ARRA²

# METROLOGY OF SEDIMENT TRANSPORT BY ACOUSTIC AND SEISMIC MEASUREMENT

## Case study experience

APRIL 17, 2025

IN SAINT-MARTIN-D'HÈRES (38)

VISIT PROPOSED BY:


Claire GODAYER, SYMBHI
Frédéric LAVAL, Ginger BURGEAP
Jules LE GUERN, University of Tours
Mohamad NASR, Ginger BURGEAP


INRAE · EDF · université de TOURS · GINGER BURGEAP

## REPORT

### CASE STUDIES EXPERIENCE FROM THE ARRA² ?

These meetings are intended to facilitate the exchange of experiences and the sharing of knowledge between professionals in the aquatic and water sectors. The ARRA² offers local authorities the opportunity to promote their actions by offering field visits (achievements, construction sites, projects) or meetings to other members of the network. The aim is to disseminate best practices and ex change ideas with peers on local pro jects.

Come and discover case studies on our website!

If you would also like to offer a field visit or meeting to network members, please do not hesitate to contact us at arraa@arraa.org

River sediment transport flows are a major challenge for managers and users of piedmont and plain rivers. Their importance is growing with the gradual restoration of sediment continuity and the hydrological effects of climate change, impacting the management of structures, risk management, and natural aquatic environments.

The study of bedload transport flows is based mainly on topographic and bathymetric data, which provide good snapshots of the state of the river at specific points in time, but which are often spaced out over time and incorporate several morphogenic flood phenomena. Quantification of bedload dynamics has progressed in recent years with the use of various techniques. One of the most widely used is RFID sensors, inserted into natural or reconstituted pebbles, which make it possible to determine the trajectories and distances traveled by the particles. The techniques are complementary, but few of them allow bedload flows to be quantified.

After 15 years of R&D involving EDF, IGE, Gipsa-Lab, INRAE, and Ginger BURGEAP, acoustic and seismic bedload measurements are now operational and provide integrated information on bedload flows in transit. Thanks to a simplified calibration curve (acoustic mapping), they can be used to estimate sediment transport flows in the form of an annual chronicle and to approximate the grain size of the sediments transported.

The day was organized around a presentation of the theoretical and practical aspects in the conference room, followed by a demonstration of the tool in the field. On this occasion, the operational results of the 2019-2023 monitoring progra m on the Drac River, established under an EDF-Ginger BURGEAP research agreem ent, has been presented, as well as the ongoing monitoring programs on the Drac River as part of the PAPI program led by SYMBHI. The University of Tours is also involved and is developing a network of sediment transport measurements on the Loire and its tributaries, in a more sandy context.


MEETING ORGANIZED WITH THE SUPPORT OF:

RÉPUBLIQUE FRANÇAISE Liberté Égalité Fraternité · agence de l'eau RHÔNE MÉDITERRANÉE CORSE

# PARTICIPANTS

| NOM | Prénom | Structure | Fonction |
|---|---|---|---|
| BOUDRY | Titouan | GINGER BURGEAP | Technicien |
| CAMENEN | Benoit | INRAE | Chercheur |
| CHAUMARTIN | Franck | DDT 38 | Chef unité risques majeurs |
| COLAUTTI | Sandra | SYMBHI | Chargée de mission GEMAPI |
| COUDREUSE | Bénédicte | GINGER BURGEAP | Ingénieure |
| DELACOUR | Lucille | SYMBHI | Technicienne rivière |
| DION | Aurélien | GINGER BURGEAP | Chef de projet |
| DRAPEAU | Margot | OFB | Chargée de mission appui technique - DR AuRA |
| DUPLAN | Alain | MÉTROPOLE DE LYON | gemapi opérationnelle |
| FAVROLT | Xavier | DÉPARTEMENT DE L'ISÈRE | Référent GEMAPI |
| FRANCAIS | Jean-Charles | DEPARTEMENT DE L'ISERE | Chef de service SET |
| FRAUDIN | Camille | SCE | Chargé d'étude |
| GODAYER | Claire | SYMBHI | Chef de projet PAPI Drac |
| GROSPRETRE | Loïc | DYNAMIQUE HYDRO | Gérant |
| GRUFFAZ | Frédéric | EAU ET TERRITOIRES | Gérant et chef de projet |
| GUILLO | Romain | SYMBHI | Stagiaire |
| GUITTENY | Laura | AGENCE DE L'EAU RMC | Ingénieure environnement |
| HUSTACHE | Sylvie | DDT 38 | Instructrice Police de l'eau et des Milieux Aquatiques |
| JOHANNOT | Adéle | INRAE | Doctorante |
| JOUSSE | Cyril | SM3A | Responsable bureau d'études |
| JUGÉ | Philippe | UNIVERSITÉ DE TOURS | Ingénieur de recherche |
| LABROSSE | Lydie | SM3A | Chargée de mission milieux alluviaux |
| LAVAL | Frédéric | GINGER BURGEAP | Directeur de projet |
| LE GUERN | Jules | UNIVERSITÉ DE TOURS | Post-doctorant |
| MAAMIR | Nelly | SYMBHI | Technicien rivière |
| MEUROU | Anne | EDF | Stagiaire |
| MOINE | Frédéric | UGA | Recherche |
| NASR | Mohamad | GINGER BURGEAP | Chef de projet |
| NOIROT | Brice | SYMBHI | Technicien de rivière |
| PARAT | Christophe | DDT 38 | Chargé d'études risques |
| RECKING | Alain | INRAE | Chercheure |
| RENOUARD | Chloé | ARRA² | Chargée de mission |
| RUHL | Cyril | SMIGIBA | Technicien |
| TERRIER | Benoit | AGENCE DE L'EAU RMC | Chef de projet |
| TRAUTMANN | David | EDF HYDRO JURA MAURIENNE | CIS |
| ZANKER | Sébastien | EDF-DTG | Ingénieur Chargé d'Affaires |

