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AN EXAMPLE OF A HIGH WATER QUALITY: THE UPPER SEGRE BASIN, EASTERN PYRENEES, FRANCE

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Abstract. The upper Segre basin is located in the Eastern Pyrenees in the South of France. The hydrogeological context is a middle mountain, between 1300 m and 3000 m, made of paleozoical rocks. The climate is a mix of mountain, Atlantic and Mediterranean influences. This river is very interesting because it is an example of high water quality, low level of mineralization and without any evident pollution. This little basin (20 km^2) can be approached by several water indicators like temperature, conductivity, total hardness, nitrates, phosphates and turbidity. This study is based on 15 samples that allowed us to characterize this basin like a patrimonial high water area, because this kind of high quality of water became more and more unusual in France.

The high river basin of Sègre is situated in the oriental part of Pyrenees, in Cerdagne, on the border between France and Spain. This small hydrological unit, of a rough surface of 20 km^2 illustrates the example of a resource of high quality the value of which can be considered patrimonial. The purpose is to show which are the hydrogeological structures that we meet in this river basin and how the quality of waters evolves spatially. This watershed is part of the geologic frame of the Pyrenean Mountain, at the same time wrinkled and faulted. This organization has as a main consequence the segmentation of watersheds in small hydrological units, within cambro-ordovician sediments. Some sectors, near ridgelines present a karstification causing an underground course of waters, in particular in the most calcareous sectors.

This complex hydrology joins within the framework of a relatively low human presence on the high river basin, even if extensive breeding is present. It is thus a question here of showing of what consists this high quality of waters and how it evolves from upstream to downstream, what is the impact of the karstic

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systems and in what way they can exercise an incidence on the mineralization of the water.

