IMPACTS OF SEDIMENT REPLENISHMENT BELOW DAMS ON FLOW AND BED MORPHOLOGY OF RIVER

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Abstract

Dams greatly influence flow and sediment discharge regimes and can have significant impact on downstream reaches below dams. Bed load sediment management in reservoirs is required to preserve the capabilities of water resources facilities and to conserve the environment in rivers and coastal areas downstream of the reservoir. The sediment deficit produces a large variety of physical (bed armouring, bank erosion, lowering water table, river incision), ecological (impoverishment of aquatic and riparian habitats) and environmental (oxygen stratification) effects. An effective means of such comprehensive reservoir sediment management is to excavate and transport part of the coarse sediment, which accumulated in reservoirs to the river channels downstream, and then the sediment is transported by flood water in the channels to the sea. Actual prototype sediment replenishment is carried out, to excavate some of the sediment deposited in reservoir of Murou dam, transported to Uda River bank, and discharged downstream river. In the present paper, parameters and process of sediment replenishment characteristics are discussed. The paper identifies the characteristics of sediment replenishment in the downstream of Murou Dam and presents results of sediment replenishment on river bed changes. Appropriate sediment excavation and treatment techniques from the upper part of the reservoir and replenishing them to downstream rivers, contributes to maintain river bed levels, and mitigate the armouring of river bed materials. The amount of sediment needed and the periodicity of the replenishment should be adapted to the deposition volume in reservoir and seasonal behaviour of every river. The field tests will provide data to validate and enhance modelling and restoration efforts.

Keywords: Management of bed load, Sediment replenishment, River restoration, Monitoring, Reservoir sedimentation, Erosion mitigation.

Introduction

Modern human activities (e.g. dam construction, channelization, gravel mining, bank reinforcement), have transformed many rivers state from dynamically active and spatially complex system to more static and homogenous ones, leading to detrimental effects on the physical habitat and ecosystem (Pedroli et al., 2002). Dams and their reservoirs are constructed and operated for multipurpose including hydroelectric power generation, flood protection,

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drinking water and agricultural water supply. Regardless of their purpose, all multipurpose dams trap sediment and inevitably lead to physical and ecological changes downstream of the reservoir site, as well as in the reservoir itself, and in some cases also upstream. Kondolf (1997) has described that, by changing flow regime and sediment load, dams can produce adjustments in alluvial channels, the nature of which depends upon the characteristics of the original and altered flow regimes and sediment loads. Downstream impacts develop through discontinuity in downstream gradients, e.g., sediment supply, water quality, temperature, flow and sediment regimes.

Figure 1 classifies the impacts of sediment deficit downstream of dam to three groups; morphological, hydrological, and ecological effects. Sediment deficit is not only an environmental issue but also a socio-economic problem, for instance due to loss of reservoir capacity (e.g., Fan and Springer, 1993). In addition, dams alter the downstream flow regime of rivers (Williams and Wolman, 1984), which controls many physical and ecological aspects of river form and processes, including sediment transport and nutrient exchange (Poff et al., 1997). Morphological effects on the river channel (e.g., Kondolf and Matthews, 1993; Shields et al., 2000) that includes riverbed incision, riverbank instability, upstream erosion in tributaries, groundwater over drafting, damage to bridges, embankments and levees (e.g., Kondolf, 1997; Rinaldi and Simon, 1998; Batalla, 2003), and changes in channel width (e.g., Williams and Wolman, 1984; Wilcock et al., 1996). Hydrological effects caused by dams include changes in flood frequency and magnitude, reduction in overall flows, changes in seasonal flows, and altered timing of releases (Petts, 1984; Ligon et al., 1995). If flows released from dams have sufficient capacity to move coarse sediment, water becomes 'hungry water' (Kondolf, 1997), which may transport sediment downstream without replacement from upstream and the ecological effects on the fluvial and deltaic systems (e.g., Kondolf and Wolman, 1993), and propagation of riparian vegetation into previously unvegetated or lightly vegetated areas (e.g., Church, 1995; Vericat and Batalla, 2005).

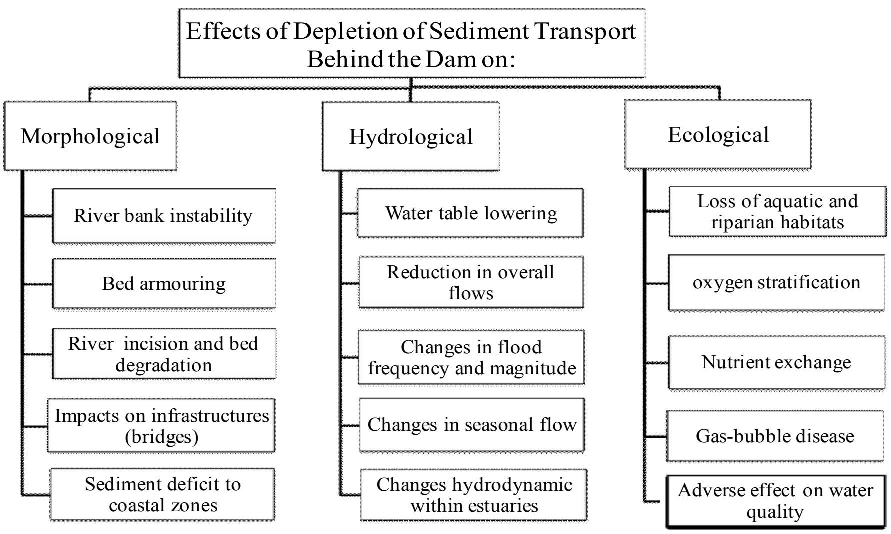


Fig. 1. Possible effects due to lack of sediment transport in the downstream reach below dams on channel morphology and environment