# DAY'S PROGRAM

- 9h30 : accueil café en salle Ecrins à l'INRAE St-Martin-d'Hères
- 10h00-12h30 : présentations en salle (20-25min + 10-15 min de questions)
  - 1) Ginger BURGEAP (Frédéric Laval) – introduction, enjeux de la mesure du charriage
  - 2) Ginger BURGEAP (Mohamad Nasr) – théorie, pratique, logiciel d'interprétation, etc.
  - 3) SYMBHI (Claire Godayer) et Ginger BURGEAP (F. Laval) – réseau de mesure du Drac aval
  - 4) Université de Tours (Jules Le Guern) : programme SSESAR sur la Loire et ses affluents
- 12h45-13h45 : pause déjeuner
  - pique-nique partagé sur le site de l'INRAE (en extérieur ou salle en cas de mauvais temps)
  - transfert à 13h45 vers la passerelle de l'Ile d'Amour
- 14h-16h : démonstration des mesures sous forme de 3 ateliers (30 min par atelier, par groupes de 10-12)
  - Atelier 1 : Station hydrométrique + hydrophone (Mohamad, Julien)
  - Atelier 2 : Cartographie acoustique (Bénédicte et Titouan)
  - Atelier 3 : Exposition de matériel complémentaire (Frédéric, Adèle)
- 16h-16h30 : fin de la journée au niveau de la passerelle
  - Mot de conclusion, dernier jeu de questions/réponses, fin 16h30 au plus tard


ARRA² meeting on April 17, 2025, in Saint-Martin-d'Hères

# INTRODUCTION - FRÉDÉRIC LAVAL – GINGER BURGEAP

The aim of this day is to present and discuss the challenges, methods, and feedback related to measuring bedload transport in rivers, using acoustic and seismic tools.

## WHY MEASURE BEDLOAD TRANSPORT?

Bedload transport refers to the transport of coarse sediments (coarse sand, gravel, pebbles) along the bottom of rivers. It influences:

- The morphology of rivers
- Biodiversity (aquatic habitats, vegetation, etc.)
- Safety (flooding, structural safety)
- Uses (hydroelectricity, navigation, drinking water, recreation, etc.)

It is therefore a challenge for GEMAPI local authorities, hydraulic structure managers, but also scientists and environmental associations.

## METHODS FOR MEASURING SEDIMENT TRANSPORT

There are two main approaches:

**1. Direct methods: sampling or traps**

These methods, which directly measure sediment transport flows, are concrete, although they have their own measurement biases. However, they are logistically cumbersome and costly.

Example of a direct method

Example of an indirect method

**2. Indirect methods: measurement of a proxy, i.e., an indirect variable that can be used to quantify sediment transport (such as water level for flow measurement). Examples include acoustic or seismic measurements using hydrophones, geophones, impact plates, etc.**

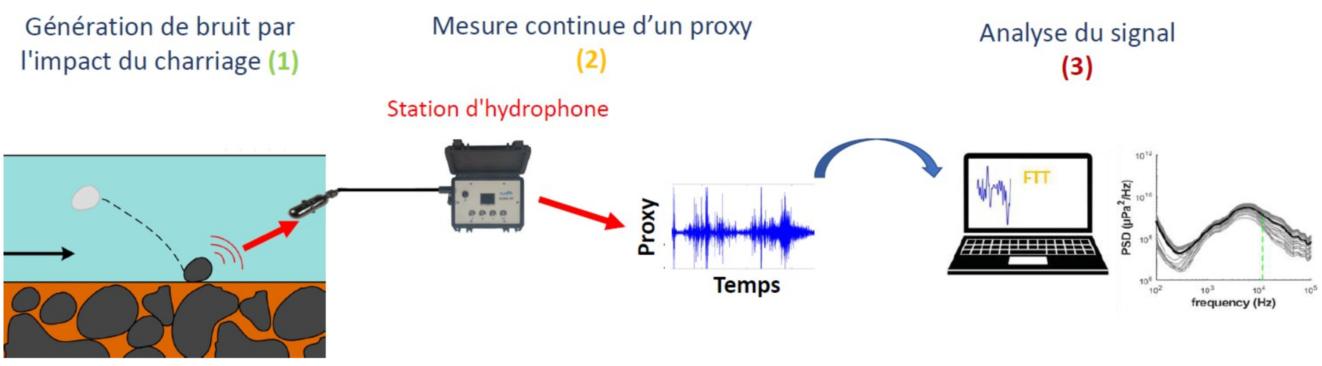
These methods have the advantage of allowing continuous measurements and are less intrusive. They require calibration via spot gauging (in the same way as a calibration curve that links water level to liquid flow).