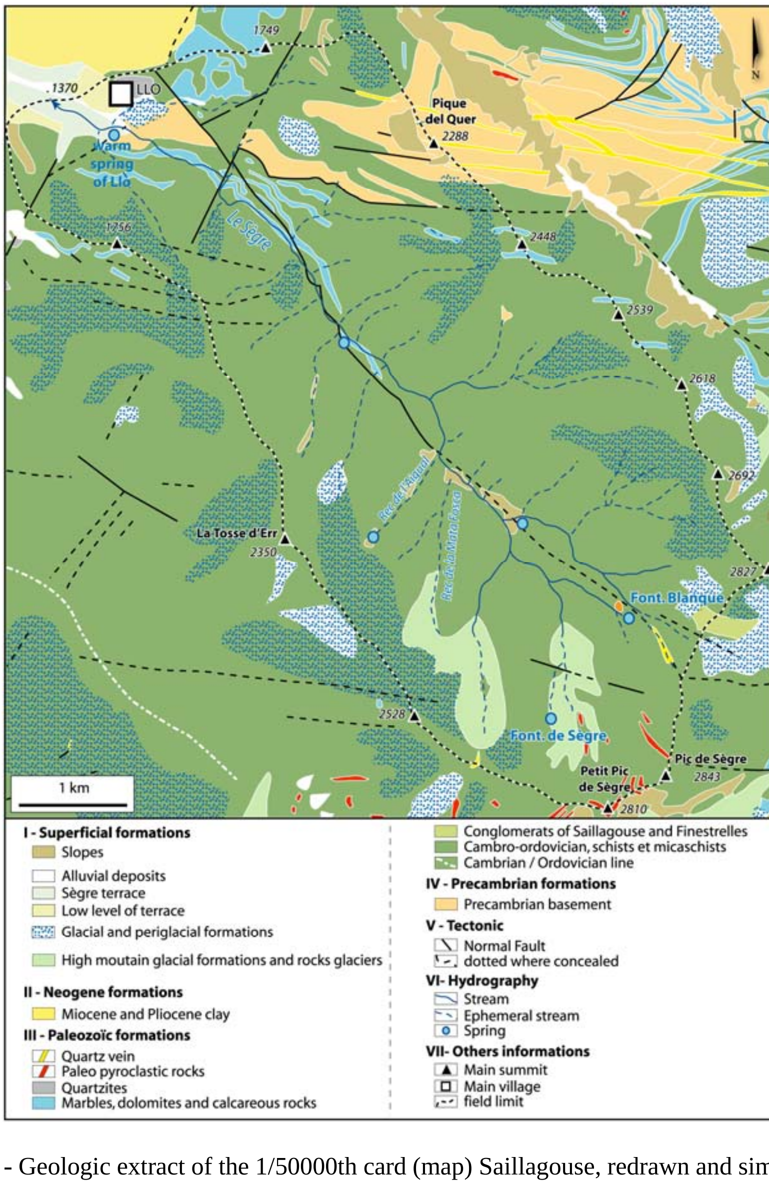

Fig. 1 - Geologic extract of the 1/50000th card (map) Saillagouse, redrawn and simplified

1. A context of wrinkled and fractured mountain in mediterranean domain

Before approaching the geomorphological frame of this cerdan river basin, some geological aspects have to be mentioned (Llac, on 1989).

1.1. A little river basin located in the axial zone of Pyrenees. The geologic frame of this region is complex. Cerdagne, to which belongs the river basin of Sègre, is part of the oriental part of Pyrenees. In broad outline, Sègre originates from the South part of the Pyrenean primary axial zone, on the border with Spain. It goes then northward, where it opens at Llo in the cerdane depression of Saillagouse. This last one is a fault basin of tectonic origin and it consists of a vast altitude plain (of 1300 m on average) of 30 km of main line, 4 to 6 km wide. This depression, filled by cenozoic detrital sediments, is framed in the North by the massif of Carlit and its altitude lakes (sector of Font Romeu and Mont Louis) and limited to the South by a big faulted structure, that of Têt-Conflent.

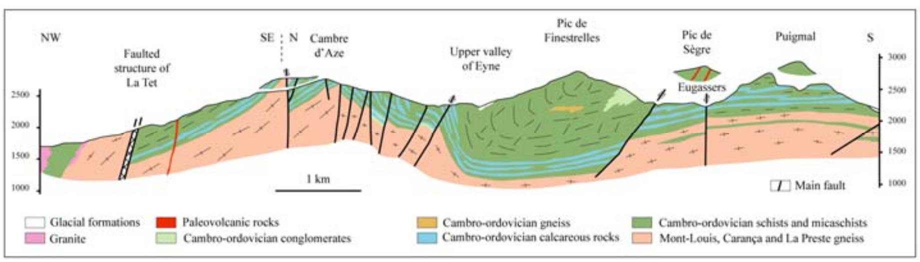

Fig. 2 - Geologic section of the South sector of the primary axial zone. The fault basin of Saillagouse is on the West of the fault structure of Tet. This geological section is extracted from the map Saillagouse in 1/50000th scale, redrawn and simplified

In the South of this faulted structure, we find mainly rocks associated with the Pyrenean Palaeozoic sequence (fig. 1 and 2). They are essentially cambro-ordovician's series consisted of schists, of calcschists and micaschists, reaching up to 1500 m of thickness in certain sectors. Inserted among them, we also find paleozoic limestones (of blue colour in the fig. 2), which allow a karstification. Certain sectors also present important rests of paleovolcanic of Palaeozoic period, essentially in acid context having the shape of veins.

All these geological sequences underwent important deformations, all the more important as we are situated in an essentially slaty domain, thus foliated and heterogeneous. It facilitated their deformation, their wrinkling and their fracture in particular in the sectors of higher resistance (fig. 3).

Fig. 3 - Wrinkled and deformed slaty sequence in the Valley of Sègre
(photo F. Hoffmann)

This structure facilitates the infiltration of in-depth meteoric waters, and amplified the frostwork during the cold periods of the Quaternary. As such, the imprints of the frostwork are numerous in this valley, following the example of very numerous Pyrenean valleys.

