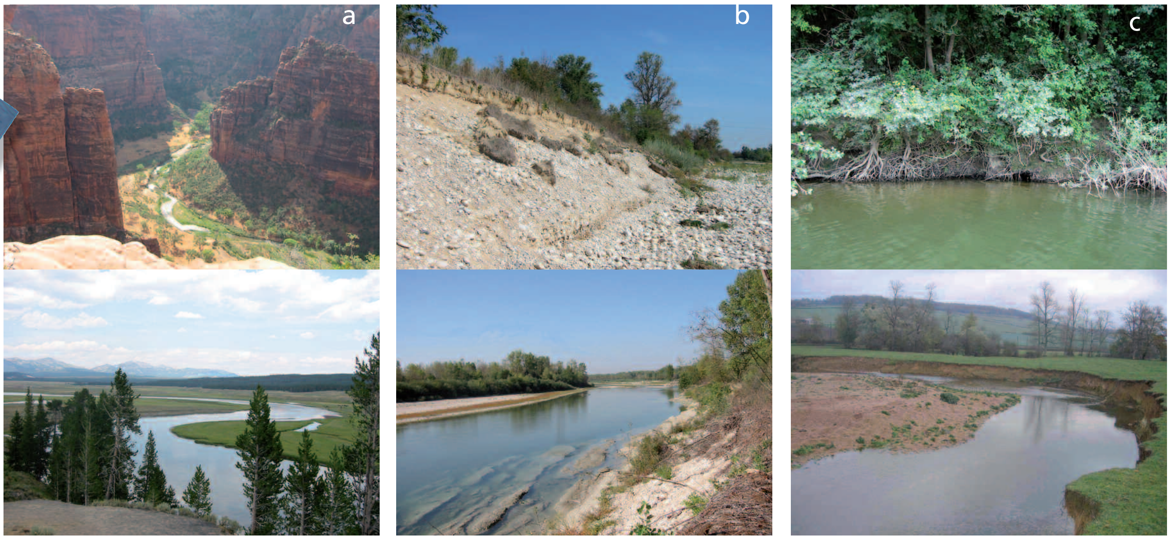
Control factors and geodynamic ranking

Additional control factors

As noted above, other control factors, in addition to the water and sediment discharges, have varying impacts on geodynamic processes and the resulting landforms (see Figure 32), namely:

- the slope and width of the valley bottom where the river flows (a);
- the greater or lesser cohesiveness of the alluvium in the valley bottom (or of the substratum), making up the banks and riverbed (b);
- the type and density of the riparian vegetation (c).

Figure 32



The additional control factors (according to Thorne, 1997).

Valley-bottom slope, width and type of alluvium

Water and sediment discharge are without any doubt the two main control factors in river geodynamic processes, however, other parameters can also heavily influence the mechanisms involved and the resulting river characteristics, notably the valley slope, its width and the type of sediment along the valley bottom. Contrary to the two main factors, these factors do not fluctuate over time and impose significant and lasting geomorphological constraints.

The characteristics of all rivers flowing today in a valley are therefore largely determined by:

- the **valley slope** which, in conjunction with the water discharge, determines the **maximum available energy.** The valley slope is the product of periods of high hydrosedimentary activity resulting in either the creation of a stored volume of alluvium (accumulation) or the removal of alluvial deposits, in which case a deposit is created below the original accumulation site which subsists as a terrace or the remains of terraces.

NB The slope of the river draining the valley is always less than (because rivers are almost always sinuous) or at most equal to the valley slope (if the river is straight or braided).

- the **width of the valley bottom,** which provides the river with more or less **mobility space** to move about;
- the **alluvium in the valley bottom**, which can be more or less erodible, depending on its cohesiveness. If the valley bottom is made up of bedrock, it is not erodible on a human time scale, unless the rock is particularly soft, e.g. certain types of non-cohesive soft sandstone or certain marls or calcareous marls, which may

be found, for instance, in the Allier riverbed in the Limagne region in France:

- high cohesiveness: clay, silt;
- low cohesiveness: sand, gravel, pebbles.

