# Ecological importance of an integrated approach to riverbed management –case study analysis

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## Abstract

There are various options for flow and sediment management at various reaches of a river basin such as: sediment bypass tunnel, dam removal, sediment replenishment, managed flows by reservoir operation, channel widening and creating secondary channels, etc., over the world. Firstly, we collect several case studies on flow, sediment, and channel management options at different reaches of a river basin in Japan, Switzerland, and USA. Secondly, we compare the effectiveness and limitation of these options from a perspective of area benefited, temporal scales, habitat heterogeneity created, ecological functions restored, etc., with due consideration to sediment characteristics. Thirdly, based on these results, we discuss ecological importance of an integrated approach to riverbed management.

Keywords: sediment regime, flow regime, riverbed management, integrated approach, spatiotemporal patterns

## 1 Introduction and objectives

River morphology is determined by sediment and flow regimes, creating and eliminating geomorphic features at different scales under given disturbances (Hyodo 2014). Dams have the potential to negatively affect its downstream rivers unless appropriately designed, e.g., reduced discharge and variability of flows and reduced longitudinal connectivity of sediment, resulting in degrading riverbed elevation and narrowing and fixing channels with intensive vegetation encroachment; and coarsening riverbed sediment particles and creating homogeneous habitats. These changes are likely to have the negative impact on ecological functions to sustain.

There are various options for flow and sediment management at various reaches of a river basin over the world. Even though these options have shown positive results to restore dynamic change in geomorphic features and ecological functions, we should look at both effectiveness and limitation of these options from spatiotemporal perspectives. For example, even though a sediment bypass tunnel for gravel, which is constructed along a dam and reservoir, can expect ecological benefits at the downstream of the bypass outlet, its benefits may be limited to some kilometers under a short-term strategy.


Fig. 1: Asahi and Koshibu in Japan and Pfaffensprung and Solis in Switzerland. Sediment bypass tunnels were installed at Asahi in 1998, Koshibu in 2016, Pfaffensprung in 1922, and Solis in 2012. Photos in Japan are from Awazu *et al*. (2015).

An objective of this study is to analyze differences in these options (i.e., both the effectiveness and limitation) and to discuss ecological importance of an integrated approach to riverbed management.

## 2 Case studies addressing flow, sediment, and channel management

We collected several case studies on flow, sediment, and channel management options at different reaches of a river basin in Japan, Switzerland, and USA. These case studies are summarized in brief in the following sections.

### 2.1 Sediment bypass tunnels

Japan and Switzerland are the leading countries for sediment bypass tunnels, for example, Nunobuki, Asahi, Miwa, and Koshibu in Japan and Egschi, Palagnedra, Pfaffensprung, Rempen, Runcahez, and Solis in Swizerland (Kondolf *et al*. 2014). A research was conducted by Awazu *et al.* (2015) in Asahi and Koshibu in Japan and Solis and Pfaffensprung in Switzerland in order to understand effects of sediment bypass on the stream ecosystem of dams by comparing riverbed material and benthic invertebrates in the up- and down-stream of a dam (Fig. 1). Sediment bypass tunnels were installed: Asahi in 1998, Koshibu in 2016, Solis in 2012, and Pfaffensprung in 1922. They are designed to bypass both gravel and sand material to the downstream of dams. Koshibu and Solis have experienced only a few years since the first operation of sediment bypass tunnels.


Fig. 2: Coarse sediment augmentation photographs. A) Construction of the first artificial spawning bed in 1972 at a river mile of 112.0 from its river mouth (RM 112.0). Photograph shows low-flow placement of oversize sediment used for grade control structure and coarse sediment augmentation for the artificial riffle; B) Low-flow placement of coarse sediment in the form of constructed point bars in 2009 (RM 110.4); C) High-flow injection of coarse sediment in 2011 (RM 104.9). Photos are from Krause (2012).

