Tools for hydromorphological studies

The basic approach to hydromorphological studies

The very first question to ask concerns the goal of the hydromorphological study that one wishes to have done (if you are the owner) or to do (if you are the consultant).

There are three main categories of hydromorphological studies (outside the field of hydrology) and thus three goals for which the suitable tools and the resolution (physical scale) may differ.

Comprehensive study. This is currently the most frequent type of study that is generally carried out when preparing an SBMP (sub-basin management plan) or a river contract. The objective of the hydromorphological section of this type of study (often carried out in conjunction with sections on water quality, hydrology, flooding risks, aquatic environments, landscape, occasionally with sections on economic and land-ownership aspects) is to:

- understand the hydromorphological operation of the river on the scale of the river basin and of uniform reaches;
- identify hydromorphological malfunctions and their causes;
- propose management techniques to repair the malfunctions and preserve the remaining functional reaches.

On large rivers, these comprehensive studies may be carried out on sub-basins (Downstream Allier River SBMP, Lower Ain River SBMP, etc.).

NB A hydromorphological study on a sub-basin must nonetheless collect a minimum amount of data on the river basin as a whole, particularly if the studied sub-basin is located in a lower section of the river basin.

Local study. In general, the goal is to solve a local, hydromorphological problem, e.g. the risk of erosion at an abstraction, of the river bypassing a bridge, of installations being undermined, of excessive aggradation over an urban reach.

NB Even for local issues, it is necessary to gain some perspective by analysing at least the hydromorphological operation of the concerned reach or of several reaches both upstream and downstream (sediment input, regressive erosion, etc.

Similar to a comprehensive study, the purpose of a local study is to:

- understand the hydromorphological operation of the river on the scale of the uniform reach in which the problem is located and at least the adjacent upstream and downstream reaches;
- identify the general and the local hydromorphological malfunctions (and their causes) that may lie at the origin of the problems requiring the study, e.g. a bridge may be undermined by regressive erosion caused by an old gravel pit located ten kilometres downstream;
- propose technical solutions to solve the local problem and management techniques designed to eliminate the overall cause of the malfunction, if it has been identified.

Topical study. This type of study generally targets a specific goal over a more or less long reach, e.g. defining a mobility space, characterising sediment transport, laying the groundwork for a hydromorphological restoration project, etc.

NB This type of study should theoretically be carried out during or after a comprehensive hydromorphological study which arrived at the conclusion that it is necessary to map a mobility space, better analyse sediment transport in the river or restore its morphology and geodynamic processes.

The greater part of a hydromorphological study and particularly the first part take place in the office, analysing maps, drawings, aerial photographs, etc. With the exception of a possible initial visit, measurements in the field are generally carried out once the main elements of the diagnosis have already been established.

A hydromorphological study is like a visit to the doctor.

During a 20-minute visit, the doctor spends 15 minutes (75%) to diagnose the illness and five minutes to select the most suitable treatment.
The work and the proportions are identical for a hydromorphological study. Most of the study is devoted to diagnosing the problem, i.e. to determining the hydromorphological malfunction (symptom) and the causes (etiology). If this part of the study, the longest, is correctly carried out, it is "easy" to identify the correct treatment.
Note that these remarks are limited to management guidelines and general orientations. The preliminary studies for work projects in a river are more complicated and may require a great deal of time (detailed drawings, additional measurements, etc.).

The goal of the field work is to:

- check the hypotheses, e.g. whether the planform stability of the river in a given sector is in fact due to the bank-protection systems, whether there is in fact general bed degradation over the reach given the excavations that occurred in the past, etc.;
- acquire certain information required for a precise diagnosis, e.g. sediment grain size in the riverbed, on the banks, stratification of bank alluvium, topographic surveys, etc.;
- meet people holding specific information (inhabitants, fishermen, etc.) and likely to assist in understanding the operation of the river.

All hydromorphological studies should also begin by reading (with a critical eye) the previous studies on the river and the basin, i.e. hydrological, hydraulic, ecological studies, etc.

Maps and drawings

Maps, both old and recent, are analysed for a number of reasons.

- Viewed individually, they provide information on the river in its geographic and historic context. This is called the **synchronic** approach.
- When compared with maps from other periods, particularly in conjunction with a GIS (geographical information system), **diachronic** analysis becomes possible, i.e. the researcher can track and, with some luck, understand the evolution of the river over time.

Modern maps

Maps and scans from IGN (French National Geographic Institute)

IGN maps (1:25 000, 1:50 000 scales, etc.) are now available on paper, as georeferenced scans (Scan25, 100, 1 000, etc.) and as vector maps on the 1:25 000 scale (BDtopo).

The data for these maps are provided by aerial photographs. Until the 1990s, they were updated approximately every 15 years, i.e. following every third series of aerial photographs.

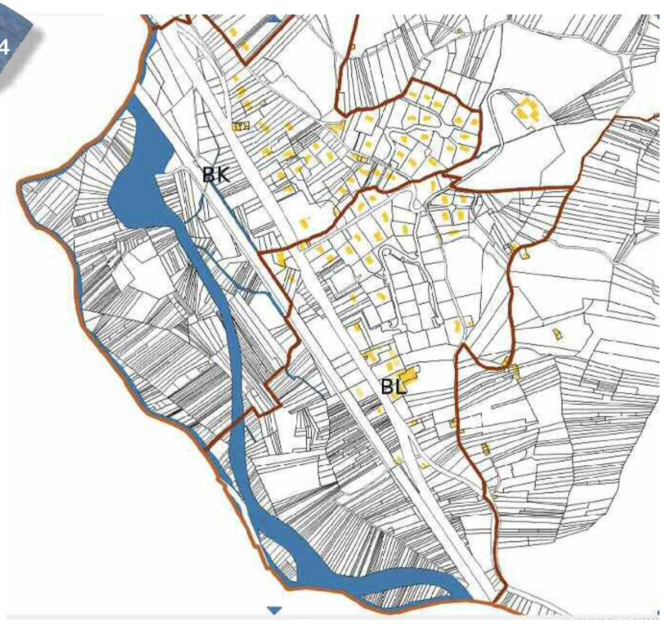
Current Land Register

The French Land Register is a mapping system set up for tax purposes, i.e. to calculate land taxes. Its primary advantage compared to standard maps is the scale between 1:500 and 1:5 000. Its main disadvantage is that the frequency of updates (and consequently its value in analysing river channels over time) is highly variable across the country (see Figure 165), however efforts to standardise update frequencies are now being made. Each French town is divided into sections presented on individual maps showing each unit of property, the **lots.**

The Land Register is currently available on paper, in digital form (raster) and as a vector map that can be used in a GIS to extract information.

It may also be displayed on the IGN Geoportal.

Figure 164



© http://www.cadastre.gouv.fr/

Example of a vector map of a town. Town of Ambérieux (Ain department) (source: http://www.cadastre.gouv.fr/).
Note the extremely small size of lots and their frequent orientation perpendicular to the river (access to water is important in agricultural zones).

Figure 165

Image of the same area drawn from the Land Register and BDortho on the IGN Geoportal. Note the difference between the river in the previous figure and the current channel of the Albarine River, due to the fact that the Land Register is updated much more slowly than the river moves laterally.

■ Maps and scans from BRGM (Mining and Geological Research Agency)

BRGM produces geological maps of France on a variety of scales. They are currently available on paper, as scans and vector maps.

These geological maps show rivers in their geological context, an important factor in a hydromorphological study, on both the:

- river-basin scale, for example, they indicate the erodibility and permeability of the substratum;
- scale of the valley, for example, they show mobility spaces and geomorphological "bottlenecks" (narrow passages for the river).

1:50 000 scale map

This is currently the most precise and useful scale for hydromorphological studies. Continental France is covered by 1 060 maps, each representing a zone approximately 20 x 30 km. Some of these maps are now available as vector maps (contact BRGM for more information) and can be used for in-depth GIS analysis.

1:80 000 scale map

A total of 55 maps cover all of France, but use of these much older maps is advised only if the 1:50 000 scale map has not yet been made available (some 30 are still in production).

1:250 000 scale map

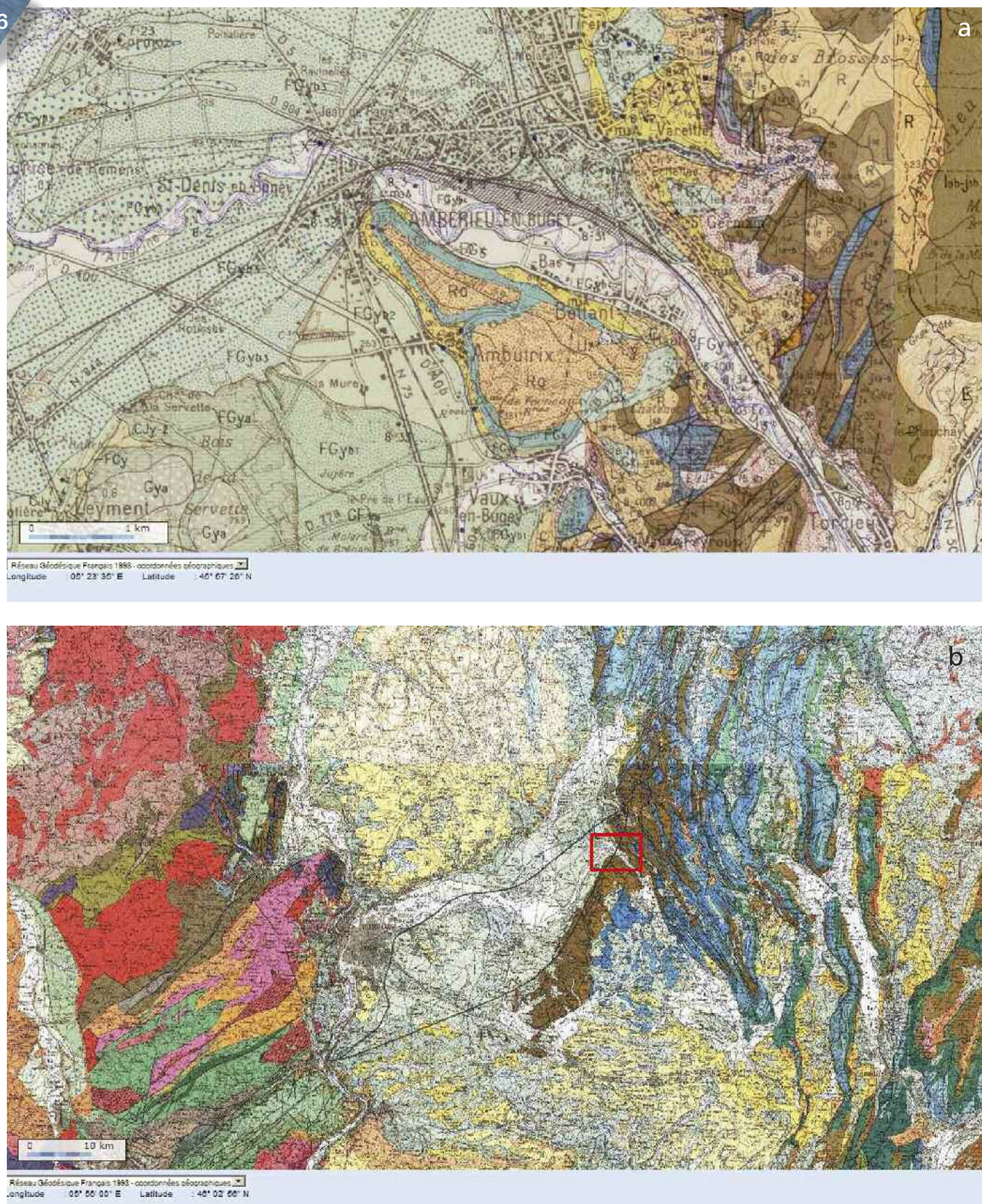
This scale is useful for analysis on the regional level of the major river basins. Fifteen maps out of the total 44 are currently available.

1:1 000 000 scale map

This map presents the geological characteristics of all of France. It is useful for an initial analysis of the overall geological context of a large or very large river basin (Loire and Rhône Rivers, etc.).

All of the above maps may now be consulted on the IGN Geoportal. The scale of the geological map is selected automatically as a function of the zoom factor (see the example below).

Figure 166

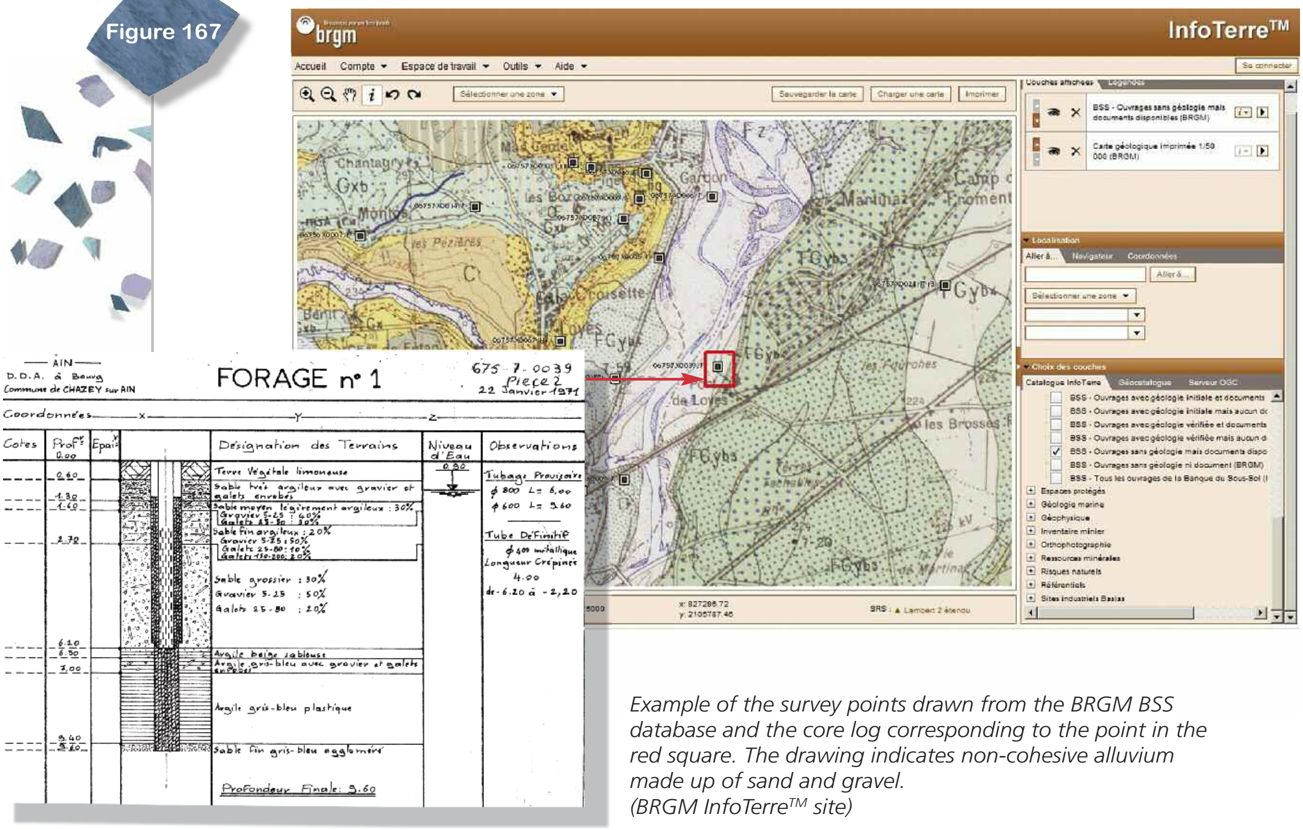


a- b- © BRGM © Géoportail IGN

The images above show two of the scales for geological maps on the Geoportal, selected as a function of the zoom factor, (a) 1:50 000, (b) 1:250 000.

Note also the existence of the BRGM InfoTerre™ site offering not only geological maps, but also stratigraphic profiles from the BSS database. When profiles of the valley bottom exist, they may provide an initial indication on the type of sediment in the floodplain, which can at some point become the sediment making up the river banks. This information may be useful in determining the cohesiveness of the bank sediment, which is one of the main control factors in geodynamic processes.

Figure 167



© BRGM

Example of the survey points drawn from the BRGM BSS database and the core log corresponding to the point in the red square. The drawing indicates non-cohesive alluvium made up of sand and gravel.
(BRGM InfoTerre™ site)

Old maps covering all of France

■ The Cassini map

In 1747, Louis XV charged César Cassini de Thury with the task of producing a map of the entire kingdom, which subsequently became the Carte générale et particulière de la France, the first systematic map to cover all of France. The first section (Paris) of the Cassini map (scale 1:86 400) was published in 1756.

The **main landmarks** were the **church steeples** in each village, considered permanent and reliable reference points for centuries to come. For each section of the map, hundreds of reference points were calculated by triangulation and linked to the general triangulation network terminated in 1744. The map was finished in 1815 by the son of César, Dominique Cassini. Watermills were positioned accurately (primarily for tax reasons because they were subject to tax). This is useful information because it is possible to know the minimum age of each mill and its legal status (most mills on the map were granted feudal title rights).

The Cassini map is available at the IGN public map service in various forms (photocopies, scanned files) and prices. It can also be fairly accurately georeferenced in a GIS, using the centre of the circles indicating church steeples (circles with a cross). Then simply determine the Lambert coordinates of the same circles using the Scan25 map, on which they should theoretically be identically positioned.

On the other hand, the accuracy of the drawn river channels is highly variable, depending on whether the river is in the low lands (fairly good accuracy) or in the mountains (low accuracy) and on whether the river is large (fairly good accuracy) or small (low accuracy for rivers less than 20-30 metres wide).

The Cassini map is also available on the IGN Geoportal.

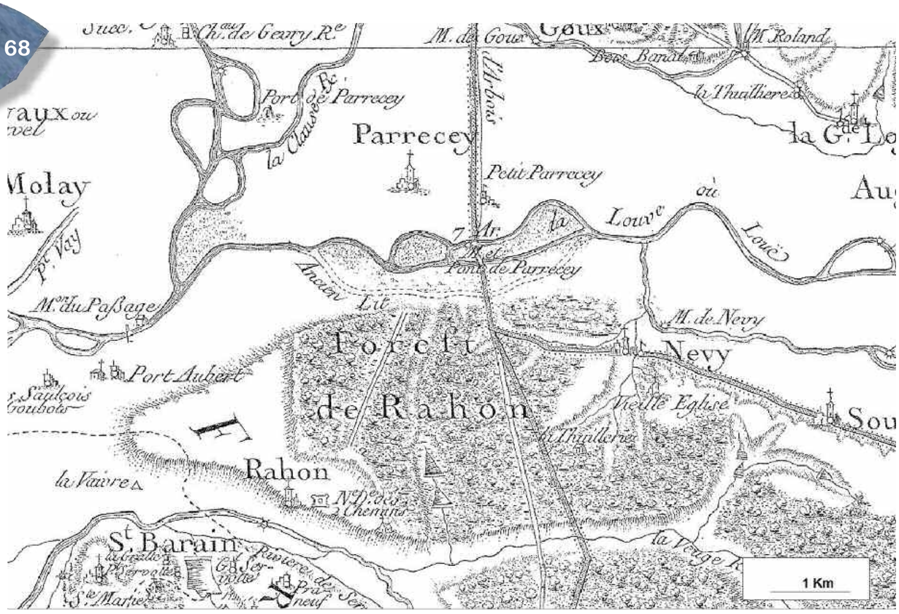
■ Military maps

Military maps covering all of France were drawn up in the 1800s. They were initially intended for military purposes, i.e. knowledge of the terrain with particular attention paid to roads and rivers. The original name was the "War Depot Map" and the scale was 1:40 000. The maps were based on a more dense triangulation network. Work started around 1820 and the first series of maps was finished during the 1860s. At the end of the 1800s, the first version of each map was still prepared on the 1:40 000 scale, while the maps themselves were published on the 1:80 000 scale.

The military maps are available at the IGN public map service in various forms (photocopies, scanned files) and prices.

NB It is possible to request the 1:40 000 initial versions of the maps, which are more precise than the final maps.

Figure 168



Excerpt of the Cassini map. © IGN 2010

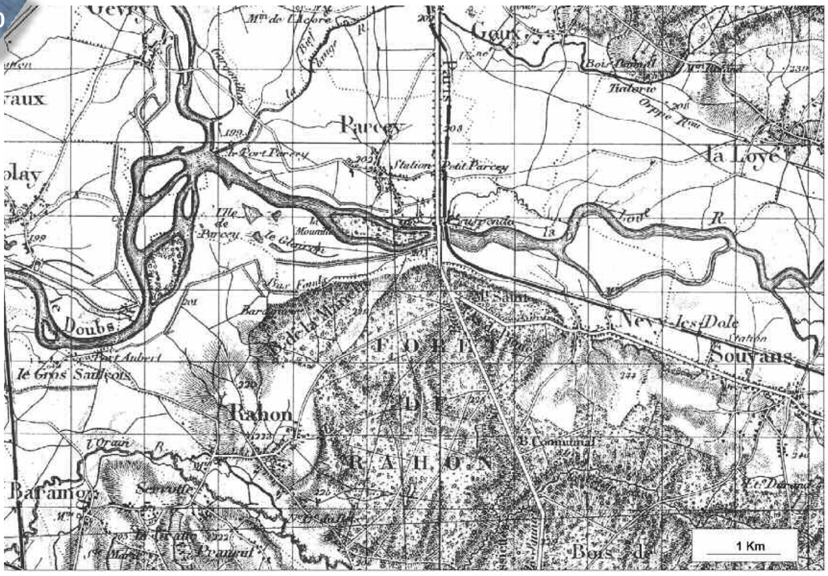
Excerpt of the Cassini map (1:86 400) in the region of Parcey-sur-Loue (Jura department).

