DETERMINATION OF PARAMETERS FOR VENTING TURBIDITY CURRENTS THROUGH A RESERVOIR

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ABSTRACT

Sedimentation is an increasing problem in Alpine reservoirs. It leads to a reduction of storage capacities of reservoirs on one hand and might endanger the operating equipment like bottom outlets as well as power conduit inlets and gates on the other hand. The presented measurements are a part of the project *Influence of turbidity currents on reservoir sedimentation – venting through a bottom outlet as an alternative*. The performed measurements, which should be showcased in this contribution, are the determination of the velocity distribution (ADCP), turbidity, temperature and conductivity in two locations in the reservoir Großsölk in Austria. The velocity measurements have been carried out with two down looking SONTEK Argonaut XR. The distance between the Argonauts and the bottom is about 8 meters. The other probes have been measured at the same locations. Besides the measurements in the reservoir additional probes are installed upstream and downstream of the reservoir. The first measurements show promising results. It could be demonstrated that during floods turbidity currents follow the Thalweg until they reach the dam, although the turbine was in operation and the bottom outlet was closed. This shows that a venting of turbidity currents might be possible during higher floods when the bottom outlet will be opened.

KEYWORDS: turbidity currents, venting, field measurements, ADCP, Austria

1 INTRODUCTION

Environmental impacts like rainfall, wind and temperatures below zero degrees centigrade (freezing of water in diaclases) lead to erosion of sediments in alpine regions. Subsequently the exposed sediments will be transported into mountain torrents, rivers and finally into reservoirs. Mainly due to the reduction of velocities in the reservoirs the inflowing sediments will be settled down. Sedimentation of reservoirs is related to security purposes, technical issues like abrasion of turbines and economical questions (lack of storage capacity). The impacts of these processes depend on the size of the reservoir, where reservoirs with large storage capacities generally meet fewer problems due to the large dead storage on one hand and the storage capacity of small reservoirs, like run-of river schemes, is less important than the occurring inflow on the other hand. Consequential mid-sized reservoirs like the Großsölk reservoir face the biggest problems because of the relatively short duration of stay of water and the sedimentation.

Besides the minimization of sediment input into a reservoir because of landuse measures in the catchment area (reduction of erosion) and sediment traps upstream of reservoirs the removal of sediment out of the reservoir by means of flushing or dredging actions might lead to a sustainable sediment management of reservoirs. Nevertheless dredging is expensive, the removed sediment has to be recycled or deposited, and flushing is expensive too and might result in ecological troubles. (Petz-Glechner et al., 1999).

2 PROBLEM DESCRIPTION AND AIMS

During flood events it occurs that the inflows into a reservoir plunge after a certain distance in the stagnant water into deeper layers. This procedure results from the difference in concentration and/or temperature between the inflows and the water in the reservoir. These density- or turbidity currents might flow along the Thalweg up to the dam where the solids settle due to the reduction of the velocity of the turbidity currents. The settled sediment might block the operating equipment on one hand and might lead to negative economical impacts on the other hand.

A possibility to avoid these problems would be to vent turbidity currents through the bottom outlet during a flood for retarding the settling of sediment in the reservoir for the most part. In the context of this work it will be analysed whether a turbidity current, which flows along the Thalweg up to the dam during a flood, may be vented through the bottom outlet in order to prevent therewith the deposition of fine material. Probes were installed to measure the turbidity and temperature of the water at the inflow, in the reservoir and at the outflow. Further conductivity and velocity has been measured in the reservoir.

The aim of this project is to verify the possibility of venting turbidity currents through the reservoir Großsölk by means of hydrological measurements.

3 BASICS

3.1 STATE OF KNOWLEDGE

In case of a developing turbidity current that flows along the Thalweg till it hits the dam the chance will arise to vent the turbid water through the bottom outlet and hence to avoid the deposition of sediments. Figure 1 gives a schematic illustration of the sediment laden inflow that plunges into deeper layers at the head of the reservoir. After following the Thalweg the turbidity current flows out the reservoir via the bottom outlet.

