Floating modular unit for controlled sediment flushing regarding sediment size and concentration

B. Mongiardino
Open Mechanics Research Ltd
Genoa
Italy

F. Binder
fmb-ingenieure.ch gmbh
Mühlegasse 18, 6340 Baar
Switzerland

G. De Cesare
EPFL ENAC PL-LCH
Station 18, CH-1015 Lausanne
Switzerland

Introduction

Sediment management is a challenging discipline, especially in regions where the storage capacity of reservoirs decreases due to sediment accumulation. This paper shows an innovative and holistic modular technical approach to the problem, considering a great variety of sediment material and taking into account the specific situation. Significantly variable size of sediment or other particles are considered from clay to large boulders or sunken driftwood. Dredging takes place from a floating unit. Excavated material is treated in an on-shore dewatering plant. Water and fine sand can be pumped to the submerged water intake, directly or passing through an intermediate-storage-pool. This controlled flushing allows controlling the solid concentration by the water discharge used for flushing, thus reducing downstream environmental and economic impacts. This method has been tested successfully in Italy, at the Champagne-1 hydropower scheme, a 10MW power plant.

1. Reservoir sedimentation

Water storage, created by the construction of dams, is essential for the sustainable prosperity and health of civilizations since it supplies drinking water for humans, provides irrigation and energy production. Moreover, reservoirs are used for recreation, navigation and they provide protection in the downstream valleys against extreme flood events and can even serve to reduce droughts.

In most cases, floods are essential events for reservoir filling with water. However, during floods events, large quantities of sediments are also transported into reservoirs. As sediments progressively settle and consolidate, reservoirs lose their storage capacity and the deposits may hinder safe operation of bottom outlets and obstruct water intakes. Reservoir sedimentation is observed in practically all reservoirs in the world (Schleiss et al. 2016).

Annually, an estimated 0.5–1 % of global storage volume is lost by sedimentation (Basson, 2009), figures that are more or less stable since the 1987 World Bank report by Mahmood (1987). Therefore, without further action, one quarter of all dams will lose their storage due to sedimentation in the next 25 to 50 years (WCD, 2000).

1.1 Origin of sediment material

The sediment yield of the watershed contributing to reservoir sedimentation must be assessed at the river basin scale with in-situ measurement or adequate theoretical models. These have to consider the relevant parameters and their relationships such as sources, pathways, transportation, deposition, erosion and local or temporal storage. The origin of sediments may be in the in the higher and middle parts of the catchment and in the reservoir itself.

The far-reach source includes production on the steep slopes of the watershed from soil erosion, rock weathering, slides and non-channelized transport through the slopes by the running water. Additionally, in high alpine catchments, the contribution of glacier retreat and permafrost disappearance has to be taken into account.

Mid-reach sediment sources include rill, gully and stream bed and bank erosion, and mobilization of temporary storage, the so-called legacy load.

1.2 Impact on the hydropower resource

In Europe or the US like elsewhere, sedimentation was addressed by providing extra reservoir capacity, dredging the sediments or replacing the lost volume by new storage reservoirs. The estimated costs were $690 million annually (Crowder 1987). The loss of storage directly influences the energy production of hydropower plants, reducing their flexibility and finally make them work merely as run-of-river plants. It impedes navigation due to shoaling, and causes unfavourable conditions for fish habitats inside the reservoir as well as downstream. Aside from storage loss, sedimentation may also cause outlet-clogging, abrasion of hydraulic machinery and downstream sediment starvation and its ecological consequences.

In the past, overdesigning the reservoir volume with a professed dead storage was considered as the option to delay the consequences of reservoir sedimentation. However, the cost of a cubic meter of stored water is constantly increasing not only due to the rising construction and environmental costs, but primarily due to the disappearing low-cost sites for new dams (Vanoni 2006).

1.3 A wide variety of solutions

There is a multitude of countermeasures to cope with reservoir sedimentation.

