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Arc-en-Maurienne

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Portrait: River Arc-en-Maurienne

A typical engineered alpine river

Benoît Camenen

Sources for the information in the table are missing

River Source	Sources-Inférieures Lake, Bonneval-sur-Arc, Savoie, Auvergne-Rhône-Alpes region, France (2 222 m NGF)
River Mouth	Aiton, Savoie, Auvergne-Rhône-Alpes region, France (290 m NGF)
Alpine States the River Flows Through (incl. Counties/Provinces)	France
Catchment Area in total / within the Alpine Arc (<i>in the Alps</i>)	1985 km ²
Total Length / Length of Alpine Arc Stretch	127.5 km
Alpine subregions the River Flows Through (following Pfiffner)	
Geological units the river flows through	Crystalline units and several sedimentary units (shale, limestone, black marls, gypsum and sandstone)
Mean discharge (m ³ /sec; at entrance in permanent settlement area/close to the mouth)	71 m ³ /s (at Aiguebelle, 1946 km ²) based on hourly-averaged data from 2011 to 2018.
Discharge regime (at source/mouth)	
Stream order (at mouth)	

The river Arc-en-Maurienne has its source near Bonneval-sur-Arc in the Haute-Maurienne, Savoie, Auvergne-Rhône-Alpes region, France. The catchment area is 1985 km² with a nival hydrologic regime, the mean slope varies downstream from 6 to 0.2%. (Marnézy, 1999). The mean water discharge is strongly influenced by hydropower infrastructures built on the valley, including three river dams located in the middle of the river stretch and derivations from Arc to Isère rivers and Isère to Arc rivers. At St-Michel (upstream of main derivation), mean water discharge varies from 9-20 m³/s in winter to 30-80 m³/s in summer; summer at Pontamafrey (downstream of main derivation, it varies from 8-12 m³/s in winter to 20-40 m³/s in. The 100-year flood is estimated to be 800m³/s at St-Michel-de-Maurienne (≈940 km²) and 930 m³/s at Aiguebelle (≈1950 km²). Main recent floods were registered at Pontamafrey in May 2008 (Q_{max}=480m³/s, Figure 1), and June 2013 (Q_{max}=355m³/s).



Figure 1: Arc River during the May 2008 flood at Ste-Marie-de-Cuines.

Because of the large SSM concentration generally observed in the Arc River, the hydrobiological and piscicultural quality of the Arc River is considered very poor, and therefore the biological issues associated with the river are low. The Arc is the main contributor of the Isère River, and one of the main contributors of the Rhône River, together with the Arves and Durance rivers (Table 1).

Table 1: SSM fluxes measured (*: estimated) at Pontamafrey.

Year	Annual Flux (t)	Major events	Q _{max} (m ³ /s)	Event Flux (t)	% year
2006	10×10 ⁵ (*)	June flush Sept. flood	130 160	4.5×10 ⁴ -	5% (*) -
2007	8×10 ⁵ (*)	June flush	130	2.2×10 ⁴	3% (*)
2008	20×10 ⁵ (*)	May flood	480	92×10 ⁴	45% (*)
2009	6×10 ⁵ (*)	June flush	155	1.7×10 ⁴	3% (*)
2010	12×10 ⁵ (*)	May flood June flush	130 145	15×10 ⁴ 2.6×10 ⁴	13% (*) 2% (*)
2011	6.5×10 ⁵	June flush	125	1.7×10 ⁴	2.5
2012	5.1×10 ⁵	June flush	175	4.9×10 ⁴	9.6
2013	12.8×10 ⁵	June flood	355	54×10 ⁴	42
2014	5.3×10 ⁵	June flush	150	1.4×10 ⁴	2.6
2015	6.1×10 ⁵	June flush	115	2.1×10 ⁴	2.8
2016	3.9×10 ⁵	June flush	195	6.8×10 ⁴	17
2017	3.0×10 ⁵	June flush	140	2.9×10 ⁴	9.7

thus strongly constrained laterally with the construction of dikes. The Upper valley remains more “natural” with less embanked reaches and several canyons (Figure 2). The river bed is made gravels but poorly sorted with presence of blocks to fine sediment deposits. The river is characterised by a system of pool and riffles where bedload transport is very active (Figure 3).