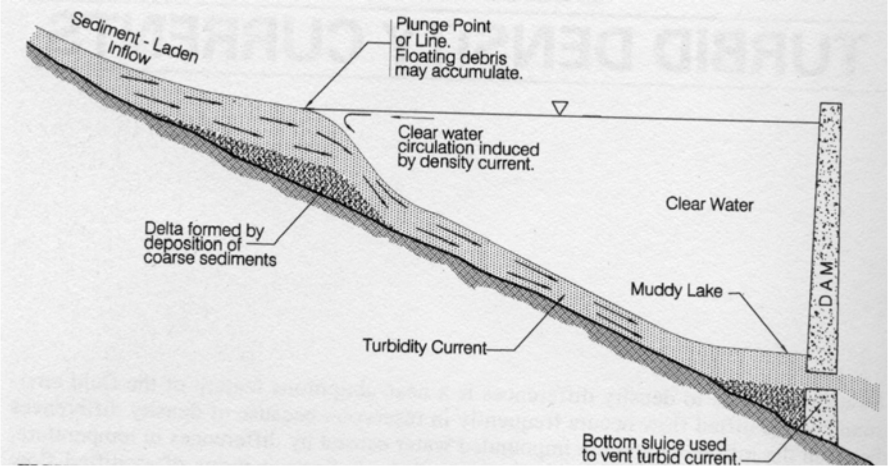

Fig. 1: *Venting through a turbidity current (Morris and Fan, 1998)*

Morris and Fan (1998) describe a successful venting e.g. at the Lost Creek Reservoir in Oregon, USA, at the Steeg Reservoir in Algeria, the Sefid-Rud Reservoir in Iran and the Sanmenxia Reservoir in China. Further observations concerning density currents are given in Cook and Richmond (2004), Bühler et al. (2004) and Molino et al. (2001) who did additional 2 dimensional numerical calculations. This was done by Firoozabadi et al. (2003) too who did comparisons with physical models. Venting of density currents resulted from temperature gradients at the Whiskeytown Reservoir, California was observed by Knoblauch and Simões (2000). Research in avoiding and scattering of turbidity currents was also done by EPFL in Lausanne, Switzerland mainly at the Reservoir Luzzone and the Lake Lugano (e.g. Oehy et al., 2000; DeCesare and Schleiss, 2004).

3.2 PROJECT AREA, GEOLOGY AND HYDROLOGY

The catchment area of the Großsölk reservoir is drained by the rivers Großsölkbach (size of the basin 140.9 km²) and the three diverted rivers Kleinsölkbach, Donnersbach and Walchenbach (subsumed catchment area 244.8 km²). These rivers are southern tributaries of the river Upper Enns in the center of Austria (see Figure 2). The average elevation of the river basin is 1,680 m above sea level of the Adria (m a.sl.) and ranges between 901.8 m a.sl. (retention water level elevation) and 2,599 m a.sl. (Grosser Knallstein).

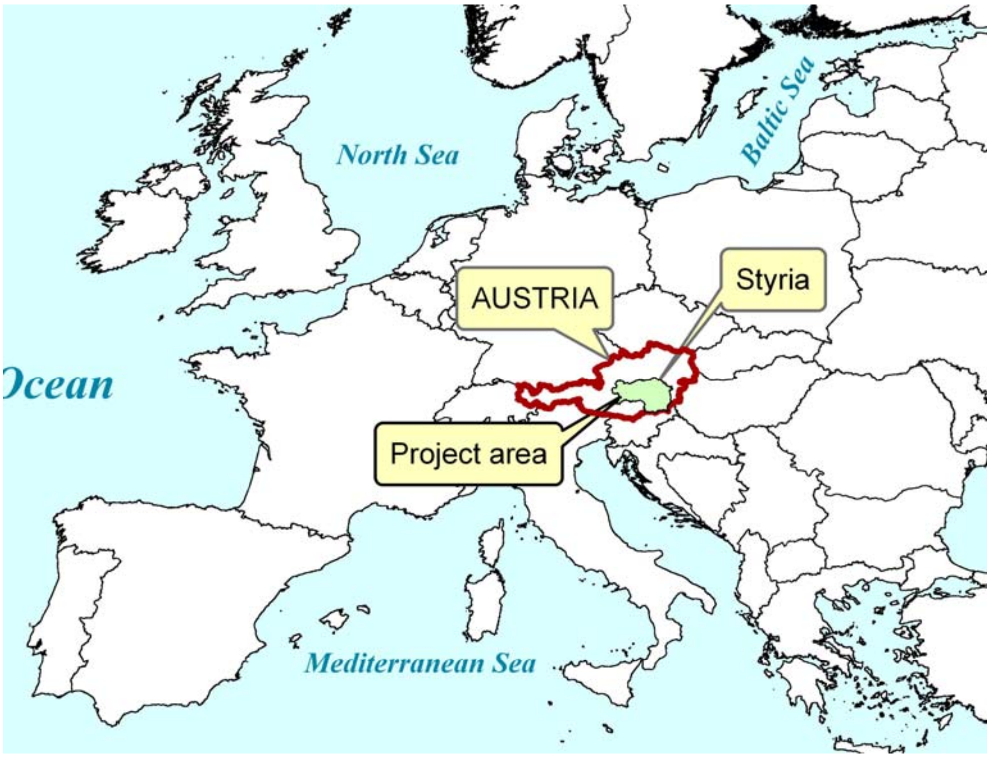

Fig. 2: *Location of the project area*

The basic geological unit of the Großsölk basin, which is the main supplier of sediment, is the Gneiss complex which consists mainly of gray, fine grained structured Gneiss of aphantic to fibrous type (Nachtnebel et al., 2002). The larger Enns catchment is dominated by the Alpine climate which is influenced by the Atlantic ad partially by Adriatic circulation patterns (Nachtnebel et al., 1999). Convective rainfall events often occur locally and might cause short and extreme floods. The mean annual rainfall in the valley is 1,195mm, wheras for the whole catchment it is 1,530mm (Styrian hydrographic department, 1975). The mean annual temperature is 4.5°C in the valley and 1.6°C for the whole basin (Styrian hydrographic department, 1975).

