Sediment control: recent developments for headworks

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Headworks in rivers with severe sediment transport can suffer from poor sediment control and poor techniques for removal of the sediments in the withdrawn water. Reliable physical modelling of the phenomena involved has always been a problem. These facts, often combined with relaxed operational attention, invariably lead to the blocking of intakes, channels, ponds and forebays by deposits of silt, sand, gravel and sometimes rock. This article deals with numerical analysis as a planning tool, and new techniques for removal of sediments. The authors comment on appropriate operational procedures.

Extreme sediment loads in rivers, mainly during monsoons, are among the major problems related to man's development of water resources. Sediment transport will remain a natural phenomenon. Reliable and efficient systems for sediment control and the removal of sediments from withdrawn water will therefore always be one of several preconditions for the successful use of water resources.

Run-of-river projects and storage schemes with large dams are today the only feasible hydropower projects in river basins with severe sediment transport problems. The reservoir sedimentation phenomenon has excluded the possibility of building medium-sized reservoirs for long-term regulation purposes. Medium-sized reservoirs in this context are defined as those with a total volume of between 3 per cent and 30 per cent of the mean annual run-off. Any project within this category must therefore be addressed as run-of-river projects with respect to the planning and design of sediment handling facilities.

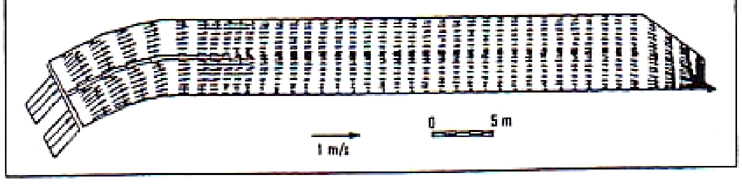
The design of diversion works and intakes in rivers with heavy sediment transport may be reduced to the question of finding ways to withdraw water from the river flow and appropriate means to return the sediment charge back to the river. Various techniques for the continuous flushing of sediments from desander facilities and run-of-river headponds have been developed and are being implemented.

Recent research has dealt with feasible methods for sediment control techniques (by-pass techniques) for medium and large reservoirs.

When these different techniques have proved successful, several of the following objectives will be able to be met:

- Headponds, daily peaking reservoirs, medium and large size second storage reservoirs will maintain their live storage.
- Sediment control can be handled without interruption to the normal operation of reservoirs and desander facilities. For example, desander flushing can be continuous or programmed independently of powerplant operation, as dewatering of the desander basins is not necessary to carry out flushing.

Fig.1. Velocity vector plot, seen from above, of the sand trap of the Jhimruk hydropower plant, Nepal. The vertical location is midway between the water surface and the bed.



- The sediment transport downstream is only marginall influenced by introducing a reservoir on a river. Toda the trapping of sediments within reservoirs is a maj environmental problem. Selective withdrawal of si or sand and gravel is of major importance for agricu tural soil improvement and as a construction materia

Physical modelling of sediment flow has always bee problematic and only very approximate techniques ai available. The latest developments in three- dimension (3D) numerical analysis provide an important step fo ward towards more reliable planning and design tool Physical modelling will not become obsolete, but wi gradually take on the role of overall quality control c proposed designs.

New techniques and the difficulty experienced in hea works operation require a major change in focus wi regard to the needs of headworks operation staff. A ne philosophy for headworks operation and staffing is b ing implemented at new hydropower plants in Nepal.

1. Numerical analysis applications

A 3D numerical model for simulation of water and sed ment flow has been developed over the last years b N.R.B. Olsen. It is called SSIIM (Sediment Simulatic in Intakes with Multiblock option). The model solves th Navier-Stokes equations describing the water flow, gi ing the 3D flow pattern. The convection-diffusion equ tion for sediment transport is also solved, which giv the sediment concentration distribution. This can be us to determine trap efficiency and bed changes. The n merical model calculates the pressure in the geometr and this can be used to calculate the water surface. Wi iterations, it is therefore possible to estimate how t water surface and bed level change over time.

The main objective of the model is to simulate wat and sediment flow for intake design purposes. T model has been used in several cases to simulate flow water and sediments in desilting basins and sand tra [Chandrashekhar, 1994[1]; Olsen and Skoglund, 199 Olsen and Chandrashekhar, 1995[3]]. The results ha been compared with physical model studies, and go agreement has been found. As an example of this ty of simulation, the flow of water and sediment in the sa trap of the Jhimruk hydropower plant has been calc lated [Andreassen, 1994[4]]. The sand trap is 52 m lor 5.5 m wide and 5 m deep. The water discharge throu the sand trap is 3.5 m^3/s.

