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The influence of a bed load bearing tributary on the water level underneath a run-of river plant

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ABSTRACT: Hydraulic model tests were performed at the Institute for Hydraulic Engineering at Graz University of Technology to improve the sediment transport underneath the run-of river station St. Veit at the river Salzach. These model tests, additional carried out measures at the river and numerical simulations proved the significant influence of a tributary on the aggregation situation at the mouth of the tributary. This silted bed load led to a significant rise of the water level underneath the power station which is located some 600 m upstream of the mouth of the tributary. Two variants were carried out aiming to reduce or avoid the aggregation at the mouth of the tributary. The scale of the model test was 1:40, the river was modelled at a length of 1000m. Especially the morphology of the river was analysed applying photogrammetry surveys. According to the results one variant was proposed for construction. A temporary installed river gauge proved the good success of the proposed measure.

Keywords: Sediment transport, Groins, Structure, Hydraulic models

1 INTRODUCTION

The development of the Middle Salzach river south of the city of Salzburg in the years between 1982 and 1996 included the construction of another six power stations. Over a stretch of 20km with a head of approximately 80 m, the river flow is being utilised for power generation in a series of run-off-river stations (Figure 1).

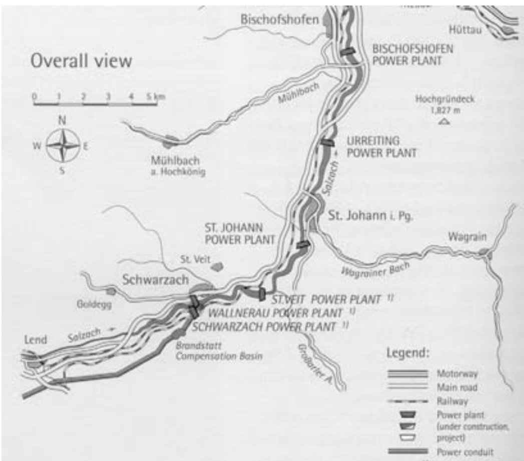

Figure 1. Hydro Power stations at the Middle Salzach river

The operating rules provide that specified flood-water levels should not be exceeded and sediment transport be enabled during floods. It should be possible in the case of floods to draw down the water level completely in all the reservoirs of the series so as to enable sediment transport through all the stations. The possibility of a total drawdown is dependent on the hydrological conditions and spawning periods (March to May).

Due to insufficient river flow during the last few years, reservoir flushing at the St. Veit power station has led to increased siltation directly downstream of the spillway. This is undesirable with respect to both hydro-generation and river morphology. In order to find an answer to the hydraulic and engineering questions involved, Verbund – Austrian Hydro Power AG (AHP) – passed a contract to the Institute of Hydraulic Engineering and Water Resources Management at the Graz University of Technology to undertake tests on an overall hydraulic scale-model with both fixed and movable beds. The model studies were intended to lead to an optimisation of the dividing structures located in the riverbed downstream of the power station, with the aim of devising suitable measures to improve sediment transport in this river section by carrying sediments further downstream. This is intended to reduce sediment deposition near the power station and reduce the head loss involved.

2 CURRENT SITUATION

The brook Grossarler Ache carries a lot of sediments into the river Salzach which deposits immediately downstream of the mouth. This situation caused an increase of the water level upstream of the mouth, and in succession led to an aggregation downstream of the St. Veit weir (Figure 2). This situation was analyzed by a 1d numerical model.

Further performed hydraulic model tests, numerical calculations and in-situ measurements proved the influence of the tributary (Grossarler Ache) some 600 m downstream of the hydro power plant on the water level downstream of the weir. This therefore increased water level caused additional sedimentation below the weir and reduced the power generation.

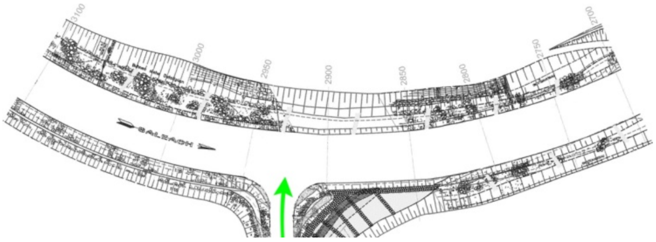

Figure 2: Mouth of the brook Grossarler Ache into the river Salzach

3 HYDRAULIC MODEL

3.1 *Overview*

A hydraulic model was performed to find a solution which reduced the negative influence of the mouth of the tributary.