Figure 2: Arc River at Aussois (Photo Liné).

The Lower Maurienne valley is characterised by a high density of infrastructure (railway Lyon-Torino, national road RN6 and freeway A43) in a narrow valley. The Arc-en-Maurienne river bed is

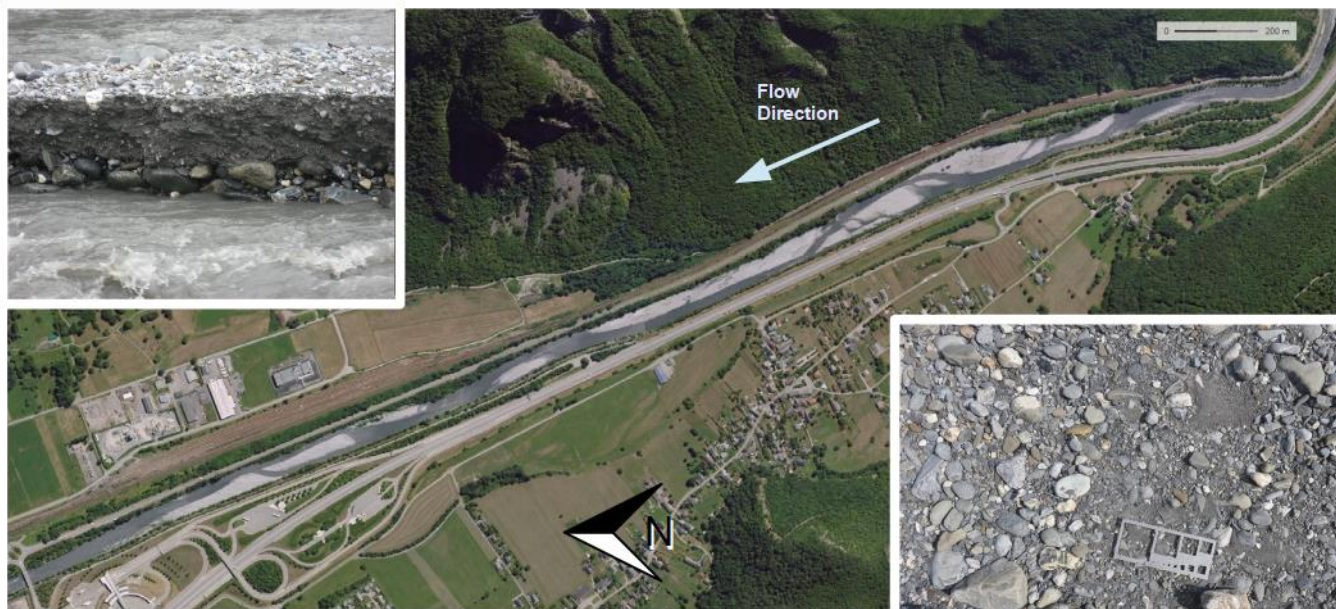


Figure 3: Ste-Marie-de-Cuines reach with alternate bars and photographs showing typical surface grain size distributions.

Spotlight: Fine sediment management

The Arc-en-Maurienne River is characterised by large concentrations of fine sediments coming from erosion of black marls. This is a significant issue for dam managers because of their impact on river dam capacity but also because of their interaction with large river bedform morphology.

One of the main issue of the Maurienne valley is the flood risk. Due to a still significant sediment input (debris flows) and a reduced sediment transport capacity (compensation water), several reaches in the Lower Arc are aggrading. As a consequence, the flood hazard slowly increases in these sectors. At the same time, due to the large fine sediment input, the dam managers need to perform regular dam flushing to maintain their reservoir capacity, and to allow a sediment continuity. Such flushing events are operated every year except if a large flood occurred (**Erreur ! Source du renvoi introuvable.**). It consists in a general opening of the three river dams (Figure 4) together with an additional water input from high altitude reservoirs. Such events produce a relatively low (negligible) fine sediment input compared to the yearly averaged fluxes (2 to 10%, see Tab. 1). However, it may significantly interact with the river bed along the Arc and Isère rivers mainly through deposition or resuspension over gravel bars (Antoine et al., 2011).