Dam effects can vary, depending on the distance to the dam and other boundary conditions. Depending on the supply from the tributaries the main river will have to erode sediments from the banks to compensate for the supply limitation. Channel erosion may lead to an interruption of lateral connectivity with the adjacent floodplain. At the same time, dams often reduce flood discharges significantly, that reduce the transport capacity of the river downstream. In general, the combination of reduced supply of coarse material and reduced transport capacity significantly reduces the potential for erosion and aggradations in the channel and floodplain, and causes a major morphological readjustment (Petts, 1984). The number of the worldwide large rivers that do not reach the ocean any more is on the rise and their river deltas suffer dramatic changes. If a river runs into the sea, regulating the river will probably have an effect in and around its mouth (Baxter, 1977). Since the construction of the Aswan High Dam, the area of the Nile Delta has been reduced because of the disturbance of the equilibrium between erosion by the sea and deposition of sediment by the river (Aleem, 1972). The sardine catches in the Mediterranean near the mouth of the Nile have decreased, owing either to the absence of nutrients formerly provided by the river or to the dispersal of the fish over a wider area (George, 1972).

Sustainable management of sediment in river basins must be done on a regional basis, restoring the continuity of sediment transport where possible and encouraging alternatives to river-derived aggregate sources. Different management and ecological restoration measures to compensate the sediment deficit downstream from dams are conducted in some rivers (Kondolf, 1997). For instance, controlled flow releases (flushing flows) and beach nourishment with imported sediment dredged from reservoirs and harbours has been implemented along many rivers (Inman 1976; Everts 1985; Sumi and Kanazawa 2006; Sumi 2005; Kantoush et al 2009). These measures range from optimising the compensation discharges, to reconnecting the river water bodies, and artificial sediment feeding (sediment replenishment). Sediment replenishment measures follows several protocols, according to the material sources (banks, alluvial terraces, excavations due to works, gravel mining, etc.) and the way of injection (pumping from ships, introduction from bank, recreation of artificial bed forms, etc.). The efficiency and potential negative effects must be investigated through studies and local tests before large-scale operations, and by detailed monitoring after such operations. Even if some reports of past test are available, the state of the art is not consolidated enough to draw general guidelines. There are gaps to quantitatively assess the sediment deficit caused by large dams on a large river system, based upon regular, systematic and extensive direct measurements of total load (both in suspension and as bed load) upstream and downstream of the reservoirs.

In Japan, Europe, and USA, large rivers are often trained to a large extent, to maintain services such as navigation, hydropower generation and flood defence. Okano et al., (2004) summarize sediment replenishment projects in large Japanese Rivers such as Tenryu, Otakine, Abukuma, Ara, Oi, Naka, Kuzuryu, Yodo, Kanna, and Tone, have been conducted by Ministry of Land, Infrastructure and Transport (MLIT). Sediment treatment system is applied by Sumi et al. (2009), to produce appropriate grain sized material with less turbidity. Investigations of effects of sediment replenishment downstream of Yahagi dam is analysed by Seto et al., (2009). Large European rivers such as the Rhône, the Rhine, or the Danube, have been undergoing ecological and hydraulic restoration measures, especially in reaches bypassed by hydraulic structures.

Today, rehabilitation of damaged and modified aquatic ecosystems has become an integral part of catchment and river management. Sediment transport and associated channel bed mobility are recognized as key processes for creating and maintaining physical habitats, aquatic and riparian ecosystems. In this context, various river restoration projects have been initiated or implemented in many countries. Some examples include creation of secondary channels along the Rhine River (Simons et al. 2001), reconnecting the Danube side-arm system to the main channel (Tockner et al. 1998), removing bank protection structures to initiate sediment transport in the Mur River (Kloesch et al. 2008), artificial gravel supply in the Ain River (Rollet et al. 2008), and removing dams in North America (Hart and Poff 2002) to re-establish the river continuum. Gravels were being artificially added to enhance available spawning gravel supply below dams on at least 13 rivers in California Sacramento, Merced, Tuolumne, Mokelumne, Stanislaus, Russian, Dry, San Juan, San Luis Rey, Cache, Dry, Stony, and Tujunga Wash Rivers (Kondolf and Matthews 1993).

In Japan, sediment replenishment projects are undertaking with different configurations and characteristics of sediment and discharges. Some of these projects are successful when placed sediments are washed during high flows. But, in the other part of these projects, sediment replenishment is not mobilized or transported according to the post- project monitoring. The central challenge in sediment replenishment research is, however, to determine sediment and flow characteristics, which operation to implement, and how to determine sediment replenishment factors. Figure 2 summarizes factors that influence the sediment replenishment research. These factors are classified in six groups as shown in Figure 2. Indeed, river morphodynamics is a complex process that involves a high degree of interactions between the flow and sediment transport. And several significant gaps in the scientific understanding of these processes remain, particularly concerning how riverbed deposition, mobility and geometry are influenced by changes in the discharge and sediment supplies. Replenishment scenarios may, therefore, induce undesirable morphological and ecological consequences as well as significant channel adjustments that can result in failure of the restoration project itself. That is, it is necessary to better understand reversibility, direction and time scale of changes, and the sustainability of a replenishment intervention before it is implemented.