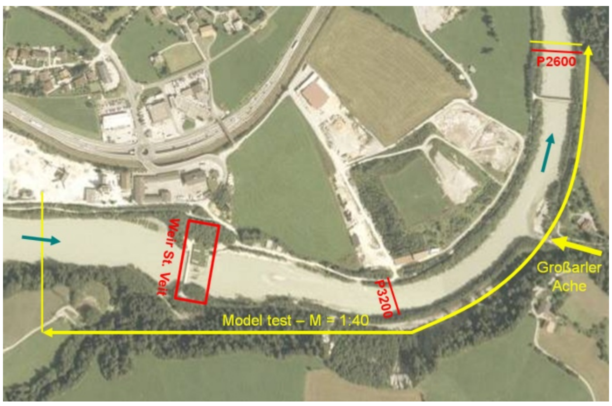

Figure 3: Layout plan of St. Veit power station

The hydraulic model covered an upstream stretch of about 220 m and a length of about 780 m downstream of the power station, as well as the spillway and power intake. The layout plan of St. Veit power station is shown in Figure 3. The river channel was modelled as a fixed or mobile bed as required. The test set-up, built to scale 1:40, was run as an undistorted overall model according to Froude's law of similitude.

Water was supplied to the model through two pipelines of internal diameter 250 mm (river Salzach) and an internal diameter of 100 mm (brook Grossarler Ache), equipped with an inductive flow meter each. Two batching stations at the water intakes supplied the sediments, which were evenly distributed over the cross-section.

For the river Salzach the hydrological conditions were simulated by supplying a flow of between Q_{model}=8.78 l/s (mean flow MQ = 88.8 m³/s) and Q_{model}=113.6 l/s (calculated maximum flood flow RHHQ=1150 m³/s) for a rated discharge of Q_{model}=19.0 l/s (Q_{rated}=192 m³/s). The discharge for starting a flushing campaign was determined with Q_{model} = 21.7 l/s (Q=220 m³/s)

For the brook Grossarler Ache the hydrological conditions were simulated by supplying a flow of between Q_{model}=0.8 l/s (mean flow MQ=8.0 m³/s) and Q_{model}=4.7 1/s (one-year flood flow HQ_1=48 m³/s).

3.2 *Model Test, Sediment Transport*

As sedimentation had changed the river-bed configuration, the river channel was first modelled as defined in the acceptance documents for the power project. Sediment transport in the model was generally simulated by ceramic sand (ρ = 2.85 t/m³) of size fraction 0.25–2.0 mm. The model sand mix, selected on the basis of six sediment samples from below the power station, corresponded to a size fraction of approx. 10–50 mm in the prototype (Figure 4).

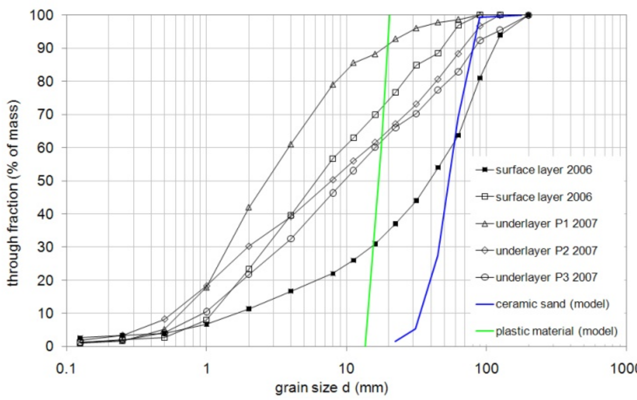

Figure 4: Size fractions bed load, prototype and model tests

Basically the moveable bed consisted of ceramic sand while the added sediment was plastic material with a desnisty of ρ = 1.28 t/m³ and a size fraction of 2.0–3.0 mm.

Following former performed calibration tests the sediment input from upstream at the river Salzach was set to 480 m³/h in prototype which equals 100 l/h in the hydraulic model.

As no values from prototype measurements were available the equation of Meyer-Peter/Mueller was applied for the calculation of the bed load transport at the brook Grossarler Ache. Considering an incline of the slope of 0.69% and a mean diameter of the grain size of d_m=50 mm the same amount for the bed load transport (480 m³/h) was achieved.

