How to win the major U.S. Competition on Sustainable Reservoir Sediment Management and Proceed

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Lead

In 2020, the two largest U.S. reservoir operators, Bureau of Reclamation (BoR) and U. S. Army Corps of Engineers (USACE) launched a public competition to develop a solution for economically tackling the sedimentation problem in reservoirs. Reservoir sedimentation is a major challenge in dam operations. It is the major threat and largest problem of reservoir operation and maintenance. In difference to hydrology, it can be significantly changed by man. And on actual hydrology, reservoir storage volume becomes significantly important.

Depending on cited source, overall storage volume decreases between 1.0 and 2.0 percent per year (Schleiss et. al. 2016). Given that most reservoirs have been built decades ago, storage loss is already significant, see example in Figure 1. The World Commission on Dams stated, that by 2050 about a quarter of all reservoirs will already be inoperable and many others facing serious storage loss (WCD 2000).

To state it clear: Sedimentation is by far the largest problem of reservoir operation and maintenance. And due to sedimentation related storage loss, the largest part of the worldwide reservoir community is so far not sustainable. In addition, when approaching the dam, sediment is causing additional load to the dam structure and, depending on the dam type, leads to dam integrity risks. Furthermore, methane emissions from reservoirs lead to GHG effects in the same large dimension as worldwide rice farming.

Overcoming these problems will regain the asset and operational value of reservoirs, secure infrastructure and investment and lead to their sustainable use. Major obstacles on this way are to identify an economic and environmentally viable technology and bring it to application.

After announcing the competition in 2020, more than 140 solving teams registered to handing in proposals for a solution. We were one of them.

Figure 1. Paonia Reservoir in northwestern Colorado with circled top of outlet structure (2014, large picture) and outlet structure (1961, small picture); source: U.S. Bureau of Reclamation

The Competition

The well-organized "Guardians of the Reservoir Challenge" was conducted in three stages which in total stretched over two years. The Aim was to reduce the number of participants stage by stage and in the end to identify a winner. In the first stage all registered teams were asked to hand in innovative concepts, addressing the given challenge. The involved jury of U.S. reservoir and sedimentation experts selected the top five teams, who made it into the second round.

The Focus of the second stage was a proof of applicability for the specific concepts. The hosts expected technical results and clear progress on the solutions. To support the solvers, technical contacts at both USACE and BoR were provided, and consultancy services offered by FedTech, which is an organization focused on strategic development support that may be relevant for several U.S. government areas.

Out of this five, a different jury of experts selected three teams to enter the third and final stage. Within this stage a pilot demonstration was expected, if possible, in real-scale dimension and under realistic operational conditions. Again, progress had been expected by each competing team. The competition was conducted during the Covid-19 pandemic, which caused significant extra effort especially during field tests. The selection of the winner was based on a major report provided, a video documentation of the field tests being shown and a presentation and interview by the final jury being conducted.

The jury then decided on the winner, which is represented by the authors.

Approach on winning

The competition guideline included outlines about the main problem and many sediment-related aspects. It was addressed to participants from within and outside the reservoir scene. By yet being deeply involved in solving sediment topics for many years, we benefitted from knowledge gathered during this time.

Given this, our aim was and is not only to win the competition, but also to turn the results into practical application at a wide operational, environmental, technical, and business range. Therefore, the equipment need to be easy to install without interrupting reservoir operation, environmentally friendly by finding a sound way for the sediment and cost efficient by autonomous operation.

Core characteristics

Our innovative idea is to regain a near-natural continuous sediment transfer, in an established reservoir, to maintain (or recover) its functionality and to restore the downstream system's morphological and ecological conditions. One or more specially designed modular sediment transfer vessels (sample Figure 2) named SediMover® will remobilize accumulated sediment from upstream of the dam and transfer this to the downstream river section through (a) dam outlets/turbines or (b) over the dam or (c) ashore for further processing (not displayed here).