According to the Styrian hydrographic department (1975) the mean discharge at the head of the reservoir is 5.23m³/s, the mean yearly low flow discharge is 0.84m³/s, the one year flood is 42m³/s, the ten years flood is 100m³/s and the 100-years flood is estimated to be 165m³/s.

3.3 POWER STATION AND RESERVOIR

The hydroelectric power plant, which is owned by the VERBUND Austrian Hydro Power AG, was put in operation in August 1978. The plant consists of the main reservoir, three diversions emptying into the reservoir, a headrace tunnel, surge tank and steel penstock and the power house in Stein/Enns containing one Francis turbine. The rated discharge is 30m³/s, the installed capacity is 61MW and the annual energy production is 221 million kWh.

The reservoir is ponded by an arch dam with a maximum height of 39m and a length of 129m. The length of the reservoir is about one kilometre and the usable storage volume is 1.4 million m³. Floods are spilled over the crest of the dam and the bottom outlet is a tunnel of 120m length. The bottom of the outlet structure is located at a height of 858.9m a.sl. and the top edge of the inlet of the bottom outlet is higher than the drawdown water level. The inlet is protected by a screen and it is operated by two gates (service and maintenance gates). The headrace inlet is situated upstream of the bottom outlet at a bed level of 875.74m a.sl. and it is protected by a fine screen. The positions of the inlets of the diversions as well as the already mentioned structures are illustrated in Figure 3.

