hydrolink

number 4 2010

75th IAHR Anniversary Issue

Experimental Methods and Instrumentation SPECIAL

IAHR AIRH
75 ANNIVERSARY 1935-2010
Supported by CEDEX

hydrolink

in this issue

Number 4 / 2010 (Supplement to JHR - Vol 48 - Number 4)

IAHR
International Association for Hydro-Environment Engineering and Research

IAHR Secretariat
Paseo Bajo Virgen del Puerto, 3
28005 Madrid SPAIN
Tel. : +34 91 335 79 08
Fax.: +34 91 335 79 35
www.iahr.org
iahr@iahr.org

Editor:
Michele Mossa,
Technical University of Bari, Italy
e-mail: m.mossa@poliba.it

Guest Editor:
Collin Rennie
Associate Professor
Civil Eng. Hydraulics Laboratory
Deptarment of Civil Engineering
University of Ottawa, CANADA
e-mail: Colin.Rennie@uottawa.ca

Contact us:

Dr. Christopher George, Executive Director
tel.: +34 91 335 79 64
e-mail: christopher.george@iahr.org

Estibaliz Serrano
Publications Manager
IPD Programme Officer
tel.: +34 91 335 79 86
e-mail: publications@iahr.org

Beatriz Comesaña
Publications Assistant
Hydro-environment Division Programme Officer
tel.: +34 91 335 79 08
e-mail: office@iahr.org

Elsa Incio
Membership and subscriptions
Hydraulics Division Programme Officer
tel.: +34 91 335 79 19
e-mail: membership@iahr.org

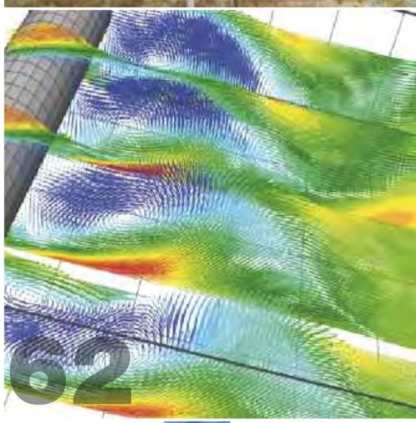
Carmen Sanchez
Accounts
tel.: +34 91 335 79 48
e-mail: accounts@iahr.org

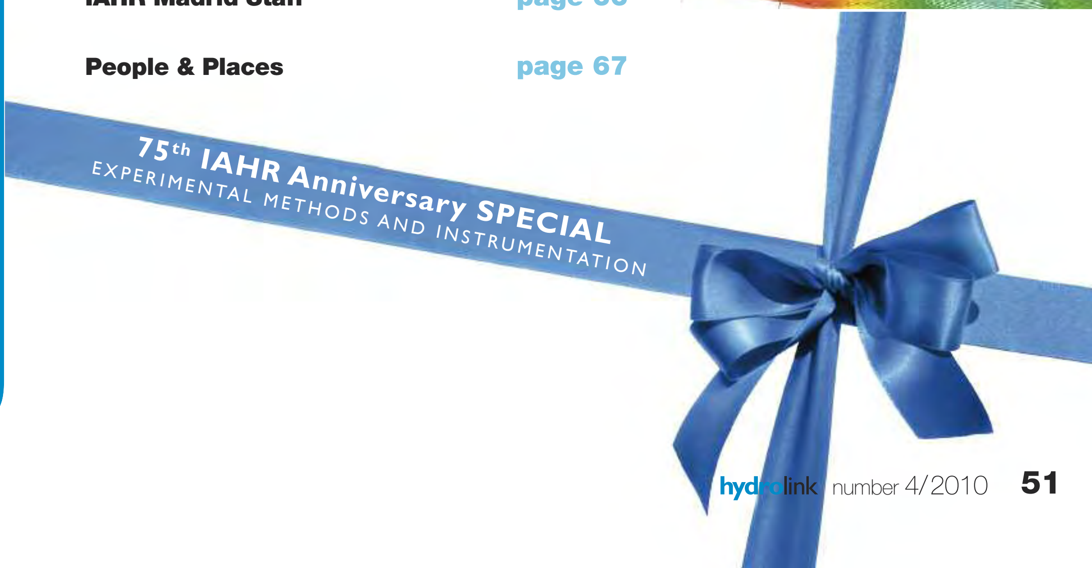
Interested in Joining IAHR?
Visit www.iahr.org

