Conference Volume	6th Symposium for Research in Protected Areas 2 to 3 November 2017, Salzburg	pages 291 - 296

An improved bedload management for the Danube River in the Donau-Auen National Park. An application of the 'principle Sisyphus'

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Abstract

The Danube River east of Vienna has been strongly affected by bedload deficit due to human impacts. The river is incising, the connectivity between channel and side-arms and floodplains is decreasing. In 1996 a first stage of a bedload management was implemented. However, this was not sufficient to stop degradation. In recent years a concept for an optimized bedload management has been developed, including the recirculation of bedload and the addition of coarser, less mobile gravel, thus the problem should be solved. However, the question emerges whether a permanent artificial bedload supply of such an extent and over unlimited duration can be truly compatible with the idea of a national park.

Introduction

In general, natural alluvial rivers are supposed to be in a state of dynamic equilibrium, or, at least, in a quasi-equilibrium (LEOPOLD & MADDOCK, 1953). However, human impacts in the form of river engineering, the construction of barrages (dams) and hydropower plants and maintenance operations (such as dredging) often have strongly disturbed the sediment balance of rivers. Due to a deficit of bedload, which is a very common problem, many river reaches have become subject to severe bed degradation (e.g. PETTS, 1980; WILLIAMS & WOLMAN, 1984), which can also be called a 'hungry water effect' (KONDOLF, 1997).

The Danube east of Vienna

Such problems are also relevant in the Danube River between Vienna and the Austrian-Slovakian border, which is the 'artery' of the Donau-Auen National Park. It was originally an anabranching river system with a mean width of the active zone of about 4600 m (HOHENSINNER et al., 2008) and a bankfull width of about 800 m (HOLUB, 2012). In the second half of the 19th century the project reach was straightened, concentrated into one main channel and channelized. The banks of the Danube were fixed by riprap, thus erosion can only take place in form of channel incision; most side arms were separated from the main channel by artificial levees, and parts of the floodplain were narrowed by a flood protection dyke (KLASZ et al., 2013).

In the second half of the 20th century about 80% of the Austrian Danube reach were impounded by ten hydropower plants. The last of it, Vienna-Freudenau (river-km 1921, which is directly upstream of our study reach) was put into operation in 1997. The project reach remained a free flowing river, but due to the retention of bedload (bedload deficit) in the upper parts of the river basin (impoundment chains) and some of its tributaries the bed degradation is ongoing, with incision rates of about 2 cm/yr in most parts of the project reach (KLASZ et al., 2013, 2016), see Fig. 1, and the hydrological connectivity between channel and side-arms and floodplains (frequency and duration of floodplain inundation) is decreasing permanently (TOCKNER et al., 1998; KLASZ et al., 2013).

The nucleus of bedload-management in this river reach

As a consequence of the hydropower plant at Vienna-Freudenau and following a water law based decision a first stage of a bedload management was implemented. The basic requirement was to avoid additional bed degradation by this hydropower plant. Thus the operating company (Verbund Hydro Power: VHP) has dumped an average of ~190'000 m³ gravel per year downstream of the barrage to compensate for the effect of this hydropower plant (SCHIMPF et al., 2009; KLASZ et al., 2013), and this artificial bedload supply will be continued as long as the hydropower plant is in operation. Thus it was (and will be) possible to maintain a stable riverbed in the upper part of the reach, directly downstream of the barrage. However, this artificial gravel supply is not sufficient to cover the complete bedload transport capacity of the river (which is supposed to be about 350'000 m³ per year, averaged over longer time periods; KLASZ et al., 2013), thus the channel incision could not be stopped completely until now, see Fig. 1 (MW-differences in the time period between 1996 to 2010).