The results showed that, in Asahi and Pfaffensprung, sediment bypass tunnels can restore the riverbed material from getting too coarse and create a formation of invertebrates similar to upstream reaches of a dam. On the other hand, in Koshibu and Solis, positive effects of the riverbed material and invertebrates could not be found, since these dams have experienced gravel supply via sediment bypass tunnels only a few years (Awazu *et al.* 2015). These results indicate that sediment bypass tunnels have the potential for restoring fluvial systems and resultant ecological processes, but it takes a certain period to obtain its effects on the downstream rivers.

## 2.2 Sediment replenishment

Sediment replenishment has been implemented, particularly in Japan and USA. For example, Miharu, Futase, Miyagase, Yahagi, Managawa, Haji, Nagayasuguchi, Hitokura, Akiha, Sagami, etc. in Japan (MLIT 2011) and Trinity in USA. (Trinity River Restoration Program 2011). Volumes of sediment replenishment differ among these rivers in Japan, ranging from 100 $m^3$ in Haji to 78,000 $m^3$ in Nagayasuguchi in Japan (MLIT 2011) and from 400 $m^3$ to 12,000 $m^3$ in Trinity (Krause 2012, see Fig. 2). Some case studies have addressed gravel material expected to restore parts of fluvial processes, creating sandbars, pools and riffles, and spawning habitats e.g., in Nagayasuguchi and Trinity in a reach scale, and to promote detachment of attached

A) Sediment replenishment just implemented below the Miyagase dam.

B) Sediment transported downstream by a reservoir operation for managed flows.

Fig. 3: Sediment replenishment at the Miyagase dam. (SRBC 2015) Approximately 200 m$^3$ of sediment was replenished on the riverbed at the downstream of Miyagase. The sediment was flushed away after a flood event. At the Miyagase dam, a reservoir operation for managed flows was also implemented with the view to detaching the attached algae.

algae to keep them in a fresh state, e.g., in Haji and Miyagase (Fig. 3). Other case studies have addressed sand material expected to restore deteriorated coastal shorelines within the river basin. In the case of Japan, most of cases have been in the demonstration processes to understand effectiveness and impact of sediment replenishment on the downstream rivers. It is noted that most of cases showed that sediment replenishment has the positive effects at a small scale, but has not reached to creating dynamic state of downstream channels due to sediment-volume shortage to be replenished. This indicates that rivers require much sediment for the downstream rivers of dams, remaining a hangry state of sediment (Kondolf 1997).

## 2.3 Combinations of sediment replenishment, channel modification, and environmental flows

There are a few case studies combining several options in an effort to restore flow and sediment regimes to the extent possible. In the Trinity River, Trinity River Restoration Program (TRRP) has been implemented with the aim to create dynamic fluvial systems for Salmon and Trout to sustain, but not to bring back to pre-dam conditions (McBain & Trush, Inc. 2000). A combination of several options has been adopted, for example, course sediment injection during high flows, channel modification for creating Salmon and Trout Habitat, and artificial floods, in order to provide variable sediment and high flows, to create spawning gravels, to build gravel bars, to provide adequate habitat conditions for fish and wildlife at different stages, and to restrict intense riparian vegetation growth (McBain & Trush, Inc. 2000).

In the Managawa River, a combination of sediment replenishment, creating secondary channels, and environmental flows has been implemented since 2003 (MLIT 2017).