Figure 169

Excerpt of the military map. © IGN 2010

Excerpt of the 1834 military map (1:40 000) showing the same area.

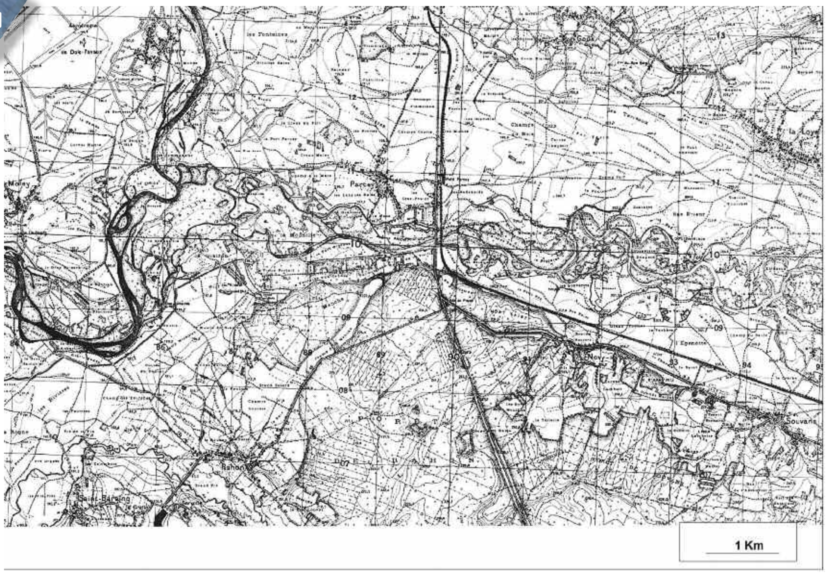
Figure 170



Excerpt of the military map. © IGN 2010

Excerpt of the 1913 military map (1:40 000) showing the same area.

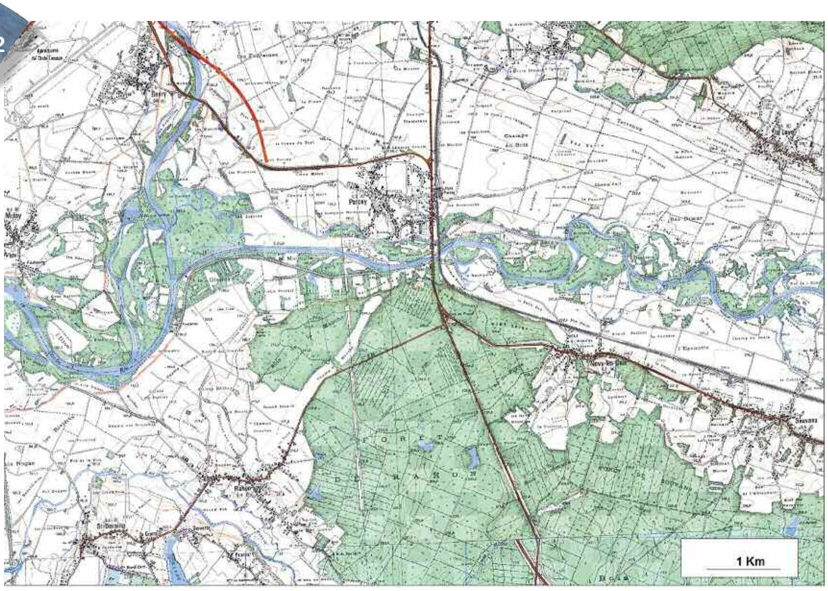
Figure 171



Excerpt of the military map. © IGN 2010

Excerpt of the 1948 map (1:20 000) showing the same area.

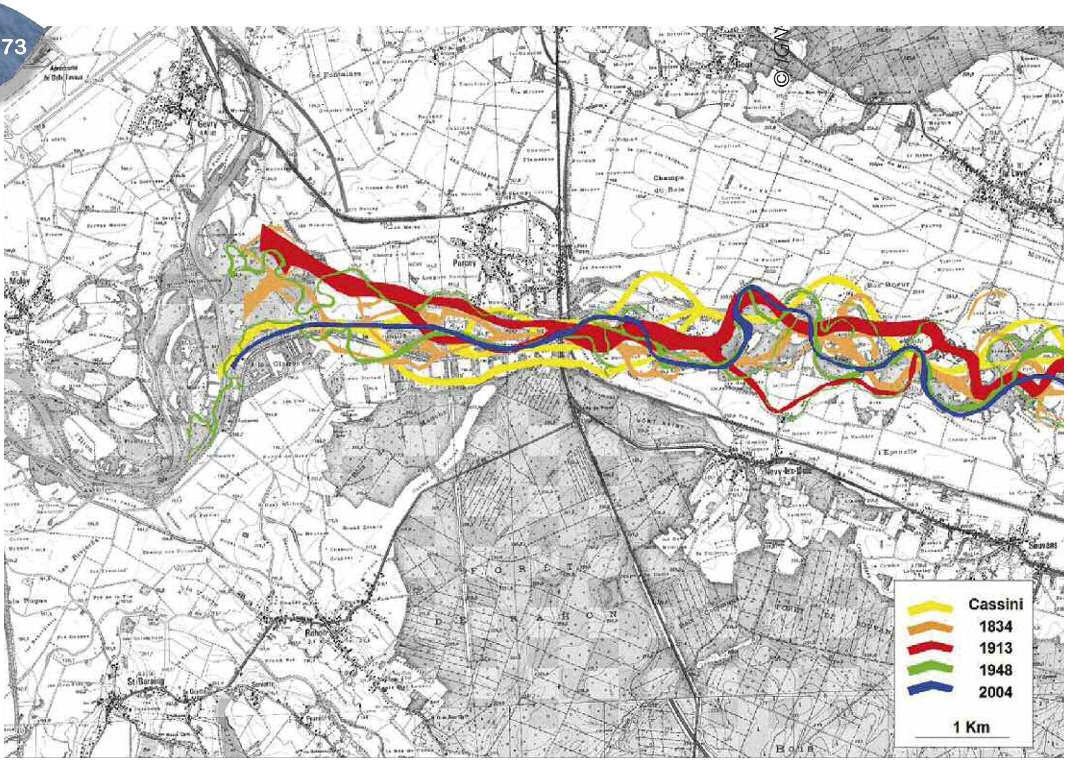
Figure 172



SCAN 25®. © IGN 2010

Excerpt of the 1985 IGN map (1:25 000) showing the same area.

Figure 173



Example of a diachronic map showing the various channels digitised using a GIS (the 2004 channel is drawn from BDOrtho) (Malavoi, 2006).

NB The military maps and other old topographical maps may be georeferenced in the same manner as the Cassini map (using the church steeples) and/or using other landmarks that appear in the Scan25, e.g. crossroads).

Other old maps, drawings and documents

Old maps and drawings may be found in various public services and local governments.

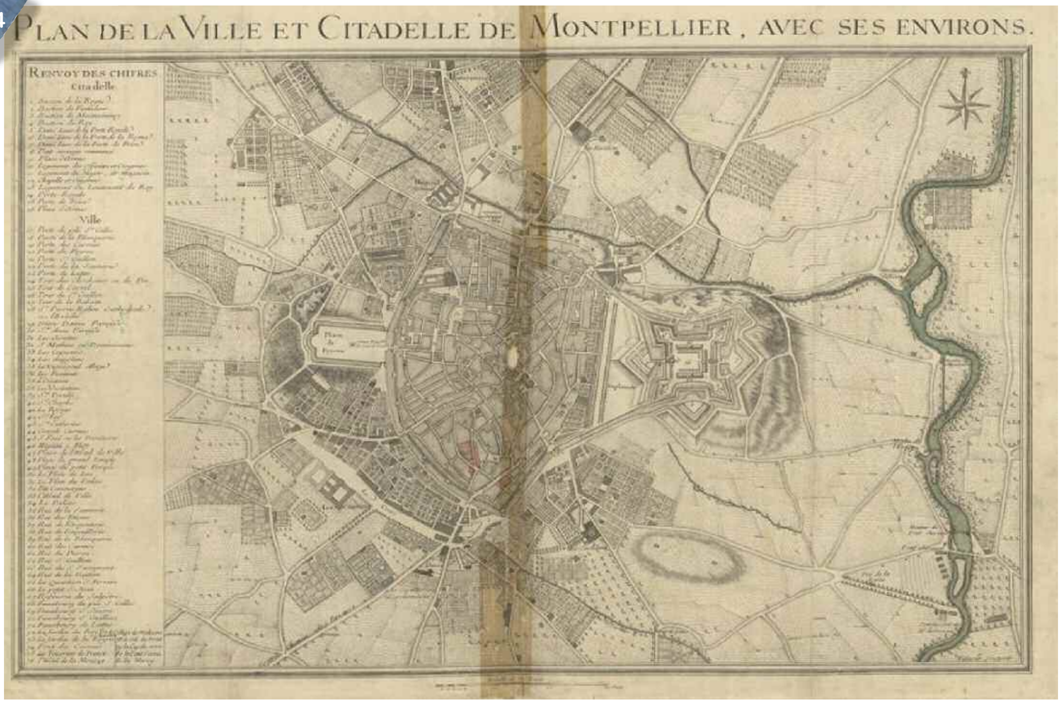
NB On older maps, North is often at the bottom of the map.

■ Departmental archives

Theoretically, all documents prior to 1940 should have been deposited in the departmental archives.

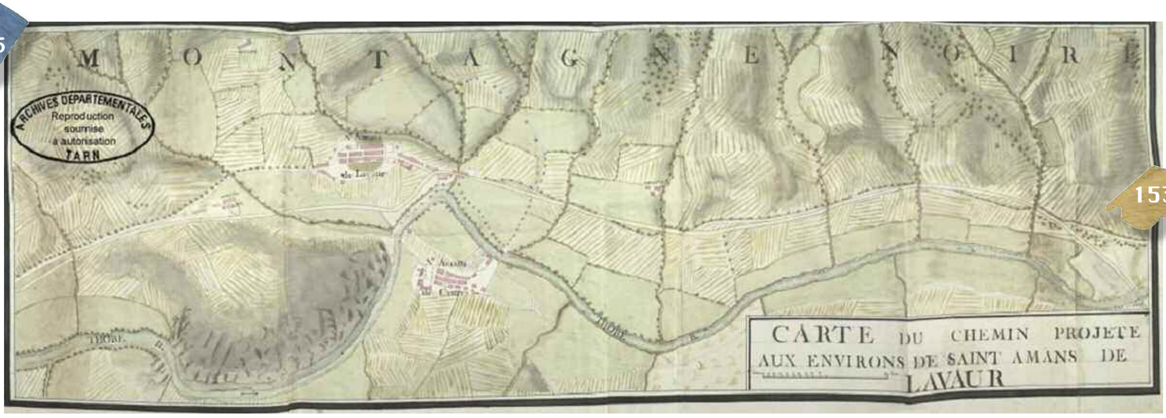
General maps

There is a wide variety of maps showing parts of the hydrographic network, even if the latter is not the topic of the map. Some may be georeferenced and thus serve for diachronic analysis.



Map of the city of Montpellier (Hérault Departmental archives, 1750).

Figure 175



Map showing a road project (North to the bottom). End of the 1700s (Tarn Departmental archives, exposition on the Maps and drawings of the Ancien Régime).

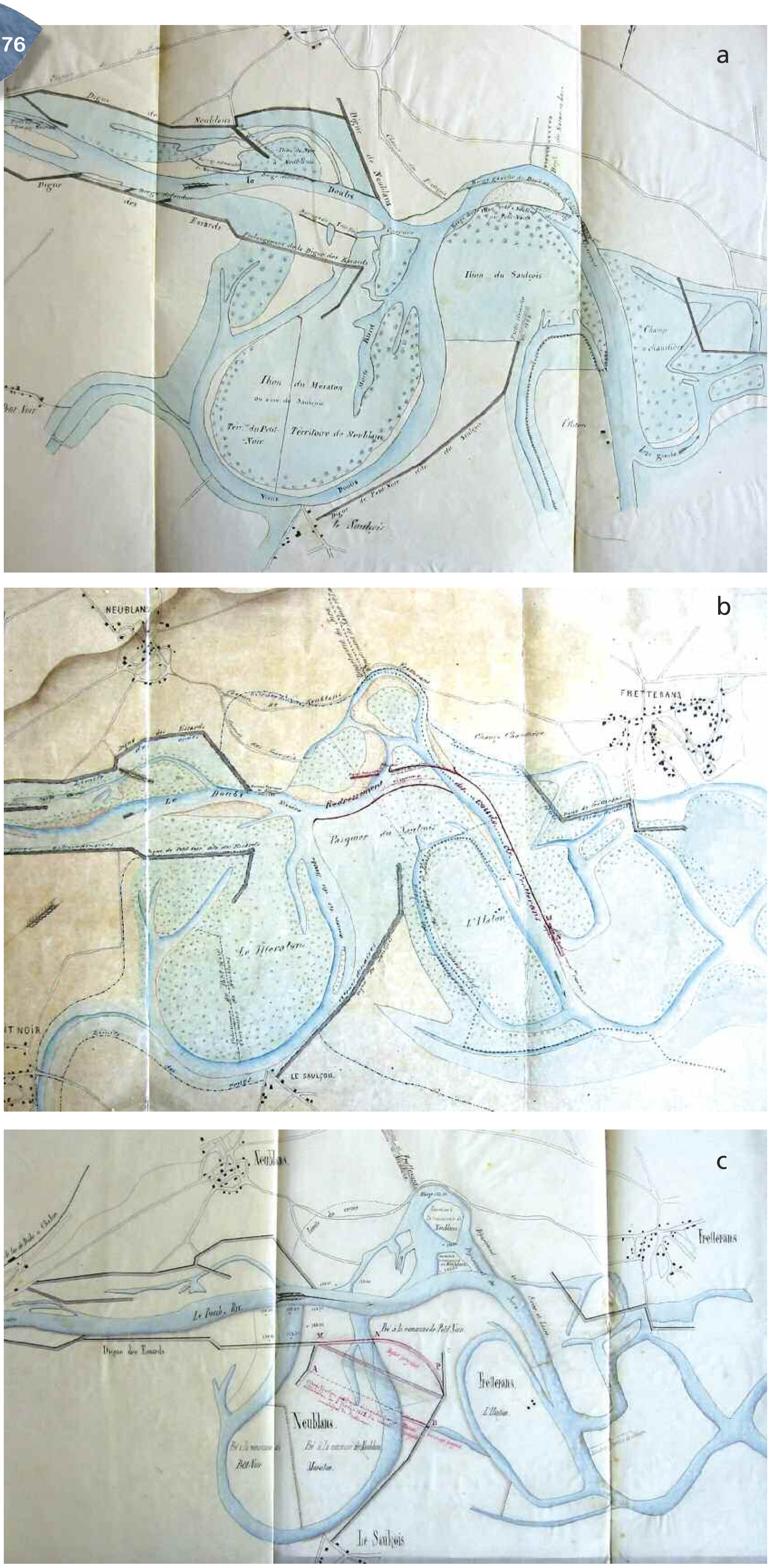
Public works - Mines - Transport - Water and Forests documents

The archives stored under these headings come from the Departmental prefectures, the Departmental bridge and road agencies (subsequently the Departmental equipment agencies), the chief engineer of mines and the Departmental water and forest agencies (subsequently the Departmental agricultural and forestry agencies).

NB The Departmental equipment, agricultural and forestry agencies have been grouped in the Departmental territorial agencies since 1 January 2010.

The archives also include drawings and preliminary studies for civil-works projects, drawings and cross-sectional diagrams of installations (bridges, dikes, etc.), and occasionally written documents appended to the drawings (project documents, reports).

Figure 176



1859

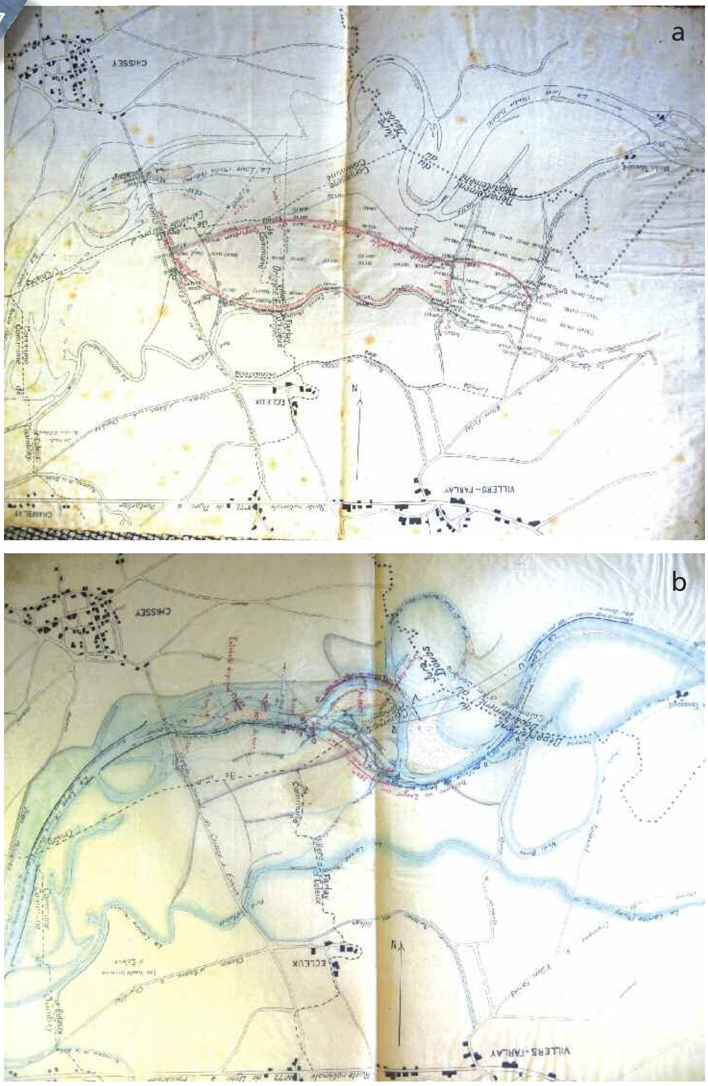
1876

1882

Three maps showing the preliminary studies that make it possible to monitor the project over time (in this case, the progression of containment work on the lower Doubs River (Jura Departmental archives). The North is at the bottom.

Some of these old maps and drawings can be georeferenced if enough landmarks are still visible (crossroads).

Figure 177

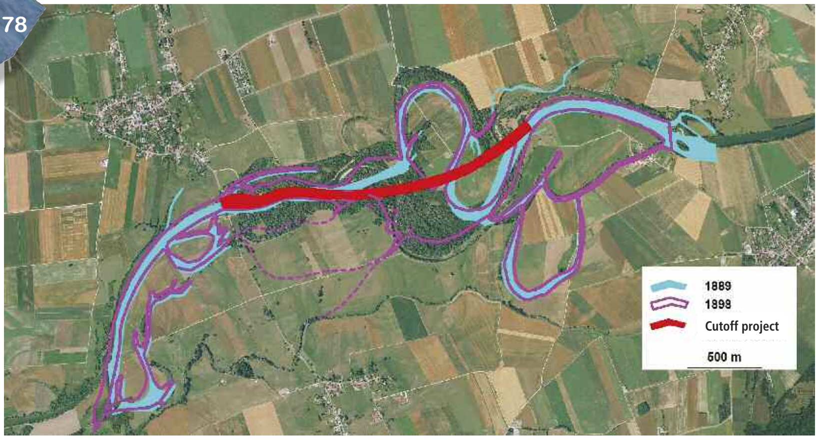


1889

1898

Two maps of the Loue River showing the preliminary studies for work (dikes and meander cutoffs). They could be georeferenced thanks to crossroads (Jura Departmental archives). The North was at the bottom in the original map and we turned it around to correspond to the Lambert projection, which explains why the text is upside down. Note also the chute cutoff followed by rapid lateral motion of the new channel.

