Lighten the load

Reservoir sedimentation problems are common the world over in both developed and developing countries. In this article, Sameh A Kantoush, Tetsuya Sumi and Yasuhiro Takemon from Kyoto University, explain how Japan is putting its experience to good use and promoting good reservoir sedimentation management for the future.

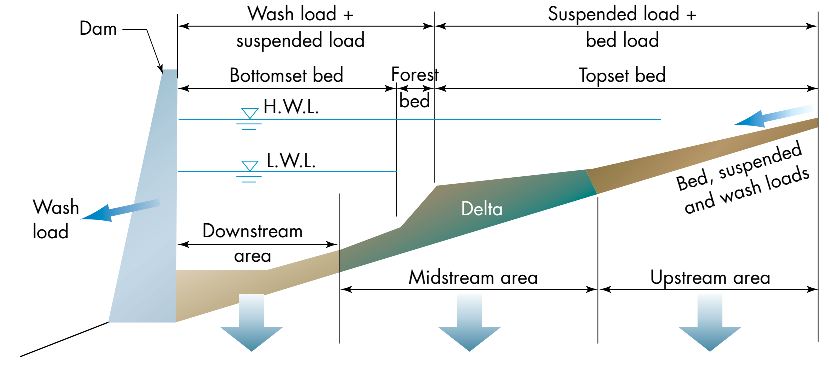
THE catastrophic hydro-geomorphological events associated with earthquakes and volcanic eruptions, landslides, debris flows and slope collapses are the major sources of sediment production in Japan, and are the most serious disasters among all water-related ones. In Japan, the annual average loss of life from landslide hazards is 170, which tragically is set to increase after the country's disaster of 11 March 2011. Japanese rivers are characterised by high sediment yields due to topographical, geological and hydrological conditions. This has consequently caused sedimentation problems for many reservoirs constructed for water resource development or flood control purposes. A significant amount of sediment storage capacity at the reservoirs, which was designed for 100 years, has already been lost because sedimentation has occurred faster than expected.

Reservoir sediment management has become necessary in Japan: to prevent the siltation of intake facilities and aggradation of the upstream river bed in order to secure the safety of dams and the river channel; to maintain the storage function of reservoir, and ensure sustainable water resource management for the next generation; and to release sediment from dams with an aim to conduct comprehensive sediment management in a sediment transport system.

Currently, Japanese reservoir sedimentation management is embarking on new methods. In addition to conventional techniques sediment replenishment, sediment flushing and sediment bypass techniques are being adopted at some dams: eg at Murou Dam on Uda river, Unazuki and Dashidaira Dams on the Kurobe river, Miwa Dam on the Tenryu river and Asahi Dam on the Shingu river.

In order to solve long term environmental problems in relation to water resources, the influences of geo-, eco- and socio-system changes on water resource systems have been analysed in our laboratory from a risk management perspective. Integrated river basin management which harmonises flood control and water use with environmental conservation is also being studied. We are working on several subjects such as: asset management of dams and development of reservoir sediment management methods; model development of eco-sediment hydraulics by habitat structures analysis; and interaction between the aquatic environment and ecological systems.

To establish effective integrated river basin management measures, several monitoring techniques have been developed and implemented at different dam projects. In Japan, a comprehensive approach has already been adopted for sound sediment circulation in the sediment transport system, which is achieved by moving sediment from mountains through to the coastal areas.



		Downstream area	Midstream area	Upstream area
Sediment Property	Soil Classification	Main component: Clay and Silt	Main component: Sand	Main component: Gravel and Sand
	Average size grain distribution (%)	Gravel = 3, Sand = 11 Silt = 50, and Clay = 37	Gravel = 12, Sand = 41 Silt = 32, and Clay = 15	Gravel = 28, Sand = 43 Silt = 21, and Clay = 8
	Fine grained fraction, Fc	Fc = above 90%	Fc = about 50%	Fc = under 30%
	Natural water content, w	w = above 100%	w = about 50 to 60%	w = under 40%
	Density Porosity	Low	↔	High
	Ignition Loss Ig	Ig = about 10%	Ig = about 7%	Ig = about 4%
	Organic materials /Nutrient	Low	↔	High
Sediment Utilization	For construction	Soil improving material, banking material, fertilizer, etc		Aggregate, base course, landfill, planting base etc
	For agriculture			
	For ceramic industry	Ceramic soil, brick cement etc		River supply, artificial beach replenishment, wetland restoration etc
	For environment			

Figure 1: Delta formation and properties of deposited sediments within reservoirs and applications of different types of sediments

Dams and sediment production

The modern development of Japanese dams can be traced back over 100 years. Dams were built originally for the utilisation of water for water supply and agricultural purposes. With subsequent economic development however, several other functions were added such as hydro generation, industrial water use and flood control At present, multipurpose dams make up the majority of Japanese dams. Approximately 3000 dams over 15m in height have been constructed but the total reservoir storage capacity is only $1Bm^3$ (Sumi, 2003).

Japan's topographical, geological and hydrological conditions have great impacts on sediment yield in river basins. There are two large fault lines, the Median Tectonic Line and the Itoigawa-Shizuoka Tectonic Line, where weathering is proceeding in particular.

UTTARAKHAND JAL VIDYUT NIGAM LTD.

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UJVNL

SHORT NOTICE INVITING BIDS
FOR
RENOVATION, MODERNISATION AND UPGRADATION OF (3x10 MW) KULHAL HYDRO-ELECTRIC PLANT DISTRICT DEHRADUN IN UTTARAKHAND, INDIA
THROUGH
INTERNATIONAL COMPETITIVE BIDDING (ICB) ROUTE

NIB No: - RMU (YV)/2010-11/01 **Dated.25-03-2011**

1. Uttarakhand Jal Vidyut Nigam Ltd., a Public Sector Undertaking of the State Government of Uttarakhand in India, invites Single-Stage Sealed Three-Envelope bids from eligible bidders through International Competitive Bidding (ICB) route for Renovation, Modernization and Upgradation of (3x10 MW) Kulhal Hydro-electric Plant in Dehradun District in the State of Uttarakhand in India.

