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POSITIVE EFFECTS OF RESERVOIR SEDIMENTATION MANAGEMENT ON RESERVOIR LIFE - EXAMPLES FROM JAPAN

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ABSTRACT

The effectiveness of different strategies against reservoir sedimentation is demonstrated herein using data sets of Asahi, Nunobiki and Dashidaira reservoirs in Japan. The applied strategies encompass sediment routing with a bypass tunnel, drawdown flushing during floods and sabo dam construction in the catchment. It is shown that bypassing and flushing are very efficient strategies enlarging reservoir life by 3 to 21 times up to many hundreds of years. Furthermore, it is revealed that also efforts in the catchment, e.g. sabo dam construction, is effective enlarging reservoir life by 2.4 times.

1. INTRODUCTION

Dam-regulated rivers interrupt continuous sediment transport along a river system and cause accumulation in the reservoir. Hence, a sustainable use of reservoirs implies first of all the application of strategies to counteract sedimentation. In man-made reservoirs it is a phenomenon attracting increasing attention worldwide (ICOLD 2009). Mean annual sedimentation rates vary from 0.2 to some 2 to 3% with a global annual average rate of about 1% and worldwide, increase in sedimentation volume exceeds increase in reservoir capacity revealing a gross storage loss in the near future (Schleiss & Oehy 2002, ICOLD 2009). Reservoir sedimentation causes various problems. Firstly, the volume decrease leads to a loss of energy production, water used for water supply and irrigation, and retention volume (Annandale 2013). Secondly, both an endangerment of operating safety due to blockage of outlet structures and an increased turbine abrasion due to increasing specific suspended load concentrations may result. Finally, a dam retains sediment causing downstream river incision and inhibiting its ecologic connectivity (ICOLD 2009, Kondolf et al. 2014). Reservoirs may be classified into three groups depending on their water turnover rate defined as ratio of reservoir capacity (CAP) to mean annual runoff (MAR) (Figure 1). Transparent reservoirs refer to a small-sized storage, e.g. run-of-river schemes. They divert flow to the power plant during normal operation, but they are *transparent* for both water and sediment during flood events and do not trap them.

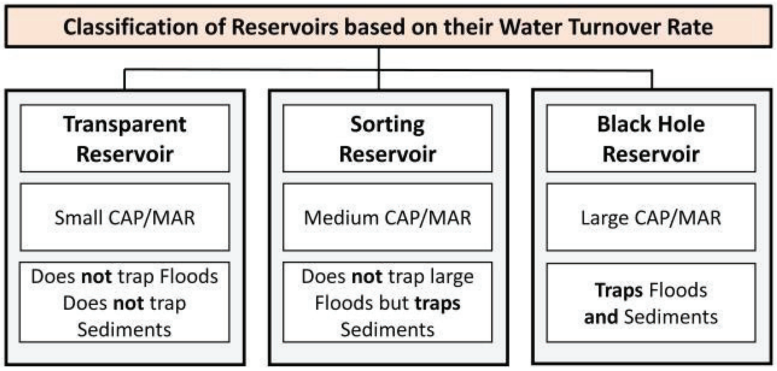

Figure 1. Classification of reservoirs based on their water turnover rate (CAP/MAR)

Most reservoirs worldwide may be classified as a sorting reservoir. The incoming sediment is trapped in the reservoir, whereas the flood water is passed (with a certain retention effect) to the downstream.

Black hole reservoirs refer to very large storage volumes with low inflow. These dams store both the flood and sediments and largely effect the downstream environment by changing water and sediment quantity (Kantoush 2014). The proposed classification refers to reservoirs, where no sediment strategy is applied. Black hole reservoirs may shift to sorting or even transparent ones in case of proper strategy application.

This paper describes possible strategies against reservoir sedimentation and aims to reveal the efficiency of different specific strategies based on data sets taken from Japanese dams.

2. STRATEGIES AGAINST SEDIMENTATION

Sediment management to minimize aggradation in reservoirs is achieved with a variety of techniques categorized in three main strategies (ICOLD 1989, 1999, 2009, Morris & Fan 1998, Kantoush & Sumi 2010, Annandale 2011, 2013, Auel & Boes 2011, 2012, Kondolf et al. 2014). Figure 2 shows an overview of these techniques and their corresponding strategies: (1) sediment yield reduction, (2) routing sediments around or through the reservoir, and (3) recover volume by sediment removal or dam heightening. Furthermore, two more strategies may be added: (4) dam removal and (5) no action.

