BENEFICIAL REUSE OF DREDGED RESERVOIR FINE SEDIMENTS

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As described in previous issues of Hydrolink on reservoir sedimentation[1, 2], the loss of storage capacity in hydropower reservoirs reduces flexibility in generation, because the hydropower facilities become dependent on seasonal flows that might not occur when energy is needed. In addition, the maintenance cost increases as the fine sediment-laden flows passing hydropower turbines may be highly abrasive. Therefore, reservoir sediments must be managed and preventative/mitigating measures must be taken to preserve the hydropower generation and facilities, while respecting the environment and complying with sediment relevant legislation.

In some cases, the feasibility of usual strategies, such as sediment flushing, sluicing and mechanical removal (*i.e.* dredging, dry excavation, hydrosuction), may not be possible for the evacuation of sediments from the reservoir and their transfer to the downstream waterways. Instead, the operators of the dam have to dredge (or excavate under dry conditions) sediments from the reservoir and dispose of the material in neighboring lands. Land application (*i.e.* land management) of the dredged sediments is possible when the chemistry of the sediments has no potential impact on aquatic life and plants within the land.

The growing difficulty in locating new disposal areas and the associated escalating costs call for innovative sustainable management of the dredged reservoir sediments. In the current European legislative framework, sediments, once removed from the reservoir and disposed on upland, are considered as waste[3]. In some cases coarse material may be reused as construction fill or for similar purposes, but reservoir sediments may consist of large volumes of fines (silt and clay) potentially contaminated.

Although fine material can be a liability, it can be viewed as an asset also (*i.e.* “waste to resource” concept). Fine material can be a valuable potential alternative resource to be integrated into a circular economy, innovatively reused on its own in place of a usable commercial product or blended, amended or incorporated into a manufactured product (Figure 1). Examples of beneficial reuses include habitat development (*e.g.* building and maintain of productive plant and animal habitat), agriculture, landscape restoration at abandoned strip mines, highway borders, construction (*e.g.* brick making, ceramics, glass tiles, lightweight aggregate), provided that the properties of the fine sediments are adequate and will not harm the environment and public health.

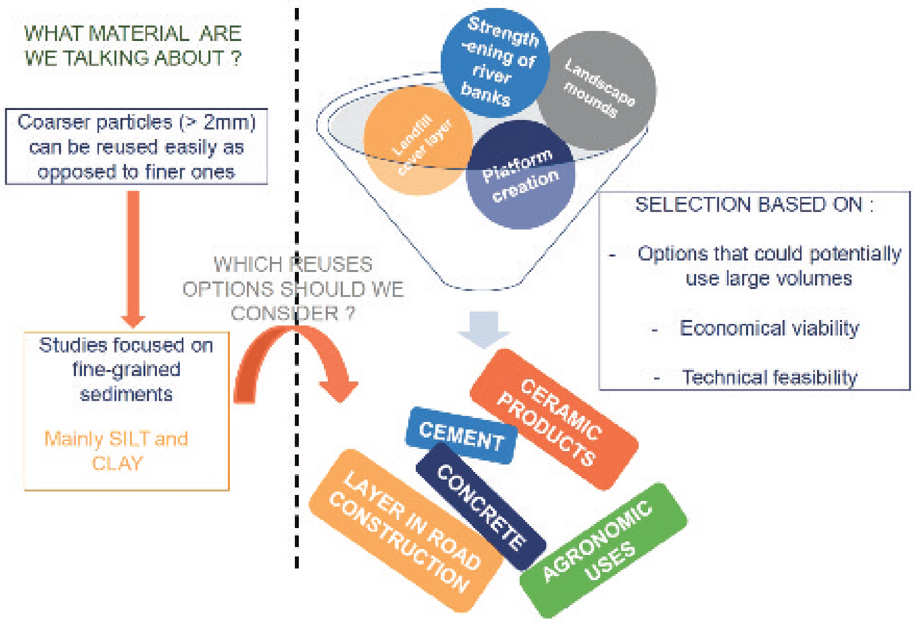

Figure 1. Illustration of potential reuses of dredged fine material disposed on landfill[4]

In this context, and as part of its hydroelectric production activities Electricité de France (EDF: www.edf.com) has set up a project over seven years to find innovative solutions for beneficial reuse of dredged reservoir fine sediments. The work undertaken within the project combine two aspects:
– investigation of the valuable part of sediments (*i.e.* mineralogical and agronomic) and their suitability for industrial reuse, and
– quantification of the chemical and organic properties of contaminants within the material to ensure the safety of the industrial reuse options.