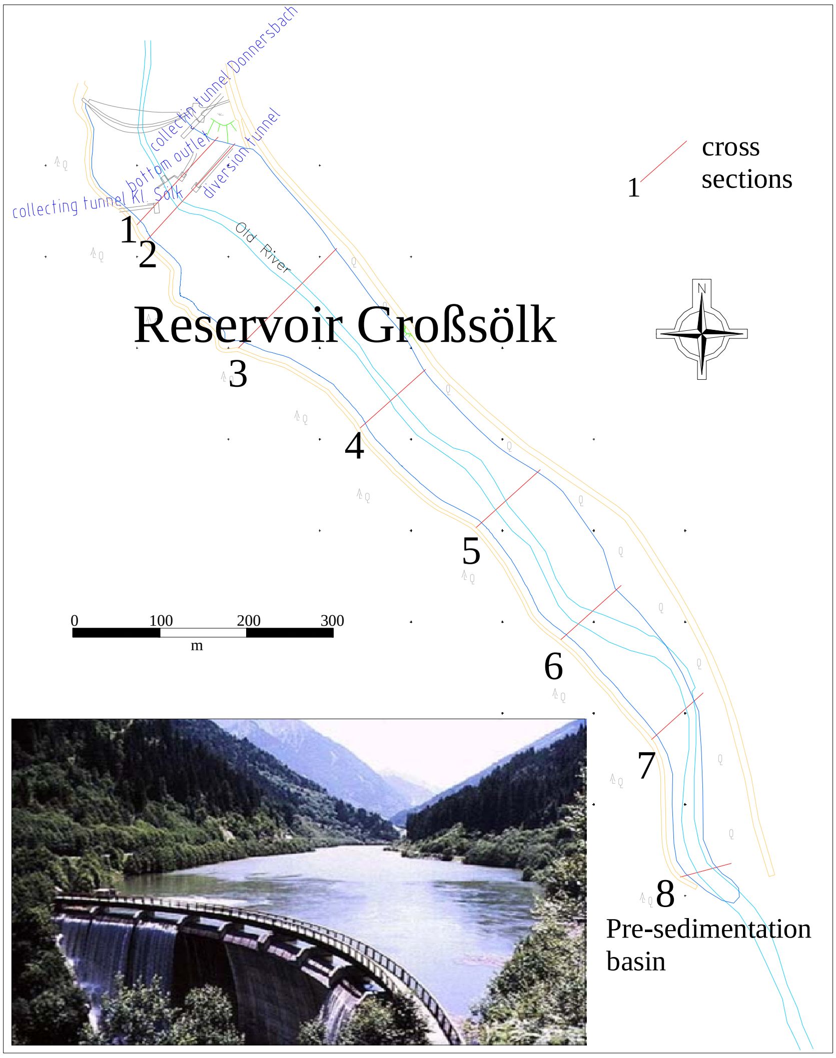

Fig. 3: *Reservoir Großsölk, pre-sedimentation basin and plant equipment*

4 METHODOLOGY, FIELD WORK, MEASUREMENTS

Whether a reservoir is appropriate to perform these venting campaigns or not depends on several parameters like the shape of the reservoir, the inlet structure of the bottom outlet as well as hydrological and sedimentological characteristics. Knowledge about flow conditions, sediment concentrations and temperature distributions in the reservoir are additional and crucial basics. For operating the bottom outlet the time of flow from the plunge point to the bottom outlet has to be known as well. Figure 4 shows the location of the measuring equipment installed in and near the reservoir. Furthermore the parameters are noticed which have been gauging since summer 2006.

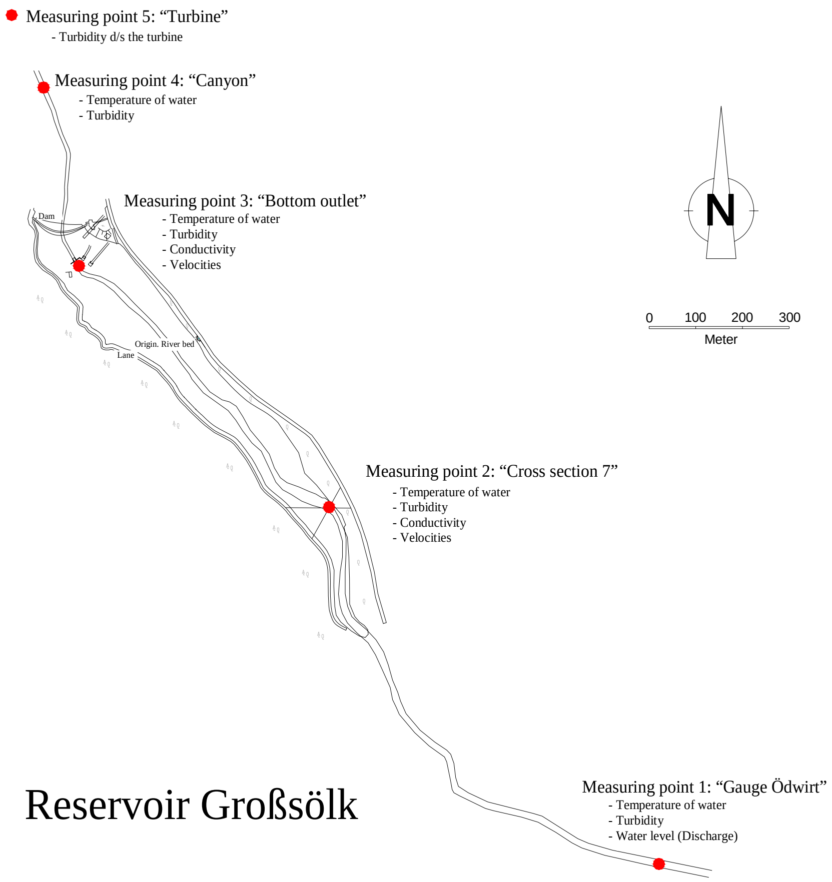

***Fig. 4:** Position of Measuring points (MP)*

The temperature measurements in Measuring point (MP) 1 as well as in all other locations are derived by a Gealog water temperature sensor RS485 and the turbidity is measured by a Gealog turbidity sensor 7001 SWNF of the company Logotronic. The measuring principle of the turbidity probe is 90° infra-red backscatter. For getting information about the suspended sediment concentration the turbidity probes have to be calibrated by taking single point water samples. The conductivity is measured by Tetracon 325 probes of the company WTW. The water level at the measuring profile "Gauge Ödwirt" is recorded by a pressure gauge.

For measuring velocities two down looking Argonaut XR Acoustic Doppler Current Meters of SONTEK are installed about 7 to 8 meters above the ground in the reservoir. Figure 5 shows a sketch of Measuring point 2. The Argonaut XR is installed on a vertical rope which is affixed to two wires that are clamped across the reservoir.

