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FLUSHING OF THE RUN-OF RIVER PLANT BODENDORF IN STYRIA/AUSTRIA IN RESPECT OF TECHNICAL AND ECOLOGICAL IMPACTS

Josef Schneider[1], Hannes Badura[2], Helmut Knoblauch[3], Rosa Frei[4] and Jürgen Eberstaller[5]

ABSTRACT

This paper deals with sedimentation and the resultant flushing of the run-of river power station Bodendorf at the river Mur in Austria. The mean annual sedimentation rate for this reservoir is approximately 35,000m³. To perform regular sediment flushings a monitoring program was developed to optimize the flushing operation in line with economical and ecological requirements. Echo sounder surveys before and after the flushing, measurements of suspended sediment concentration, bed load transport and hydraulic gauging were undertaken (1) to determine a sediment balance of the flushing event, (2) to evaluate the effects of groins and an initial flushing channel and (3) finally to get data for numerical modeling concerning hydraulics and sediments. The ecological monitoring was performed by determining substrate conditions (freeze corer), ground fauna (invertebrates) and fish ecological aspects. These data should document the flushing of the reservoir Bodendorf and go towards improving the flushing management of the series of hydro power plants respectively. This work was performed for the Interreg IIIb Project ALPRESERV "Sustainable Sediment Management in Alpine Reservoirs" (www.alpreserv.eu)

1. INTRODUCTION

The run-of river power station Bodendorf is the upstream storage facility of a series of power stations at the river Mur. The Alpine river Mur is characterized by a mean discharge of 25m³/s and an annual flood of 130m³/s. The average slope of the river Mur in this reach is about 0.7%, the mean width is 40m and the depth up to 3m. The fish region can be defined as hyporhitral (grayling region). Figure 1 shows the location of the project area.

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[1] Assistance Professor, Institute of Hydraulic Engineering and Water Resources Management, Graz University of Technology, Stremayrg. 10, 8010 Graz, Austria (schneider @tugraz.at)

[2] Scientific Assistant, Institute of Hydraulic Engineering and Water Resources Management, Graz University of Technology, Stremayrg. 10, 8010 Graz, Austria (h.badura @tugraz.at)

[3] Assistance Professor, Institute of Hydraulic Engineering and Water Resources Management, Graz University of Technology, Stremayrg. 10, 8010 Graz, Austria (helmut.knoblauch @tugraz.at)

[4] Assistance Professor, Institute of Hydraulic Engineering and Water Resources Management, Graz University of Technology, Stremayrg. 10, 8010 Graz, Austria (rosa.frei @tugraz.at)

[5] Technical Bureau for Hydrobiology, Eberstaller Zauner Büros, Währinger Straße 156/6, 1180 Vienna, Austria (eberstaller@ezb-fluss.at)

