Effects of releasing fine sediment from the reservoir on river morphology

1- Mehran Dadpour, UNESCO-IHE Institute for Water Education, Delft, The Netherlands and Tooss Ab Consulting Engineers Company, Mashhad, Iran.
2- Alessandra Crosato, UNESCO-IHE Institute for Water Education and Delft University of Technology, Delft, The Netherlands.
3- Maximo Peviani, Environment and Sustainable Development, CESI RICERCA, Seriate, Italy.

Abstract

Hydropower is one of the most interesting types of renewable energy sources in most countries. According to the 2001/77 (RES-e Directive), European countries must increase their share of renewable electricity production. To enhance the use of water energy, the first step is the construction of dams on the rivers. Construction of dams will inundate a large area upstream and change the flow patterns, as well as the morphology of the river upstream and downstream of the dam, and consequently have environmental impacts.

Accumulation of sediments in the reservoir gradually reduces the active capacity of the reservoir. In addition, sediment trapping behind the dam reduces the sediment input to the downstream river. This, combined with changes of sediment transport capacity of the river leads to morphological changes downstream of the dam.

To increase the life of the dam and decrease the negative impacts of damming, it is necessary to find a good sediment-water management strategy allowing to increase the productive life of the reservoir as well as electricity generation, to keep enough capacity for flood protection and to mitigate the impact on the downstream river morphology and ecosystem.

In this study different scenario of sediment releases are studied, for the Piave River, Italy, and the Shirin Dareh River, Iran. A 1-D morphological model accounting for different sediment sizes, designed for applications on mountain rivers, is applied to simulate different amounts of water and sediment release to downstream. For the Piave River, the work investigated the possibility of releasing fine sediment, which is deposited in the last part of reservoir near the dam, with the environmental flow. This is the minimum discharge that should be released to the river according to the Italian law and is 10% of the averaged annual river discharge. Releasing of fine sediment with low flows is based on the idea of maintaining suspended sediment concentrations within acceptable limits for the aquatic environment.

Due to lack of data, the release of sediment in the Shirin Dareh River was only studied on a steep reach upstream of Shirin Dareh Dam, with the only aim of comparing the response of two different water courses to this type of operation.

Due to different catchment's characteristics, (high slope and finer sediment in Shirin Dareh River compare with milder slope with coarser sediment in Piave River), although similar scenarios (with difference in parameter values) were defined for the two catchments under study, two different results were achieved. Releasing fine sediment with the environmental flows appears feasible on the Piave but not on the Shirin Dareh

Keywords: river morphology, sedimentation, hydropower, environmental flow, sediment transport, river ecology.

1- Introduction

The most important morphological effects on the downstream river are caused by sediment trapping behind the dam and by the variation in discharge regime. Sediment transported by the river settles in the reservoir and clean water is released to the downstream river. Water without sediment has significant capacity for sediment transport but there isn't enough sediment coming from upstream so, water starts to erode the banks and the bed of the river. These effects can extend up to 100 kilometers downstream. This phenomenon may have negative effects on the structures built downstream, such as bridges. By reducing flow strength, sediment supply, frequency and intensity of floods, dam construction over a river can change a braided river into an incised meandering river (Crosato, 2011).

2- Case studies

2-1 Piave River

The Piave River is located in North-East of Italy. The source of the river lies in the Alps and the mouth in the Adriatic Sea. The surface of its catchment is about 3900 km^2. The major tributaries of the Piave River are the Boite, the Ansiei, the Cordevole and the Mis rivers. 13 major dams have been built in this catchment to generate electricity and flood protection. By means of diversion the river flow in the basin is managed.

2-2 Shirin Dareh River

The Shirin Dareh River is located in a mountain area in North- East of Iran, in the Khorasan Shomali Province. Shirin Dareh is a perennial river with a catchment area of 1614 km^2. The source of the Shirin Dareh River is Bash Tapeh mountain and it discharges to the Atrak River. The Shirin Dareh dam was constructed on the Shirin Dareh River in 2004 in order to regulate the river discharge and store water for drinking and irrigation purposes.

2-3 Comparison between two catchments (Piave and Shirin Dareh)

2-3-1 Relevant aspects

Both the Shirin Dareh and the Piave Rivers are located in mountain areas. Both rivers have a capacity of dam construction. The Pieve di Cadore dam was constructed in 1949 on the Piave River and the Shirin Dareh dam was constructed on the Shirin Dareh River in 2004. The hydrology of both catchments is relatively the same and the highest amount of precipitation in both catchments occurs in spring and fall. In both case studies some villages and structures are located close to the river so, during the investigations the possible effect of different scenarios must be taken into account.