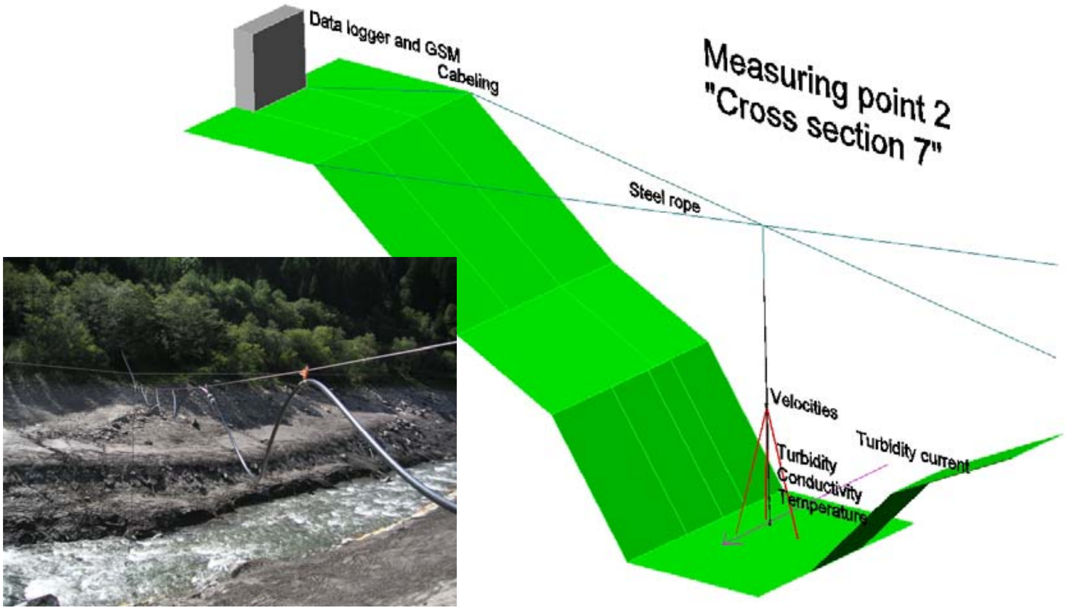

Fig. 5: *Sketch of Measuring point 2, photo of empty reservoir during installation*

In Figure 6 one may see the installed equipment at Measuring point 3 near the bottom outlet. In this case the Argonaut XR is mounted directly on a 12 meters long steel girder which is fixed directly at the bottom outlet inlet structure. Both Argonauts XR are measuring velocities in three-dimensions with a frequency of 0.75 MHz and a cell-size of 0.8 meter. Below the Argonaut XR (MP 2) and nearby the Argonaut XR (MP 3) two multi-parameter probes are installed, which houses the three single probes. The near-ground probes are mounted about 1 meter above ground and the higher probes are 2.5 meters (MP 2) and 4 meters (MP 3) above ground respectively. All data are transmitted via cable to the Gealog SG data loggers of the manufacturer Logotronic and are stored in an interval of 10 minutes. Measuring points 1, 2 and 3 are equipped with GSM modems which allow a long-distance data transmission.

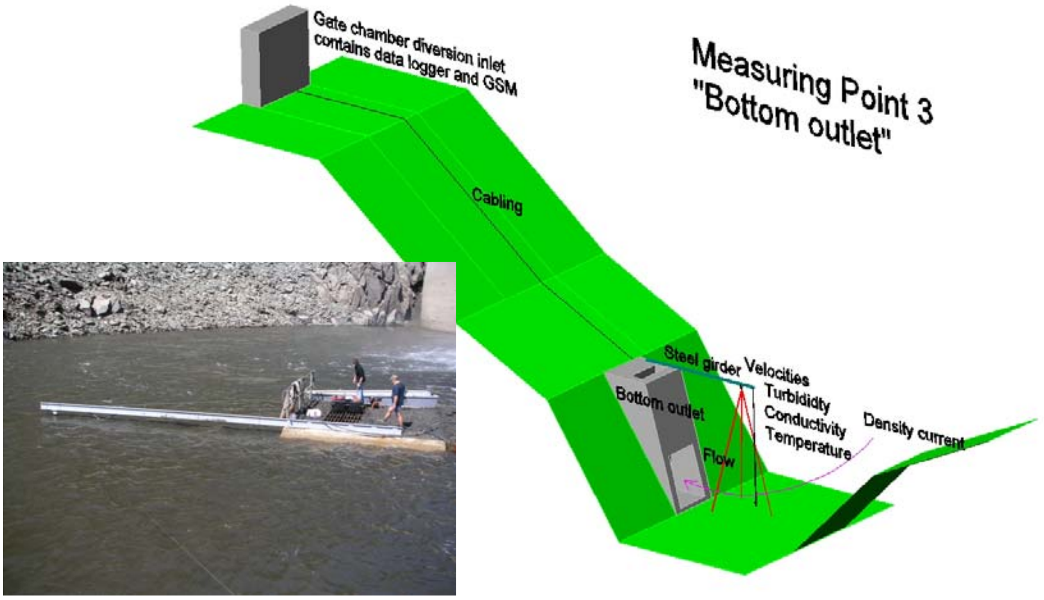

Fig. 6: *Sketch of Measuring Point 3, photo of empty reservoir during installation*