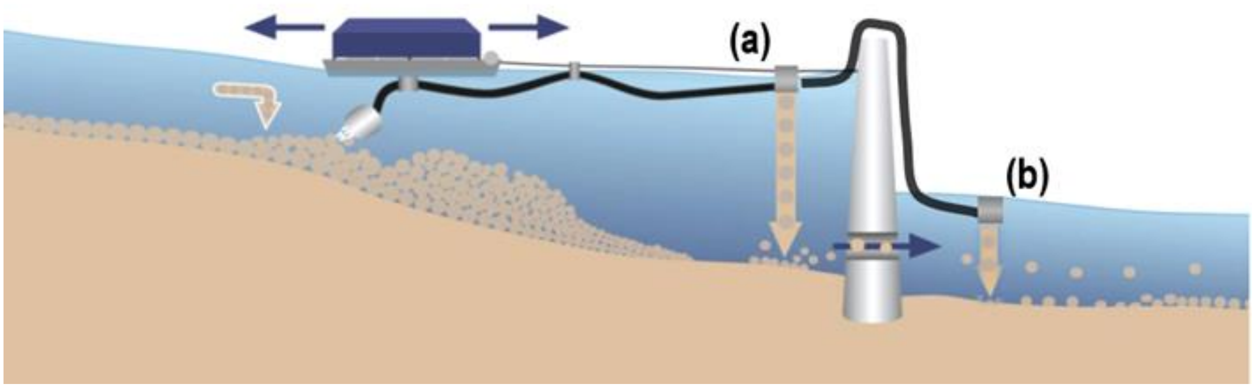

Figure 2: Principle Continuous Sediment Transfer

The continuous sediment transfer technology is an automated system allowing for 24/7 operation. It is equipped with a mass-flow meter and density meter for sediment transfer gauging and monitoring as well as GPS for positioning. The operational pattern is controlled and automatically adjusted to account for changing conditions. The equipment is of modular design, allowing adaptation to a project specific configuration for increasing the installation's efficiency. In contrast to conventional methods, this new concept considers the reservoir and retained sediments as part of a river system to restore the sediment balance. Operation is performed in conjunction with reservoir operation, hydropower generation, water extraction or recreation, without interference, including during installation. The vessel moves over a predefined reservoir area.

Positioning is done by a winch system (Figure 3). Usually, the vessel and its equipment are electrically powered with a cable power supply connection at the reservoir bank. The anchor points of the positioning cables are generally located at the shoreline but can also be created within the reservoir in case part of the reservoir area needs to be clear for naval traffic/boating or to overcome great reservoir width.