A velocity vector map of the sand trap seen from abo is shown in Fig. 1. The concentration is also calculat for several sediment sizes. The resulting concentratio are shown in a longitudinal profile along the centreli

Notes; Source: "Sediment control: recent developments for headworks" by D.K. Lysne, N.R.B.Olsen, H.St∅le and T.Jacobsen, The Norwegian Institute of Technology, Trondhelm, Norway, pp.46 – 49 of Hydropower and Dam March 1995.

of the left chamber in Fig. 2, for a particle size of 0.2 mm.

The numerical model has also been used to calculate water and sediment flow in reservoirs [Olsen, 1991[5]; Olsen and Melaaen, 1993[6]; Olsen et al., 1994[7]]. The sediment deposition pattern was simulated, including how the reservoir fills up over time. The trap efficiency of the reservoir and how much of the sediment enters the intake was also calculated.

The photo on page 48 shows the velocity field (seen from above) at the Garita hydropower reservoir in Costa Rica. The reservoir is about 500 × 300 m, and has an average depth of 5 m. Water is taken in from a river 2 km away, and led through tunnels and channels into the reservoir. The flow field has been calculated with a water discharge of 17 m^3/s. Field measurements were carried out, which show that the water flow field is fairly well simulated, including all recirculation zones.

Another application of the numerical model is to simulate local scour. This has been done by Olsen and Melaaen [1993[6,8]], and is still an active field of numerical research. It is also possible to simulate the flow in a river which has large rocks [Olsen and Stokseth, 1993[9]], and research is continuing on this topic.

Research is also being conducted to simulate turbidity currents. Results from this work for a laboratory flume will be published soon [Olsen and Tesaker, 1995[10]], and there are also plans for simulating turbidity currents in reservoirs.

Another topic for numerical research is the simulation of reservoir flushing. This is important when it comes to investigating the possibilities for reducing the negative effects of sediment deposition in reservoirs.

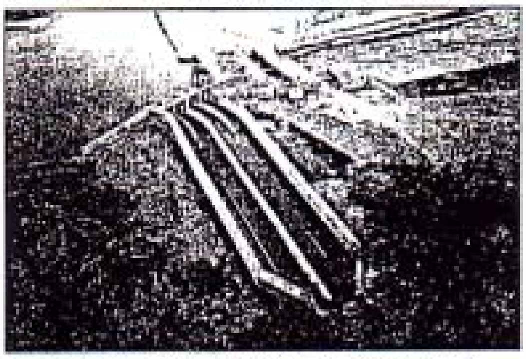
(The SSIIM model is available as freeware and can be downloaded from the Internet, from the address: *ftp.cdrom.com* in directory *pub/os2/32bit/educate*.)

2. The S4: a cure for Himalayan hydro projects

The 'Serpent Sediment Sluicing System', or simply 'S4', was invented by H Støle in 1988. The patented S4 concept has now developed from an idea, through a research and development process, to a commercial product [Støle, 1993[11]], and the first two commercial S4 installations began to operate in Nepal during the 1994 monsoon season, at two plants built and operated by the Butwal Power Company.

When the settling basins at the 5 MW Andhi Khola hydropower and irrigation project were refurbished in 1994, the original continuous flushing system was replaced by the S4 in both settling basins, after a test rig had performed well in one of the basins for two years.

By applying the S4 for sediment control in the settling basins of the 12 MW Jhimruk hydropower project, the costs of the headworks were reduced considerably during the planning process (lower construction costs, as well as the saving of farmland in the fertile Jhimruk valley).



A Serpent Sediment Sluicing System at the 12 MW Jhimruk hydropower project in Nepal.

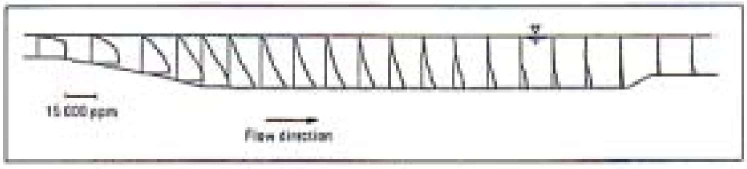


Fig.2. Longitudinal profile of sediment concentration, size 0.2 mm, in the middle of the left chamber of the sand trap at the Jhimruk hydropower plant, Nepal.

The inventor's own company, Sediment Sluicing Systems Dr. ing. H. Støle AS, is supplying S4 to the Nepalese market, while Statkraft has licensed the technology for the world market.

Fig. 3a shows an S4 installation in a settling basin operated in opening mode. The 'serpent' is a heavy-duty rubber tube which seals a slit between the settling basin and a flushing channel along the bottom of the basin when the tube is filled with water. The flushing channel is provided with a gate at its downstream end, and an operating valve is applied for filling or emptying the serpent. When the serpent is gradually dewatered, it rises and opens the slit like a zip fastener. The sluicing area moves along the bottom of the basin with the slit opening.