2-3-2 Relevant differences

A big difference between these two case studies is the surface cover. Although Piave catchment is covered by dense forest, the vegetation cover of the Shirin Dareh catchment is very poor. According to the available sediment samples, bed particles of the Shirin Dareh are composed of medium gravel and finer materials (D<16 mm) while in the Piave River about 20% of the bed materials is composed of cobbles (D>64 mm), about 30% is gravel (16-64 mm) and the rest is finer than 16 mm. Since the study area in the Piave catchment is located downstream of the Piave dam, sediment supply to downstream of the Piave River is restricted, but the presence of unregulated tributaries downstream of the dam introduces new sediment to the Piave River. On the other hand in the Shirin Dareh study area there is no artificial obstacle to restrict sediment supply from upstream.

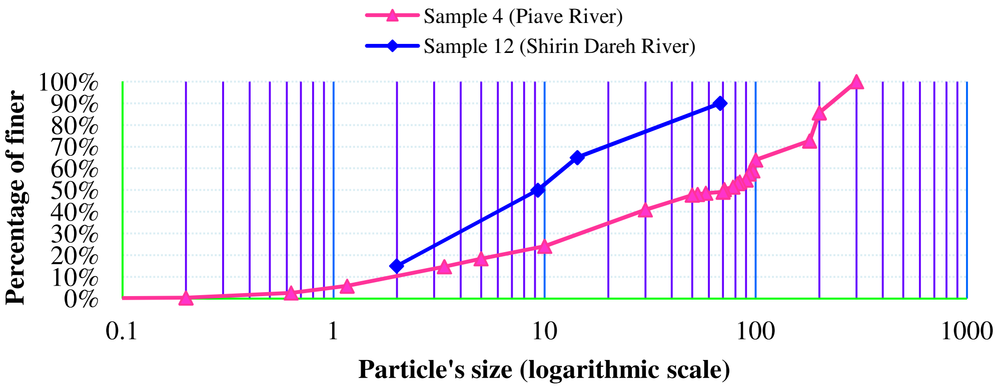

Figure 1- Particle size distribution curves for Piave River and Shirin Dareh River.

The big difference between the highest and lowest point of the Shirin Dareh catchment (2687 m a.s.l-723 m a.s.l) caused quite a high slope (about 1.5%-2.5%). Another reason for the high slope in the Shirin Dareh study area is the location upstream of the Shirin Dareh dam and in the beginning of the Shirin Dareh River in high mountains. On the other hand the Piave study area is located downstream of the Pieve di Cadore dam, during 63 years after dam construction, the bed slope became smoother and the highest bed slope exists in the upstream parts with the value of about 1.6% and the in the rest of the river is less than 1%.

3- Sediment transport equation

MORIMOR model is a Tool used to do this study which is a 1-D model able to simulate scenarios in mountain areas with non-uniform sediment. By taking into account hydrodynamics and sedimentological parameters, the sediment transport for each class is computed by means of the following equation (Di Silvio, 1983):

$$T_i = \alpha \frac{Q^m I^n}{B^p d_i^q} \beta_i \xi_i \quad (1)$$

Where d_i is grain diameter corresponding to the i-th class, I is the bottom slope and α, m,n, p, q are coefficients. α is a coefficient which includes all quantities assumed constant in the above equation. α is a site specific value and must be determined for each catchment with its own climatic and physical characteristics (Di Silvio, 1983).

For computation of sediment transport of non-uniform grain size sediments, Di Silvio (1990) introduced equation 1. In this equation, the fraction related to the i-th class present in the streambed (β_i), and the "hiding and exposure" coefficient used for comparison between the smaller (higher) mobility of finer (coarser) particles in a mixture. The mobility of the same particles in a uniform grain size material which is introduced as:

$$\xi_i = \left(\frac{d_i}{d_m}\right)^s \quad (2)$$

Where d_m is the mean grain diameter:

$$d_m = \sum_{i=1}^{4} \beta_i d_i \quad (3)$$

A typical structure of many sediment transport formulas including Di Silvio is:

$$q = mu^b \quad (4)$$

where q is a volume of sediment transport per unit of width, m is a coefficient, b is a exponent.

Generally a constant Chezy coefficient is more suitable for rivers in flat areas where dune resistance dominates while it is better to use a constant Manning coefficient in mountain rivers with a flat bed where grain resistance dominates. The parameter s of the hiding-and-exposure coefficient has a tendency to increase in mountain rivers with strongly sorted material and to reduce to a value equal to q for a really high value of Q. The parameter s can be equal to s=0.8 in big floods and increase for strongly sorted material (mountain rivers) and a smaller value of almost zero in some cases for plain rivers (Di Silvio, 1983).

