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Continuous Sediment Transfer (ConSed-Method)
A way to reduce the risk of sedimentation and siltation, flooding, soil and coast erosion, and saltation of groundwater.

Abstract
Almost every reservoir is affected by sedimentation. The World Commission on Dams WCD estimated that each year around 1 % of worldwide storage capacity is lost due to this effect. Even the actual new build of reservoirs does not level out overall storage decrease. Dredging and disposing reservoir sediment is extremely expensive. On the other hand the caused lack of sediment downstream of reservoirs leads to erosion damages, substrate deficits and ground water problems. An innovative technical approach makes reservoirs permeable for sediment on a very cost effective basis. The application does not affect reservoir management and is performed during daily reservoir operation. The process restores overall sediment transport to a near nature state with overall benefits to ecology and the rivers morphological state, giving the operator back the desired reservoirs operational range. The new technical sediment management approach is transferable on almost any range of plants, small to large and run-of-river to pumped-storage.

As a best practise example, the new process has already been applied to reservoirs in Germany. Large reservoir capacity had been lost due to siltation. By applying the new equipment for the Continuous Sediment Transfer the reservoir will permanently deminish the risk of siltation without lowering the water level or compromising plant operation. Ecological benefits have already been proven in numbers by an accompanying monitoring program.

1 SEDIMENTOLOGICAL BACKGROUND

The general effects of reservoir sedimentation are known to a wide audience. Already decades ago the range of this worldwide problem has been assessed (Mahmood 1987). The World Commission of Dams estimates that annually 0.5 to 1% of global storage volume is lost by sedimentation. Without further action one quarter of all dams in the next 25 to 50 years will lose their storage function by sedimentation (WCD 2001).

Sedimentation is still probably the most serious technical problem faced by the dam industry (McCully 1996). Given this scale it is surprising what little attention is often given to the field of sediment monitoring, control and operational solutions.

1.1 Benefits of sediment

Sediment is not a merely evil. Like water and organisms also sediment is an essential ingredient of every river. This solid fraction mostly is of natural origin and finds its way via erosion processes into the water body. Starting at the rivers source solid components usually begin their career as eroded massive rock. Transport processes changes rock size first to gravel size bedload and furthermore to fine-grained sediment. This sediment settles at the river floor. Depending on the local current this sediment does also come loose again by erosion effects. In middle and lower parts of natural rivers sedimentation and erosion usually balance each other and effectively prevent river beds from erosion damages (Figure 1.1). Sediment deposition at and beyond coastal estuaries is required to preserve groundwater from becoming brackish.

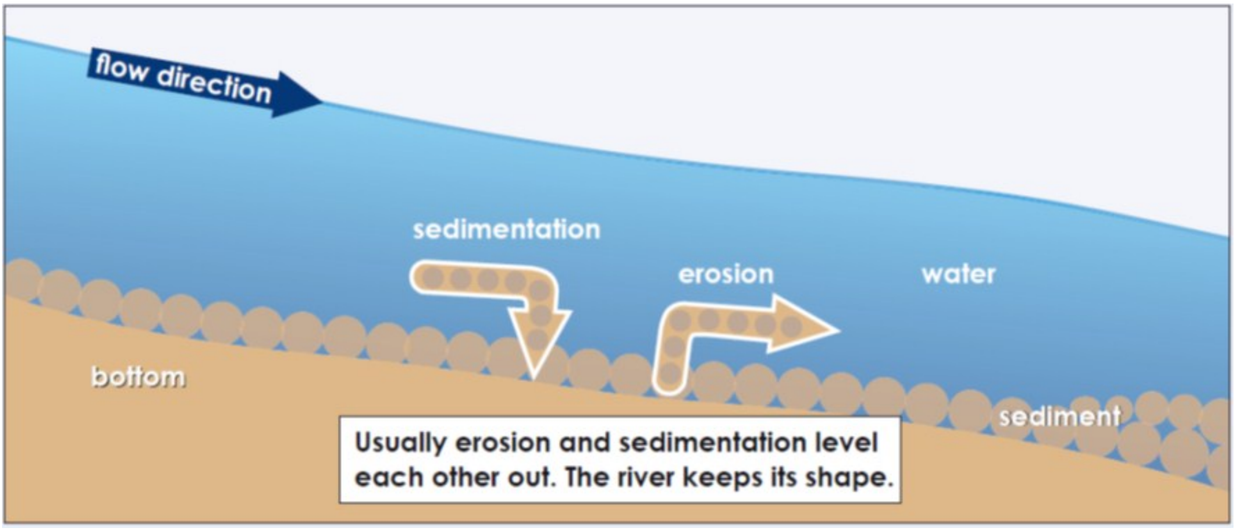

Figure 1.1 Sedimentation/Erosion equilibrium in natural rivers.