1.2. The Sègre Valley: a gorge with clear glacial imprints and a modest karstification. The river basin of Sègre is part of a context of mountain steep slope: in extreme upstream, the peak of Sègre has an elevation of 2843 meters, while in its outlet in the plain of Saillagouse, the stream is situated at 1370 meters, so a difference in height of more than 1000 m.

Certain sectors of the high valley present a morphology in gorge, (very narrow sector of flow of the water surmounted by an extension very clear enlargement of the upper part of mountainsides. It's not a complete U-shaped valley because only the top part of the valley is enlarged, the bottom is a gorge incised by the melt water just like that perfectly visible in the Valley of Sègre (fig. 4), since the sector of the San Feliu chapel.

In this context of hard rocks but sensitive to cold, the frostwork sculptured all the morphology of detail connected to the glacial and periglacial conditions:

revealing of rocky bars, U-shaped valley redrawing the profile of valleys in gorges, cirque in half bowl accumulating the snow, the important moraines and slope deposits (Viers, on 1971). Even if the quaternary glaciers were not fed as well as those further on the West, they left some tracks and printed their imprint in the morphology and the size of valleys (fig. 5).

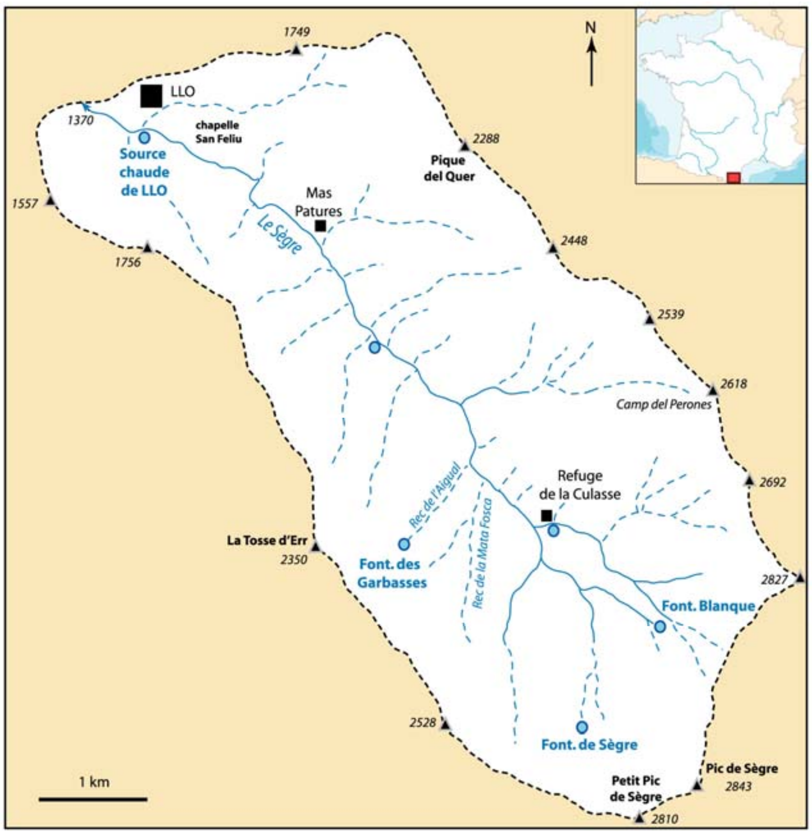

Fig. 4 - Drainage pattern of the Sègre river basin

Finally, the karstification remains moderated in this valley even if we indicate a cave of about forty meters deep to San Feliu. For the main part, it is a "linear" karstification adapting itself to the structural device.

Its main appearance manifests in the presence of springs, generally with relatively modest flows.

2. Hydrology and quality of waters of the upper Segre river basin

Before presenting the qualitative aspects of the water, it is necessary to precise some characteristics of the climatic functioning and mainly of the precipitation regime of this sector.