Cover picture:
article page 52

IAHR AIRH

Supported by
CEDEX





Physical Model Experiments

Written by:
Anton J. Schleiss,
Ecole polytechnique fédérale de Lausanne (EPFL), Switzerland
anton.schleiss@epfl.ch

Dr. Giovanni De Cesare,
Ecole polytechique fédérale de Lausanne (EPFL), Switzerland

Dr. Anton J. Schleiss graduated in Civil Engineering from the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. He is full professor in hydraulic structures and director of Laboratory of Hydraulic Constructions (LCH) at the Ecole polytechnique fédérale de Lausanne (EPFL) in Switzerland. The LCH activities comprise education, research and services in the field of both fundamental and applied hydraulics and design of hydraulic structures and schemes (http://lchwww.epfl.ch). Actually 13 Ph.D. projects are ongoing at LCH under his guidance. Prof. Schleiss is also involved as an international expert in several dam and hydropower plant projects all over the world as well as flood protection projects. He is Director of the Civil Engineering program of EPFL and chairman of the Swiss Committee on Dams.

Dr. Giovanni De Cesare, Senior Research Associate, Laboratory of Hydraulic Constructions (LHC) at the Ecole polytechique fédérale de Lausanne (EPFL), Switzerland. He is lecturer in hydraulic structures and networks at EPFL in the civil engineering programme as well as at the University of Applied Sciences of Western Switzerland. The main research topics concern numerical and physical modelling of hydraulic structures and reservoir sedimentation, sustainable reservoir sediment management as well as ultrasound and other laboratory measurement techniques.

Reservoir sedimentation a key problem of sustainability

Even if the reasons and the involved processes of reservoir sedimentation are well know since a long time, sustainable and preventive measures are rarely taken into consideration in the design of new reservoirs. In order to avoid operation problems of powerhouses, sedimentation is often treated for existing reservoirs with measures, which are efficient during limited time only. Since most of the measures will loose their effect, the sustainable operation of reservoirs and the production of valuable peak energy are endangered. Today's worldwide yearly mean loss of storage capacity due to sedimentation is already higher than the increase of capacity by the construction of new reservoirs for irrigation, drinking water and hydropower. In Asia for example 80% of the useful storage capacity for hydropower production will be lost in 2035.
In Alpine regions the loss rate in reservoir capacity is significantly below world average. The main process in narrow reservoirs is the formation of turbidity currents, which transport the fine sediments regularly near the dam, where they can increase sediment levels up to 1 m per year. The outlet devices such as intakes and bottom outlets are therefore in many reservoirs after 40 to 50 years of operation already affected. The effects of climate change will in future increase the sediment yield entering the reservoirs. Turbidity currents may be stopped and forced to settle down by obstacles situated in the upper part of the reservoir in order to keep the outlet structures free of sediments. They can also be whirled up near the dam and intakes and kept all the time in suspension, which allows a continuous evacuation through the turbines. In certain cases fully venting of turbidity currents is possible.

Research at the Laboratory of Hydraulic Constructions LCH) of the Ecole polytechnique fédérale de Lausanne (EPFL) in Switzerland focuses since a long time on this problem. Several experimental studies tried to answer the following questions:

1) How turbidity currents influence the process of reservoir sedimentation?
2) Is it possible to manage turbidity currents inside a reservoir by technical measures?
3) Which geometry of shallow reservoirs is favorable in view of sedimentation by suspended sediments
4) How turbulence in front of an intake can be created with the purpose to keep the sediments in suspension and to evacuate them continuously through the headrace system of hydropower plants?
5) Which are there optimal pumping and turbining sequences in pumped-storage power plants in view of reservoir sedimentation by suspended sediments?