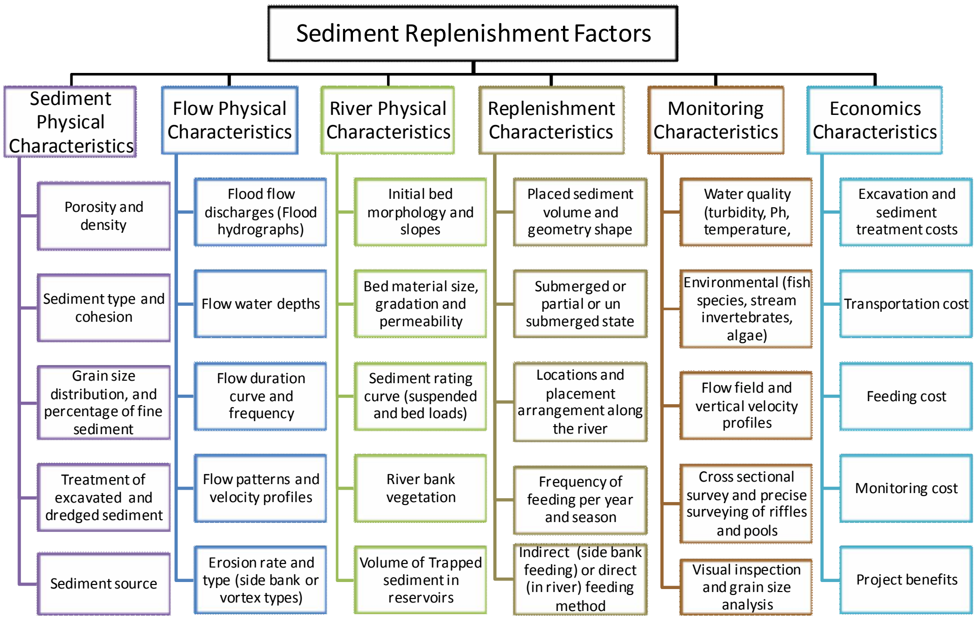


Fig. 2. Main groups of sediment replenishment characteristics and managing factors

Aim Of The Study

The study focuses on the design criteria for sediment replenishment projects in Japan to improve river bed conditions. The investigations are based on field measurements for field tests. The study will answer on the following questions:

- How much sediment volume has to be supplied in order to avoid bed degradation or aggradations?
- What are the suitable sediment characteristics, grain size distribution and percentage of fine sediment?
- What is the most appropriate sediment source to use in terms of quality and economics?
- What is the best method of sediment replenishment in order to maximize effects for improvement and minimize adverse environmental impacts and riparian ecology?
- Which geometry shape of the placed sediment has to be chosen in order to ensure sediment transport and erosion process?
- Where the sediment should be supplied in the sediment deficit reach (several positions or only one place)? What is the best arrangement for the placed sediment positions and locations?
- Which season and how often the sediment has to be injected?
- What is interaction between the sediment supply and sediment bed? How, when and where the sediment will be transported and deposited?
- How much is the sediment transport capacity?
- What are the impacts of the supplied sediment on the physical parameters of the river?

The objectives of this paper are: (a) to make a general review of impacts of dam on downstream reach; (b) to discuss the role of different factors influencing the sediment replenishment research; (c) to illustrate and analyse the sediment replenishment through a regulated fluvial system, Uda River, during actual field tests on 2008 and 2009; (d) to draw some general conclusions in terms of future strategies for sediment management.

Replenishment Procedure

In Japan, it is common practice, as a means of reservoir maintenance, to remove accumulated coarse sediment by excavation and dredging, and to make effective use of the removed sediment. Sediment replenishment method is consisting of trapping coarse sediment in the upstream area of the reservoir (Figure 3). In this method, trapped coarse sediment is periodically excavated (or dredged depending on the site conditions) and then transported and placed temporarily on the channel downstream of the dam, in a manner decided according to the sediment transport capacity of the channel and the environmental conditions, so that the sediment is returned to the channel downstream in natural flooding processes.

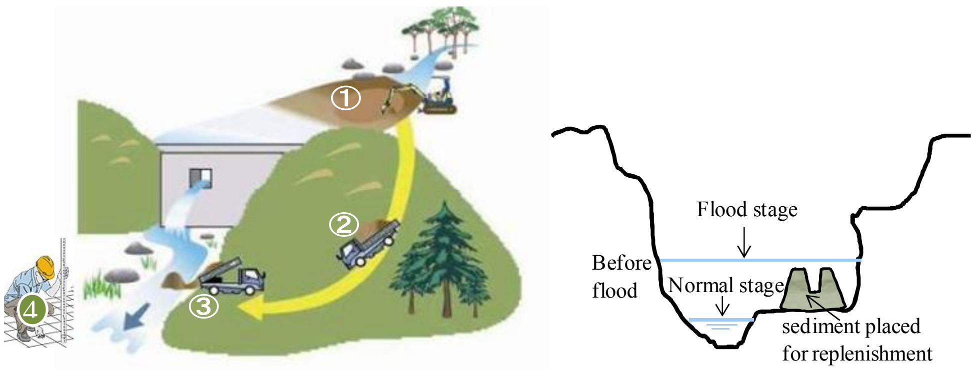


Fig. 3. Concept of sediment replenishment: (1) Extracting mechanically the accumulated sediment; (2) Transporting it by truck to the downstream river bank; (3) Putting the coarse sediment and pours; (4) Monitoring of river flow, sediment, and environmental parameters

The procedure of the sediment replenishment test is shown in Figure 3. Four procedure steps to prepare the sediment replenishment test are shown in Figure 3. Sediment hauled to the river channel is placed so that it does not get waterborne in times of normal flow and it is gradually transported downstream after flooding river water begins to become turbid. Thus, replenishment sediment is placed at such an elevation that it does not become a source of turbidity in times of normal flow and bank erosion occurs as stream flow increases. The top of the sediment placed for replenishment is adjusted so that the sediment is completely submerged in flood water several times a year and all sediment is eventually transported downstream (see Fig. 3).

The Study Area

Figure 4 shows the 75 km long Yodo River (Yodo-gawa) system, located in the central part of Japan. It encompasses 6 prefectures, namely Mie, Shiga, Osaka, Hyogo and Nara, and is the seventh largest river basin in Japan with a catchment area of 8,240 km^2. Flowing south out of Lake Biwa, the largest lake in Japan, first as the Seta River and then the Uji River, it merges with the Kizu and Katsura Rivers near the border between Kyoto and Osaka Prefectures. There are five completed dams in the Kizu River System, Murou, Shourenji, Hinachi, Takayama, and Nunome dams as shown in Figure 4. The Japan Water Agency (JWA) maintains water resource development of the five dams. Murou dam is a gravity dam for flood control and water supply, located in Uda River, was completed 32 years ago, in 1974. The dam height is 63.5 m and has a catchment area of 169 km^2. The Murou reservoir has storage capacity of 16.9 Mm^3.