2. 1. A rather dry climate presenting a contrasted pluviometric regime. The regime of precipitations of this river basin integrates various influences connected to the double context, at the same time of mountain and situated in Mediterranean zone. The main part of the supply of the precipitation comes from the West and presents a decrease from West to East. An average of 1500 to 2000 mm of precipitation a year falls on the highest massifs (Duquesne, 2008).

Fig. 5 - Morphology in U-shaped valley and gorge (photo F. Hoffmann)

This zone also receives, less frequently, precipitations connected to the minimums of low pressure situated in the Mediterranean Sea, in particular during the autumn and winter. The reduction to the East of the elevation of Pyrenean mountains stopped the mechanism of orographic precipitation, coupled also with a frequently intense Tramontana. The mix of these influences determines a complex climate, facilitating the drying out of the atmosphere, and contrasted between the tops of mountain and the basin of Saillagouse.

The trend is all the same towards a relative drought and a strong luminosity, with only 600 mm / year on average in Cerdagne. Mount Louis presents a slightly higher pluviometry (780 mm), while the Valley of Tet remains relatively dry.

A part of these precipitations falls in form of snow. The wintry snow coverage becomes really efficient only as of 1500 m of height, even more durable over 2000 m. All in all, the cerdan climate remains relatively dry (Izard M., 1988) with a characteristic minimum in winter and a maximum at the end of the spring (in May, June). We can truly classify it as “dry oroclimate”.

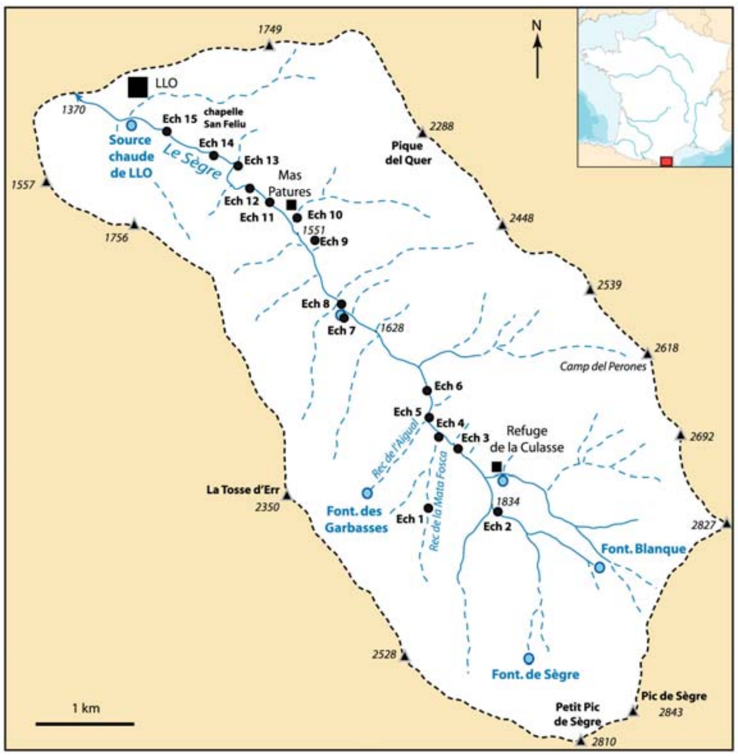

Fig. 6 - Location of samples on the river basin; for numbering see table n°1

2.2. General hydrology. Sègre illustrates well the typical example of the cerdan stream (fig. 4). Indeed, these valleys in the hydrological sense of the term play a fundamental role in the redistribution of waters and for landing in a way the hydric deficit of the cerdane depression.