They all have in common that they require either high investments or an appreciable amount of water that is no longer available for energy production, thereby reducing revenues. Nevertheless, to keep hydropower facilities economical, environmentally friendly and socially acceptable over the long term, there is no alternative to finding sustainable solutions to cope with sediments.

Moreover, water protection acts in many countries today require sediment continuity to be re-established in river systems where sediments are partly or fully trapped upstream of weirs, dams or other engineering structures across a river.

Interesting solutions that have already proven to be technically feasible and environmentally favourable include the following:

- Constructing sediment bypass tunnels around reservoirs
- Venting turbidity currents
- Regularly flushing through low-level dam outlets
- Removing sediments using by mechanical means

2. A technical solution

An advanced technical solution requires that:

- the extracted sediment is reused
- hydropower plant's machinery remains protected
- the remaining fauna and flora present in the riverbed downstream the dams, resp. power plant must be preserved.

These three fundamental parameters were taken into consideration when designing the modular dredging installation presented in this paper. It was necessary to extract the sediment from the bottom of the basin, to transfer the material to be treated in-line with the extraction, either floating or on-shore. Finally valuable sediment material can be used and the very fine part can be released into the water intake for downstream transit via the turbines.

2.1 Details of the installation

In this configuration, two units operate in-line:

- the dredger that sucks sediments from the bottom of the basin with a concentration of 20% solid and 80% water.
- a dewatering-screening plant which separates the dry sediment from the liquid part that may contain very small particles which do not damage the turbines (< 0.2 mm)

This configuration partially reconstructs, only for sediments that do not damage the turbines, the natural flow of sediments retained by the dam.

At the same time, the reusable sediments are extracted dry from the basin, with a grain size greater than 0.2, mm, which means valuable building materials.

Fig. 1 shows detailed drawings of the floating modular unit.

