DAM BREAK ACCIDENT AND RESULTING SEDIMENT MANAGEMENT AT DOWNSTREAM DAMS IN LAO PDR - HIGHLY TURBID FLOOD-FLOW AND SEDIMENT FLUSHING AT NAN NGIEP 1 HYDROPOWER PROJECT –

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ABSTRACT

In September 2017 a dam of the A Project, which is located 90 km upstream of the Nam Ngiep 1 Hydropower Project (NNP1) in Lao PDR, collapsed during construction and partially stored water of around 500,000 m³ in the reservoir was flushed away to the downstream river course. The highly turbid water had a serious impact on the ecology of the downstream river course, and sediment of around 700,000m³ was accumulated in main dam and the re-regulation dam reservoirs of the NNP1, while the turbid water flew through the diversion of the main dam of the NNP1 located 7 km upstream of the re-regulation dam which was under construction. It was feared from the beginning that when starting the operation of the re-regulation dam reservoir, the anaerobic and deteriorated clay and silt could be released together with the environmental flow through the re-regulation dam reservoir, and thus impact the ecology of the downstream river basin. In order to mitigate this harmful impact, the NNP1 determined to implement sediment flushing in the early dry season of 2017, when the NNP1 River had a certain volume of the flow before starting the initial impounding scheduled in May 2018. This paper presents the dam break impact on the downstream river course and the resulting sediment management at the downstream NNP1 reservoirs.

1. INTRODUCTION

The Nam Ngeip1 Hydropower Project is an Independent Power Producer (IPP) Project invested by Kansai Electric Power Company (KANSAI) in Japan, Electricity Generation Authority of Thailand (EGAT) in Thailand and Lao Holding State Enterprise (LHSE) in Lao PDR. The NNP1 will be transferred to Lao PDR after 27 year operation. The NNP1 is located along the Nam Ngiep River, which is a tributary of the Mekong River and 130 km north-east from the Vientiane capital and consists of two couples of dam and powerhouse, namely the main dam of 167 m high and the main powerhouse with 273 MW installed capacity and the re-regulation dam of 20.6 m high and the re-regulation powerhouse with 17 MW installed capacity. The former supplies the electricity to Thailand and the latter does to Lao PDR. The NNP1 concluded the financial close in September 2014, started the initial impounding in May 2018 and commenced the commercial operation in September 2019.

Several hydropower projects are being operated or under construction at the upstream river of the NNP1. “A project” located 90 km upstream from the NNP1 was being developed by a local company in Lao PDR. The location of the NNP1 and the A project is shown in Figure 1. The construction of the A dam, which is an earthfill dam, started in 2015 and breached in September 2017 when its progress reached 85 %. Since in Lao PDR such small hydropower projects are frequently developed by Lao local companies with the permission of provincial level, there may exist a possibility that the technical and environmental examination are not sufficiently conducted by authorized agencies.