Formula selection must be made according to the characteristics of the river and the size of sediment particles. In both catchments in this study (Piave river and Shirin Dareh river Di Silvio 1983 has been selected which is adopted for mountain rivers.

4- Scenario definition

This study analysis the effect of releasing fine sediment with the environmental flow. In particular it is important to evaluate whether fine sediment is deposited on the river bed and where and if this deposited sediment can be flushed away by higher floods. Five different scenarios are investigated in this study. The difference between these scenarios is the amount of water (artificial flood magnitude) used to remove deposited fine sediment along the river. In the first scenario (scenario A) no flash flood occurs while in other scenarios, artificial floods with different magnitude are released from the dam for removing fine sediments deposited on the river bed. According to the hydrological data, the environmental flow for Piave river is assigned to be 2 m^3/s and for Shirin Dareh river is assigned to be 0.1 lit/s. The duration of environmental flow releases for both rivers is one year.

Table 1- Main scenarios characteristics

Scenario	Flood discharge (m^3/s)		Flood duration (day)	
	Piave River	Shirin Dareh River	Piave River	Shirin Dareh River
Scenario A	-	-	-	-
Scenario B	20	10	2	2
Scenario C	30	15	2	2
Scenario D	40	20	2	2
Scenario E	100	-	2	-

5- Results

5-1 Piave River

In consequence of sediment discharge, the released material will be transported by the river flow and deposited along the river. Since the total amount of fine sediment (0.15 mm) passed through the Pieve di Cadore dam and river discharge (2 m^3/s for 365 days) before flash flood (environmental flow) for all scenarios is the same therefore, the morphological and ecological change that occurs before the floods are the same for all scenarios. According to Figure 2 the critical area for fine sediment deposition is located in the first 5 km of the Piave River after Pieve di Cadore dam. Here the major part of deposition occurs because the amount of water for transporting sediment is limited to the output of the Pieve di Cadore dam (2 m^3/s). In the first 300 meters due to high bed slope (3.4 %) erosion is the dominating phenomena in all scenarios. In the part of the river located in 300 m to 2,350 m from the dam the bed slope decreases to 1%. This decrease in slope leads to decrease in flow velocity therefore, sediment deposition happened. Again, between 2,350 m and 3,000 m downstream of the dam, the bed slope increases again up to 2.5% and that is why erosion is visible in this length of the river. By bed slope decreasing from 3,000 m far from the dam to downstream of the study area and the channel become wider, deposition is the governing phenomenon in this part, in all scenarios. Another reason for occurring smaller deposition in the river after 5 Km downstream of the dam to the end of study area is the river flow of other tributaries discharges to the Piave River therefore river flow in Piave River increases. Increase in river discharge leads to increase in sediment transport capacity of the river so, fine sediment coming from upstream is partly washed away.

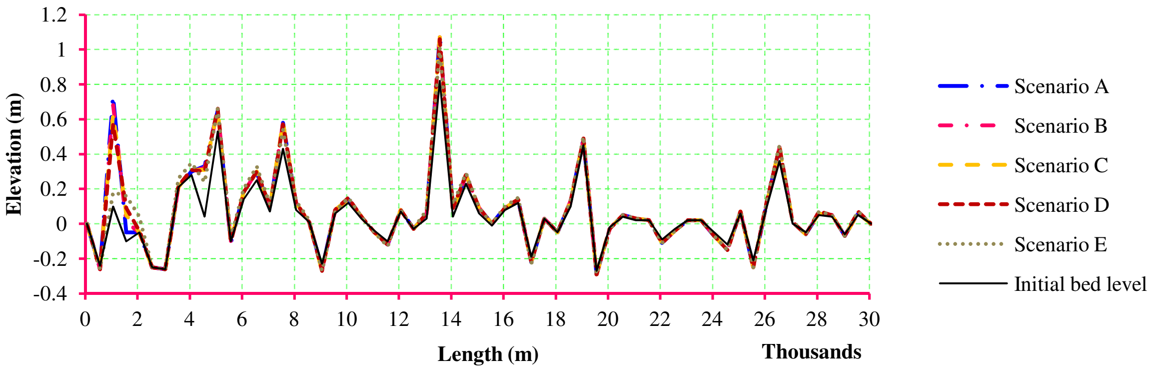

Figure 2- Bed level changes after flood, Piave River (Table 1).

