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RESEARCH AND OBSERVATORY CATCHMENTS: THE LEGACY AND THE FUTURE

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Long term high frequency sediment observatory in an alpine catchment: The Arc-Isère rivers, France

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Abstract

We present a dataset on to the Arc-Isère long-term environmental research observatory, which is part of the Rhône Basin Long Term Environmental Research Observatory. This alpine catchment located in the French Alps is characterized by high Suspended Particulate Matter (SPM) in anthropogenized valleys. Suspended Sediment Concentrations (SSC) naturally observed in the river are very high, ranging from a few tens of milligrams per litre at low flow to tens of grams per litre during major natural hydrological events (floods, debris flows) or river dam hydraulic flushes. One research objective related to this site is to better understanding the SSC dynamics along the river using a system of nested catchments (Arvan, Arc, and Isère) in order to assess both temporal and spatial dynamics. The data allow the quantification of fine sediment yields and also the evaluation of possible morphological changes due to fine sediment deposition or resuspension. Additionally, the observatory database support studies on contaminants (either dissolved or particulate contaminants). Our monitoring includes six stations with high frequency (2–30 min) streamflow, SSC measurement using turbidity sensors, and associated automatic sampling. Discharge is measured via water level measurements and a rating curve. The oldest station (Grenoble-campus) started recording discharge and concentration data from April 2006 while others stations were built between 2009 and 2011. Data are available in an online data website called 'Base de Données des Observatoires en Hydrologie' (Hydrological observatory database, https://bdoh.irstea.fr/ARC-ISERE/) with a DOI reference for the dataset. The hydrological and sediment transport time series are stored, managed and made available to a wide community with unfettered access in order to be used at their full extent. This database is used as a data exchange tool for both scientists and operational end-users and there is an associated online tool to compute integrated fluxes.

KEYWORDS

Alpine rivers, database, long term observatory, sediment fluxes, suspended sediment concentration, turbidity, water discharge

1 | DATA SET NAME

High frequency suspended sediment flux database on a French Alpine river system.

2 | OBJECTIVES AND SITE DESCRIPTION

The Arc-Isère observatory is located in the French Alps (outlet of the observatory near Grenoble: longitude 5.7689497E/latitude 45.1974416N/

altitude 207.8 m). The site was designed to study alpine rivers that carry large amounts of fine sediments, typically yielded by erosive badland sub-catchments such as in the Arvan river system. The bed river sediment material consists of a mixture of coarse (gravel and cobble) and fine (sand, silt and clay) particles. The Arc and Isère rivers were significantly modified due to anthropogenic changes such as dykes linked to the construction of motorways and railways, numerous hydroelectric diversions and dams, and sediment mining. It resulted in the formation of a system of alternate gravel bars within a constrained river (Jaballah et al., 2015). In addition, a decrease of pasture land area and restoration works within the catchment modified the relative input quantity of the different types of sediments to the river. Since the end of the 20th century, there has been a relative shortage of coarse particle input, and an excess of fine particles. The resulting imbalance led to erosion of the main channel, aggradation and fixation of gravel bars due to massive fine sediment deposits and riparian vegetation growth (Jourdain et al., 2020).

The hydrological monitoring and resulting data from the catchments are useful in the assessment of:

- The characterization of deposition and erosion of fine sediments over gravel bars along alpine rivers;
- The assessment of the exchanges of fine sediments between flow and bed matrix (infiltration, exfiltration);
- The understanding of the spatial and temporal variations of fine sediment transport including sand in the river system;
- The quantification of the forcing effects of bar morphology, hydrology, sediment supply, riparian vegetation on fine sediment dynamics;
- The study of the contaminant transport.

The Arc-Isère river system is a reference site of the ZABR (Zone Atelier du Bassin du Rhône [Rhône Basin Long Term Environmental Research Observatory], https://www.zabr.assograie.org/) that has been monitored for more than 15 years (Antoine et al., 2020; Mano et al., 2009; Némery et al., 2013). Six hydro-sedimentary stations (see Figure 1) have been established in a system of nested catchments (Arvan, Arc and Isère catchments), and provide data for both water discharge and sediment concentration (operated by INRAE, IGE). The network is completed by stations operated by partners (EDF, DREAL Rhône-Alpes Auvergne: Directions Régionales, de l'Environnement, de l'Aménagement et du Logement [Regional board for the environment, planning and housing]). All the partners work in synergy, for example in choosing the location of the stations, to better investigate the whole catchment.