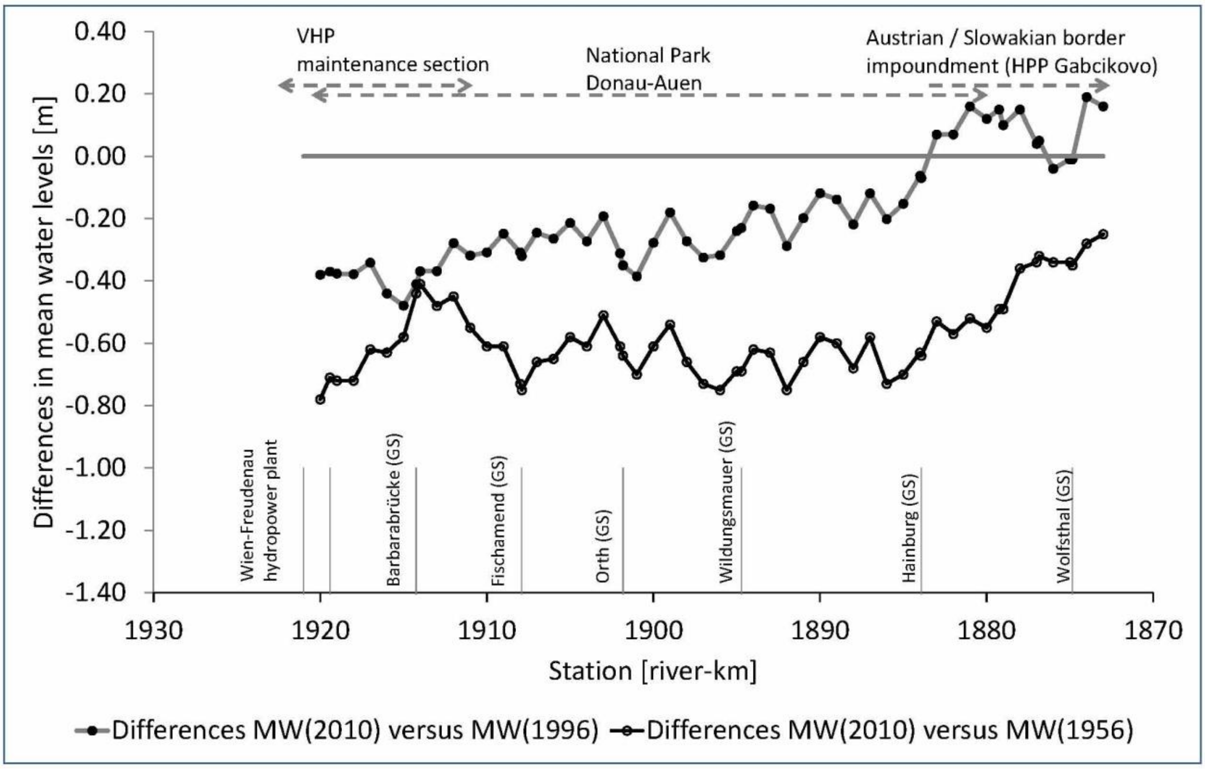

Figure 1: Differences (temporal changes) in mean water levels (MW) in the longitudinal section, MW(2010) and MW(1996) relative to MW(1956); data sources: Bundesstrombauamt (1959), Wasserstraßendirektion (1998), viadonau (2012). GS=gauging station; HPP= hydropower plant.

Concept for an optimized bedload management

The described incision is unacceptable from ecological point of view and within the national park. Thus, a concept for an optimized bedload management has been developed (KLASZ, 2014), including the recirculation of bedload, the addition of coarser and less mobile gravel and a monitoring program (including an efficiency control of all technical measures), see Tab. 1.

River management tools:	Important elements:
increase of the amount of gravel supply (up to the transport capacity) mainly in the upper parts of the section	bedload recirculation (from a bedload trap at the downstream end of the reach or from the downstream reach, which is impounded by the hydropower plant Gabcikovo)
increase of the amount of gravel supply (up to the transport capacity) mainly in the upper parts of the section / reduction of bedload transport capacity	compensation of abrasion loss by coarser gravel and cobble fraction (e.g. 16/120 mm)
reduction of bedload transport capacity	coarsening of grain-size of bed material in order to decrease the intensity of transport (granulometric bed improvement)
	side-arm reconnection
	(slight) bankfull widening by riverbank restoration
additional local measures	local scour control (local bed armoring)
Monitoring, evaluation, efficiency control	river bed surveys (repeated cross-sectional suveys or multibeam survey; analysis of bed changes)
	measurement and analysis of mean water level / reference low water level (analysis of water level changes)
	bed material sampling (analysis of grain-size distribution curves)
	control of grain-size of added material (gravel / cobble)
	optional: bedload transport measurements by basket sampler and artificial tracer stones (radio-tracking)

