ADCP measurements in a reservoir of a run-of-river Hydro Power Plant

Clemens Dorfmann[1] and Helmut Knoblauch[2*]
[1] Institute of Hydraulic Engineering and Water Resources Management, Graz University of Technology, Stremayrgasse 10/II, 8010 Graz, Austria

[2] Institute of Hydraulic Engineering and Water Resources Management, Graz University of Technology, Stremayrgasse 10/II, 8010 Graz, Austria (*Corresponding author, e-mail: helmut.knoblauch@tugraz.at)

The impoundment of the run-of-river hydro power plant Feistritz at the river Drau, Austria, formed a 15 km long reservoir. After 40 years of operation the hydro power plant has to confront severe sedimentation problems. To counteract this problem a special kind of flushing in case of an annual flood should be applied to transport the suspended load into the tail water of the power plant. Both a physical model and a numerical model will be used to simulate different constructive options such as guide walls for a maximal flushing effect. The exact knowledge of the velocity distribution has therefore a crucial influence on the ideal line management and the location of the training structures as well as on their effectiveness. First results of 2-D numerical calculations show that due to the complex reservoir geometry, the flow pattern depends highly on the turbulence model that is applied. Recently performed ADCP velocity measurements (WorkHorse Rio Grande 1200 kHz, RDI) indicate distinct flow patterns of a main stream entering the reservoir with zones of low velocities on the orographic left bank of the reservoir. These results serve as an excellent basis for calibrating both the numerical and the physical model.

Keywords: ADCP measurements, 2-D numerical model, calibration of the constant Eddy Viscosity

1 INTRODUCTION

The hydro power plant Feistritz is part of a chain of hydro power plants, which consists of ten plants. The impoundment created a 15 km long reservoir with maximal water depths of 20 m and a 1000 m wide expanded area upstream of the weir. The large amount of sediment input into the flow represents a severe problem to the power plant. Concepts for the future aim at enabling the transport of suspended load in the case of a flood. To support this project, numeric calculations and related physical model tests will be carried out. As an additional construction measure, guide walls will be installed to prevent disordered movement of suspended load in the reservoir. The goal of the presented ADCP measuring campaign is the analysis of the velocity distributions that occur in nature in the wide area of the reservoir as well as the calibration of the parameter for the Eddy Viscosity in the 2-D numerical simulations.

An ADCP WorkHorse Rio-Grande 1200 kHz© of the company RD Instruments was applied. ADCPs (Acoustic Doppler Current Profiler) use as measuring principle the Doppler effect by transmitting sound at a fixed frequency and listening to echoes returning from sound scatterers (small particles) in the water. A key assumption is that these scatterers float in the water and on average they move at the same velocity as the water [1]. RD Instruments ADCP devices use four beams to obtain velocity in three dimensions. One acoustic beam is required for each current component. Currents must be horizontally homogeneous, that is, they must be the same in all four beams. The fourth beam obtains an additional vertical velocity and therefore the difference between the two estimates of vertical velocity allows to evaluate the assumption of horizontal homogeneity and therefore data quality [2].

2 ADCP VELOCITY MEASUREMENTS

2.1 Measurement procedure and configuration

Previously carried out 1-D numerical calculations showed that the velocities in the measuring area fluctuate between 0.01 and 0.4 m/s that means, they are very low. The water depths in the measuring area are in the range from 6 to 20 m. The ADCP appliance had to be specifically configured for these complicated conditions in order to reduce the large standard deviations that are typical for this type of measurement application. The ADCP WorkHorse Rio-Grande provides different water profiling modes for different water flow conditions. Because of the above described flow conditions, Water Mode 12 was used. This Water Mode is an improved version of the standard Water Mode 1 offering higher sampling rates (up to 20 Hz) and more precise velocity measurement. Contrary to the standard Mode 1 with Water Mode 12 the device transmits and receives a series of sub-pings. The system then averages the sub-pings to produce ping velocity values [3]. Normally the number of sub-pings is 12 and the time between transmitted sub-pings is 40 msec. These values can be adjusted according to the water flow condition. In Water Mode 12 the nominal standard deviation amounts to 6.95 cm/s which is twice as low as in Water Mode 1 [4]. The measurement configuration was additionally improved by changing some default values of Water Mode 12. The WV-command (ambiguity velocity) is used to adjust the characteristics of the transmission pulse and is set based on the maximum apparent velocity (ADCP motion plus water speed). The lower the value of WV, the lower the single-ping standard deviation. The WV-value was set to 100 cm/s (minimum) for all measurement points according to the 1-D numerical calculations and the predicted ADCP device motion. The BX-command sets the maximum tracking depth used by the ADCP during bottom tracking. This prevents the ADCP from searching too long and too deep for the bottom, allowing a faster ping rate when the ADCP loses track of the bottom. The BX-value was determined based on available echo sounder surveys and adjusted for every measurement point. The default depth cell size (WS-command) of 25 cm was increased according to the water depth to account for the maximal recommended number of depth cells (60 in Water Mode 12) and therefore to achieve high sampling rates.