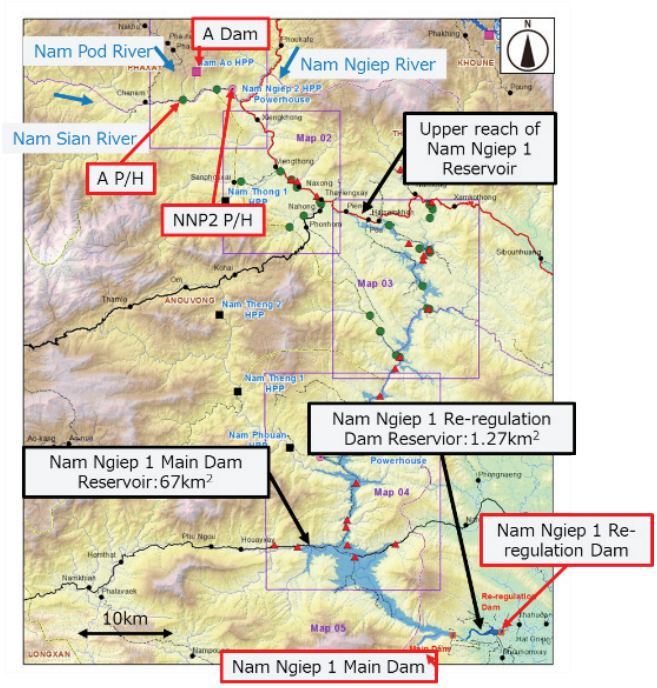


Figure 1 : Location of the NNP1 and A Project

2. DAM BREAK OF A PROJECT

2.1 Dam break and highly turbid water flush

The A Project takes the water from the Nam Pod River to the reservoir through a diversion channel. The powerhouse is located downstream of the confluence of the Nam Pod River and the Nam Sian River. A part of the dam breached with 20 m high, 20 m wide, and 100 m long at 13:45 11th September 2017. Almost all the stored water around 500,000 m^3 was released from the reservoir due to dam break (See Fig. 3) and the released water seemed to be flushed away along 3 km downstream gully in 100 m wide with the state of the bore (Muraoka 2012 in Japanese) by swallowing clay, silt, and rubble (See Fig. 2). By the way, the photos of the incident were uploaded on Facebook on 13th September (Himel 2017).

Though so far no injuries and human loss were not reported, damages on infrastructure, agricultural land cattle and so on were seen at eight villages of Thavieng district located downstream of the A dam. The powerhouse of the Nam Ngeip 2 hydropower project (NNP2), which is located 3.5 km downstream from the A dam, was damaged due to the intrusion of the highly turbid water (See Fig. 4 left). The residents along the Nam Nigep River started evacuation by themselves before the caution was announced by the public agency. The status of the damages was uploaded on Facebook and was noticed by people all around Lao PDR. It is still very hard to negotiate compensation with local investor of the A project due to their fewer funds.

The NNP1 has established communication for information sharing with the related governmental agencies and the other major projects in the Nam Ngiep River Basin. For example, the NNP1 get daily discharge of the NNP1 every day from the NNP2. However, the A project is not included in the communication network. Actually, the NNP1 noticed the dam break of the A dam from Facebook two or three hours later from the dam break and NNP1 shared this information with NNP2 soon. After that, the highly turbid water reached the NNP1 site seven hours later of the dam break. By the way, residents around the NNP1 site didn't evacuate, since the fluctuation of the river flow when the turbid water reached the NNP1 site was small.

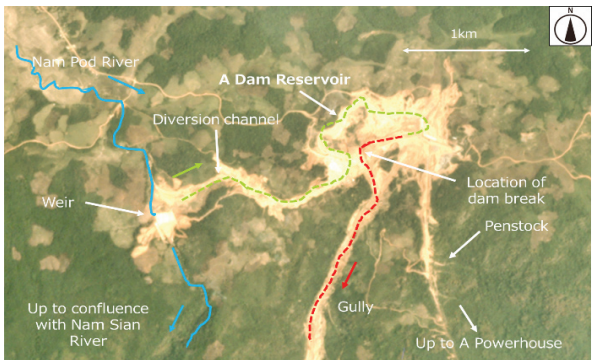
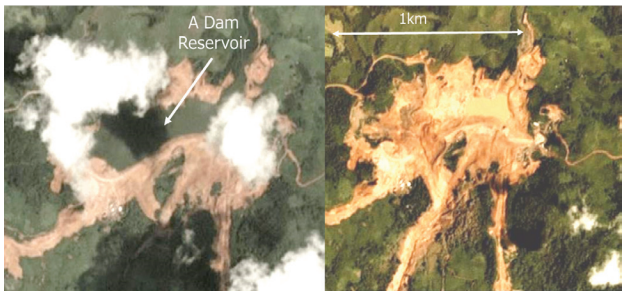