2. SCOPE OF WORK:

Refurbishment/Replacement of:
- Vital parts of the generating units such as turbine runner blades, guide vanes, governors and excitation system, stator and rotor etc., Station Auxiliary Systems.
- Hydraulic Steel Structures, Civil Works.

The work of RM&U shall include reverse engineering, design and engineering, manufacture, shop fabrication, assembly, testing and inspection at Supplier's works, packing, loading and forwarding, dispatch, delivery at site, unloading and storage at site, insurance, handling at site, complete erection, including associated civil works, testing, start-up, commissioning, successful performance testing and handing over of all facilities.

3. GENERAL DETAILS

3.1 Bid Security INR 23.1 Million (Indian Rupees Twenty Three Million and One Hundred Thousand only)
3.2 Cost of bid documents INR 100,000.00 (Indian Rupees One Hundred Thousand only) in the form of Demand Draft / Bankers Cheque drawn in favour of "Uttarakhand Jal Vidyut Nigam Ltd." ,(STATE BANK OF INDIA, Account no. 30024638487) and payable at Dehradun, plus applicable Trade Tax. Presently, Trade Tax is 13.5%.
3.3 Commencement of sale of bid documents/Date of start of downloading of bid documents : 15-04-2011
3.4 Date for Pre-Bid meeting : 25-05-2011
3.5 Last date/time for submission of bids : 26-07-2011 upto 1200 hours, Indian Standard Time (IST)
3.6 Date/time of opening of Techno-commercial bids : 27-07-2011 at 1100 hours, Indian Standard Time (IST)
3.7 Validity of bid : 180 (one hundred eighty) days from the date of opening of Bids.
3.8 Date of execution and completion: 3 (three) lean seasons, starting from October 01, 2011 to May 31, 2014.

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- Deputy General Manager (M&U), Yamuna Valley, Uttarakhand Jal Vidyut Nigam Ltd., Dhalipur -248142, Dehradun, Uttarakhand, India
- Manager (A&S), Uttarakhand Jal Vidyut Nigam Ltd. , Ujjwal, Maharani Bagh, GMS Road, Dehradun-248006, Uttarakhand, India.

Dy. General Manager
M&U - Yamuna Valley, Dhalipur,
Uttarakhand Jal Vidyut Nigam Ltd.
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H.O. "UJJWAL", Maharani Bagh,
G.M.S. Road. Dehradun - 248006
(Phone.: 0135-2763508, Fax: 0135-2763507)

NOTICE
Uttarakhand Jal Vidut Nigam Limited is now
"UJVN Limited"

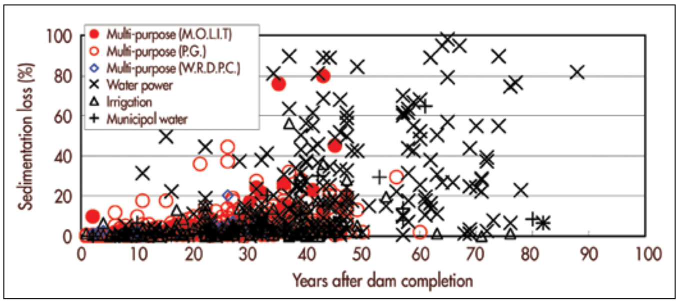
This is to inform all concerned that Uttarakhand Jal Vidut Nigam Limited, which was originally incorporated on 12.02.2001 under the Companies Act, 1956 as Uttaranchal Jal Vidut Nigam Limited, having duly passed the necessary resolution in terms of section 21 of the Companies Act, 1956 and the approval of Central Government/Registrar of Companies accorded thereto the name of Company, with effect from 4th April, 2011 stands changed to "UJVN Limited".

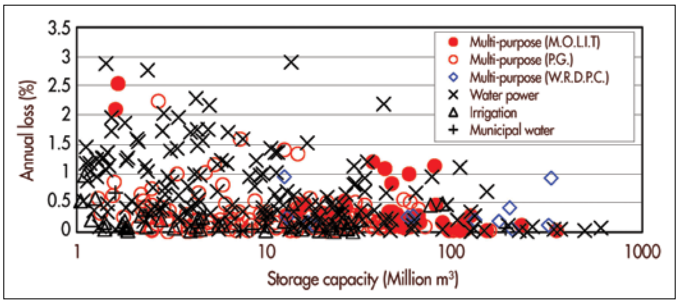
Therefore the company should be known as "UJVN Limited" for all Government, Non-Governement and other purposes.

पत्र संख्या: 160 (क) उ0ज0वि0नि0लि0 / विज्ञापन
दिनाँक : 15.04.2011

G.P.Patel
Managing Director

"Avoid Wasteful Use of Electricity"





Top: Figure 2; Relationship between reservoir sedimentation rate and years after dam completion. Above: Figure 3; Relationship between annual storage capacity loss and gross storage capacity

Weathering is also seen in many other regions. The annual average precipitation is approximately 1700mm, and sometimes intensive rainfall such as 100mm in an hour or 200-500mm in a day can be recorded. Consequently reservoir sedimentation has been accelerated especially in the Chubu and Hokuriku regions in the centre of the main island.

Reservoir sedimentation problems in Japan originated with siltation at power plant intakes at small hydro projects on the mainstream, and then scoring gates were set up as a countermeasure. Later on as sedimentation proceeded to affect medium sized dams, the increased flood risk caused by sedimentation at the upstream channel of reservoirs became an object of public concern, and the importance of sedimentation management was recognised on a nationwide scale. Storage capacity can be secured without difficulty at run-of-river projects. However, maintaining storage capacity becomes a major issue at hydropower and flood control dams.