Table 1: Tools of an optimized bedload management (from KLASZ, 2014)

The basic and simple idea of bedload management in a degrading reach is to fully compensate the bedload deficit by gravel augmentation (‘artificial bedload supply’). In our context this results in a refilling of erosion zones downstream of the barrage, see Fig. 2. This concept was first developed by Felkel for the free flowing Rhine River downstream of Iffezheim (FELKEL, 1970, 1987), and this program is successfully running since 1978 (GÖLZ, 2008). It should be mentioned, that such an alternative for our river reach has been already investigated in the 1980th (ZOTTL & ERBER, 1987), and it was found to be feasible, however it was eliminated from further consideration, because it was thought be far away from a sustainable solution, and another alternative was proposed (dumping of a layer of large gravel and cobbles, grains large enough to ensure ‘static stability’).

A central issue is the availability of large amounts of gravel with suitable grain-size distribution. Until now, most of the added gravel was obtained from the Danube River at Krems, which is about 80 km upstream (bedload output from the free-flowing Wachau-section into the impoundment of the Altenwörth hydropower plant), transported by barges and dumped by hopper barges). This part of bedload management (M1 in Tab. 2) can be seen as an artificial bedload bypass through the impoundments of three upstream hydropower plants (Altenwörth, Greifenstein, Vienna-Freudenau) by barges (Fig. 2). However, this source of gravel is limited. Of course, there are several gravel-pits in the Vienna Basin (within a distance of 10 to 60 km from the project reach), but this material is quite expensive, gravel is a limited and valuable resource, and furthermore, it could only be transported by trucks to the river, which would be associated with severe environmental stress (including CO_2-emissions (equivalent) of ~4.6 kg CO_2e per m^3, provided a transport distance averaged 30 km and specific CO_2-emissions of ~90 g/t.km).

