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Sediment Bypass Tunnels

Challenges on reservoir sedimentation management for sustainable hydropower operation

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1 Overview of hydropower development in Japan

A. History & expectations

The development of hydropower in Japan began with the Keage Power Station in Kyoto, which was built about 130 years ago (operation began in 1891). A large number of small-scale, low-head power stations were built according to the scale of factories and other power consumption in the area. But as advances were made in dam technology and long distance power transmission technology, development shifted to major rivers and mountain areas away from areas consuming power. There is a long history of development together with areas along every river, and strong relationships of trust and mutual prosperity have been formed with local communities. Until around 1960, hydropower was more widely developed than thermal power, making up more than half of the total supply capacity. But this has since shifted, with thermal power becoming more developed than hydropower and accounting for a majority of the supply capacity. Electricity from nuclear power was transmitted for the first time to Japan World Expo venues in 1970. And pumped-storage hydropower was

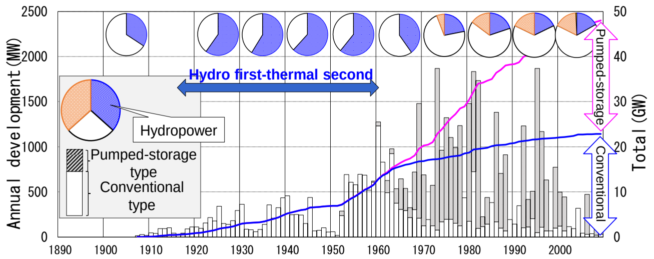


Fig.1.1 Progress of Hydropower Development in Japan

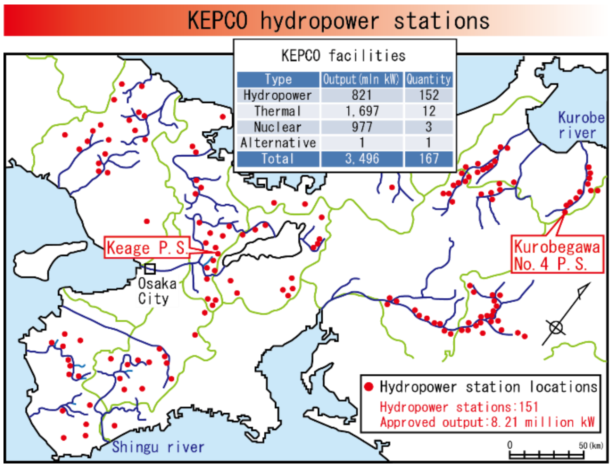


Fig. 1.2 KEPCO hydropower stations

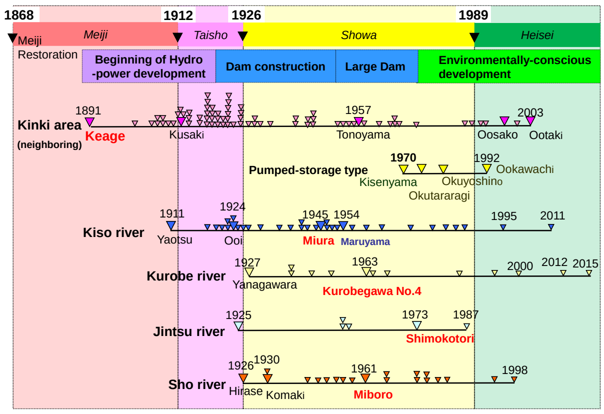


Fig.1.3 Progress of Consistent Hydropower Development in KEPCO

developed, allowing low-cost surplus nuclear power at night to be used to run water through pumps, this water being used to generate electric power during peak demand in the daytime.

Over their long history, some power stations were discontinued due to natural disasters and redevelopment, but most continue to be carefully maintained with the warm cooperation of local communities. The Kansai Electric Power Co., Inc. (KEPCO) currently operates 152 hydropower stations (including 4 pumped-storage hydropower stations) with a total generating capacity of 8,200 MW. Through these power stations, KEPCO continues to deliver clean hydropower.

Next, we would like to give a history of hydropower development in the Kurobe River Basin.