1.2 Morphological changes

A natural river changes it morphology fundamentally when installing a dam or other barrage across a river section. Permeability is still given for water and mostly for aquatic life by discharge elements and if applicable fish ladders. The extended cross-section upstream of a barrage leads to low current velocities and therefore to profoundly more sedimentation while erosion is minimized. Therefore a barrage often is a massive barrier for sediment transport (GWSP 2009). Many reservoirs are affected by massive sedimentation and consequently a loss of storage volume (Figure 1.2). The same is true for pump storage reservoirs in a similar way.

Largely extracting the sediment from the river at the concerned reservoir also leads to massive changes downstream. By trapping sediment in its tributary reservoirs, the German river Rhine alone - which certainly does not represent a major sediment carrier concerning worldwide average - is facing an annual sediment deficit of 2.5 million tons. To heal only major riverbed erosion damages an annual mass of approximately 1 million tons of soil is dropped into the Rhine at its middle and lower reaches, causing significant expense.

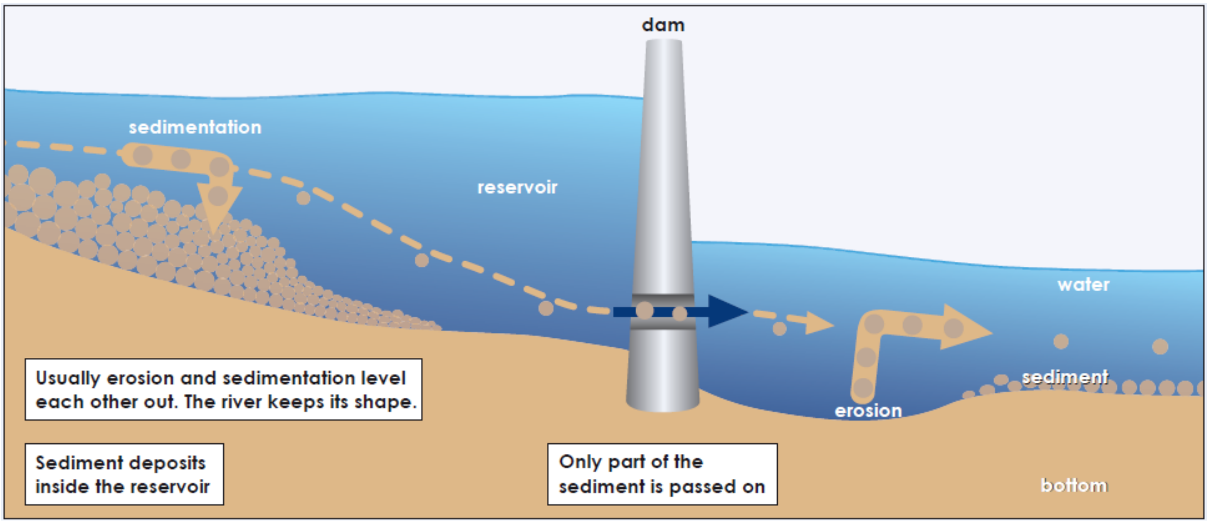

Figure 1.2 Reservoirs change the sediment balance profoundly.

1.3 Operational consequences

Operational restrictions for reservoir users caused by sedimentation do not come overnight. They increase gradually over long time periods, usually years. Therefore many operators get used to live with these restrictions and consider them as normal, though they are not. Even worse, they grow over time if no counteraction is taken. Foreseen dead storage capacity to store a bulk of sediment below the actively operated reservoir range often does not fully apply because sediment does not tend to settle plain but accumulates within the foreseen active storage volume.