Table 1: Bed load prototype and model tests

Parameter	**Prototype**	**Model**
Bed load (plastic material)	480 m³/h	100 l/h
Bed load (ceramic sand)	480 m³/h	17 l/h
Duration flushing	25,3 h	4 h
Time turbine operation	44,3 h	7 h

3.3 *Load cases*

Each load case consisted of the same scheme (Table 2).

Table 2: Scheme of each model test

phase	Salzach		Großarler Ache	
	Q [m³/s]	bed load [m³/h]	Q [m³/s]	bed load [m³/h]
flushing I	220	480	48	480
turbine op. I	192	-	8	-
flushing II	220	480	48	480
turbine op. II	192	-	8	-

Following each step an aerial survey (photogrammetry) was performed.

4 MEASURES DOWNSTREAM OF THE WEIR

For all performed load cases the same configuration for the area downstream of the weir was applied (Figure 5). This configuration consisted of

- A training wall in between the turbine outlets and the stilling basins
- An increase in height of the two separation walls between the three stilling basins
- The construction of four groins at the left side of the river bed and 2 groins at the right side

Following results from former model tests the gates at the left-sided weir kept being closed during the flushing situations. The water levels were measured in profile P3200 and in the middle of the turbine outlet.

Figure 5: Measures downstream of the weir St. Veit

5 INITIAL STATE

The initial situation is shown in Figure 6. This formation causes sedimentation at the mouth of the brook and in a series an increase of the water level upstream.

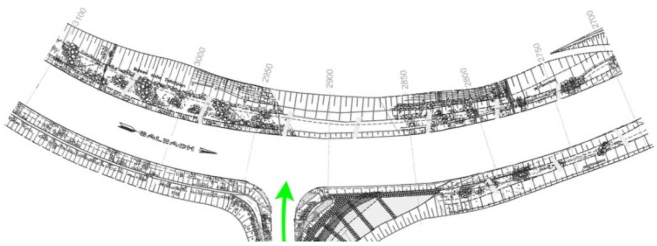
Figure 6: Initial Situation at the mouth of the brook

Corresponding to this situation the hydraulic scheme was applied which resulted in the following results (load cases according to Table 2):

Table 3: Water levels at profile P3200

Flushing I	573.10 masl
Turbine I	572.42 masl
Flushing II	573.20 masl
Turbine II	572.28 masl

For calibration the water level in the prototype would give a value of 573.20 masl (Q=200 m³/s) which fitted well with the results from the model tests.

Figure 7 shows the image of aggregation, following load case flushing I.

A strong sedimentation zone up to 2m in height could be observed downstream of the turbine outlets. The sedimentation zone at the mouth of the brook forced the river Salzach to the left side of the riverbed.

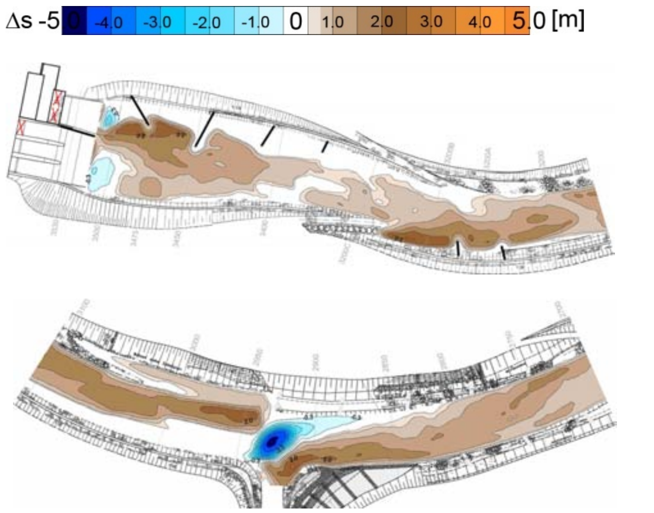

Figure 7: Initial state, image of aggregation, downstream of weir (above) and mouth of brook (below)

6 VARIANT 1

The following 2 variants form the new proposed hydraulic situation at the mouth of the Grossarler Ache.

Variant 1 (Figure 8) consists of 7 groins on the left side of the river Salzach, 3 groins on the right side and in addition the shift of the mouth. This shift is directed into the flow direction of the Salzach and should prevent the aggregation of the mouth.