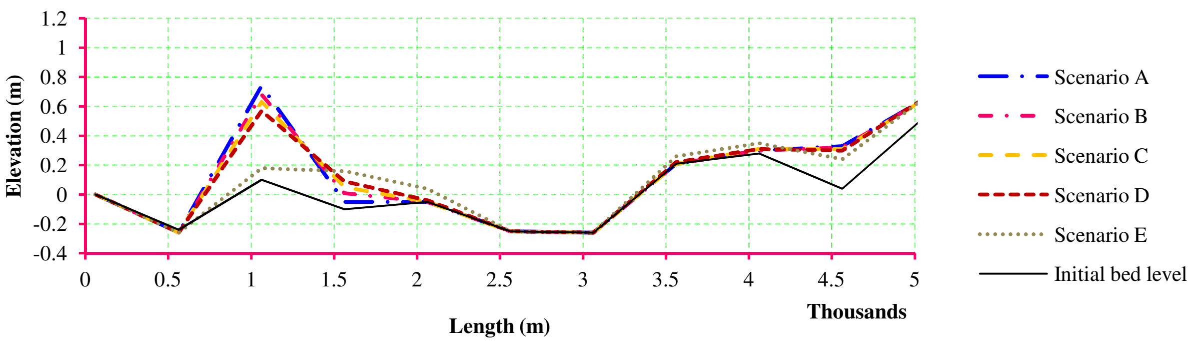

Figure 3- Bed level changes after flood, Piave River (Table 1), first 5 Km.

5-2 Shirin Dareh River

It is necessary to mention that since the data of Shirin Dareh river are related to a reach located upstream of the dam, the effect of the dam on morphology of the river downstream (changes in bed slope, bed material composition and channel width) is not presents in these data. Therefore, the result of this simulation cannot be extended to river reaches located downstream of old dams. However, the results can apply for sediment management strategy of young dams in which downstream river morphology is not completely adapted to the dam intervention.

Since the width variation of main channel in Shirin Dareh River is small and the river bed slope is approximately constant in most part of the river (1.7%-2%) therefore, as shown in Figure 4 erosion and deposition pattern occurs along the Shirin Dareh River after simulation starts. In some parts with narrower channel and higher slope erosion is the governing phenomena, while in parts where the main channel became wider depositions occurs. On the other hand because there is no tributary in Shirin Dareh study area so, the river discharge is constant along the river and no other source of sediment introduction exists. This can be another reason of uniform erosion and deposition pattern.

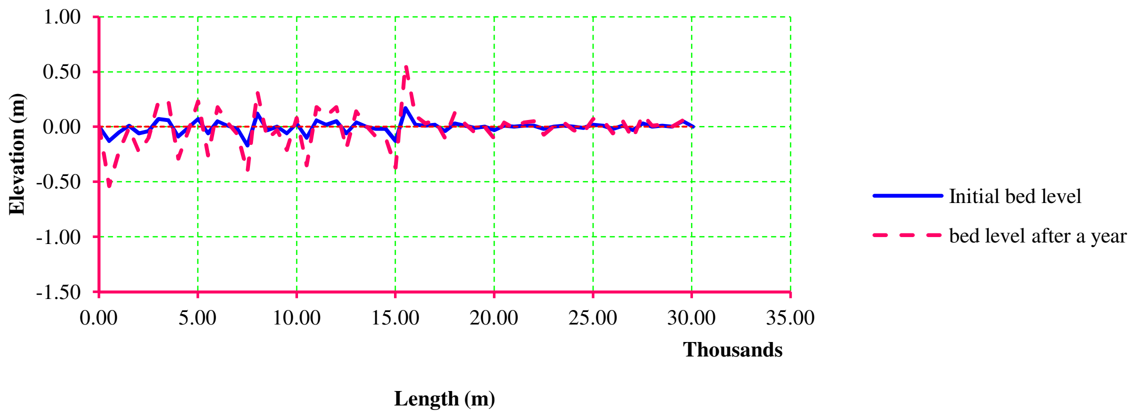

Figure 4- Bed level change due to sediment release for 1 year (Shirin Dareh River).

Figure 5 presents that artificial floods may cause considerable bed level changes in the most part of Shirin Dareh River. Since the Shirin Dareh study area has high bed slope (1.7%-2%) most part of bed material composed of coarse gravel and finer materials (1mm-64mm) therefore, increasing in river discharge leads to increase in river transport capacity of the river and consequently higher erosion in the narrower and steeper parts. As the river approaches a wider area, the sediment starts to settle. This phenomenon is completely visible in Figure 5 in which floods with higher magnitudes cause both higher erosion and higher deposition.