2 SOLUTION ATTEMPTS SO FAR

In many cases of sediment issues action is taken not until problems are in far progressed stage. Previously conducted solutions attempts are briefly outlined below.

2.1 Former Procedures

2.1.1 Opening the base outlet.

Sedimentation processes usually start at the up-stream entrance into the reservoir which typically is the most distant point from the dam axis. As sedimentation increases the settled sediments eventually reach the dam. To prevent the dams discharge elements from plugging the operator is now forced to flush the base outlets periodically (e.g. every six months). If neglected the equipment will become inoperable within short term because the sediment will cover the gear. The tremendous runoff generated by opening the outlets erodes the sediment right upstream of the intake. The eroded sediment is transported downstream in short time and at a high rate (Figure 2.1).

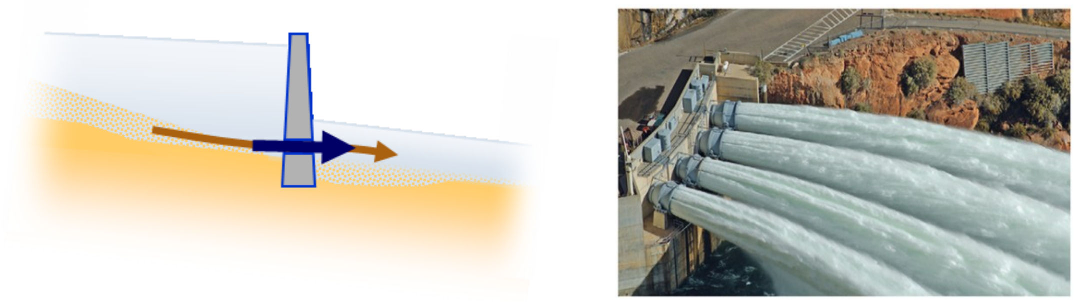

Figure 2.1 Opening the base outlet.

Performing this method is quite simple and requires no further physical facilities. However, with this technique a tremendous quantity of water for power generation or water supply is lost. Furthermore, significant amounts of sediment are moved into the downstream river section in a very short time period. This can lead to negative morphological and ecological effects.

Anyway, the method is applicable only when sedimentation already reached the dam line. Opening the base outlet then only leads to a dissipation of sediments in close vicinity of the outlets. The overall operative range of the reservoir is not restored.

2.1.2 Manual dredging.

Another procedure is manual removal of sediments. Here the sediment is excavated by suction dredgers, hydraulic excavators or - after lowering the reservoirs water level and initial draining - wheel loaders (Figure 2.2). After the often expensive removal and transport the sediment has to be stored on separate drainage fields for years or decades in order to reduce the water content. Thereafter it may be used as covering material for simple ground work applications. The relatively high percentage of organic ingredients (usually 2 … 30 %) prevents a use as a ground construction material even after dredging. In many cases, landfill is required.

The procedure allows for a thorough cleaning of reservoirs, but at exorbitant costs. Expenses consist of sediment dredging activities, plant/reservoir shutdown of several months as well as transport and dump expenditures which are in a million dollar range even at small reservoirs.

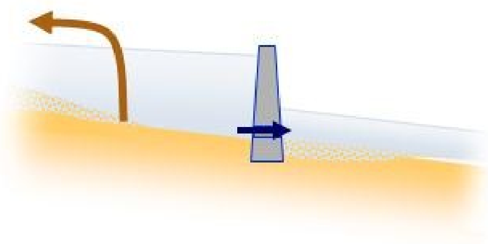

Figure 2.2 Manual dredging.

2.1.3 Sludge dredging and disposal downstream.

This method involves several suction dredging campaigns where sediment is dug, transferred over the barrage and dumped downstream (Figure 2.3). For good reason this is not allowed in many countries. The loss of great amounts of flushing water for power production or irrigation may be even acceptable. The short-time transfer of large sediment quantities into the downstream river section however causes a massive intrusion into the river morphology and ecology.