The challenge of understanding and managing of turbidity currents in reservoirs

In narrow reservoirs with quite steep bottom slopes, turbidity currents (Figure 1) are frequently the main process for the transport and deposit of sediments. These turbidity currents with high sediment concentrations mainly occur during floods and follow the thalweg to the deepest zones of the reservoir near the dam. Depending on the slope of the thalweg, density currents reach velocities in the range of 0.5–0.8 m/s, and exceptionally up to 2 m/s during floods (De Cesare et al., 2001). Sediments, which have already settled down, can therefore be eroded again and transported toward the dam. The resulting introduction of additional suspended sediments into a turbidity current increases its density and consequently its velocity. On the other hand, turbidity currents slow down on low slopes or after a hydraulic jump, which causes the sediments to settle and the current to die out.
If turbidity currents can be entirely stopped in a reservoir, or influenced in such a way that the sediments are not deposited in critical locations like in front of intakes and bottom outlets, the sustainability of the reservoir operation may be increased considerably. Such technical measures to control reservoir sedimentation due to turbidity currents have in principal the purpose to stop, dilute, or divert the flow influencing the location of major sediment deposits. This can be done by a solid or permeable obstacle (Oehy and Schleiss, 2007) or a jet screen placed inside the reservoir (Oehy et al., 2010) (Figure 2).

on Reservoir Sedimentation

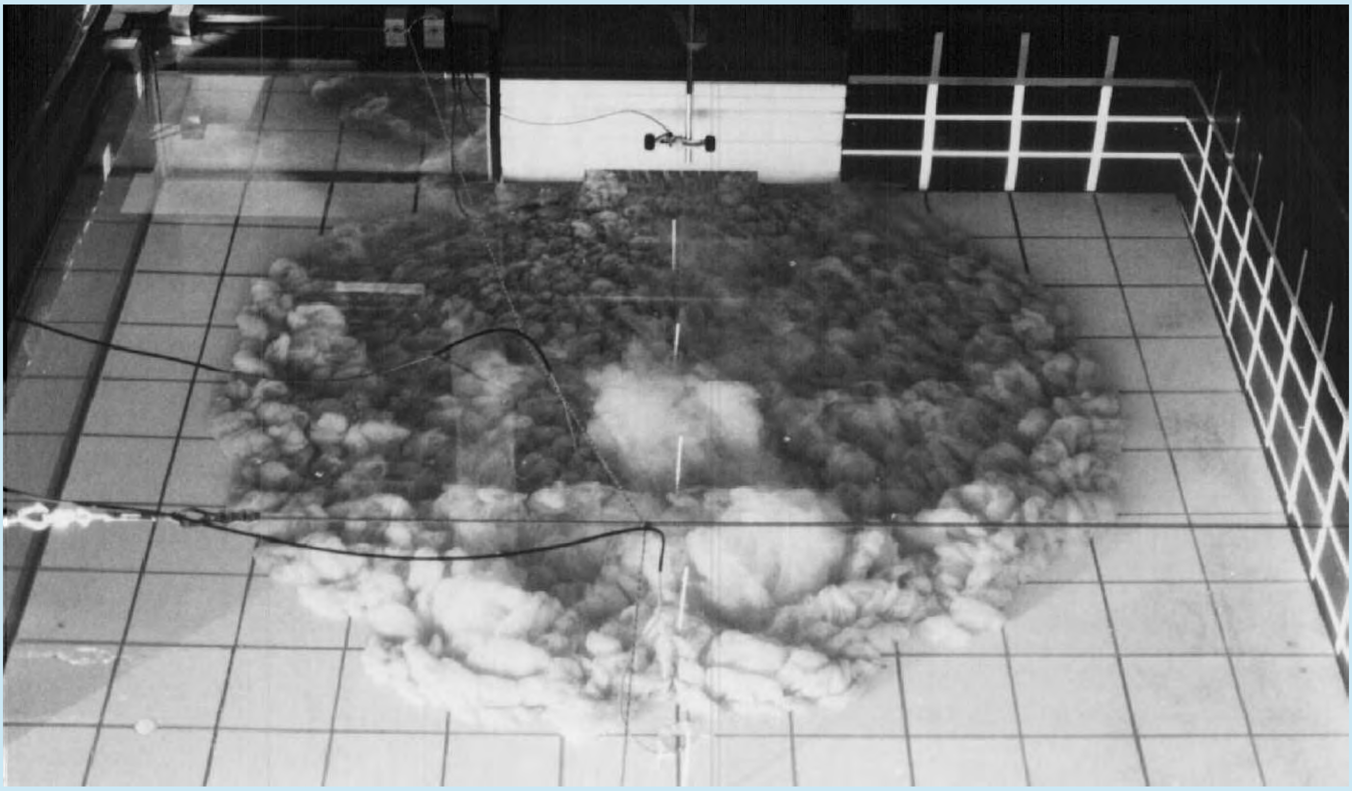


Figure 1: Experimental horizontally spreading turbidity current in a shallow reservoir, streamwise velocity measurement using 5 ultrasound Doppler UVP transducers