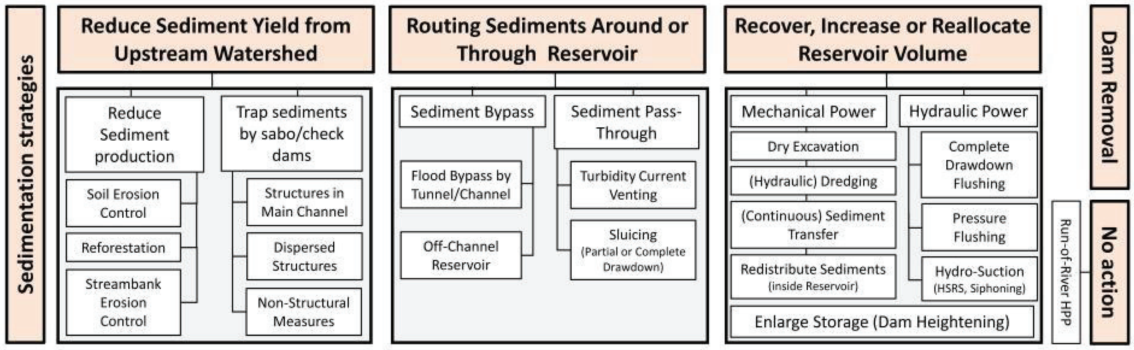

Figure 2. Classification of strategies against reservoir sedimentation

The first strategy refers to a reduction in the sediment inflow into the reservoir, i.e. soil erosion control in the catchment area by reforestation and upstream sediment trapping by sabo dams (check dams). The second one deals with routing of sediments into the tailwater downstream of the dam. Within this strategy various effective techniques can be applied: direct bypassing around the dam using tunnels or channels, diverting to an off-channel reservoir, and passing sediments through the reservoir by either sluicing or turbidity current venting. Sluicing and venting are closely related except for the operated reservoir level and the outlet opening. Both techniques route incoming sediments to the tailwater without settling in the reservoir (Müller & De Cesare 2009, Schleiss et al. 2010, Kantoush et al. 2010, Esmaili et al. 2015). Sluicing requires a partial water level drawdown to transport incoming and to some extent accumulated sediments to the dam outlet structure, whereas venting of turbidity currents can be performed without water level lowering. Sluicing includes both bedload and suspended sediment, whereas venting is only possible for the latter. Sluicing is conducted through dam bottom outlets, which have to be appropriately designed in order to sluice large water discharges and withstand abrasion by coarse sediments (Sumi et al. 2015). In contrast venting of turbidity currents is possible not only through the bottom outlets but through the power intake (Schleiss et al. 2010). However, a drawback of venting through the turbines is the wear, depending on both the sediment properties such as the quartz content and the specific sediment concentration (Bajracharya et al. 2008). In contrast, sediment routing using a bypass tunnel (SBT) is very effective regarding both bed and suspended sediment load (Sumi et al. 2004a, Auel et al. 2010, 2011, Auel & Boes 2011, 2012, Sumi & Kantoush 2011, Kantoush et al. 2011, Boes et al. 2014, Auel et al. 2015). All sediments are guided into the tunnel intake using guiding structures such as walls (Auel et al. 2010, 2011) or weirs (Kashiwai et al. 1997) and the reservoir is kept free of sediments downstream of the intake. Only if the tunnel design discharge is exceeded, a partial flow is entering the reservoir leading to suspended load entrainment (Auel et al. 2010, 2011, Auel & Boes 2011). This technique is best applicable for small and medium-sized reservoirs ($<10^7$ m^3) as tunnel length plays a crucial role limiting the application due to high construction costs.

Sediment routing in general is ecological favourable compared to other strategies as operation is conducted during high flows. River bed erosion downstream of the dam can be significantly decelerated or even completely stopped resulting in an increase of morphological variability (Fukuda et al. 2012, Facchini et al. 2015, Martín et al. 2015). Moreover, only sediments provided from the upstream river reach are conveyed, while hardly any removal of sediments that have already accumulated in the reservoir occurs. The sediment concentration in the tailwater of the dam is therefore not affected by the reservoir itself and keeps its natural character, which is advantageous regarding fish fauna aspects (ICOLD 2009, UVEK 2010).

The third strategy refer to increase the capacity by removing accumulated sediments or dam heightening to re-suspend or reallocate the deposited sediment. Strategies are either using mechanical or hydraulic power. The former implies dry excavation during complete water level drawdown, hydraulic dredging with pumps during high reservoir levels, continuous sediment transfer into the downstream and redistribution of sediments inside the reservoir. Dredging is applicable at small to medium-sized reservoirs, while it is not economical for large ones. It has to be performed continuously over a certain period. Hence, negative ecological effects in the downstream reach are to be expected as this technique is not necessarily applied during high flows. Also dry excavation and sediment flushing during complete water level drawdown have drawbacks as they result in a complete storage water loss. Furthermore, a complete drawdown is only reasonably applicable when the reservoir capacity is small compared to the annual inflow, i.e. for a low water turnover rates. In case of annual storage reservoirs, refilling is a long-term process, depending essentially on the hydrologic conditions. Strategies using hydraulic power refer to flushing through the outlets either during complete water level drawdown or pressure flushing at high reservoir levels. The latter is not very effective, because of its local impact resulting in a funnel-shaped crater only in the bottom outlet vicinity (Lai & Shen 1996). A disadvantage of flushing sediments in general is the high quantity of eroded material leading to immediate ecological impacts on the biota of the downstream river reach (Kondolf et al. 2014). Pools may be filled, sediment size distribution may change, and suspended sediment may clog the bed surface (Facchini et al 2015, East et al. 2015). However, although biota may be harmed in the short term, in the long term recovery even due to extensive sediment impact is possible, likely with slight change of macroinvertebrate species and flora (East et al. 2015). Negative effects of flushing may be largely decreased if operated during a natural flood event. Also consecutive annual flushing is favourable as the sediments only accumulate during one year. In Japan, flushing of sediments is frequently applied in times of comparatively high reservoir inflow such as typically one-year floods (Sumi 2005, 2008, Kantoush et al. 2011, Esmaili et al. 2015, Sumi et al. 2015). Enhanced flushing techniques include cascade flushing of subsequent reservoirs to shorten and decrease the negative impacts on the downstream reach and improve flushing efficiency (Esmaili et al. 2015, Sumi et al. 2015). Furthermore, by adding clear water during flushing, high peak suspended sediment concentrations may be damped diminishing negative ecological impacts (Sumi et al. 2009). One further removal technique is termed hydro-suction (siphoning) where sediments are pumped to a lower level using only the hydraulic head (Hotchkiss & Huang 1995). Advantages are low costs and no use of mechanical power.