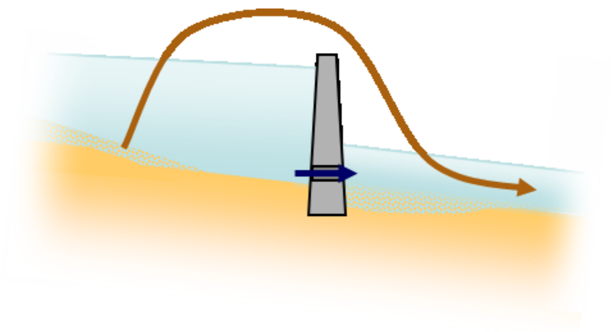

Figure 2.3 Sludge dredging and disposal downstream.

2.2 Direct impact on river morphology

When opening the base outlet the downstream riverbed is often blocked for months. In any case the morphology is changed significantly. With manual removal, the sediment is extracted permanently from the water body. This leads to increased erosion in the lower reaches and therefore also affects the river, albeit with opposite effect.

Dredging and disposal downstream usually is not compatible with river morphology due to the large amounts that need to be transferred in a short period of time. So all previously described existing methods are problematic in a morphological point of view.

2.3 Ecological aspects

Via morphological effects also ecological topics are directly concerned in all described dredging methods. In addition the emptying of the reservoir required for a manual dredging leads to a destruction of the current reservoir's fish population. With sludge dredging and direct disposal downstream the underwater benthos structure is widely destroyed within a few days. Opening the base outlet or even failing to do any maintenance on the reservoir and risking siltation ends in a profoundly long-term change of the developed ecosystems. Some coastal river deltas already face salt water infiltration into ground water reservoirs by missing fresh sediment coverage. Coastal erosion (e.g. East coast of Egypt, and to countries up North along the coast) can also be faced, when formaly sediment transport through rivers (e.g. Nile), is stopped.

2.4 Legal constraints

The above presented methods usually require permission by local or regional authorities before starting any physical activity. For permission the authorizing body will take into account appropriate guidelines as European Water Framework Directive or U.S. sediment acts. Usually the facility owner has to expect more or less extensive obligations for project execution even if permission is granted.

When digging the sediment and extracting it from the water body the contractor or plant operator usually becomes owner of the removed material. If critical ingredients are detected, the extracted sediments have to be dumped as contaminated material at enormous expense. This also applies in the case that the critical components found are of endogenous and thus natural origin (e.g. certain heavy metals).

2.5 Economic evaluation

The opening of the base outlet initially appears as a cheap solution. However, the above-mentioned constraints have to be taken into account. If opening the base outlet seems to be a suitable solution, the degree of sedimentation is already far advanced with often severe operational restrictions on reservoir management. The base problem and also the operational restrictions are not resolved by this method as are resulting financial implications. Both will continue because sediment is eroded only in the up-stream area near to the barrages outflow, not at the far end of the reservoir where most sediment is found. In addition it has to be taken care that no damage compensation liabilities are caused when discharging large quantities of sediment downstream in a short period of time.

The latter aspect also is valid for suction dredging with direct disposal into the downstream river section. For this reason, this variant in most cases is not licensable or generally unlawful.

Excavation of sediment from the reservoir usually is exorbitant expensive due to high direct construction costs, enormous disposal expenditures and long plant/reservoir downtime. For this reason, operators choose this option usually only when threatened by plant/reservoir loss.

3 INNOVATION

As a promising alternative to the previous discussed methods a new approach is paving its way. According to Water Framework Directives or Sediment Acts a barrage should not only be penetrable for water and fish, but also for sediment. The general approach is to bring the balance of sedimentation and erosion in a river back to a naturally acceptable or aspired degree to provide a sustainable and permanent solution.

3.1 Required hardware

The process is set up by devices allowing continuous and controlled transfer of sediment within the reservoir in a relatively small scale but permanent mode. Key element is an automatically working vessel with a suction dredging system installed that can be diesel or preferably electric driven (Figure 3.1). To allow for an exact positioning the vessel is directed by tractor cables. Sediments are loosened by a suction head, pumped towards the reservoir's outlet and dumped in front of the outflow elements. The vessel gradually strikes the reservoir floor until the complete surplus sediment is removed.

Figure 3.1 Sediment transfer vessel "SediMover" (automatic, electrically driven, Type 101).