When estimating design sediment storage capacity, various proposed equations (on the basis of topography, geology or reservoir capacity) and the actual sedimentation records of neighbouring dams or erosion control dams have been referred to. However, in some cases, because the amount of inflowing sediment was assumed to be significantly large, a sediment storage capacity of less than 100 years (eg 30 or 50 years) had to be used. And in other cases, where a 100-years design sediment storage capacity was secured, the actual sediment yield largely surpassed the originally estimated sediment yield. Consequently, more sediment has already accumulated than the design sediment yield and active storage capacity is decreasing year by year.

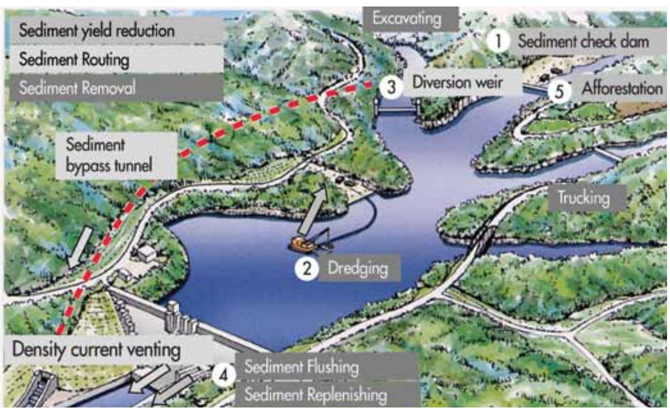


Figure 4: Sediment management strategies in reservoirs

Reservoir sedimentation in Japan

In Japan, following the widespread recognition of sedimentation problems, all dams with a storage capacity over 1Mm³ have been obliged to report their sediment condition to the authorities every year since the 1980s. As of 2000, 877 dams (one-third of all dams in Japan), reported annual changes in sedimentation volume and the shape of accumulated sediment. Such a nationwide survey with accumulated data is regarded to be a valuable asset on a global basis.

Reservoir sedimentation is a complex process which differs for each river and reservoir. However, it is almost characterised by the delta formation as shown in Figure 1.

The schematic view of Figure 1 has been drawn by field boring data of 30-40 reservoirs in Japan. After flowing into a reservoir, sediment forms a delta composed of deposits graded according to the deposition characteristics of the reservoir (JDF 2003). As shown, the longitudinal profile of sediment deposits is not necessarily horizontal; areas at higher elevations are more prone to such phenomena as a reduction in effective capacity and backwater formation. Coarse sediment composed mainly of gravel and sand deposited in the upstream zone of the topset bed is not easy to move by lowering the reservoir water level or dredging the shoulder region of the midstream zone.

Figure 2 shows the relationship between reservoir sedimentation rates and the ageing of dams. Here, the sedimentation rate is calculated using sedimentation volume to gross storage capacity. With dams constructed before World War II and used for more than 50 years, sedimentation proceeded in the range from 60 to beyond 80% in some hydroelectric reservoirs. Likewise, for the dams constructed between 1950 and 1960, or from the postwar years of recovery through the high economic growth period and used for more than 30 years, sedimentation rates beyond 40% were found in many cases. The influence of sedimentation in those hydroelectric reservoirs depends on the type of power generation.

Following this period, large numbers of multi-purpose dams were constructed. This type of dam does not have high sedimentation rates compared with hydroelectric ones, although the rates of 20% to beyond 40% were found in some dams. Since maintaining storage capacity is directly linked to maintaining the function of dams such as flood control, the influence of sedimentation in the multi-purpose reservoir becomes greater.

Figure 3 shows the relationship between the annual storage capacity loss and the gross storage capacity. The annual storage capacity loss generally decreases with an increase in the gross storage capacity and the reservoir life is extended. Figure 4 shows the relationship between the annual storage capacity losses and specific storage capacity (mm), which is defined as a ratio of gross storage capacity to catchment area. Many multipurpose dams have specific storage capacities of 50-1000mm and annual storage capacity losses of approximately 1.0 to 0.1%. The schematic diagram of Figure 4 shows how such comprehensive sediment management is undertaken and classified in Japan. It can be summarised into the following three points (Kantoush and Sumi, 2010):

1) To prevent the siltation of intake facilities and aggradations of the upstream riverbed to secure the safety of dams and river channel.
2) To maintain the storage function of reservoirs and realise sustainable water resource management.
3) To release sediment from dams. A new policy in Japan in relation to comprehensive sediment management is a sediment transport system. The amount of sediment supplied from rivers to coasts was radically reduced with the construction of erosion control Sabo dams or storage dams in mountain areas, and acceleration of aggregate excavation from riverbeds after World War II. As a result, various problems arose including riverbed degradation in downstream channels, oversimplification of the river channel, and retreat of the shoreline due to the decrease in sediment supply to the coast.

Sediment of approximately 200Mm³ is produced from mountainous areas every year. A volume of 100Mm³ is deposited in reservoirs, and the remaining 100Mm³ is discharged into downstream rivers.

In the latter, 4Mm³ is allocated for gravel excavation. From 1950-60, however, a considerable amount of aggregate was taken so that the amount of sediment supplied to coasts through estuaries was remarkably reduced. Regarding the sediment budget for sand along the coastline, erosion (350,000m³) surpasses deposition (250,000m³) and therefore coastal erosion is still proceeding. At present, it is said that eroded coasts account for approximately 60% of the Japanese shoreline of about 34,000km. Furthermore, approximately 40% of such erosion is attributed to the decrease in the amount of sediment supplied from rivers, including reservoir sedimentation.

A sediment transport system represents a target region for management, in which attention is focused on the movement of sediment from mountainous regions to coastal regions, compared with a water system representing the conventional movement of water. There is a growing need for the broad-based management of sediment, which covers mountain sediment supply through the downstream river channel and coastal region.