Figure 178

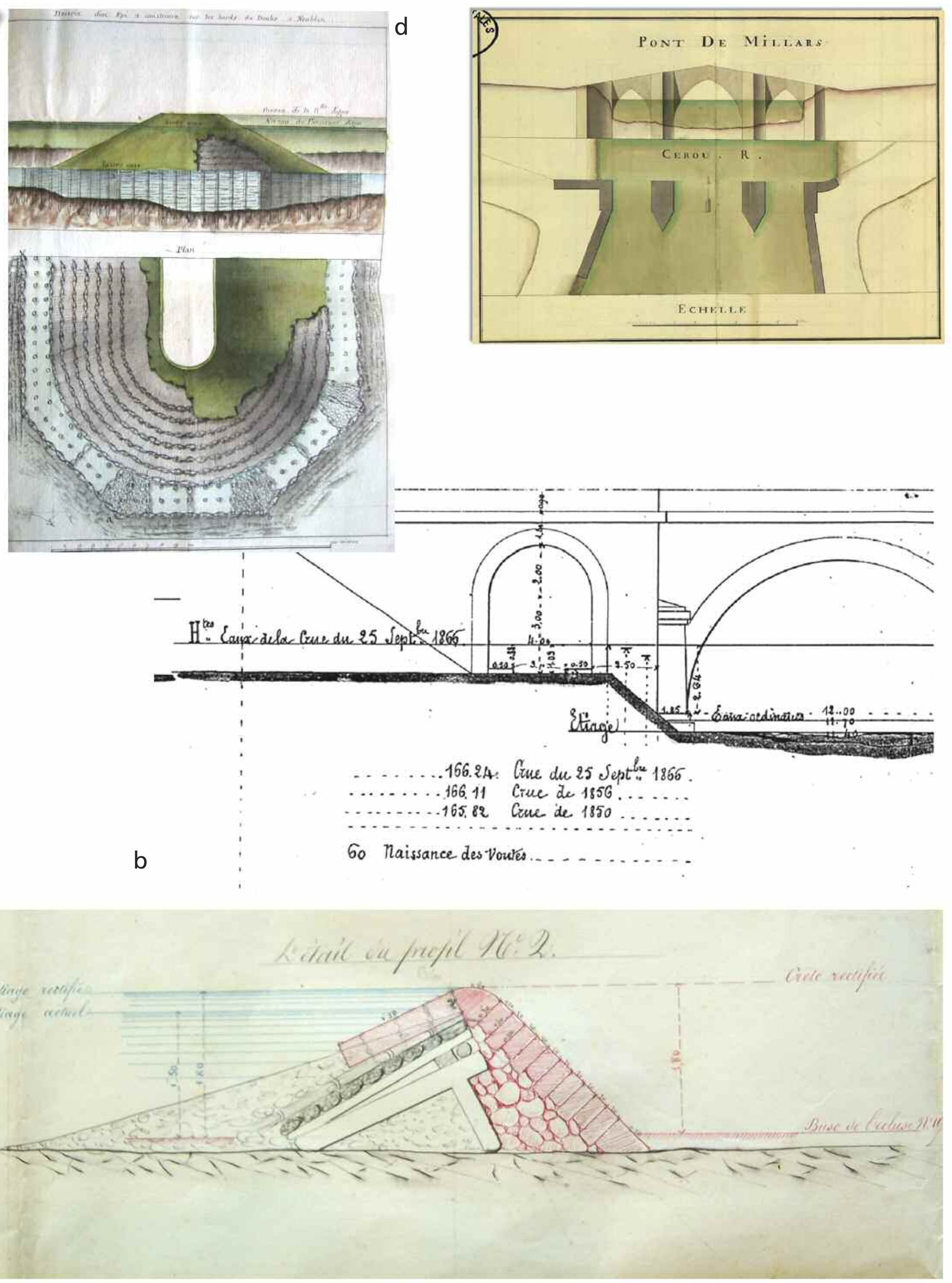


BD Ortho® 2006. © IGN 2010

The channels of the Loue River in 1889 and 1898 (including the preliminary studies for the artificial meander cutoff).

Examples of structural drawings and cross-sectional diagrams

Figure 179



(a) Milhars bridge (map from 17??) (Tarn Departmental archives). (b) Tonnerre bridge (1866). (c) Preliminary study for a groyne on the Doubs River (1844) (Jura Departmental archives). (d) Cross-sectional drawing of a weir on the Doubs River (Doubs Departmental archives).

Structural drawings and cross-sectional diagrams are very useful in diagnosing certain malfunctions such as riverbed incision (downcutting) and even in quantifying the malfunctions. Information on past flood levels is also often available (see above).

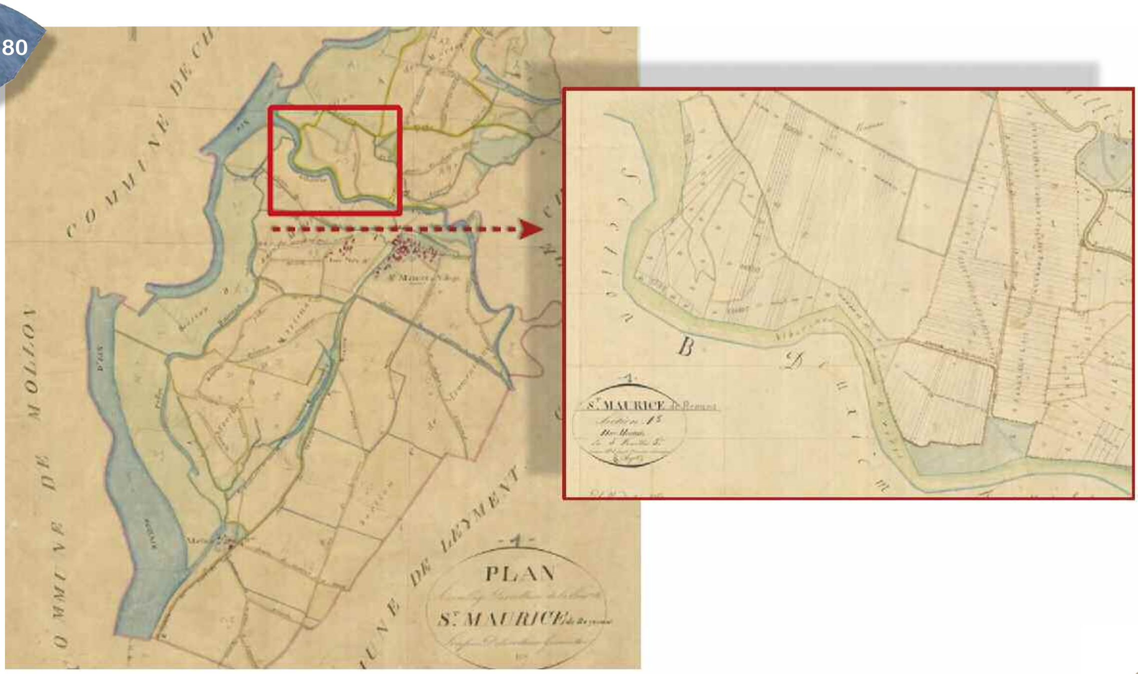
Napoleonic Land Register

In 1807, Napoleon ordered his finance minister, N. F. Mollien, to create a land register for all towns in the French empire, including survey data for each lot of property and maps. The goal was to enhance knowledge of land ownership in order to improve the tax system. The work on this project, known as the Napoleonic Land Register, was terminated in 1847.

For each town, an overall map was drawn up, on a scale between 1:10 000 and 1:20 000, and accompanied by more detailed sectional maps on a scale between 1:1 000 and 1:2 500.

The many landmarks noted on these maps, notably crossroads (except in very rural areas in the middle of fields), often make it possible to georeference the Land Register and use it as a precise tool for diachronic analysis.

Figure 180



Excerpts from the Napoleonic Land Register, with (a) an overall map and (b) a zoom on zone A5 (town of St-Maurice-de-Remens, Ain department).

Note that during the Empire, even before the Napoleonic Land Register, there existed the "Land-use Map" showing the major zones according to each type of use, e.g. arable land, pastures, woodlands, etc.

Sardinian maps

The Sardinian Land Register covered the area that is today the Savoie and Haute-Savoie departments. It was created between 1728 and 1738 by the administration of the Kingdom of Sardinia-Piedmont and constituted the first land register containing maps in Europe. The scale was approximately 1:2 400.

NB In the departmental archives, one may also find information on court cases dealing with rivers, which is very useful in learning more on the social and historic context of a river and the territories crossed.

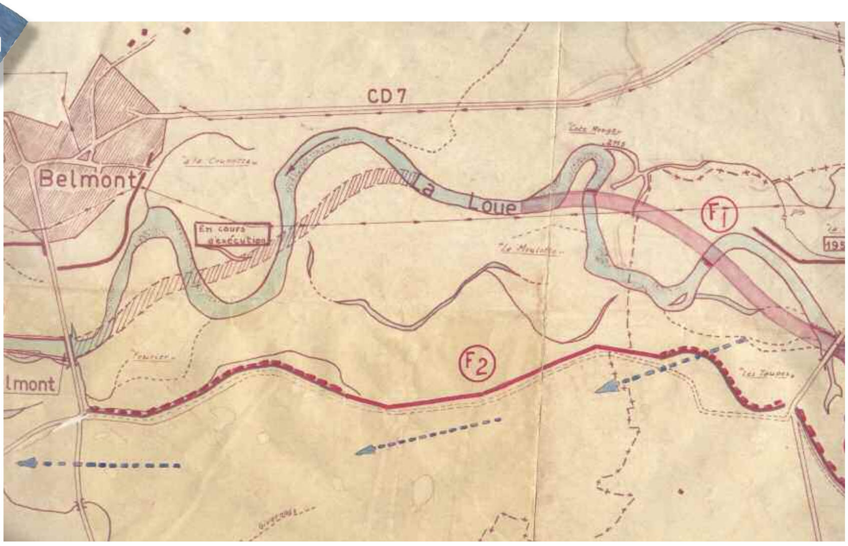
■ The archives of State services

It is possible to find in the archives of various State services, notably the Departmental equipment and agricultural agencies (now the Departmental territorial agencies), the post-1940 documents that have not yet been sent to the departmental archives. It is best to foresee a long visit because the time is well spent. The main difficulty lies in the fact that archiving techniques vary greatly from one department to another.

Explanatory documents, drawings and diagrams of preliminary studies for projects

Numerous documents, drawings, etc. provide fairly precise information on the recent history of development work on a river. The accuracy of drawings is such that it is often possible to precisely locate cross profiles which can then be used as reference points for new measurements.

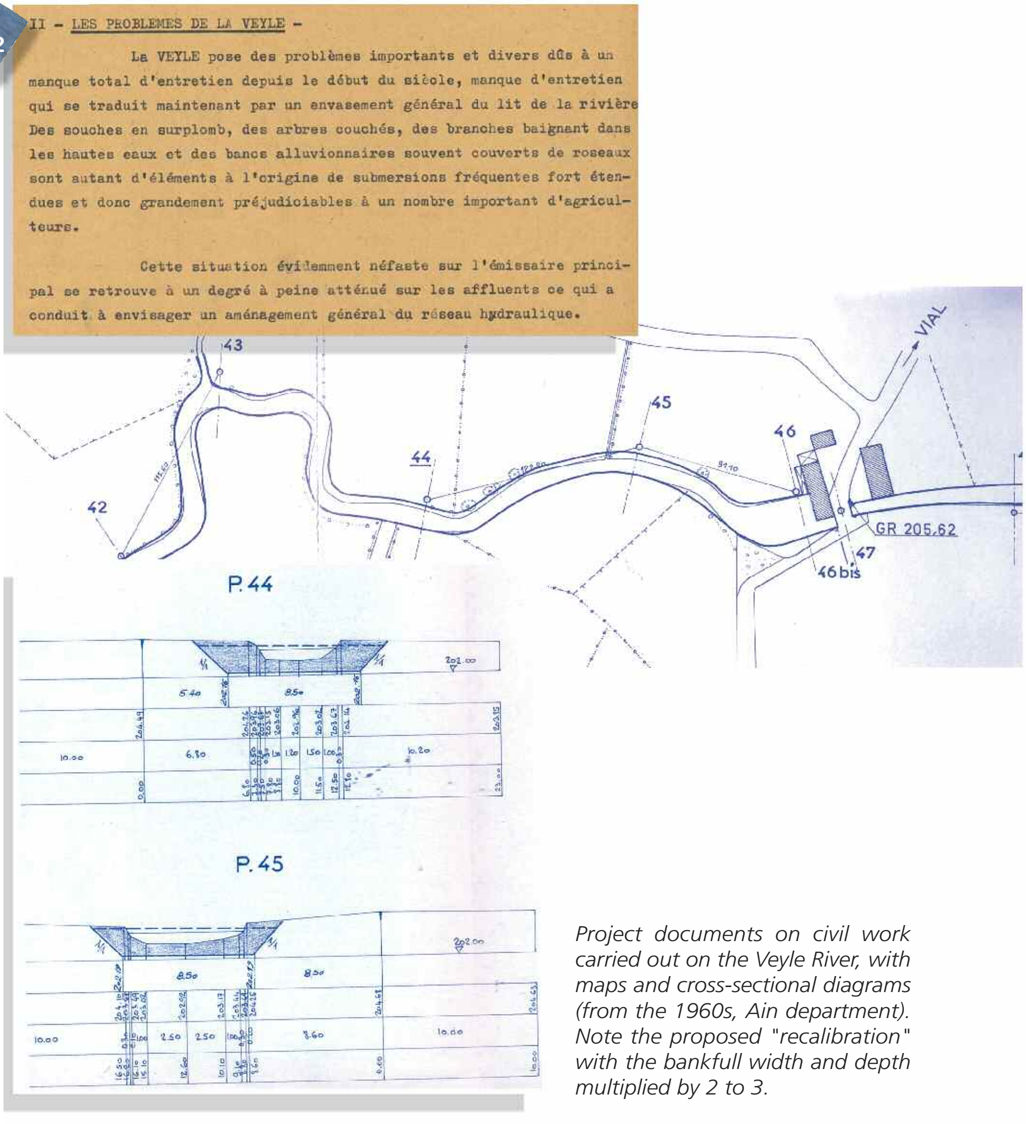
Figure 181



© DDE 39

Preliminary study for work to cut meanders on the Loue River (1958).

Figure 182



II - LES PROBLEMES DE LA VEYLE -

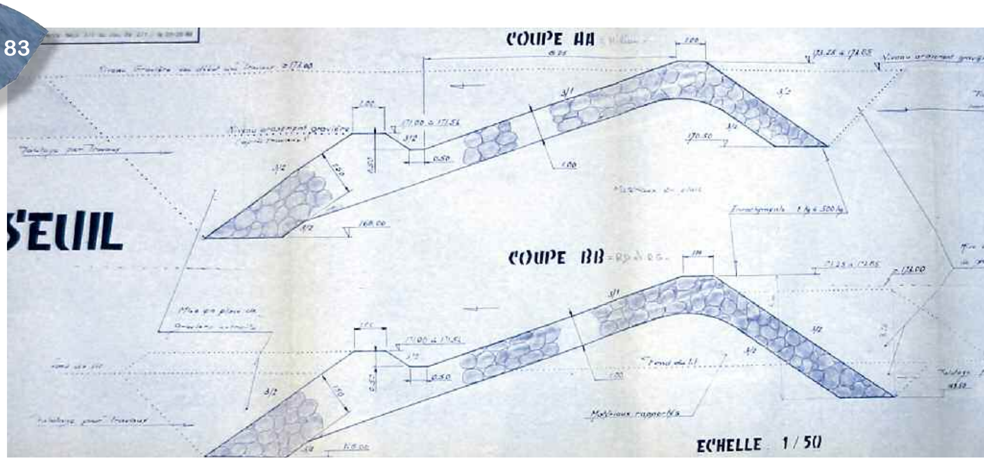
La VEYLE pose des problèmes importants et divers dûs à un manque total d'entretien depuis le début du siècle, manque d'entretien qui se traduit maintenant par un envasement général du lit de la rivière Des souches en surplomb, des arbres couchés, des branches baignant dans les hautes eaux et des bancs alluvionnaires souvent couverts de roseaux sont autant d'éléments à l'origine de submersions fréquentes fort étendues et donc grandement préjudiciables à un nombre important d'agriculteurs.

Cette situation évidemment néfaste sur l'émissaire principal se retrouve à un degré à peine atténué sur les affluents ce qui a conduit à envisager un aménagement général du réseau hydraulique.

© DDAF 01

Project documents on civil work carried out on the Veyle River, with maps and cross-sectional diagrams (from the 1960s, Ain department). Note the proposed "recalibration" with the bankfull width and depth multiplied by 2 to 3.

Figure 183



© DDE 71

Cross-sectional drawing of a weir (from the 1980s, Saône-et-Loire department).

Photographs

On occasion, land or aerial photos may be found, notably before, during and after work.

Figure 184

© DDE 39

Oblique aerial photographs of work sites on the lower Doubs River (from the 1960s, Jura department).

Figure 185

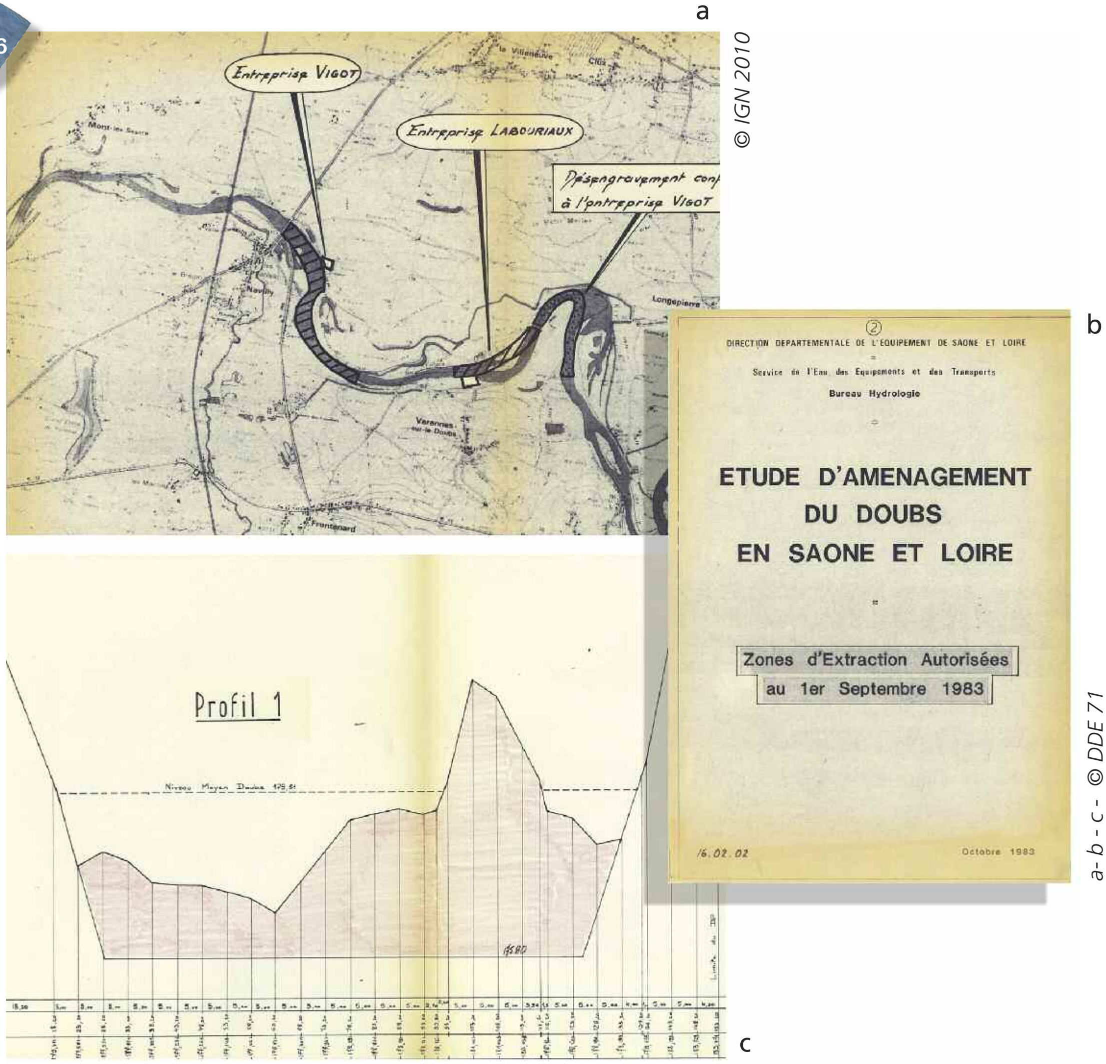
a- b- c- d- © DDE 39

(a) Maps (D4 site), (b) aerial photos and (c, d) land photos of work to cut a meander on the Loue River upstream of the Ounans bridge (from the 1960s).

Data on extracted materials

For State-owned rivers, it is fairly easy to find data on extracted materials, notably concerning the sites where work took place and occasionally the authorised profiles. This information is very useful in diagnosing hydromorphological operation in terms of sediment transport.

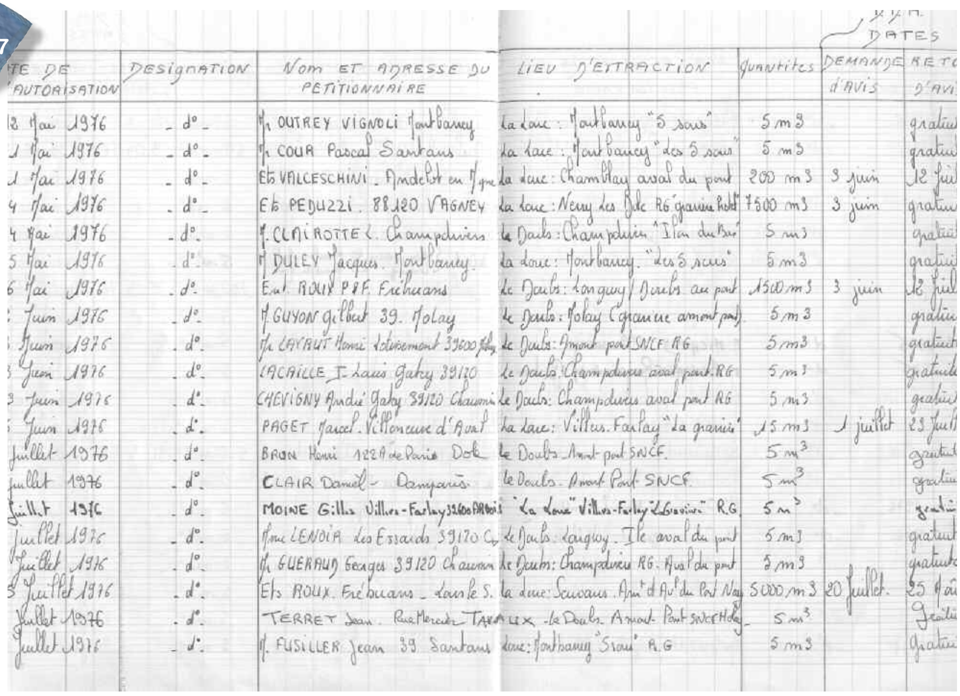
Figure 186



Examples of data on former excavations in the riverbed of the lower Doubs River (Jura DDE), including the authorised profile. Note the dredging work to remove excess deposits, assigned to some of the extracting companies in order to maintain the public river property (which is not subject to the same rules as excavations).