The S4 installation may also be operated in the opposite mode, as shown in Fig. 3b. The serpent floats in the basin while sand and silt are settling out. To flush the basin, the serpent is filled with water and the flushing

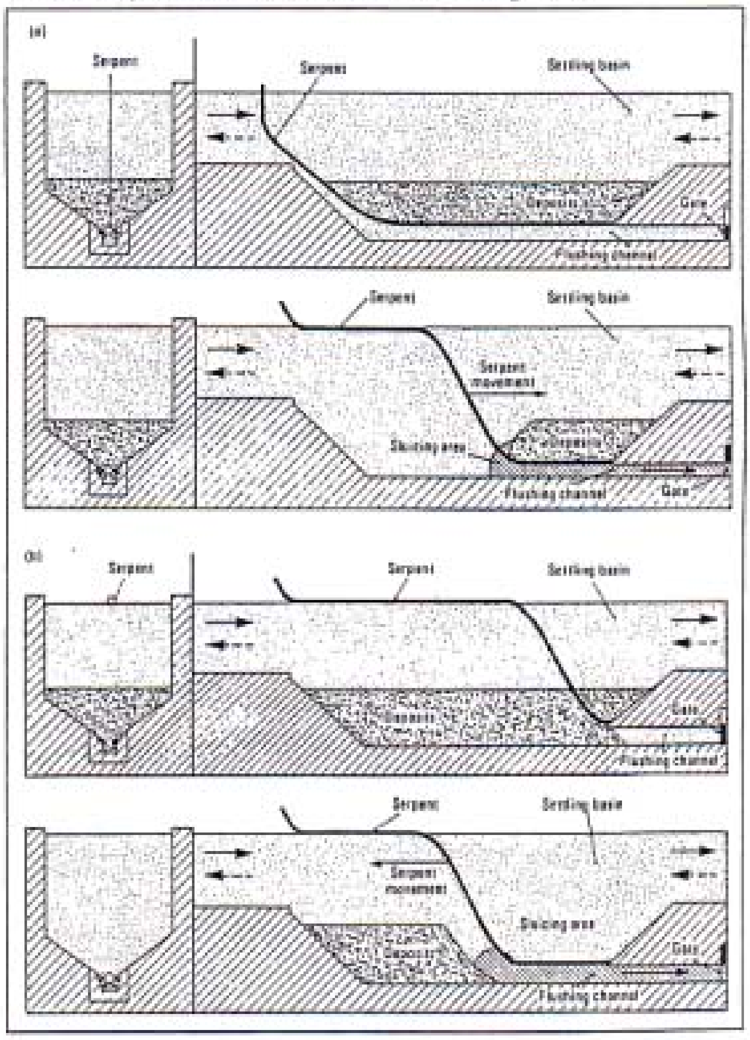
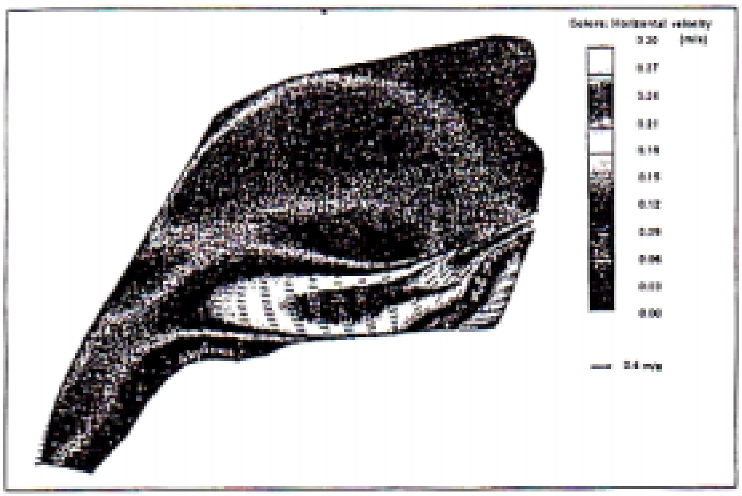


Fig.3. The Serpent Sediment Sluicing System. (a) opening mode; and, (b) closing mode.



Colour plot of velocities (from above) at the Garita hydro-power reservoir, Costa Rica. The vertical location is midway between the water surface and the bed.

gate opened. The slit opening will then move in the opposite direction, thus moving the sluicing area through the entire basin.

S4 facilitates the continuous operation of settling basins, head-ponds or small reservoirs. The flushing process is, however, intermittent. An S4 installation is therefore flexible, and the flushing frequency may be adjusted to comply with the sediment load of the river. The flushing process is carried out using gravity forces alone, and therefore no power input is required. The required flushing head is low and the sediment concentration in the flushing water can be maintained at a high level. The two modes of operation make the system robust, eliminating the risk of a 'point of no return' situation during operation.