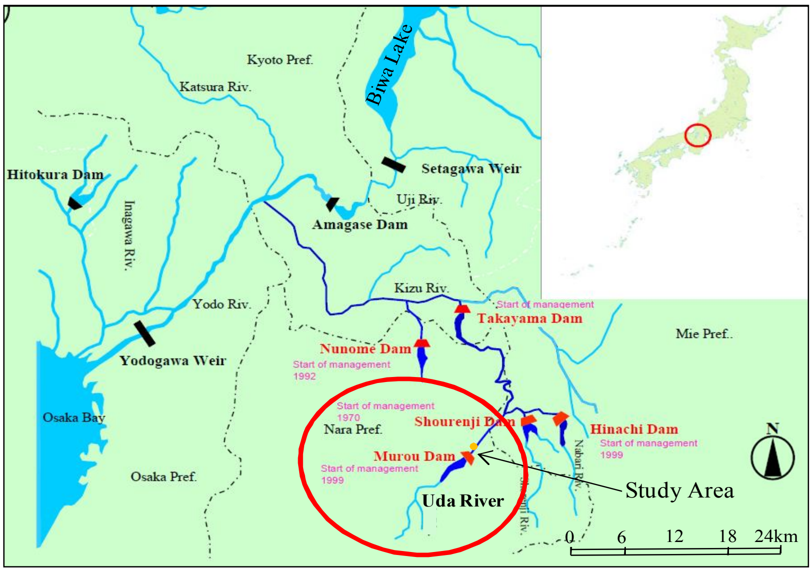


Fig. 4. Map of Yodo River system showing location of Murou dam in Kizu River system.

Cumulative sediment in Kizu River upstream reservoir

Dam reservoirs are normally designed to have a capacity to store 100 years' worth of sediment in the deepest parts close to the dams, but sediment flowing from the upper rivers is often deposited in areas of effective storage capacity near the entrances to the reservoirs. Sediment accumulation in the Kizu River upstream group dams up to the end of fiscal 2006 are shown in Table 1. The table shows that sedimentation in all five dams has progressed faster than that of the original plan. In Japan, the planned sedimentation capacity is set by the sedimentation of 100 years. Sedimentation of Murou dam that were constructed more than 30 years ago have already reached 40 to 50% of planned sedimentation. Regarding annual fluctuation of sediment load of Murou dam, maximum annual sedimentation in a single year is 314,000 m^3. The maximum annual sedimentation is about 12% of planned sedimentation capacity.

Table 1. Sedimentation rate of Kizu River upstream dam group (Sumi, 2009)

Name of Dam	Elapsed time (Years)	Planned sedimentation capacity in 100 years (MCM)	Actual sedimentation in 2006 (MCM)	Sedimentation rate (%)
Murou	32	2.6	1.12	43.1
Shorenji	36	3.4	1.484	43.6
Nunome	16	1.9	0.243	12.8
Hinachi	9	2.4	0.41	17.1
Takayama	37	7.6	3.648	48.1

Sand replenishment projects below Kizu River upstream dam

In Japanese reservoirs the check dams are effectively used to trap sediment due to the higher percentage of sediment bed load to the total sediment load. In general, reservoir deposits are attractive sources of aggregates to the extent that they are sorted by size. Figure 5(a) shows the location map of check dam and reservoir shape. Check dam is small dam constructed at the upstream end of the reservoir. It has low trap efficiency for suspended sediments and traps primarily sand and gravel sediment. These coarse sediment deposits can be removed periodically as shown in Figure 5(b). Designers of replenishments projects are faced with the challenges of estimating the sediment deficit volume and determine sediment grain size distribution. Sand for replenishment can be obtained from the deposition upstream of check dam. The deposited sediment usually require more processing and often require longer transportation. Although their production costs are commonly higher, the sediment excavation provide other benefits, such as partially restoring reservoir capacity lost to sedimentation and providing opportunities for ecological restoration in downstream rivers.

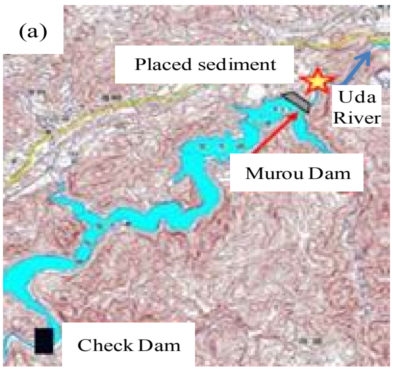


Fig. 5. (a) Location map of the check dam at the end of Murou reservoir in the Uda River; (b) Mechanical removing of deposited sediment in front of check dam

Recently, several sediment replenishment field tests are conducted. Some cases in below Kizu River upstream dam are summarized in Table 2. The volume of sediment replenishment is small compared to the deposited volume in reservoirs. Below Murou dam the sediment replenishment has been started in 2006 with volume of 225 m^3, which is 0.6% of the annual deposited sediment in reservoir (see Table 2). In fact the effective volume ratio of sediment replenishment should be at least 30 to 40% of the annual deposited volume in reservoir. Furthermore, that sediment should be from coarse sand. The present paper deals with the results and analysis of Murou dam sediment replenishment field test.