These secondary control factors are highly dependent on the geological history (both old and recent) of the region.

The figures below, showing the Loue River basin (Franche Comté, France, Malavoi, 2006), illustrate these concepts.

The basin is part of an extremely varied geological context.

Over the first 90 kilometres (sector 1), the Loue drains the limestone Jura range (first plateau). In spite of millions of years of erosion by the river, the Loue valley is fairly narrow (100 to 600 metres). The slope is greater than 0.002 (2 metres per kilometre) and the alluvium in the valley bottom are rather cohesive.

The last 30 kilometres (sector 2) lie in the Bresse Plio-Quaternary basin, made up of soft, easily erodible rock, where the major Quaternary erosive processes, driven notably by the glacial periods that impacted the Jura range (particularly during the Riss stage), resulted in an alluvial valley several kilometres wide, covered with coarse river and fluvio-glacial sediment. The slope is less steep (0.001) and the alluvial deposits are not cohesive, i.e. more easily erodible.

Figure 33

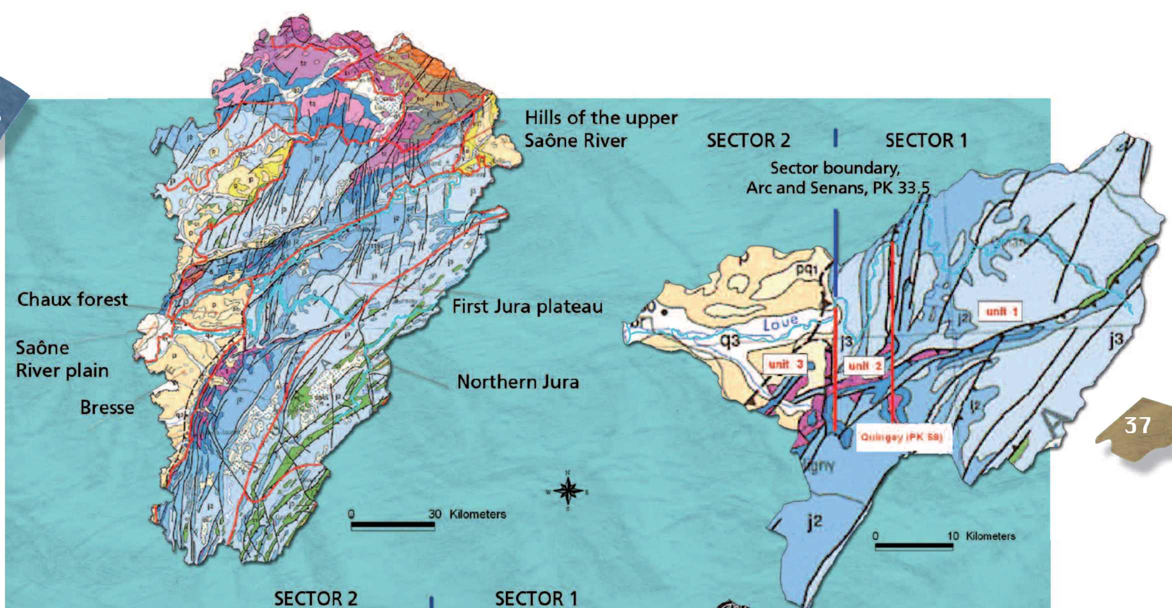
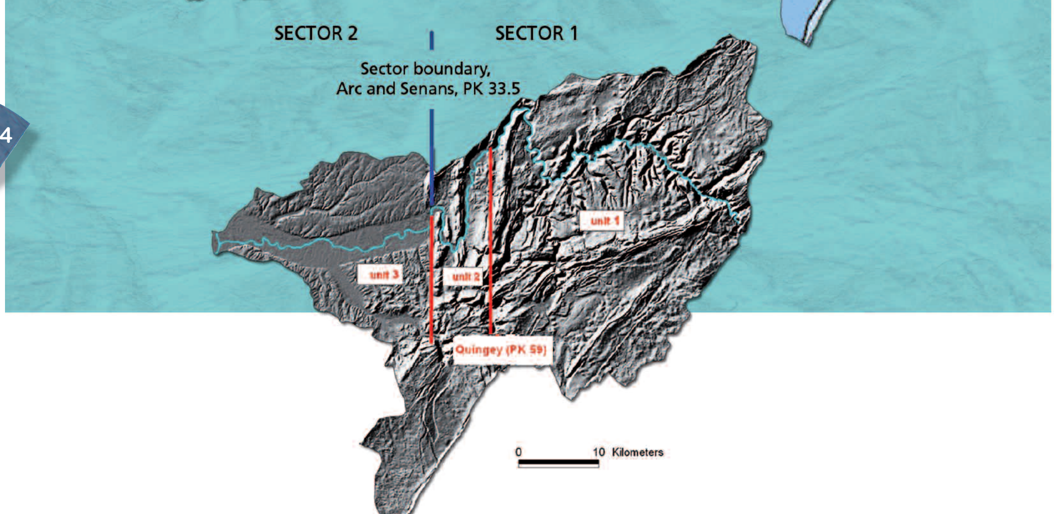


