PhD Thesis LNHE EDF R&D – LHSV

Measuring and modeling sand transport in high-energy rivers: application in the bypass reaches of the Aude river

Duration: 36 months starting from the second half of 2025

Context

Globally, sand consumption exceeds that of any other solid natural resource (approximately 50 billion tons/year). Sediment deficits caused by sand extraction activities in rivers are considered one of the main factors responsible for coastal erosion. In France, sand extraction in riverbeds is now prohibited, but sand stocks are slow to renew due to the complexity of hydrosystems and significant land use changes over the past century.

Additionally, sand is common in reservoirs upstream of dams, and its accumulation can pose challenges for ensuring safety (not increasing flood risk), performance (useful volume), and the proper functioning of hydraulic structures (safety and maneuverability of dam gates). Sediment flushing, which involves lowering the water level to erode sediments retained by a dam, is effective, less costly than mechanical dredging and enables sediment continuity but must be carefully managed to minimize environmental impacts (in terms of frequency, intensity, duration, and seasonality/timing).

In this context, a study is being conducted to understand the mechanisms of sand transport in the bypass reaches (BR) of the Aude River, characterized by a step-pool morphology conducting to local trapping and complex regulation of sand transport. Given the influence of climate change on river hydrology, it is necessary to adapt sediment management practices and address the following questions: for which discharges does sand start to move? When are the sand fluxes most intense? How fast does sand propagate? How does it redeposit after a flood?

Observations are essential to understand the main drivers of sediment transport in this river and its tributaries. BACI (Before-After-Control-Impact) monitoring has proven effective, particularly with the use of fluorescent sands for pre- or post-event diagnostics. However, continuous monitoring of fluxes is needed to objectively assess the spatial and temporal variability of sands in the Aude river. Current measurement methods are limited, and there are significant challenges in their development. Using effective and innovative metrology, sand flux modeling would allow for i) quantifying their transfer in the BR of the Aude river, and ii) testing hydro-sedimentary scenarios, e.g., according to different management modalities and considering climate projections. Modeling tools must be adapted and validated in this context.

Figure 1 : Gesse water intake (GU Aude amont, 2020). After the flood of January 2020, sand deposits are present in the reservoir and in the river.

Scientific Challenges

In the upstream BR of the Aude river, sand represents a potentially mobilizable material under all hydraulic conditions. Sand transport in such rivers can occur both by bedload and suspension. The distribution between these two transport modes depends on flow conditions that vary in space and time. This spatio-temporal dynamic must be considered in measurement and modeling tools. This is key to establishing relevant and effective sediment management at the hydroelectric concession scale.

Field data form the basis of this thesis. While sand flux metrology has advanced in large rivers, few developments concern mountain rivers similar to the upstream Aude river. Technically, sand flux metrology in well-mixed sections (high turbulence) is operational. However, at low flows, sand transport becomes graded in the section. Currently, there is no operational measurement tool capable of distinguishing between suspension and bedload. A multi-sensor approach seems essential. While suspended flux could be addressed with a classic approach, tests/developments of sensors are planned for bedload flux.

A good understanding of sand fluxes will enable the development of modeling tools. EDF has various tools for hydro-sedimentary modeling (Telemac-Mascaret system or Saturne/Neptune codes). Their maturity level for modeling the continuum of sand transport varies. The doctoral student will rely on the latest code developments to build numerical models. The goal is to utilize available tools. A comprehensive strategy for modeling, considering the deployment of complementary tools, is expected.

This work will contribute to improving the robustness of hydro-sedimentary calculation codes. At the end of the thesis, metrological developments, modeling feedback, and recommendations can be applied locally and to other rivers with similar characteristics.

Objectives and structure of the phD Thesis

This thesis aims to answer two questions:

1. What is the spatio-temporal dynamics of sands in the BR of the Aude river, and how can it be measured?
2. How can these dynamics be predicted using modeling?

The thesis will:

- Understand and model sand propagation in the TCC (scientific objectives);
- Propose management strategies for flushing to minimize environmental impacts (operational objectives).

The approach involves iterative steps between in-situ observations, laboratory experiments, and the improvement of existing numerical tools. The thesis is structured into three axes:

1. Testing under-development techniques for continuous sand measurement (R&D LNHE & DTG):
   - Quantifying uncertainty of low-cost sensors like impact plates;
   - Sand flux measurement through sampling and imaging;
   - Estimating sand flux using acoustic technology.
2. Utilizing a sand flux measurement network in the upstream Aude river:
   - Acquiring robust event-scale data;
   - Continuous monitoring between events.
3. Numerical modeling based on physical principles:
   - Defining a modeling strategy with potential complementary models at different spatial and temporal scales;
   - Building a numerical model of the BR;
   - Integrating sand flux measurements, calibration, and validation of the models;
   - Using the models to improve sand management in the BR.

The results will be compiled into a thesis manuscript and two articles in international journals. The work will be presented at conferences and information meetings with local stakeholders.

Supervision and collaborations

The thesis will be conducted at LNHE (National Laboratory of Hydraulics and Environment, EDF R&D) and LHSV (Saint Venant Hydraulics Laboratory) in Chatou. It will be supervised by Magali Jodeau and Guillaume Brousse (EDF - R&D – LNHE - LHSV), and Oldrich Navratil (UMR 5600 Environment City Society – University of Lyon 2 - MCF).
The thesis scholarship is funded by EDF and ANRT (CIFRE scholarship). An annual thesis committee will include scientific experts and may include local operational representatives.
This thesis is part of a research project that includes a second thesis starting in 2025. The project is led by CIH (EDF Hydraulic Engineering Center). The second thesis is led by VEODIS 3D and Hervé Piegay, focusing on characterizing sand fluxes at the watershed scale of the Aude.

Localisations:

- The doctoral student's office will be based at LNHE in Chatou (78);
- Metrological developments will be carried out in the LNHE experimental halls in Chatou (78);
- Frequent and regular field missions on the Aude will be organized for network maintenance;
- Missions may be organized in Lyon to interact with the entire working group.

The work will involve interactions with:

- EDF-CIH (Hydraulic Engineering Center);
- EDF-DTG (General Technical Division);
- EDF HYDRO (Aude Amont Plant Group);
- VEODIS 3D: Stéphane Petit & Nils Dumarski;
- EVS Laboratory (UMR 5600 Environment City Society – University of Lyon 2): Hervé Piégay.

Applicant profile

The candidate for this project should have at least basic knowledge in the following disciplines:

- Knowledge of hydro-sedimentary processes;
- Experience and motivation for hydro-sedimentary numerical modeling, previous use of codes would be appreciated;
- Experience and motivation for physical modeling;
- Experience and motivation for field metrology;
- Proficiency in programming languages such as Fortran, Python;
- Dynamic, organized, and capable of managing multiple data sets;
- Enjoys teamwork and mountain fieldwork.

Applications

Applications should be sent to magali.jodeau@edf.fr and guillaume.brousse@edf.fr. The application should include:

- CV;
- Motivation letter specific to the topic;
- Links to study reports and recent articles;
- Two recommendation contacts..