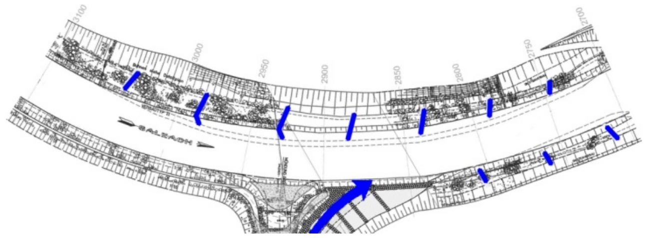

Figure 8: Mouth of Grossarler Ache; variant 1

Corresponding to this situation the hydraulic scheme was applied which resulted in the following results (load cases according to Table 2):

Table 5: Water levels at profile 3200

Flushing I	573.06 masl
Turbine I	572.44 masl
Flushing II	572.94 masl
Turbine II	572.44 masl

According to the initial state the results of variant 1 do not show significant altered water levels.

Variant 1 includes seven groins at the left side of the riverbed. Due to their effect of narrowing the width of the river these groins cause an increase of the water level in profile P3200. Therefore the water levels at profile P3200 reflect a quite small decrease according to the initial state (Table 5). Following this effect the measures of this variant result in a small decrease of aggregation at the mouth according to the initial state (Figure 9).

A more distinct flushing channel is formed than in the initial state.

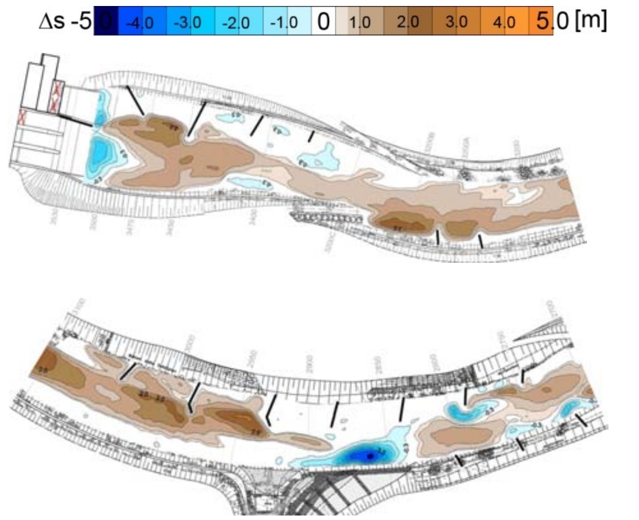

Figure 9: Variant 1, image of aggregation, downstream of weir (above) and mouth of brook (below)

7 VARIANT 2

7.1 *Design variant 2*

In a further step variant 2 was applied by removing the groins at the mouth of the brook. Only the shift of the brook Grossarler Ache was considered. The idea was to lower the water levels in this area by preventing the strong aggregation at the mouth.

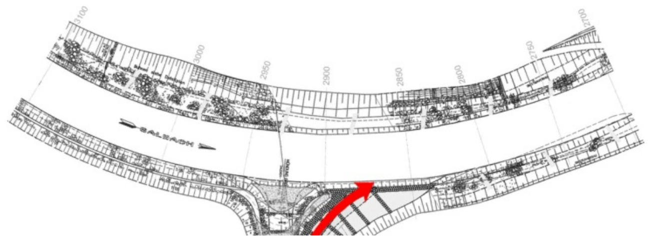

Figure 10: Mouth of Grossarler Ache, variant II

Corresponding to this situation the hydraulic scheme was applied which resulted in the following results:

Table 6: Water levels at profile 3200

Flushing I	572.72 masl
Turbine I	572.12 masl
Flushing II	572.80 masl
Turbine II	572.20 masl

In this case the water levels show a significant decrease (15-40cm), according to the initial state.

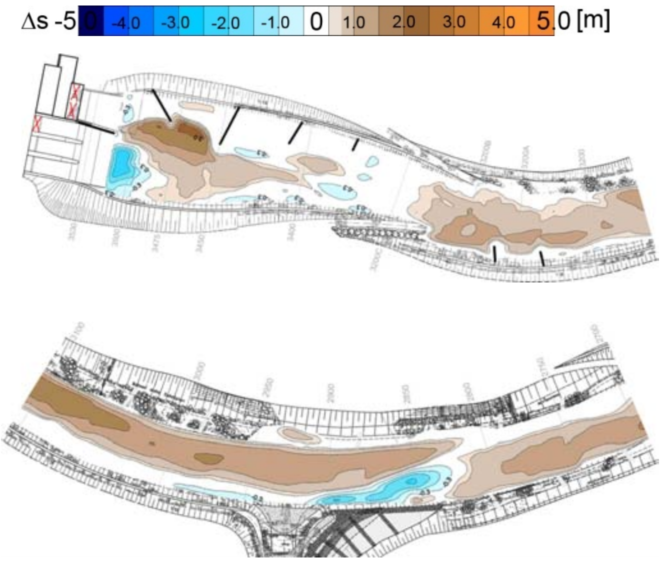

Figure 11: Variant II, image of aggregation, downstream of weir (above) and mouth of brook (below)