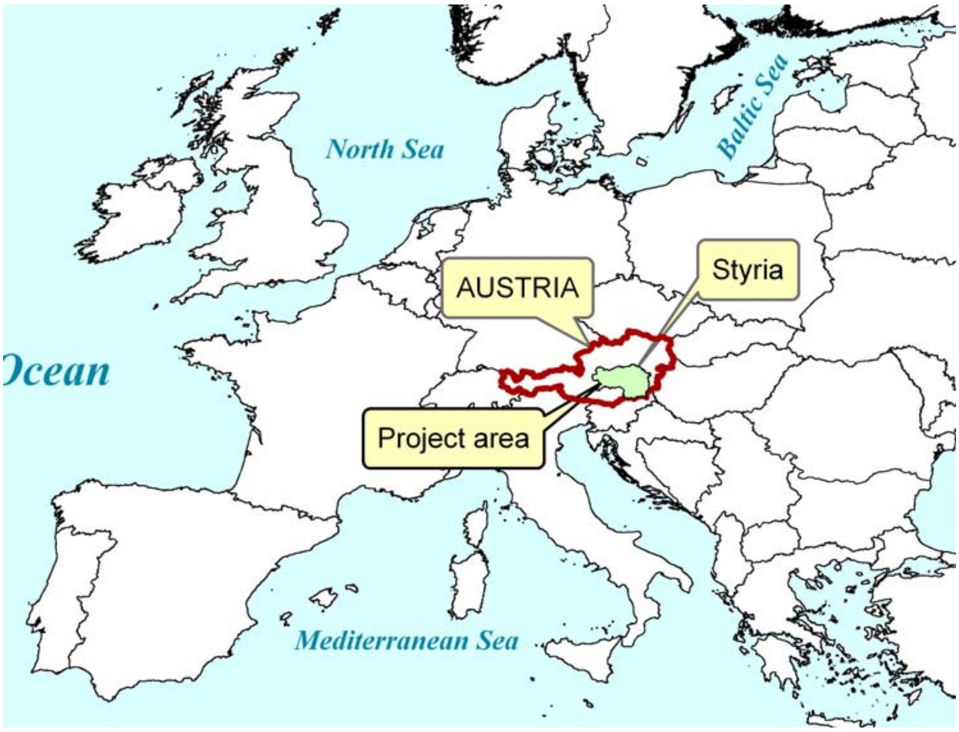


Figure 1 Project area in Styria

The weir of the Bodendorf power station is 16m high while the reservoir is 2.5km long. Bodendorf may be defined as a twin power plant consisting of a run-of river and a pressure hydraulic system. The Kaplan turbine is designed for an average discharge of 50m³/s and the Francis turbine for 11m³/s respectively. Figure 2 shows what the lower reservoir area looks like during a flushing event.

Figure 2 Bodendorf Power plant during flushing

The mean annual sediment deposition of this reservoir is about 4% (35,000m³/s) of its original storage capacity which is about 900,000m³/s. Since the power plant was set up five flushings were performed in total. Flushing as a means for improved sediment management is expected to prevent reservoir sedimentation and to help transfer the inflowing sediment load so as to balance with the river downstream, which is one of the requirements of the EU Water Framework Directive.

2. PROBLEM DESCRIPTION AND AIMS

Damming of rivers means sediment deposition. This implies coarse as well as fine material. The results are a decrease in storage capacity in the reservoir on one hand and a shortage of sediment in the downstream area with a potential river bed degradation on the other hand. A decrease in storage capacity means accumulation of sediment which is not often recyclable. Only clean coarse material could be used for the construction industry, but in many cases the gravel is mixed with fine sediment or the fine sediment may be polluted by deposited environmental pollutants. River bed degradation and sediment shortage downstream may lead to ecological problems like the damage to fish-breeding areas and even to a dropping of the groundwater level.

It is a well-known fact that coarse material is deposited in the upstream part of reservoirs. This leads to a reduction in discharge area with a resulting higher risk of flooding, which could be observed at Bodendorf reservoir too. A remobilization of this material is required. Therefore the operator of the power plant installed several groins at the upstream part of the reservoir on one hand and dredged an initial flushing channel in 2003 (as described in Batuca and Jordaan (2000) and Morris and Fan (1998)) on the other hand. These measures (see Figure 3) should have increased the shear stress to improve bed load transport to the downstream section during the flushing. The main objective of these measures was to keep the bed of the reservoir at its original level to prevent flooding of surrounding areas. Monitoring and the resulting sediment management improvement is one of the main aims of this project.

Figure 3 Short groin at the upstream part of the reservoir, excavation of the flushing channel in 2003

3. OVERVIEW OF THE MONITORING PROGRAMME AND FLUSHING STRATEGY

A naturally occurring flood is a precondition for performing a reservoir flushing, because a minimal discharge is necessary for remobilizing deposited material on one hand and a dilution of suspended sediments is necessary for ecological reasons on the other hand. In order to be able to remove the accumulated sediments during the flushing, a minimal discharge (Q_{min}) well exceeding the critical shear stress τ_{cr} has been determined beforehand. A flood forecasting system is used to estimate the discharges. Austrian experts have agreed on, where HQ_1 defines the annual flood:

$$Q_{\min} = 0.5 * HQ_1 - 0.7 * HQ_1 \qquad (1)$$

This is the guideline for the minimal water supply in a flushing event (ÖWAV 2000). As for the Bodendorf power plant the accurate rate was defined as:

$$Q_{\min} = 0.62 * HQ_1 \tag{2}$$

This corresponds to 80m³/s, which has to last for a minimum of 2 days. The period fixed for flushing was between May 15 and September 30. For the last flushing event in 2006 the basic conditions were changed insofar as flushing may be performed with a minimum discharge of 80m³/s before May 15 as well. Though, the minimum discharge has to be 120m³/s between May 15 and September 30 (peak 160m³/s).