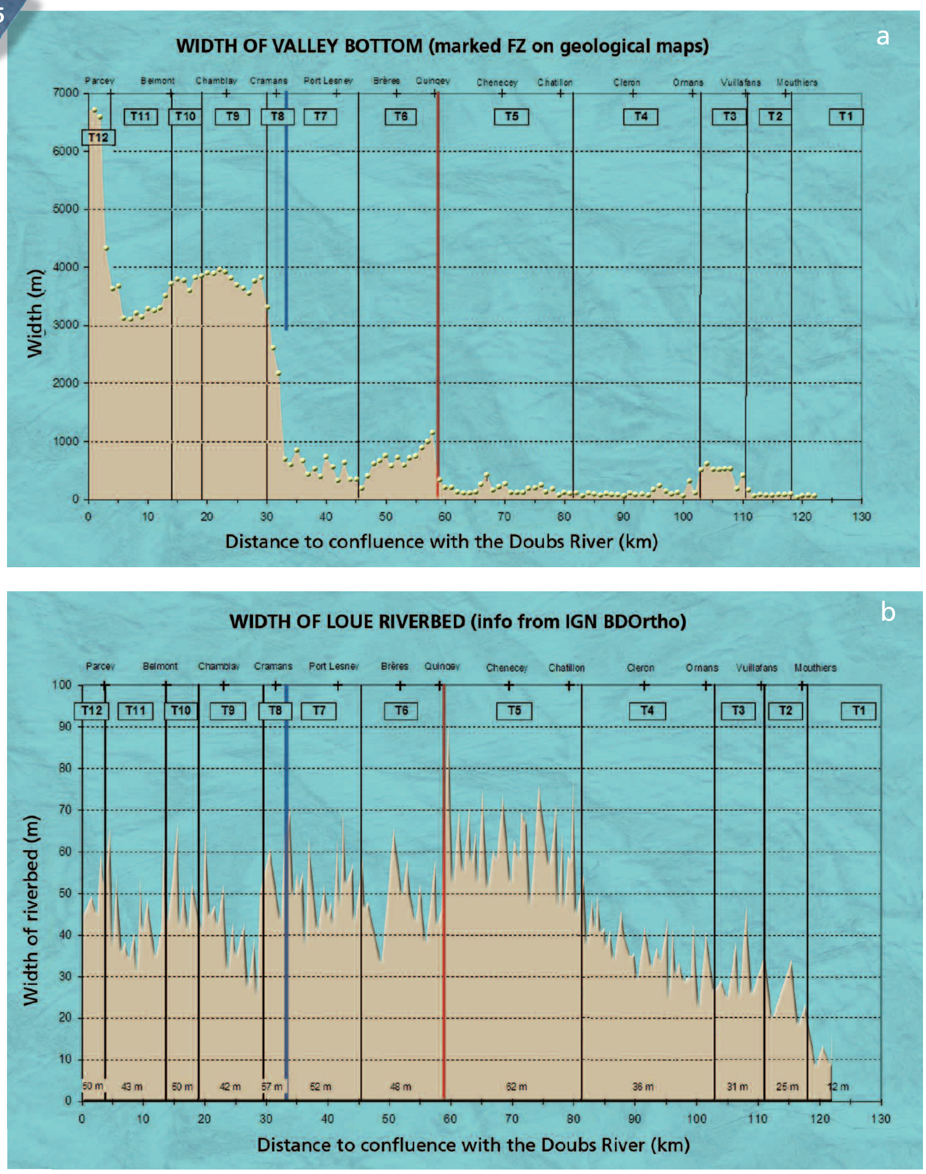
Figure 34



Simplified geological map of the Franche-Comté region with a zoom on the Loue River basin. The thick blue line is the Loue riverbed, the finer blue line is the Doubs riverbed. BRGM map on the 1:1 million scale.
Figure 34 shows the relief of the same river basin (Malavoi, 2006).

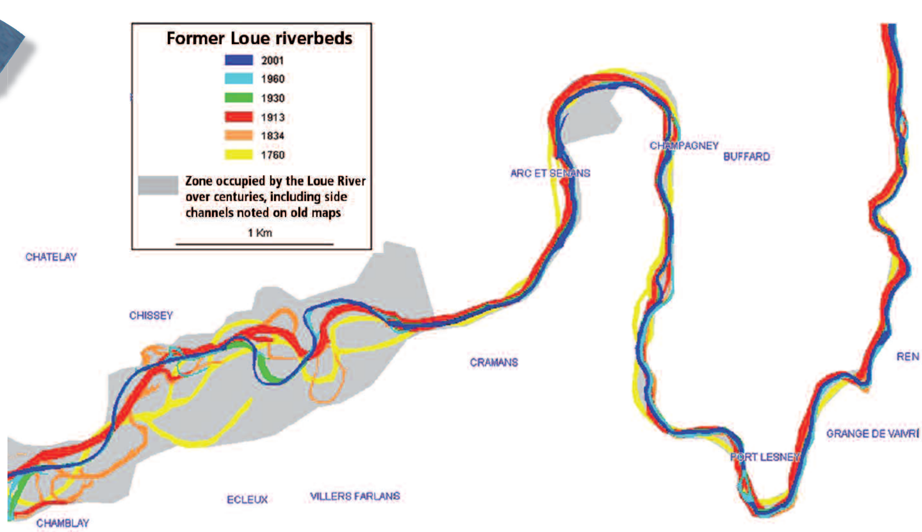
It is fairly obvious that the processes at work in the Loue River and its morphologies differ between the upstream section (unit 1), where it flows in a narrow, steep valley, and the downstream section where flows into the Bresse basin (unit 3).

Figure 35



Change in the width of the valley bottom and the Loue riverbed from the source of the river to the confluence with the Doubs River. The blue line separates the sectors and marks the beginning of unit 3. The red line marks the beginning of unit 2. The black lines indicate the reaches (see the chapter on determining river divisions). (Malavoi et al.*, 2006)*

Figure 36



Note the sudden change in the level of geodynamic activity of the Loue River on leaving unit 2 and entering unit 3 (the map shows the former river patterns). (Malavoi et al.*, 2006)*