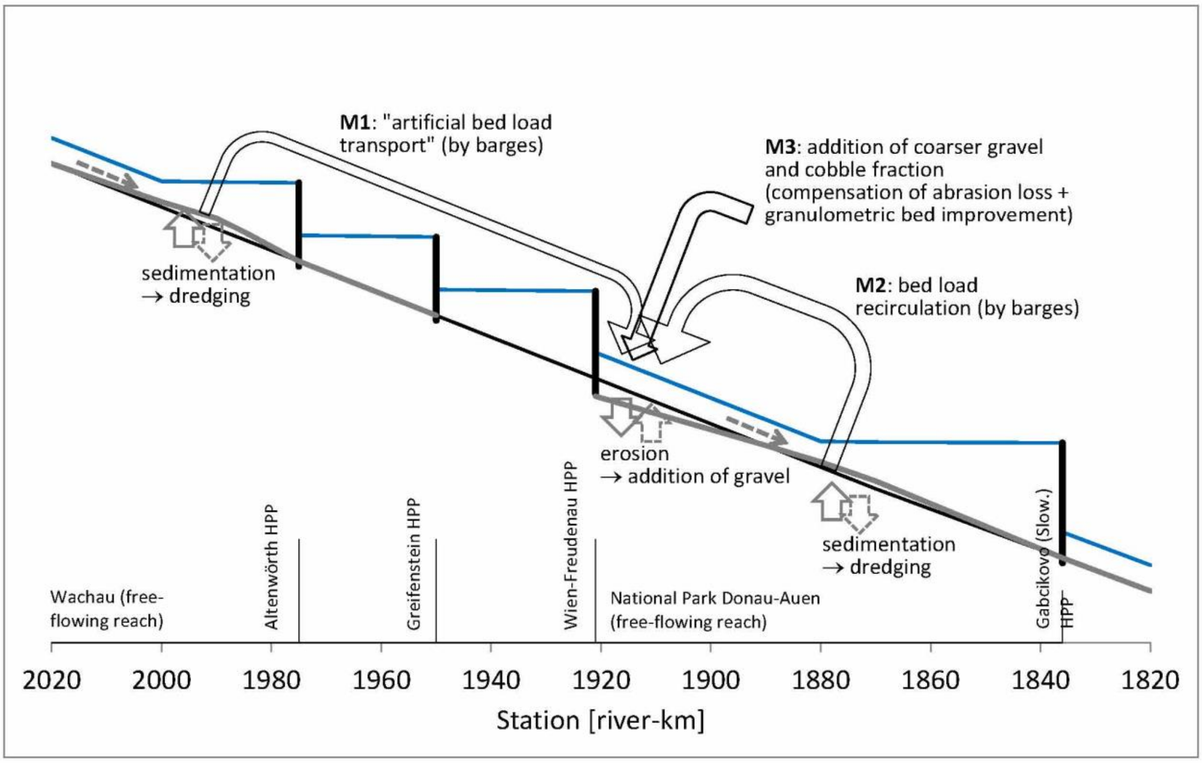

Figure 2: Schematic diagram, longitudinal section, Danube River, impoundments upstream and downstream of our project reach, including the key measures of bedload management east of Vienna (M1, M2, M3); HPP= hydropower plant.

Considering the special situation of the river reach (a relatively short free-flowing section between a hydropower plant upstream and another hydropower plant downstream, Fig. 2), the recirculation of bedload is the most obvious and cost-efficient solution (M2 in Fig. 2 and Tab. 2). The bedload output from our reach is deposited in the impounded section of Gabcikovo (since 1992), which will incrementally reduce the flood protection level for Bratislava; therefore these sediments have to be removed anyway. The gravel should be dredged at a bedload trap at the downstream end of the reach, afterwards it will be transported by barges to the upstream end of the free-flowing reach and dumped by hopper barges (Fig. 3).

Bedload transport is associated with abrasion, grains are getting smaller on their way downstream (between river-km 1920 and river-km 1880 the median diameter D_{50} declines from ~27 mm to ~19 mm, KLASZ et al., in prep.), thus this abrasion loss should be compensated by a coarser gravel and cobble fraction (M3 in Fig. 2 and Tab. 2, grain-size distribution: see Fig. 4). The mobility of coarse grains is lower than those of smaller ones; thus, by coarsening of the surplus material (more than the compensation of abrasion loss would require), the efficiency of artificial bedload supply can be improved, that is, the amount of needed material can be reduced ('granulometric bed improvement'). As coarser gravel and cobble fractions (such as 16/120 mm) can only be provided by gravel-pits, which means, that it is more expensive, there is a trade-off between costs and the reduction of mobility, and this optimizing may require further trial and error procedure. Coarsening of bed material below barrages (or dams) can also occur without augmentation of coarser material, leading to an armor layer (KONDOLF, 1997) and in this context it can be understood as a self regulation or adjustment process. In our river reach the potential of self-generated coarsening is not sufficient (as such an armour layer with maximum grain size diameter D_{max}~120 mm and a medium diameter $D_{50,D}$ of ~58 mm is too small to resist flows larger than ~1-year-floods; ZOTTL & ERBER, 1987).

The amounts M1, M2 and M3 for different temporal perspectives are given in Tab. 2.

component	present state	medium term scenario (initial stage)	long term scenario	Remark:
	~ 350'000 m^3/a ([a]	~ 350'000 m^3/a	~ 330'000 m^3/a ([d]	bedload transport capacity
M1 =	~ 190'000 m^3/a ([b]	~ 190'000 m^3/a	~ 80'000 m^3/a ([e]	~0/240 mm (D_{50}~25…30 mm) ([f]
M2 =	~ 50'000 m^3/a ([c]	~ 140'000 m^3/a	~ 230'000 m^3/a	0/120 mm (D_{50}~20…25 mm) ([g]
M3 =	0	~ 30'000 m^3/a	~ 40'000 m^3/a	16/120 mm (D_{50}~55 mm) ([h]
effect:	no balance, incision	balance, small excess		