It is also possible to find less detailed, but nonetheless useful information in the **extraction registers** held by the various services.

Figure 187



…te de autorisation		Designation	Nom et adresse du petitionnaire	Lieu d'extraction	Quantites	Dates: Demande d'avis	Dates: Reto… d'avi…
12 Mai	1976	- d° -	M. OUTREY VIGNOLI Montbarrey	La Loue : Montbarrey "5 sous"	5 m3		gratui…
…1 Mai	1976	- d° -	M. COUR Pascal Santans	La Loue : Montbarrey "des 5 sous"	5 m3		gratui…
…1 Mai	1976	- d° -	Ets VALCESCHINI . Amdelot en Montagne	La Loue : Chamblay aval du pont	200 m3	3 juin	12 juil…
4 Mai	1976	- d° -	Ets PEDUZZI . 88120 VAGNEY	La Loue : Nevy les Dole RG graviere…	7500 m3	3 juin	gratui…
4 Mai	1976	- d° -	M. CLAIROTTE L. Champdivers	Le Doubs : Champdivers "Ilon du Bo…"	5 m3		gratui…
5 Mai	1976	d°	M DULEY Jacques . Montbarrey	La Loue : Montbarrey . "des 5 sous"	5 m3		gratui…
6 Mai	1976	d°	Ent ROUX P&F Fraisans	Le Doubs : Longwy / Doubs au pont	1500 m3	3 juin	12 juil…
… Juin	1976	d°	M GUYON Gilbert 39. Molay	Le Doubs : Molay (graviere amont pont)	5 m3		gratui…
… Juin	1976	d°	M. LAYAUT Henri lotissement 39600 [illegible]	Le Doubs : Amont pont SNCF RG	5 m3		gratui…
… Juin	1976	d°	LACAILLE J. Louis Gatey 39120	Le Doubs : Champdivers aval pont RG	5 m3		gratui…
…3 Juin	1976	d°	CHEVIGNY André Gatey 39120 Chaumi…	Le Doubs : Champdivers aval pont RG	5 m3		gratui…
… Juin	1976	d°	PAGET Marcel . Villeneuve d'Aval	La Loue : Villers Farlay "La graviere"	15 m3	1 juillet	23 juil…
Juillet	1976	d°	BRON Henri 122 Av de Paris Dole	Le Doubs Amont pont SNCF	5 m3		gratui…
Juillet	1976	d°	CLAIR Daniel - Dampierre	Le Doubs . Amont Pont SNCF	5 m3		gratui…
Juillet	1976	d°	MOINE Gilles Villers-Farlay 39600 Arbois	"La Loue" Villers-Farlay "La Graviere" R.G	5 m3		gratui…
Juillet	1976	d°	Mme LENOIR Les Essards 39120 C…	Le Doubs . Longwy . Ile aval du pont	5 m3		gratui…
Juillet	1976	d°	M. GUERAUD Georges 39120 Chaumin…	Le Doubs : Champdivers RG . Aval du pont	5 m3		gratui…
…5 Juillet	1976	d°	Ets ROUX . Fraisans - Loue le S.	La Loue : Souvans . Am.t et Av.t du Pont Na…	5000 m3	20 juillet	25 Aoû…
Juillet	1976	d°	TERRET Jean . Rue Mercier TAVAUX	Le Doubs . Amont Pont SNCF Molay	5 m3		Gratui…
Juillet	1976	d°	M. FUSILLER Jean 39 Santans	Loue : Montbarrey "Sous" R.G	5 m3		Gratui…

© DDE 39

Example of an extraction register held by the Jura DDE (Departmental equipment agency). The register contains data on individual wagon loads (in units of 5 cubic metres) as well as much larger volumes.

■ Town archives

Town archives contain maps of all types and scales. The documents were theoretically created after 1940 because all others should have been sent to the departmental archives.

■ Other archives

The SNCF archives (national train company) contain documents on rivers for each train line running along a river or over a bridge. Documents include maps, river cross profiles, cross-sectional diagrams of installations, etc. The SNCF centre for historical archives is located in the town of Le Mans.

Aerial photographs

Compared to maps, aerial photographs have two main advantages:

- they are updated much more frequently;
- they offer much more information for analysis, i.e. it is possible to distinguish the type of land cover, alluvial bars in rivers, the type of vegetation along banks (with some experience), etc.

Current aerial photographs

■ ORTHO® database at IGN (French National Geographic Institute)

The IGN ORTHO® database contains digital, georeferenced, aerial photographs. The database covers the entire country and is updated every five years (soon every three years). The available resolutions are 0.5, 1, 2.5 and 5 metres (however the last two, though much less expensive, are not well suited to hydromorphological purposes). **The average cost per square kilometre for the 0.5-metre resolution is one euro** (the price varies with the total surface area ordered, see the IGN site).

NB The ORTHO Agglo® database contains photos of large urban areas with a resolution of 0.2 to 0.3 metres.

Figure 188

a- b- BD Ortho® 2006. © IGN 2010

Above is an image drawn from the ORTHO® database with a resolution of 0.5 metres. The zoom shows microtopographic features of the banks and the transiting alluvial forms, the relative water levels, the type of vegetation and even the eroded banks.

■ Satellite photographs

Satellite photographs may complement and even replace aerial photographs. They are less expensive and can be updated much more frequently (every few days) than the aerial photographs in the ORTHO® database. They can also be used for spectral analysis, i.e. for more complex data processing (soil humidity, status of vegetation, etc.).

Below is a partial list of the private companies supplying satellite images.

- Spot Image. A number of SPOT satellites now produce images with a ground-level resolution of 2.5 metres and should provide a resolution of 0.5 metres in the future.
- Digital Globe. This company provides images with a resolution of 0.5 metres (Worldview1 satellite for panchromatic images) or 2.5 metres (Quickbird multispectral images).
- Geo Eye. This company can provide images with a resolution of 0.4 metres.

■ High-resolution aerial photographs

It is now possible to obtain high-resolution aerial photographs (each pixel representing just a few centimetres) thanks to the development of digital cameras offering ever lighter weight and higher performance.

The photos can be taken from aircraft flying at very low speeds (ULM, helicopters, drones). Depending on the needs of the particular study, they may be taken vertically over the zone (then orthorectified and georeferenced under certain conditions) or from an oblique angle. Miniature GPS devices on board the aircraft provide precise positioning data for each photo.

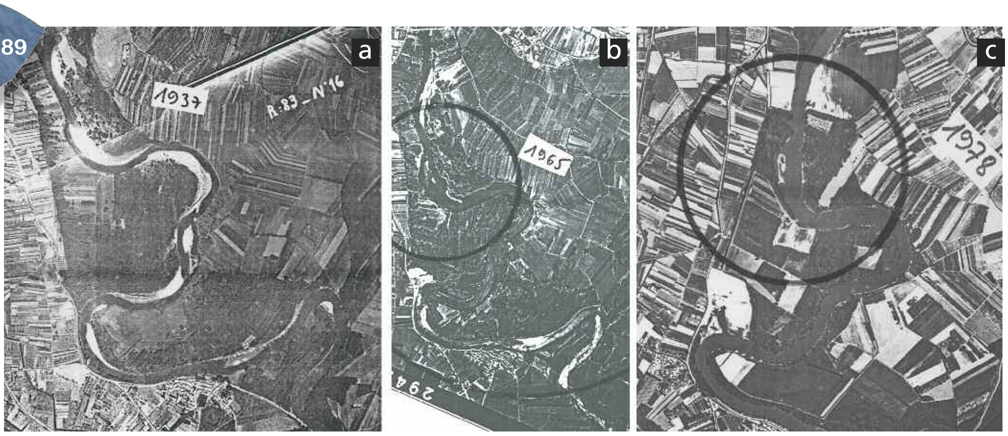
Old aerial photographs

The oldest **vertical** aerial photographs in the IGN photo library date back to the 1920s and were initially made for the mapping departments of the armed forces. It was only after WWII that aerial-photography campaigns became more regular with a stable five-year frequency. The photos served as the basic material for the new maps, first on the 1:20 000, then the 1:25 000 scale.

Caution. Aerial photographs (with the exception of the ORTHO® database) are not orthorectified or otherwise corrected. Only the central third of the photo is not deformed by the photographic conditions. However, there is now software and companies specialised in such corrections. It is also possible to purchase a large number of overlapping photos for photogrammetric analysis, retaining only the central third and reassembling them.

A certain degree of error due to the deformation (highly variable depending on the relief) may not represent a significant problem, for example for diachronic studies of river channels which do not require a high level of precision.

Figure 189



Example of a series of aerial photographs that can be used for a diachronic study. The goal here was to study the evolution of the Gardon River where a bridge for the TGV train line was planned (black circle). Note the progressive narrowing of the southern meander, upstream of the village of Comps.

Aerial-photography records a - 1937, b - 1965, c - 1978 © IGN 2010

Low-altitude flights

Photographs taken at oblique angles during low-altitude flights provide very useful information because they represent an intermediate scale for analysis, between field data acquired literally "on the ground" and photographs taken from a vertical position.

On large rivers and those where the riparian vegetation is not too dense, low-altitude flights are a means to precisely locate bank-protection systems, to assess the status of installations such as weirs, etc. One of the main advantages of this technique is that an entire river may be completely examined in just a few hours.

Under ideal conditions, the photos should be taken at **100 to 200 metres from the ground.** The most practical aircraft is a helicopter (300 to 400 euros per hour for a two-seater, twice that amount for four to five seats), but a ULM is also very good and much less expensive (100 to 150 euros per hour). An airplane (preferably high wing) flies a bit too fast, but can be used if nothing else is available. It is often useful to take video footage in addition to the photographs.

Figure 190

a- b - © C. Thévenet

c- d- © J.R. Malavoi

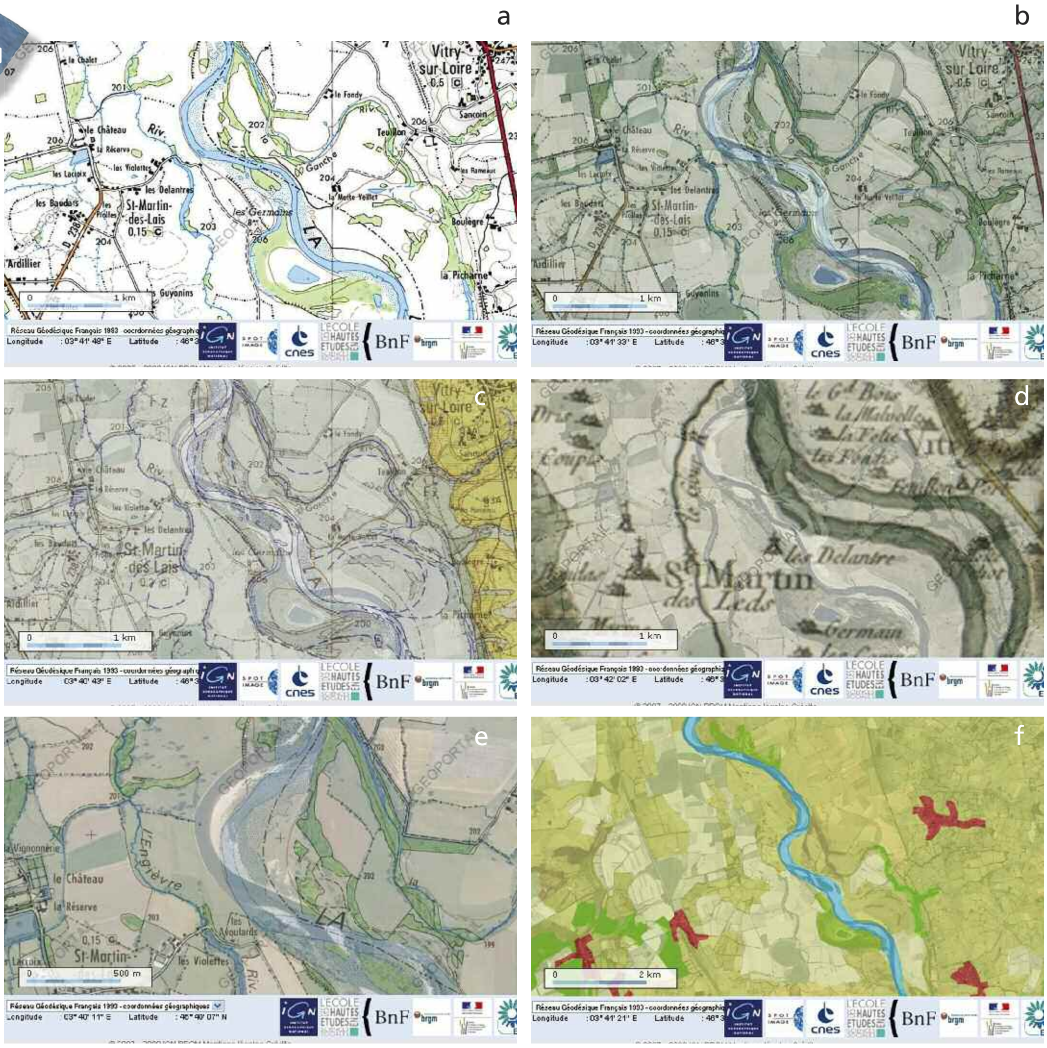
Examples of photographs taken a low altitudes (100 to 200 metres above the ground). Numerous details are visible, e.g. bank erosion and protection systems, the general status of bridges and weirs, the river facies, etc.

IGN Geoportal and Google Earth

These two internet tools can be used to obtain aerial photographs (airplane or satellite) very quickly. Google Earth provides images from around the world with variable resolutions depending on the site, but occasionally as good (or better) than 0.5 metres.

The IGN Geoportal covers all of France (including the overseas territories) with a theoretical resolution of 0.5 metres (ORTHO® database), but the quality is often inferior because the zoom tool is (to date) limited. The main advantage of Geoportal is that it has the very latest aerial photographs (Spot or ORTHO® depending on the zoom level) and a great deal of additional information, e.g. the IGN maps (all scales, depending on the zoom level), geological maps (again all scales, depending on the zoom level), the entire hydrographic network in digital format, administrative boundaries, relief, the digital Land Register, Corine Land Cover, etc. A 3D version displays relief and provides tools to calculate distances and surface areas.

Figure 191



165 a- b- c- d- e- f- Géoportail. © IGN 2010

Examples of the layers available on Geoportal. (a) Scan25 (old version). (b) Scan25 + Spotimage, using the opacity of layers to measure active erosion levels (at a higher zoom level, the ORTHO® database is displayed (see (e)). (c) Geological map on the 1:50 000 scale +Spotimage. (d) Cassini + Spotimage. (e) ORTHO® + Scan25, the active erosion in the meander is clearly visible. (f) Corine Land Cover + Spotimage at a lower zoom level.

Figure 192

a- b- Géoportail. © IGN 2010

Examples showing the 3D version of Geoportal used to measure distances and surface areas.

NB The above information is likely to change because the Geoportal site is constantly upgraded.

Topographic data

Topographic data are an essential element in a hydromorphological study, notably in identifying and, where possible, quantifying incision and aggradation processes. Unfortunately, older topographic data are rarer, less consistent on the national level and less frequently available than planform data.
When they exist (long profiles, cross profiles, scattered topographic points), they can be extremely useful to produce new data in order to quantify and qualify any topographical changes in the river, on both the local and larger scales.

NB Practically speaking and particularly for installation owners, it is important to plan on a fairly large budget for topographical work. Ideally (though this is rarely the case, due in particular to legal procedures for public contracts), topographical aspects should be detached from the hydromorphological study and needs in terms of topographical work should be determined only once the study has made sufficient progress. A contract adapted to the precise topographical needs can then be signed with a surveyor.

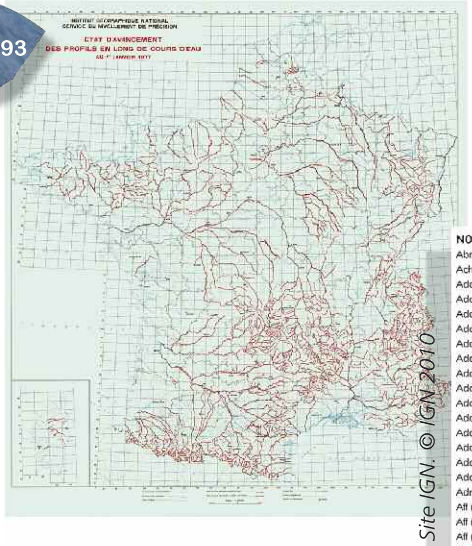
Long profiles

■ Profiles of rivers with major hydraulic potential

Surveys to determine the long profile of certain rivers were initially carried out by NGF (French Topographical Survey, which became IGN) for the Large Hydraulic Forces Agency. The survey addressed primarily those rivers deemed to have high hydroelectric potential. It is possible to access the map of France showing the surveyed rivers and the long profiles on the IGN site
(http://geodesie.ign.fr/fiches/index.php?module=e&action=e_profils).

Figure 193

a



b

NOM RIVIERE	NOM FICHIER	DOSSIER	PLANCHE	NOM TRONCON
Abriès (l')	91098 17.jpg	91098	1	l'Abriès
Achard (émissaire du lac d')	91078 15.jpg	91078	1	rau de la salignière et l'orselle
Adour (l')	91112 9.jpg	91112	9	entre les ponts de st sever et de cazères
Adour (l')	91112 10.jpg	91112	10	entre les ponts de cazères et de riscle
Adour (l')	91112 11.jpg	91112	11	entre les ponts de riscle et de hères
Adour (l')	91112 12.jpg	91112	12	entre les ponts de hères et d'artagnan
Adour (l')	91112 13.jpg	91112	13	entre le pont d'artagnan et le pont du chemin de fer à tarbes
Adour (l')	91112 14.jpg	91112	14	entre le pont du chemin de fer à tarbes et le pont de pouzac
Adour (l')	91112 15.jpg	91112	15	en amont du pont de pouzac
Adour d'Arises (l')	91112 18.jpg	91112	1	l'Adour d'Arises
Adour de Garet (l')	91112 21.jpg	91112	1	l'Adour de Garet
Adour de Garet (l')	91112 21.jpg	91112	1	affluents de l'Adour de Garet en amont de l'émissaire du lac de
Adour de Gripp (l')	91112 18.jpg	91112	1	l'Adour de Gripp
Adour de l'Esponne (l')	91112 19.jpg	91112	1	l'Adour de l'Esponne
Adour de Payolle (l') et le rau de morère	91112 17.jpg	91112	1	l'Adour de Payolle et le rau de morère
Adour du Tourmalet (l')	91112 18.jpg	91112	1	l'Adour du Tourmalet
Adrets (rau des)	91083 19.jpg	91083	1	le ruisseau des Adrets
Aff (l')	91119 4.jpg	91119	1	l'aff
Aff (l')	91119 5.jpg	91119	2	l'aff
Aff (l')	91119 6.jpg	91119	3	l'aff
Aff (l')	91119 7.jpg	91119	4	l'aff
Agly (l')	91125 1.jpg	91125	1	en aval de rivesaltes
Agly (l')	91125 2.jpg	91125	2	entre rivesaltes et estagel
Agly (l')	91125 3.jpg	91125	3	entre estagel et caramany

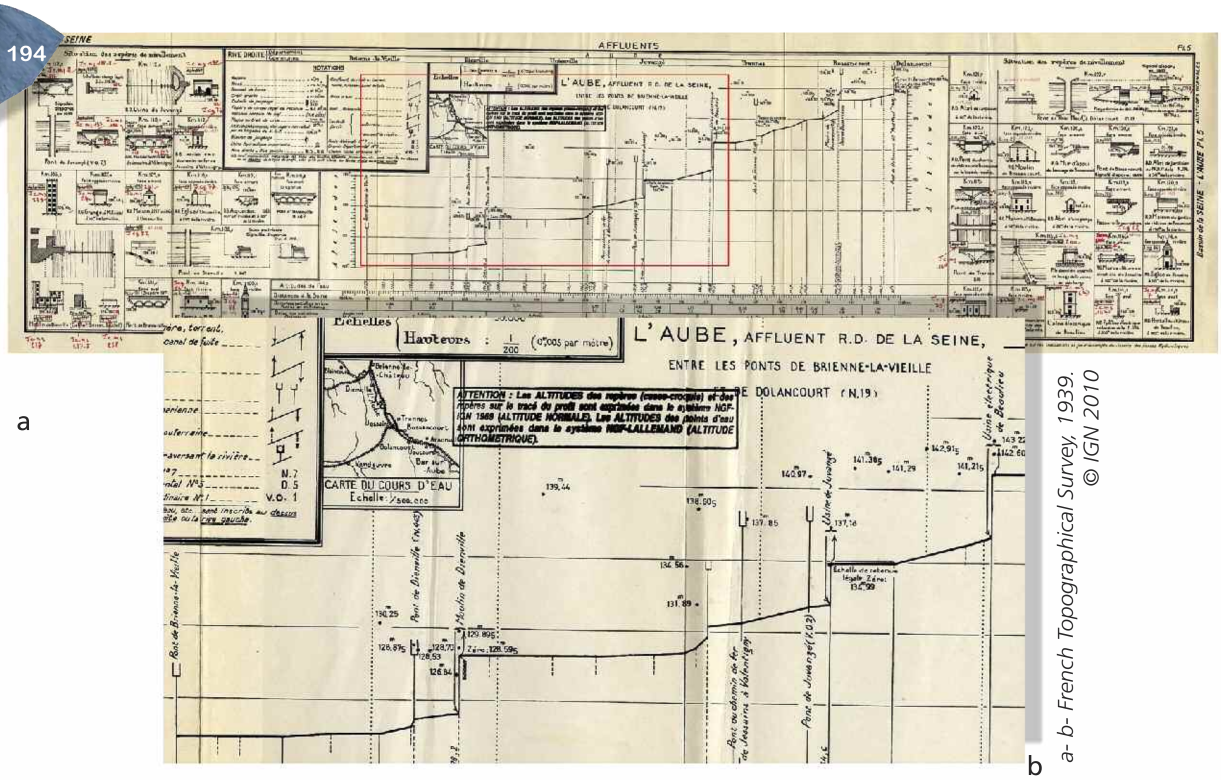
(a) Map of surveyed rivers as of 1 January 1977 and (b) the internet site providing access to the long profiles (JPG format).