Despite these strategies, a dam removal could be another option to restore the original river reach (East et al. 2015, Randle et al. 2015). However, all benefits provided by a reservoir as hydropower generation, water supply, and flood protection are thereby eliminated making this option literally not an adequate strategy against reservoir sedimentation as no reservoir remains.

Finally, taking no action against reservoir sedimentation may be an option in case of reservoirs used for hydropower generation. The plant may operate as a daily reservoir or a run-of-river scheme. The Maigrauge dam in Switzerland is operated in such a way. The dam was put into operation in 1872 being the oldest European concrete dam. Today the reservoir is completely filled with sediments but drawdown flushing is prohibited as the site is located in a protected natural zone (Mivelaz et al. 2006). The dam was retrofitted from 2000 to 2004 to comply new safety standards but sedimentation strategies were not applied leaving the plant in run-of-river operation (Mivelaz et al. 2006). Also in Japan, many older dams such as Senzu and Ooma in the Ohi River, Sennindani and Koyadaira at Kurobe River, and Yasuoka and Hiraoka dams at Tenryu River are operated as run-of-river hydropower schemes after prone to large sedimentation volumes. In these dams only dredging or local sediment flushing is implemented to clean up just upstream of the intake facilities.

3. CASE STUDIES

In Japan, class A rivers (supervised by the Ministry of Land, Infrastructure, Transport and Tourism) and associated reservoirs are monitored before and after floods. Therefore, extensive reservoir sedimentation data sets are available in Japan allowing for an analysis of strategy efficiency if suitable countermeasures were applied. The Asahi and Nunobiki reservoirs are equipped with sediment bypass tunnels, whereas at the Dashidaira reservoir annual drawdown flushing is applied. Additionally, a large number of sabo dams were installed in the catchment of Nunobiki reservoir during the last century. Hence, the present paper comprises three different strategies: sediment yield reduction, routing and flushing. The main objective is to quantify the long term efficiency of each technique.

3.1 Asahi reservoir

The 86 m high Asahi arch dam impounds the lower reservoir of the 1206 MW Okuyoshino pumped-storage hydropower plant in Nara Prefecture operated by Kansai Electric Power Co., Inc. (KEPCO) (Nakajima et al. 2015). Operation started in 1978 with an original reservoir volume of 15.5×10^6 m^3. The catchment area is 39.2 km^2 and mostly covered by forest with a maximum altitude of 1,800 m a.s.l. The upstream Asahi river reach is a mountainous gravel bed stream with steep slopes of 2% at the reservoir head up to 3.8% at some 1500 m further upstream. Severe typhoons in 1989 caused large landslides in the catchment leading to high sediment load transported into the reservoir. During subsequent typhoons in 1990 more sediment was entrained causing high turbidity inside and downstream the reservoir (Akiyama 2012). To improve the reservoir water quality, KEPCO repaired some collapsed hillsides within company-owned land and installed filtration systems to improve natural filtration into the river (Akiyama 2012). However, reservoir sedimentation progressed compromising the power intake and discharge function. Therefore, KEPCO initiated the construction of a SBT put into operation in 1998 (Harada et al. 1997, Akiyama 2012, Nakajima et al. 2015). The SBT is opened during flood events to divert the sediments into the dam tailwater. The total tunnel length of 2,383.5 m includes a 18.5 m long steel-lined inlet section, a 2,350 m long concrete-lined tunnel and a 15 m long concrete-lined outlet. The tunnel consists of an archway cross section of 3.80 m width and 3.80 m height with a slope of 2.9%. The design discharge is 140 m^3/s corresponding to a three years flood event. Higher floods are partially diverted into the reservoir by means of an overtopping weir. Since its inauguration the tunnel faces severe abrasion up to several decimetres (Nakajima et al. 2015) due to high flow velocities in the tunnel of about 12 m/s in combination with coarse bedload transport (Auel & Boes 2011). Annual maintenance works are conducted in order to repair the concrete invert.

The efficiency of Asahi SBT is revealed analysing the annual reservoir sedimentation survey data together with the amount of bypassed sediments (Akiyama 2012, Fukuroi 2012, Nakajima et al. 2015). The bypassed sediments were estimated applying a 1D numerical model for the upstream river reach. Estimated sediment volumes were calibrated with both reservoir sedimentation data and bed elevation survey data downstream of the dam. Figure 3 shows both the actual and accumulated sediment volumes versus time from 1989 to 2013.