Figure 2 : Image of highly turbid water flush



(a) Before dam break (b) After dam break

Figure 3 : Image around the dam before after dam break

Figure 4 : Damage on powerhouse of NNP2 and agricultural land

2.2 Impact on fish

The turbid water reached the NNP1 7 hours later from the dam break. While the NNP1 measures the water level two times per day, the increase in the water level due to the dam break was slight, 14 cm. The water quality of the NNP River was tested at several points as shown in Figure 5. As seen in the time series of Total Suspended Solids (TSS), an extremely high TSS was observed upstream of the main dam NNG09 (See Fig. 5). It was 1,000 times TSS (125,172 mg/liter) as much as the past measured maximum TSS. The high TSS continued for five days after the dam break. The high TSS was also observed in the re-regulation dam reservoir NNG04, which is 4 km downstream from the main dam, however, it was one-hundredth of that measured at the main dam. At that time the main dam was under construction and the turbid water flowed through the diversion tunnel of the main dam. The TSS measured downstream of the re-regulation dam NNG05 was one-forty of that at the main dam NNG09 and high TSS continued for rather long time. It is assumed that highly turbid water flowed quickly around the main dam where the narrow valley is formed and the Suspended Substance (SS) settled in the re-regulation dam reservoir, of which capacity is 7,700,000 m^3 at a high water level 179 m. It means the re-regulation dam reservoir had a role of diluting the turbid water. The time series of the Dissolved Oxygen (DO) is shown in Figure 7. The minimum DO was observed on 12th September 2017. The DO was 4.93 mg/liter lower than 6 mg/L, which is a criterion of the NNP1 for maintaining habitat. A large amount of fish was died due to the highly turbid water. It was assumed that the direct cause of death of fish was not DO but clogging of the gill due to the high density clay and silt in the water.

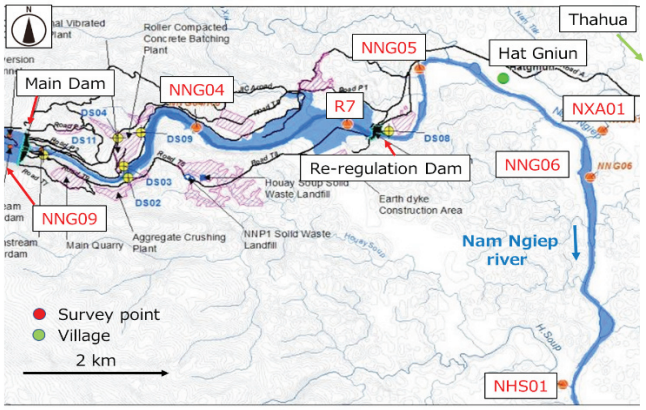


Figure 5. Location of water quality testing

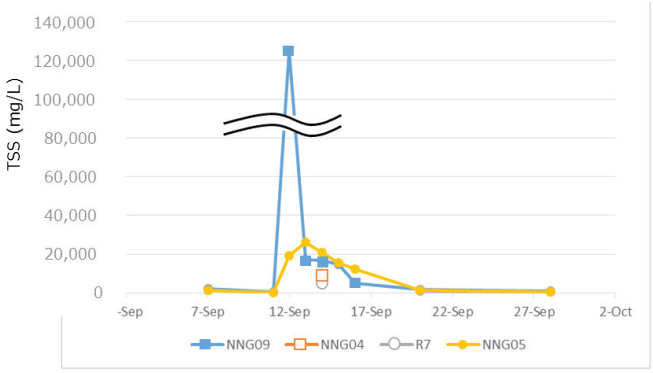


Figure 6. Time series of Total Suspended Solids (TSS)