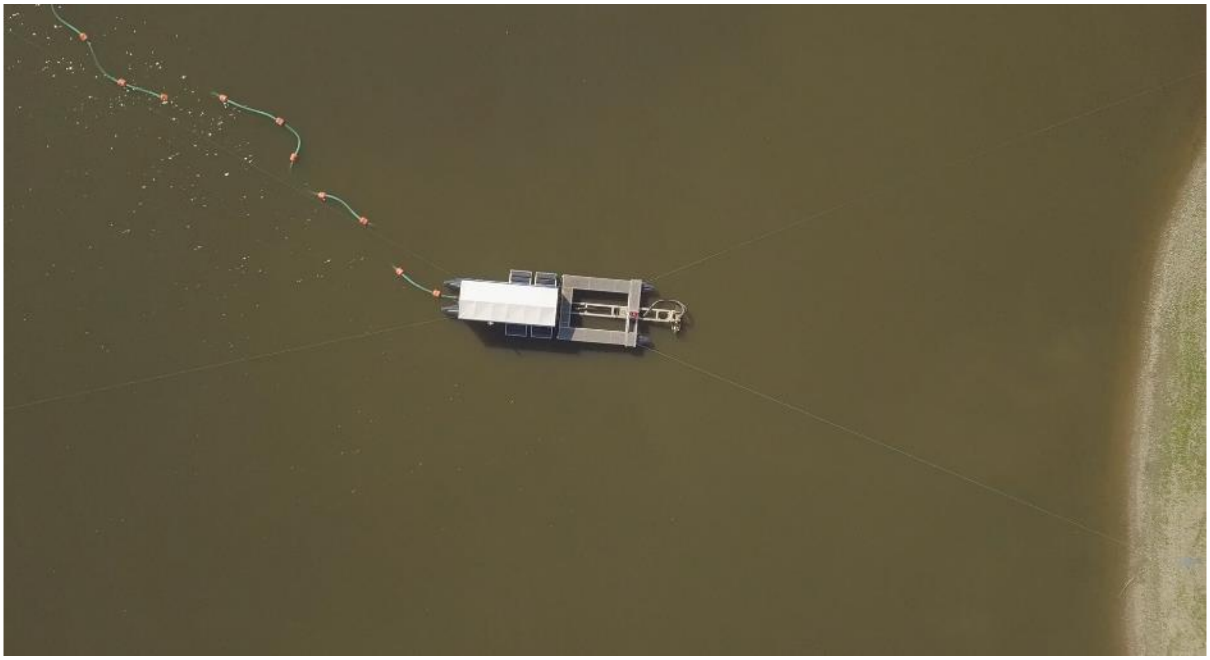

Figure 3: SediMover with visible cable connections to anchor points

Transferrable maximum particle size can be selected with an actual maximum of 100mm / 4in, depending on suction equipment and pump type. Smaller particle limits can be applied, leaving larger particles on the reservoir floor, or separating these from/within the ongoing transfer line. This is important in case of optional turbine passage, where we recommend not to exceed 40mm / 1.5in. The maximum transferable grain size is also adaptable to the type of turbine. Kaplan turbines are relatively resistant to abrasion compared to Pelton turbines, for example. However, smaller particle limits such as 3mm (1/8in) can also be applied if required. Since large particles usually comprise less than 1-2 % of all sediments and are usually found in the upstream inflow zone of the reservoir, this fraction of sediment may be excavated and placed downstream with conventional construction equipment.

The choice of the recommended suction head, which are now available, depends on the particle size distribution, sediment compactness, water depth and presence of debris. We developed mechanical sediment removal units, high-pressure jets, or a combination of both. A hydraulic driven screw cutter head breaks up the sediment mechanically. The rotating screw transfers the sediment to the centered suction hose. Alternatively, a high-pressure water-jet suction head can be used for concentrated sediment remobilization of heavy cohesive sediment from relatively sensitive locations. Furthermore, a combination of the two systems is possible by adding the jet system to a screw cutter. The system allows changes in water level of ± 15 - 75 feet within 1 hour, depending on the type of suction head.

Unlike conventional dredging equipment, the suction devices do not focus on always gaining a smooth basin floor as required e.g., in harbor basins. Instead, emphasis is given on robust operation in sediment containing a certain degree of obstacles (debris, stones etc.) without stopping the operation and to optimize fully automated sediment mass transfer.

Standard transfer distance capacity for vessel pumps is around 1-2 miles, depending on selected type. However, booster pumps which can be land based or on floating platforms can be used for range extension or capacity increase. Transfer length and pump head are only limited by economic constraints, not from a physical perspective. In practice, overcoming a 50ft high dam has already been conducted during our testing; also overcoming a 200ft high dam (from actual water level) is no problem from a hydraulic standpoint.

We have not faced any major equipment failure yet, however the sediment transfer ratio will be reduced for very hard sediment. Other issues are river flood events where the equipment needs to be secured to shore for equipment security reasons, requiring a proper reaction time. We have handled this previously by integrating local contractors with short response times.

By selecting appropriate equipment and sufficient units, continuous sediment transfer is scalable to any dimension to accommodate the required size of the project. The modular design of the equipment and the fully controlled and adjustable operation process allows for applicability to virtually any kind of reservoir.

As shown in the demonstration during phase 3, the equipment installation is fast and usually does not require any interruption of reservoir use, power production and does not conflict with recreational use or navigation.

The transferred sediment quantity and other parameters are documented in terms of transferred solids and overall medium (see Figure 4).

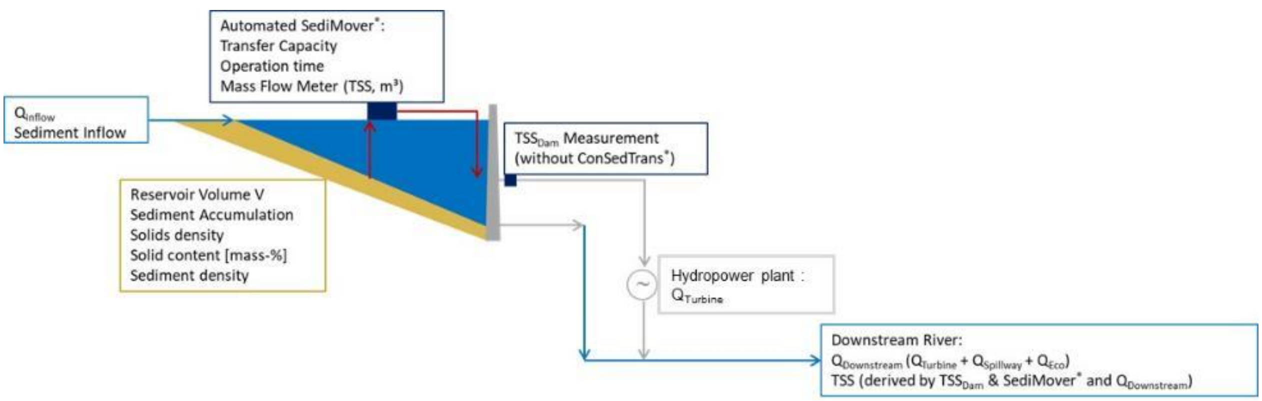

Figure 4: Continuous sediment transfer solution process overview and parameter measured