Monitoring techniques

In order to evaluate environmental influences and the effectiveness of sediment management measures, such as sediment replenishment, sediment flushing and sediment bypassing, various types of sediment monitoring techniques should be developed. Here, new measurement techniques for suspended sediment concentration, surface velocities, and sediment morphological changes such as sediment erosion and deposition in reservoirs are introduced.

Suspended sediment concentration

Monitoring the quantity and the quality of sediment transport during flood events in rivers and reservoirs is very important. Automated measurement of suspended sediments (SS) is crucial to the study of sediment transport. We have developed and implemented various SS monitoring techniques for both continuous turbidity measuring (SMDP, turbidity, and image processing techniques) and bottle sampling for calibration. SS monitoring systems based on a differential pressure transmitter (SMDP) were implemented in Miwa, Unazuki and Dashidaira dams. The turbidimeter that uses optical backscatter and relates nephelometric turbidity unit NTU to SS is known for continuous and automated field sampling, were installed for sediment monitoring in the Kurobe river. Digital optical cameras recorded the sediment-water mixture in-situ, to determine the SS. We used a method to measure SS which relates light intensity with SS in the flow, and is considered linearly correlated with SMDP measurements. A calibration procedure was carried out for the camera and for each single pixel in the region, to establish the relation between SS and the values of gray scale in the frames representing light intensities. Almost every two seconds, measurements for SS and SMDP measurements were correlated with corresponding images. The same calibration procedure was applied to all pixels in the region of analysis. The estimation of pixels density is made by DigiFlow software.

Two dimensional surface velocity

Large-scale particle image velocimetry (LSPIV) is an extension of a quantitative imaging technique to measure water surface velocities. In the present applications we utilised the monitoring video camera, CCTV (CIT-7300) from Mitsubishi Electric Corporation. The camera was connected with a computer to record the data directly. The flow videos recorded at 30fps and 740 x 480 pixels. Naturally occurring turbulence, sediment clouds, differences of water colour and bed feature reflections on the flow surface were used as seeding tracers. The combination of these tracers is present during floods or sediment bypassing in reservoirs and tunnels as well.

Three dimensional sediment deposition and morphology

Laser scanning uses surveying techniques to generate digital terrain models (DTMs), a fundamental tool to detect, classify and observe morphological changes in river channels during and after sediment management. The 3D reconstruction of the terrain with Reigle laser scanning methods is one of the modern ways to reproduce the natural surface of the ground with high accuracy and high automation. Such a methodology offers the advantages typical of noncontact techniques, and moreover permits to collect in short time dense 3D point clouds over the surface of interest, to record a perspective image (intensity data and sometimes RGB data).

There are various terrestrial laser scanners available, characterised by different accuracy, measurement range and speed of data acquisition. The distance is measured applying different principles: the time-of-flight principle (ranging scanners), the phase difference, and triangulation. Ranging scanners are able to survey objects and scenes with greater distances and so were adopted for the sediment flushing project. The 3D Laser Scanner Riegl LMS-Z210 system was used to realise in different epochs the side bank erosion process of the sand bar formed in the Unazuki reservoir (Sumi and Kanazawa, 2006). This scanner covers wide areas and collects four measurements for each impulse: two angles, the distances and the intensity of the received echo impulse. The polar coordinates are immediately transformed in a local 3D Cartesian system (sensor system). Automatic recognition of targets by intensity images matching is supported

Tracing of bed load transport

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. Recently, the radio frequency identification (RFID) method was successfully employed in various streams using mobile antennae to determine the displacement of single transponder-tagged particles.

The RFID system consists of a reader and control unit, antennae and transponder (tags) used for tagging the object of interest. Several types of passive and active tags have been developed. The active tags have a battery inside, which increase the reading distance for 5m.

Projects and case studies

Controlling reservoir sedimentation means in fact the control of sediment deposition in reservoirs. Sediment flushing is a removal strategy to pass the sediment through the reservoir and sediment bypassing is a routing technique to pass sediment inflow around so as not to accumulate in reservoirs. In Japan, it is common practice to trap mainly coarse sediment by sediment trapping with check dams which have been constructed just upstream of the reservoir areas and remove accumulated coarse sediment by excavation. The sediment replenishment method is one of the new measures of sediment management.

Sediment flushing is vital for the preservation of long-term storage in reservoirs. However, downstream impacts can act as a constraint in the planning and operation of sediment flushing. In order to understand the processes and the impacts of flushing, two examples are given of the Unazuki and Dashidaira reservoirs, located at the Kurobe River. For both reservoirs sediment inflow is extremely high compared with storage capacity. During minimum pool level the incoming floods erode a flushing channel in the deltaic deposits. The channel is gradually increased in width by bank-erosion processes during this period. Quantitative and qualitative monitoring measurements during flushing have been conducted for the sediment erosion process with 3D laser scanning, surface velocity (LSPIV), and suspended sediment concentrations (Kantoush et al, 2010a). The flushing channel within Dashidaira reservoir has a stable profile and extends across the entire impoundment width of 170m at distance of 640m from the dam (Sumi et al., 2009.

The Kurobe river originates in mountainous areas with peak elevation above 3000m. The main river flows for about 85km into Toyama Bay. The average river bed slope which ranges from 1/5 to 1/80 is about 1/30. The mean annual precipitation ranges from 2400-4100mm. Sediment flushing has been conducted on the Dashidaira Dam since 1991.