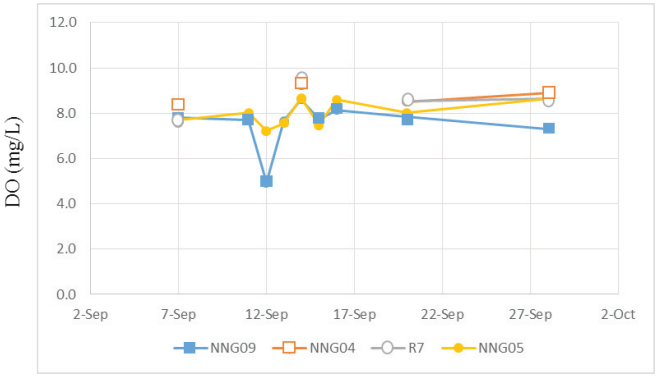


Figure 7 : Time series of DO

The amount of dead fish caught by the residents from 12th to 13th September 2017 and the photos of dead fish are shown in Table 1 and Figure 8 respectively, while small dead fish was not counted in the table since the residents didn't catch the small fish which does not deserves eating or selling. The amount of dead fish at Hat Gniun village, which is located downstream of the re-regulation dam, was the maximum of 6,410 kg, which was six times as much as the monthly maximum fish yield from 2015 to 2016. The kinds of dead fish and their ratio are shown in Table 2. The majority were carp and catfish and several kinds of the eel were contained. There is a clear difference in kinds of fish between the upstream area and at Ha Gniun village, however, it has not been analyzed whether there existed difference in habitat or resistance of fish between them. Among dead fish there existed Endangered Species and nearly Threatened Species in Red-List of IUCN. On the other hand, a huge difference in the amount of dead fish between the upstream area and Hat Gniun was observed. The amount of dead fish caught in Thavieng was just 5 kg/household and that at Hat Gniun was 100 kg/household. Though information on water quality in the upstream area during the incident was not obtained, it is assumed that the density of the turbid water was low in the upstream area where the rather wide river flows but quite high around the NNP1 main dam site. Then quite a lot of fish died at the narrow valley due to the highly turbid water concentration and were flowed to downstream Hat Gniun. The death of fish was informed to residents at Hat Gniun by those in the upstream area and then many residents at Hat Gniun rush into the river to catch dead fish without evacuation. Almost all large dead fish were picked up at Hat Gniun and only small dead fish were moved downstream.

Figure 8 : Photos of dead fish

The environmental impact survey was conducted in March 2018 by the NNP1 lead by Dr. Kottelat who is a specialist in fish in Switzerland (Kottelat 2018). The aquatic plant along the Nam Sian River was completely removed by the incident and the shape of the Nam Sian River was also changed. The thick sedimentation of clay was observed from the confluence of the Nam Sian River and the Nam Ngeip River to Thavieng area downstream. The habitat was significantly changed in this area. Several kinds of fish were disappear and the number of fish dramatically decreased from the confluence towards the NNP1 dam site. The residents at Hat Gniun recognize that the number of fish staying in the river decreases and it may take five years to recover the number of fish.

Table 1 : Amount of dead fish which were caught by residents.

Area	Village	Number of household catching fish (nos)	Amount of fish yield (kg)
Upstream	Xienkong	15	110
	Vientong	19	68
	Na Xong	11	79
	Thevianxay	17	118
Upstream of reservoir of main dam	Pow	13	197
	Hatxamkhone	12	168
	Piengta	23	248
Downstream of re-regulation dam	Hat Gniun	49	6,410
	Thahua	3	60
	Xomsone	11	432
	Nam Pa	2	17
	Thon Noi	32	85
Total		187	7,991

Table 2 : Kinds of dead fish and ratio.