Development and Field Tests

Unlike other competing teams, at the start of the challenge we were already ahead of model-scale or laboratory tests. Instead, we directly headed towards real scale pilot applications. During phase 2 of the competition, we had already successfully completed two pilot projects (*Figure 5, Figure 6*). The two projects showed different de-sedimentation requirements and reservoir characteristics, making it necessary to modify equipment and operational modes. This gave us the opportunity to regain a lot of experience in project implementation and operation in varying conditions. Between the projects, we integrated some improvements on first pilot project experience. Within the latest demonstration projects, more than 25,000 m³ / 33,000 yd³ of sediment accumulation could be removed by transferring the sediment into the downstream river section in a near natural way, successfully meeting project requirements and operators' needs. By proving the functionality in operational scenarios, we rated our sediment transfer system improving its technology status from TRL 8[1].

Figure 5: SediMover field test in 1st reservoir

Figure 6: SediMover field test in 2nd reservoir

With already 25,000 tons (solid mass) of sediment successfully being transferred by the SediMover in two consecutive test projects during phase 2, in actual phase 3, we concentrated on:

- Installation work improvements,
- Technology demonstration and
- Video documentation.

With a staff of six (four craftsmen and two engineers), the overall site installation including unloading, earth anchor placement, pipe/hose and cable connections, power supplies, hose floater mounting, data access and system start up took less than six hours (Figure 7). First sediment was transferred on the same day.

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[1] Technology Readiness Level according to NASA definitions to rate the maturity of technical developments from 1 to 9.

Figure 7 (a-f): a) unloading the SediMover; b) installation works; c) SediMover afloat and ready; d) start of system; e) initial outflow after less than 6 hours from start of installation; f) no abrasion on piping even after 25,000 tons of solid transfer (i.e., identical pipe material as from phase 2)

We did not use a sound meter during demonstration, but as with the earlier pilot projects, in a natural environment the SediMover' s noise emissions were not detectable anymore from more than 90' (30 m) distance, even under full load.

The video documentation of our demonstration application is available here [2].

Findings and technical improvements

Most notably during the first pilot application, we encountered significant operational challenges (see *Figure 8*):

- frequent floods with strong currents

[2] see https://youtu.be/5nqG4qT6e1w or for download https://1drv.ms/v/s!AjsYWiUpEgRegoIW0aJhKuqFMVtlbA?e=ecmcWg

- frequent reservoir and SediMover dry fall (reservoir being emptied for flood protection without prior information)
- very shallow sections
- debris (car parts, branches, machinery, carpets, …)
- plant growth
- power limits due to a poor local electric grid
- difficult reservoir access (truck access only via a quarry)
- transfer line needed to be longer than planned, requiring a booster pump to achieve planned capacity
- remote site/long travel
- and not to forget: Covid-19, with strict lockdowns and travel restrictions

We are proud to say that despite all these additional challenges, we were still able to successfully complete the first pilot application, though with less sediment transfer than intended.

Figure 8: a) SediMover in dry fallen reservoir; b) SediMover in shallow water among strong underwater plant growth

During the competition prototype and field tests, we made several improvements on the SediMover. We also further improved ease of installation and maintenance friendliness. But generally, the developed concept and technology proved to be adequate.

Accompanying Work

Developing guidelines

One thing is to develop an applicable technology for sediment management. But this should be accompanied by an according framework and other aspects, to allow easy implementation and handling by operators and authorities. In many countries, including the U.S., no guidelines existed for environmental compliance and technical dimensioning of sediment transfer from reservoirs.

Given our prior involvement in sediment solutions, we were asked to contribute to the development of several guidelines on sediment management. In cooperation with authorities and environmental agencies two major guidelines were developed. DWA M-513-1 deals with general sediment criteria including allowable contamination. DWA M-513-3 concentrates on application at reservoirs and on sediment yield, including a near-nature sediment transfer and its operational design. Since sediment features and hydraulic aspects do not generally differ around the world, the developed recommendations may also be of help in other regions.

We also provided input to ICOLD's Technical Committee on Sedimentation, who is actually publishing an according guideline.