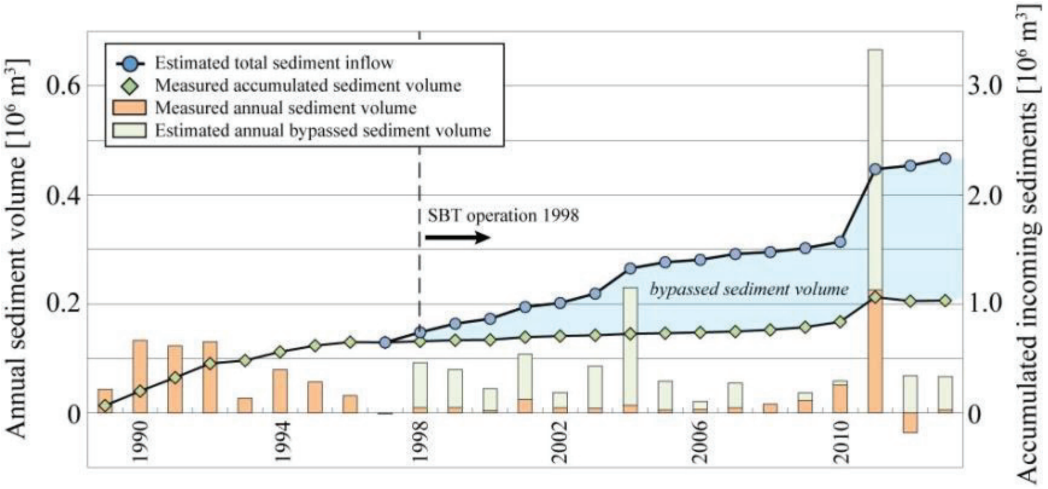

Figure 3. Aggregated and bypassed sediment volume in Asahi reservoir (adapted from Fukuroi 2012 with additional new data by KEPCO).

Since SBT operation in 1998, 77% of all incoming sediments were diverted through the tunnel revealing the high efficiency. 23% were deposited in the reservoir during high flood events where the inflow discharge exceeded the tunnel design capacity. Even in 2011, when typhoon Talas hit Japan causing severe landslides in the catchment (Fukuroi 2012), still 66% of the sediments were bypassed. Besides the bypass efficiency, positive ecological effects downstream the dam were observed shortly after operation commencement. Akiyama (2012) reported substantially reduced turbidity, improved water quality, and restoration of bed morphology due to bypassed sediments.

3.2 Nunobiki reservoir

The 33 m high Nunobiki dam in Hyogo Prefecture was constructed in 1900 and impounds a reservoir with an original volume of 7.59×10^5 m^3. The catchment area is 9.8 km^2 and entirely forested (Sumi et al. 2004b, Sumi 2015). Two sedimentation strategies were applied: Construction of 29 sabo dams in the upstream catchment from 1939 to 1989 with a total volume of 9.57×10^4 m^3; and construction of a SBT in 1908 to divert sediments around the reservoir. This SBT is the oldest in the world (Sumi et al. 2004a). The tunnel is 258 m long; the cross section is of archway type with 2.97 m width and 2.97 m height; and the design discharge is 39 m^3/s.

The efficiency of both sabo dam construction and SBT routing at Nunobiki reservoir was analysed by Sumi et al. (2004b). Figure 4 shows accumulated data of measured reservoir sedimentation, theoretical sedimentation without bypassing, and sabo dam volume increase due to construction versus time from 1900 to 1990. The theoretical values are estimated based on catchment size, upstream river bed slope, daily rainfall data, and sabo dam trap efficiency. Hence, they imply the sabo dam but neglect the routing technique.

The data revealed that high sedimentation occurred from 1900 to 1908 with 30% of the original volume being occupied by sediments. The reservoir capacity would have been exceeded already in 1927, if no countermeasure taken. However, SBT operation from 1908 on largely reduced the reservoir sediment input. 81% of the incoming sediments were bypassed leading to a further increase by 1939 of only 1.1×10^5 m^3 being 14.5% of the original volume. However, 36% of the reservoir volume was filled by that time. Since then, sabo dam construction started in the catchment leading to a further sediment input decrease indicated by a slight flattening of both sediment volume curves. This behaviour is more pronounced for the estimated sedimentation data since 1970, where the accumulated sabo dam retention volume reached a considerable scale with about 3.3×10^4 m^3. Measured reservoir volume increased by only 6.2×10^4 m^3 in 50 years being 8% of the original volume. More than 94% of the theoretically incoming sediments were routed to the downstream by the SBT. Interestingly, the SBT efficiency increased from 81% to 94% comparing the periods of 1908 to 1939 and 1939 to 1989. An explanation may be that the trapped sediments by sabo dams effectively reduce the sediment yield in the catchment. Even during high floods exceeding the tunnel design capacity, almost all coarse sediments seem to enter the SBT.