Figure 1: ADCP measurements with bottom-dump barge

As measuring ship a bottom-dump barge was used to meet the slow flow velocities. The ship was anchored along a cross profile in specific distances and within the 20 m long opened dump gate the ADCP measurements were performed (Figure 1). A GPS was located on the ship to determine the exact position of each single measuring point.

2.2 ADCP measurement results

To maintain the complete flow pattern in the reservoir, the mean flow velocity and its mean flow direction were analysed in every measurement point. The mean horizontal flow velocity (Eq. 1) was computed by averaging all of the ensembles for each bin together to a mean east and north velocity component and computing the mean water speed from the mean velocity components in each bin,

$$\left|\overline{V}\right| = \sqrt{\left(\frac{\sum V_e}{n}\right)^2 + \left(\frac{\sum V_n}{n}\right)^2} \qquad (1)$$

where $\left|\overline{V}\right|$ is the mean flow velocity, V_e is the east component of the water velocity in each bin, V_n is the east component of the water velocity in each bin and n is the number of depth cells with valid water velocity components [5]. The mean flow direction in the measurement points was simply determined by calculating the angle from the two mean velocity components.

In the site chart (Figure 2) the resulting velocity vectors in the measurement points are represented and in Table 1 the corresponding mean flow velocities are depicted.

Table 1: Mean flow velocities

Measuring point	$\left\|\overline{V}\right\|$ (m/s)	Measuring point	$\left\|\overline{V}\right\|$ (m/s)
100_1	0.063	304_3	0.039
100_2	0.067	304_4	0.026
100_3	0.061	400_1	0.047
100_4	0.038	400_2	0.044
200_1	0.076	400_2_1	0.043
200_2	0.070	400_3	0.038
200_3	0.056	400_4	0.031
200_4	0.031	500_1	0.057
300_1	0.081	500_2	0.102
300_2	0.072	500_3	0.071
300_3	0.040	600_1	0.090
300_4	0.028	600_2	0.141
300_5	0.030	700_1	0.122
304_1	0.071	700_2	0.163
304_2	0.036		

The results represented in the site chart (Figure 2) show that the velocities downstream of the gorge portion are very low and reach values between 2 (measuring point 300_4) and 16 cm/s (700_2). On the basis of the flow directions it is recognizable that the mainstream of the flow is located near the orographic right bank of the reservoir. In the vicinity of the orographic left bank of the reservoir the velocities show the lowest values (measuring points 400_4, 304_4 and 300_5). No clearly determined flow direction could be detected in this part of the reservoir.

All in all it can be said that due to the large device-specific standard deviations for such measurement conditions the values of the velocities are affected by a great imprecision. However, it can be determined that in cases of turbine operation the higher velocities appear on the orographic right side of the reservoir downstream of the gorge portion. On the orographic left side of the reservoir zones with low velocities and light backflow could be detected.