Since the completion of the Unazuki Dam in 2001, seven sediment flushing and seven sediment sluicing operations have been conducted. When a flood in excess of 300m³/sec (250m³/sec in some special cases) of inflow occurs at the Dashidaira Dam between June and August, a coordinated sediment flushing is performed. Whenever a flood in excess of 480m³/sec occurs at the Dashidaira Dam after sediment flushing, a secondary draw-down flushing is performed. These sediment flushing and sluicing practises have been taking place by agreement between the Kurobe River Sediment Flushing Evaluation Committee and the Kurobe River Sediment Management Council, considering the natural flow regime in the Kurobe River as well as the impacts of sediment discharge downstream. The floods occur primarily due to melting snow in May and the rainy season from June to August. The flushing period of June to August was chosen by considering these natural flow regimes and the impacts on fishing and agricultural water use both in the downstream river and the connected sea shore area.

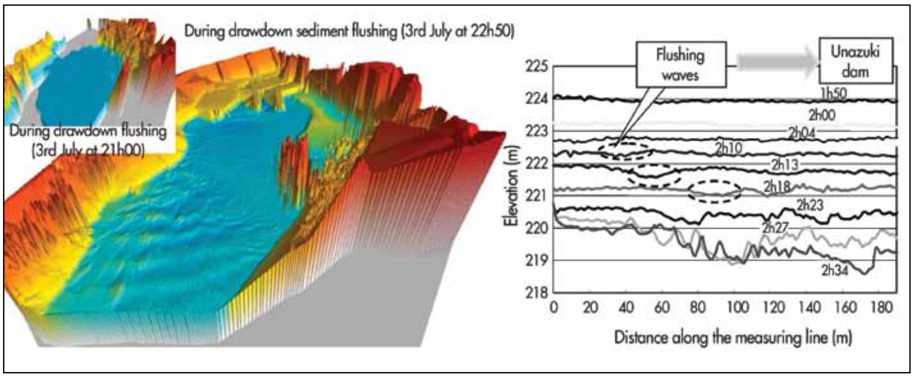
In recent years, water flow in excess of 300m³/sec (sometimes 250m³/sec) of inflow at the Dashidaira Dam has been occurring several times a year, and a flood in excess of 480m³/sec has occurred about once a year. The threshold values are considered to be appropriate to perform sediment flushing operations regularly.

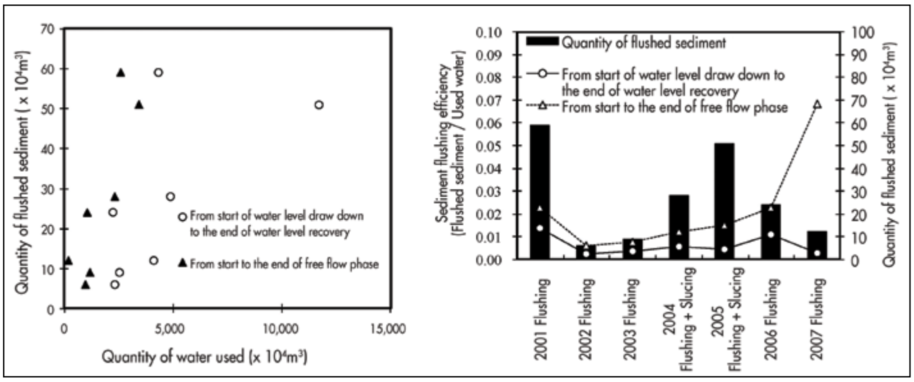
Morphological process at Unazuki reservoir

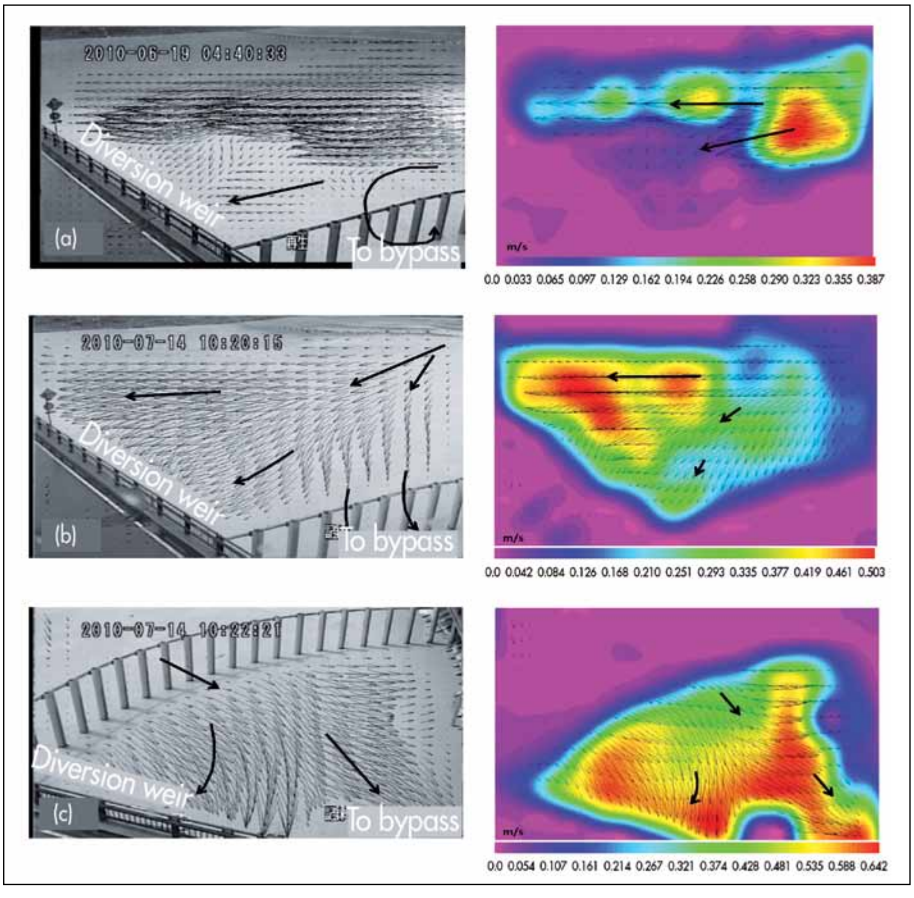
Several field measurements were conducted in order to evaluate the morphological evolution during drawdown flushing within Unazuki reservoir. By using 3D laser scanning technology the morphological changes of sediment in the reservoir were measured during and after flushing in July at different times as shown in Figure 5. The morphological topography with the water surface is clearly visible in Figure 5. Field measurements of time and spatial variations of the water surface during drawdown flushing at night were also conducted. The water surface elevation along the measuring line is shown in Figure 5(right). This figure shows how the shock waves generated by the scouring gate propagated over the sediment bed. The observed flushing wave propagates along the measuring line at different time steps.