[a]) … estimated value based on hydrographic findings (Klasz, 2014; Klasz et al., 2016);
[b]) … arithmetic mean, period: 1996 – 2010 (Klasz et al., 2013, 2016);
[c]) … recirculation by dredged bed material from maintenance dredging (viadonau); equivalent surplus volume (Klasz et al, in prep.), arithmetic mean (period: 2009 – 2016), resulting from a mean annual dredging volume of ~160'000 m^3/a and a mean upstream transport distance of ~6 km (see Sect. 5);
[d]) … slight reduction (estimation) by coarsening of bed material, widening the (bankfull) channel, and similar measures; Klasz (2014);
[e]) … taking into account, that the bedload output from the Wachau-section is about 60'000 … 100'000 m^3/a (estimated value), anyway less than 190'000 m^3/a; higher value for dredging in the past were obtained because there were larger deposits from the time before 1996;
[f]) … estimated grain-size distribution;
[g]) … grain-size distribution from bed material sampling (Zottl & Erber, 1987);
[h]) … grain-size distribution in order to compensate abrasion loss and to reduce mobility of surplus material, that is, to increase its efficiency, see Fig. 4 (Klasz, 2014);

Table 2: Components (amounts) of bedload management from KLASZ (2014, modified); M1= bedload (gravel) from upstream (at Krems, dredging in the upper part of the impoundment of hydropower plant Altenwörth); M2= recirculation of bedload (from the downstream end of the free-flowing reach); M3= additional gravel supply, coarser gravel and cobble fraction;

There are additional possibilities to reduce the bedload transport capacity of the channel (especially by channel widening and the reconnection of side-arms); however, the potential to optimize bedload management by such measures is relatively small, as they may worsen conditions for inland navigation (a decrease in available navigation depth at low water).

All measures should be implemented and integrated in an adaptive management framework (LINKOV et al., 2006), that is, monitoring, evaluation (efficiency control), modeling (planning) and implementation should form a feedback loop, including adaptive learning both as basic principle and surplus value.

Figure 3: Artificial gravel supply by hopper barges; process of dumping.

Current situation

In the study by KLASZ (2014) it is argued, that an increase of gravel augmentation related to the hydropower plant operator (VHP, see Sect. 3) should be decided and ordered by the water authority (considering the effects of the impoundments of all other hydropower plants upstream of Vienna and the cost-by-cause-principle) and based on Austrian Water Act (§21a, amendment of approval). Recently a working group was formed by the Austrian Ministry of Agriculture, Forestry, Environment and Water Management in order to discuss such open questions.

Since 2009 a first stage of bedload recirculation has been implemented by viadonau (waterway company for the Austrian Danube) as dredged material usually is transported and dumped some kilometers upstream (averaged over the period 2009-2016 about 160'000 m³/a of dredged bed material has been transported ~6 km upstream; SIMONER, 2016; KLASZ et al., in prep.); in 2015 and 2016 these recirculations have been increased (SIMONER, 2016); however these measures are not regulated by law (until now) or contracted, which means, they could be stopped at any time. All in all we are close to a solution, but the problem is not yet solved completely.