A monitoring program has to be undertaken during the flushing for avoiding negative impacts on the ecosystem. The maximum sediment concentration downstream of the dam has to be 4.5g/l. If this rate is exceeded, the velocity of drawing down the water level has to be reduced and even stopped. The oxygen concentration must not fall 5mg/l short as an additional lower limit.

Besides ecological monitoring, a-biotic measurements before, during and after the flushing were implemented. By means of reservoir measurements and the design of digital terrain models before and after the flushing, a mass budget concerning erosion and sediment deposition was done. Sediment measurements concerning bed load and suspended sediment load facilitated conclusions of the natural sediment transport upstream of the reservoir. By gauging the suspended sediment load at three different locations during the flushing 2004, the rate of suspended sediments in the entire transport system could be specified. Grain size analyses in the reservoir have conveyed the grain size distribution after the flushing. All measures of the monitoring program are pointed out in Table 1.

Table 1 A-biotic monitoring program

Measurement	**Method**	**Location**	**Purpose of the measurement**
Gauges	Ultrasonic probe	Bridge at the beginning of the reservoir and at the weir	Water level / 2D numerical model calibration
Suspended sediment	Single point measurements	At 3 different bridges	Suspended sediment load / part of the mass budget
Bed load	Large Helley - Smith Sampler	Bridge at the beginning of the reservoir	Bed load transport / part of the mass budget
Echo soundings	GPS – echo sounding system	Reservoir and upstream	Digital terrain model, before and after flushing / part of the mass budget
Grain size analyses	Sieving	Reservoir	Grain size distribution in the reservoir

4. RESULTS

4.1 A-biotic monitoring

The 2004 flushing event lasted for 31.5 hours with a free flowing condition of 17 hours. The maximum outflow discharge was 163m³/s. The period of this flushing event was relatively short. The reason for that was the shortfall of inflowing discharge below 80m³/s.

Due to the exceeding of the suspended sediment concentrations downstream of the reservoir, which led to an overstraining of the river fauna, the increase of the discharge was interrupted and the drawdown velocity of the reservoir was reduced (Figure 4). This resulted in a reduction of the sediment concentration of the outflowing water. The measurements showed a maximum inflowing sediment concentration of 0.23 g/l and a maximum outflowing concentration of 5.70 g/l. This difference indicates the remobilized fine material.