Scientific name		Upstream	Thavieng	Hat Gniun
1	Tor Sinensi	26.4 %	23.2 %	1.7 %
2	Poropuntius sp.	15.7 %	16.7 %	1.7 %
3	Hemibagrus wyckioides	10.7 %	16.6 %	24.6 %
4	Mastacembelus sp.	9.6 %	2.8 %	0.1 %
5	Hampala sp.	2.4 %	9.3 %	1.5 %
6	Cyprinus carpio	6.3 %	8.5 %	0.1 %
7	Hypsibarbus sp.	4.3 %	3.1 %	12.3 %
8	Labeo sp.	0.0 %	0.0 %	34.2 %
9	Others	24.6 %	19.8 %	23.8 %
Total (ratio)		100 %	100 %	100 %
Total amount (kg)		612 kg	375 kg	6,410 kg

The dissection of dead fish was conducted by the NNP1 in 2018 to confirm the cause of death (NNP1PC 2018). The gill was clogged with clay and silt (See Fig. 9 left).

Figure 9 : Photos and figure of gill of dead fish (Syougakukan 1992 in Japanese)

2.3 Sedimentation in re-regulation dam reservoir

The average inflow in September 2019 was 260 m^3/s and the maximum TSS was 100,000 mg/L, then sedimentation volume is estimated to be 100,000 m^3/hour. The state might continue for hours and the total volume of sedimentation in the re-regulation dam reservoir is estimated to be at least 700,000 m^3 by considering the above fact and survey results of riverbed survey in the re-regulation dam reservoir. The state of the sedimentation in the re-regulation dam reservoir is shown in Figure 10.

Figure 10 : Sedimentation in re-regulation dam reservoir in November 2017

3. SEDIMENT FLUSHING

3.1 Planning of sediment flushing

The initial impounding of the main dam started in May 2018. During the initial impounding, the environmental flow release was planned by using the stored water in the re-regulation dam reservoir. The environmental flow requires 5.5 m^3/s during the initial impounding, which is equivalent to specific index of 0.15 $m^3/s/100\ km^2$. It was feared that a large amount of the clay and the silt accumulated in the re-regulation dam reservoir got anaerobic and highly turbid water might be released through a small channel being formed on the surface of the sedimentation in the re-regulation dam reservoir due to a slight volume of the environmental flow release. To solve this issue, sediment flushing before initial impounding was planned by using a gate installed at the re-regulation dam, which is used for discharging the environmental flow of 27 m^3/s during operation period according to the concession agreement with the Lao Government. The discharge capacity of the gate is designed to be 213 m^3/s. The plan and profile of the re-regulation dam reservoir are shown in Figure 11 and Figure 12. The width of the river varies around 50 m to 100 m and sedimentation was mainly accumulated at the flat area 2.5 km upstream from the re-regulation dam reservoir. The NNP1 implemented the sediment flushing in November 2017 when the inflow was still abundant in the dry season 2017 to 2018. At first, the reservoir water level was lowered in the initial three days by keeping 130 m^3/s discharge from the gate. And then the sediment flushing was conducted in the middle three days by keeping the water level at the lowest with 100 m^3/s discharge. Finally the reservoir water level was raised in the last three days with 70 m^3/s discharge. By the way, before implementation, the program of the sediment flushing was informed to the residents through consultation meeting and finally approved by the Resettlement Management Committee of Bolikhamxay Province.