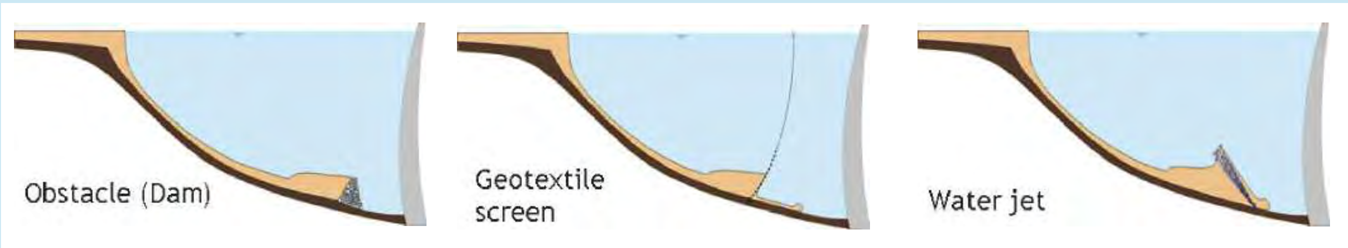


Figure 2: Investigated methods to stop turbidity currents in deep storage reservoirs

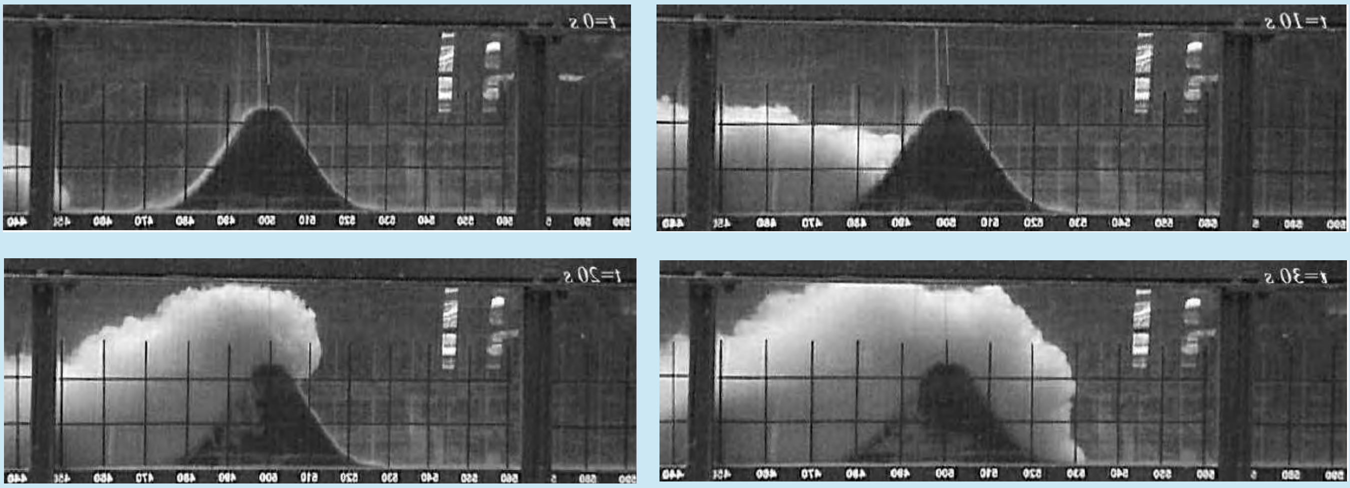


Figure 3: Sequence of a turbidity current flowing over a Gaussian obstacle at time intervals of 10 s. Approach front flow velocity Uf = 0.039 m/s, height of the current h = 0.106 m, grid spacing 0.10 m.