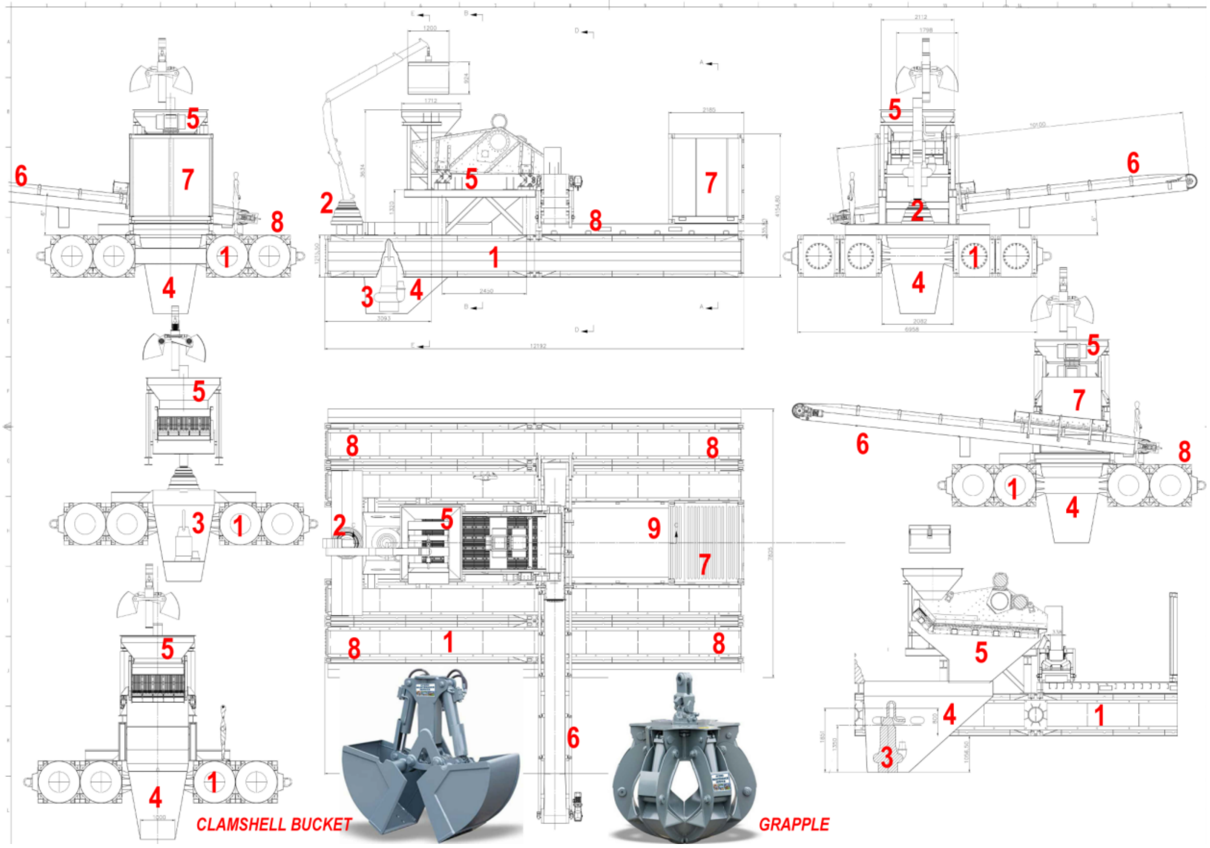


Fig. 1. Detailed drawings of the floating modular unit

1 - FLOATING UNIT - CATAMARAN: Length: 12.19 m (40 ft.) Width: m 12.19 (40 ft.) Height: 6.00 m (20 ft.), Average weight: 40 ton - draft 0.6 m - Shipping: the floaters are approved for marine shipment as ISO Containers - cabins and deck as well
2 - HYDRAULIC MARINE CRANE - Average capacity 5 ton @ 15 m
3 - ELECTRIC SUBMERGED PUMP Average capacity: 450 m³/h - 20 m working depth: Up to 65 m - Discharge Ø: 200 mm - 250 mm - Average Solid Handling: 60 mm, Power: 80 kW
4 - SUBMERGED RESERVOIR
5 - HOPPER AND SCREENING PLANT
6 - CONVEYOR BELT
7 - OPERATOR CABIN - Control panel for drive and equipment status check
8 - MANEUVERING DEVICES - 4 Electric Winches 4 ton capacity
9 - DIESEL ELECTRIC GENERATOR - 250 kVA

In Fig. 1 the selection system is present on board, this configuration is necessary to face sediment extractions with large particle size (> 40 mm), in the case of the on-site tests performed for this paper; the selection system (#5) has not been installed on board the floating unit as shown in Fig. 2, but on-shore.

The sediment present in the basin under study are very common in the Swiss, Italian, French and Austrian Alps, glacier sediments with fine grains.