The day will focus solely on the issue of indirect seismic and acoustic measurements.

# "METROLOGY OF BEDLOAD TRANSPORT BY ACOUSTIC AND SEISMIC MEASUREMENT" MOHAMAD NASR – GINGER BURGEAP

## ACOUSTIC MEASUREMENT USING HYDROPHONES

Passive acoustic measurement relies on the use of hydrophones that record self-generated noise (SGN) produced by the movement of bedload on the riverbed.




This method can be used:

- for continuous measurements over time, using a fixed hydrophone installed on the bank,
- for one-off measurements over time, at a specific section, using acoustic mapping.

Acoustic mapping involves acoustic measurement from a raft (or an aquatic drone if there is no bridge) that is left to drift in the current over a certain distance at different positions on the flow section. Acoustic mapping allows:

Hydrophone installed on a raft

- calibrate continuous measurements.
- quantify sediment transport flows (in kg/s) using a global calibration curve (Geay et al., 2019; Nasr et al., 2023). This scientific work has made it possible to correlate direct measurements taken from samples
(1) with indirect acoustic measurements on a raft (2).

Continuous measurements on the riverbank make it possible to:

- monitor the temporal dynamics of sediment transport, in particular the onset of bedload transport, dynamics during floods, and seasonal variations.
- to ensure continuous, long-term monitoring of solid transport (by accumulating the volumes transported per day, month, year, etc.).

This approach is applicable to a wide variety of rivers—sandy, gravelly, or pebbly—such as the Loire, Romanche, or Drac. Acoustic measurements also make it possible to identify the grain size of the sediments being transported.

### Examples of application

Monitoring has been carried out in recent years on several French rivers:

- Romanche: continuous monitoring from 2020 to 2023, with hydrophones on the riverbank, calibration by sampling and acoustic mapping. This monitoring has enabled the calibration of a digital hydro-sedimentary model.
- Drac: continuous measurement since 2019 with hydrophones on the riverbank, and calibration using acoustic mapping.
- Buëch and Rhône (Miribel canal): combination of hydrophones, geophones, and acoustic mapping (including including by drone).

These experiments demonstrate the growing reliability of these different methods for monitoring sediment transport.

### Limitations of hydrophone-based sediment transport measurements

In the event of turbulence, low water levels, or strong hydraulic forces, acoustic propagation may be poor, thereby reducing the quality of acoustic measurements taken using a fixed station on the riverbank. This requires a thorough understanding of the hydraulic conditions at the measurement site, or even conducting a test phase beforehand.

The acoustic mapping method remains sensitive to low water levels (a minimum depth of 40-50 cm is required for measurements), but it is less affected by hydraulic turbulence or poor acoustic propagation, as the hydrophone sensor is close to the source of the noise.

## Seismic measurement using a geophone

Seismic measurement is based on the same principle as acoustic measurement: solid transport at the bottom of the riverbed generates seismic microwaves that are recorded on the bank by a seismometer (or geophone). The continuous signal can be calibrated in the same way, either by direct measurements (sampling) or by indirect measurements (acoustic mapping).

The limitations of this method are related to the seismic environment, which can produce interference signals (roads, factories, urban or agricultural activity, etc.) and generally requires signal processing after recording.

In general, the seismic signal is less sensitive than the acoustic signal for the start of sediment transport, but it is more robust at high flows because it is not sensitive to hydraulic turbulence.

In summary, seismic measurement can be a solution for rivers with steeper slopes and hydraulic turbulence, as an alternative or complementary measure to acoustic measurement.

## Costs

The costs of installing and monitoring a station vary depending on the objectives, the project, the initial investment, and the calibration effort (sampling campaigns, type and number of acoustic mapping campaigns).

Two different scenarios can be distinguished:

### "Light" scenario:

The measurement equipment is provided by BURGEAP, with a station on the riverbank and the possibility of performing acoustic mapping from a bridge.

- Initial investment: approximately €5,000 (installation of equipment without civil engineering).
- Annual cost (test phase): €15,000 to €30,000 per year, depending on the number of acoustic maps.

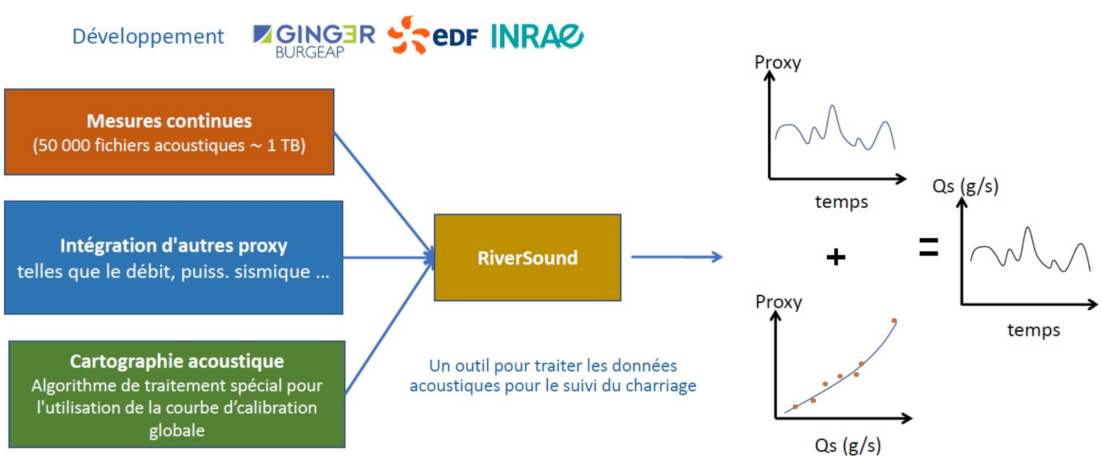
### "Complex" scenario:

Customer purchases equipment, with the option of remote data transmission, and creates acoustic maps using a remote-controlled aquatic drone.

- Initial investment: approximately €20,000 to €40,000
- Annual cost: €25,000 to €40,000/year, depending on the acquisition/recording equipment and the number of acoustic maps.

## Processing tool

A software program called "RiverSound" is currently being developed by GINGER BURGEAP, with the participation of EDF and INRAE, and the support of the University of Tours, with completion scheduled for the end of 2025. It will enable the processing of large volumes of acoustic data and the integration of other proxies such as flow rate and seismic power.



## Conclusions

The proposed method for measuring bedload transport (acoustic and/or seismic) makes it possible to analyze the dynamics of solid transport by bedload and to quantify bedload flows. Currently, this is the only indirect measurement method that can be used to quantify bedload flows.

It also makes it possible to identify the grain sizes in transit, thanks to a correlation with the measured frequencies. However, these measurements involve a certain degree of uncertainty, which is inherent in the bedload transport processes observed.

This approach is of great interest because it can be applied to all rivers with active bedload transport. It is suitable for rivers with coarse sand, with or without gravel, such as those in the Loire or Massif Central regions, as well as rivers with gravel and pebbles, such as those in the Alpine foothills.

From a scientific point of view, the method makes it possible to identify the flow rates at which sediment transport begins, to assess the flows and dynamics of sediment transport (before/during/after flooding), to observe the variability of sediment transport for a given flow rate, etc. Sediment transport measurement is a complementary tool to liquid flow measurements, suspended matter measurements, bathymetric monitoring, and the tracking of pebbles equipped with RFID chips. It can be used to improve the calibration of digital or physical sediment transport models through real-world observations.

Finally, with regard to management and restoration actions, these measures optimize the management of sedimentary areas in support of bathymetric surveys. They also help to more accurately scale hydromorphological restoration actions and sediment reinjections, as well as to monitor and evaluate the effectiveness of management or restoration actions undertaken.

# THE "SOUNDS OF SEDIMENT IN SANDY RIVERS" PROJECT - JULES LE GUERN - UNIVERSITY OF TOURS

## CONTEXT

A study on the quantification of sediment transport in large sandy rivers, particularly in the Loire river basin, was conducted by researchers at the University of Tours: J. Le Guern, P. Jugé, and S. Rodrigues (APRIR project: Sounds of Sediment in Sandy Rivers). This study addresses the technical and scientific issues related to this quantification, the methods used, and the prospects for improving the understanding and management of sediment transport processes.

There is a significant sediment deficit in the Loire basin, leading to impacts such as riverbed incision, loss of habitat diversity, disconnection of secondary channels, etc.

As previously noted, two types of techniques are used to quantify bedload transport in large sandy rivers
are used:

- Direct techniques (sampling);
- Indirect techniques (passive acoustics with hydrophones).

The acoustic signal was calibrated using background load samplers (Le Guern et al., 2021). The calibration law valid for a site on the Loire River is very similar to the calibration law established on 16 gravelly rivers (Geay et al., 2020; Nasr et al., 2024). Given the similarity of the two relationships established in different geomorphological contexts, an overall trend seems to be emerging between the flows measured by direct methods and the acoustic power measured by hydrophones. Researchers at the University of Tours therefore decided to apply the Loire calibration equation to the entire watershed.

## MEASUREMENT PROTOCOL AND ESTIMATION OF RESULTS:

A sediment transport measurement network was therefore set up across the Loire river basin (seven acoustic stations distributed across the Loire and its main tributaries). Acoustic gauging (acoustic mapping) was carried out for different flow rates at each station.