Table 1 shows the actual amount of sediment flushed out of Dashidaira Dam since 2001. The flushing volume data was obtained by measuring the cumulative amount of sediment in the dam reservoir after the previous year's sediment flushing operation to the end of May. (Sumi et al, 2009).

The relationship between the quantity of flushed sediment and the quantity of water used during sediment flushing operations can be seen in figure 6(a). To measure the quantity of water used, we calculated the total discharge in two periods: (1) from the start of drawing down the reservoir water level to the completion of recovering the water level, and (2) from the start to the end of the free flow flushing phase.







Top: Figure 5; (left) 3D laser scanner measurements of deposition and water surfaces within Unazuki reservoir and time series of measured water surface elevations (right). Middle: Figure 6; (a) Relationship between the quantity of water used; (b) the quantity of flushed sediment and flushing efficiency. Above: Figure 7; Stationary flow fields and corresponding velocity in the reservoir of Miwa dam for (a) Mode 1, (b, c) Mode 2. (Kantoush et al, 2011)

As shown in Figure 6, the duration of sediment flushing (namely the total discharge) is planned to be longer depending on the quantity of sediment to be flushed as seen by the 2005 flushing example. Figure 6(b) shows sediment flushing efficiencies at the Dashidaira Dam, which are calculated by the quantity of flushed sediment and the quantity of water used defined by the above two periods. The sediment flushing efficiency which is calculated by the quantity of water used during the free flow phase was about 0.01 to 0.03. The sediment flushing efficiencies became much higher in 2007 as a relatively lower water level operation was maintained for a long time prior to the sediment flushing. This operation pushed the accumulated sediment to the dam prior to the free flow operation, which made the flushing more efficient than usual during the free flow operation.

To make the sediment flushing operation more sophisticated at the Kurobe river, work is in progress to develop rainfall-runoff models using radar data, to monitor sediment transport using 3D laser scanners and LSPIV technology, and to monitor highly turbid water and the sediment transport rate.

Management techniques

In the following part of the article three different sediment management techniques were evaluated at different projects. The hydraulic behaviour of flow and sediment in tunnels still needs to be clarified in order to design safe and economical sediment bypass tunnels, as well as establish countermeasures for abrasion damage on channel bed surfaces. The number of bypass tunnel is expected to increase in the future and some are under construction (Koshibu and Matsukawa dams), or in the planning stages (Yahagi, and Sakuma dams).

Several parameters have been monitored namely, upstream precipitation, turbidity, water quality, fish, benthic animals, and attached algae. This data can be used for switching operation modes. The first normal mode is that all incoming flood flow will overflow the diversion weir into the main reservoir (Mode 1). While the second mode is some part of the incoming flood flow will be diverted to the bypass tunnel after opening the main bypass gate (Mode 2). The last mode is the refilling mode by closing the main bypass gate (Mode 3). Generally we can use inflow discharge to design and guide the timing for switching these operation modes. In order to increase the performance of sediment bypassing and removal efficiency, we need to focus on surface flow patterns and suspended sediment concentration in the approach flow area to the bypass tunnel according to different modes.

Miwa dam bypass system

The sediment bypass tunnel at Miwa Dam was Japan's first experience of a sediment management technique which diverts mainly suspended sediment concentration at a multipurpose dam. Miwa dam is located on the Mibu river, a tributary of the Tenryu. It is a 69m high gravity concrete dam with a 29.95Mm^3 gross storage reservoir and a 311km^2 catchment area. Since the dam was completed, several extreme runoff events caused serious disasters and sediment yield. About 20Mm^3 of sediments were deposited by 2002 since the completion of the dam and a sediment bypass system was completed in March 2004.

Based on theoretical considerations and recorded field data, the annual sediment inflow at Miwa dam was evaluated at an average amount of 0.68Mm^3, of which 0.525 Mm^3 was wash load and 0.16 Mm^3 was bed load combined with suspended load. The complex sediment countermeasure system consists of the following installations:

- Check dam; the sediment is periodically excavated and transported by private gravel agencies.
- Diversion weir of 0.51 Mm^3 combines the functions of training and trapping the sediment. The wash load that flows down through the check dam is directed together with the flood water from a bypass channel into a bypass tunnel. Here two cameras (3 and 4) are installed to monitor the flow velocity in the bypass channel. During high flood the facility allows the training dikes and trap weir to trap the coarse grain sizes that overflow from the check dam in order not to flow into the tunnel. The approach flow infront of the main gate is monitored by camera 1 and 2 for flow field analysis before and after the gate opening for switching modes. Moreover, for SS monitoring two points with two different instruments are installed.
- Flood bypass tunnel of 4.3km long, 7.5m diameter, 1% slope, and 300m^3/sec capacity.
- Auxiliary reservoir sediment discharge facility is under planning to discharge wash load that flows into the reservoir together with floodwater, into the downstream reaches as a flood control measure.

The main purpose of this project was to evaluate the effectiveness of the sediment bypassing system and develop digital image techniques to measure SS and flow field. These will assist in operating sediment bypass tunnels efficiently for managing diverted floods with wash load from the reservoir. The observed efficiencies of bypassed sediment reported hereafter will provide a basis for determining the best management practice for existing and future planned bypass tunnels.