The first rivers were surveyed almost immediately after WWI and the last at the end of the 1970s.

The main disadvantage of the profiles is that they measure the **water surface** and not the river bed. In addition, in the older profiles, it is difficult to know the discharge at the time of the survey. The dates for each survey (third line from the bottom) provide a general indication on whether the survey took place during low or mean flows.

One of their main advantages is that they precisely indicate the position of weirs, the upstream water level (and consequently the available head), the length of the raised water level and the purpose of the weirs (mills, forges, paper mills, etc.).

Figure 194



a- b- French Topographical Survey, 1939.
© IGN 2010

Example of a long profile. Overall view and zoom (caution, orthometric heights).

Caution. Values indicated on the long profiles are generally **NGF Lallemand Orthometric** heights and not NGF IGN69 Normal heights. To transform the orthometric data into NGF69 heights, it is necessary **to add a value** ranging from a few centimetres (e.g. in the Aquitaine region) to several dozen centimetres (e.g. over 60 cm in the Nord department).

$$Z\ NGF69 = Z\ Ortho + \triangle Z$$

IGN provides the corrective data on its internet site for each 1:50 000 map (see Figure 195). Using the table on the next page, it is necessary to add 0.34 metres (map 2917) to the heights indicated in the profile above. The head of the weir is thus at 128.54 NGF69 and not 128.2.

Figure 195

—	—	—	—	—	2202 60	2302 60	2402 61	—	—	—	—	—	—	—	—	—
—	—	—	—	2103 63	2203 63	2303 61	2403 60	2503 62	—	—	—	—	—	—	—	—
—	—	—	—	2104 64	2204 62	2304 62	2404 60	2504 60	—	—	—	—	—	—	—	—
—	—	—	—	2105 64	2205 61	2305 59	2405 58	2505 58	2605 59	—	—	—	—	—	—	—
—	—	—	—	2106 61	2206 59	2306 58	2406 58	2506 57	2606 57	2706 59	2806 60	—	—	—	—	—
—	—	—	2007 50	2107 54	2207 54	2307 58	2407 60	2507 58	2607 56	2707 57	2807 58	—	3007 45	—	—	—
—	—	1908 45	2008 47	2108 48	2208 55	2308 58	2408 58	2508 56	2608 55	2708 55	2808 52	2908 47	3008 45	—	—	—
1709 33	1809 35	1909 43	2009 45	2109 47	2209 55	2309 56	2409 54	2509 53	2609 55	2709 51	2809 46	2909 45	3009 44	3109 43	—	—
1710 34	1810 40	1910 40	2010 43	2110 46	2210 52	2310 55	2410 52	2510 52	2610 53	2710 47	2810 45	2910 44	3010 44	3110 43	3210 42	3310 42
1711 34	1811 35	1911 35	2011 36	2111 42	2211 47	2311 46	2411 49	2511 50	2611 49	2711 45	2811 44	2911 44	3011 43	3111 42	3211 42	3311 42
1712 30	1812 32	1912 35	2012 35	2112 40	2212 45	2312 44	2412 47	2512 48	2612 42	2712 43	2812 43	2912 43	3012 44	3112 42	3212 42	3312 41
1713 32	1813 34	1913 35	2013 34	2113 37	2213 38	2313 39	2413 40	2513 43	2613 36	2713 37	2813 40	2913 42	3013 41	3113 42	3213 42	3313 40
1714 33	1814 35	1914 34	2014 34	2114 33	2214 34	2314 34	2414 36	2514 38	2614 34	2714 37	2814 39	2914 41	3014 38	3114 40	3214 41	3314 40
1715 35	1815 35	1915 34	2015 35	2115 30	2215 31	2315 33	2415 34	2515 32	2615 36	2715 37	2815 38	2915 37	3015 36	3115 37	3215 37	3315 38
1716 33	1816 31	1916 30	2016 31	2116 30	2216 32	2316 31	2416 33	2516 34	2616 32	2716 33	2816 37	2916 36	3016 34	3116 35	3216 36	3316 35
1717 31	1817 28	1917 28	2017 32	2117 30	2217 30	2317 29	2417 29	2517 30	2617 31	2717 33	2817 34	2917 34	3017 36	3117 33	3217 35	3317 34
1718 27	1818 26	1918 26	2018 31	2118 29	2218 29	2318 30	2418 28	2518 30	2618 31	2718 34	2818 34	2918 34	3018 34	3118 38	3218 34	3318 32

ZONE NORD-PICARDIE

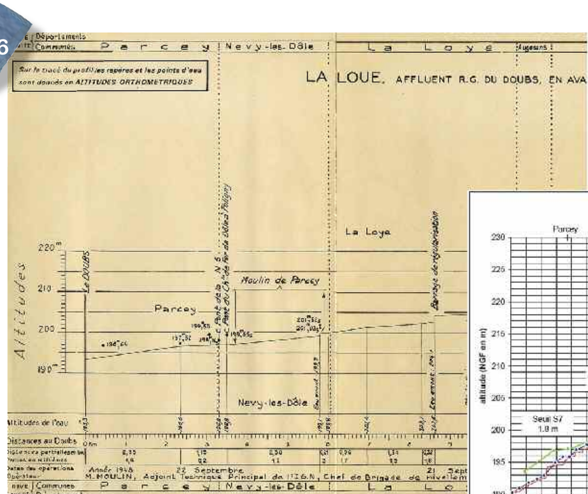
Example of a table showing the corrective data for the orthometric heights in the northern Picardie region. It is necessary to add the value (in centimetres) under the map number to the orthometric height.

In spite of the difficulties with these profiles (water levels and insufficient data on discharge levels), they may be useful as reference data when drawing up a new long profile (complete or partial) of the river. However, the uncertainty concerning discharges represents a major problem in determining and quantifying incision and aggradation, unless the differences are considerable (several metres).

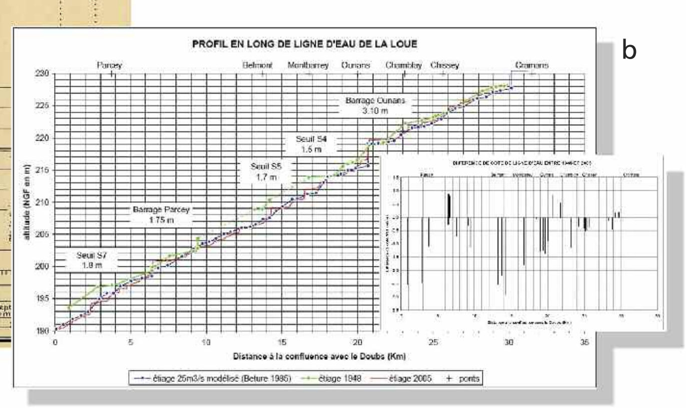
Caution is also advised concerning the x-axis (kilometre indications) which may be a source of major errors on highly mobile (or artificially rectified) rivers. Meander development and cutoffs may add or subtract hundreds of metres (even kilometres) to the length.

Figure 196

a



b

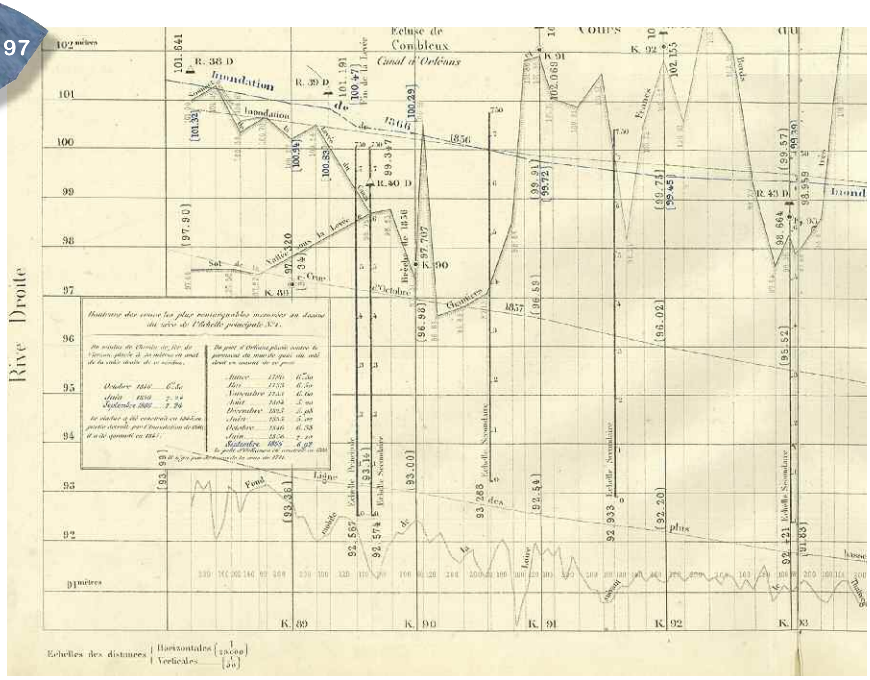


French Topographical Survey, 1948. © IGN 2010

Comparison between the profile (water level) of the Loue River drafted in 1948 for the Large Hydraulic Forces Agency and the profile surveyed in 2005 under low-flow conditions (Malavoi and Adam, 2006). The dotted lines indicate where modifications in the planform made it impossible to reuse the x-axis of the 1948 profile. It is necessary to find a stable reference point and adjust the x-axis. The diagram on the right compared the two profiles.

In some cases for navigable State-owned rivers, the profiles indicate not only water levels under low-flow conditions, but also talweg data and the levels of certain historic floods (see figure below).

Figure 197



© DIREN

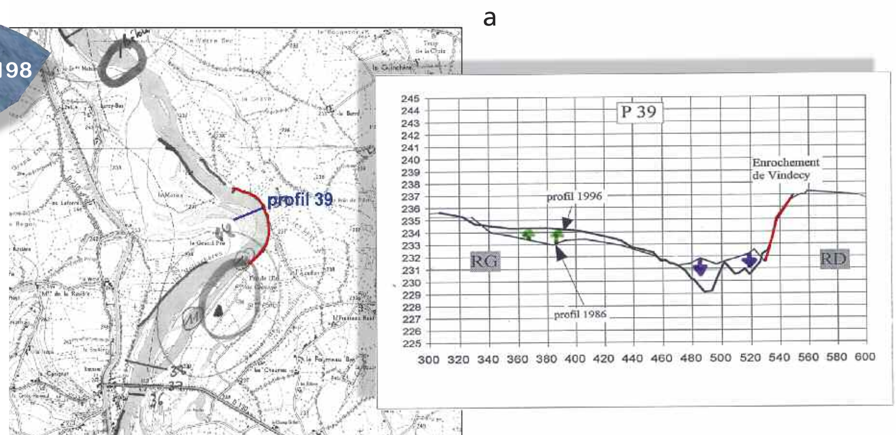
Long profile of the right bank of the Loire River, showing dikes, the talweg and levels of the 1856 and 1866 floods. Note the difference of almost 7 metres between the low-flow level and the 1866 flood.

Cross profiles

Contrary to other documents such as maps and long profiles, there is no national collection of cross-profile surveys. They may be found, however, for most of the navigable rivers whose bed (and the corresponding maintenance) is the responsibility of the State (public river property), up to the bankfull level (*plenissimum flumen*). They may be consulted in State archives or in the departmental archives if they predate 1940. A number of long and cross profiles may be found on the internet site of the central regional environmental agency.

It is also possible to find old profiles for work projects, for preparatory studies (Figure 182) or for excavation work in riverbeds (Figure 186). If they are noted on a map, these profiles can be resurveyed to gain precise information on the vertical evolution of a river section.

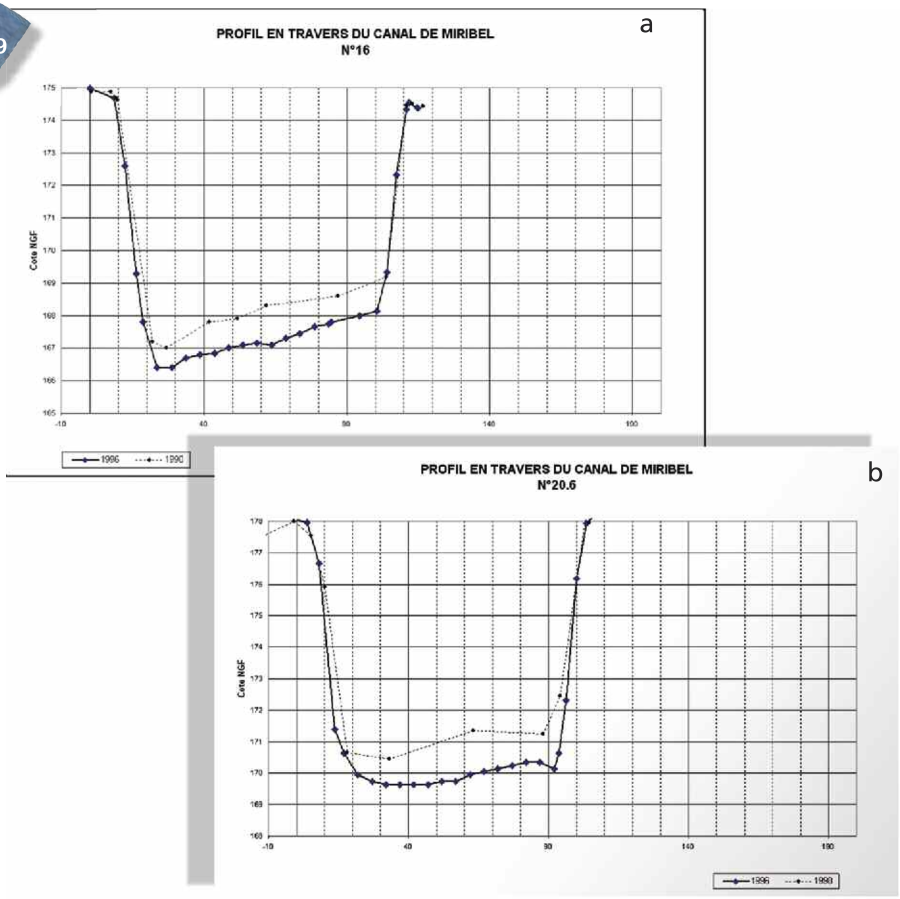
Figure 198



a- SCAN 25®. © IGN 2010

Comparison of cross profiles for the Loire River at ten-year intervals (Malavoi, 1996).

Figure 199



Comparison of cross profiles for the Miribel canal (Malavoi, AREA, 2000). Note the incision of one metre in six years.

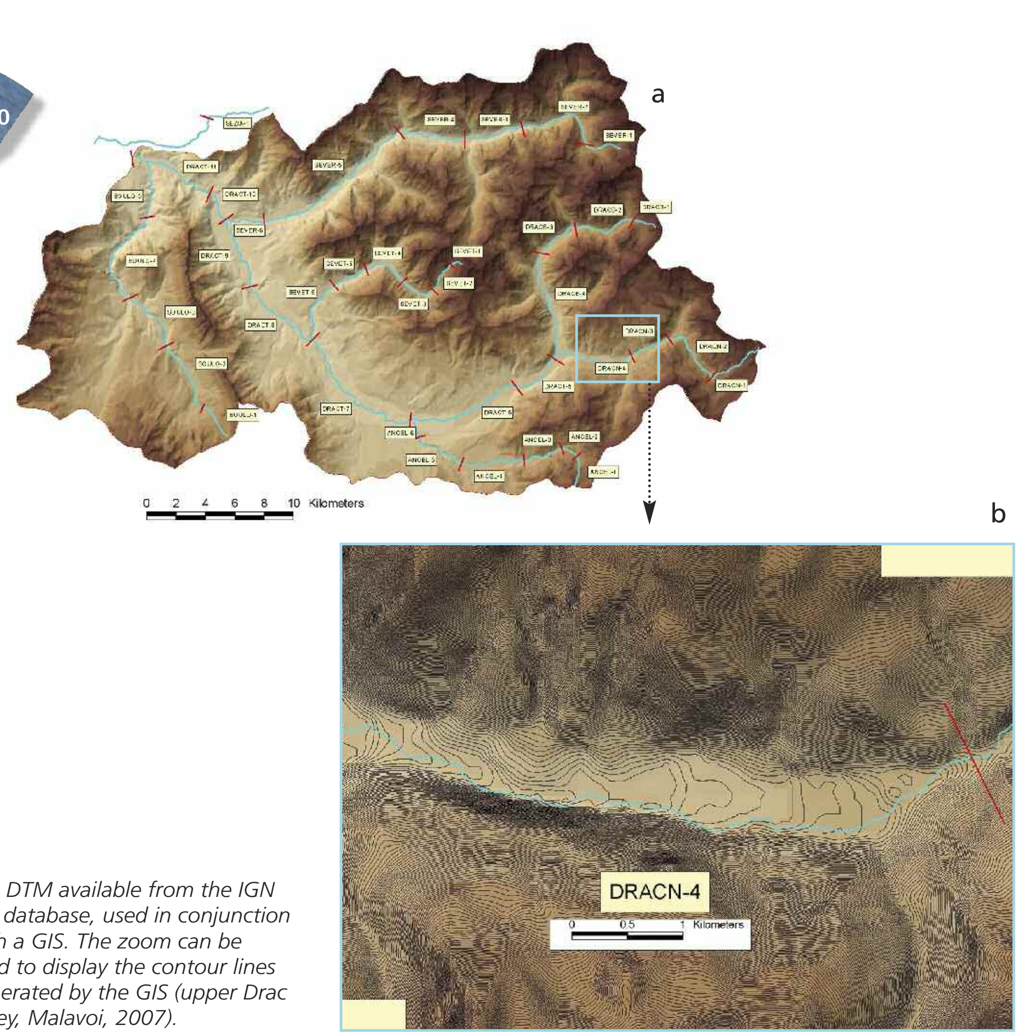
Digital terrain models

Digital terrain models are computer software used to produce a virtual topography of an area that may be terrestrial or subaquatic (in which case one speaks of bathymetric DTMs).
A DTM can generate a virtual image of the terrain in three dimensions, calculate surface areas and volumes, draw topographical profiles, simulate flows, etc. To use a DTM, which is generally made up of a computer file comprising three columns (the x, y and z (altitude) coordinates), a computer application, such as a GIS or topographic software, is required.
The **quality of a DTM**, i.e. its accuracy with respect to the actual terrain, depends on how the data are obtained, e.g. data derived from contour lines, photogrammetry (accurate to within a few dozen centimetres), field surveys using differential GPS systems (accurate to within a few centimetres). It also depends on the sampling density (an x,y,z data point every metre is better than every 50 metres) and on the interpolation method (if used).
DTM precision depends on the data input. For example, the IGN Alti database is precise to the metre (altitude z is indicated in metres with no digits after the decimal point). The actual accuracy of the elevation data is to within a few metres.
A DEM (digital elevation model) is used to model buildings, for example, and not only terrain.

■ DTM on the river-basin scale

A DTM can be used on the scale of an entire river basin or a river reach to determine its overall operation, the valley shape and width, the bordering relief, etc. For this type of work, a DTM with a sampling density of 50 or 100 metres and data precision to the metre, e.g. that available in the IGN Alit database, is more than sufficient. If a GIS capable of managing DTMs is used, it is also possible to run simulations, notably concerning flows.

Figure 200

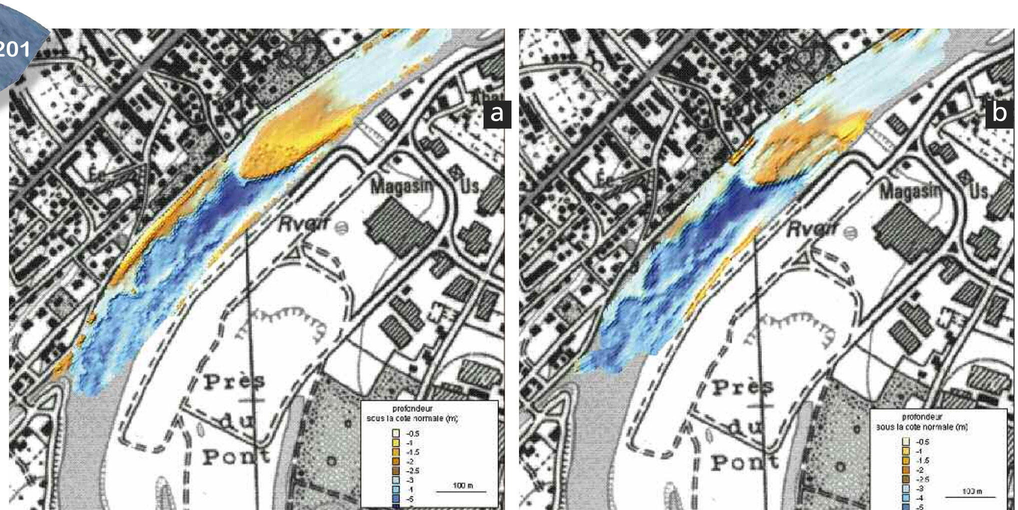


The DTM available from the IGN Alti database, used in conjunction with a GIS. The zoom can be used to display the contour lines generated by the GIS (upper Drac valley, Malavoi, 2007).