Figure 12 presents the progression of the water levels according to the duration of the performed model tests. Presented are the water levels in profile P3200 and at the turbine outlet. Figure 12 includes load case flushing I and flushing II, according to table 2. All dimensions in Figure 12 represent prototype units.

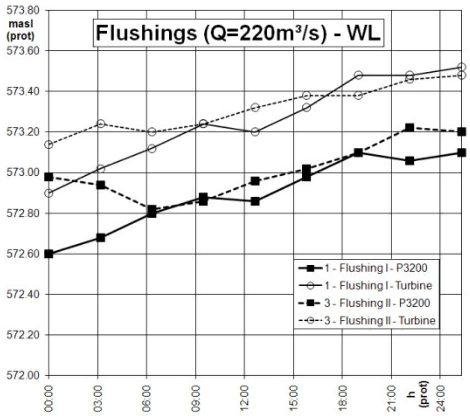

Figure 12: Variant II, progression of water levels over time

7.2 *Results training wall and groins downstream of the weir*

The installation of a training wall to reduce sedimentation at the turbine outlets did not show a significant influence on the water levels and the energy height downstream of the weir.

For example: applying a discharge of Q=192 m³/s would give a difference in water levels between the turbine outlet and profile P3200 of Δh=19 cm in the prototype. According to the situation without the installation of a training wall this situation would give a difference in water levels between the turbine outlet and profile P3200 of Δh=13 cm in the prototype.

The model tests proved the positive influence of the training wall on the aggregation downstream of the weir (Figure 7, 9, 11). Additionally one have to consider the high momentum acting on the first groin situated at the left side.

The proposed and installed groins downstream of the weir form an erosion channel at the right side of the riverbed which enhances the sediment transport in cases of floods or flushing situations (Figure 7, 9, 11).

7.3 *Results measures at the mouth of the brook*

The proposed shift of the brook Grossarler Ache into the river Salzach reduces the water levels downstream of the weir significantly (Table 6). This situation yields to a minor aggregation downstream of the hydro power station (Figure 11). Because of the new design of the altered mouth the Grossarler Ache passes the transported bed load further downstream than in the initial state. A distinct erosion channel is formed on the right side of the river.

8 MEASURES AT THE PROTOYPE

All the proposed measures of variant 2 were performed in summer 2009. Figure 13 presents the rating curve for profile 3200. The water levels were collected between September and December 2009 with a mobile gauging station.

The results illustrate the good performance of the performed construction.

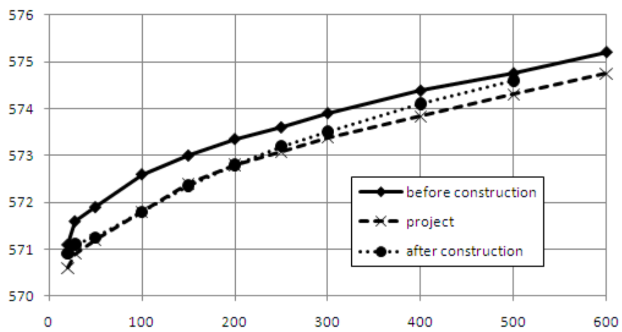

Figure 13: rating curve profile 3200

9 CONCLUSIONS

Hydraulic model tests were performed at the institute for hydraulic engineering at Graz University of Technology to improve the sediment transport underneath the run-of river station St. Veit at the river Salzach. Model tests proved the influence of a bed-load carrying brook on this sediment transport. Following the model test of the initial state two variants were developed focusing on the mouth of the brook. A proposed measure downstream of the hydro power plant was applied to the two variants. According to the results one variant was proposed for construction. The construction was performed in summer 2009. Since then a temporary installed river gauge proved the good success of the proposed measure. Nevertheless the water levels and the morphology will be monitored in a regular interval.

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