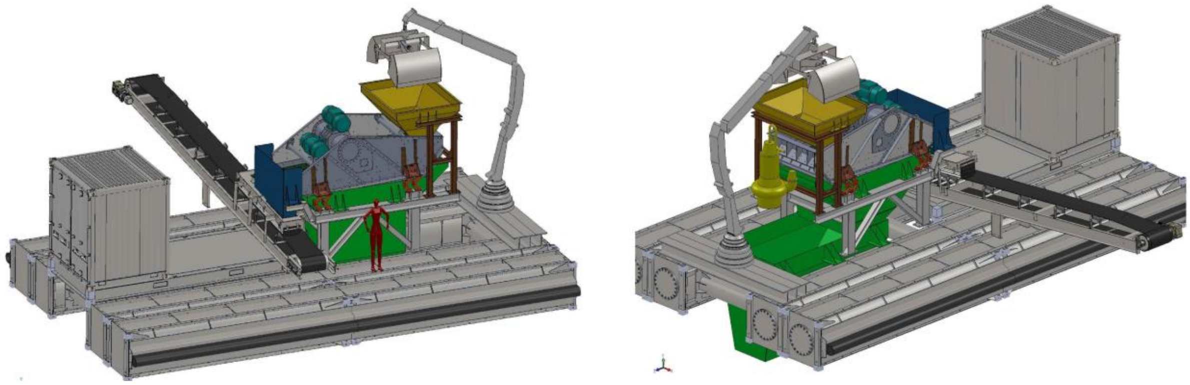


Fig. 2. Isometric views of the floating modular unit

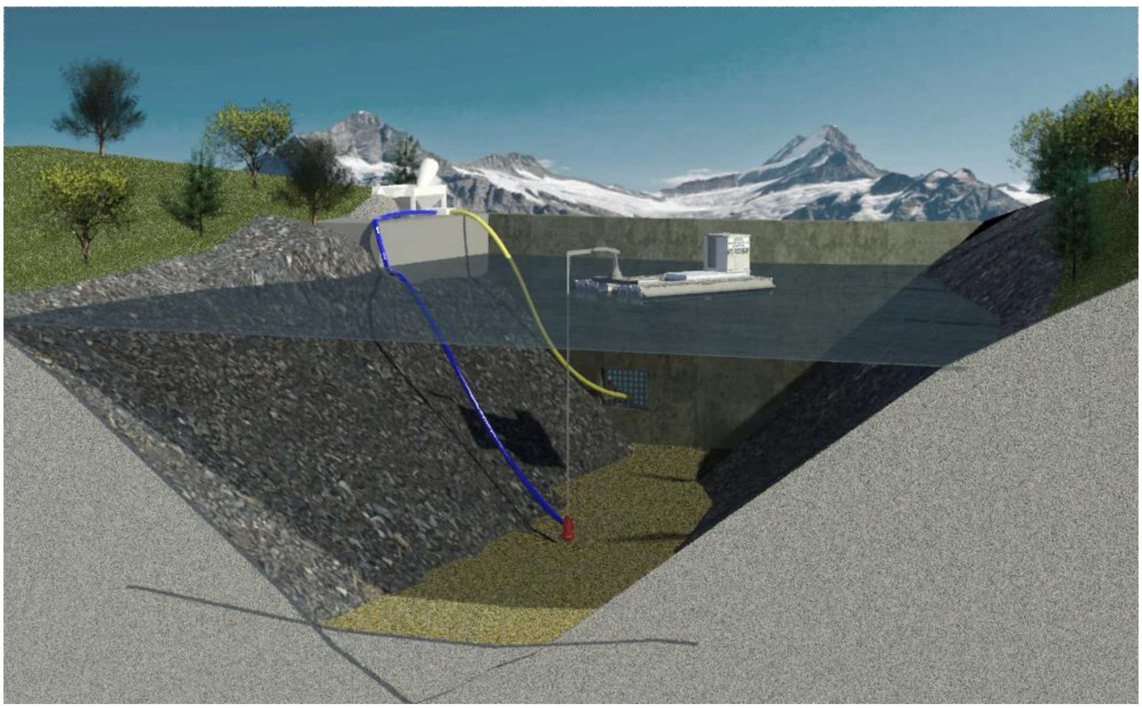


Fig. 3. Schematic drawing of the functioning principle the floating modular unit, connected to on-shore sediment treatment plant and the introduction of the fine sediments into the water intake

3. Testing of the modular unit

The modular floating unit has been mounted in the upstream accumulation basin of the Champagne 1 power station in the Italian Region Valle d'Aosta and connected to the on-shore plant that treated and selected the sediments.

The dredging and selecting plant only worked when the power plant was operating and producing energy. The operation was carried out in full coordination with the Plant Operator. The power plant functioned according to the operator's plans and Distribution network operators, without any interference with the dredging operations.

3.1 The Champagne 1 hydropower scheme

The Champagne 1 hydropower station, put into operation in 1921 is located in Villeneuve in the Italian northern region of Valle d'Aosta. The Champagne 1 plant uses the waters of the Dora de Rhêmes through two 2'250 m long penstocks that start from the Sorressamont basin. It is operated by the Compagnia Valdostana delle Acque owned by the regional administration. The Champagne 1 power station is a genuine industrial monument of the Belle Epoque, famous for its wooden roof, frescoes and artistic decoration (Fig. 4).