Table 2. Sediment replenishment projects downstream of dam group of Kizu River

Name of Dam	Replenishment project starting year	Annual mean volume of sediment replenishment below dam (m^3)	Annual mean volume of actual deposition in reservoir (m^3)	Sediment volume ratio of supplied over deposited (%)
Murou	2006	225	35,600	0.6
Nunome	2004	430	18,600	2.3
Hinachi	2008	65	51,800	0.1
Shorenji	2009	70	41,600	0.2

Case Study Of Murou Dam Actual Sediment Replenishment Tests

Since 2006, several replenishment projects with different sediment volumes have been undertaken below Murou dam. Tracking the history and performance of these projects is helping to answer some of questions in objectives section. Table 3 summarizes the replenishment history, flushing flow and sediments characteristics. The volume of placed sediment is limited to several hundred cubic meters each time. Two types of flow are used to transport the placed sediment; natural flood and artificial flushing flows (Table 3). To implement this method, consideration has to be given to environmental problems in the lower river basins, to the occurrence of turbid water, and to safety risks due to sediment deposition in the channel. Concrete means are being explored, taking into consideration the particle sizes of sediment, such as the scale of flood suitable for the safe implementation, and appropriate ways to place sediment in riverbeds. Fishery workers association and local residences are often against the occurrence of turbid water and excess sediment deposition in river channel.

Table 3. History of the sediment replenishment tests downstream of Murou dam

Year	Setting and placing sediment period	Time of artificial or natural flow	Type of flushing flow	Volume of placed sediment (m^3)	Volume of sediment transport
2006	From 12-5-2006 To 16-5-2006	13,14-5-2006	Natural flood	90	90
		17,18-5-2006	Natural flood	50	50
2007	From 8-5-2006 To 10-5-2006	18-5-2007	Artificial flushing	250	150
		24-5-2007	Natural flood		100
2008	From 12-5-2006 To 15-5-2006	16-5-2008	Artificial flushing	230	170
		25-5-2008	Natural flood		60
2009	From 7-5-2006 To 12-5-2006	14-5-2009	Artificial flushing	280	230
		31-5-2009	Natural flood		50

Monitoring efforts of pre- and post- replenishment methods show the effect of improvements in riverbed formation, riverbed materials, benthic organisms, and algae. The data in Table 3 indicates that there is a need to increase the amount of the supplied sediment downstream of Murou dam every year. The increasing amount of the placed sediment should be proportional to the bed load transport capacity of the river. Furthermore, the period and the discharge of artificial flow flushing should be suitable for the sediment transport capacity. The artificial flushing duration for Murou dam is approximately 10 hours during one day only (see Table 3). Neither the flushing discharge nor the flushing period is able to transport all the placed sediment volume. The remained sediment is transported during the natural flood periods that have large discharge and period. The descriptions and the results hereafter related to the last year sediment replenishment below Murou dam in right side bank of Uda River.

Field Methods

The test site for this study is placed by the Japan Water Agency (JWA) on the right side bank of Uda River downstream of Murou dam in Nara prefecture (Figure 6). Planning, design, implementation and long-term monitoring of Murou dam replenishment tests have been guided by JWA. Photographs in Figure 6 show the 2009 field test of Murou dam stilling basin and the placed sand in downstream reach at 150 m from the dam site.

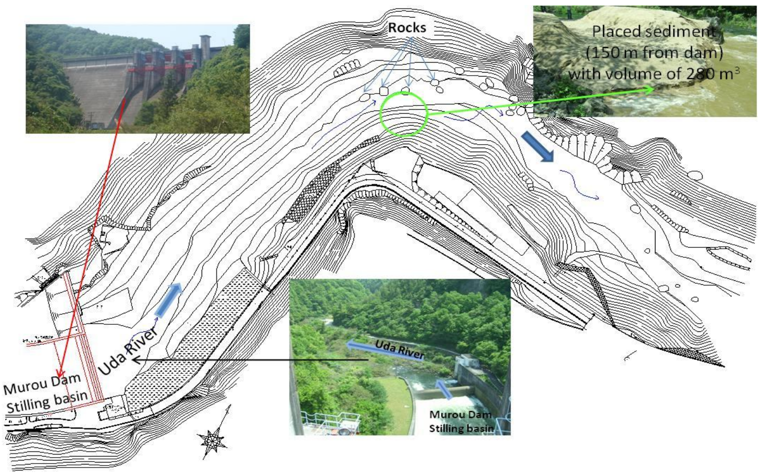


Fig. 6. Sediment replenishment site in Uda River downstream reach of Murou dam.

Placed sediment geometry and grain size distribution

Below the Murou dam 280 m^3 of sand are artificially placed to the Uda River in 2009. Figure 7 shows plan view and cross section of the placed sediment geometry. To construct the placed sediment geometry 80 sand package of 1.1 m x 1.1 m were used. The placed sediment has a trapezoidal shape with a groove channel near the river right bank. The top width of the geometry is 12 m.

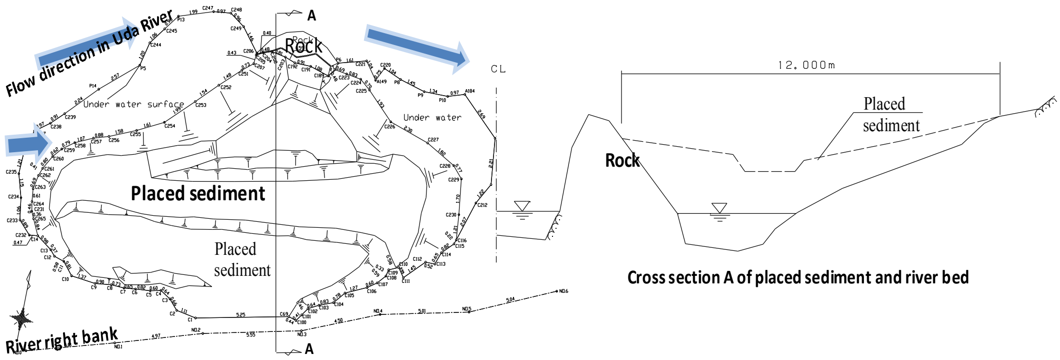


Fig. 7. Plan view and cross section geometries of the placed sediment.

Grain size is the most fundamental physical property of sediment. The supplied sediment is composed of sand and gravel with grain size of 19 mm or less. There are a lot of medium gravel with size of 10 mm and medium sand size of about 0.25 mm. The placed sediment median grain size d_{50} is 1.25 mm as shown in Figure 8. The grain distribution is well sorted.