Vegetation on river banks

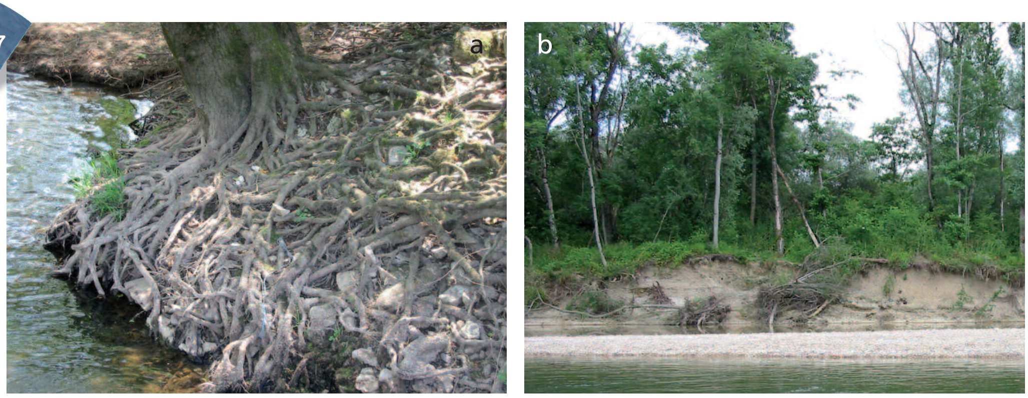
Many authors are of the opinion that the type and density of the vegetation growing on river banks constitute a major control factor weighing on geodynamic processes and the resulting river morphologies.

Contrary to the other control factors, this is a **living** factor, i.e. it is particularly sensitive to both natural and anthropogenic influences.

Ceteris paribus, it has been shown that a river with banks naturally vegetated with plant species dependent on river biomes is narrower and deeper than a similar river with banks that are not or are only slightly vegetated.

Widths differing by a factor of two are not rare between two rivers, one with heavily vegetated banks and the other with non-vegetated banks. However, this control factor would seem to produce results inversely proportional to the size of the river. Small rivers are highly affected, whereas in large rivers, the geodynamic processes dominate. This is due notably to the fact that, for equivalent river patterns, small rivers have proportionately lower banks on which the roots of plants can provide physical protection virtually down to the foot of the bank. Conversely, in large rivers, the banks are generally higher and the roots of trees and shrubs, even when the riparian vegetation is dense, often do not reach the foot of the bank, the part of the cross profile most exposed to erosion.

Figure 37



a- b- © J.R. Malavoi

(a) Bank of a small river highly stabilised by the roots of the riparian vegetation (alder tree). (b) In a large river, the high banks limit the protection provided by the vegetation because the roots do not descend low enough.

Concerning lateral erosion, many studies have demonstrated the stabilising role played by vegetation, even if, once again, the effects produced are greater in small rivers than in large ones.

For example, Beeson and Doyle (1995) studied 748 meanders in British Columbia, just after heavy floods. Using aerial photographs pre- and post-flood, they showed that non-vegetated banks suffered **five times more erosion** than vegetated banks. Similarly, events causing significant erosion occurred 30 times more often along non-vegetated banks.

Base level

One last significant control factor is the variability of the **"base level"** (e.g. sea levels) that can provoke major geodynamic adjustments following sizable rises or drops in the level.

This factor will be discussed in the section on adjustments in the long profile.

Geodynamic ranking

As noted above, the type and intensity of river geodynamic processes and the resulting landforms depend on a number of control factors, namely water and sediment discharges, the type of alluvium in the valley bottom, etc.

In the absence of a standardised, functional river typology, the authors (Biotec, Malavoi, 2007) thought it might be possible to propose a simplified typology determined, for consistent geomorphological reaches, by measuring or at least estimating three factors:

- stream power;
- bank erodibility;
- volume and type of sediment injected directly or indirectly into the river.

Though these three factors do not represent all the control factors, they nonetheless significantly determine:

- the geomorphological characteristics of rivers, i.e. their cross profile, pattern, type of alluvial substrata, current or potential intensity of processes resulting in lateral erosion, vertical erosion and sediment transport;
- overall ecological characteristics;
- geomorphological-adjustment capacity following channelling or restoration work.

We postulate the following points.