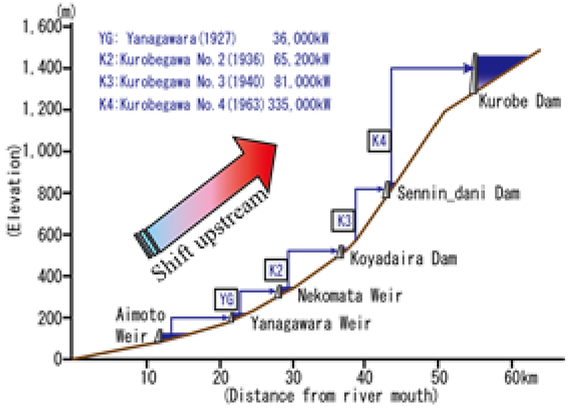
B. Development in the Kurobe River Basin

The Kurobe River is one of steepest rivers in Japan. It has a basin of 682 km2, is 85 km in length, and has a gradient of 1/5 to 1/100.

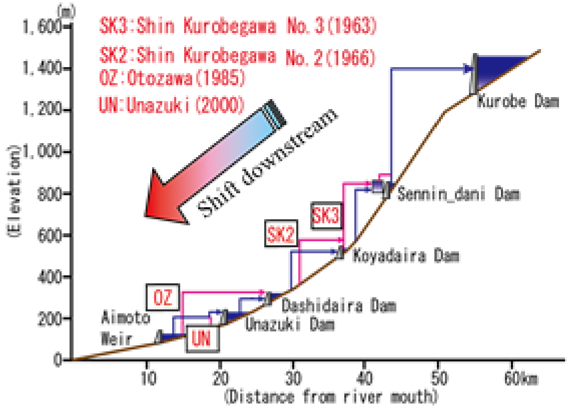
In 1934, Dr. Jokichi Takamine of Toyo Aluminum—famous for the invention of adrenaline—ordered Yutaka Yamada to research hydropower potential on the Kurobe River. Yamada entered the remote, unexplored mountains of the Kurobe River and formulated a plan for power development. Based on this plan and starting with the Yanagawara Power Station, which began operation in 1927, development continued upstream with the Kurobegawa No. 2 Power Station (Koyadaira Dam) in 1936 and the Kurobegawa No. 3 Power Station (Sennin-dani Dam) in 1940. Later, the Kurobegawa No. 4 Power Station was built further upstream in 1963 with the Kurobe Dam, which is Japan's tallest dam at 186 m. By storing floodwater and snowmelt in the reservoir of the Kurobe Dam and adjusting the annual flow rate of the river, the useable volume increased. As a result, development continued downstream with the Shin-Kurobegawa No. 3 Power Station in 1963, the Shin-Kurobegawa No. 2 Power Station in 1966, and the Otozawa Power Station in 1985 (Dashidaira Dam). Then in 2000, the Unazuki Power Station was constructed through involvement in the Ministry of Land, Infrastructure, Transport and Tourism's Unazuki Dam project.

Photo 1.1 A look at materials and equipment being carried during the reconnaissance of the Kurobe River.

Photo 1.2 Kurobe Dam



(a) Development moving upstream (1934–1963)



(b) Development moving downstream (1963～)

Fig. 1.4 Steps in the development of hydropower on the Kurobe River

C. Influence of intensifying natural disasters

In July 2018, torrential rains struck western Japan, causing serious damages in various places. In recent years, sudden changes in weather—such as torrential rain, storm surges, wind storms and high waves, and heavy snowfalls—and natural disasters due to climate change are becoming more frequent and severer.

Photo 1.3 Sediment runoff and flooding due to torrential rain in July 2018 (Kure, Hiroshima Prefecture)[1)]

A Cabinet Decision was made on December 14 last year regarding 3-year emergency measures to prevent and mitigate disasters and increase national resilience totaling about 7 trillion yen. These measures compile structural and non-structural measures that require urgent implementation based on the following;

- Maintaining infrastructure critical to disaster prevention

- Maintaining infrastructure critical to the national economy and civilian life

Among these, ensuring the supply of power during a disaster is one of critical issues.

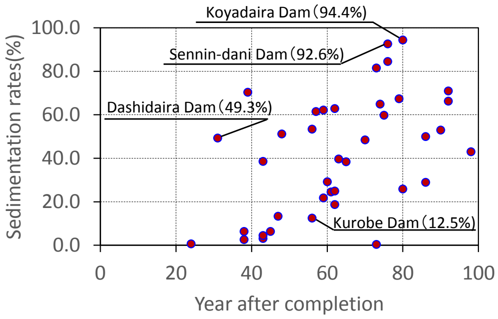


Fig.1.5 Sedimentation rates for dams of KEPCO

How to proceed with measures against sedimentation in situations of accelerated sediment inflow to reservoirs and regulating ponds is a major issue that affects the future of hydropower projects. Fig. 1.5 shows the relationship between the year of completion of the dam and the sedimentation rates for dams of KEPCO.