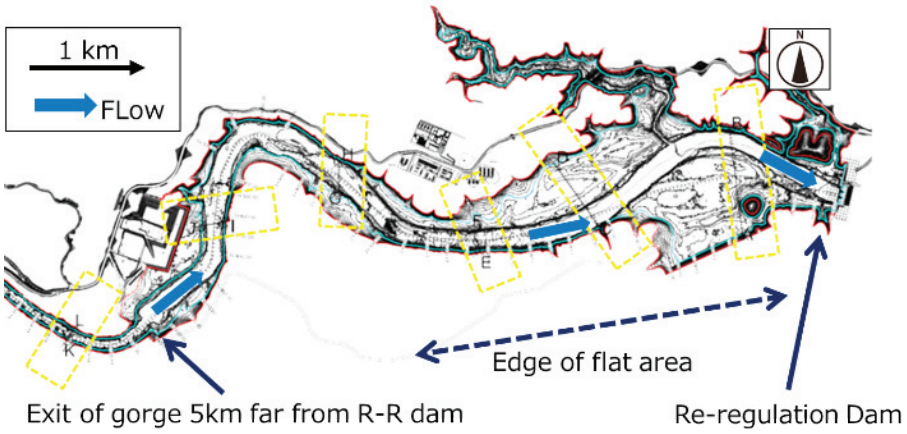


Figure 11 : Plan of re-regulation dam reservoir

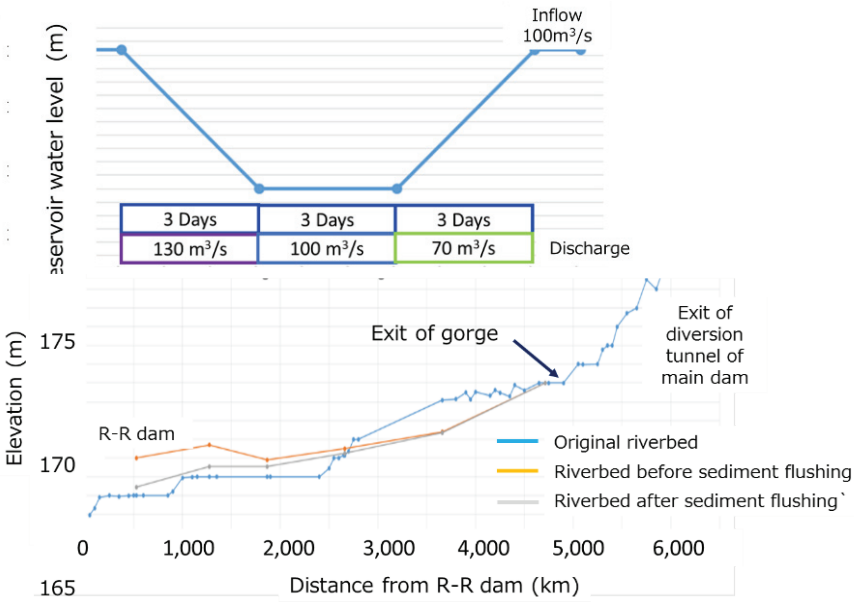
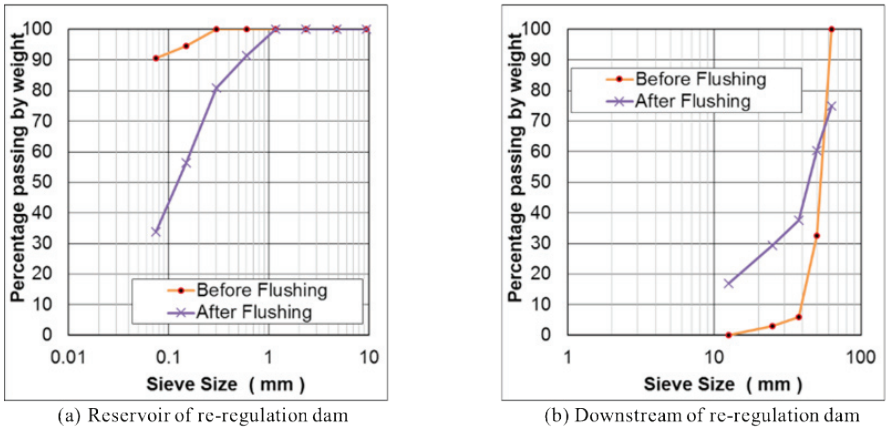


Figure 12 : Profile of re-regulation dam reservoir

3.2 Effect of sediment flushing

By the sediment flushing, total 200,000 m³ sediment accumulated downstream area of the re-regulation dam reservoir was discharged. The particle size distribution of the sediment in the re-regulation dam reservoir collected before and after the sediment flushing is shown in Figure 14. The particle size distribution in the re-regulation dam reservoir became large by sediment flushing, since clay and silt were mainly flushed away. On the other hand, the particle size distribution downstream of the re-regulation dam became small. The gravel of which particle size around 10 mm increased downstream of the re-regulation dam, that is to say, gravel forming the riverbed in the re-regulation dam reservoir was also flushed away as well as clay and silt. A rapid of the original riverbed in the re-regulation dam reservoir is shown in Figure 15 and rather large size of stones existed. These materials were flushed away and accumulated around the tailrace of the re-regulation dam and the tailrace water level increased slightly.