- The higher the stream power
- The more the banks are erodible
- The higher the volume of sediment input

⇒ the more intense the geodynamic processes
⇒ the higher the resilience of the river to anthropogenic "aggression" and the greater its capacity to recover, both physically and ecologically
⇒ the longer the benefits drawn from hydromorphological restoration and the lower the cost, because the river itself will do most of the restoration work

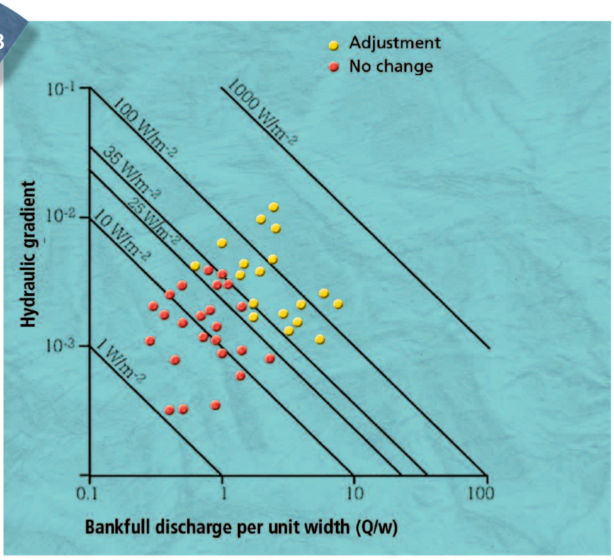
Scientific basis

■ Unit stream power

It has been known for years that the adjustment capacity of a river depends largely on its unit stream power. The pioneering work by Brookes (1988), followed by Wasson *et al.* (1998), made major progress on the subject. In highly condensed form, it may be said that the results produced by Brookes identified two thresholds for unit stream power:

- a "major" threshold of approximately 35 W/m², above which the natural power of formerly channelised rivers enabled them to readjust and recover, slowly but surely, a more natural configuration;
- a minor threshold of approximately 25 W/m², below which the river dynamics were not sufficient for a return to the former morphology;
- no other power values revealed any additional thresholds.

Figure 38



Unit stream power thresholds (according to Brookes, 1988, in Wasson et al.*, 1998).*

■ Bank erodibility

Studies carried out by the authors would indicate that the 25 and 35 W/m² thresholds can be determined more precisely and adapted taking into account the sediment characteristics of river banks and notably their erodibility, which itself depends on the cohesiveness of the alluvium along the valley bottom.

Rivers with low power levels (10 to 15 W/m²) may have relatively high levels of geodynamic activity if their banks are not very cohesive and if they receive from upstream a certain quantity of coarse sediment which, by forming point bars, increases the erosion along the opposite bank.

Conversely, **rivers with high power levels** (40 to 50 W/m²), but flowing in alluvial plains comprising more cohesive sediment (clay, silt, sandy loam), are less active, particularly if the sediment from upstream is limited in volume and made up of small grain sizes.

To date, there is no standardised method to determine the erodibility of banks (with the exception of the Schumm coefficient which quantifies the percentage of clay and silt, the elements conferring cohesiveness to sediment and enhancing bank resistance to erosion, see the section on hydraulic geometry). In the chapter on "Tools for hydromorphological studies", we discuss methods and provide some visual examples for a simplified technique to estimate this factor.

■ Sediment input

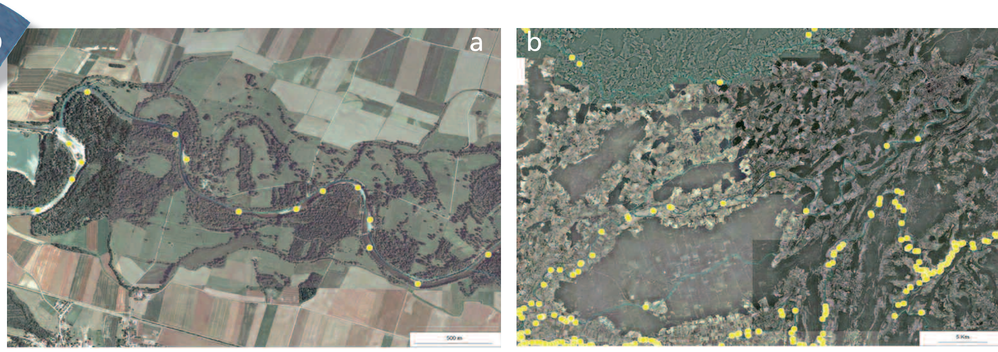
In addition to their role in activating lateral erosion (flow deflection, an effect that we will discuss later), input and deposition of coarse sediment are extremely important factors for the geodynamic equilibrium (Lane's balance). They also produce the **alluvial substratum** providing an indispensable habitat for many species making up the aquatic and riparian living communities.