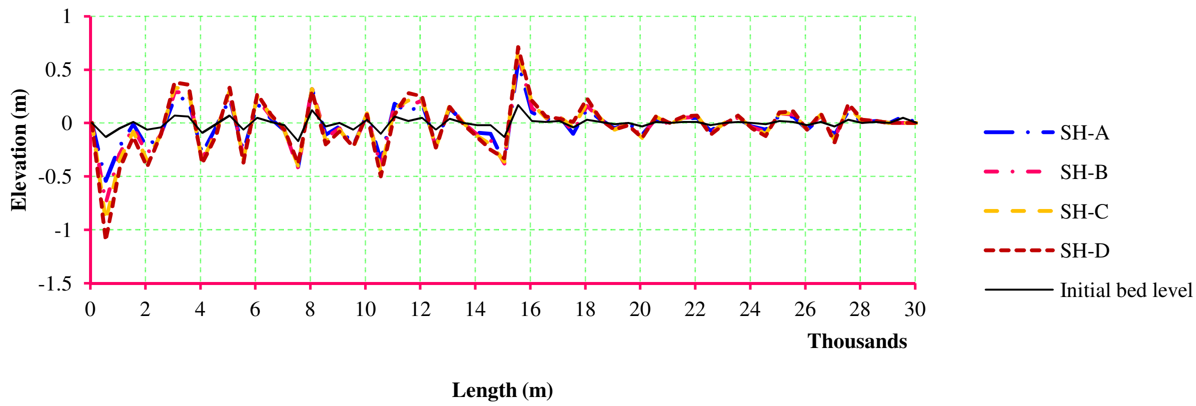

Figure 5- Bed level changes after flood, Shirin Dareh River (Table 1).

6- Conclusions

This study states that sediment and water management strategies must be selected according to the characteristics of catchments. In other words, implementation of the same strategy for catchments with different characteristics is not allowed unless their impacts are investigated before. Although similar scenarios (with difference in parameter values) were defined for the two catchments under study, two different results were achieved. According to these results, changing in sediment concentration in environmental flow in Piave River may be useful both for dam operation and river morphology and ecosystem but, in case of Shirin Dareh River these strategies are not recommended.

References

Alterach, J. Peviani., M. Danelli, A. Sosio, S. (2007). "Analysis of the best practices for flushing operations of the Forni barrage."

Alterach, J. Peviani., M. Danelli, A. Sosio, S. (2007). "Analysis of the practice for the flushing operation of the Forni barrage." 10.

Botter, G., S. Basso, et al. (2010). "Natural streamflow regime alterations: Damming of the Piave river basin (Italy)." Water Resources Research 46(6).

Crosato, A. (2010). River Morphodynamics, Brief Introduction, UNESCO-IHE Institute for Water Education.

Crosato, A. (2011). "River morphology lecture note."

Di Silvio, G. (1994). "Floods and sediment dynamics in mountain rivers."

Di Silvio, G. (2009). Erosion and sediment dynamics from catchment to coast, UNESCO.

G. Botter, S. B., A. Porporato, I. Rodriguez-Iturbe, A. Rinaldo, (2010). "Natural streamflow regime alterations: Damming of the Piave river basin (Italy)." WATER RESOURCES RESEARCH 46: 14.

Milhous, R. T. (1998). "Modelling of instream flow needs: the link between sediment and aquatic habitat." Regulated Rivers: Research & Management 14(1): 79-94.

Peviani, M. (2011). "Mountain river morphology lecture note."

Peviani, M. A., J. (2005). "Sediment transport analysis using the MORIMOR model for the assessment of downstream river effects due to flushing in reservoirs." 10.

Peviani, M. A., J. Danelli, A. (2006). "MORIMOR – GIS, MODELLO NUMERICO IDRAULICO-MORFOLOGICO PER LA SIMULAZIONE DEL TRASPORTO DI SEDIMENTO MULTIGRANULARE NEI CORSI FLUVIALI A FORTE PENDENZA."

Wilcock, P. R., G. M. Kondolf, et al. (1996). "Specification of Sediment Maintenance Flows for a Large Gravel-Bed River." Water Resour. Res. 32(9): 2911-2921.

Wohl, E. and S. Rathburn (2003). "Mitigation of sedimentation hazards downstream from reservoirs." International Journal of Sediment Research 18(2): 97-106.

Wohl, E. E. and D. A. Cenderelli (2000). "Sediment deposition and transport patterns following a reservoir sediment release." Water Resour. Res. 36(1): 319-333.