The newly dumped sediments are eroded by the hydraulic discharge and therefore carried out of the reservoir, passing turbines or outlet valves (Figure 3.2). Both types of outflow elements are able to handle water flow with some degree of sediment load. The sediment transfer rate can be adapted to the outflow rate and parameters to guarantee a compatible process speed. For an environmentally sound project implementation the time span should be set to months or years, depending on local conditions. A commercially competitive project performance is still assured by a high degree of automation.

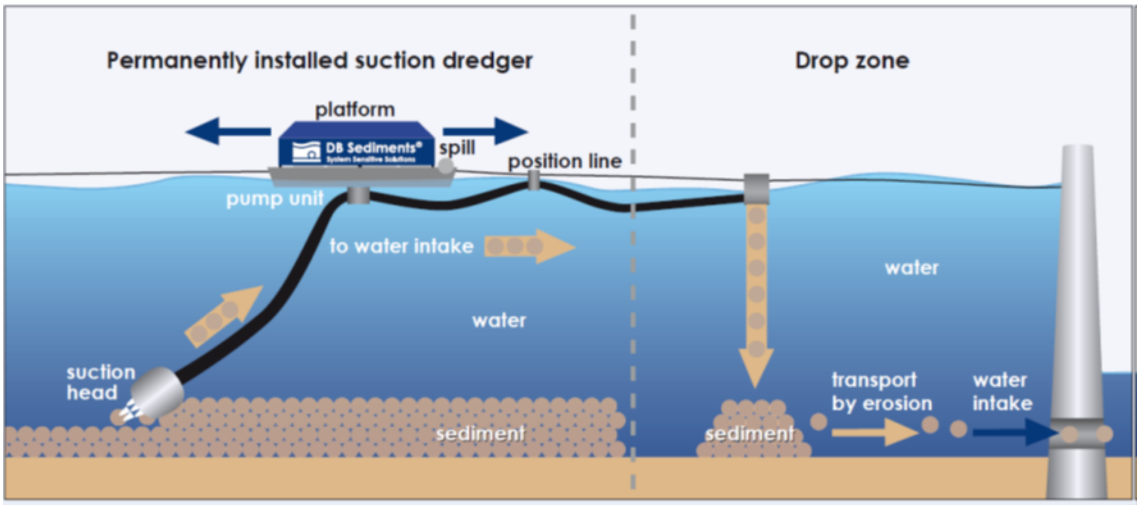

Figure 3.2 Continuous sediment transfer (ConSed-Method).

The process is also applicable in pump storage reservoirs. When starting up a new pump storage plant, the newly created upper basin does not contain any sediment. After several years of operation the owner will frequently find a substantial degree of sedimentation, often limiting the plants operational parameters and commercial benefit. By using the process described here the initial state can be restored in an environmental friendly and commercially effective way.

As mentioned above the sediment leaves the reservoir via the usual outflow organs consisting of turbines, spillways, weirs etc. Wear on the discharge elements (e.g. turbine blades) remains within normal range unless you increase sediment content to a considerably higher level. Anyway, process benefit should easily outrange slightly higher rehab costs or useful turbine blade coating.

Special care should be given to the turbines shaft main sealing. In many hydro power facilities a seal flushing with clear water already is installed. In these cases usually nothing else has to be done to prevent the seal from additional wear. At older turbines it is easy to add this feature or the operator simply accepts a slightly higher wear on the sealing.

3.2 Impact on river morphology

When attaching a dam to a natural waterway the river morphology changes considerably. By inventing the described method the natural morphology is widely restored. During the time span required for the reservoirs surplus sediment removal the concentration of solid components in the outflow will be slightly higher than long time average. Even this is a natural condition as sediment processes often are not continuous. Natural sediment layers of several meters are absolutely common and may be washed away in a single flood.

The scale of the 'removal time span' depends on sediment characteristics such as grain size / specific surface, organic constituents, salinity, cation exchange capacity, pH-Value and temperature and has to be adapted to local constraints (Schweim 2005). Assessment of these and other aspects is part of ongoing research within the Institute for Hydraulic Engineering and Water Resources Management at German Aachen University of

Technology. Project results of the ConSed project have shown the positive impact on river morphology (Schüttrumpf, Detering et. al 2012).