Experiments for testing the efficiency of these measures were carried out in a 8.55 m long, 0.27 m wide and 0.90 m deep multipurpose flume (Figure 3). The flume can be tilted in a slope range between 0% and 5%. In the upper part of the flume a sluice gate allowed the release of the turbidity current in the downstream part simulating a 7.1 m long straight reservoir. An adjacent mixing tank was used to prepare the dense fluid mixture. For the experiments a cohesionless, fine polymer powder with a density of 1'135 kg/m3 and a particle diameter of d50=90 μm was chosen.
In each experiment vertical velocity profiles in the body of the turbidity current were measured with an ultrasonic velocity profiler (UVP). The velocity measurements were made at three locations upstream of the various obstructions and one location downstream. The front velocity of the turbidity current head was determined from video recordings. In order to assess the time and space evolution of deposits due to the turbidity current, a device to measure the local evolution of sediment layer thickness during the experiments was developed based on the fact that the electrical resistance of a layer of particles depends on its thickness.
The investigations showed that turbidity currents can be influenced effectively by properly designed constructive measures. Based on the results of the physical experiments and numerical simulations, some design recommendations for solid (Figure 3) and permeable obstacles as well as for a jet screen are proposed. As an example, the results showed that, in certain configurations, turbidity currents can be partially stopped by a 45° upstream inclined water jet screen (Oehy et al., 2010). Furthermore the deposits downstream of the screen could be reduced up to a factor 2 compared to deposits of a free flowing turbidity

Figure 5: Picture from the interior of the experimental basin showing the jets fed from above in the foreground and the front wall with the water intake in the back

current. The height of a solid obstacle should be at least twice as high as the approaching turbidity current (Oehy & Schleiss, 2007).

Influence of geometry of shallow reservoirs on flow pattern and sedimentation by suspended sediments

The effect of different reservoir geometries on flow and sediment deposition was examined in a rectangular shallow reservoir with a smooth horizontal bottom. The maximum depth is 30 cm and maximum horizontal dimensions are 6 m x 4 m. Movable PVC walls allowed changing the length L and the width B of the reservoir, in a way to test different L/B ratios. A horizontal movable square grid (overall dimensions: 1 m x 1 m) formed by 8 UVP transducers (2 MHz) allowed to measure the two horizontal velocity components in 16 points, placed at the intersections between the velocity profiles recorded by each transducer. The distance between each point of measurement is about 24 cm. LSPIV was also used to assess the surface flow pattern in the reservoir (Figure 4).