Sediment cleaning

Since the developed technology can generally be combined with conventional equipment or new inventions, we also started to develop additional technical options. One problem at water bodies around or downstream of industrial sites, harbors, marinas or shipyards is contaminated sediment, which can cause environmental harm. Sediment treatment usually is extremely costly. Therefore, we are developing a cost-efficient sediment cleaning process for specific contaminants. Analytics showed that we are able to improve the ecotoxic load[3] in the sediment from aquatic ecotoxic level VI ("very high toxic contamination" to ecotoxic-levels I and II ("uncritical contamination"), which then allows for transfer or other use of the cleaned sediment. The continuous sediment transfer is especially beneficial for this cleaning process, since it allows not a batch-supply as in conventional dredging, but a smooth feed of sediment, good process stability and equipment efficiency.

Tackling GHG Emissions

As mentioned in the lead, methane emissions from reservoirs are one of the major worldwide greenhouse gas emissions, being generated within the sediment. Methane and other climate relevant gasses are produced in anoxic reservoir sediment accumulation during biological degradation processes. During sediment movement, as in dredging processes, high amounts of stored gas can be released with a 80x higher green-house potential than CO_2 (referred to 20 years, IPCC 2014[4]). Aquatic ecosystems are assumed to contribute to up to 53% of the global methane emissions including reservoirs with about 6% (Rosentreter et al 2021[5]).

We have developed a technology for "harvesting" methane during sediment transfer. This does not only eliminate the GHG effect of the collected methane, but even allows its energetic use, since methane ratios in the collected gas were between 55 and 90 %. We were successfully able to operate conventional mobile power generators on "sediment gas" only.

During the competition, our patent application was successfully turned into a valid patent, issued now by the U.S. Patent Office as Patent No. US 11 041 280. Additional applications included methane harvesting are pending.

Additional Vessel Series

Besides improving our already existing system, during phase 2 we established a supplementary, simplified sediment transfer vessel (Figure 9). This smaller, lighter, and cost-effective vessel (MiniMover) is suitable for areas with limited space and shallow water bodies like forebays,

[3] see „OECD Guidelines for the Testing of Chemicals, Section 2 - Effects on Biotic Systems"

[4] IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R. K. PACHAURI, L. A. MEYER]. IPCC, Geneve, Swiss

[5] ROSENTRETER, J. A. et al 2021: Half of global methane emissions come from highly variable aquatic ecosystem sources. Nature Geoscience, Vol 14, p. 225-230

ponds and inflow or bank-side reservoir ranges. The MiniMover has an approximate length of only 15ft, a height of 6 feet (submerged 5 feet) and a width of 9.5 feet. This makes transportation and installation fast and easy.

Figure 9: MiniMover – left: under construction; right: during field test & operation

Like the initial technology line, it is composed of a modular system, which can be adapted to different requirements. Further developments and improvements of the MiniMover (like an appropriate graphical user interface) are still in progress, but the general system is already successfully in operation in a drinking reservoir forebay in Germany (Figure 9, right). In this installation, the MiniMover overcomes a transfer length of more than 0.7 miles towards the downstream river section without an additional booster pump. The measuring data of a downstream-installed turbidity sensor is integrated into the automated control system, allowing for a controlled and balanced sediment transfer to the river.

Perspective on Application, Environment, and Business Potential

Our aim from the beginning was not limited to the competition, but to head for a broad and scalable application of developed technologies. The practical need for application is evident. Reservoir operators and government will need to invest significant sums in the coming years to ensure water provision in several U.S. regions.

From a commercial standpoint, this again will provide a suitable business perspective for a profound application of the developed and patent protected technologies with significant business volume. The achieved automation will ensure that our technology is able to undercut any conventional reservoir dredging application cost, thus saving cost to reservoir operators. Nevertheless, the new technology is combinable with conventional dredging and other equipment. Following the pilot application within the challenge, we already have 3 major commercial projects in preparation in Germany.

To allow for a proper start of solving the sedimentation problems in the U.S., we prefer to partner with a suitable domestic company, also allowing equipment production and service within the United States.

The sound application of autonomous dredging will not only ensure a cost-efficient rehabilitation of reservoirs and ensure their future operation, but also re-establish sediment continuity in

American rivers in a near-nature way. The benefit will not be restricted to the immediate downstream river sections, but leads far downstream to estuaries and coastal regions, preventing further erosion damage. By this, environmental benefit is achieved without extra cost.

References

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