(a) Reservoir of re-regulation dam (b) Downstream of re-regulation dam

Figure 14 : Discharge plan of sediment flushing

Figure 15. Particle size distribution of sediment

Time series of the reservoir water level of the re-regulation dam reservoir, turbidity (NTU), and TSS are shown in Figure 16, 17, and 18 respectively. The reservoir water level decreased to the minimum water level at midnight on 4th November 2017. The maximum TSS of 7,350 mg/L was observed at 7:00 of 5th November 2017 and the maximum turbidity of 12,370 NTU was observed at 11:00 of 5th November 2017. Though the exact time of the peak of them is not identified due to limitation of the water quality test during the night time, it is assumed that sediment flushing succeeded effectively when the reservoir water level got the minimum water level and the sediment flushing continued until the reservoir water level was raised to the full tank level on 7th November 2017. The turbidity downstream of the re-regulation dam decreased to the normal level on the same day. On the other hand, turbidity at the confluence of the Mekong River and the Nam Ngiep River (NNG08) continued high till 8th November 2019. The amount of dead fish during the sediment flushing along several kilometers downstream from the re-regulation dam was only 2 kg. Therefore the impact of the sediment flushing on the habitat was not significant. The photos of the reservoir before and after sediment flushing are shown in Figure 19. The riverbed appeared upstream right side of the reservoir, of which surface was covered with mainly the silt and the sand.

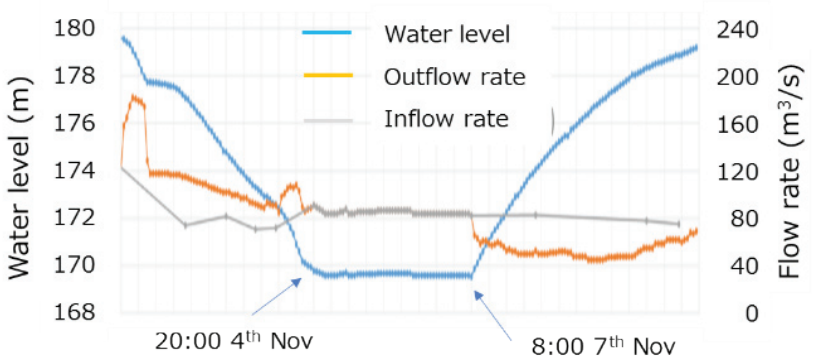


Figure 16. Photo of rapid of original river

The initial impounding started in the middle of May 2018. The environmental flow was discharged from the re-regulation dam reservoir for the next three months. The death of fish and the claims from the residents were not reported during this term. However, the sediment of 500,000 m³ still remains in the reservoir and will be supplied from upstream. The further study for implementation of sediment flush will be considered.