To date, no method exists to rank, in a simple manner, the intensity of sediment inputs in a river. The simplified method that we currently use is based on analysis of aerial photographs produced by IGN (French National Geographic Institute) and notably those in the BDOrtho database offering an image resolution of 0.5 metres (see the chapter on "Tools for hydromorphological studies"). This approach is purely qualitative because it deals exclusively with mapping of storage areas. It is presented here for informational purposes only and would require further work before it could be used as a standardised method.

Two levels of precision are possible:

- alluvial macroforms can be identified by simple dots (see Figures 39 and 40);
- macroform shapes may be more precisely defined in a digital system for better quantification of the processes at work (macroform surface areas, see Figure 41).

Figure 39

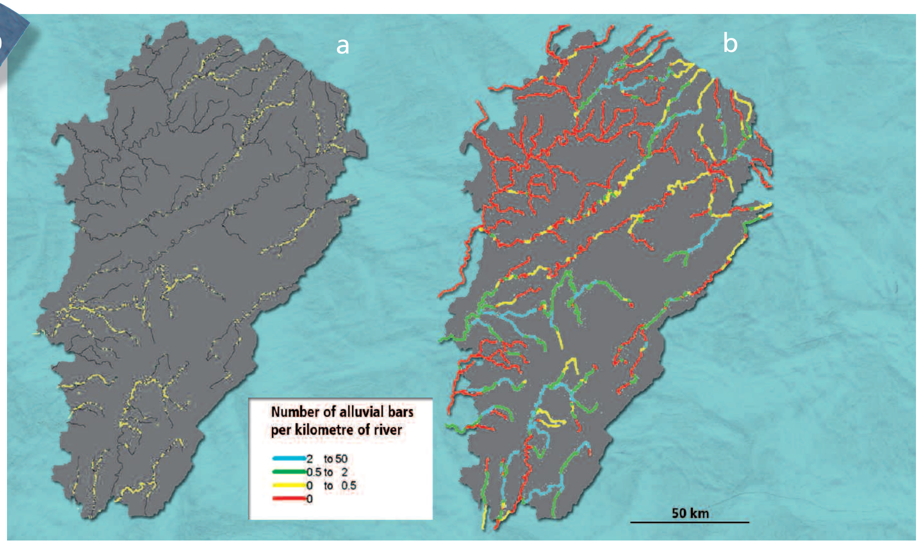


a- b- BD ORTHO ® 2001. © IGN 2010

Franche-Comté. Examples of locating and simplified mapping of visible alluvial bars using a GIS (geographic information system) (Malavoi et al.*, 2006). Each alluvial bar is represented simply by a dot.*