■ DTM on the river scale (topo-bathymetric application)

For more detailed work, e.g. to better understand the evolution of a riverbed, a DTM offering better sampling density and precision (approximately a few centimetres for the z-axis) is required.

Figure 201



a- b- SCAN 25®. © IGN 2010

The two maps above produced by a high-quality DTM reveal the gravel extractions in a submerged alluvial dune in the Doubs River (Malavoi, 2002). The DTM, provided by VNF, has a sampling density of one metre (downgraded to five metres) and is precise to the centimetre.

Hydrological data

A hydrological study must analyse the hydrological operation of the river. In that the discharge is one of the two major control factors in geodynamic processes, it is absolutely necessary to know (whatever the spatial scale covered by the study):

- the long-term overall hydrological operation of the river, i.e. its average regime, flood recurrence intervals, the role played by dams in modifying the flood regime, etc.;
- recent (two to three years preceding the study) to very recent (several months) hydraulic conditions.

In addition to general data from hydrology manuals, monographs and previous hydrological studies, hydrological data on rivers is available from the HYDRO database managed by the Ecology ministry.

HYDRO database

Hydrological and hydrometrical data on French rivers is managed by the HYDRO national database. HYDRO stores measurement data on water levels (variable time steps) from 3 500 gauging stations, of which 2 400 are currently in operation. The system calculates instantaneous, daily and monthly discharges, etc., based on the water-level data and the rating curves (which translate levels into discharges). The results are updated in step with modifications to the water-level data and the rating curves (addition, improved precision, correction, etc.). The information available on-line at http://hydro.eaufrance.fr/ includes the following:

- STATION. A presentation of each hydrometric gauging station;
- QJM. Daily and monthly discharges over a given year;
- ENTRE2. Comparison of daily discharges in a given year with those in the past, presented in graphs;
- SYNTHESE. A summary of the hydrological data;
- TOUSMOIS. Monthly discharges over a given period;
- VCN-QCN. Minimum discharges over N consecutive days;
- QMNA. Annual minimum monthly discharges.

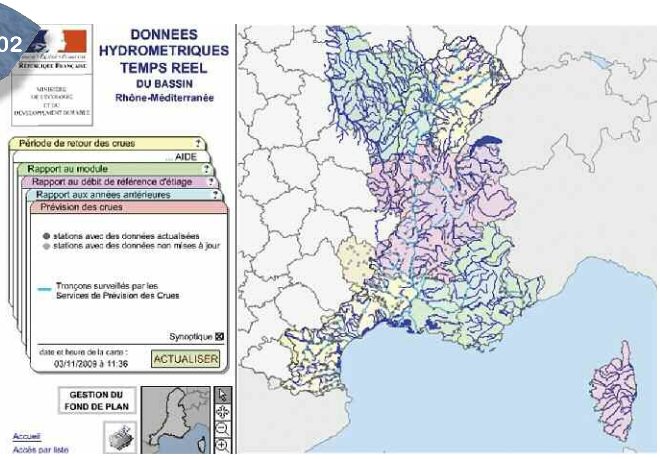
Other, more complex information is available with a **subscription**.
The hydrological data are supplied primarily by State services (DIREN, DDE, etc.), Électricité de France, research organisations (Cemagref, renamed Irstea in 2012, universities, etc.) and local-development companies (Compagnie d'aménagement des Coteaux de Gascogne (CACG), Compagnie nationale du Rhône (CNR), etc.). These data producers set up gauging stations along rivers, maintain them, then collect and check the data before sending them to the databank. They not only collect the gauging data, but also plot the rating curves that are also stored in the database. Finally, they validate and, if necessary, correct the data. They are responsible for the data supplied and monitor data quality.

Data are generally available in the database less than 40 days following collection.

Real-time data

Some State services have set up servers to provide real-time hydrological data via the internet. An example is the Hydroréel site (http://www.rdbrmc.com/hydroreel2/carto.php), managed by the Rhône-Alpes regional environmental agency which is responsible for the Rhône-Méditerranée basin. The site is open to the public and provides information on the hydrological situation in rivers in real or near-real time. The data are provided by the data producers presented above.

Figure 202

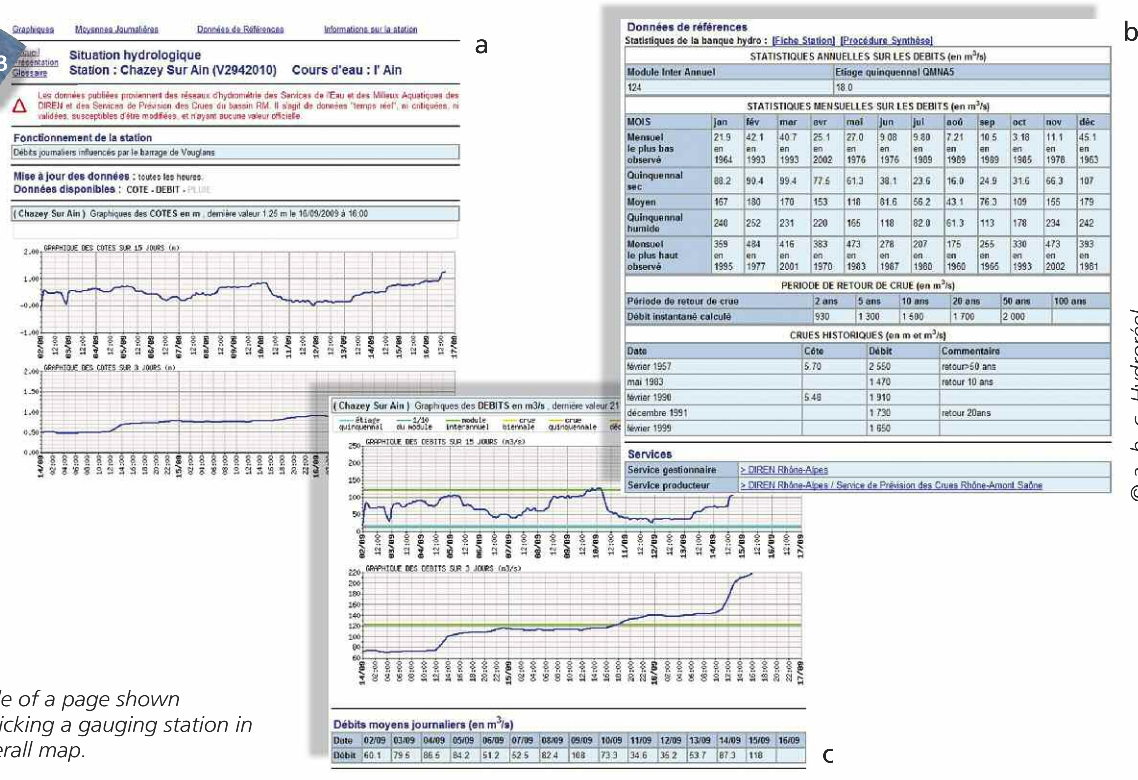


Home page of the Hydroréel site (Rhône-Méditerranée regional environmental agency). Each dot represents a gauging station.

The overall map provides an immediate overview of the hydrological situation in the entire basin, in terms of floods, low flows and mean discharges.

When a gauging station (the dots) is clicked, the system displays a page showing the hydrological data over the past two weeks with a zoom on the last three days (levels and discharges), summary data for the station and a link to the HYDRO database.

Figure 203



Example of a page shown after clicking a gauging station in the overall map.

© a- b- c- Hydroréel

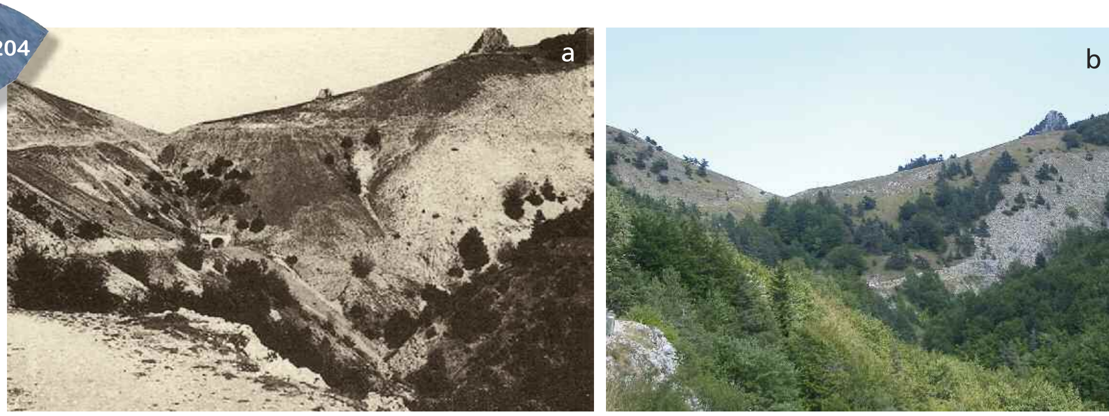
Other useful data

Old postcards and photographs

■ Postcards showing landscapes

When compared with current postcards and photographs, old postcards reveal changes in land cover and in landscapes in general. They complement the analysis of aerial photographs for periods prior to 1940.

Figure 204

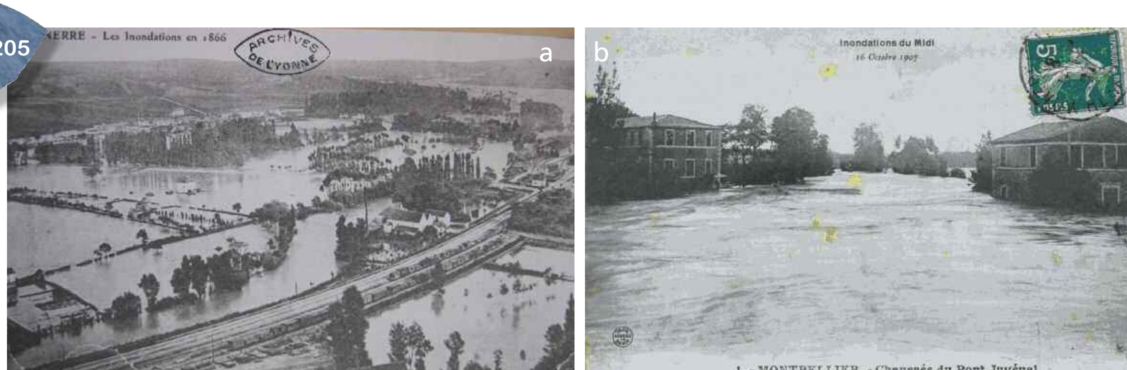


b- © Bravard

(a) Example of an old postcard (1935) showing a mountain river basin and the change in vegetation in 2005 (b). The slopes have been stabilised with as a result reduced erosion and less primary input of bedload.

Old postcards are extremely useful if the photo was taken during hydrological events such as floods because they can replace flood-level data (even if not taken at the height of the flood).

Figure 205

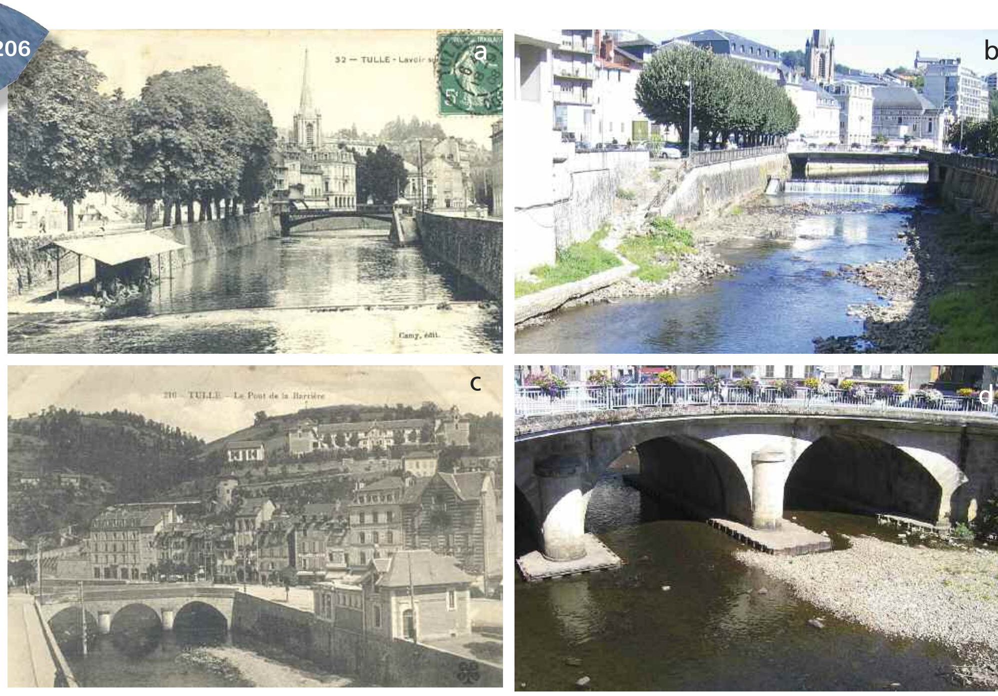


Examples of postcards showing floods (note the oblique aerial photograph of the Armançon flood in Tonnerre in 1866).

■ Postcards showing installations (bridges, dikes, wash houses, mills)

In addition to structural drawings and cross-sectional diagrams found in the archives, postcards can assist in diagnosing certain malfunctions, such as incision (downcutting) in the river bed.

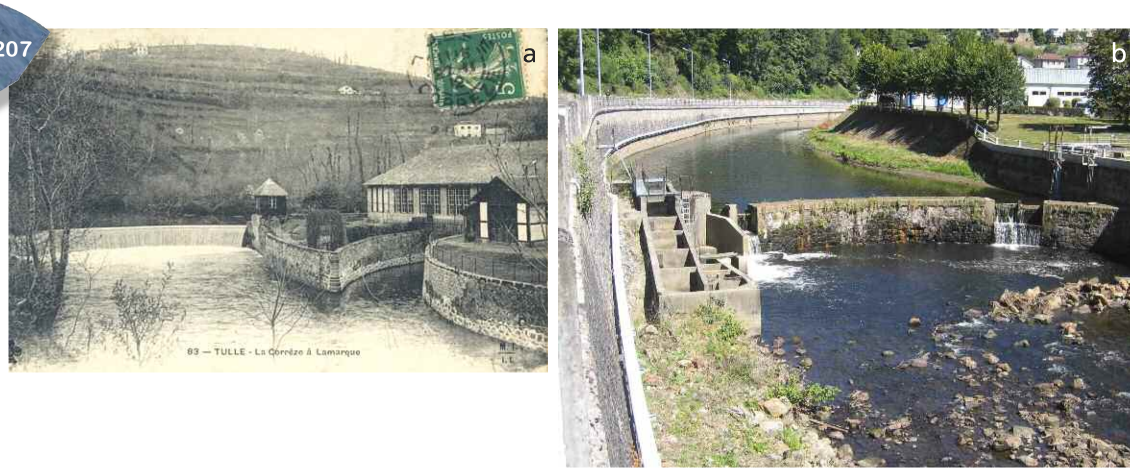
Figure 206



b- d- © J.R. Malavoi

Examples of old postcards used to analyse, more or less quantitatively, changes in a river (the Corrèze in Tulle). Note the disappearance of the small weir next to the old wash house and the reinforced bridge pilings (concrete poured into steel sheet piles), which is a sign of probable incision occurring at least locally.

Figure 207



b- © J.R. Malavoi

Examples of old postcards showing changes (the Corrèze River in Tulle, at the Lamarque weir).

Measurements in the field

Measurements in the field are generally carried out when the analysis of maps, aerial photographs and all the other documents collected during the study have made it possible to understand the general operation of the river, its evolution over time and perhaps the main malfunctions observable over the given spatial and temporal scales (artificially straight sections, weirs, dikes, etc.). The goal is then to:

- fill out the information on the hydrological operation of the river, i.e. hydromorphological alterations, bank texture and condition (natural or stabilised banks, etc.), grain size of alluvial bars, etc.;
- confirm or prove wrong any hypotheses.

Measurements in the field are generally carried out over the entire river and even its tributaries. They may be filled out with specific measurements at **representative sites**.

NB A simplified, standard protocol to acquire hydromorphological data in the national surveillance-monitoring network was drafted by Onema. This approach, called CARHYCE and focused on station measurements, will not be discussed here.

Mapping of pressures and alterations

The first part of a hydromorphological study generally serves to identify the mains sources of pressures and alterations affecting a river and its basin. 177

The SYRAH national database, managed by Onema and addressing the river basin and reach level, provides an overview of the main pressures and alterations affecting 225 000 km of river. Field measurements are nonetheless required for certain pressures and alterations that the SYRAH approach cannot detect.

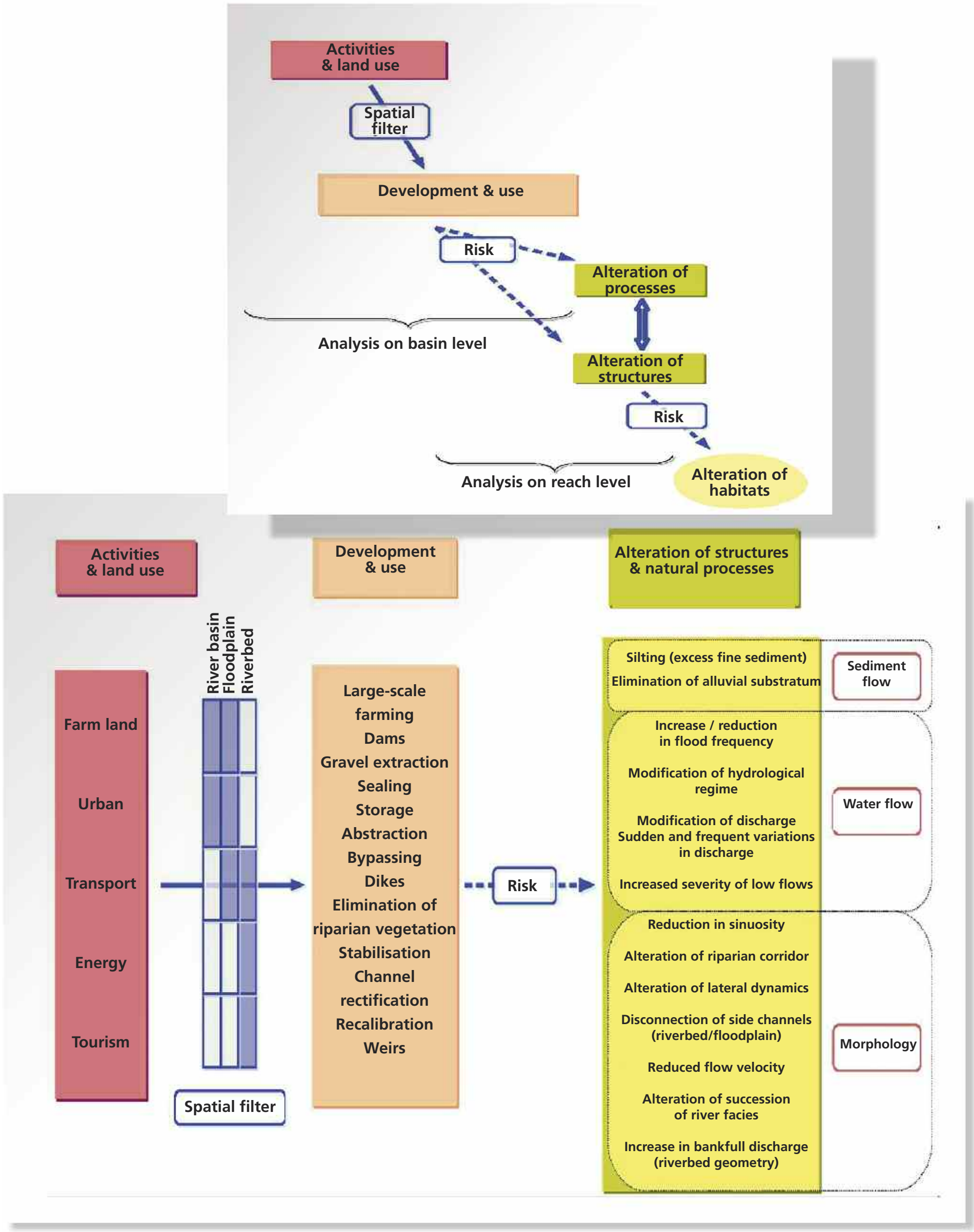
■ The SYRAH concept and associated databases

The **SYRAH-CE** audit system analyses the hydromorphological operation of rivers and assesses the risk of alterations likely to influence aquatic habitats and consequently the ecological status of the river as defined by the WFD (Chandesris *et al.,* 2007). The proposed "top-down" approach is based on an assessment of alteration risks on the river-basin scale (large scale), consolidated with an analysis of uniform hydromorphological river reaches (reach scale).