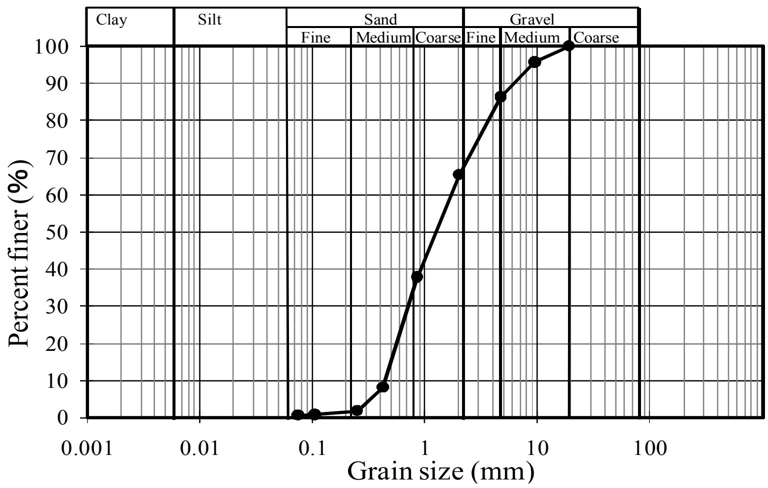


Fig. 8. Grain size distribution of placed sediment used for replenishment in Uda River

Flow regimes and conditions

Figure 9 shows the monthly inflow and outflow discharges of Murou reservoir in 2009, with the reservoir storage capacity. The reservoir has the highest flow discharges during July and October. The post-dam hydrograph shows a significant reduction in flood peaks and the maximum use of the outflow discharge is about 14.0 m^3/s. The timelines of sediment setting, placement, starting of artificial flushing, and monitoring measurements are shown in Figure 9.

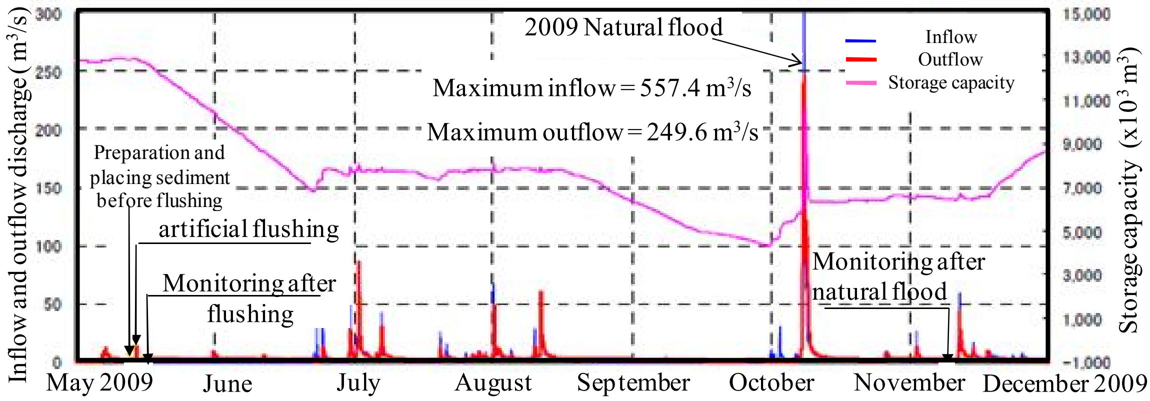


Fig. 9. Flow duration curves for before and after artificial flushing and natural flood discharges at the Murou dam gauging station for the study year 2009.

There are three monitoring phases; (1) before artificial flushing, (2) after artificial flushing, and (3) after natural flood. In fact, the sediments are placed during the normal flow stage. Then, to erode and transport the supplied sediment artificial flood by opening the Murou dam lateral gate is discharged as shown in Figure 10. During one day the dam gate is opened from 8:00 with discharge of 1.34 m^3/s and gradually increases till reach to the peak discharge around 12:00 with 14 m^3/s (Figure 10(a)). The peak discharge remains two hours then a gradually decrease till recover the normal flow stage by the end of the day at 18:00.

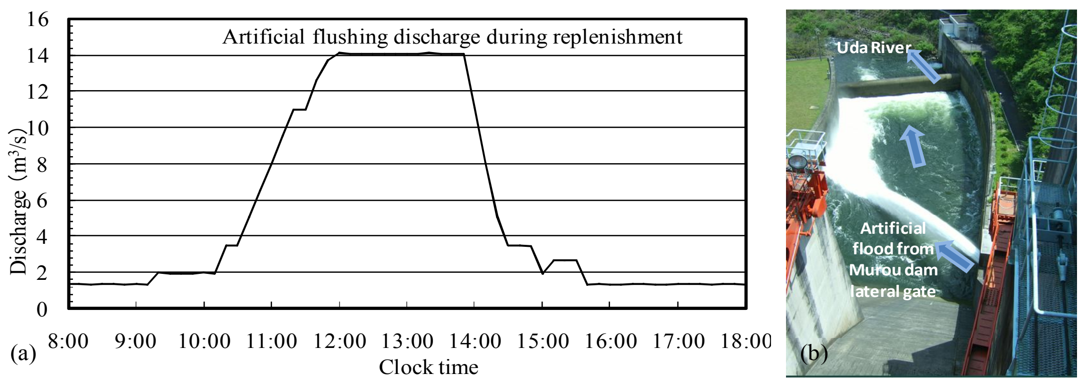


Fig. 10. (a) Artificial flushing discharge curve on 7-5-2009; (b) Jet of Murou dam gate

The duration of the peak flow during artificial flood should be longer to erode and transport all the placed sediment. Figure 10(b) shows the jet plunging in the stilling basin of Murou dam before flowing over the weir to the downstream reach of Uda River. During 2009, field test of 280 m^3 supplied sediment, only 230 m^3 are transported further downstream. The rest of 50 m^3 are transported after the natural flood. To investigate the influence of the dam and flow duration curves another scenarios will be simulated in future study.