Not only does sediment inflow into reservoirs and regulating ponds damage power generation functions, such as the capacity to adjust river flow, it also has potential impacts on the relationships of trust developed with local communities by such as increased damage from floods due to rising riverbeds in river channels upstream, prolonged turbidity of the water in the reservoirs and so on.

We will describe the examples of KEPCO's Dashidaira Dam (flushing) and Asahi Dam (bypassing) and discuss the obtained findings below.

2 Countermeasures against reservoir sedimentation and Efforts to maintain relationships with local communities

A. Case of Dashidaira Dam (flushing)

A1. Outline of Flushing facilities at Dashidaira Dam

With the floods in July 1995 and July 2017, the riverbed at Nekomata near the end of the Dashidaira Dam reservoir rose. This caused damage, including burying the water outlets at the Kurobegawa No. 2 Power Station and the Shin-Kurobegawa No. 2 Power Station, and increased tailwater levels.

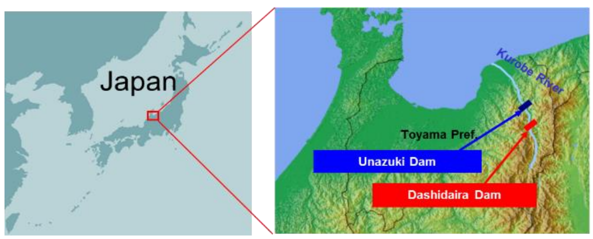


Fig. 2.1 Location of Dashidaira Dam

A large-scale flushing facility was built at the Dashidaira Dam (completed in 1985) in order to prevent damage from flooding upstream and to solve the problems of decreasing riverbeds and coastal erosion downstream.

Two flushing channels have been installed at the bottom of the Dashidaira Dam (Fig. 2.2). Each flushing channel features three gates; an upper, middle, and lower gate (Fig. 2.3).

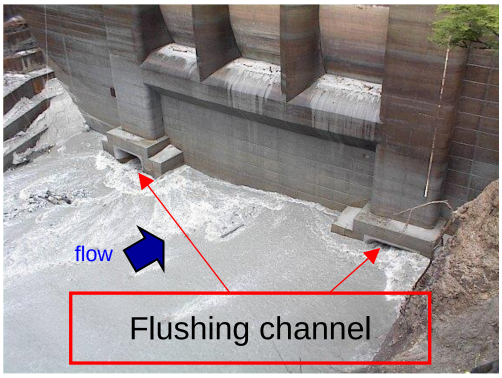


Fig. 2.2 Dashidaira Dam flushing channel inlet

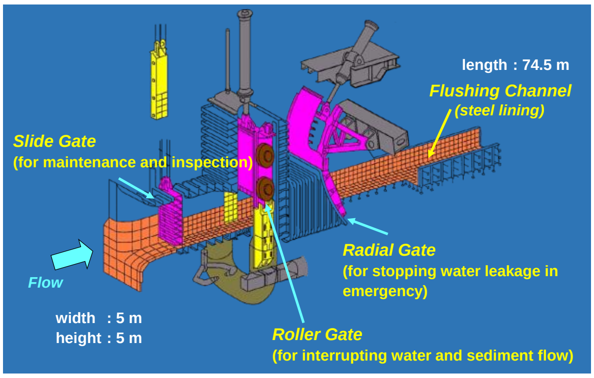


Fig. 2.3 Bird's-eye view of flushing facilities

A2. Flushing at the Dashidaira Dam

Similar facilities were also built at the Unazuki Dam (completed in 2001), which was constructed about 7 km downstream. Efforts to flush sediment are conducted cooperatively. A chronology of flushing at the Dashidaira Dam and amounts of sediment flushing are shown in Fig. 2.4. The history of sediment flushing at Dashidaira Dam can be split roughly into two periods: flushing conducted by Dashidaira Dam alone, and flushing conducted in cooperation with Unazuki Dam downstream. We will describe each in detail below.