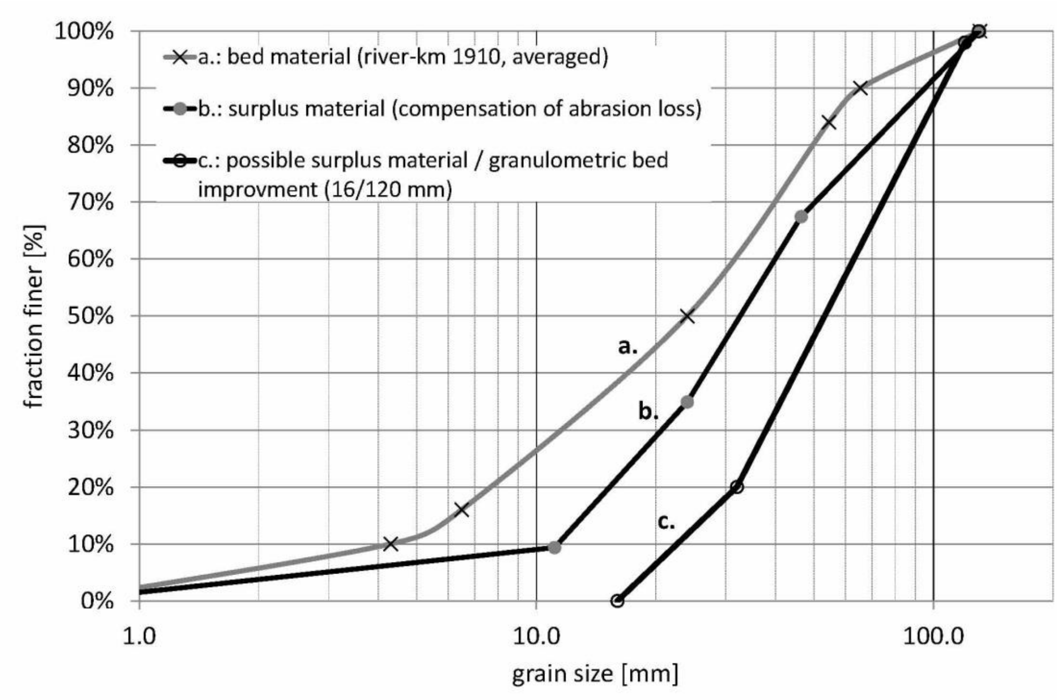

Figure 4: Grain-size distribution of bed material ('a.') and possible surplus material ('c.': a coarser gravel and cobble fraction, e.g. 16/120 mm, compensation of abrasion loss and additional coarsening, to decrease the intensity of transport); the grain-size distribution 'b.' exhibits minimum coarsening, to compensate for abrasion only; all data from KLASZ (2014)

Sisyphus, rolling stones forever. A basic question

'Maintenance', as an ongoing activity, is a necessary and unavoidable consequence of manmade technical measures and infrastructure, but not an inherent principle of 'nature'. In river management, maintenance can be understood as an indication of an existing deviation of the given state from a dynamic and natural equilibrium state. From conservation point of view, technical maintenance measures should not take the lead in the search for a solution, on the contrary, to minimize or to exclude human impacts.

In the case of the considered Danube River reach the situation is rendered even more difficult as the National park Donau-Auen has not been established in an area of 'untouched nature' (wilderness) but rather in an area that is subject to substantial pressure from many human influences in the area. This is particularly true for the Danube River reach itself which – connecting two large and growing cities (Vienna and Bratislava) – is burdened by the continuous river bed degradation, a legacy of the past, and by the current demands of river navigation and flood protection.

When intending to solve the existing problems, a fundamental dilemma becomes obvious: it is, that the desirable ecological improvements can only be achieved by permanent human interventions, that is, by an activity in accurately the sense of maintenance. Furthermore, the question emerges whether a permanent artificial bedload supply of such an extent and over unlimited duration ('rolling stones forever') can be seen to be truly compatible with the idea and requirements of a national park.
We cannot make a final judgement on that issue.

In 1942 Albert Camus wrote an essay, 'The Myth of Sisyphus'. Sisyphus has duped the gods, has put Death in chains. His punishment (rolling up a large stone up a hill, only to have it roll back down as soon as he reaches the top) will never end. There is no meaning. There is no sense. However: *'[…] I leave Sisyphus at the foot of the mountain! One always finds one's burden again. But Sisyphus teaches the higher fidelity that negates the gods and raises rocks. He, too, concludes that all is well. This universe henceforth without a master seems to him neither sterile nor futile. Each atom of that stone, each mineral flake of that night-filled mountain, in itself forms a world. The struggle itself toward the heights is enough to fill a man's heart. One must imagine Sisyphus happy'* (CAMUS, The Myth of Sisyphus).

Acknowledgment

This contribution is a spin-off of a study on bedload management in this river reach (KLASZ, 2014), which was funded by the Nationalpark Donau-Auen. We would also like to thank Markus Simoner (viadonau – Österreichische Wasserstraßengesellschaft mbH., head of team waterway management) for providing data and information on waterway management activities of viadonau and Roland Schmalfuss (Verbund Hydro Power GmbH) for data and information on bedload supply related to the hydropower plant Vienna-Freudenau and both colleagues for helpful discussion.

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