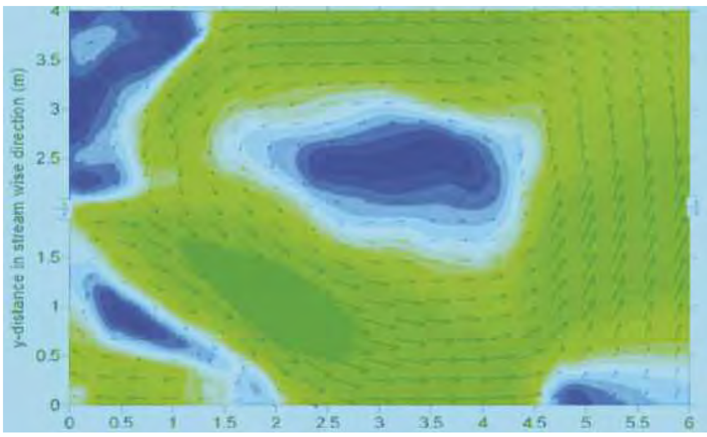
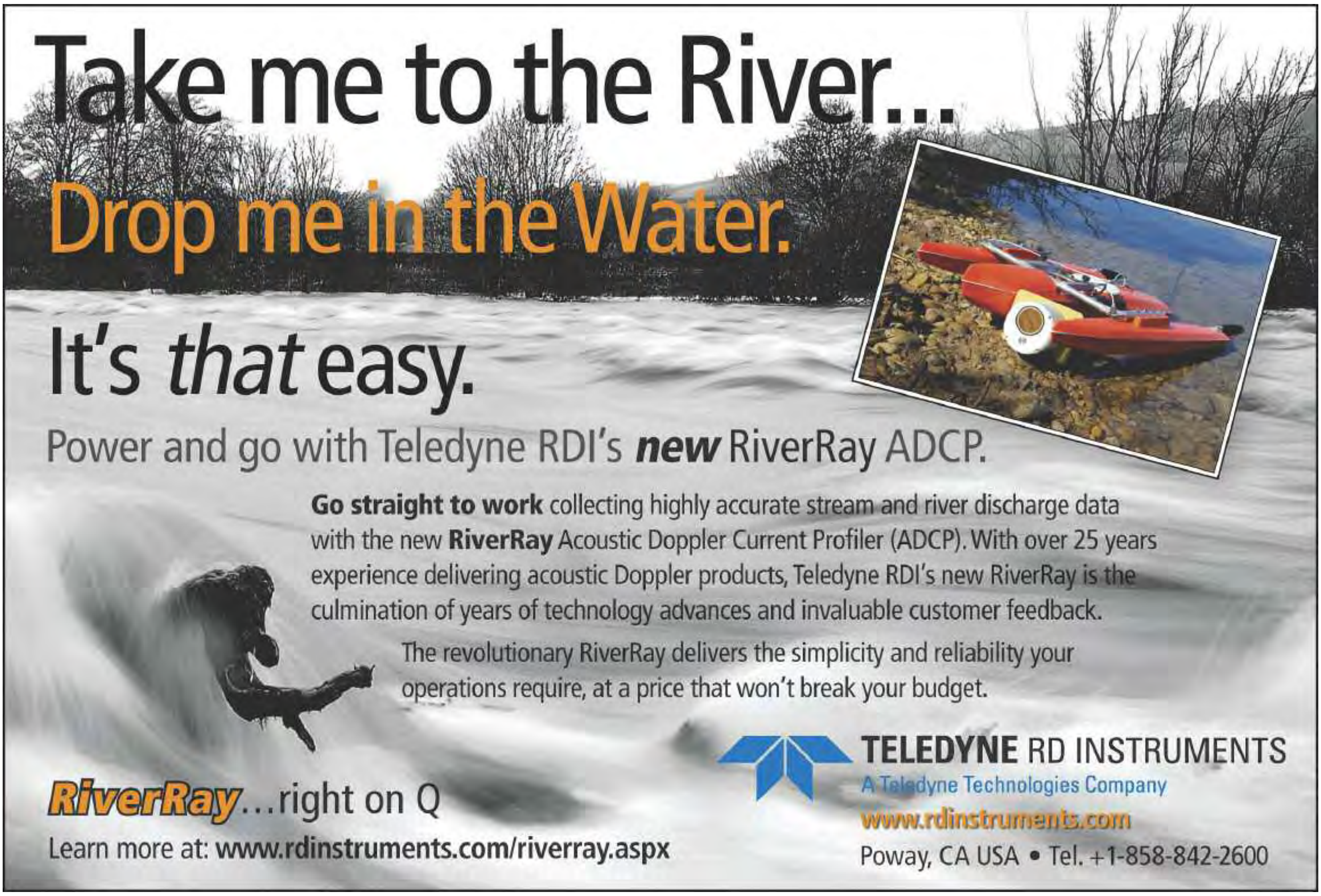


Figure 4: Stationary flow field in a shallow reservoir with sediment transport obtained with LSPIV technique

After carrying out measurements of the velocity flow field developing in clear water conditions for the different reservoir configurations, a sediment supply was added to the inflowing discharge by a mixing tank. Sediments were fed from a sediment tank into the mixing tank, where they were mixed uniformly with water by a rotating propeller. The resulting mean inflowing concentration was about 2 g/l that corresponds to a solid discharge of 50 kg/h. The sediment supply lasted for 4 hours, for a total sediment inflow of 200 kg. The experiment was stopped after the first 2 hours, to measure the intermediate thickness of sediments deposited on reservoir bottom by a laser. Then, other 2 hours of sediment supplying were performed, and the final thickness of sediments deposits was measured. The concentration was monitored at the inlet and at the outlet channels by two turbidimeters. The sediments used for the experiments were crashed walnut shells of mean diameter d50 = 50 μm, with bulk density of the dry sediments ρdry = 550 kg/m3 and bulk density of the wet sediments ρwet = 1150 kg/m3. Their mean settling velocity is vsed = 0.5 mm/s, according to the Stokes' law applied on the mean diameter.
The influence of the geometric parameters was expressed by a geometry shape factor SK and examined for symmetric inflow and outflow conditions (Kantoush et al., 2007 and 2008). As elongated gyres are not stable, the transition from short to a long basin results in a change from one pair to two pairs of gyres. Eventually one large gyre and two upstream satellite gyres are formed (Figure 4). The Coanda effect stabilizes the asymmetric pattern. Adjusting the lateral expansion of the sidewalls, results only in suppression of the satellite gyres. The basin length has a strong influence on the change of the flow field from asymmetric to stable symmetric flow. However, the basin width does not influence the asymmetric separation of the issuing jet. The expansion angle has an influence on the flow pattern and number of circulation cells. The flow instability increases by decreasing the expansion jet angle. It was observed that the basin geometry expressed with a geometry shape factor strongly influences the behaviour of the large turbulence structures. The experiments revealed a critical geometry shape factor SK of 40, above which an initially asymmetric flow will develop towards a symmetric flow due to the Coanda effect. Three types of jet flow regime