Investigation of the valuable part of dredged sediments

The first work package of the project has addressed the technical conditions required for a beneficial reuse of dredged fine sediments. The generic requirements usually employed for traditional raw materials, likely to be replaced by the dredged fine material, were used. A wide range of mineralogical (*e.g.* grain size analysis, water content, organic matter content, Atterberg limits or methylene blue value, carbonate content, quantitative analysis of the elementary composition, thermal analysis) and agronomic (*e.g.* apparent density, N, P, K, Ca, Mg, organic matter content, pH) properties were reviewed[5]. A protocol for a minimal mineralogical and agronomic characterization of the dredged sediments was proposed to assess material suitability for beneficial reuse in the following pre-selected industrial ends[4]:
– Roadway bed material;
– Ceramic material (*e.g.* bricks, tils);
– Concrete or mortar;
– Portland cement clinker;
– Agricultural soil amendment (*e.g.* structure, texture, thickness);
– Soil construction;
– Filling of abandoned strip mines.

The above seven reuse options were chosen taking into account the following aspects: minimization of the volume of fine sediments to be disposed, while maximizing potential reuse;

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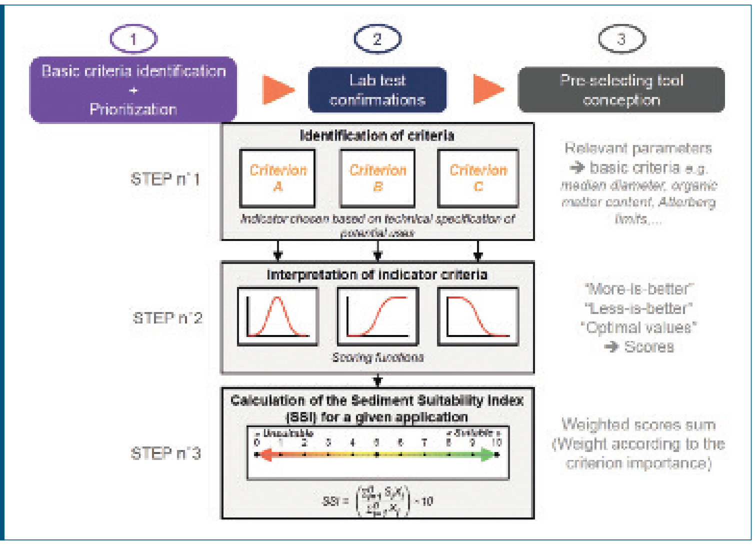
Figure 2. Decision-making tool for potential reuse of dredged reservoir fine sediments[6]



ability to valorize large volumes of fines; implementation should be achieved at low cost; proximity of hydroelectric plants and dams; and respect of legislation and environmental policy[4].

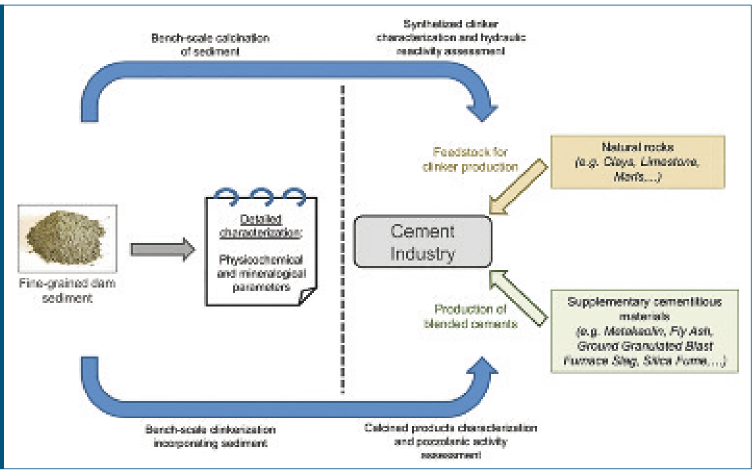
Anger[5] proposed a decision-making tool for pre-screening the dredged sediments toward potential reuse among the seven options (Figure 2). For each industrial reuse, key input parameters were identified; for example particle size distribution, organic matter content and Atterberg limits for roadway bed material reuse. The tool systematically accounts for the territorial eligibility through a geographical inventory of industries close to the areas where the dredged material is disposed of. Two beneficial reuses qualified as the most realistic ones were retained by EDF for further investigation, namely cement clinker production and fertile land production for urban soil construction or ecological remediation.