The three catchments have distinct characteristics (see Table 1): the Arvan River is a steep mountain torrent, highly responsive to precipitation and snow melt events. The Arc River is a mountain river with an average slope of 1%, with several river dams. Regular dam flushes (yearly if no significant flood occurs), produce substantial fine sediment transport. Lastly, the Isère River is a larger piedmont river where gravel bars are affected by fine sediment deposits and vegetation spreading and where flood risk is a significant issue. The Arc and the Arvan catchments produce substantial yields of suspended particulate matter (SPM), which is transported along the river system or temporarily stored over gravel bars or within dam reservoirs.

3 | DESCRIPTION OF HYDRO-SEDIMENTARY STATIONS

Water discharge and suspended sediment concentrations (SSC) are measured at each station. Data are recorded with time steps varying from 2 to 30 min. Times steps are adapted to accurately measure natural variations of these parameters.

Flow discharge time series are based on water level measurements recorded continuously on a datalogger. Using different gauging methods on each station (see Table 2), rating curves were established by applying either a classical stage/discharge relation or the index velocity method coupled to a stage/area relation with an average velocity (Thollet et al., 2017). The uncertainty of the calculated

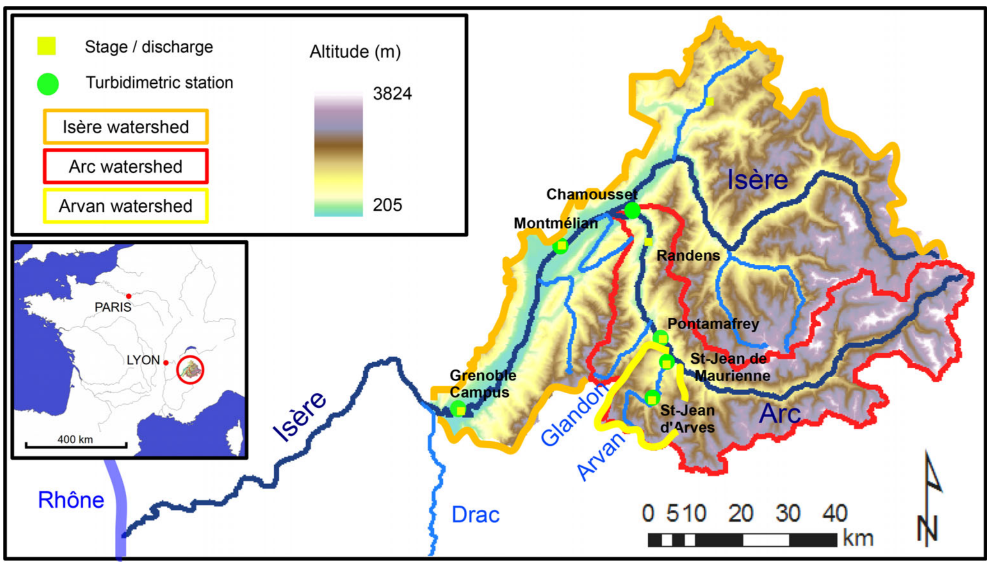

FIGURE 1 Location of hydro-sedimentary stations on Arc - Isère catchment

TABLE 1 Mean interannual suspended sediment fluxes (SSF) on the Arc-Isère catchment (https://dx.doi.org/10.17180/OBS.ARC-ISERE)

Station/river	Start year	Catchment area (km^2)	Annual average SSF (kt)	Specific SSF (t/km^2)
Saint Jean d'Arves/Arvan	2010	58	50.3	867
St Jean de Maurienne/Arvan	2009	222	250	1126
Pontamafrey/Arc	2009	1510	515[a]	341[a]
Chamousset/Arc	2011	2000	1200[a]	600[a]
Montmélian/Isère	2010	4840	1500	310
Grenoble–Campus/Isère	2006	5720	1440	251

[a]Because of hydropower plants and water diversions, specific fluxes at Pontamafrey and at Chamousset are underevaluated and overevaluated, respectively.