The main goal is to **detect unnatural hydromorphological alterations** clearly linked to a degradation of the ecological status. The most common hydromorphological alterations and those most likely to impact the ecological operation of rivers have been identified. To process the alterations, the audit calls on various layers of geographic data and existing databases, and blends them with the information required to programme, approve, manage and assess restoration work.

The analysis is run on successive levels from the river basin down to each river reach.

Figure 208



Design diagram of the SYRAH audit technique (Chandesris et al.*,2007).*

The resulting maps may be used for river management and work planning, while keeping in mind that due to their design, their precision is limited, notably concerning "local" morphological aspects. This approach is therefore not sufficient to precisely diagnose malfunctions and fully plan local restoration work. It is, however, highly useful in obtaining an overall view of a large territory.

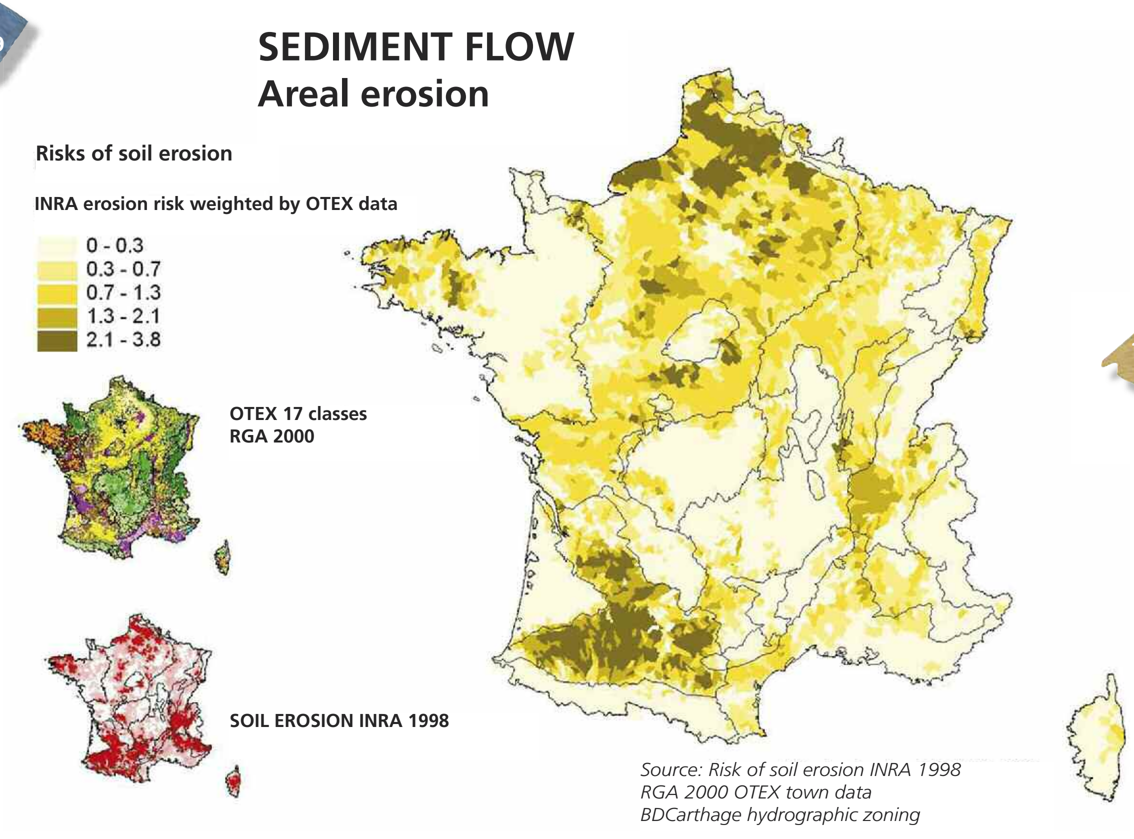
Analysis on the scale of geomorphological reaches makes it possible to describe "Development & use" with a degree of precision compatable with efforts to determine the causes of observable degradation in the ecological status. Such precise analysis is possible thanks to the availability of rich geographic databases such as BDTOPO IGN®.

In addition to **mapping the risks of hydromorphological alterations** in rivers, SYRAH-CE can also be used to assist in river management and functional restoration. Even the unprocessed results of the audit clearly identify the parts of the hydrological network subjected to limited pressures. This information, combined with data on the chemical quality of water, can help in identifying the sectors likely to achieve excellent status as defined by the WFD and that must therefore receive **priority in preservation efforts.**

Mapping of pressure indicators is the means to identify the most common, to determine where problems are located and to establish priorities.

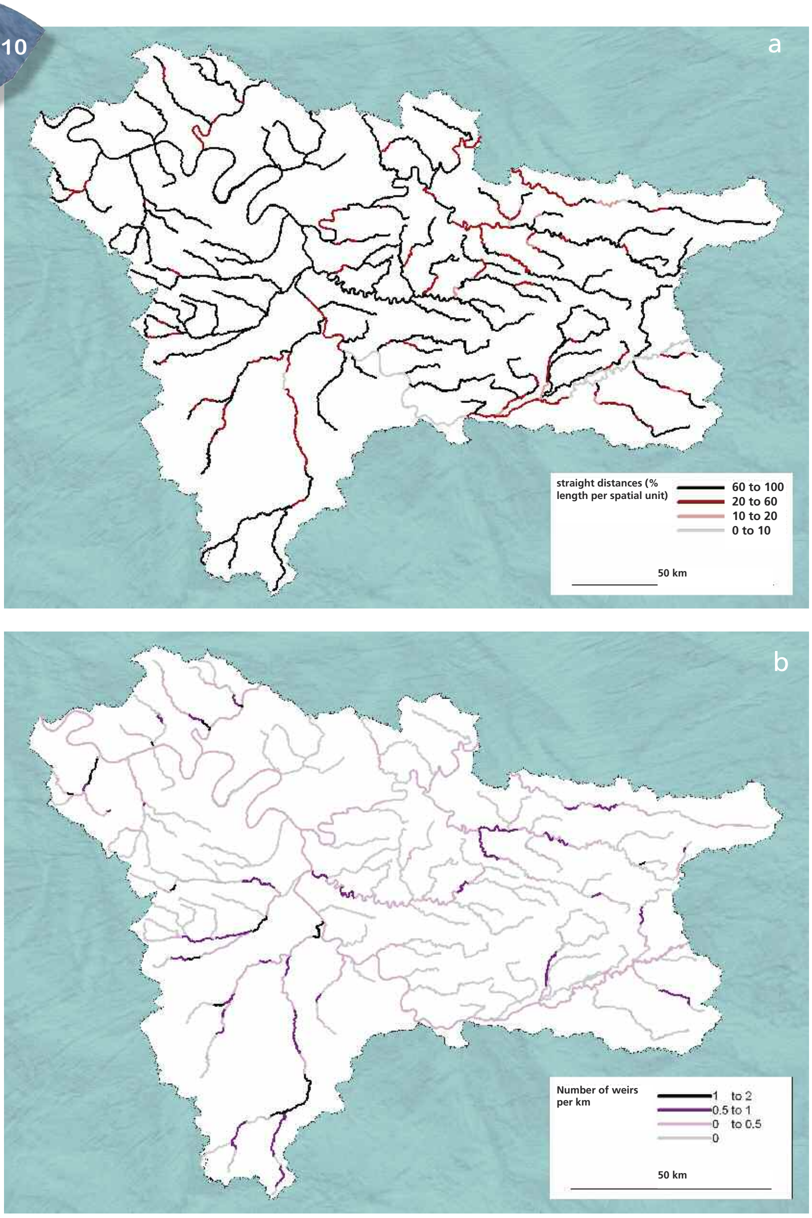
Expert analysis of the available information can serve to assist in setting up multi-scale management plans, thus facilitating identification of useful restoration work and its programming.

Figure 209



Example of a "large-scale" map identifying zones at high risk of soil erosion which can lead to silting in rivers.

Figure 210



Example of maps on the reach scale, showing pressures/alterations, e.g. planform rectification or number of weirs per kilometre (Île-de-France region, Malavoi, 2007). The darker the line, the poorer the hydromorphological operation.

The pressures/alterations currently listed in the SYRAH Reaches database are the following:

- degree to which the river is covered by a physical structure;
- channel straightness;
- cross-channel installations in the riverbed (weirs);
- no riparian vegetation;
- probable obstruction of lateral dynamics, e.g. infrastructure (roads, bridges, etc.) likely to be the cause of bank-protection systems hindering the lateral movement of the river;
- dikes (the data is fairly imprecise and must be filled out with observations from the field);
- gravel pits in the floodplain;
- urbanisation, i.e. general urban pressures (category 1 artificialised territories);
- presence of ponds along the river;
- encroachment of trees in the river corridor.

■ Necessary additional information

To date, a certain number of hydromorphological pressures and alterations are not (or only poorly) identifiable by SYRAH. It may therefore be necessary, depending on the purpose of the study, to acquire further data. The required degree of precision in describing the terrain also depends on the purpose of the hydromorphological study.

For example, it is not necessary to map in detail the river facies (an expensive undertaking) for a general study that does not explicitly require an assessment of aquatic habitats. Similarly, the position of dikes and their precise dimensions (height, width, exact position) are not always necessary if no flood concerns have been explicitly expressed.

NB A standard GPS system, i.e. non differential, is precise to within a few metres on the x and y-axes and should be more than sufficient for this type of work.

Recalibration

Recalibration is a voluntary widening or deepening of the riverbed in order to increase the bankfull cross section and convey floods having a (much) larger discharge than the natural bankfull discharge.

1- Hydromorphological alterations that generally result

- Riverbed incision (see "Incision").
- Reduction of the flow depth through widening of the cross profile, leading to more severe conditions during low-flow periods.
- Uniform river facies or at least a reduction in the types of facies present and/or facies different than those found in the natural river.
- Increased sediment-transport capacity during floods leading in some cases to additional incision.

2- Ecological alterations that generally result

- Critical conditions for habitats, particularly during low and high-flow periods.
- More severe effects of eutrophication.
- Increased water temperatures during low-flow periods.

3- Information available in SYRAH

Some pressures indicating a high probability of recalibration (over more or less long distances) may be identified by SYRAH, e.g. urban and periurban zones, large-scale farming (this factor has not been confirmed). However, there has also been significant recalibration work in sectors where these "large-scale" pressures do not exist. The degree of channel rectification is a further indicator because the two operations are often carried out together.

4- Possible additional approach

- Check the archives (DDE, DDAF, departmental archives) for documents on work projects (see above).
- Measure the bankfull hydraulic geometry (width, depth, slope) on various sites (the selection strategy must be determined on a case by case basis). Compare the results with the natural values of the width/depth ratio for the given hydromorphological type.
- Calculate the bankfull discharges and their recurrence interval. Compare the results with the natural values for the given hydromorphological type.

Dredging

Dredging removes from the riverbed alluvial deposits that hinder one or more human activities. It is often carried out very locally (at a bridge, through a village), but occasionally long distances are dredged.

1- Hydromorphological alterations that generally result

- Riverbed incision (see "Incision").
- Reduction of the flow depth through widening of the cross profile, leading to more severe conditions during low-flow periods.
- Uniform river facies or at least a reduction in the types of facies present and/or facies different than those found in the natural river.

2- Ecological alterations that generally result

- Disturbances to living communities.
- Critical conditions for habitats.
- Increased water temperatures during low-flow periods.

3- Information available in SYRAHH

Some "large-scale" pressures indicating a high probability of riverbed dredging (more or less frequent and over more or less long distances) may be identified by SYRAH, e.g. urban and periurban zones, large-scale farming (this factor has not been confirmed). However, significant dredging has occurred (and continues) in sectors where these "large-scale" pressures do not exist.

4- Possible additional approach

- Contact the various water-police units in charge of monitoring these activities, river boards, local inhabitants.
- Look for tell-tale traces in the field (recent bunds, alluvial land fill on rural paths and trails, etc.).

Gravel extraction from the riverbed

Gravel extraction is essentially the removal of alluvium from a river for commercial purposes. Extractions from riverbeds have been forbidden in France since 1994 (even earlier in certain departments) and only older gravel pits may be found today. The distances over which gravel was extracted, the processes employed and the volumes extracted varied greatly from one river to another.

1- Hydromorphological alterations that generally result

- Widespread incision of the riverbed (see "Incision").
- Types of facies present and/or facies different than those found in the natural river.

2- Ecological alterations that generally result

- See "Incision".

3- Information available in SYRAH

Certain pressures indicating a high probability of former extractions in the riverbed may be identified by SYRAH, e.g. extractions in the floodplain, lakes in the floodplain (this factor has not been confirmed). Other pressures that still require further testing include proximity to a town or to a major transportation line (major road, highway, high-speed train line).

4- Possible additional approach

- Contact the various services and agencies (DDE, DRIRE, DIREN, Onema).
- Look for the traces of incision that generally accompany extractions (see below).

Dikes

Dikes are man-made structures along the river designed to limit flooding. They are higher than the natural terrain and located in the floodplain at a variable distance from the riverbed..

1- Hydromorphological alterations that generally result

- Hydraulic disconnection between the riverbed and the floodplain, including any side channels. Disconnection can be highly variable depending on the river, the width of the area between the dikes, the height of the dikes, etc. Disconnection can be permanent or temporary.
- Riverbed incision due to the increased discharge between the dikes, particularly if the channel is narrow.
- More severe flooding downstream.

2- Ecological alterations that generally result

The degree of "disconnection" and of the incision (if it exists) determines the impact on natural environments and whether it is more or less reversible. Generally speaking, consequences include a drop in the vitality of natural environments in the riverbed due to a lack of frequent submersions, a drop in the abundance of the linked terrestrial living communities and in certain compartments of the aquatic living communities whose life cycle depends on the connections (notably the reproductive cycle of certain fish species).

3- Information available in SYRAH

The dike layer in the TOPO database used by SYRAH lacks the necessary degree of reliability.

4- Possible additional approach

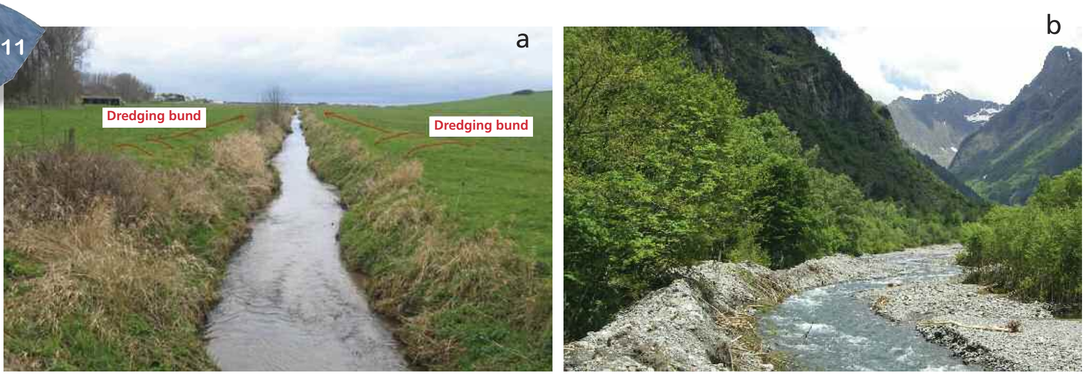
- Contact the various services and agencies (DDE, DRIRE).
- Systematic field work (if the study justifies the effort) and/or a very precise DTM.

Dredging bunds

Bunds are artificial mounds along river banks composed of the sediment dredged from the riverbed (see "Dredging").

Figure 211

a b



a- b- © J.R. Malavoi

(a) Long-term dredging bunds (low river dynamics) and (b) short-term bunds that will be removed by the first flood (high river dynamics).

1- Hydromorphological alterations that generally result

In some cases, they may produce the same effects as small dikes (see "Dikes").

2- Ecological alterations that generally result

See "Dikes".

3- Information available in SYRAH

Certain pressures indicating a probability of dredging may be identified by SYRAH (see "Dredging").

4- Possible additional approach

Systematic field work (if the study justifies the effort).

Bank-protection systems

Bank-protection systems include all the techniques designed to block lateral erosion.

1- Hydromorphological alterations that generally result

- Blocked lateral dynamics which result in a general drop in the morphological diversity of the river corridor.
- Drop in the "internal production" of coarse sediment, due to the lack of entrainment of alluvial deposits on the banks. This leads to an imbalance between the water and sediment discharges which is an essential factor in the hydromorphological equilibrium.

2- Ecological alterations that generally result

- Impacts caused by the reduction in geodynamic processes and consequently less vitality in the associated environments (notably pioneer environments).
- Drop in the ecological quality of the banks.

3- Information available in SYRAH

Certain pressures indicating a high probability of bank-protection systems may be identified by SYRAH, e.g. urban and periurban zones, transportation infrastructure near the riverbed. However, there has also been significant use of bank-protection systems in sectors where these pressures do not exist.

4- Possible additional approach

- Systematic field work (if the study justifies the effort), on foot or by boot if the river is large enough.
- On rivers with little riparian vegetation, a low-altitude aerial inspection is a means to gather information on significant sections of the river.
- It may be useful to determine the type of protection (sheet piles, concrete, dry-stacked or mortared stone banking, planted surfaces, etc.) and any damage to the system (this is more difficult because damage often occurs at the foot which is generally under water).

Incision (downcutting)

Incision is a major hydromorphological alteration where the river cuts down into its alluvial bed. The river can also cut into the substratum of the talweg if it is not particularly resistant, e.g. the Loire River in the Forez plain and the Allier River in the Limagne region both cut into marls from the Oligocene period.

1- Hydromorphological alterations that generally result

- Paving of the riverbed (large alluvium gradually forms a rigid layer that is of little use to aquatic fauna). That is often the case downstream of large dams.
- The alluvial layer may be entrained, revealing a resistant, rock substratum.
- Drop in the alluvial water table (groundwater in the aquifer of the floodplain).
- Undermining of various installations (bridges, dikes, bank-protection systems, etc.).

2- Ecological alterations that generally result

- Critical conditions for habitats in the riverbed, particularly if large sections of the bedrock are exposed.
- Disconnection of side channels in the floodplain.
- Fewer connections with the floodplain itself and decline of the alluvial forest.

3- Information available in SYRAH

Certain pressures likely to cause incision in the riverbed over more or less long distances may be identified by SYRAH, e.g. large dams blocking the sediment load, large numbers of weirs, extractions in the floodplain (often indicative of former extractions in the riverbed), lakes in the floodplain (this factor has not been confirmed). The system may also list the effects of RTM projects (work to stabilise mountain slopes and torrents), which can provoke deposits or scouring at the foot of dams and weirs. The main problem is that the actual alteration (incision, paving, exposure of the substratum) is not always clearly linked to the above pressures. For example, it generally takes a large dam several decades to produce an effect on riverbed incision several kilometres downstream and the effect may continue over centuries.

4- Possible additional approach

In areas where there is a high probability of incision (downstream of dams, former sites of extraction in the riverbed, rectified reaches, etc.), there are a number of possible approaches.

- Look for old long profiles (IGN hydraulic gradients) and cross profiles. Then determine the current cross profiles on the same sites and the long profiles at discharge levels close to those prevalent when the old long profile was drafted (the necessary information is not always available). These three steps were theoretically carried out during the first part of the hydromorphological study.
- Look for indicators of incision, e.g. undermining of structures (bridge pilings or abutments, the foot of dikes and stone banks), exposure of bedrock.

Caution. Apparent and undermined root systems are not a systematic indicator of incision. They may simply be the result of lateral erosion. The only conclusion that may be drawn (see Figure 212) is that the soil previously surrounding the roots has disappeared..

Similarly, a bridge piling or abutment reinforced with sheet piles and concrete does not necessarily signal generalised incision. This type of obstacle to river flow often results in local scouring that may require reinforcement. A weir under or immediately downstream of a bridge may however indicate a more general form of incision and particularly regressive erosion. If incision does occur, it may be strictly local. It is necessary to find a number of indicators along the river pointing toward incision before deducing that widespread incision is taking place, which is the purpose of the study.

Figure 212

a- b- © J.R. Malavoi

The exposure of roots and trees falling down the bank may signal riverbed incision. That is the case in (a), following the removal of a mill dam. The cause may also simply be lateral erosion (b). It is very difficult to distinguish between the two if the recent history of the river is not known.

Figure 213

a- b- c- d- e- © J.R. Malavoi

The photos show some sure signs of incision. (a, b) Riverbed entrenchment into its own recent, alluvial deposits. (c) Significant reinforcement of bridge pilings. (d) Visible alluvium under the foundation of structures (here a retaining wall for a road). (e) Construction of a weir downstream of an older structure.

■ Analyse the hydraulic geometry (the selection strategy must be determined on a case by case basis). A low width/depth ratio (less than 3, for example) may be a sign of incision, even though such low values can exist naturally under certain conditions, e.g. a single channel with highly cohesive banks).

Caution. Regressive and progressive erosion may occur over several kilometres. That is why it may be worthwhile to look for signs of incision well beyond the zones directly impacted by the pressures causing the probable incision, e.g. former extractions in the riverbed, sections downstream of dams, narrow sections between dikes.

Silting / clogging

The deposition of fine sediment (ranging from clay to sand) is called silting when it occurs on the surface of the riverbed and clogging when the voids between coarser sediment are filled.

1- Hydromorphological alterations that generally result

■ Reduced permeability and porosity of the substratum.
■ Reduced exchanges with air and water.

.

2- Ecological alterations that generally result

■ Modification of benthic and interstitial habitats leading to disturbances in the structure of invertebrate populations, an increase in drift and a reduction in the overall abundance of organisms. Sensitive species that depend on coarse substratum disappear and are replaced by species adapted to fine sediment (Gayraud *et al.,* 2002).
■ Malfunctions in spawning grounds and in the habitats of certain fish species.
■ Modification in the exchanges of water and matter between the surface and the hyporheic zone.