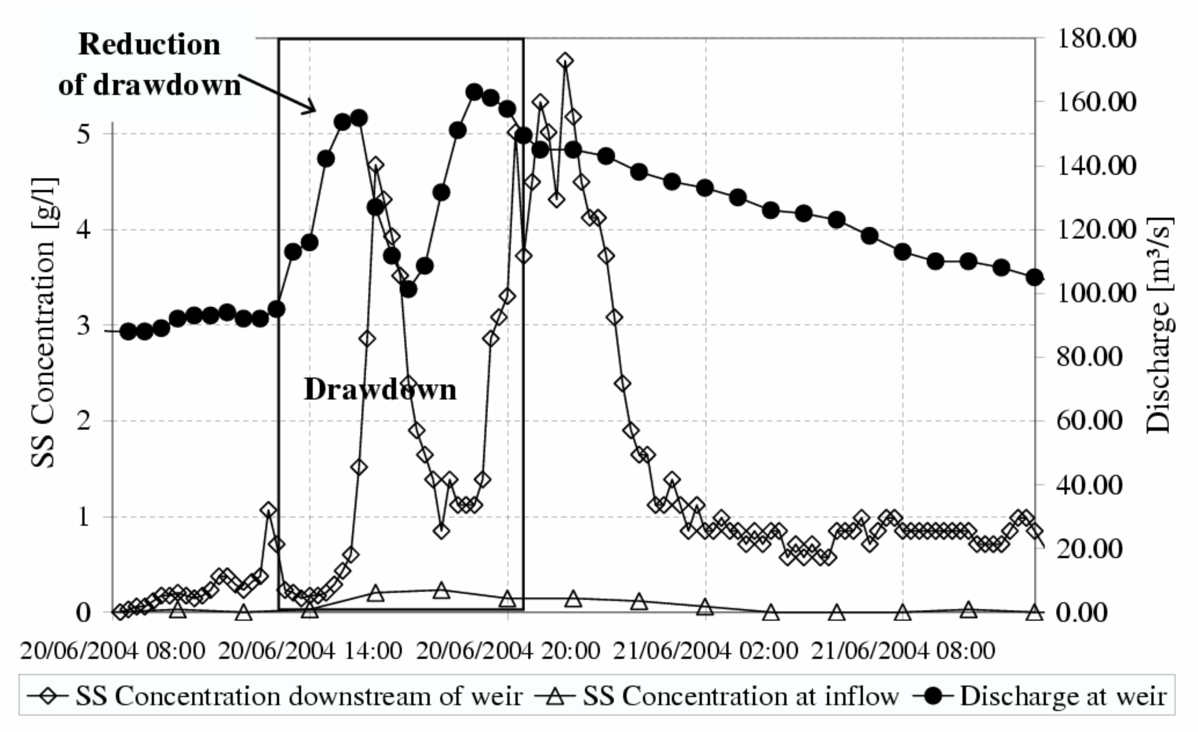


Figure 4 Suspended sediment concentrations upstream of the weir

Diving enabled the extraction of bed material at different locations in the reservoir. The extracted material and Helley-Smith samples at the upstream part of the reservoir were analyzed to obtain grain size distributions. As shown in Figure 5 the fraction of sand is increasing downstream towards the weir whereas gravel is the dominant fraction at the upstream beginning of the reservoir. This confirms the "fractions wise" deposition along a reservoir.

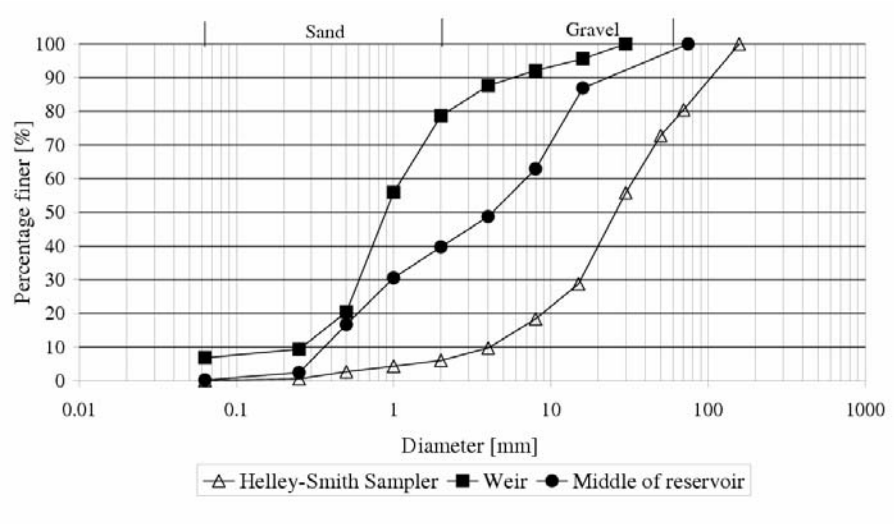


Figure 5 Representative grain size distributions at the reservoir Bodendorf

The installed groins fulfill partly the task of increasing the shear stress at the beginning of the reservoir. By means of a GPS - echo sounding system transverse cross-sections were measured and the data were implemented into GIS. The interpolation method was Kriging and an example of the upstream reservoir is given in Figure 6. Flow direction is from left to right. As far as the effect of the groins is concerned, the evaluation is somewhat ambiguous. The first upstream two groin groups on the orographic left side have been directing the flow towards the center of the stream thus causing increased erosion in this section. The third group on the right side has not shown any noteworthy effect and has been completely covered by sediment. Thus it could be seen that some of the groins failed to show any positive effect whereas others worked quite successful.

In addition to this it has been observed that inflowing sediments from upstream partly failed to be transferred through the whole reservoir during the flushing event 2004. The flushing channel had no effect. Echo-sounding showed that the channel was filling continuously during the year and was not re-emptied during the flushing.