2.1 Flushing conducted by Dashidaira Dam alone

Flushing was not conducted just after the completion of the dam in 1985, and the sedimentation volume in the dam in 1991 was 3 million m3. As the effective capacity of some 6 million m3 of the regulating pond decreased and the potential for impediments to drawing water to generate power increased, a plan involving flushing was devised and implemented with a free flow of 7 days, with the target value for amount of sediment flushing set at 600,000 m3. However, because sediment that had accumulated over six years since the dam's completion was flushed, the sediment was accompanied by a black color and putrid odor, which flowed out to the sea. This free flow was stopped in three days. This initial flushing was covered heavily by the media and it became a social problem.

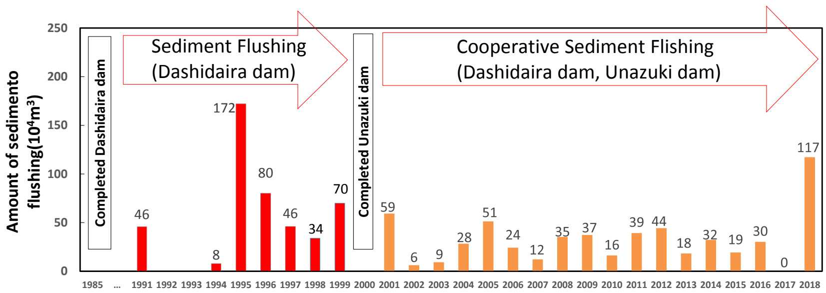


Fig. 2.4 Amount of sediment flushing (Dashidaira Dam)

In February 1992 a committee consisting of academic experts, local government officials, etc. was established in order to study the impacts of flushing at the Dashidaira Dam. This committee discussed future flushing methods at the Dashidaira Dam and so on. With reducing the impact on the river basin as much as possible as its basis, a recommendation was made in April 1995 based on local opinions and trial Dashidaira Dam flushing data that said it is necessary to move forward with flushing using flushing gates. In addition, the committee also requested the implementation of continuing surveys, implementation of flushing when there are floods, and the separate establishment of systems for the evaluation of flushing survey results.

Heavy flooding occurred immediately after trial flushing in July 1995, and over 3 million m3 of sediment was deposited in the reservoir. Emergency flushing was conducted over three years following 1995. Flushing has been conducted when flooding occurs ever since this emergency flushing. Operations are currently stable, and public relations are actively maintained to disseminate related information throughout the region.

2.2 Cooperative flushing with Unazuki Dam

Since 2001, cooperative flushing with the Unazuki Dam has been implemented via the methods shown in Fig. 2.5. This contributes greatly to reducing the volume of sedimentation.

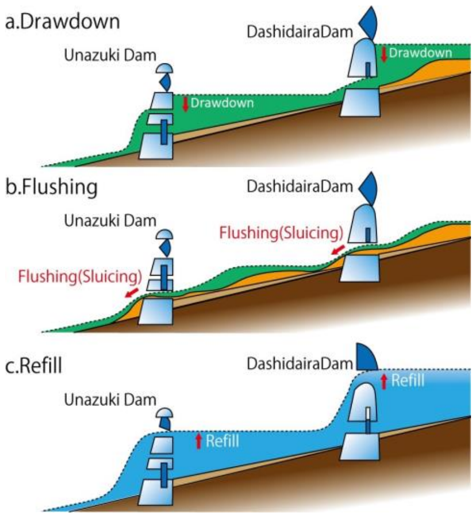


Fig. 2.5 Schematic diagram of cooperative

B. Case of Asahi Dam (bypassing through SBT)

B1. Overview

The KEPCO’s Okuyoshino Power Station (Pumped-Storage) is located in the Shingu River, Nara Prefecture, which is home to national and quasi-national parks. Because of this, since the dam was originally constructed (completed in 1978), efforts have been made to preserve water quality by putting selective water intake facilities in place at the dam in order to give proper consideration to environmental issues. However, the river basin had become devastated around 10 years after the dam’s completion. The occurrence of large-scale floods caused by typhoons in 1990 in particular caused a large quantity of suspended matter supplied from landslides upstream to flow into the reservoir. This in turn caused

Fig. 2.6 Location of Asahi Dam

pronounced, prolonged turbidity. Despite measures being taken, none delivered sufficient effects, and progressing sedimentation became observable.