LSPIV and Fx-8100 techniques were applied for two different study areas in front of bypass tunnel approach flow in the reservoir of Miwa Dam. Recorded images at two modes were treated to evaluate the approach flow in three zones, considering the possibility of the vortex formations that can influence the bypass efficiency. Flow field measured by LSPIV are shown in Figure 7. The main flow was directed towards the diversion weir at Mode 1 and a circulation in front of the bypass tunnel was formed.

The velocity magnitudes inside the reservoir have low values of 30cm/sec (Figure 7(a) right). Two zones in front of the bypass were measured, before and after the log boom. The flow field of zone 1 (see Figure 7(a) on the left), reveals the effect of the bypass opera-

Sediment flushed out of Dashidaira Dam since 2001

	Maximum discharge Inflow (m^3/sec)	Average Discharge Inflow (m^3/sec)	Flushing Volume (10^{3}m^3)	Maximum SS (mg/l)	Average SS (mg/l)
2001 Flushing	333	277	590	90,000	15,000
2001 Sluicing	491	273	-	29,000	6700
2002 Flushing	362	215	60	22,000	4500
2003 Flushing	777	217	90	69,000	7100
2004 Flushing	356	229	280	42,000	10,000
2004 Sluicing	1152	281	-	16,000	7300
2005 Flushing	958	290	510	47,000	17,000
2005 Sluicing 1	835	275	-	90,000	16,000
2005 Sluicing 2	790	250	-	40,000	7300
2006 Flushing	308	246	240	27,000	5200
2006 Sluicing 1	378	203	-	12,000	2500
2006 Sluicing 2	685	264	-	27,000	5200
2006 Sluicing 3	529	196	-	7400	1800
2007 Flushing	418	245	120	25,000	3500
Average of Flushing	502	246	270	46,000	9100
Average of Sluicing	694	249	-	31,600	6700
Average of all data	598	247	270	38,800	7900

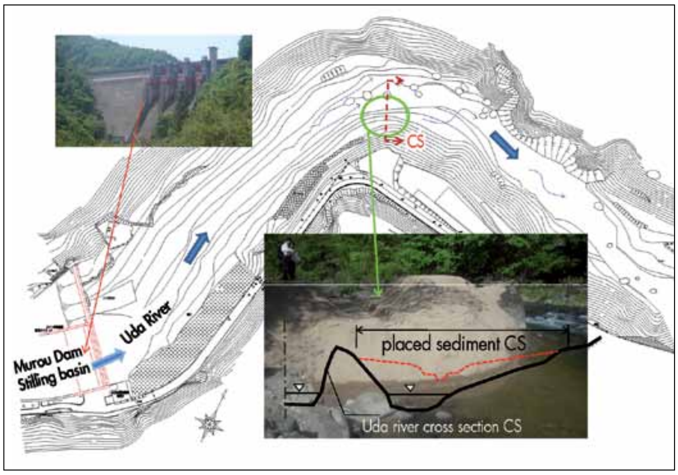


Figure 8: Sediment replenishment site in Uda River downstream of Murou Dam

tion in Mode 2. The separation of the flow in the reservoir leads to a small retention in the immediate upstream part of the reservoir and therefore to high turbidity. This process is localised in the left side of the reservoir. This result in flow separation on the right and left to the weir and bypass can be illustrated clearly in Figure 7(c). Interesting effects of the flow separations in front of the bypass, such as a concentration of inflow to the bypass and an increase in velocities, can be detected by the measurements Figure 7(c) on the right. The LSPIV measurements in zone 2 (see Figure 7(c) on the right) reveal the impact of the contraction due to the trap weirs.

Inflow suspended sediment concentration were recorded by four different monitoring techniques (Image processing, SMDP, turbiditymeter, and Sampling). The peak concentration is almost equal to inflow discharge peak and turbid flow from 2500 to 1000mg/l was bypassed. Turbidity trend was well monitored by several measurement data and very much helpful to switching from Mode 1, Mode 2 and Mode 3. Sediment bypass system in Miwa dam is effectively routing incoming fine sediment directly to the reservoir downstream. The measured efficiency of sediment bypassed by optical turbidity meter was up to 80% of the total inflow sediment. This efficiency was also measured at selected events by image processing which is a very useful tool in characterizing the performance of bypass tunnel operation. Moreover, the measured surface flow velocities and suspended sediment concentrations in the context of sediment management in reservoirs are important for the validity of the numerical analysis of Miwa Dam.

Sediment replenishment technique

In Japan, it is common practice to remove accumulated coarse sediment by excavation and dredging and to make effective use of the removed sediment. The sediment replenishment method is one of the new measures of sediment management. Here trapped sediment (mainly at sediment trapping check dams) is periodically excavated and then transported to be placed temporarily downstream of the dam in a manner decided according to the sediment transport capacity of the channel and the environmental conditions. Therefore, the sediment is returned to the channel downstream in the natural flooding processes.

The procedure consists of four steps: Extracting mechanically the accumulated sediment at the check dam; Transporting it by truck to the downstream river; Placing the sediment with specific geometry; Monitoring flow, sediment, and environmental parameters.

The replenished sediment is placed at such an elevation in order to reduce the turbidity during normal flow periods. The top of the sediment is adjusted so that the sediment is completely submerged during flood at several times a year and all sediment is eventually transported downstream. Several considerations have to be given to environmental problems in the lower river basins, occurrence of turbid water, and safety risks due to sediment deposition in the channel. Concrete means are being explored taking into consideration sediment particle sizes and the scale of flood that is suitable for safe implementation.