TABLE 2 Main characteristics on flow discharge measurements

Station/river (owner)	Frequency (min)	Range (min-max in m^3/s)	Technology	Gauging methods and devices	Uncertainty	Data availability over the period[†]
Saint Jean d'Arves[‡]/Arvan (DREAL Auvergne Rhône-Alpes)	6	0.4–35	Stage Radar Cruzoe Paratronic (France) and velocity Radar RQ30 Sommer (Austria)	Ott C31 current meter (Germany), water surface velocity with radar SVR Decatur (Finland)	10%[b]	2010–2015 93%
St Jean de Maurienne/ Arvan (INRAE)	2	0.2–80	Stage and velocity radar sensors Sommer RQ24 (Austria)	Electromagnetic current meter Flo-Mate 2000 Marsh Mc Birney (UK), water surface velocity with radar SVR Decatur (Finland)	20%[b]	2010–2018 73%
Pontamafrey/Arc (EDF)	6	1.6–356	Pressure sensor Hydrologic LPN8 (France)	ADCP Teledyne Rio Grande (USA)	5%[b]	2011–2020 97%
Chamousset/Arc (DREAL Auvergne Rhône-Alpes)	6	2.6–427	Stage and velocity radar sensors Sommer RQ30 (Austria)	Gauging truck equipped with OttC31 current meter, ADCP Teledyne Rio Grande (USA), water surface velocity with radar SVR Decatur (Finland)	10%[a]	2011–2019 98%
Montmélian/Isère (DREAL Auvergne Rhône-Alpes)	6	26–780	Pressure sensor Hydrologic LPN8 (France)	Gauging truck equipped with OttC31 current meter, ADCP Teledyne Rio Grande (USA)	10%[a]	2009–2015[‡‡] 99%
Grenoble–Campus/ Isère (EDF/IGE)	30	33–866	Pressure sensor Ott PLS 0–10 m (Germany)	Gauging via cableways with Ott C31 current meter (Germany), ADCP Teledyne Rio Grande (USA), ADCP SonTek M9 (USA)	5%[a]	2005–2019 99%

[†]Percentage of the time series period without gap (0 means no data, 100% means no gap). Gaps are represented in the data product as −9999 values.
[‡]The station was moved 5 km upstream in 2019 because of the installation of a new hydraulic power station. Since there is no significant tributary on this section, the discharge could be affected only due to the small difference in the catchment area.
[‡‡]Only water level from 2015 to 2019. Flow discharge will be soon available for 2020.
[a]Mean deviation between the measured flow rates and the rating curve.
[b]Bayesian method.

discharge is determined from the mean deviation between the measured flow rates and the rating curve using a dynamic approach described in Morlot et al. (2014) or a Bayesian method (Baratin; Dramais et al., 2011; Le Coz et al., 2014) depending on the station.

Suspended Sediment Concentrations (SSC) are measured indirectly from a turbidimeter signal (see Table 3). Hach Lange SC100 or SC200 controllers are used in addition to numerical Solitax SC probes, all equipped with a mechanical cleaning system (wiper). Sensors use the infrared scattered light method with the optical response being dependent on sediment characteristics in the water. Therefore, a site- and sensor-specific calibration across a wide range of concentrations was established for each location. Each site relationship, SSC = f

TABLE 3 Main characteristics on sedimentary measurements

Station/river (owner)	Frequency (min)	Range (min-max in g/L)	Technology (turbidimeter–datalogger–sampler)	Uncertainty	Data availability/for the period[a]
Saint Jean d'Arves[b]/ Arvan (INRAE)	2	0–114	Hach Lange SC100 and Solitax 0–150 g/L (Germany)–Ott Duosens (Germany)–Automatic sampler Sigma SD900	10%–20%	2010–2020 53%
St Jean de Maurienne/Arvan (INRAE)	2	0–132	Hach Lange SC100 and Solitax 0–150 g/L (Germany)–Ott Logosens (Germany)–Automatic sampler Sigma SD900	15%–25%	2009–2018 76%
Pontamafrey/Arc (INRAE/EDF)	2	0–137.6	Hach Lange SC100 and Solitax 0–150 g/L (Germany)–Ott NetDL (Germany)–Automatic sampler ISCO 3700 (USA)	10%–20%	2009–2020 95%
Chamousset/Arc (INRAE/EDF)	2	0–83.5	Hach Lange SC100 and Solitax 0–150 g/L (Germany)–Ott NetDL (Germany)–Automatic sampler ISCO 3700 (USA)	8%–20%	2011–2020 91%
Montmélian/Isère (EDF)	60	0–31.4	Hach Lange SC100 and Solitax 0–50 g/L (Germany)–Ott NetDL (Germany)–Automatic sampler ISCO 3700 (USA)	15%–25%	2009–2019 67%
Grenoble–Campus/Isère (IGE/EDF)	30	0–46.9	Hach Lange SC200 and Solitax 0–50 g/L (Germany)–Campbell Scientific CR1000 (USA)–Automatic sampler ISCO 3700 (USA)	8%–20%	2006–2019 99%

[a]Percentage of the period without gap (0% means no data; 100% means no gap). Gaps are represented in the data product as −9999 values.
[b]The turbidity sensor at Arvan amont is wintered to prevent from freezing. Only half of the year is taken into account. Winter flows are assumed to be negligible.