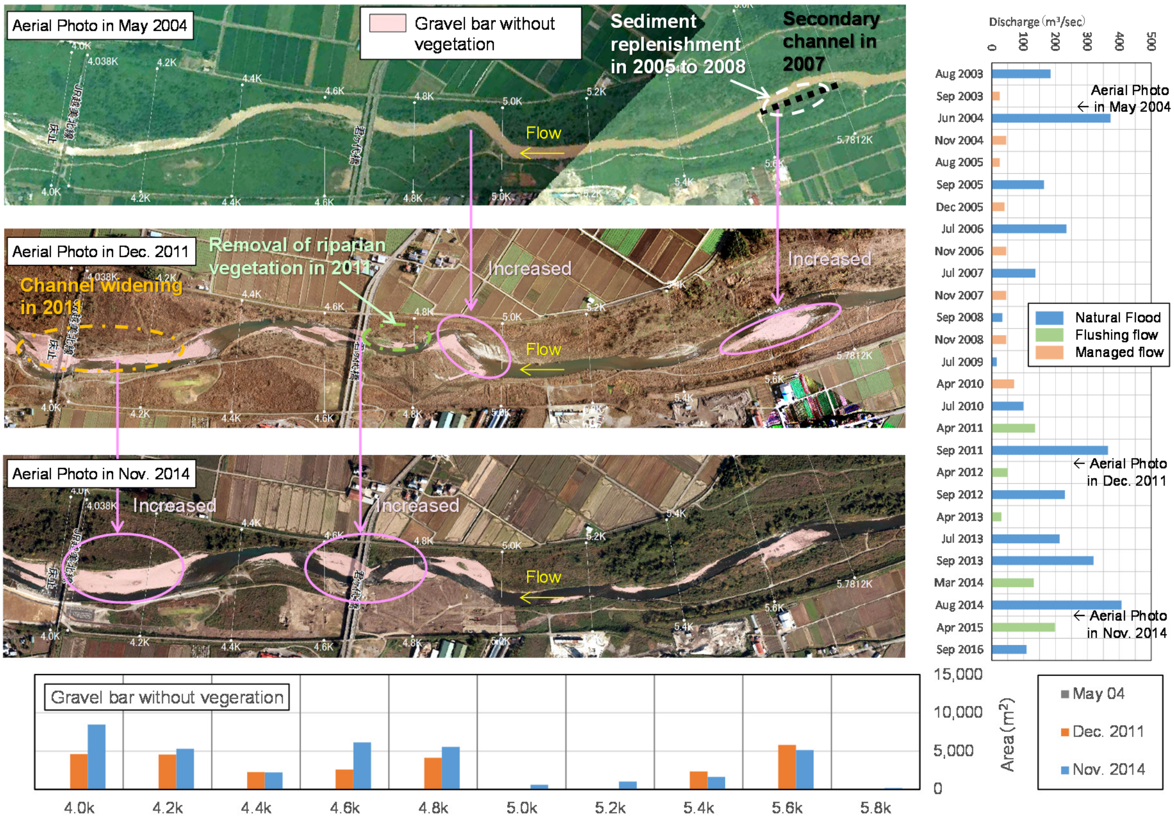


Fig. 4: Relationships between change in areas of gravel bars and a combination of options, i.e., channel modification, sediment replenishment, and managed flows in Managawa River in Japan. Modified based on MLIT (2017). Gravel bar area was increased when channel modification and sediment replenishment were carried out. These area have been maintained even it past several years.

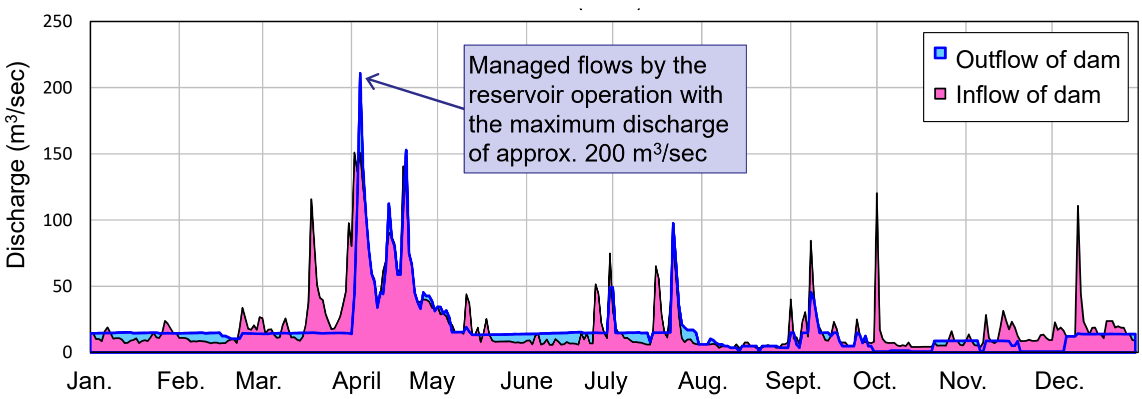


Fig. 5: Discharge hydrograph of inflows and outflows of the Managawa dam in 2015 (MLIT 2015). Under the low flow conditions, outflows are larger than inflows, positively contributing to increase in discharge to for fish species to sustain their lives. Managed flows were carried out during the snowmelt season by reservoir operation with the maximum discharge of 200 $m^3/s$ for 6 hours. Analysis showed that discharge more than 170 $m^3/s$ has been reduced due to dam operation and therefore play an important role in bring back to near pre-dam conditions.