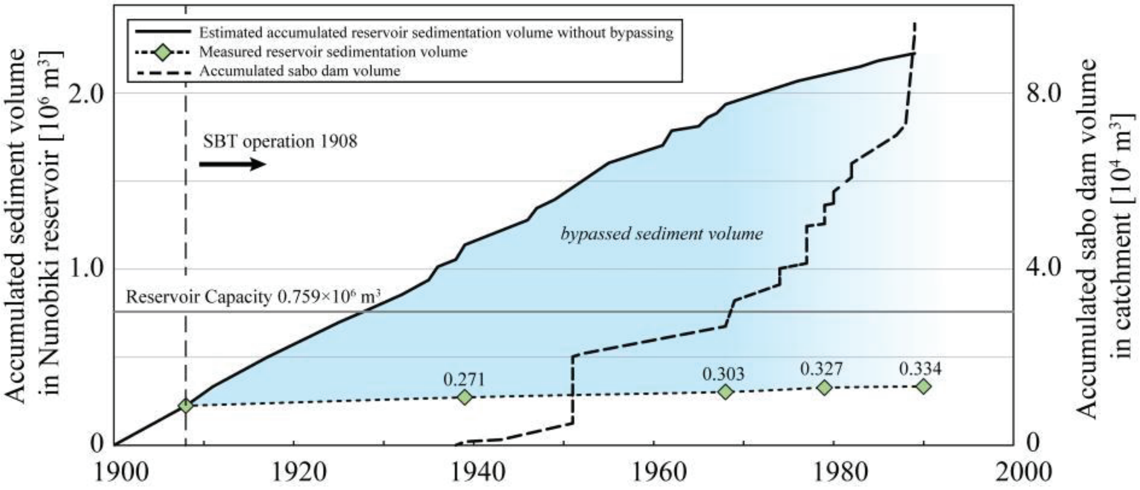

Figure 4. Aggregated and bypassed sediment volume in Nunobiki reservoir, and accumulated sabo dam volume versus time (adapted from Sumi et al. 2004b).

The sabo dam detention efficiency is analysed comparing the periods 1909 to 1929 before sabo dam construction and 1979 to 1989 with and without consideration of the SBT. The estimated mean annual sediment inflow decreased in the two compared periods from 1,455 m^3 to 601 m^3 (with SBT) and $30.5×10^3$ m^3 to $12.5×10^3$ (without SBT), i.e. by almost 60% in both cases.

3.3 Dashidaira reservoir

The 76.7 m high Dashidaira dam was put into operation in 1985 by KEPCO. It impounds the Kurobe River to an original reservoir volume of $9.01×10^6$ m^3 and $1.66×10^6$ m^3 gross and effective storage capacity, respectively (Liu et al. 2004). The catchment area is 461 km^2 large and mostly forested. The river originates at Mount Washibadake at about 3000 m a.s.l. and flows into Toyama bay in the Sea of Japan. The bed slope is steep and varies between 1% and 20% (Esmaili et al. 2015) classifying Kurobe River as a mountain gravel bed river in its upper catchment. The average annual rainfall and total sediment yield are 4000 mm and $1.4×10^6$ m^3/a, respectively, being one of the highest in Japan (Minami et al. 2012). Annual sediment flushing is performed at Dashidaira dam since 1991. Since 2001, a coordinated flushing and sluicing in both Dashidaira and Unazuki reservoirs, located 7 km downstream, is conducted (Liu et al. 2004, Sumi & Kanazawa 2006, Sumi et al. 2009). Flushing is done annually around June during the first major flood event in the rainy season (Esmaili et al. 2015). In 1991, a flushing operation was executed for the first time. Due to low experience in the flushing process, flushing was done in winter during low flows. Furthermore, large amount of organic matter deteriorated inside the reservoir during seven years after the dam construction. These conditions resulted in severe environmental problems in the aftermath of the flushing process (Sumi & Kanazawa 2006). After shifting the flushing to the flood season accompanied by intensive monitoring, flushing is executed successfully since 1995 and a stable flushing channel in the reservoir developed (Kantoush et al. 2010).

Figure 5 shows both the measured deposited and total sediment inflow in Dashidaira reservoir versus time since 1985 (Sumi & Kanazawa 2006). The flushed amount is the difference between these two curves. The flushed sediment is calculated comparing reservoir survey data before and after the event. Consequently the sediment amount which is entrained into the reservoir during the flushing operation is directly sluiced into the downstream and not considered in the data analysis. The total sediment inflow is therefore even higher.

The data reveal that sedimentation significantly decreased since 1991. Remarkable is the large flood event in 1995 leading to an accumulation of $7.34×10^6$ m^3 sediments in the reservoir corresponding to almost 82% of the gross storage. One successful flushing operation in November 1995 reduced the volume again to $5.61×10^6$ (62% of the total volume). Without flushing technique the reservoir would have been filled in 1999. From 1991 to 2014, the aggregated volume increased only by 9% to $4.29×10^6$ m^3. In total 88% of all incoming sediments were flushed.

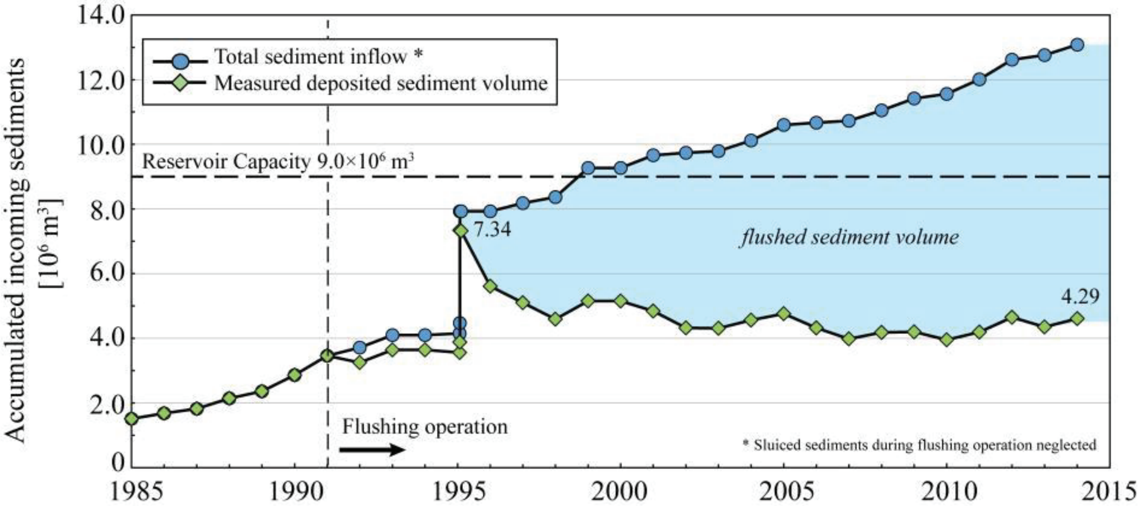

Figure 5. Aggregated volume and total sediment inflow in Dashidaira reservoir versus time (adapted from Sumi & Kanazawa 2006 with additional new data by KEPCO).