3.3 Ecological benefit

Before starting the permanent sediment transfer the relevant ecological aspects have to be determined for the reservoir and the downstream river. The process has a positive impact on changes in storage volume. Periodically striking the reservoir floor with the suction dredging tools however affects the benthos structure. This is similar to natural erosion. As the suction dredging never affects the overall floor at once and the process is stretched on a wide time span the reservoirs ecosystem should compensate the interference even better than natural erosion events (Figure 3.3).

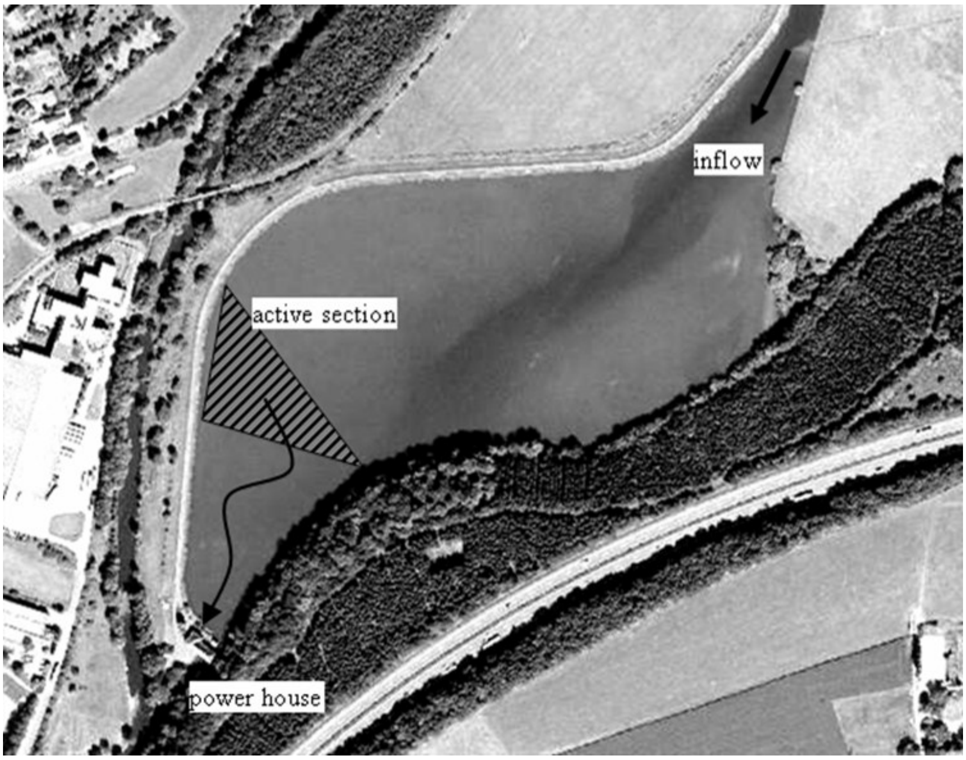

Figure 3.3 Sectional treatment of reservoir (Ehreshoven II reservoir/Germany).

At the beginning of a sediment transfer the downstream river will experience a higher than average but not unnatural sediment concentration. When transitional effects fade out the river will be set back to natural sediment equilibrium. This is the aspired ecological state where natural conditions are restored and many regulatory frameworks fulfilled.

The ecological benefit ranges far downstream, restoring the desired nutrition properties of sediment and also reestablish the flux of terrestrial sediment to the global coastal ocean.

3.4 Legal aspects

In many countries the method requires no riparian permission of local authorities because it represents a way of maintaining the hydraulic system, the active sediment transfer takes place only inside the reservoir, a natural condition is restored and the appropriate sediment acts/water directives are fulfilled. Due to these benefits the process has actively been supported by authorities so far.

In fact, the effects provided by the described process are asked for in many ecological programs. The 'European Water Framework Directive' identified Sediment deficit as a major problem and in its Annex 5 actively promotes sediment permeability for rivers in there entire length including reservoirs. In any way the operator should consult the relevant administrative bodies in advance. The same procedure is significant for patent legislation (PCT 2008).