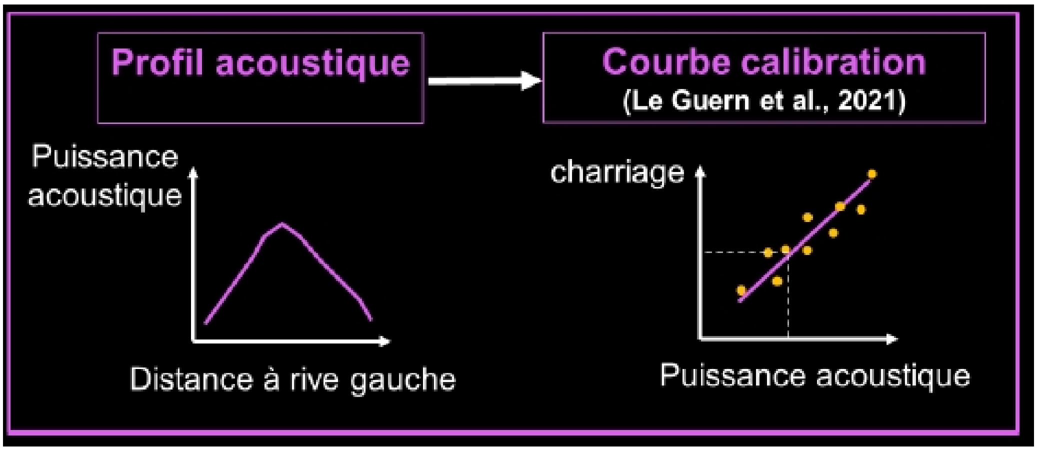
The protocol is carried out by two people in a small boat. They perform around 10 drifts over a period of 30 minutes. Additional measurements are taken, including current metering, bathymetry, and sediment sampling.

The calibration curve is then used to convert the acoustic signal into sediment transport and to construct sediment calibration curves (relationship between liquid flow and solid flow) in order to estimate average annual flows for each station. A sediment transport map of the Loire watershed has been produced, enabling analysis of the longitudinal evolution of sediment transport flows.

Other measurements were taken at the level of the riverbed features (dunes, bars). These measurements enabled detailed mapping of the flows to visualize the preferential sediment transport areas on the riverbed features.

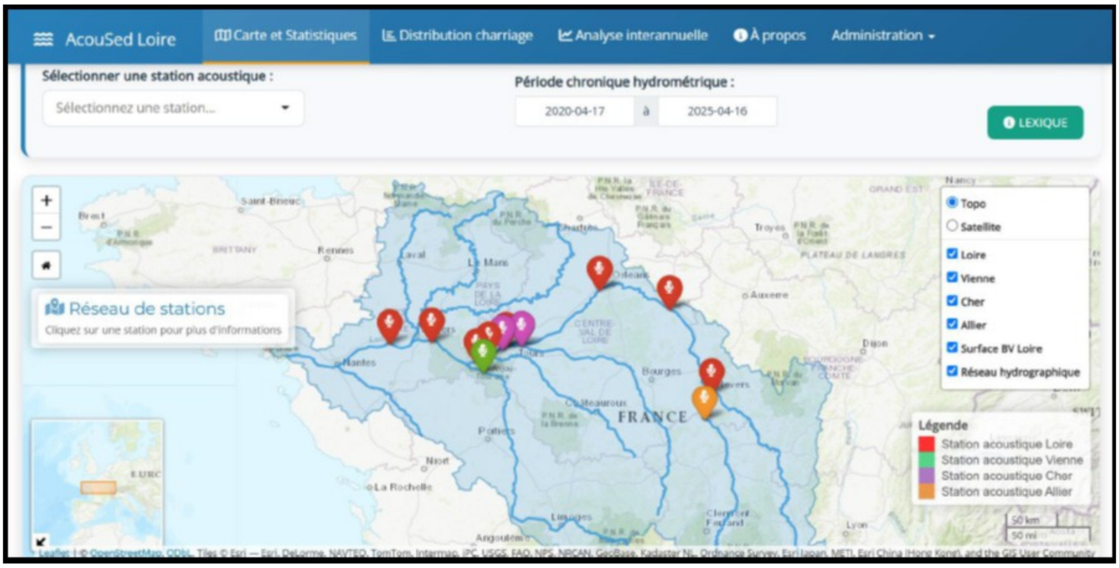
An initial trial of an acoustic station for continuously measuring sediment transport on a sandy river was also carried out as part of this project.