(turbidity), is assumed linear with a single segment. The calibration of this relationship is done using water samples obtained using ISCO 3700 or Sigma SD900 automatic samplers controlled by the turbidimeter (i.e., triggered if a minimum turbidity value is reached with a frequency of one sample every 30 min unless the turbidity drops again below the minimum value) or by the datalogger (i.e. triggered for a specific programmed period with a frequency of one sample every 30 min). SSC were determined by filtration of a precise volume of each water sample (ranging from 50 to 500 mL) through pre-weighed fibreglass filters and by drying them at 105°C for 2 h (Standard NF EN 872, ISO 4365, 2005). Results are expressed in mg/L, and the uncertainty on triplicates was estimated to be below 5%. Sand was recently excluded from the analysis (Dramais et al., 2018). The evaluation of the SPM fluxes as a product of discharge and concentration is premised on SPM concentration being homogeneous throughout the river section, which is not the case for sand concentration. Moreover, since turbidity is inversely sensitive to the size of the particles (Thollet et al., 2014), the inclusion of sand particles may significantly bias the turbidity/SSC relationships.

A particular effort has been made to quantify uncertainties of turbidimetric measurement and associated variables. The uncertainty of the calculated SSC is determined from the mean deviation between the measured SSC and the SSC obtained with the turbidity calibration curve (Table 3). Taking into account the calibration curve and sample analysis, uncertainties on high frequency SSC data series are variable, generally between 10% and 20% (Arnaud et al., 2013; Navratil et al., 2011). More precisely, on the Isère River calculated uncertainties reach 20% for SSC below 2 g/L and 8% for SSC above 2 g/L (Némery et al., 2010). Because the turbidimeter is sensitive to the variation in size of suspended particles (Thollet et al., 2014), the established relationship turbidity/SSC can be unstable for stations that are relatively close to sediment production areas, for example on the Arvan River or on the Arc River at Pontamafrey. We also observed for these stations a seasonal effect according to hydrological event types (storm event, snow melt, flood event, low flow). At Pontamafrey, depending on the event type, the calibration coefficient for turbidity/SSC varies between 0.8 and 1.6. In contrast, on the Isère River at Grenoble, grain sorting with flow propagation yields a more stable grain size distribution and a more stable relationship. Sampling is carried out regularly to ensure there is no change in the relationship between turbidity and SSC (see Table 4). Such sampling is also necessary when a turbidity probe is replaced or after maintenance. Results of SSC analysis are displayed on the SSC time-series to check the accuracy of the turbidity/SSC relationships and to better appreciate the samplings frequency.

4 | DATA PROCESSING AND ONLINE STORAGE

Raw data is processed manually and individually for each station from one to four times a year, using DP+, a specific software from French hydrometric services (only available to the French hydrometric community), spreadsheets and custom R programs. Processing includes removal of duplicated data, identifying gaps and aberrant points, applying linear corrections when staff gauges show data drifts, and so on. The process takes into account all the observations (maintenance and events that affected data values, staff gauge readings) made by technical staff during station visits. A quality level code is assigned to each data value related to the metrology and the corrections