Indeed, the climate shows easily a deficit of precipitation, in particular in the low sectors, and which contrasts with the flows sometimes supported by certain

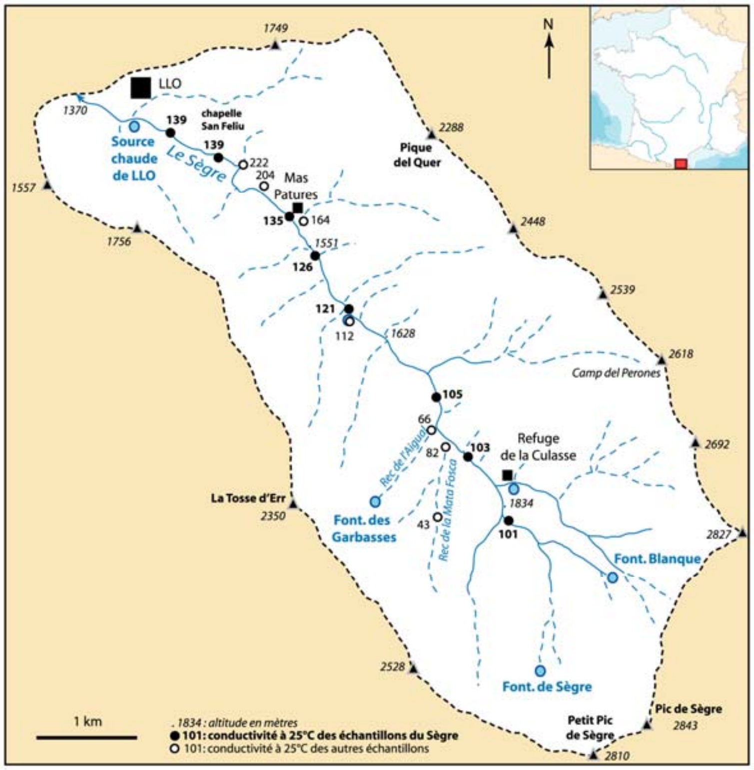

Fig. 7 - Water conductivities of the Sègre basin (august 2009)

streams. This situation is explained by several factors; this general plan can fluctuate from one year to the next according to climatic variability:

- *an upstream downstream redistribution*: the heights that peak about 3000 meters in height allow hanging on somehow the clouds and receiving more important rain quantities. A part of these precipitation falls in the form of snow and explains the seasonal gap in the return of waters;

- *the period of rains*: the main part of the precipitation is going to fall at the end of spring and in form of thunderstorms and is going to contribute to limiting the effect of maximal drought in summer. It explains the greenery of certain photos, all taken in August (after a relatively wet spring)!

- *the role of groundwater table and karst:* locally, these two types of structures can play a role in the gap of return of waters; there is at first storage of the in-depth water and the deferred return afterward.

About these structures, it is necessary to underline the significant role played by springs in the flow of streams. Distributed along streams, we often notice their hydroqualitative difference underlined by their thermal regime. They often present indeed temperatures lower than brooks because they are less affected by the summer reheating of waters (underground circulation). It is necessary to set apart also the warm spring of Llo (approximately 30°C) connected to a circulation in bigger depth in connection with the important fracturing of the sector. This spring, which we can qualify almost "as hypothermal" remains relatively little mineralized (0,5 mg / l of dissolved salts - Llac, on 1989).

The second element, which contributes to the distribution of waters is “Rec”. This term of Catalan origin, indicates a small more or less permanent stream corresponding to a "brook". Very numerous throughout the Valley of Sègre, they participate in the drainage of the valley side and they are often in connection with a small spring of valley side.

Therefore, the high ponds of valleys cerdanes generally present a good water supply in summer, allowing vegetation to develop. This water leaves then in the direction of the depression of Saillagouse by crossing more or less narrow gorges and meets this basin in order to take a West trajectory and to feed down South the important basin of Ebre, in Spain.

2.3. High quality waters. One of the initial means to approach the "natural" quality of waters, is to study the conductivities intrinsically linked to the mineralization of waters (fig. 7), expressed here at 25°C (Hoffmann F., 2005). Let us remind you that we talk about measurements made on a survey, in quiet hydrological conditions, but the obtained values remain indicative. They could not replace a regular diachronic and squeezed in time follow-up.