Monitoring and operation of the headworks with S4 is simple. An S4 installation may be operated automatically or manually by the use of the operating valve and the flushing gate. A control unit is developed for automatic operation. The flushing frequency can be varied from one flushing per week to 12 flushings per day, to comply with the sediment characteristics of the river and the water available for flushing.

The system is set in the standby mode during the dry season. No valuable water will therefore be lost during the dry season, but the system will automatically start to flush the basin when a sediment-loaded flood appears.

3. Sustainable reservoirs

Sedimentation is a major obstacle to the sustainable management of reservoirs. Water demand is increasing worldwide, and thus reservoirs for storing water are becoming more important. Developing countries have the majority of undeveloped water storage potential, but many of these same countries also have severe sedimentation problems. In industrialized countries, as some older reservoirs suffer from sedimentation, the possibilities for building new reservoirs are limited. Two methods

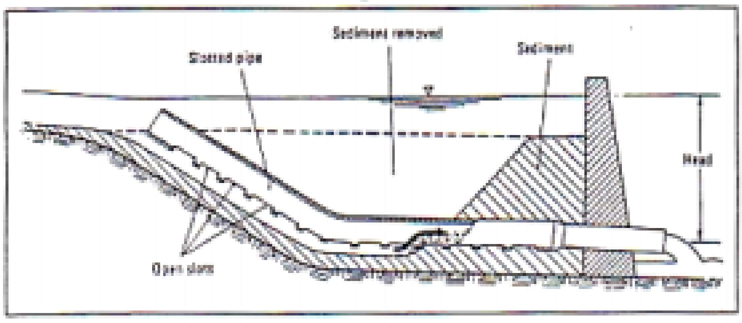


Fig. 4. Sluicing sediments with the Slotted Pipe Sediment Sluicer. Water and sediments are drawn through the bottom slots. The suction point moves downstream along the slotted pipe until all the sediments are removed.

for sluicing sediments developed by PhD student T Jacobsen are presented here. The Slotted Pipe Sediment Sluicer is a fixed sluicing system, while the Saxophone Suction Head is a suction head for siphoning.

3.1 Slotted Pipe Sediment Sluicer

The Slotted Pipe Sediment Sluicer can be described as a pipe with a continuous row of slots on the bottom. It is fixed close to the bottom of the reservoir and connected to a pipeline with an outlet downstream of the dam, as shown in Fig. 4. The upstream end points upwards, so that it is always above the sediment deposits. The Slotted Pipe Sediment Sluicer is operated in two phases:

- Sediments are allowed to settle on top of the slotted pipe until the thickness of deposits is sufficient for flushing.
- The valve on the pipeline is opened, and flushing of the sediments starts. Water is drawn through the slots and sediments are picked up close to where the slotted pipe emerges. As the sediments are sluiced, the suction point will move downstream along the pipe until all sediments that cover the slotted pipe are removed.

The advantages of the Slotted Pipe Sediment Sluicer can be summarized as follows:

- Sediments are sluiced without interrupting the water supply.
- The system can operate under different heads and sluice different types of sediments without modification.
- There are no movable parts except for a valve on the pipeline, and the driving force is gravity. Pipeline clogging will not occur because the transporting capacity will always be larger than the suction capacity.
- The sediments are released in a controlled manner, either back into the river or to a special site (for construction or land reclamation, for example).

3.2 Siphoning with 'Saxophone' suction head

As the name indicates, this suction head looks like a saxophone, as shown in Fig. 5. Its main feature is that it draws water from two places. At the bottom there is a row of slots. During normal operation most of the water and all the sediments are drawn through the bottom slots. The upper opening will always be above the sediments. Slides around the suction head that may cover all of the bottom slots are no problem, because clean 'balancing' water will be drawn from the upper opening, preventing clogging of the pipeline.

The main advantage of the Saxophone is that it is easy and safe to operate. Operators need little training and the system will not clog, in view of its special design. Like the Slotted Pipe, the transporting capacity will always be larger than the suction capacity, and stones up to the size of the bottom slots can be sluiced without problems.

3.3 Successful pilot tests

Pilot tests were performed for both methods at the Jhimruk hydropower plant in Nepal, during 1994. Both the Slotted Pipe Sediment Sluicer and the Saxophone were made from 150 mm HDPE pipe. Sediments (fine sand and some small stones) were sluiced through a 45 m-long, 125-mm diameter flexible pipe.

An 8 m-long version of the Slotted Pipe was tested. The head was limited to 2 m, resulting in a net gradient for the pipeline of about 3 per cent. The test runs gave a result of 7 m^3 removal of sediment deposits in 25 minutes. Concentrations of up to 11 per cent by volume were measured.

Some 30 hours of pilot testing with the Saxophone Suction Head were performed. During one hour of testing, 5 m^3 of sediment were removed, and an average