In Japan, sediment replenishment projects are being undertaken 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 mobilised or transported according to the post-project monitoring. The central challenge in sediment replenishment research is to determine sediment and flow characteristics, which operation to implement, and how to determine sediment replenishment factors. Indeed, river morphodynamics is a complex process that involves a high degree of interaction 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 flow discharge from the upstream dam and replenishing sediment volumes. 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. It is necessary to better understand reversibility, direction and time scale of changes, and the sustainability of a replenishment intervention before it is implemented.

Murou Dam sediment replenishment

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. Planning, design, implementation and long-term monitoring of Murou dam replenishment tests have been guided by JWA. Photographs in Figure 8 show the 2010 field test of Murou dam stilling basin and the placed sand in the downstream reach 150m from the dam site. The cross-section of the placed sediment geometry which has a trapezoidal shape with a groove channel near the river right bank is shown in Figure 8.

Various sediment volumes since 2006 have been supplied to Uda river downstream of Murou Dam (Kantoush et al, 2010b). 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 discharge from the dam. 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.

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 is obtained with relative ease, and will be used for further calculation or validation

Figure 9: Looking downstream photographs of morphological evolution during artificial flushing of placed sediment at Uda River bank.

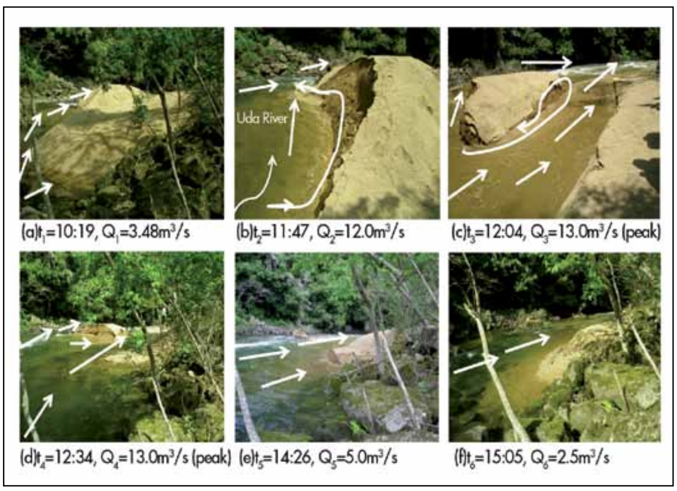
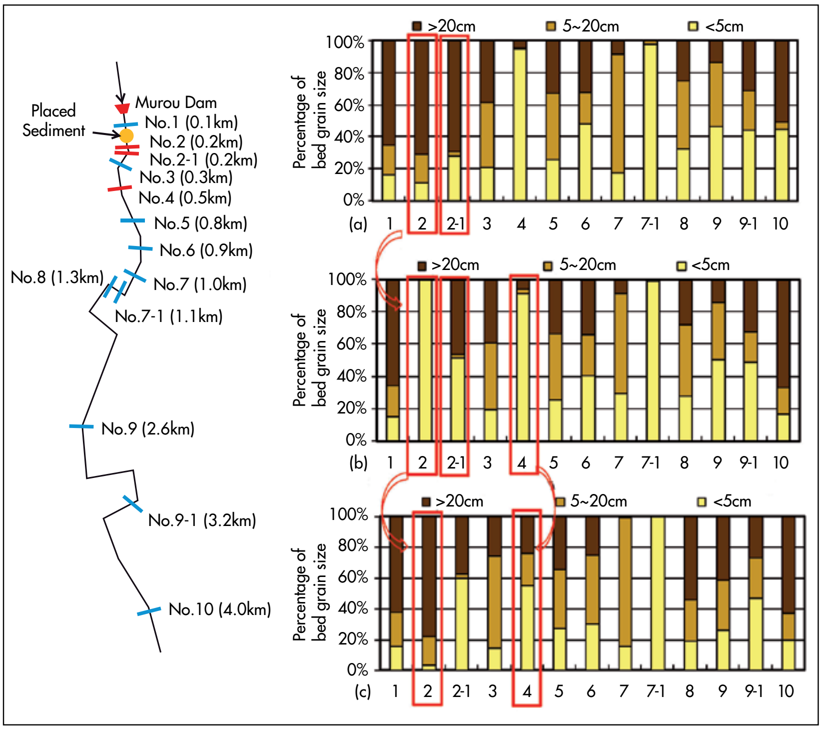


Figure 10: Variations of river bed material size in 13 cross sections along Uda River



of numerical models. 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 Figure 9.

The figure clearly depicts the process of erosion and flow behaviors. 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 9 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 9(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 4%. Reduction of discharge at t_5 reduces the erosion rate, therefore $50m^3$ of the placed sediment remains as shown in Figure 9(f). By looking downstream in Figure 9, 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 9(a, b).

Figure 10 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 10(a)). After flushing, the fine material content of the channel deposits 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 10(b)). But after natural floods there less sediment volume is placed and the bed material is transported. Much of the coarsest sediment is supplied to point No 2, and No 4 (Figure 10 (c)). The amount of supplied sediments is not effectively influenced on the river bed after natural flood occurs.

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. There is a need to increase the amount of the supplied sediment and artificial flow discharge every year. The increasing amount of flushing flow discharges should erode the placed sediment and move typical size gravel of 10cm.

Integrated management

In case of sediment management, it is necessary to find out the appropriate combination of flow and sediment release to meet the demands of various functions based on hydrology, water quality, river morphology and the ecosystem. Furthermore, an integrated sediment management approach should be considered in a sediment routing system which covers not only the river basin but also connecting coastal area.

Selected sediment management measures should be evaluated by a benefit/cost analysis. Sediment management of reservoirs is a complicated process which will affect reservoir sustainability and downstream river health. So we should start to implement it on a step by step basis by conducting field monitoring under an adaptive management concept. IWP&DC

Sameh A. Kantoush, Tetsuya Sumi, and Yasuhiro Takemon, Disaster Prevention Research Institute, Kyoto University, Goka-sho, Uji-shi, 611-0011, Japan,

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