays a key role both for dam and reservoir sustainability, and restoration and rehabilitation of the river environment by balancing sediment inflow and outflow across the reservoir while maximising the long-term benefits and minimising the adverse effects below dams.

Two out of seven completed dams on the Mimi River system have been upgraded under integrated basin management plans by Miyazaki prefecture in Japan. Figure 3 shows both upgraded Yamasubaru and Saigou dams. The two central spillway gates of Yamasubaru dam were removed by cutting down the spillway crest height about 9.3m, and installing a single large spillway gate. The four spillways of Saigou dam were cut by 4.3m and replaced by two larger gates. The sluiced sediment flux with partial removal of dam spillway is an optimal measure and comparable to the one obtained by complete dam removal at much less cost.

Sediment Bypass Tunnels

Among several methodologies, sediment bypassing can be considered to be one of the permanent remedial measures. Sediment Bypass Tunnels (SBT), however, have many advantages such that they can be constructed even at existing dams and prevent a loss of stored reservoir water caused by lowering of the reservoir water level. They are also considered to have a relatively small impact on the environment downstream because inflow discharge can be passed through tunnels naturally during flood time.

Figure 4 shows the outline of the Koshibu dam f

Above: **Figure 3 – Case studies for dam retrofitting works on Yamasubaru and Saigou Dams** (Sumi et al., 2015)

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Above: **Figure 4 – Sediment Bypass Tunnel of Koshibu dam completed in 2016 including outlines and facilities** (Ishida et al., 2019)

j and its SBT facilities. The Koshibu Dam, a 105m high arch concrete dam, was built in 1969 for flood control, irrigation and power generation.

This article highlights the need for a paradigm shift in dam water and sediment management on a river basin scale, and shows how important it is to design effective sediment management strategies. The latter is required to build future dams, maintain reservoir functions of existing dams, and contribute to total basin scale development. Numerous dams are malfunctioning with tens of thousands of sediment deposition volumes in deep, middle, and upstream tailwater parts of the reservoir.

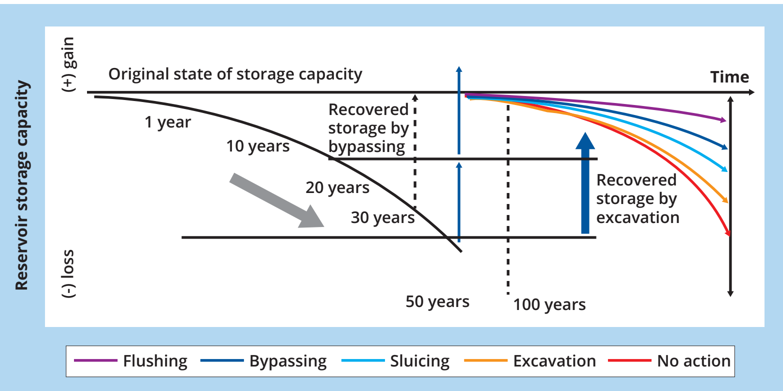
Figure 5 illustrates the various sediment management methods suitable for each part of the reservoir as excavating, dredging, bypassing, flushing, and sluicing. These methods often compete, and one of the most common trade-offs involves choosing between no action or recovering dam function, and extending dam life. At the beginning, various options for sediment management are available. Without action, in 100 years the excavation cost will be extremely high and at times unfeasible. Comparatively, installation of sediment bypass tunnels would yield significantly less sediment deposition rates. Combining both measures alternatively, would recover reservoir functionality and extend the dam's life. Implementation of these strategies is deemed prudent for recovery after 10, 20, 30, 50, 100 years and is crucial for project recovery. Sediment management necessitates performing economic feasibility studies for the recovery method under consideration. The costs and benefits of asset management in coordination with changes in dam operation and downstream should be put in perspective during decision making. To this end, a new concept and methodology should be conceived prior to designing an intergenerational, sustainable, self-supporting rehabilitation system for river basins with reservoirs. Measuring the benefits and costs of an improvement in water quality is often difficult.

Global warming

In Japan, most of snowfall-snowmelt driven river basins will be affected by global warming since winter snow will be drastically changed to winter rainfall which will runoff earlier without being stored in upstream mountain catchments. These effects will increase the risk of water shortage for agricultural and portable uses in the next summer seasons. In order to reduce those risks, reservoir operation should be adapted on the changing flow regimes and/or increase storage capacity enough to compensate decreasing water resources provided by snowfall-snowmelt processes. For efficient comprehensive sediment management in the river basin, it is necessary to find a balance between flow and sediment release. This is dictated by numerous constraints including hydrology, water quality, river morphology and ecosystem, etc. Impacts of dams on the downstream river conditions can be evaluated by a combination of sediments and flow regime. In order to add new value for dams and reservoirs by solving sediment related issues, clear and strong initiatives are needed to change the management concept drastically.

Further work is needed to guide the future management of ageing dams around the world and support the huge investment decisions that will have to be made. Important directions include reservoir longevity issues and the necessity of upgrading and retrofitting ageing dams. This should extend to include a thorough assessment of climate change impacts on ageing and determination of ecosystem response to ongoing loss of reservoir functionality. In that regards, further research is needed to know how climate change will have impacts on rainfall-runoff and sediment production-transport intensity. These effects are critical for future reservoir storage reliability. Additionally, changing flow regime itself also has big impacts on seasonal water storage scenarios. ●

Below: **Figure 5 – Scenarios for sediment management options to recover dam functions and extend dam life** (Kantoush and Sumi, 2017)



References

Kantoush, S.A. and Sumi, T., 2017. The aging of Japan's dams: Innovative technologies for improving dams water and sediment management, River Sedimentation – Wieprecht et al. (Eds) © 2017 Taylor & Francis Group, London, ISBN 978-1-138-02945-3

Kantoush, S. A., Suzuki, T., Takemon, Y., El Kadi Abderrezzak, K., Ata, R. and Sumi, T., 2018. Numerical study on reservoir sediment management through adding excavated sediment downstream of dams in Japan. Lyon- Villeurbanne, 9th International Conference on Fluvial Hydraulics, River Flow 2018, Lyon, France.

Sumi T., Yoshimura T., Asazaki K., Kaku M., Kashiwai J., and Sato T. (2015) "Retrofitting and change in operation of cascade dams to facilitate sediment sluicing in the Mimikawa River Basin," The 25th Congress of ICOLD, Stavanger, Q.99–R.45.

Sumi, T. and Kantoush, S.A., 2018. Innovative strategies for managing dams and reservoir sedimentation in japan, IAHR Journal, Hydrolink ISSN 1388-3445, number 4/2018.

Katsushi Ishida, Toshiyuki Sakurai and Tetsuya Sumi, (2019). Operation Results of the Koshibu Dam Sediment Bypass Tunnel Completed in 2016. 3rd International Workshop on Sediment Bypass Tunnels, Taipei, Taiwan.