Measurement protocol



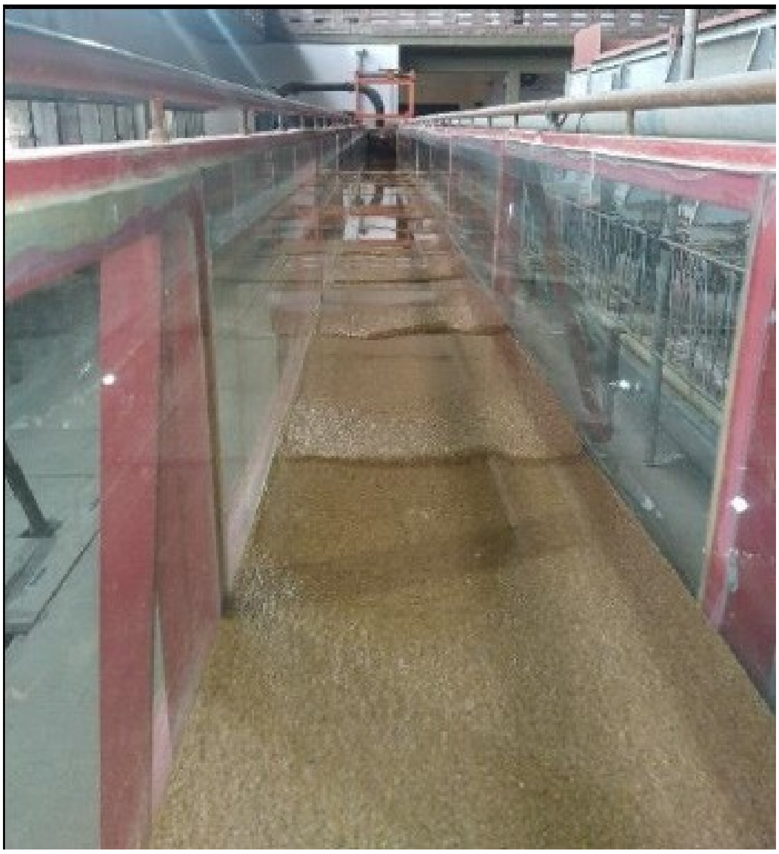
## Outlook

The University of Tours is committed to sustaining the network of measurements established in the Loire river basin and is taking several steps to achieve this: training river metrology teams to assess skills transfer, developing international collaborations to test the limits of hydrophones in the context of fine sand transport (e.g., Paraná, Argentina; Chippewa River, USA). The University of Tours also participated in the development of the RiverSound software mentioned above.




Loire basin measurement network

Finally, experiments in artificial channels and 2D numerical modeling are planned in order to continue exploiting the potential of the passive acoustic method for understanding morphodynamic processes in rivers.

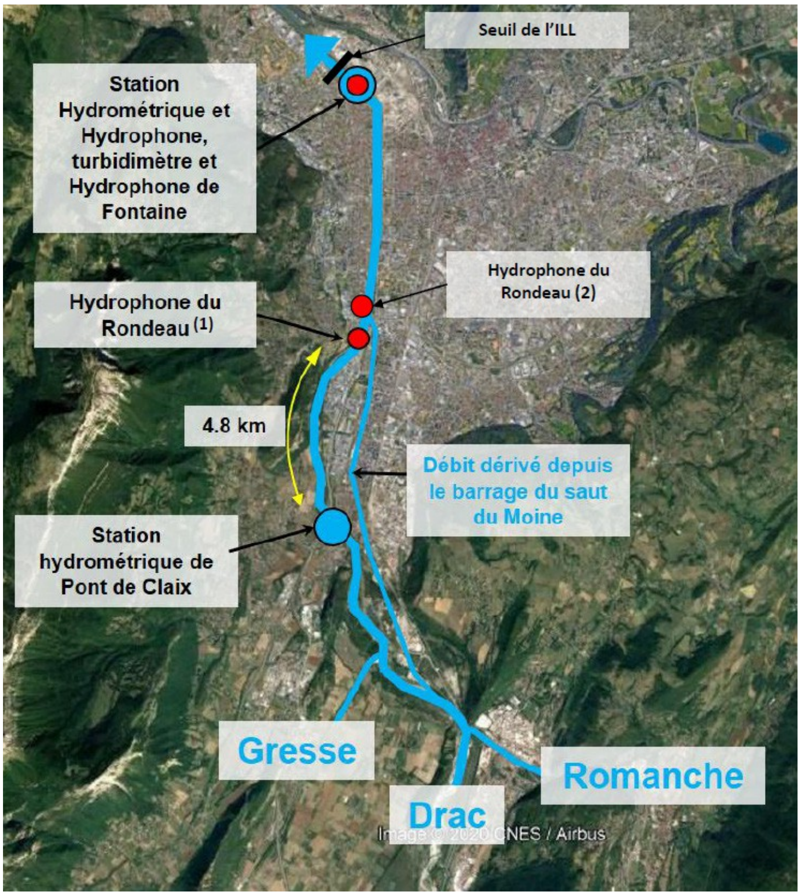


FICH hydraulic artificial channel (UNL, Argentina)

## "MONITORING BEDLOAD ON THE DRAC RIVER"
## CLAIRE GODAYER - SYMBHI AND FRÉDÉRIC LAVAL - GINGER BURGEAP

### CONTEXT AND CHALLENGES

The project is part of a project to lower the ILL threshold in late 2019/early 2020 and develop the Drac Flood Prevention Action Program (PAPI). Studies highlight significant sediment-related issues linked to flood risks and the quality of natural habitats in the Grenoble metropolitan area. A pre-existing agreement between EDF and BURGEAP already covered the measurement of sediment transport on the Drac. The relevance of extending this partnership to benefit PAPI stakeholders was recognized in order to improve the monitoring of sediment flows and provide objective data for hydrosedimentary management and modeling.