Therefore, considering the characteristics of the river basin, it was decided a sediment bypass tunnel would be installed as a measure to radically solve these sediment-related problems. As there was no case studies of full-scale sediment bypass tunnel facilities at the time, issues such as the effects and avoiding tunnel blockages were solved through various studies by making use of numerical calculations, hydraulic model experiments, and so on. Solutions were designed and constructed, the tunnel completed and put into operation in 1998.

After the operation of the bypass discharge facilities, the prolonged turbidity mitigation and reduced sedimentation effects were pronounced. In addition to the intended objective being achieved, the local community was extremely happy to see the white stones, characteristic of the area, became visible again. Today, various measures are taken to make it a sustainable hydroelectric power generation facility operating in harmony with the local community, including studies on appropriate maintenance methods for handling bypass channel bed abrasion.

B2. Outline of facilities

The sediment bypass facilities consist of a sediment weir, inlet, bypass tunnel, and outlet. Using the sediment weir constructed at the upstream end of the Asahi Dam reservoir, water is taken from the inlet on the right bank. Water and sediment travel through a bypass tunnel 2.35 km in length and are discharged from the outlet located downstream of the Asahi Dam directly into the river. The discharge capacity of the bypass tunnel was designed to be 140 m3/s so that the number of days of prolonged turbidity due to the peak flow rate of 200 m3/s for one-year return period floods can be reduced. Here, the designed flood volume of Asahi Dam is 1,400 m3/s. Fig. 2.7 shows the specifications and layout of the sediment bypass facilities.

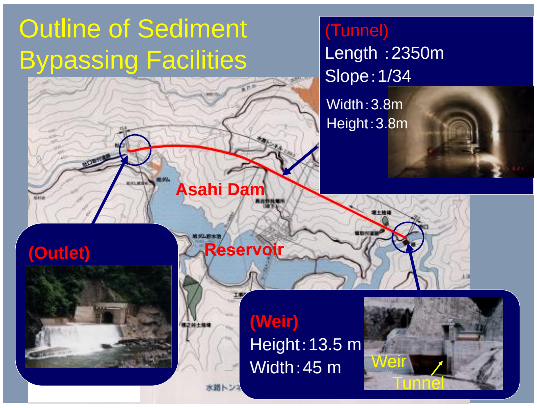


Fig. 2.7 Asahi Dam bypass specifications,

B3. Bypassing results

Compared to the levels before the operation of the sediment bypass facilities, the number of days of prolonged turbidity has been greatly reduced since the start of operation in 1998 (Fig. 2.8). Based on these results, the bypass facilities were seen to be effective in mitigating prolonged turbidity. Fig. 2.9 shows changes in sedimentation volume before and after installation of the sediment bypass facilities. According to this, since the sedimentation rate shows almost no upward trend after operation began, we see that the bypass is effective in mitigating sedimentation.

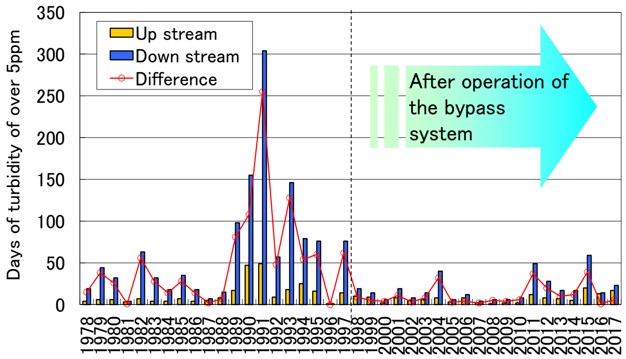


Fig. 2.8 Number of days with turbidity over 5ppm

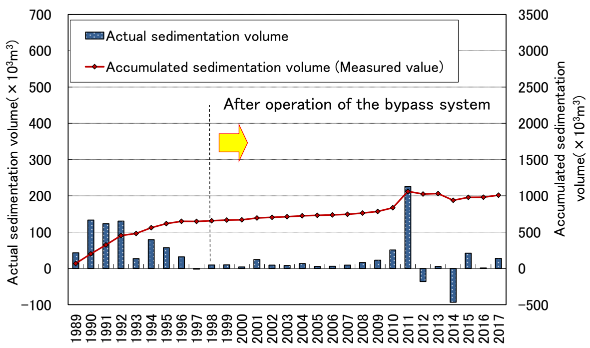


Fig. 2.9 Measured sedimentation volume in the Asahi Dam

C. Lessons learned

C1. Dashidaira Dam

Lessons learned from Dashidaira Dam's flushing operation is as follows;