4. STRATEGY EFFICIENCY

The expected reservoir life span is a useful parameter to compare the efficiency of different sedimentation strategies before and after implementation. It can be expressed as the ratio of reservoir capacity (CAP) to the mean annual sediment yield (MAS). The ratio CAP/MAS can be plotted as a function of the water turnover rate (CAP/MAR) (ICOLD 1999). In Figure 6 these ratios are shown for the herein described strategies revealing their effectiveness by shifting the reservoir life to higher values. All analysed techniques (bypassing, flushing and sabo dam construction) are successful. The reservoir life of Nunobiki is enlarged by SBT operation from 60 to 1264 years, e.g. by 21 times. Even the effect of the sabo dam construction in the catchment by 2.4 times from 25 to 60 years is remarkable. Life of Asahi reservoir is enlarged due to SBT routing by 3.3 times from 198 to 644 years. And finally, also the flushing technique at Dashidaira reservoir is very effective enlarging reservoir life about 9 times from 23 to 203 years.

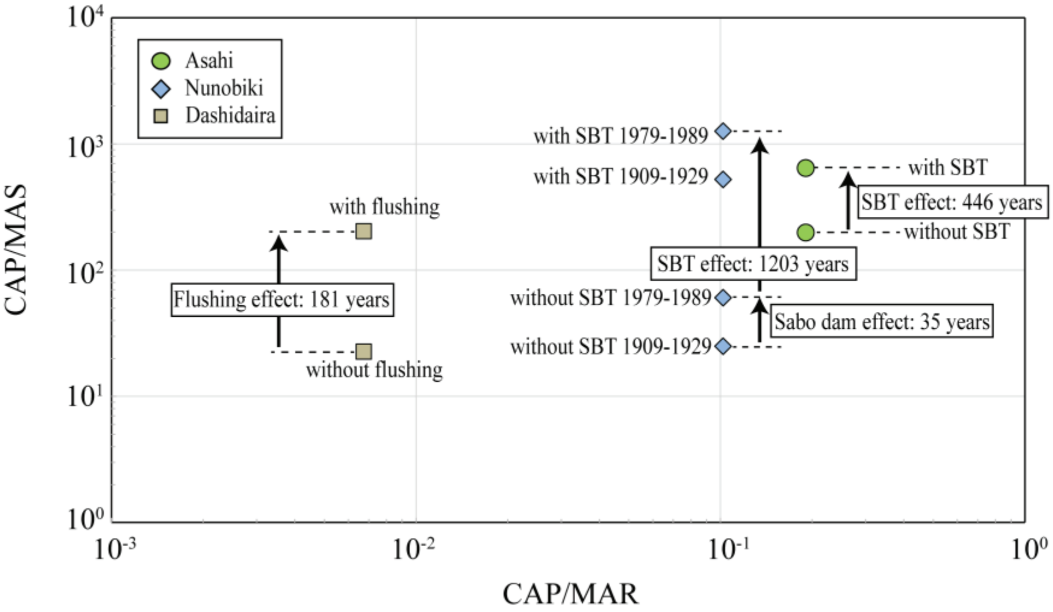

Figure 6. Reservoir life (CAP/MAS) versus water turnover rate (CAP/MAR) with and without implementation of sedimentation strategies.

5. CONCLUSION

This paper aims to show the effectiveness of different strategies against reservoir sedimentation using examples of Asahi, Nunobiki and Dashidaira reservoirs in Japan, where large data sets are available. The applied strategies are (1) sediment routing with a bypass tunnel, (2) drawdown flushing and (3) sabo dam construction in the catchment. It is shown that bypassing as well as flushing during large flood events are very efficient strategies enlarging reservoir life by 3 to 21 times to many hundreds of years. Furthermore, it is shown that also efforts in the catchment, e.g. sabo dam construction, is very effective enlarging reservoir life 2.4 times. These examples underline the necessity of proper reservoir sedimentation management and reveal its positive effects on reservoir life span if effectively applied as done in Japan.

Engineers have to combine and enhance strategies to significantly enlarge reservoir life towards a sustainable water use. Moreover, sediment management has to be considered from the beginning in the early stage of dam planning and designing. Such early consideration has be taken into account by all players involved, i.e. engineers, stakeholders and decision makers. It would reduce the cost for future generations being in alignment with the definition of sustainability from the Brundtland Commission in 1987: *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*.

The authors furthermore recommend that reservoir sedimentation management has to be considered not only for specific dams but at the river basin scale. Strategy selection should base on water turnover rate (CAP/MAR) and reservoir life (CAP/MAS) and their classification as transparent, sorting or black hole reservoirs. More research has to be conducted to evaluate the positive environmental effects of sediment management on both the river channel downstream of the dam and the coastal zone.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Akiyama, T (2012). *Management of sedimentation and turbid water at the Asahi dam*. Proc. Hydro, Session 17, Bilbao, Spain, pp 1-8.