The Sorressamont basin collect glacial waters from the Gran Paradiso. It loses some 20% of its active storage volume due to sedimentation per year.

Fig. 4. Picture of the Champagne 1 hydropower plant (source: Compagnia Valdostana delle Acque)

3.2 The on-site installation

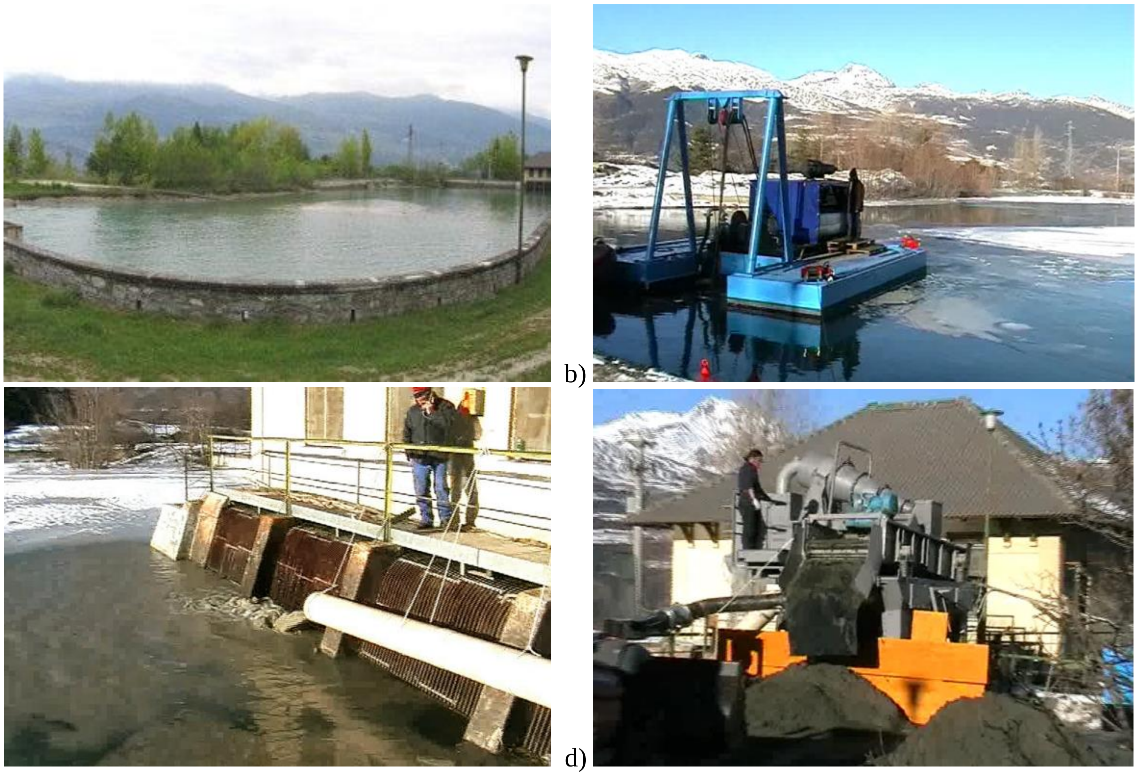
The dredger worked about 90 days to extract some 20'000 cubic meters of glacial sediment.

About 15'000 cubic metres of sand were recovered for construction purposes with grain sizes from 0.2 to 3 mm.

The working hours of the dredger were the same as those of the power plant operations, daytime hours required by the free European electricity market.

About 5'000 cubic metres of fine sediment returned to the riverbed, reconstructing the natural flow of fine sediments.

No direct damage on the turbines could be observed, the sediment concentration that was released into the water intake to pass through the pressure system was assured by the vigilance of the trained on-site operator.



a) b) c) d)

Fig. 5. a) View of the Sorressamont accumulation basin (source: ARPA Valle d'Aosta), b) installation in 2006 of the floating modular unit, c) the introduction of the fine sediments into the water intake and d) the on-shore sediment treatment plant

3.3 Experience gained through the operation

The experience of this method, which we can appropriately call controlled dredged flushing, has been positive.