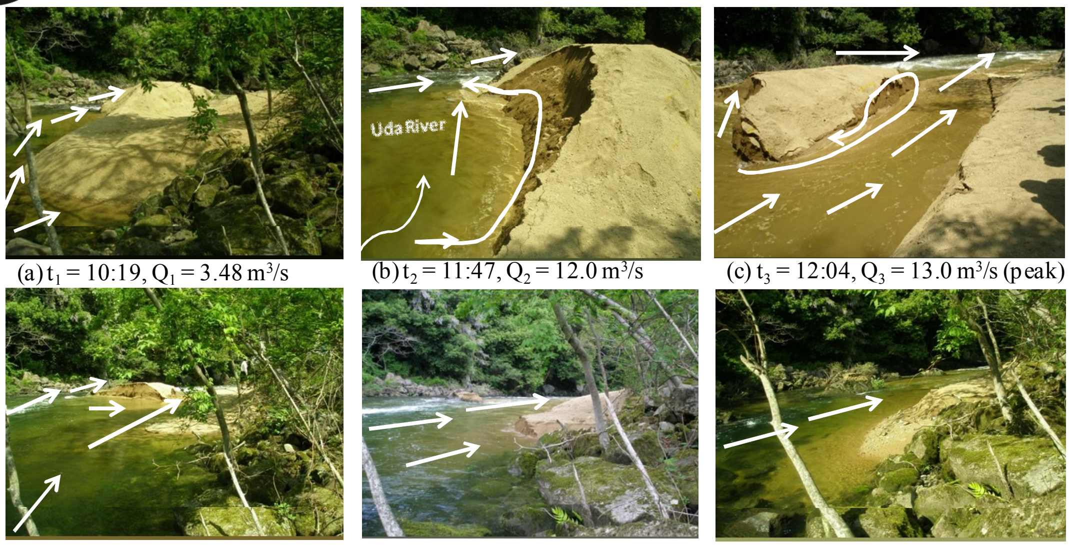
Results Of Replenishment Downstream Of Murou Dam

The evolving bed topography and grain size distribution are monitored, along with water surface, velocities and rate of sediment transport at the downstream end of the river. Measurements are performed at various cross sections along the river. With the field experiments the processes are directly visible and a wealth of valuable data are obtained with relative ease, and thereby will be used for further calculation or validation of numerical models.

Morphological evolution and corresponding flow field

To understand the process of scouring and deposition during the artificial flushing of the placed sediment series of pictures are taken at different time and discharge as shown in Figures 11 and 12. The figures clearly depict the process of erosion and flow behaviours. The erosion at the base of the placed sediment causes the sand mass of placed sediment bank to slide downward and deposit. Deposited sand mass is then flushed due to water flow. The width of erosion during the whole flushing periods is one to three times the height of the placed sediment. The erosion region developed from a straight bank line into the crenulated shaped (half moon shape) as seen in Figure 11 (b). At the peak discharge the water level increased at t_3 produce a greater erosion area and the water enters the grove channel in the placed sediment as shown in Figure 11(c). Artificial flushing increases the erosion rate and transports the sediment out of the placed sediment region.

The peak discharge lasts for two hours and permits a deeper cut in the placed sediment bank. With peak flow, the eroded volumes increase in the range of 45 percent. Reduction of discharge at t_5 reduces the erosion rate, therefore 50 m^3 of the placed sediment remains as shown in Figure 11(f). By looking downstream in Figure 11, the erosion start at the inner bank of the placed sediment till the half moon shape is formed due to gradually increase of the discharge at t_1 and t_2, see Figure 11(a, b). Looking upstream to the dam side, during the peak discharge one part of the placed sediment is isolated and collapsed as a block (Figure 12 (c,d,e)). Apparently, 20 percent of the placed volume that were placed in higher elevation on right bank is not transported because of low water level during peak flow.



(a) t_1 = 10:19, Q_1 = 3.48 m^3/s (b) t_2 = 11:47, Q_2 = 12.0 m^3/s (c) t_3 = 12:04, Q_3 = 13.0 m^3/s (peak)

(d) t_4 = 12:34, Q_4 = 13.0 m^3/s (peak) (e) t_5 = 14:26, Q_5 = 5.0 m^3/s (f) t_6 = 15:05, Q_6 = 2.5 m^3/s

Fig. 11. Looking downstream photographs of morphological evolution during artificial flushing of placed sediment at Uda River bank

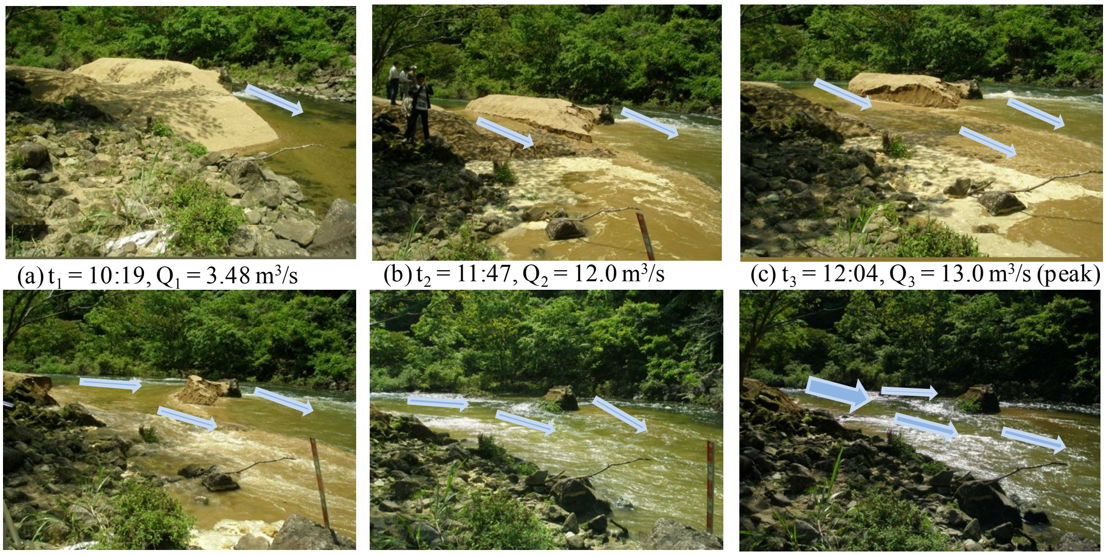


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Fig. 12. Looking upstream photographs of morphological evolution during artificial flushing of placed sediment at Uda River bank