Annandale, G (2011). *Going full circle*. Int. Water Power & Dam Construction (4), pp 30-34.

Annandale, G (2013). *Quenching the thirst. Sustainable water supply and climate change*. CreateSpace Independent Publishing Platform, North Charleston, USA.

Auel C, Berchtold T, & Boes R (2010). *Sediment management in the Solis reservoir using a bypass tunnel*. Proc. 8th ICOLD European Club Symposium, Innsbruck, Austria, pp 438–443.

Auel C, & Boes R (2011). *Sediment bypass tunnel design – review and outlook*. Proc. ICOLD Symposium - Dams under changing challenges (Schleiss & Boes, Eds.), 79th Annual Meeting of ICOLD, Lucerne, Switzerland. Taylor & Francis, London, UK, 403–412.

Auel C, Boes R, Ziegler T, & Oertli C (2011). *Design and construction of the sediment bypass tunnel at Solis*. Hydropower and Dams 18(3), pp 62–66.

Auel C, & Boes RM (2012). *Sustainable reservoir management using sediment bypass tunnels*. Proc. 24th ICOLD Congress, Q92 R16, Kyoto, Japan, 224–241.

Auel C, Hagmann M, Albayrak I, & Boes RM (2015). *Optimizing the sustainability of sediment bypass tunnels to counter reservoir sedimentation*. Proc. 25th ICOLD Congress, Q99 R2, Stavanger, Norway.

Bajracharya TR, Acharya B, Joshi CB, Saini RP, & Dahlhaug OG (2008). *Sand erosion of Pelton turbine nozzles and buckets: A case study of Chilime Hydropower Plant*. Wear 264(3-4), 177–184.

Boes RM, Auel C, Hagmann M, & Albayrak I (2014). *Sediment bypass tunnels to mitigate reservoir sedimentation and restore sediment continuity*. Reservoir Sedimentation (Schleiss et al., Eds.), Taylor & Francis Group, London, UK, pp 221-228.

Esmaili T, Sumi T, Kantoush SA, Kubota Y, & Haun S (2015). *Numerical study on flushing channel evolution, case study of Dashidaira reservoir, Kurobe River*. Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering) 71(4), pp. I_115-I_120.

East AE, Pess GR, Bountry JA, Magirl CS, Richtie AC, Logan JB, Randle TJ, Mastin MC, Minear JT, Duda JJ, Liermann MC, McHenry ML, Beechie TJ & Shafroth PB (2015). *Large-scale dam removal on the Elwha River, Washington, USA: River channel and floodplain geomorphic change*. Geomorphology 228, pp 765-786.

Facchini M, Siviglia A, & Boes RM (2015). *Downstream morphological impact of a sediment bypass tunnel – preliminary results and forthcoming actions*. Proc. 1st Int. Workshop on Sediment Bypass Tunnels, ETH Zurich, VAW Mitteilungen 232 (Boes, Ed.), pp 137-146.

Fukuda T, Yamashita K, Osada K, & Fukuoka S (2012). *Study on flushing mechanism of dam reservoir sedimentation and recovery of riffle-pool in downstream reach by a flushing bypass tunnel*. Proc. Intl. Symposium on Dams for a changing world, Kyoto, Japan.

Fukuroi, H (2012). *Damage from typhoon Talas to civil engineering structures for hydropower and the effect of the sediment bypass system at Asahi dam*. Proc. Int. Symposium on Dams for a changing World, Kyoto, Japan.

Golz, E (1999). *Dynamic bed stabilization of navigable rivers*. Proc. IAHR Symposium on River, Coastal and Estuarine Morphodynamics, University of Genoa, Italy, pp 101–110.

Harada M, Terada M, & Kokubo T (1997). *Planning and hydraulic design of bypass tunnel for sluicing sediments past Asahi reservoir*. Proc. 19th ICOLD Congress C9, Florence, Italy, pp 509–539.

Hotchkiss RH, & Huang X (1995).*Hydrosuction sediment-removal systems (HSRS): Principles and field test*. Journal of Hydraulic Engineering ASCE 121(6), pp 479–489

ICOLD (1989). *Sedimentation control of reservoirs*. Bulletin 67, International Commission on Large Dams, Paris, France.

ICOLD (1999). *Dealing with reservoir sedimentation*. Bulletin 115, International Commission on Large Dams, Paris, France.

ICOLD (2009). *Sedimentation and sustainable use of reservoirs and river systems*. Bulletin 147, International Commission on Large Dams, Paris, France.

Kantoush, SA (2014). *Effect of black hole dams in the Eastern Nile River basin: Changes in water quantity and quality of downstream countries*. Proc. 7th River Flow, Int. Conference on Fluvial Hydraulics (Schleiss et al. eds.), Taylor and Francis, pp 1849-1855.

Kantoush SA, & Sumi T (2010). *River morphology and sediment management strategies for sustainable reservoir in Japan and European Alps*. Annuals of DPRI 53B, pp 821-839.

Kantoush SA, Sumi T, Suzuki T, & Murasaki M (2010). *Impacts of sediment flushing on channel evolution and morphological processes: Case study of the Kurobe River, Japan*. Proc. 5th River Flow, Int. Conference on Fluvial Hydraulics (Dittrich et al. eds.), Braunschweig, Germany, pp 1165-1173.

Kantoush SA, Sumi T, & Murasaki M (2011). *Evaluation of sediment bypass efficiency by flow field and sediment concentration monitoring techniques*. Annual Journal of Hydraulic Engineering JSCE 55.