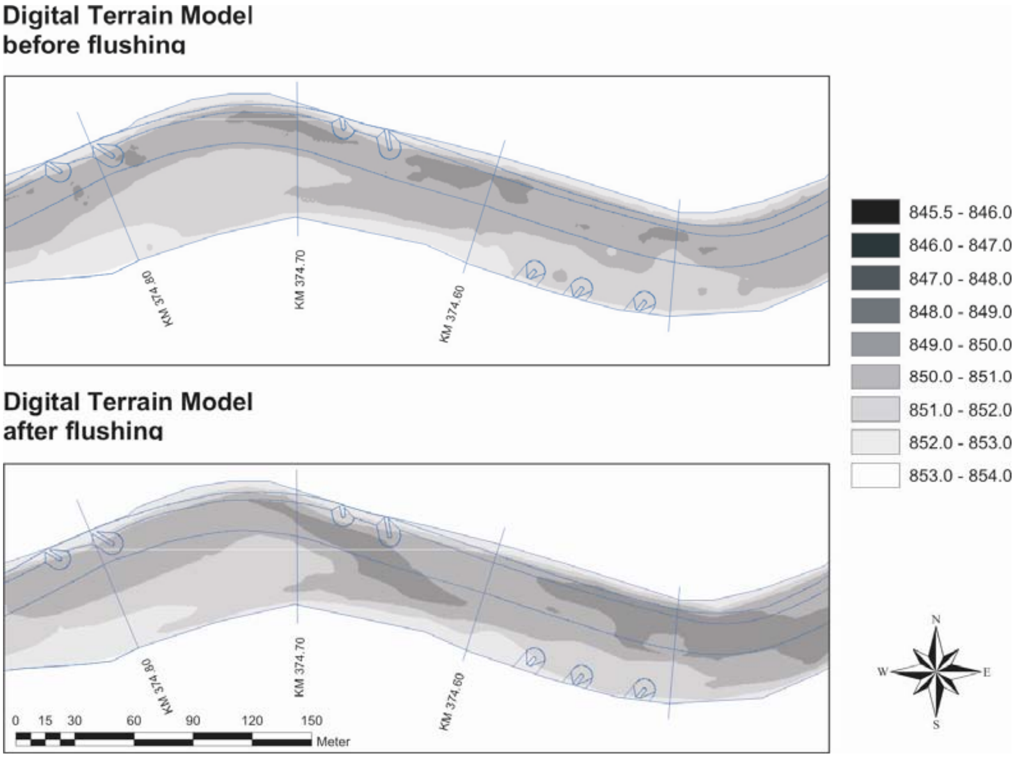


Figure 6 Digital Terrain Model of the reservoir, effects of groins

For determining a mass balance the reservoir was divided into six sections (Figure 7) with a length of 300m each as a first step (with exception of the first upstream section which is 150m long). Then, the mass balance was calculated based on Digital Terrain Models designed before and after the flushing. By way of this, it could be determined which section of the reservoir showed satisfying erosive effects and in which section flushing capacity still has to be improved.