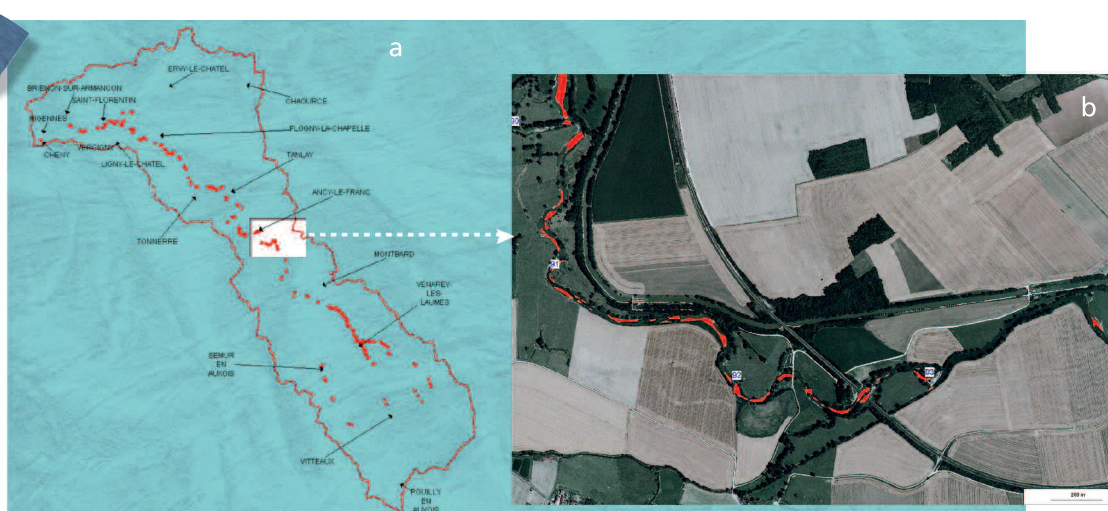
The results can then be shown on a map to distinguish between rivers depending on the density of their alluvial storage areas. The information can be shown directly (e.g. the number of bars per kilometre of river in the figure below) or in dimensionless form (number of bars per unit channel width).

Figure 40



Example of mapping the density per kilometre of exposed alluvial bars in Franche-Comté rivers (Malavoi et al.*, 2006). (a) Bars represented simply as dots, (b) Map showing density levels.*

Figure 41



BD ORTHO ® 2002. © IGN 2010

Example of a digital presentation of alluvial bars (Armançon River). The blue numbers indicate the distance in kilometres from the confluence with the Yonne River (Malavoi and Hydratec, 2007).

Unfortunately, three factors can introduce considerable uncertainty when evaluating the actual sediment transport in a river.

- If the discharge is high when the IGN images are taken, it can mask alluvial bars and if it is very low, it can exaggerate their density. Under ideal conditions, this study should be carried out using an equivalent discharge for all rivers (e.g. the interannual mean discharge of the low-flow month). However, by comparing the image date and the available hydrological data for the river sector, it is possible to eliminate most of the uncertainty.
- Riparian vegetation can occasionally mask all or part of the river. This method produces good results in reaches where the vegetation has been cleared out (!). This factor may result in the observed sediment flows being significantly underestimated in reaches where the channel is hidden.
- Turbulence caused by weirs and dams can also mask existing bars, however, in this case, they are submerged. Note that a major part of the sediment is trapped until a steady gradient is created behind the obstacle.

NB Additional measurements in the field may be necessary to fill out the data, depending on the particular study, e.g. it may be necessary to measure the volume, thickness and/or grain-size distribution of alluvial bars for a study attempting to determine sediment transport in a river.

Proposal for a simplified geodynamic typology

On the basis of the three factors discussed above and in spite of the remaining difficulties in obtaining good measurements, a simplified geodynamic typology would appear possible. It could be implemented nationally or progressively improved during specific studies (river contracts, sub-basin management plans, etc.). The three factors are:

- unit stream power (ω);
- natural potential erodibility of banks, not taking into account any protective systems (B);
- sediment inputs (A).

Table 3 *The four factor classes used to distinguish the geodynamic reactivity of rivers.*

	1	2	3	4
Unit stream power (ω)	< 10 W/m²	10 - 30 W/m²	30 - 100 W/m²	> 100 W/m²
Bank erodibility (B)	Zero	Low	Medium	High
Sediment inputs (A)	Zero	Low	Medium	High

For example, a river of the ω4/B3/A3 type (high unit stream power, medium erodibility and sediment input) is probably highly reactive and any restoration work would be very effective and rapidly produce positive results. On the other hand, a ω1/B2/A1 river (very low unit stream power, low erodibility and no sediment input) is not very dynamic, is more sensitive to hydromorphological alterations and more difficult to restore.