Changes in river bed materials

The effects of sediment replenishment are investigated on cross section bed deposition, flow velocity, grain size distribution, water quality and organisms. Thirteen monitoring points below Murou dam are investigated and their locations are shown in Figure 14. The distribution of river bed materials are analysed by visually determining the sizes of river bed material in quadrates of 1 to 2 m in dimensions and preparing a two dimensional map, which enabled changes in distribution before and after sediment replenishment to be compared. Figure 13 present the changes in the river bed material before and after sediment replenishment and after natural flood. By comparing Figure 13(a) and 13(b), a significant riverbed changes can be identified from cross sectional surveys, and visual inspections. But after the natural flood the newly deposited sediment grace to the replenishment is eroded again and replaced by a larger boulders and rocks.

(a) before flushing (b) after flushing and replenishment (c) after natural flood

Fig. 13. Photographs of Uda river bed depositions in different months in 2009

Figure 14 shows bed material size in three different monitoring times and 13 observation points along the river. Before sediment replenishment in point No 2 and No 2-1, the material is coarser gravel than in the farther downstream points No 4 and No 7 (Figure 14(a)). After flushing, the fine material content of the channel deposits strongly increased. The sediment deposition in point No 2 and No 2-1 after replenishment consist of a nearly continuous layer of fine sand, but no change occurs further downstream (Figure 14(b)). But after natural flood where a less placed sediment volume, the bed material is transported and much of the coarsest sediment is supplied to point No 2, and No 4 (Figure 14 (c)). The mount of supplied sediments is not effectively influenced on the river bed after natural flood occurs.

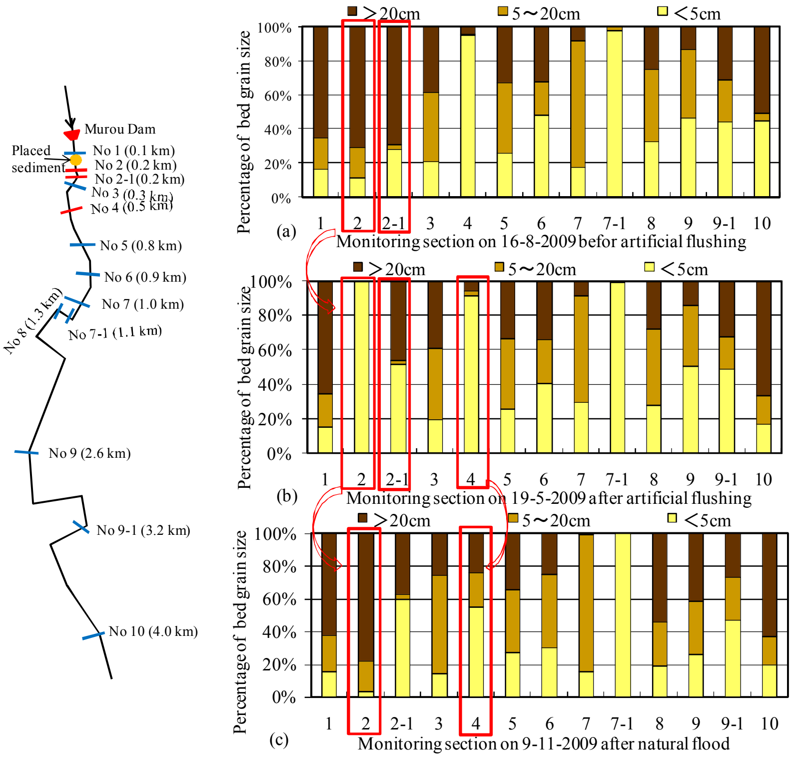

Fig. 14. Variations of river bed material size in 13 cross sections along Uda River

Conclusions

The first results of ongoing research on the artificial sediment replenishment downstream dams are presented. This paper has pointed out the alteration of sediment transport and, subsequently, of the fluvial dynamics due to dam impacts in a large river system. The downstream sediment replenishment method is currently being field tested at Murou dam, but so far not enough knowledge has been accumulated about its influence on lives in rivers and coastal areas. The authors think that the only way to gain necessary knowledge is to conduct a monitoring study on changes in the physical environment of the river downstream and their influence on various forms of lives.

By replenishing sand at different locations of the Uda River within the downstream reaches, the replenishment may direct future supplements for a more widespread dispersal of suitable sand for fish spawning. In order to put the downstream sediment replenishment method to practical use, it is also important to share information with the people concerned in the same river basin, such as fishery workers associations and environmental groups, and endeavor to make the method socially acceptable. Sediment replenishment for the purpose of keeping a dam functional needs to be performed semi-permanently. If the downstream replenishment method is to be used as a means of reservoir sedimentation control, cost reduction is also an important consideration.

Regarding the continuation of this research project, the major goal is to find out which sediment geometry, volume, and feeding frequency leads to environmental and physical improvements below dams. This requires tests of long duration combined with numerical modelling techniques that include the processes as observed in this study. Firstly, validation and verification of 2D numerical model will be conducted by using actual data of sediment replenishment projects. Secondly, investigation of selected scenarios to examine sediment replenishment geometry, volume, erosion rate and positions for different grain size distribution. Finally, examine the application of the numerical model by using the field data will be carried out.

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