were classified according to the basin geometry and flow conditions; symmetric with straight jet, meandering with a wavy jet, and asymmetric with question mark jet. Furthermore the experiments revealed that an asymmetric flow pattern with large stagnant zones and one circulation cell is favorable to minimize retention of sediments.

Continuous release of sediments through intakes by water jet induced cyclonic circulation in the reservoir

The idea is to release continuously the sediments out of the reservoir in order to achieve almost the natural conditions before the dam construction. The method may apply for fine sediments only. This can be done even without loosing precious water for energy production by releasing them through the turbines.

A well arranged set of four water jets creates an artificial turbulence, that means a rotational and upward flow, which lift the fine sediments to the height of the water intake from where they are evacuated during operating hours. In alpine reservoirs, these jets are fed by water convey tunnels from neighboring catchment areas. Different such jet configurations near the intake were tested (Jenzer Althaus et al., 2009). The experimental facility consists of a cubic basin, in which four equal water jets are placed in a circle on a horizontal plane near the bottom where each jet directs in a right angle to the outflow of its neighbouring jet (Figure 5). This jet arrangement creates a cyclonic circulation. Light weight crushed walnut shells with an average diameter of 60 microns are used as sediments. Turbidity measurements give information about the time evolution of the sediment concentration at strategically interesting locations. Flow velocities and patterns were measured by UVP technique.

It could be observed that the flow velocities produced by this jet configuration are strong enough to keep fine sediments in suspension. A sensitivity analysis regarding the momentum flux, the jets Froude Number and the position of the jet cyclone was performed in order to evaluate which configuration gives the optimal combination regarding the suspended sediment release.

Outlook

Because of sedimentation the sustainable use of the reservoirs is not guaranteed in long term. Many possible measures against sedimentation are known from practice, but they are strongly depending on the local conditions. The problematic of sedimentation and sediment management should be considered in the early stage of the design of the reservoir in order to obtain sustainable solutions. Unfortunately this is still not yet the case in many projects today. Innovative research on reservoir sedimentation is therefore still needed in order to define new methods and measures which allow designers to face the serious problem from the very beginning.

Main literature references:

De Cesare, G., Schleiss, A., Hermann, F. (2001). "Impact of turbidity currents on reservoir sedimentation", Journal of Hydraulic Engineering, Vol. 127, no 1, pp. 6-16

Jenzer Althaus, J., De Cesare, G., Schleiss, A. J. (2009) "Experiments on flow pattern and suspended sediment concentration in water jet induced cyclonic circulation in a cuboidal basin" Proceedings of the 33rd Congress of IAHR, ISBN: 978-94-90365-01-1, Vancouver, Canada, 9.-14. August 2009, CD-Rom, pp.3527-3534

Kantoush S., De Cesare G., Boillat J.-L., Schleiss A. (2007) "Flow field investigation in a rectangular shallow reservoir using UPV, LSPIV and numerical modelling", Flow Measurement and Instrumentation, http://dx.doi.org/10.1016/j.flowmeasinst.2007.09.005, pp. 1-6

Kantoush, S. A.; Bollaert, E.; Schleiss, A. J. (2008) "Experimental and numerical modelling of sedimentation in a rectangular shallow basin". International Journal of Sediment Research, Volume 23, Issue 3, September 2008, pp. 212-232

Oehy Ch., Schleiss A. J. (2007). "Control of Turbidity Currents in Reservoirs by Solid and Permaeable Obstacles", Journal of Hydraulic Engineering ASCE, Vol. 133, No. 6, June 2007, pp. 637-648

Oehy, C., De Cesare, G., Schleiss, A. J. (2010)."Effect of inclined jet screen on turbidity current", Journal of Hydraulic Research, Vol. 48, No. 1, DOI: 10.1080/00221680903566042 (2010), pp. 81-90