5 RESULTS

The probes are in operation since August 24th, 2006 and there is a large quantity of data available since then. Nevertheless the inflowing discharge (and sediment concentration) did not suffice to open the bottom outlet for venting turbidity currents through the bottom outlet until now. However in 2006 three small floods were observed where the last one should be presented in this paper. In November 19th a small flood was observed with a discharge peak of 12.61m³/s (attend: annual flow is 42m³/s). Figure 7 shows the discharge hydrograph of the inflow into the reservoir. The two vertical lines define the beginning (0:30) and the peak (5:00) of the event. The other lines show the observed turbidity values. The green line (Gauge Ödwirt) shows an almost simultaneous increase of turbidity and discharge. The peak of the turbidity was achieved at 3:20 and was ranged until 5:00.That means that the turbidity peak occurred significantly before the peak of discharge. The turbid water was detected at MP 2 at 2:00 (peak 6:20) and at MP 3 at 5:30 (peak 8:30). It is noticeable that the turbidity peak at MP 2 almost has the same size as for the inflowing water. The peak of MP 3 is significantly lower. The descent of the turbidity curves for MP 2 and MP 3 lasted longer than for MP 1, though. The reduction of the peak is allegeable by a mixing with clear water and the lag may be explained by the reduction of flow velocity.

Nevertheless a turbidity current could be observed at MP 3 (for all three floods) and this is a remarkable result because the headrace inlet, which is located upstream of MP3 (see Figure 3), was in operation. That means that the turbid water could bypass the headrace inlet although water was syphoned off.

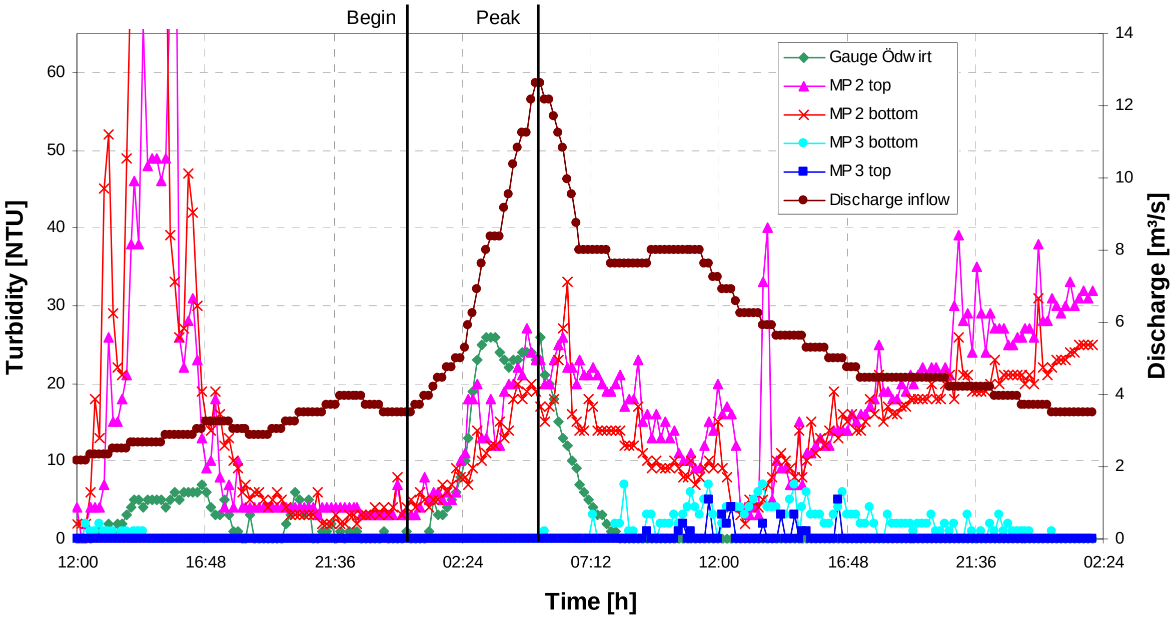

***Fig. 7:** Inflow into reservoir and turbidity distributions at three locations*

Temperature measurements showed ambivalent results e.g. with the first flood a very distinctive temperature reduction at all three locations could be observed when the turbid water passed by the probes. Even for the second "flood" (max. discharge 3.25m³/s) this reduction was recorded. Flood 3, which showed for the other parameters like turbidity and conductivity a similar behaviour than flood 1, no significant temperature distribution was observed.

The conductivity probes (Figure 8) recorded a reduction because of the dilution with the inflowing water (rainwater has a conductivity of 5-30 µS/cm) at MP 2 at 2:00 and at MP 3 at 5:30. The vertical shift between MP 3 *top* and MP 3 *bottom* has to be referred to an error in the probes.