- Flushing be implemented at the time of large discharge, that is, floods in order to prevent concentration of SS and organic substances and to mitigate impacts on downstream fishery, farming, sightseeing and so on.
- Flushing be implemented at least once a year in order to prevent deterioration of deposited organic substances.
- Flushing time could be limited within 12 hours in most cases as shown in Fig.2.10.
- To prevent over-flushing it is important to know the relationship between flushing time and expected sediment volume to be flushed by using the advanced riverbed simulation model.
- Releasing river water for a certain period of time after flushing be considered in order to move flushed sediment further downstream.
- Delaying drawdown rate of water be helpful to lower the concentration of SS and organic substances.
- Releasing river water through flushing gates without drawdown of water be helpful to mitigate deterioration of organic substances on the surface of sedimentation.

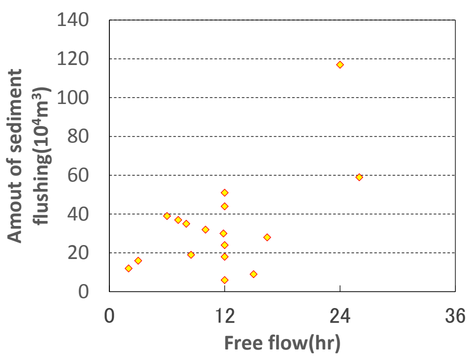


Fig. 2.10 The relationship between the amount of sediment flushing and the free flow time at Dashidaira Dam (Based on data after cooperative flushing began in 2001)

C2. Asahi Dam bypass

Lessons learned from Asahi Dam's bypassing operation is as follows;

- Local abrasion much deeper than the average may take place inside of bend in the SBT, which could be prevented by careful choice of the alignment of the SBT. High performance concrete could be applied to fill the void.
- It is important to make environmental investigations in advance of the project on ecosystem and profile of the river both upstream and downstream in order to evaluate the performance of the SBT operation.
- Sedimentation in the reservoir taken place in case of big floods be taken attention to and possible countermeasures against it be studied.

C3. A comparison of flushing and bypassing

We compared the performance of flushing and bypassing based on cases of Dashidaira Dam and Asahi Dam from the viewpoint of hydropower operators as shown in Table 2.1.

Table 2.1 Comparison of flushing and bypassing

performance items	Flushing	Bypassing
reduction of sediment inflow to the reservoir	never	higher
reduction of sediment in the reservoir	higher	never
impact on environment downstream	higher	lower
impact on hydropower generation	higher	lower
time duration of operation	shorter	longer
opportunity	limited	as needed
operatability	lower	higher
maintenability	higher	lower
initial cost	lower	higher
adaptability to existing dam	lower	higher

3 Roles of civil engineers for sustainable hydropower operation

For hydropower operators, who have a history of development together with local communities, understanding and cooperation from local communities is crucial for the continuation of business.

For this reason, KEPCO implemented various countermeasures ahead of other companies while collaborating with academic and local authorities.

The main cause of sedimentation problems is that the construction of dams interrupts the continuity of sediment transportation. It is therefore essential to properly transport sediment downstream. As discussed so far, flushing and bypassing would give better solutions than only excavating and dredging because they would also give solutions to issues of decreasing riverbeds and coastal erosion downstream. It must be desirable if such countermeasures against sedimentation as would transport the same amount of sediment downstream just as before the dam was constructed. We believe that the large amount of knowledge gained through the operation of the Dashidaira Dam and Asahi Dam would contribute to the future progress of reservoir sediment management.

The point is that, due to the recently increasing severity of localized torrential rain, these problems may be facilitated and become even more explicit and evident in the near future.

The sedimentation volume for the Kurobe Dam already exceeded the design value of 100-year worth in 58 years after its completion. Since the difference of flow rates between flood and drought is extremely large in Japan, how to maintain the effective capacity of the reservoir furthest upstream on a major river is the most important issue for the durability of hydropower generation.

Photo.3.1 Dr. Sumi on the backsand of Kurobe Dam

To solve this problem, we do expect civil engineers, with the cooperation of not only hydropower operators but also stakeholders of the whole river basin upstream and downstream, to establish a comprehensive and sustainable sediment management scheme including afforestation, erosion control, sediment transportation downstream to the river mouth in an environment friendly manner, which we believe, would be beneficial to create more resilient and peaceful society.

References

Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT): Sediment disaster in July 2018