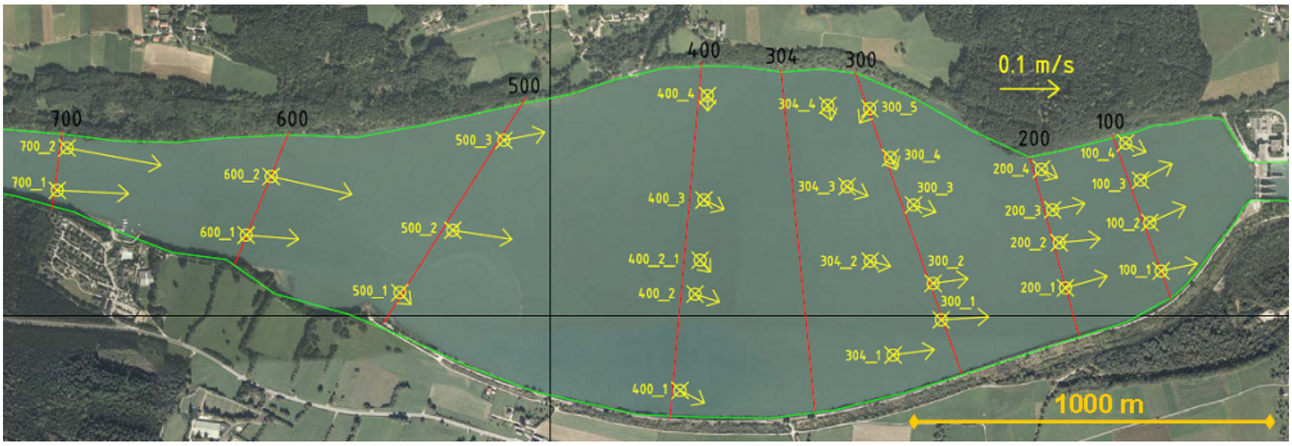

Figure 2: Measuring points with resulting velocity vectors

3 TWO-DIMENSIONAL NUMERICAL MODEL

3.1 Introduction

The results of the numerical models will provide a useful preselection for the measures to be taken in the physical model tests. In a first step, transport and sedimentation behaviour of the suspended load, applied to the cases of turbine operation and weir operation, will be examined in the range between the weir and approximately 5000 m upstream of the weir.

The calculations are executed by the 2-D dimensional hydraulic software MIKE 21C (Danish Hydraulic Institute, DHI), which was especially designed for the calculations of sediment transport respectively bed load and suspended load transport for multiple grain sizes. MIKE 21C solves the vertically integrated equations of continuity and conservation of momentum in two directions by the means of the finite difference method based on structured curvilinear grids [5].

3.2 Constant Eddy Viscosity concept

In MIKE 21C the influence of turbulent stresses on the flow field is parameterised by a one-equation model, respectively a constant Eddy Viscosity formulation. Due to the fact that the Eddy Viscosity depends strongly on the state of turbulence, respectively on the mean velocity gradients and may vary significantly from one point in the flow to another, and also from flow to flow, the value of the constant Eddy Viscosity has to be found directly from available empirical informations or from trial and error calculations to match the observations to the problem considered [6]. On the other hand the Eddy Viscosity does not have a large role to play for most applications in rivers [7], if the model area does not have any abrupt expansions or contractions in the horizontal or vertical direction which would lead to high velocity gradients. Recommended values for the constant Eddy Viscosity formulation range between 0.2 m²/s and 1.0 m²/s [8].

3.3 Calibration of the Eddy Viscosity constant

As mentioned in chapter 1, the reservoir Feistritz is marked by a gorge portion 3500 m upstream of the weir which merges into a 1000 m wide area with change in water depth from 5 to 20 m. For such an irregular geometry the value for the Eddy Viscosity has to be calibrated by field data like ADCP measurements.

Three hydrodynamic steady simulations with a constant inflow of 400.0 m³/s (design flow) as upstream boundary condition and a constant water surface elevation of 461.0 masl (normal operating level) as downstream boundary condition are conducted. For the roughness a constant Strickler-coefficient of $k_{ST} = 45\ m^{1/3}/s$ is set within the entire reservoir. The three simulations diverge in the choice of the parameter of the constant Eddy Viscosity (Table 2).

Table 2: Eddy Viscosity values in the 2-D model

Simulation	Constant Eddy Viscosity [m²/s]
Simulation 1	0.2
Simulation 2	0.5
Simulation 3	1.0

The results of simulation 1 (Figure 3, chart top), downstream the gorge portion, are showing a trend of the main flow direction to the orographic right bank, having back flows mainly at the orographic left bank. In the expanded area of the reservoir there could be seen few back flows at the orographic right bank. In simulation 2 (Figure 3, chart centre) a distinct flow at the orographic right bank can be noticed and, in comparison to simulation 1, a stronger back flow at the left bank can be observed. Simulation 3 (Figure 3, chart bottom) shows nearly the same flow pattern as in simulation 2, whereas the main flow is pushed with even more intensity to the orographic right bank and the back flows are also more intense. The velocity distribution in the zone of the turbine inlet is very similar in all simulations. Upstream of the gorge portion with a water depth of about 5 m and considerably higher flow velocities, all three simulations have shown nearly identical velocity distributions.