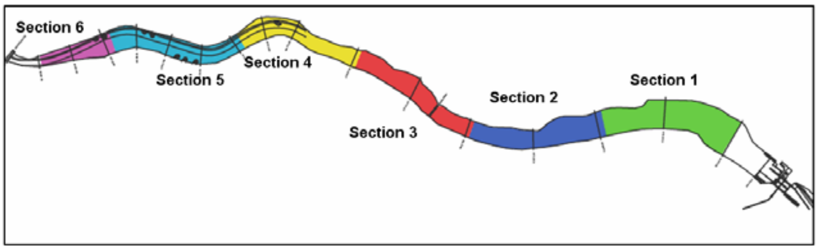


Figure 7 Reservoir Bodendorf, divided into sections

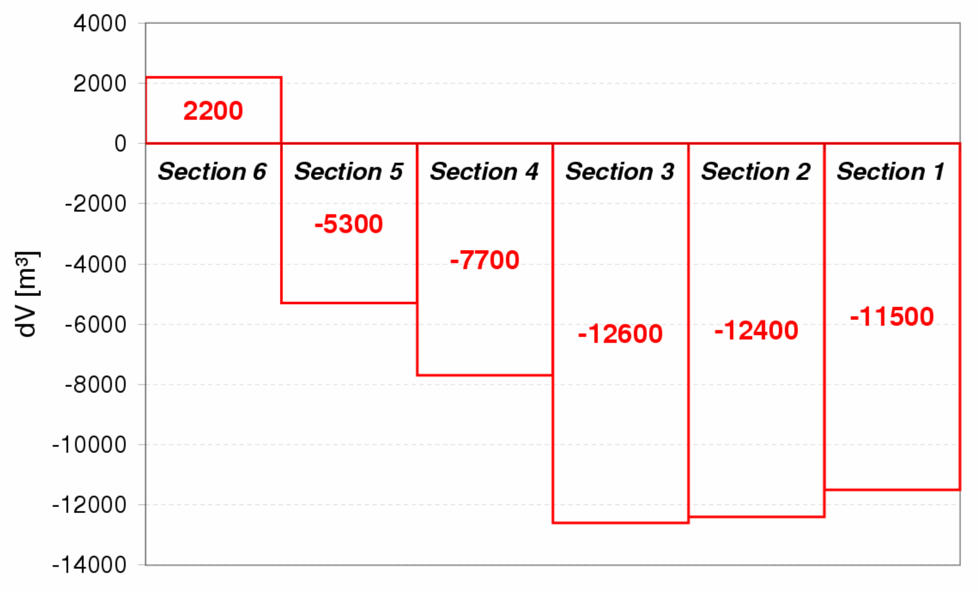


Figure 8 Erosion and deposition in the sections during the flushing 2004

Figure 8 shows the amounts of sediment, deposited or eroded in the single sections during the flushing 2004. All in all the difference in the volume of the transferred sediment was estimated to be 47,300m³. This number contains approximately 11,000m³ of outflowing suspended sediments as well as 4,700m³ of transferred bed load having deposited at the beginning of the reservoir. Table 2 gives a compilation of the mass balance for the flushing event 2004. Position 1 shows the inflow into the reservoir and position 2 the outflow respectively. Position 3 indicates the combination of position 1 and position 2 which was determined by the echo-sounding measurements. The inflow and the outflow are composed of suspended sediment and coarse material where the inflowing and outflowing fine materials were measured values. The incoming bed load was estimated with the help of the Helley-Smith measurements. The ratio of sediment input and output could be defined as 1:8.1. This mass balance contains inaccuracies because of estimations and measuring errors.

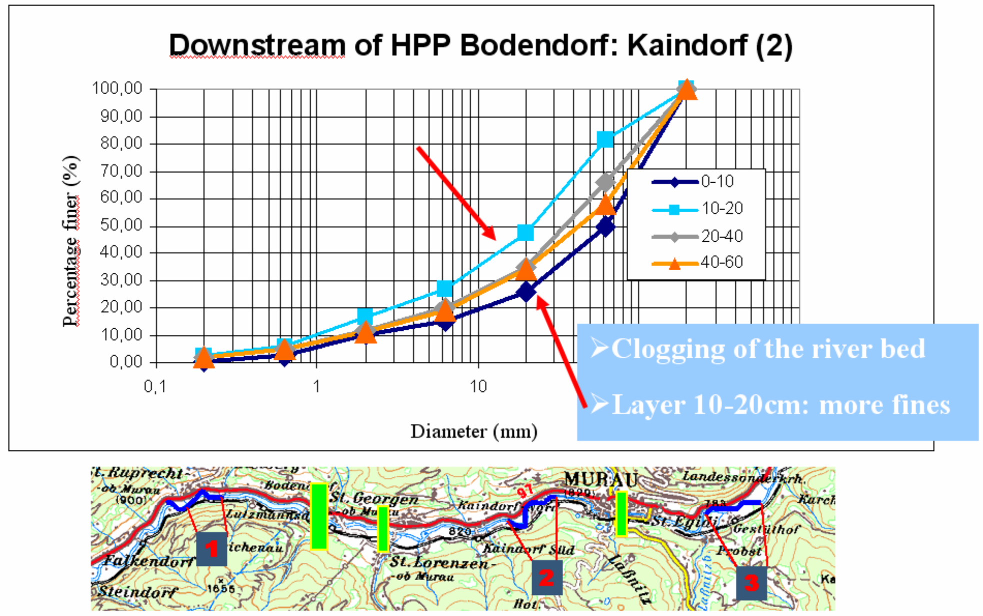
Table 2 Mass balance

Pos.		**Mass** [t]	**Volume** [m^3]	Vol.% of Pos. 3
1	Inflow	8,850	5,200	11.0
1a	Bed load (est.)	8,000	4,700	9.9
1b	Susp. sed.	850	500	1.1
2	Outflow	71,550	42,100	89.0
2a	Bed load	53,550	31,500	66.6
2b	Susp. sed.	18,000	10,600	22.4
3	Inflow and outflow	80,400	47,300	100

One main problem is the measurement of suspended sediment. Single point measurements done at bridges do not describe the sediment concentration profile which is variable over the depth. Because of higher concentrations near the bed an underestimation of suspended sediment has to be expected. Furthermore the sampling rate of 15 minutes has the disadvantage of missing peaks that might occur in between the samplings. Hence turbidity probes with a better time resolution were installed for the flushing event in 2006. These turbidity data were calibrated by water samples and the final analyses for the flushing event 2006 is under way.