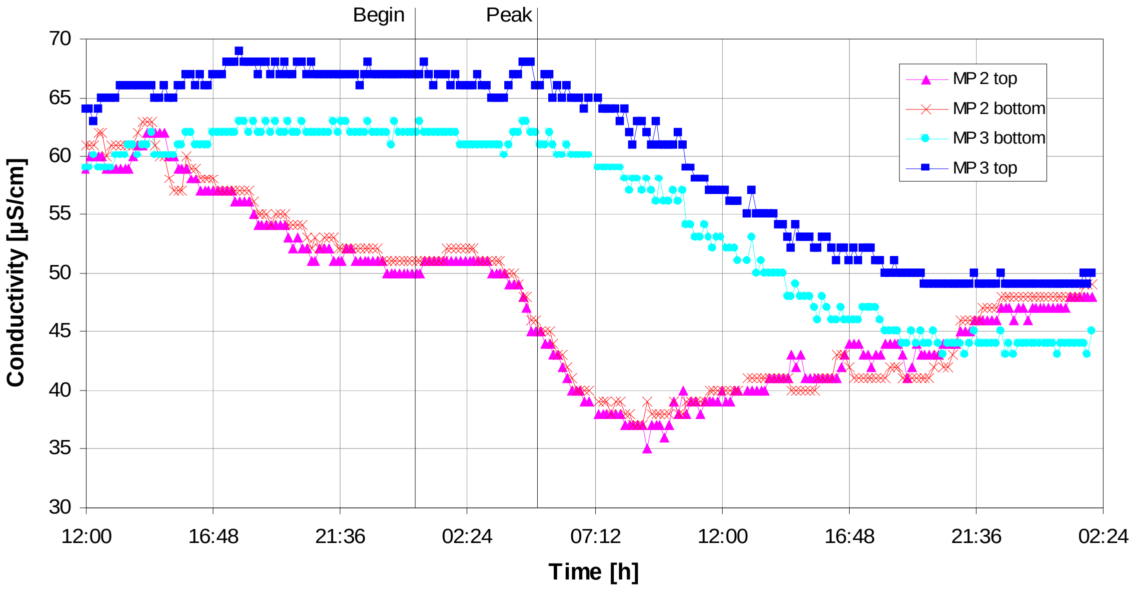

Fig. 8: *Conductivity at MP 2 and MP 3 during the event in August 2006*

Finally Figures 9 and 10 show the velocity distributions in flow direction (v_x) at MP 2 and MP 3 during the small event in November 2006. The values in the range of 0.8 and 1.6 m below the Argonauts can be defined as outliers (0 to 0.8 m is blanking). It is evident that in range 1 (Figure 9) the flow is directed downstream and no influence of the turbidity current could be observed. Interestingly the flow direction changed at 10:40 (range 2). As an effect of this a re-increasing of turbidity could be observed as it can be seen in Figure 7. At this time the inflow already declined and the turbine was full in operation since 07:00. Consequently the reservoir level fell. So it is not clear yet why the flow direction changed.

The measured data at MP 3 showed the following results. Three different ranges could be observed where range 1 and 3 show mainly downstream (v_x up to 10 cm/s) and range 2 upstream (v_x up to -8cm/s) flow directions. These turnarounds of the flow direction can be explained by the starting of the turbine and the resulting reduction of the reservoir level.

Nevertheless a verification of turbidity currents by means of velocity measurements was not possible until now. Results may be expected when the bottom outlet will be opened for the first time to vent turbidity currents because then the velocities will be significantly higher.