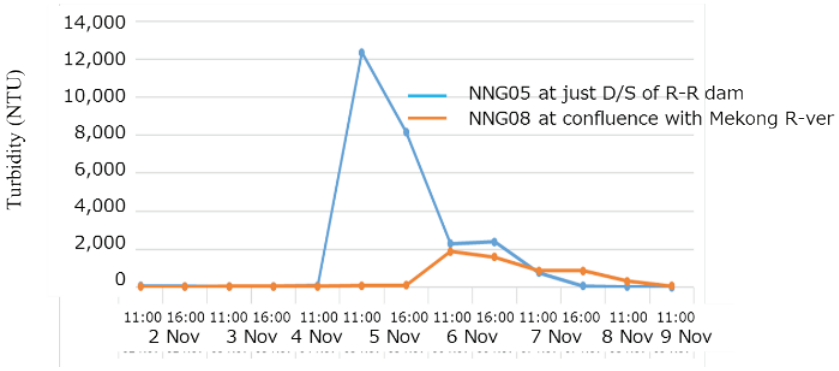


Figure 17. Time series of water level of the re-regulation dam reservoir

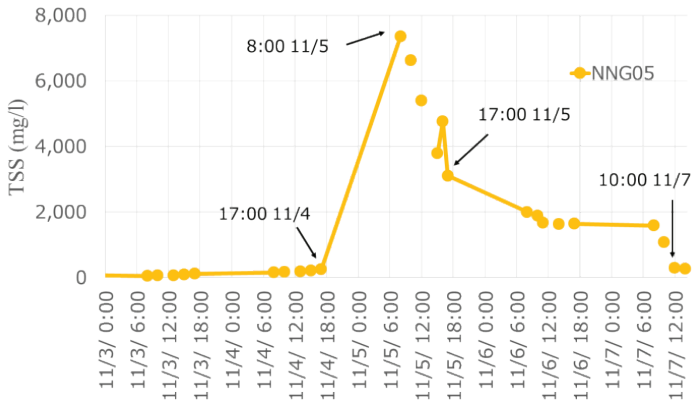


Figure 18. Time series of turbidity (NTU)

Figure 19. Photos of reservoir before and after sediment flushing

4. FURTHER STUDY

It is expected that the sedimentation in the re-regulation dam reservoir increases since the inflow of the sediment increases due to activities upstream such as construction of road, development of mining, expansion of agricultural land and so on. The timing of the sediment flushing should be considered carefully through monitoring of water quality and the sounding of the riverbed.

The NNP2, which has 60 m high earthfill dam, is located upstream of the NNP1. The NNP1 conducted climate change analysis (Doi 2018 in Japanese) according to recommendations by Lenders Asian Development Bank. Assuming the dam break of the NNP2, the safety of the NNP1 dam was assessed and verified to be stable against this kind of extraordinary incident. However, still environmental issues such as sedimentation and water quality deterioration remain to be studied.

5. CONCLUSIONS

Incidents such as dam break and damages related to environmental aspects may frequently occur in the developing countries resulting from defects or lack of technical and the environmental standards, difference of in the approval system by public institutions, immaturity of contractors and design, inadequate consideration for the environmental issues and so on.

In the case of the NNP1, the dam break of the upstream project created the highly turbid water flow, and it caused the significant impact on the habitat in the river course directly and the secondary adverse impacts such as sedimentation and anaerobic in the re-regulation dam reservoir, and the increase of the tailrace water level of the re-regulation powerhouse.

The NNP1 conducted the sediment flushing at the re-regulation dam, which is located downstream of the upstream project by using the gate for the environmental flow to avoid the subsequent environmental issue during the initial impounding. And the sediment flushing had an effect to mitigate the issue that the anaerobic clay and silt would be released during the initial impounding. On the other hand, the re-regulation dam reservoir might have a role to dilute the highly turbid water flowing downstream.

The NNP1 has developed the hydropower project with compliance with safeguard polices imposed by the Lenders and NNP1 established the communication network to share information with the governmental agencies and major projects in the Nam Ngiep Basin in terms of conservation of the basin. However, the dam break occurred at the small hydropower project upstream probably due to the immaturity of the technical level. And it had an impact on the NNP1's re-regulation dam reservoir by sedimentation of clay and silt caused by the highly turbid water flow. These environmental issues should be recognized as one of risks in the developing countries. By the way, the NNP1 has commenced the commercial operation since September 2019 and will continue monitoring and efforts to mitigate environmental impacts.

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