TABLE 4 Calibrations of turbidimeter and sampling

Station/river	Scale set period	Turbidity/SSC coefficient	R^2	Minimum SSC (mg/L)	Maximum SSC (mg/L)	Nb of sample analysed
Saint Jean d'Arves/Arvan	04/2010–01/2014	1.00	0.91	4	45 880	170
	01/2014–01/2015	4.01	0.91	12	4290	27
	01/2015–12/2017	0.76	0.900	15	173 278	103
	12/2017–12/2018	1.05	0.96	21	32 794	71
	12/2018–in progress	0.6	0.70	5	22 374	94
St Jean de Maurienne/ Arvan	10/2009–08/2012	1.25	0.95	44	82 580	215
	08/2012–04/2013	0.82	0.98	9	27 713	43
	04/2013–04/2014	0.95	0.98	172	32 658	73
	04/2014–05/2015	0.80	0.86	27	8832	153
	05/2015–01/2017	0.88	0.96	35	16 637	67
	01/2017–11/2017	1.09	0.98	7	83 963	79
	11/2017–08/2018	0.87	0.99	8	43 758	75
	08/2020–in progress	–	–	–	–	1
Pontamafrey/Arc	04/2009–05/2010	0.99	0.95	40	52 486	110
	02/2011–04/2019	1.08	0.92	2	45 000	680
	04/2019–in progress	1.32	0.93	300	23 000	116
Chamousset/Arc	05/2011–10/2012	1.08	0.98	2	18 349	215
	10–2012 – 05/2017	1.03	0.92	6	19 818	205
	05/2017–06/2017	0.75	0.99	79	6895	18
	06/2017–in progress	1.00	0.89	1	15 920	161
Montmélian/Isère	01/2011–04/2017	0.91	0.91	21	3071	215
	05/2017–06/2017	0.90	0.72	100	430	22
	06/2017–in progress	1.15	0.83	32	88 000	386
Grenoble–Campus/Isère	03/2006–05/2010	1.07	0.98	6	13 700	678
	05/2010–01/2012	0.93	0.93	4	10 210	530
	01/2012–10/2012	1.07	0.98	6	13 700	678
	10/2012–03/2015	0.72	0.91	4	7140	565
	03/2015–05/2017	0.54	0.96	3	6731	298
	05/2017–09/2017	0.66	0.95	41	6478	145
	09/2017–08/2018	0.66	0.92	9	28 448	161
	11/2018–in progress	0.88	0.96	10	5578	149

made during data processing. The quality codes are categorized as 'valid', 'doubtful', 'estimated', a 'no code' (because of no traceability for example). When no data are reported, the code is either 'gap' (no measurement) or 'invalid' (irrelevant measurement that was removed). Gaps and invalid measurements are marked as −9999 and they are graphically identified with a red line (Branger et al., 2014).

5 | CONCLUSION

Acquiring this high-frequency database on the Arc-Isère observatory requires a significant investment in equipment, but above all an investment of technical and scientific labour and expertise. The length of the time-series exceeding a decade allows a study of sediment transport processes at inter-annual scales in connection with meteorological variability and land use planning. A nested basin scale approach is also relevant for the detailed spatio-temporal study of the flow and sediment propagation along the river for specific events such as spring (snowmelt) floods, debris flows, or hydraulic dam flushes. It also allows identification of deposition or resuspension processes, which are fundamental in the construction of hydro-sedimentary models. Finally, this study site, while highly developed for the production of hydroelectricity, is characterized by a mountain river with extreme suspended solid transport, and fine sediment deposit and vegetation issues. Thus, the database is of interest for river managers and water operators but also and above all for research at the regional level of the Rhône basin and the Mediterranean basin.

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18-CE01-0019-01 (Deposition and Erosion of fine sediments in Alpine Rivers—DEAR-project) and by other project funds (EC2CO Bioheffect Structurante Initiative). Flow discharge and SSC data for each station belong to the producer (contributor), that is, INRAE, IGE, EDF, DREAL Auvergne-Rhône-Alpes as presented in Tables 2 and 3.

DATA AVAILABILITY STATEMENT

The time series are made available on a public online database named 'Base de Données des Observatoires en Hydrologie (BDOH)' (Branger et al., 2014) for Database of Hydrologic observatories (https://bdoh.irstea.fr/ARC-ISERE/) with a DOI reference (10.17180/OBS.ARC-ISERE). The database is available in French and in English. This database gives access to data in a homogeneous form that can be used by all scientists. Data can be browsed and visualized without limitation by anyone. However, an individual registration is requested to be able to download data. This allows us to keep in touch with data users, and let them know when updates occur. In addition, the registration provides us some statistics about the different user profiles that support our requests for funds to maintain and develop the BDOH application. Registered users can select and freely download the data they are interested in with functionalities like time step interpolations, average calculation. Data are exported as flat text files that contain all the necessary metadata (producer, variable, unit, time zone, conversion factors) and can be processed by any software (Excel, R, Matlab, etc.). Data managers also have access to additional functionalities, such as detection of duplication or inconsistency when importing new data in BDOH, rating curve management for stage to flow discharge or turbidity to SCC conversions, automatic calculations of derived data including integrated fluxes, and reporting tools. These tools help them to maintain complete, consistent and quality-controlled datasets. Currently 37 users are registered on the Arc-Isère observatory. Since the database was created in 2013, an average of 70 downloads have been made every year.

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