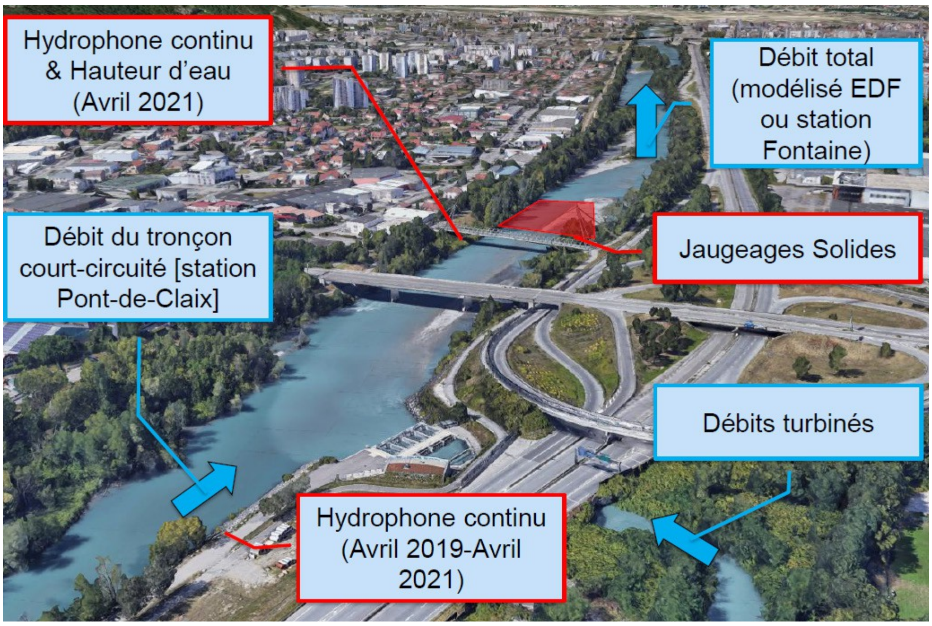

### PARTNERSHIP ORGANIZATION AND OBJECTIVES

An amendment enabled the initiative to be incorporated into the Drac's PAPI (Intentions Plan) and formalized a partnership between EDF, BURGEAP, the French government, AERMC, SYMBHI, and ILL. The main objectives are to find sites for two permanent stations, carry out regular acoustic mapping gauging to establish calibration curves, and compare acoustic measurements (hydrophones) with bathymetric data in order to calibrate and validate sediment transport measurements. The monitoring program covers several campaigns (2020, 2021, 2022) and station maintenance activities, with a follow-up mission planned for 2024–2026.

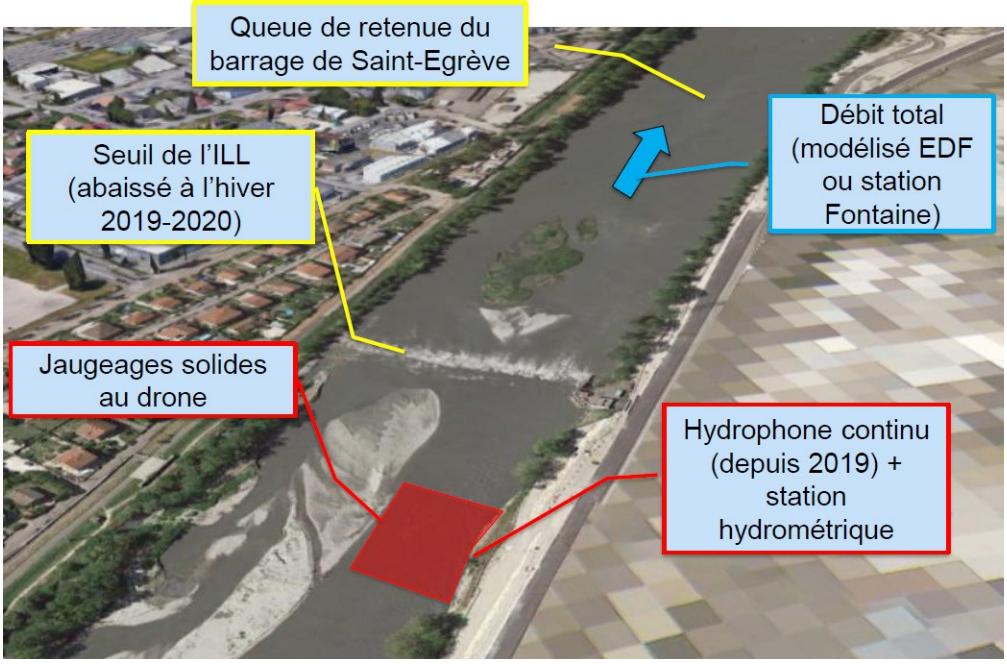
### DESCRIPTION OF STATIONS AND MEASURING DEVICES

Two stations have been set up: the Rondeau station, in service since 2019, and the ILL station, installed in 2019 but was swept away by flooding in December 2023.

The Rondeau station has operated in two successive configurations (Station 1 from April 2019 to April 2021, Station 2 since April 2021). The system combines hydrophones on the riverbank for continuous measurement, water level measurement, and gauging using acoustic mapping. As explained above, acoustic mapping involves allowing a raft equipped with a hydrophone to drift to different points along the section. A footbridge over the Drac river makes it easy to take these measurements, and 24 maps have been produced; they are relatively stable over time and confirm the reliability of the calibration curve. Hydrological flows are given by the flow of the bypassed section measured at Pont-de-Claix, the turbine flows, and the total flow provided by EDF modeling or upstream stations.



The ILL station was equipped with a hydrophone on the riverbank, a hydrometric station, and a protocol for acoustic mapping measurements using an aquatic drone. This station had additional value, linked to sediment management in the reservoir and monitoring the effects of the levelling of the ILL threshold. After its destruction in winter 2023, a temporary hydrometric station was installed in April 2024 and, during 2025, a more permanent station will be installed at a suitable site.