Research work has been conducted by Faure[7] on the reuse of dredged reservoir sediments as alternative raw materials in the industry of hydraulic binders (Figure 3). Two reuse options were considered for the fine sediments: on one hand, as raw material for clinker production, and on the other hand as Pozzolanic additional constituent of Portland-composite cement[8]. The reuse of sediments as raw meal in the clinker production, instead of the clay fraction, was studied in the laboratory with fine sediments being sampled by EDF in various hydropower reservoirs. Clinkers maximizing the fine-grained sediment content, between 25 and 35 % (depending on the sediments), were synthetized. These clinkers showed some microstructural features that can be corrected by adding clay as a third compound. *In fine*, it was found that most fine sediments can replace part (10 to 15%) of the usual raw materials and that the clinker characteristics can be anticipated and adjusted for cement manufacturing. For instance, a CEM I 52.5 N cement was obtained by incorporating 11.4 % of fine sediments into the raw meal.

Concerning the valorization of fine sediments as Pozzolanic additional constituent of Portland-Composite, a survey of the physical and mineralogical properties of the dredged sediments according to the calcination temperature was conducted. In parallel, the Pozzolanic reactivity was assessed with both chemical and physical tests, with a partial substitution of Portland cement by calcined sediments in cement pastes, in order to determine an optimum calcination temperature. The Kaolinite content of approximately 10% for some of the studied samples led to a moderate to high Pozzolanic reactivity, which can be comparable to fly ash. However, for all the sediments containing calcite and only illite and chlorite clays, activation was found low or null.

Fourvel[9] conducted research on the suitability of dredged sediments for beneficial reuse in the construction of functional urban soils, such as green space and landscaping. Based on laboratory tests using fine sediments sampled from different hydropower reservoirs in France, he found that the agronomic quality of sediments was contrasted and directly related to the initial physicochemical properties of sediments[10]. A typology of sediments suitable for soil construction has been proposed, based on the intrinsic properties of the sediments combined with the envisaged utilization of the soil.

Figure 3. Reuse of fine sediments as alternative raw materials in the industry of hydraulic binders[8]



Environmental characteristics of sediments and industrial reuse options

In the second package of the project, the environmental constraints have been analyzed to determine whether a specific beneficial reuse of dredged material is possible without adverse impacts to the environment and public health. The French National Institute for Industrial Environment and Risks (INERIS) database of pollutants and corresponding concentrations in fine sediments (10,000 samples[11]) was compared to the database of EDF (500 samples from hydropower reservoirs).

The environmental characteristics used are:

- the total content of contaminants (*i.e.* trace metals, organic contaminants and emerging contaminants), and
- the leaching behavior of the constituents of the material to determine whether the material exhibits the characteristics of hazardous wastes according to the Decree of October 28th 2010.

For each of the seven reuse options, the environmental requirements for potential reuse of the dredged material are related to both the regulatory and technical aspects. However, the technical requirements are not always available. To fill this gap, stakeholders were contacted and the characteristics of materials usually incorporated into manufactured products were used.

A cross-analysis of the environmental characteristics and specific requirements was performed. This cross-analysis made it possible to estimate the proportion of potentially recoverable sediments for each of the seven end uses and to identify the most blocking chemical elements. Finally, it was found that based on both the EDF database and INERIS database, the sediments are mostly inert and not contaminated according to the criteria required by the seven envisaged reuse options.

Conclusions and perspectives

The EDF Group supports the use of reservoir dredged material as a valuable resource and works to prioritize beneficial reuse options over traditional dredged material placement methods. Past and current studies have shown that the mineral and agronomic characteristics of fine sediments meet the entry criteria for beneficial reuse in the industrial and agronomic sectors. From a technical point of view, the dredged fine sediments can be considered as raw materials. However, further work must be performed to optimize the economic conditions to actually implement the reuse practices. This includes the drying process of sediments, the regulatory conditions so that sediments are no longer considered as waste, and the economic conditions for beneficial reuse near the source of the dredged material. ■

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