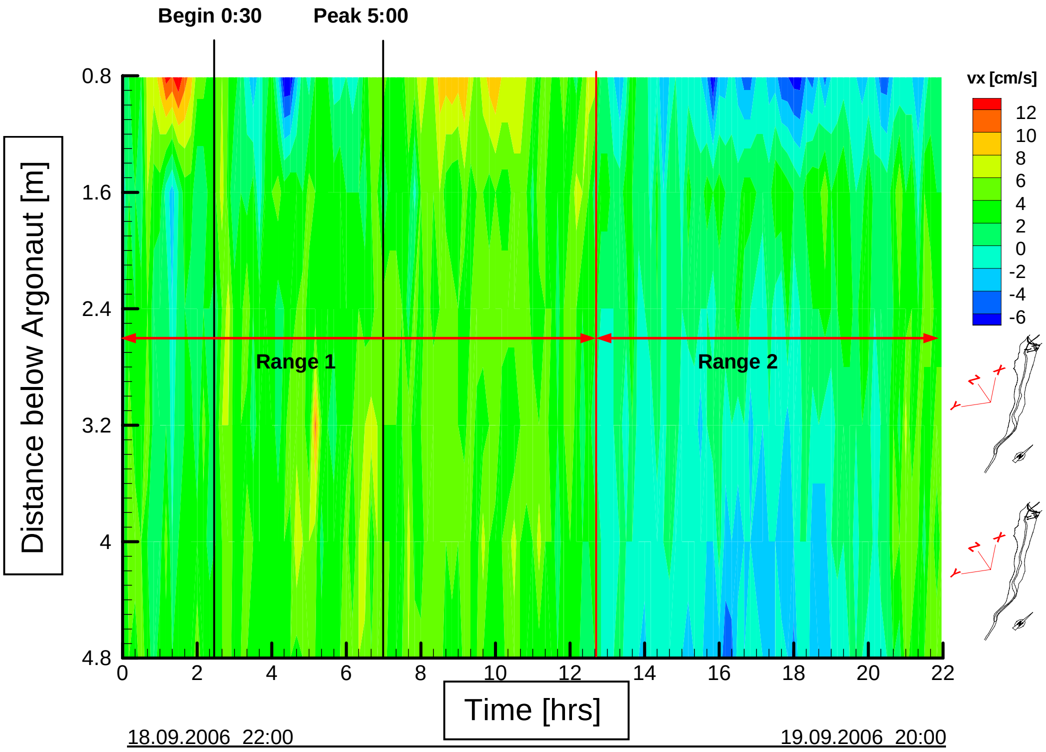

***Fig. 9:** Velocities at MP 2 during the event in September 2006*

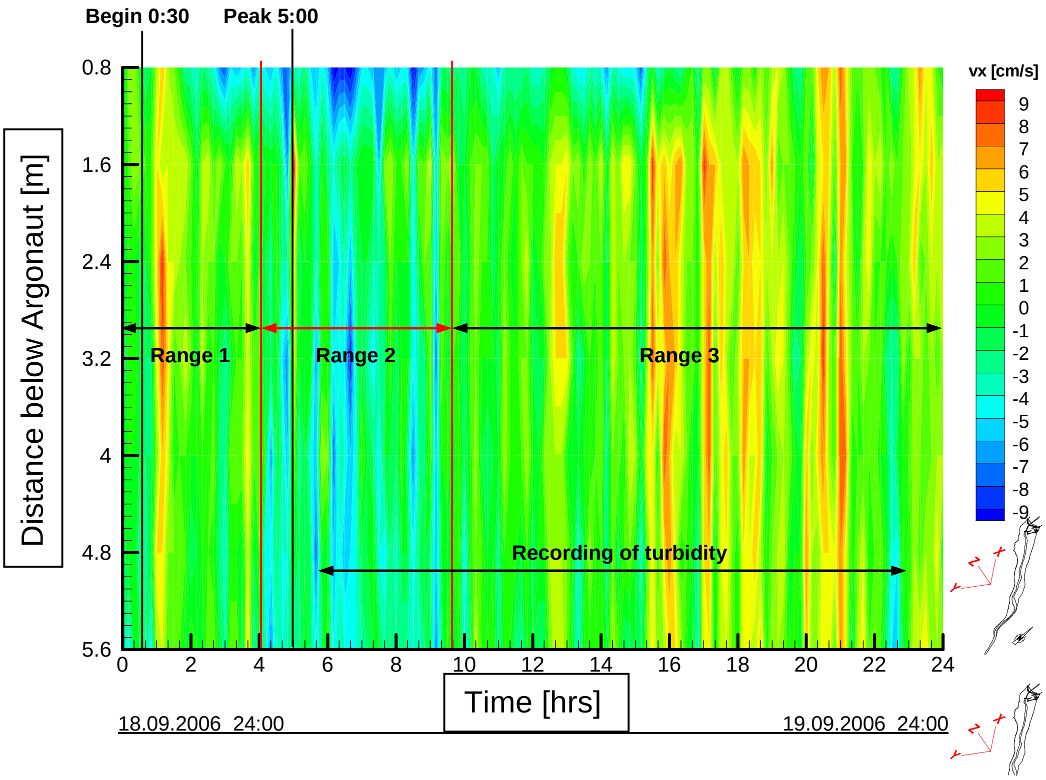

***Fig. 10:** Velocities at MP 3 during the event in September 2006*

6 CONCLUSION

This contribution shows the beginning work of the research project *Influence of turbidity currents on reservoir sedimentation – venting through a bottom outlet as an alternative*. The choice of the location of the probes upstream, inside and downstream the reservoir showed highly satisfying results during the first months in operation. Temperature, conductivity and turbidity as well as velocity measurements could detect inflowing and traversing turbidity currents even for very small “floods”.

It could be demonstrated that inflowing turbidity currents plunge at the head of the reservoir into deeper layers, flow along the Thalweg up to the dam and might be vented through the bottom outlet.

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