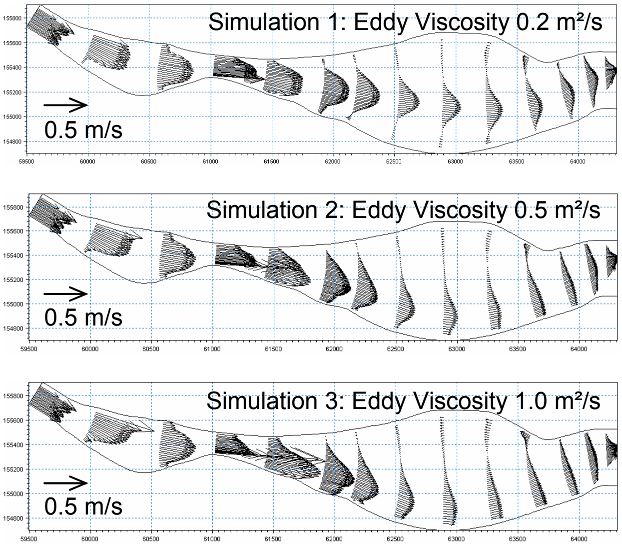

Figure 3: Velocity distributions, 2-D simulations 1, 2, 3

4 COMPARISON BETWEEN NUMERICAL MODEL AND ADCP MEASUREMENTS

The ADCP velocity measurements confirm the results of the numerical simulations. The velocity distributions in all three simulations tend to match the results from the ADCP measuring campaign. The flow field in simulation 2 with the constant Eddy Viscosity of 0.5 m²/s corresponds very well to the measured velocity distributions. The absolute values of the velocities are considerably higher in the numerical simulations. This is due to fact that the calculations were performed for constant discharges of 400 m³/s. However, the actual discharge through the turbines varied from 200 to 400 m³/s during the measuring campaign.

5 CONCLUSIONS

The unsorted sedimentation of suspended load in the reservoir should be registered with the help of numerical calculations and a physical model test. The measures at the physical model will start at the beginning of 2009. For a first calibration of the numerical model an ADCP measuring campaign was carried out determining the velocity distribution within the reservoir. The constant Eddy Viscosity value could be determined, which can be applied in further turbine case simulations. Uncertainties in the appearance of the stream patterns downstream of the gorge portion could be solved. The measurements show a good agreement with the results from the numerical calculation according to the qualitative stream patterns. The ADCP measurements and the 2-D numerical simulation results show that the main part of the discharge tends to the orographic right side of the reservoir downstream of the gorge portion. Further planned measuring campaigns in the case of higher discharges (up to the design discharge) should verify further results of the numerical simulations. In Summer 2008 ADCP measurements in combination with turbidity measurements and sampling of suspended sediments are going to be performed, which in addition to velocity data will provide the basis for the analysis of backscatter data.

ACKNOWLEDGEMENT

We would like to thank the Verbund Austrian Hydro Power Company (AHP) and the Styrian Government of Austria for their help and assistance while performing the ADCP measuring campaign and providing the authors with helpful informations.

REFERENCES

[1-2] RD Instruments: Principles of Operation - A Practical Primer, 2nd Edition for Broadband ADCPs (1996).
[3] RD Instruments: High Resolution Water Profiling Mode 12, Application Note FSA-014 (2002).
[4] RD Instruments: WinRiver II User’s Guide (2007).
[5] Mueller DS, Rehmel M: Determining Mean Velocity for Stationary Profiles using WinRiver, HydroAcoustics, U.S. Geological Survey (2005).
[6] Danish Hydraulic Institute: MIKE 21C Scientific Reference Manual (2002).
[7] Rodi W: Turbulence Models and their Application in Hydraulics - a State of the Art Review, 2nd Edition, IAHR, Delft (1984).
[8] Danish Hydraulic Institute: MIKE 21C Scientific Reference Manual (2002).
[9] Steffler P, Blackburn J: River2D - Introduction to Depth Averaged Modeling and User’s Manual, University of Alberta (2002).