4.2 Ecological monitoring

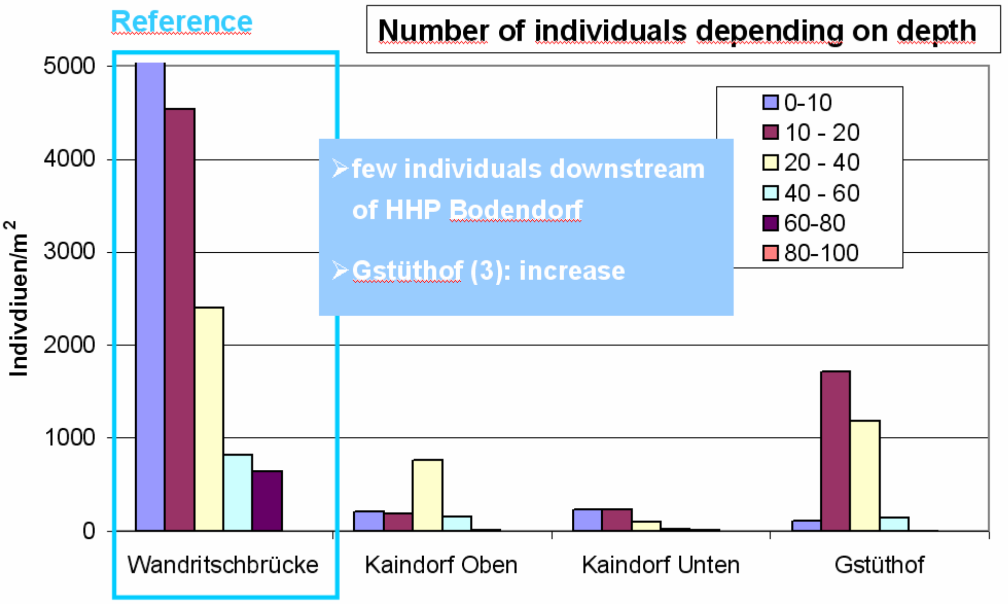
Besides the a-biotic aspects an ecological monitoring was performed too. By means of freeze-coring the riverbed downstream the weir was assessed. For the fish population and the benthos respectively the clogging of the riverbed during and after flushing events may have negative and even catastrophic consequences. The lower part of Figure 9 gives an overview of the area. The green bars indicate the power stations and the numbers mark the monitored sections. The river bed of the reference section showed a consistent substrate in all layers with a typical armored layer situation. Downstream the power station Bodendorf (Figure 9) a clogging of the river bed was observed. This indicates the influence of the flushing.



➢Clogging of the river bed

➢Layer 10-20cm: more fines

Figure 9 Grain size distribution obtained by freeze-coring



➢few individuals downstream of HHP Bodendorf

➢Gstüthof (3): increase

Figure 10 Observed benthos

In Figure 10 the number of individuals of collected benthos in several depths is shown. One can see that the highest quantities of animals in all depths were observed in the reference section, which was not influenced by the flushing. The number of individuals increases again in section 3 “Gstüthof” which is a relatively natural free flowing section.

Fishing of juvenile fish and collecting of fish eggs in so called “Vibert boxes” gave a good indication for the effects of the flushing too.

5. CONCLUSIONS

Monitoring is essential for ecological and economical reasons during a reservoir flushing. In the present case the monitoring program has proved to be successful. The partly positive effect of groins could be verified on one hand and the failure of a positive effect of an initial flushing channel could be observed on the other hand. For not exceeding the threshold concerning sediment concentration during the flushing a reduction of outflow had to be conducted. Furthermore it could be observed that inflowing sediments from upstream partly failed to be transferred through the reservoir. The reason for that are the rapid decrease of inflowing water below 80m³/s and the refilling of the reservoir. Therefore a recommendation would be an *after-flushing phase* that would lead to a transfer of the whole incoming sediment. The successfully applied mass balance is a tool for getting an idea of the effectiveness of a flushing event.

This monitoring program helped to obtain data for numerical calculations and analyses (Badura et al. 2005) to produce a good basis for a long term sediment management strategy.

The collected ecological data suggests amongst others that floods and flushing events in June/July result in more negative consequences for the ecosystem than later ones (in late summer or fall).

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