Tab. 1 - The main hydrochemical characteristics of samples in the basin of Sègre

Sample of the high basin of Segre, 3 et 4/08/2009

Sample	localization	T°C	C25 (µS/cm)	Turbidity (FTU)	Total Hardness (mg/l)	Carb. hardness (mg/l)	NO3 (mg/l)	PO4 (mg/l)
Ech 1 : Rec1	Rec Mata fosca amont	10°3	43,0	16,7	-	-	2,39	0,102
Ech 2 : SE1	Sègre : amont refuge de la culasse (1834 m)	10°1	101,0	0,3	71,2	17,8	0,88	0
Ech 3 : SE2	Sègre : aval refuge de la culasse	11°2	103,0	2,2	-	-	0,88	0
Ech 4 : Rec2	Rec Mata fosca aval	10°8	82,0	3,0	-	-	0,88	0
Ech 5 : Rec3	Rec de l'Aigual	11°0	66,0	5,6	-	-	2,39	0,037
Ech 6 : SE3	Sègre	11°8	105,0	3,2	-	-	1,16	0
Ech 7 : Sce1	Petite source (?) avant la barrière	8°6	112,0	3,5	80,1	35,6	0,44	0
Ech 8 : SE4	Sègre bassin médian (barrière)	12°1	121,0	3,0	-	-	0	0
Ech 9 : SE5	Sègre bassin médian (passerelle cote 1551)	12°3	126,0	2,0	-	-	0	0
Ech10 : Rec4	Rec Mas patures confluence avec segre	12°8	164,0	6,9	106,8	53,4	0,44	0,009
Ech11 : SE6	Sègre aval confluence Mas Patures	12°6	135,0	2,2	-	-	0	0
Ech12 : Rec5	Ecoulement de versant	13°7	204,0	4,2	124,6	80,1	0,71	0,01
Ech13 : Rec6	Ecoulement de versant mousse noirâtre	14°0	222,0	15,6	142,4	80,1	0,22	0
Ech14 : SE7	Sègre aval (au soleil)	13°6	139,0	3,2	-	-	0,49	0
Ech15 : SE8	Sègre aval (ombre)	13°0	139,0	1,7	-	-	0,27	0