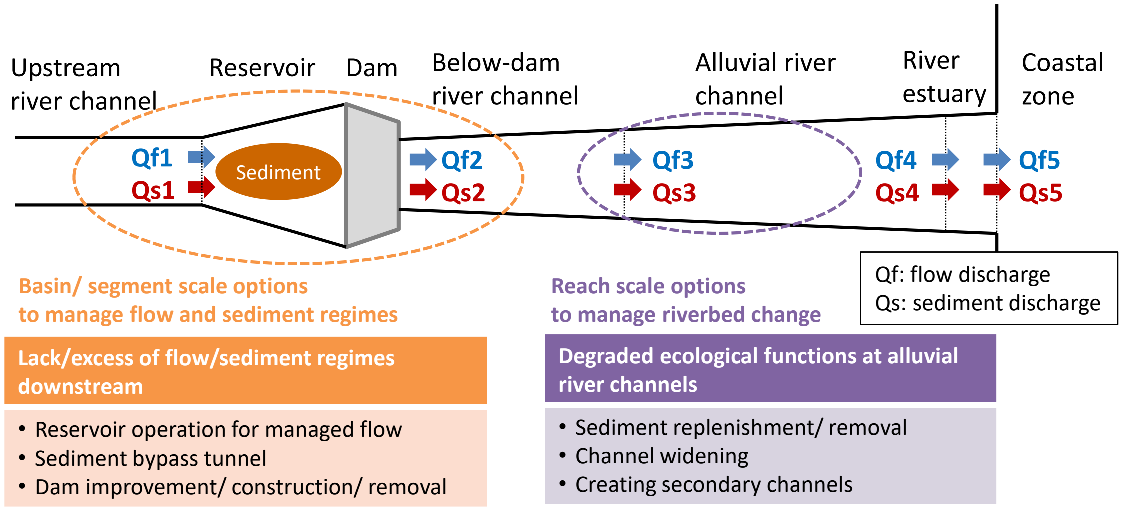


Fig. 6: A schematic diagram on options for riverbed management at basin/segment and reach scales.

This case study identified three key components of managed flows, sediment replenishment, and channel modifications such as secondary channels and removal of riparian vegetation. As shown in Fig. 4, the result shows that adopting combination of secondary channels and sediment replenishment can have the potential to create and maintain gravel bed river and number of riffle and pools that are important as habitat of fish and macroinvertebrates (MLIT 2017). Fig. 5 also shows the positive effects of managed flows on the downstream rivers of a dam from a perspective of requirements of flow regimes to be fulfilled.

# 3 Discussion and conclusions

## 3.1 An integrated approach to river basin management

Fig. 6 shows a schematic diagram on options for riverbed management at basin/ segment and reach scales. For basin/segment scale options, flow and sediment discharge into and/or from reservoirs can be managed, which are likely to influence flow and sediment regimes further downstream such as alluvial river channel, river estuary, and coastal zone depending on characteristics of flows and sediment (volume and particle size) and downstream geomorphology. Gravel material can be transported within a short distance during a flood event, indicating that it can have the potential to restore fluvial systems just rivers below a dam within a relatively short period and it requires long time to restore fluvial systems in rivers below further downstream of a dam. However, sand material has the potential to be transported further downstream to restore deteriorated coastal shorelines of the river basin.

For reach scale options, sediment discharge supplied to alluvial river channels can be managed by sediment replenishment. Flow discharge can be managed in collaboration with basin/segment scale options in an integrated manner. Effects of these options for restoring fluvial processes can be increased by combining channel modifications, e.g., channel widening, creating secondary channels, etc. Channel modifications can play a role as a trigger for dynamic changes of rivers under given disturbances induced by flow and sediment discharge. However, they may not be influential to the further downstream geomorphology. Therefore, we suggest that an integrated approach to riverbed management is required to restore fluvial systems and resultant ecological processes.