3.5 Economic advantages

Since sediment is simply transferred back to the natural flow using an intelligent mechanism, no disposal or dump costs occur. Even the necessary technical facilities are relatively small and cost effective. The process benefit is achieved by continuous small and sustainable changes on a large timescale instead of large interventions in a short period. The cost of the necessary components is a fraction of the cost of conventional methods. Plant shutdown is limited to a few hours for equipment installation instead of months for excavation works. The former storage volume and operating range is restored within some months or few years - permanently.

For these reasons, in many applications the method is economically very attractive, even if no immediate action in terms of solving sediment problems is obligatory. Additional benefit can be gained if the above described improvement of the ecological status is financially honored as in Germanys Renewable Energies Act (EEG).

For reservoirs that are almost inoperable due to sedimentation the operator should first think of restoring the existing facility by sediment transfer instead of placing an additional new reservoir, the latter including major construction work and flooding of additional land.

4 OPERATIONAL RESTRICTIONS

The process can be applied on almost any reservoir size. Of course equipment needs to be adjusted for different dimensions. For small applications fully automated vessels are available which completely fit into a 20'-container. Large applications require sectional built vessels with manned operation. Actual equipment is able to deal with water depths up to 20 m though no real constriction consists that would restrict operational range. Tests with up to 160 m water depth have already been performed with successful results.

For most hydro stations sediment abrasion is not a topic concerning machinery, but only within the reservoir. Nevertheless hydro operators faced with heavily sediment loaded waters may fear additional wear on plant installations, especially on turbine equipment. Factors to sediment abrasion and erosion are multiple, ranging from involved materials to particle size and shape (Neopane 2010). Little is known about critical sediment loads yet while at the same time modern coatings like Wolframcarbide gives reliable surface protection if applied properly.

From a practical perspective additional wear is not a topic unless sediment ration exceeds 1,000 mg/l, Francis heads range more than 200 m or Pelton turbines are involved. Even then in most cases cost savings on reservoir operation will more than level out additional wear on turbine equipment.

5 CONCLUSIONS

With the presented method a transfer of sediment is performed in a very elegant way. Ecological permeability of dams is improved and sediment problems in reservoirs are not only eliminated, but permanently resolved. The procedure is in line with and supported by U.S. Sediment Acts, European Water Framework Directive and similar guidelines. Moreover, the process is very cost effective, so that a fast spreading can be expected – a rare and ideal combination of economical and ecological benefit. A rising number of applications will give the chance to analyze additional aspects which will be especially interesting for river sciences.

Before starting to implement the continuous sediment management process, an in-depth analysis of the state of the overall reservoir with a special focus on sedimentation issues, is a solid base for a valuable, technical, economical and ecological approach.

The described analysis is a holistic method, including the following points: Assessment of the original storage volume, by processing of the original layout of the reservoir; determination of the lost, silted or sedimented volume of the reservoir, the sedimentation and siltation rate of the dam, and the estimation of the probable dam life, under consideration of the necessary operational range of the reservoir. Furthermore, an analysis will comprise an assessment of possible consequences of sedimentation, like the blockage of the bottom outlet of the dams by sliding sediments and risk of flooding caused by the reduction of the retention volume of the reservoir.

In context of the analysis the flowing topics might need to be covered: Flood risk in the down- and upstream area, economic analysis in terms of dealing with the sediments, and possible potential re-use of the sediments. Appropriate, system-compatible method for sediment transfer (environmentally, economically, technically) will then be taking into account by regarding the individual and local conditions.

As a best practise example, the new process has already been applied to reservoirs in Germany. Large reservoir capacity had been lost due to siltation. By applying the new equipment for the Continuous Sediment Transfer the reservoir will permanently deminish the risk of siltation without lowering the water level or compromising plant operation. The projects economics and ecological benefits have already been proven in numbers by an accompanying monitoring program.

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Born in 1961, he studied mechanical engineering at the University of Duisburg, as well at the University of applied sciences Düsseldorf, Germany. Since 1996 he has been active in different engineering jobs, ranging from a job as a Commissioning Engineer for ThyssenKrupp EnCoke, to a job as an application engineer for the technical supplier Perceptron GmbH of the automobile industry. In 2009 he joined DB Sediments and is the CEO of the company.

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