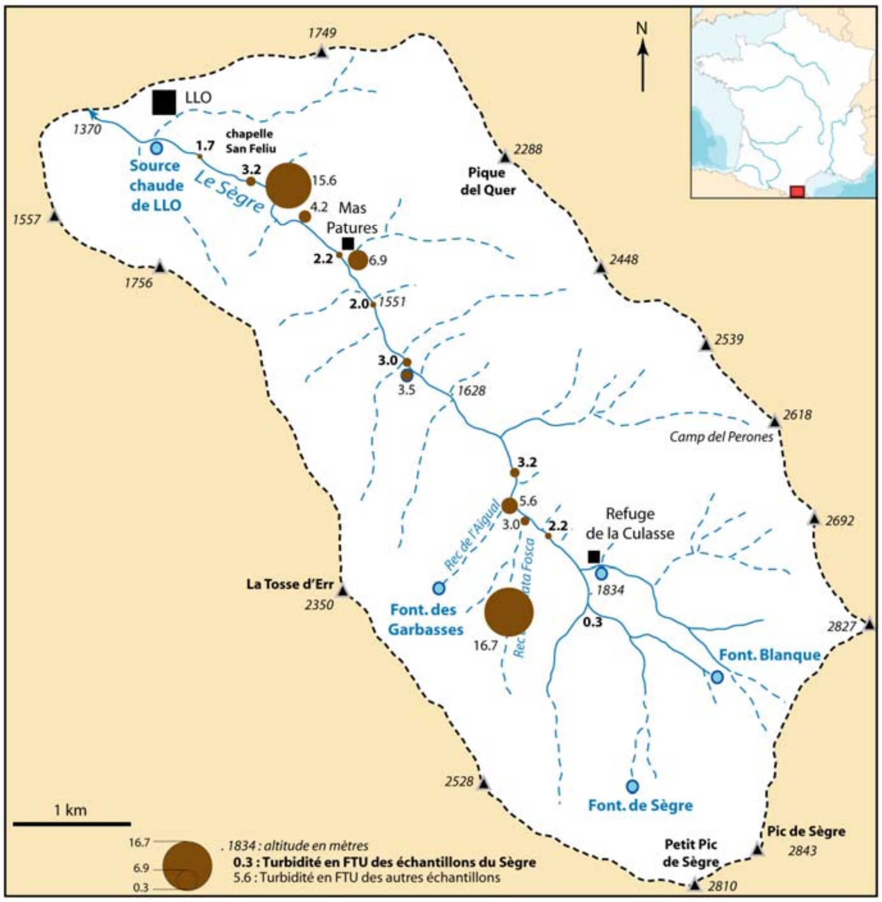

Fig. 8 - Water turbidity rates (august 2009)

Globally, the mineralization of waters remains relatively low, revealing the hydro-geologic context of the basin :

- a relatively fast transit of waters,
- minerals difficult to solubilize,
- the weakness of grounds, even under wooded or forest place setting.

The conductivities evolve between 43 µS/cm (Ech. 1, value close to those that we can find in rainwater), up to 222 µS/cm in certain sectors (Ech 13, tab.1). In a general way, the conductivities of Sègre increase from upstream towards downstream, going from 101 µS/cm to 139 µS/cm as those recs also increase. The strongest conductivities correspond to the most "karstified" sector, in particular that of the San Feliu chapel. There, Palaeozoic limestones are potentially more soluble and this means higher total hardness (142,4 mg/l or 2,85 méq/l or mé/l of CaCO3). The temperatures of surface waters are almost in thermal balance, warmed by the summer gentleness. They contrast with certain temperatures of springs (Ech 7: 8°7).

The content of chemical pollutants, nitrates and phosphates is very weak, absent in certain sectors. The highest values are close to what we can consider as "natural" values, that is close to 2 mg/l for nitrates (Hoffmann, 2005). The values equal to zero also indicate a phenomenon of consumption of the nitrogenous elements by the vegetation and the water plants. The rare traces of phosphates cannot be connected to wastewater, as is frequently the case of waters in France. Here, their origin is credibly natural, maybe mineral. Even there, it is necessary to be cautious regarding results isolated and disconnected from any hydroqualitative follow-up. Overall, waters have during this survey a high quality that confers them a patrimonial value, so difficult it is in France to find waters free from traces of pollution.

Finally, considering the location of the stream in the mountain area, it seemed interesting to deliver a snapshot of the values of turbidity in hydrological calm conditions (fig. 8). This parameter is directly linked to the conditions of circulation of waters in the basin, possibly to human activities (low impact here), slopes and losses in the ground. Globally, values are very low, for certain samples close to zero, indicating the high transparency of waters. Unlike the values of conductivity, we do not notice significant evolution of the contents of the upstream towards downstream. The highest values correspond to a transit of terrigenous particles, that are trapped by mosses in connection with local conditions. Let us remind you in the end that this turbidity can strongly increase thanks to a thunderstorm (muddy aspect of waters noticed visually during the period of the survey).

Conclusion

Waters of the upper basin of Sègre have a high quality in correlation with still relatively protected "natural" conditions. Even if this basin is the object of a Contract of river, this aims more at restoring the vegetation and the good state of the banks, than at restoring the quality of waters, as it is the case usually. It confers on this basin an almost patrimonial value, meaning it is necessary to preserve these spaces of high biological and hydrological quality (just like the botanical reserve of the Valley of Eyne situated east of that of Sègre). These spaces are always rarer in our country and particularly in the southwest of France.

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