## Measurement and calibration methodology

The method is based on the use of hydrophones to measure the acoustic power associated with solid transport. These stations are calibrated to convert the acoustic signal into sediment transport flow using acoustic mapping carried out either by manual raft (Rondeau station) or by aquatic drone (ILL station).

Work has been carried out on acoustic signal inversion to improve the reliability of measurements and calibration. This additional analysis is useful for rivers such as the Drac, which have good signal propagation in water (due to low suspended solids content).

## Outlook and follow-up

SYMBHI has high expectations regarding the monitoring of PAPI works, particularly in terms of tracking sediment flows in the urban area in relation to flood risks, managing sediment management zones, and assessing the impact of actions (leveling of banks, completion of ILL threshold destocking, etc.). In fact, the Drac cannot carry all of the sediment load from upstream through the Grenoble metropolitan area; it is therefore necessary to encourage deposits in sediment management areas designed to manage excess sediment. Sediment load measurements thus make it possible to monitor changes in the bottom load along the river. Acoustic measurements can also be used to calibrate digital hydro-sedimentary models.

The 2024–2026 agreement promoted by SYMBHI provides for continued monitoring and the reinstallation of a hydrophone station at the ILL, as well as a follow-up mission to consolidate the methodology and ensure the long-term availability of data useful for managing and planning actions on the Drac.

## Conclusion

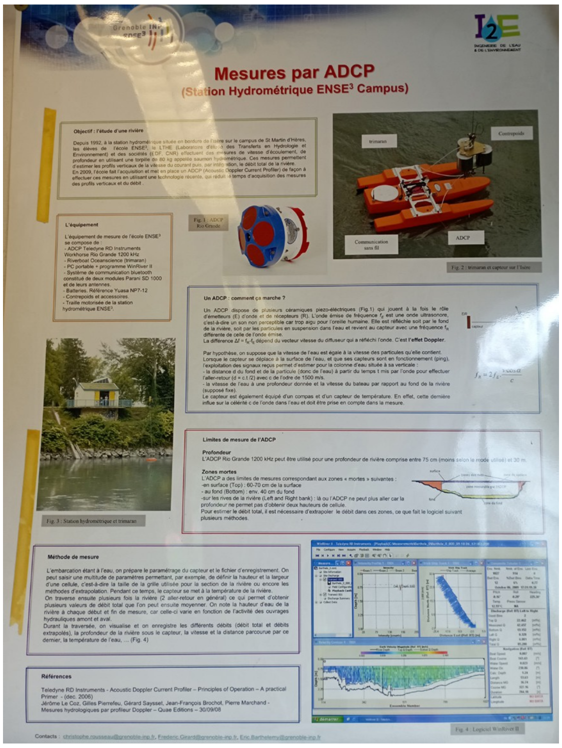
The sediment transport measurement approach used on the Drac River has proven its relevance by providing estimates consistent with other approaches and offering a better understanding of local sediment dynamics. However, the method requires ongoing maintenance, regular calibrations, and risk management to ensure long and reliable series. Strengthening the partnership and continuing measurement campaigns will help improve knowledge and support management decisions within the framework of the Drac PAPI.

Three workshops were held on the Isère River, near the university campus and the INRAE site. The workshops were led by the GINGER BURGEAP team with support from EDF, INRAE, and the University of Tours.

## Workshop 1: Hydrometric station + hydrophone (Mohamad NASR/BURGEAP and Jules le GUERN/University of Tours).

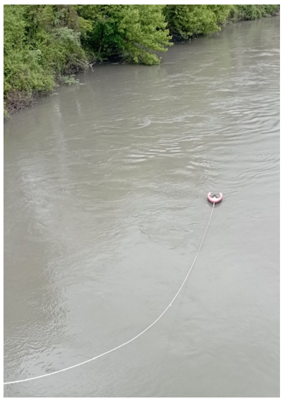
The continuous bank sediment transport measurement device is installed at the same level as the campus's historic hydrometric station. The hydrophone sensor is installed at the end of a tube fixed to the bank. The recorder is located in a specific room that has a power supply. Data is collected periodically.


Room housing the recorder




## Workshop 2: Acoustic mapping (Bénédicte COUDREUSE and Titouan BOUDRY/BURGEAP).

The acoustic mapping process was demonstrated on the campus footbridge, under the same conditions as the mapping carried out for the calibration of the riverside station (Workshop 1). A hydrophone was installed at the rear of a raft, and a recorder was attached to the raft. A rope was attached to the front of the raft. The raft was launched at different points along the width of the footbridge, then released to begin drifting, which would allow for accurate record the drift without interference from hydraulic noise. After drifting for approximately 20 m, the rope is taken up and the raft is pulled back to the next position. A stopwatch is used to define the drift periods for which the signal will be processed. Acoustic mapping requires approximately 15 to 20 drifts, and it is advisable to repeat a series of measurements at least once to ensure the reliability of the results.



Raft with hydrophone

## Workshop 3: Exhibition of additional equipment (Adèle JOHANNOT/INRAE and Frédéric LAVAL/BURGEAP).

Several additional tools and equipment were presented or illustrated with photographs: sediment sampler, sis-meters (or geophones), noise source for performing an active test (inversion method), etc.

Demonstration of equipment by Frédéric LAVAL


Demonstration of equipment