The turbidity of the water downstream of the power plant is adequately controlled.

Valued sediments have been recovered as construction material in dry transportable ready-made condition, the impacts on the environment could be very limited and the turbidity parameters imposed by the authorities have been respected. The energy used for the dredging was supplied by the plant itself limiting further the environmental impact of the installation.

4. Summary and conclusion

The presented controlled flushing technique based on a floating modular unit can be used in many cases to reduce the volume loss in various storage basins, especially where local authorities impose strict limits of turbidity of the watercourse downstream of the power plant or in the basin itself, e.g. for drinking water supply.

This situation can be found merely everywhere in Europe, North America and part of South America.

Direct hydraulic flushing remains the principle type of operation for reservoir sediment control. Nonetheless based on reservoir size, accessibility of work site and environmental constrains such as the protection of fauna and flora downstream of dams or powerhouses, this innovative mechanical method can help solving the problem of reservoir sedimentation delivering as by-product highly appreciated construction material.

The presented state-of-the-art dredging system can be adopted for sediment masses up to 100'000 cubic meters; it can be a temporary installation such as presented here, or resident in the basin as an integrated installation working upon demand similar to a vacuum cleaner robot.

The integrated system comes into action at the same time as the power plant and remains active 24/24. It can now work without any operator on board, self-controlling the positioning of the dredging head, the wet and dry sediment flow as well as the turbidity of the outflow downstream to the turbine.

References

1. **Schleiss, A. J., Franca, M. J., Juez, C., and De Cesare, G.,** "Reservoir sedimentation". *Journal of Hydraulic Research*, 54(6), 595–614, 2016
2. **Basson, G. R.,** "Management of siltation in existing and new reservoirs". General Report Q. 89. Proc. of the 23rd Congress of the Int. Commission on Large Dams CIGBICOLD (vol. 2), 2009
3. **Mahmood, K.**, "Reservoir sedimentation: Impact, extent, and mitigation". Tech. Rep. No. 5. International Bank for Reconstruction and Development, Washington, DC, USA, 1987
4. **WCD,** "The report of the world commission on dams". London: World Commission on Dams/Earthscan Publications, 2000
5. **Crowder, B. M.,** "Economic costs of reservoir sedimentation: A regional approach to estimating cropland erosion damage" *Journal of soil and water conservation*, 42(3), 194–97, 1987
6. **Vanoni, V. A.,** "Sedimentation engineering", *American Society of Civil Engineers*, 2006

The Authors

Bartolomeo Mongiardino graduated in Mechanical Engineering from the University of Genoa, specializing in the design of special purpose robots and off-shore equipment. He has been involved in a large number of international Oil & Gas projects in the 90s, before approaching the sediment management engineering, patenting many innovative submarine machineries, manufacturing them and testing them on-site. He is currently founder and CEO of Open Mechanics Research Ltd.

Fernando M. Binder graduated in Civil Engineering at the ETH Zurich, specializing in the design of hydro power plants. Since his graduation, he is designing hydro power plants. The first five years he worked in a big Swiss engineering firm, bevor he started with his own firm of consulting engineers. With now twenty years of experience, he is an expert in the region of central Europe. Since over ten years, he is developing solutions for the cleaning of water intakes and bottom outlets from sediments and trees. In these circumstances, he met Bartolomeo Mongiardino and started to work with him. He is currently CEO of fmb-ingenieure.ch ltd. and co-founder of Hydro Maintenance Service Ltd.

Dr. Giovanni De Cesare graduated in Civil Engineering from the EPFL, Switzerland, in 1992. He holds a PhD in technical sciences in the field of reservoir sedimentation. He studied for one year at the Georgia Institute of Technology in Atlanta, USA. Currently, he is operational director of the Platform of Hydraulic Constructions PL-LCH of the EPFL. He has more than 25 years of experience in physical and numerical modelling in all domains of hydraulic structures and schemes.