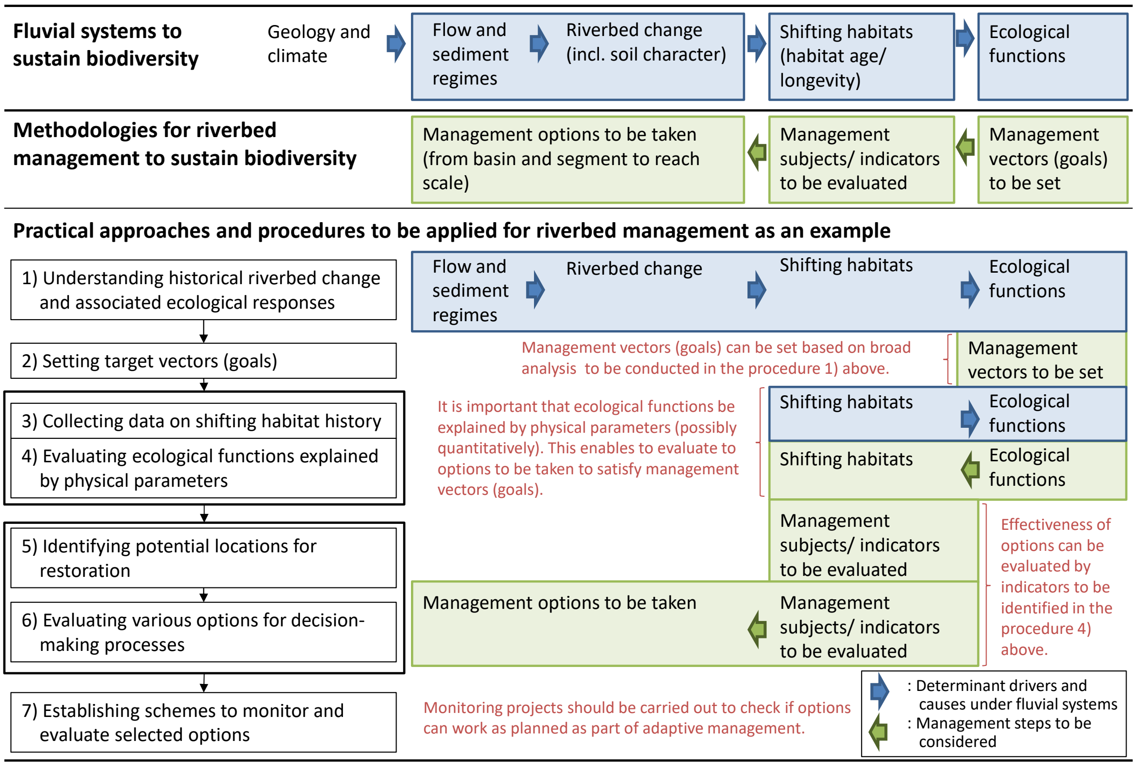


Fig. 7: A schematic diagram on fluvial systems to sustain biodiversity and methodologies for riverbed management.

## 3.2 Methodologies for riverbed management

We suggest methodologies for riverbed management. Fig. 7 shows a schematic diagram on fluvial systems to sustain biodiversity and methodologies for riverbed management. Methodologies for restoring fluvial systems to sustain biodiversity should have reverse steps against determinant drivers and causes of fluvial systems to work. In brief, firstly management vectors (goals) can be set in the procedure 2), based on broad analysis to be conducted in the procedure 1). Secondly, analyses under the procedure 3) and 4) are of particular importance, even though this has not been discussed in this article, and would be that ecological functions should be explained by physical parameters (possibly quantitatively). This enables to evaluate options to be taken to satisfy management vectors (goals). Thirdly, in the procedure 5) and 6), effectiveness of options can be evaluated by indicators to be identified in the procedure 4). Finally, monitoring projects should be carried out to check if options can work as planned as part of adaptive management in the procedure 7).

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