Kashiwai J, Sumi T, & Honda T (1997). *Hydraulic study on diversion facilities required for sediment bypass systems*. Proc. 19th ICOLD Congress Q74 R59, Florence, Italy.

Kondolf GM, Gao Y, Annandale GW, Morris GL, Jiang E, Zhang J, Carling P, Fu K, Guo Q, Hotchkiss R, Peteuil C, Sumi T, Wang H-W, Wang Z, Wei Z, Wu B, & Yang CT (2014). *Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents*. Earth's Future 2(5), pp 256-280.

Lai JS, & Shen HW (1996). *Flushing sediment through reservoirs*. Journal of Hydraulic Research 34 (2), 237–255.

Liu J, Minami S, Otsuki H, Liu B, & Ashida K (2004). *Prediction of concerted sediment flushing*. Journal of Hydraulic Engineering ASCE 130(11), pp 1089-1096.

Martín EJ, Doering M, & Robinson CT (2015). *Ecological effects of sediment bypass tunnels*. Proc. 1st Int. Workshop on Sediment Bypass Tunnels, ETH Zurich, VAW Mitteilungen 232 (Boes, Ed.), pp 147-156.

Minami S, Noguchi K, Otsuki H, Fukuri H, Shimahara N, Mizuta J, & Takeuchi (2012). *Coordinated sediment flushing and effect verification of fine sediment discharge operation in Kurobe River*. Int. Symp. on Dams for a Changing World, Kyoto, Japan.

Mivelaz L, Favez B, & Lazaro P (2006). *Upgrading the Maigrauge dam*. Proc. 22nd ICOLD Congress, Barcelona, Spain.

Morris GL, & Fan J (1998). *Reservoir sedimentation handbook*. McGraw-Hill Book Co., New York, USA.

Müller P, & De Cesare G (2009). *Sedimentation problems in the reservoirs of the Kraftwerke Sarganserland - venting of turbidity currents as the essential part of the solution*. Proc. 23rd ICOLD Congress Q89 R21, Brasilia, Brazil.

Nakajima H, Otsubo Y, & Omoto Y (2015). *Abrasion and corrective measures of a sediment bypass system at Asahi Dam*. Proc. 1st Int. Workshop on Sediment Bypass Tunnels, ETH Zurich, VAW Mitteilungen 232 (Boes, Ed.), pp 21-32.

Randle TJ, Bountry JA, Ritchie A, & Wille K (2015). *Large-scale dam removal on the Elwha River, Washington, USA: Erosion of reservoir sediment*. Geomorphology 246, pp 709-728.

Schleiss A, & Oehy C (2002). *Verlandung von Stauseen und Nachhaltigkeit (Sedimentation of reservoir and sustainability)*. Wasser, Energie, Luft 94(7/8), pp 227–234 (in German).

Schleiss A, De Cesare G, & Jenzer Althaus J. (2010). *Verlandung der Stauseen gefährdet die nachhaltige Nutzung der Wasserkraft (Sedimentation of reservoirs endangers the sustainable use of hydropower)*. Wasser Energie Luft 102(1), pp 31–40 (in German).

Sumi T, Okano M, & Takata Y (2004a). *Reservoir sedimentation management with bypass tunnels in Japan*. Proc. 9th International Symposium on River Sedimentation, Yichang, China, pp 1036–1043.

Sumi T, Takata Y, & Okano M (2004b). *Quantitative evaluation of a bypass tunnel to prevent reservoir sedimentation*. Journal of Japan Society of Civil Engineers, Advances in River Engineering 10, pp 197-202, (in Japanese).

Sumi T (2005). *Sediment flushing efficiency and selection of environmentally compatible reservoir sediment management measures*. 2nd EADC Symposium - Int. Symposium on Sediment Management and Dams, Yokohama, Japan.

Sumi T, & Kanazawa H (2006). *Environmental Study on Sediment Flushing in the Kurobe River*. Proc. 22nd ICOLD Congress, Q85 R16, Barcelona, Spain.

Sumi T (2008). *Evaluation of efficiency of reservoir sediment flushing in Kurobe River*. Proc. Int. Conference on Scour and Erosion 4, Tokyo, Japan, pp 608-613.

Sumi T, Nakamura S, & Hayashi K (2009). *The effect of sediment flushing and environmental mitigation measures in the Kurobe River*. Proc. 23rd ICOLD Congress, Q89 R6, Brasilia, Brazil.

Sumi T, & Kantoush SA (2011). *Comprehensive sediment management strategies in Japan: Sediment bypass tunnels.* 34th IAHR World Congress, Brisbane, Australia, pp 1803–1810.

Sumi, T (2015). *Comprehensive reservoir sedimentation countermeasures in Japan*. Proc. 1st Int. Workshop on Sediment Bypass Tunnels, ETH Zurich, VAW Mitteilungen 232 (Boes, Ed.), pp 1-20.

Sumi T, Yoshimura T, Asazaki K, Kaku M, Kashiwai J, & Sato T (2015). *Retrofitting and change in operation of cascade dams to facilitate sediment sluicing in the Mimikawa River Basin*. Proc. 25th ICOLD Congress, Stavanger, Norway.

UVEK (2010). *Bundesgesetz über den Schutz der Gewässer (Federal law for the protection of the water body)*. Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation (UVEK), Switzerland (in German).

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