Figure 4: Saint-Martin-la-Porte dam opened during the June 2017 flushing event.

The fine sediment dynamics over gravel bars remain complex since deposits are very sensitive to local hydrodynamics and flood hydrogram. In 2015, a massive deposit was observed on a specific gravel bar after a flushing event due to a long submersion at a constant discharge (Figure 5). These deposits may also evolve due to hydro-meteorological conditions (Camenen et al., 2013). Indeed,

rain drops and wind may easily disperse fine sediments and enhance infiltration in the gravel matrix. Since gravel bars may contain up to 30% in mass of fine sediments (see photographs in Figure 3), this presence of fine sediments over gravel bars may impact bedload dynamics by modifying inception of transport or enhancing the bedload rate (Perret et al., 2018). Also the remobilisation of the coarse sediments during a flood would release a significant amount of fines that could settle further downstream.



Figure 5: Large deposits observed on a gravel bar after the 2015 flushing event.

One important issue is the interaction between fine sediment and vegetation. Fine sediment deposits are one of the main conditions for pioneer vegetation to grow. If the vegetation is established (after a relative long period without large flood), it may reduce velocities over the gravel bar during a flood and enhance fine sediment deposits. Such behaviour may be irreversible with gravel bars being higher and eventually vegetated with hardwood (Jourdain et al., 2017). If an alternate bar system made of bare migrating bars is also impacted by flow regulation and/or a lack of sediment input (due to gravel mining for example), it may evolve towards a less dynamic equilibrium configuration characterized by longer, mostly non-migrating, vegetated bars (Jaballah et al., 2015; Serlet et al., 2018).

River managers are concerned about such a possible evolution and vegetation colonization on the Arc River as observed on the Isère River at the Combes de Savoie (Jourdain et al., 2017). Indeed, due to an overall reduced flow capacity of the river, it would lead to a higher flood hazard and so to a higher flood risk. The fine sediment deposits and the vegetation colonization also have a strong impact on biodiversity: pioneers riparian plants and species of birds needing gravel bars to grow are dramatically decreasing. Vegetation colonization is often composed by invasive non-native plants on fine sediment deposits. Costly engineering works are

carried out to reduce these undesirable environmental impacts. These works mostly consist in mechanically removing the existing vegetation and fine deposits and remodelling the gravel bars in order to improve sediment dynamics. A typical example is the restoration project of the Isère River at the Combe de Savoie managed by SISARC. Approximately 450 000 m³ of fine sediments have been excavated in 2017 and 2018 from gravel bars after removal of the vegetation on a 10 km long reach, for a total cost of nearly 4.7M€ (Figure 6). One of the main concerns of these high-priced operations is related to the long-term sustainability. Current research is focused on the a specific river management (testing new dam management guidelines and mechanical intervention) that could increase the gravel bars mobility and limit fine sediment deposits over gravel bars (such as observed in Figure 5) or enhance fine sediment resuspension.

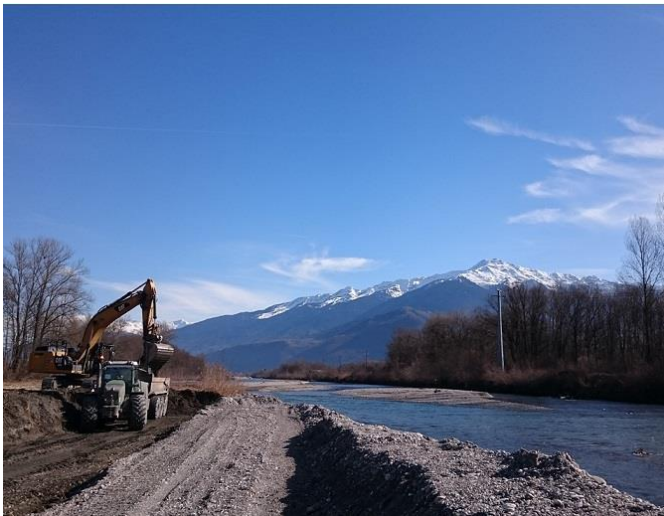


Figure 6: Large mitigation works on the Isère River at the Combes de Savoie in 2017 (Photo SISARC).

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