3- Information available in SYRAH

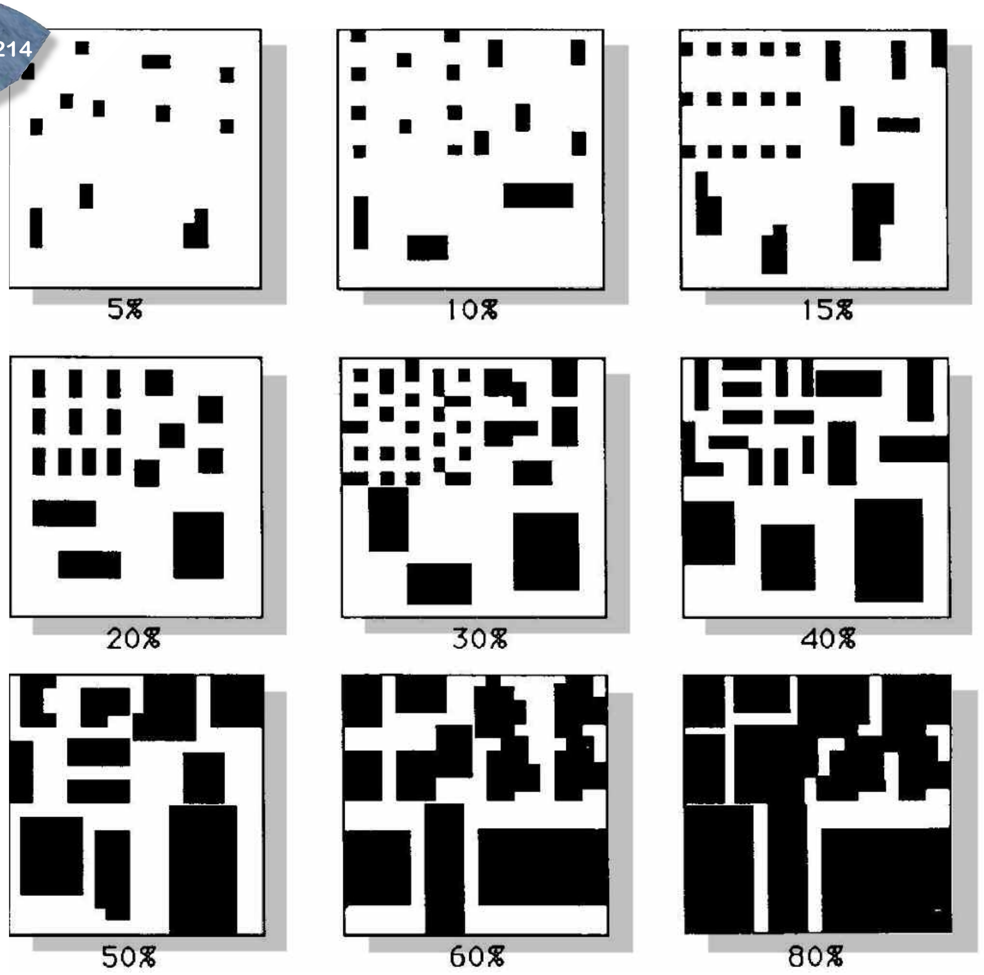
Certain pressures likely to cause non-natural silting/clogging in the riverbed over more or less long distances may be identified by SYRAH, e.g. farming areas identified in conjunction with the INRA soil-erodibility map.

4- Possible additional approach

There are currently a number of assessment methods to determine the degree of silting/clogging of the alluvial substratum of a river, but none have been standardised.
On the reach level, the goal is to describe the **degree of silting/clogging in lotic facies,** such as riffles and runs, where theoretically the least deposition should occur.

There are three degrees of precision among the existing methods.
■ The most precise involves obtaining samples using liquid nitrogen. This expensive and cumbersome technique is generally used for research projects, but it does provide useful information on deposition fairly deep into the alluvial substratum.
■ A technique offering intermediate precision measures the permeability of an alluvial substratum on site (and consequently the degree of clogging) by injecting a certain amount of water in a strainer tube (Déscloux *et al.*, 2009). This method, called the hydraulic-conductivity method, is currently being standardised in view of its use in a WFD measurement network.
■ The method offering the lowest level of precision consists of evaluating visually or using very rudimentary techniques the surface area covered by fine sediment (e.g. using the diagrams on the next page) and the thickness of the sediment. An additional aspect is the degree to which coarse alluvium is embedded in the finer sediment.

Figure 214



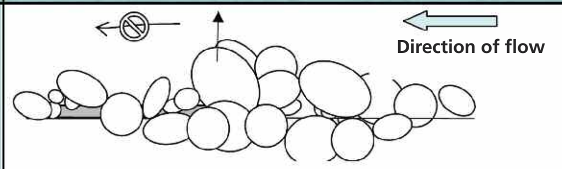
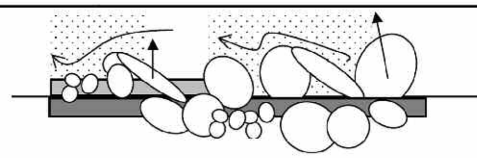
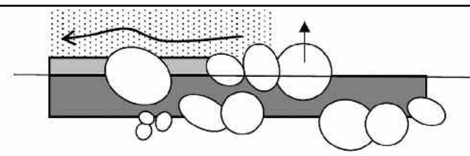
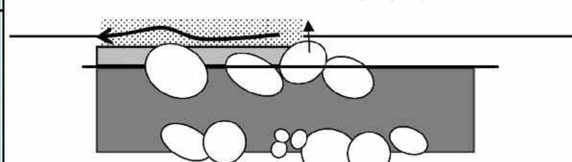
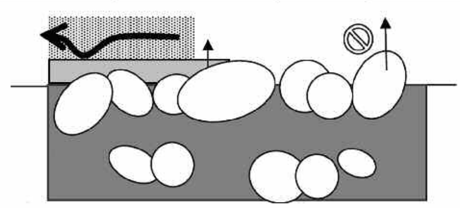
Visual evaluation of the surface area of a coarse alluvial substratum covered by fine sediment (Northcote, 1979).

The Cemagref unit in Aix-en-Provence (Archambaud *et al.*, 2005) developed a basic, but reproducible assessment method for silting on the riverbed surface and the degree to which coarse alluvium is embedded. It consists of lifting a coarse element and estimating both the difficulty of extraction and the density of the cloud of fine sediment freed during extraction.

On the basis of these two criteria, five classes of silting/clogging have been defined.

- **Code 1.** The coarse elements may be easily lifted. They rest on the underlying coarse substratum and do not release a cloud of silt when removed.
- **Code 2.** The coarse elements are more difficult to lift, but the cloud released from underneath is not dense, i.e. the surface elements are bound together by an underlying layer of silt.
- **Code 3**. The coarse elements are significantly embedded, but can still be lifted and the cloud of silt is fairly thick.
- **Code 4**. The coarse elements are difficult to lift and the cloud of silt is very thick. The coarse elements are firmly embedded in a compact underlying layer forming a tight bond.
- **Code 5.** The coarse elements cannot be lifted or only with great difficulty ("cemented" or paved structure). They are covered by a thick layer of silt, which is the dominant type of substratum.

Figure 215

Code	Silting class	Description of silting/clogging (when a coarse element is removed)
1	] 0 - 25%]	 The coarse elements rest on the bottom. There may be a fine layer of slightly bonding silt (left) or no silt (right).
2	] 25 - 50%]	 The coarse elements are bonded by an underlying layer of silt (with or without an overlying layer). The released cloud of silt is not dense.
3	] 50 - 75%]	 The coarse elements are significantly embedded and release a fairly thick cloud of silt when removed from the underlying layer.
4	] 75 - 90%]	 The coarse elements are firmly embedded and release a thick cloud of silt when removed. The cloud may be intensified by an overlaying layer.
5	] 90-100%]	 The coarse elements are covered and release a very thick cloud of silt when removed (left) or are "cemented" in place and cannot be remove (right).

Example of a method to evaluate the degree to which silting/clogging has occurred and the coarse elements are embedded (Archambaud et al.*, 2005).*

Modification of river facies

River facies have frequently been altered by human intervention, e.g. channelling, weirs, dams, gravel extraction, etc. These alterations may be signalled by types of facies and/or proportions of facies different than those found in the natural river.

1- Hydromorphological alterations that generally result

- Modification of flow characteristics (depth, velocity, sediment grain sizes).
- Modification of the self-cleansing function, i.e. certain facies (runs, riffles) seem to clean themselves better than others.

2-Ecological alterations that generally result

Modification of the linked habitats and living communities.

3- Information available in SYRAH

Certain pressures likely to cause significant modifications in the river facies may be identified by SYRAH, e.g. rectified channels, high numbers of weirs (turbulence caused by the structure replaces the natural facies), possible overwidening due to former extractions of gravel.

4- Possible additional approach

In zones where there is a high probability of facies modification (see the SYRAH data), one approach is to map the facies, either directly along the river or using low-flying aircraft. Methods to identify and map facies are discussed in detail in Malavoi (1989) and Malavoi and Souchon (2002).

Sediment transport and grain size of alluvium

In the previous chapters, we discussed how to locate and map alluvial bars in rivers using the ORTHO® database, low-flying aircraft or carrying out measurements in the field.

In addition to this first step in the analysis, it is indispensable to collect information on the quantity and the grain size of the transiting alluvium.

The method consists of carrying out measurements on sample sites along the entire river (the selection strategy must be determined on a case by case basis) or, if complete and detailed information is required, on each alluvial bar identified during the first phase of the study.

■ Evaluating the volumes of transported sediment

A standardised method does not exist.

For a "general" hydromorphological study, i.e. a study not specifically addressing sediment transport, the simplest technique is to evaluate the surface area of the sampled alluvial bar and its average thickness compared to the talweg (lowest part of the riverbed).

NB The quantity (vertical height) of alluvium entrained during a flood can significantly exceed the thickness of the bars. The goal here is simply to have a general idea of the volumes involved.

■ Evaluating the size of the transported particles

Different levels of precision for the grain-size measurements are available, depending on the needs of the study. Once again, if the study does not specifically address sediment transport, it is probably sufficient to carry out basic grain-size measurements on the **armoured layer** (for information on the **underlying layer** representing the actual bedload transported, more difficult and complex volumetric sampling is necessary).

We propose to carry out the grain-size measurements (or observations) on the part of the moving bars with the largest sediment, generally located on the upstream end of bars along the main axis of flow during floods. It is clear that the results will be voluntarily biased toward the coarsest elements in the transported bedload.

Two methods are available (note that they measure the grain sizes of the surface or **armoured** layer only).

■ The visual method (Malavoi and Souchon, 1989) determines the grain sizes using a scaled "gauge". The observed substratum is coded using up to six letters (see the table below).

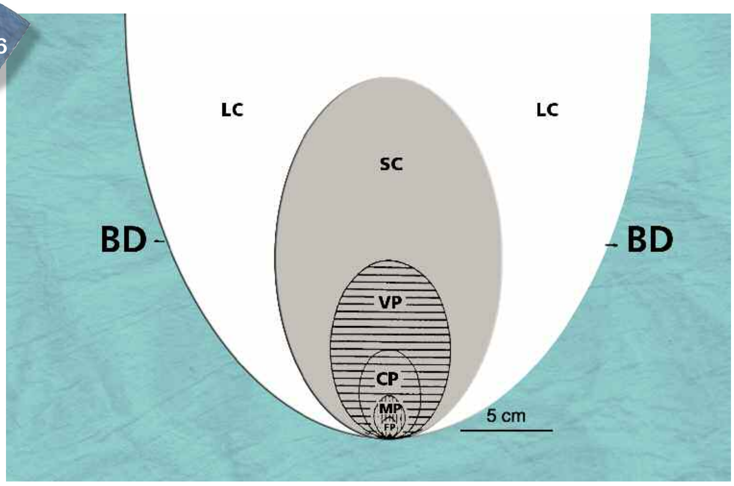
- The largest element (approximately D90) is coded using two letters, e.g. LC.
- The most common element (approximately D50 if there is only one dominant element) is coded using two letters, e.g. LC if this class is both the largest and dominant.
- If a second dominant element exists, it is coded using two letters, e.g. VP.

The substratum described above is coded LCLCVP, i.e. very coarse substratum.

Tableau 11 *Classification system created by Wentworth (1922) and microhabitat codes by Malavoi and Souchon (1989).*

Type of grain	Size in mm	Microhabitat code
Large boulder or slab	> 1024	LB
Boulders	256 - 1024	BD
Large cobbles	128 - 256	LC
Small cobbles	64 - 128	SC
Very coarse pebbles	32 - 64	VP
Coarse pebbles	16 - 32	CP
Medium pebbles	8 - 16	MP
Fine pebbles	2 - 8	FP
Coarse sand	0.5 - 2	CS
Fine sand	0.0625 - 0.5	FS
Silt	3.9 - 62.5 µ	ST
Clay	< 3.9 µ	CL

Figure 216

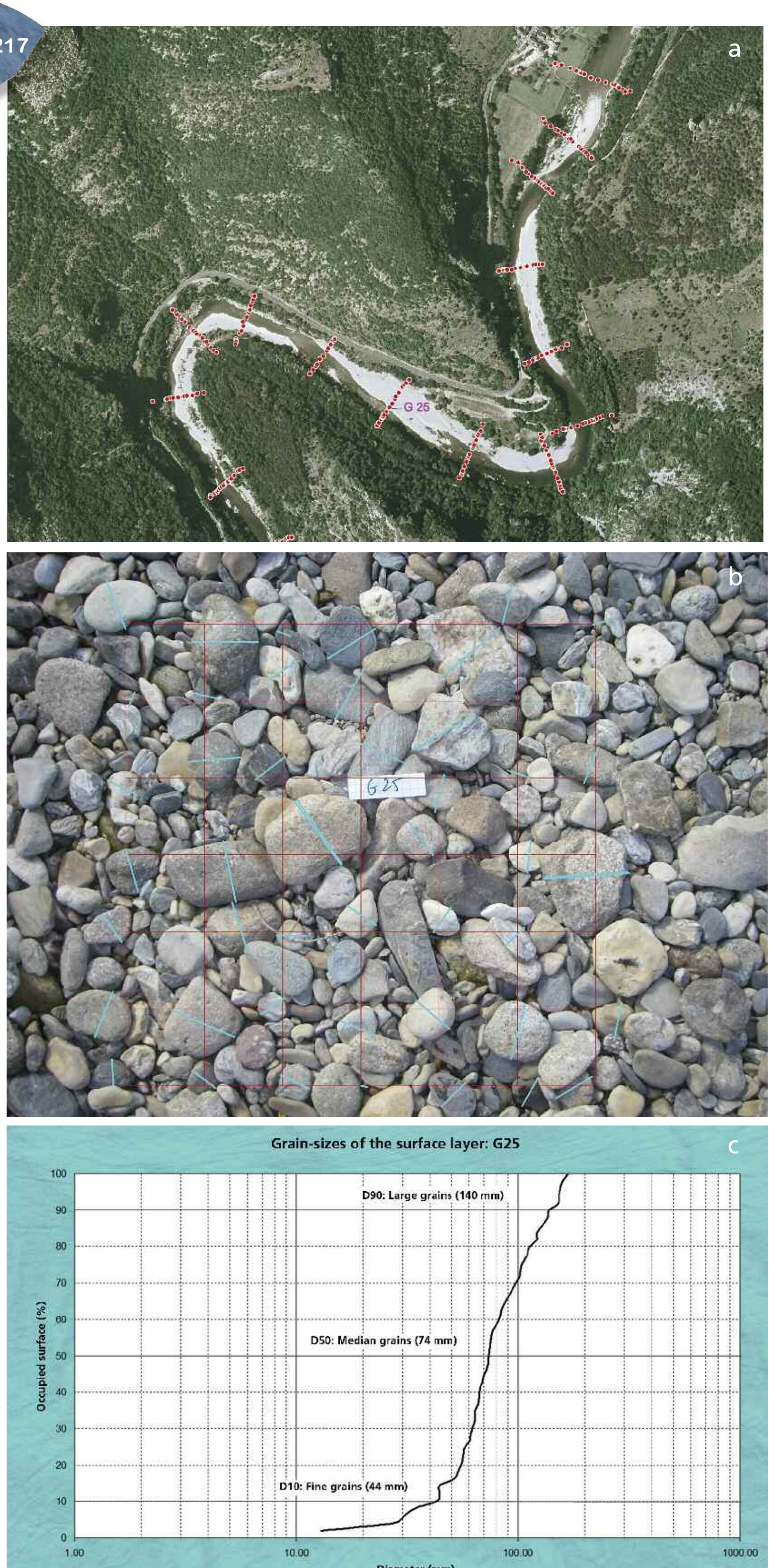


Visual "gauge" for grain-size classes (must be correctly scaled before use). (Malavoi and Souchon, 1989).

The more objective Wolman method consists of randomly selecting 100 elements in the section of the bar with the coarsest material, measuring the second longest axis (b) perpendicular to the longest (axis a) and plotting a curve with grain-size percentiles (D50, D90, etc., see the figure below).

NB For exposed alluvial bars, a solution superior to the Wolman method is a vertical photograph including a scale element. It is then very easy, using suitable software, to set up a sampling grid and measure the b-axes. Similarly, it is highly worthwhile to carry out grain-size measurements at sites where cross profiles are measured (see the example below) in order to refine the hydraulic analysis (e.g. determine the discharges required to transport sediment).

Figure 217



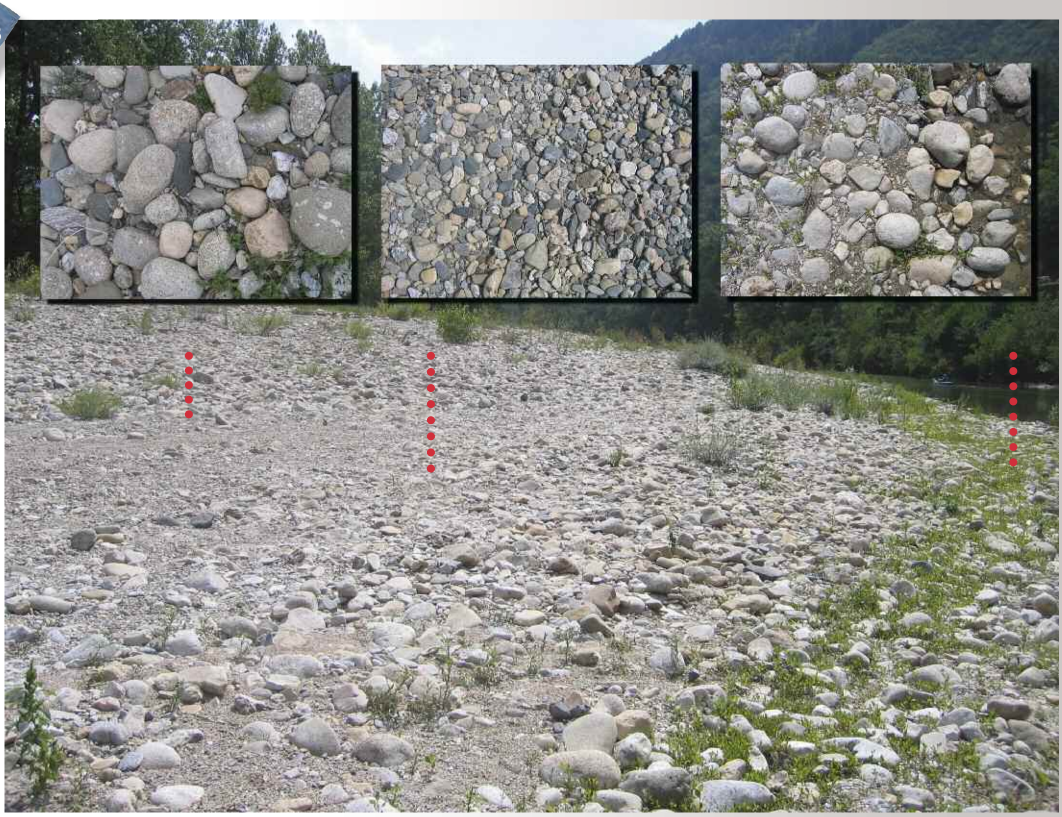
a- BD Ortho 2006. ©IGN 2010. b- © J.R. Malavoi

Example of grain-size measurements on the armoured layer, using a vertical photograph taken at a cross-profile transect (a) and the resulting grain-size curve (c). Measurements of the b-axes (blue lines) are carried out using a GIS after scaling the photo (the ID slip for the sample is ten centimetres wide). Each element at a grid intersection (red lines) is measured, i.e. 49 elements for a 7x7 grid (Malavoi and Adam, 2007).

The main difficulty in grain-size measurements on alluvial bars lies in determining the sampling strategy. It has been demonstrated a number of times, notably by Mosley and Tindale (1985), that transported sediment is distributed very unevenly over the surface of deposition zones (bars and dunes), depending on the flow currents, the elevation of the various parts of the bar, the presence of vegetation and jams, etc. In addition, the deposits of different floods or different phases of a single flood may be superposed.

Consequently, depending on where the measurement is carried out, the grain-size curve (percentiles) may vary by a factor of 2.5 (see the figure below) or even by a factor of 100 if a slowing current at the end of a flood deposits sand (e.g. D50 = 0.5 mm) next to coarse material (e.g. D50 = 50 mm) deposited at the height of the flood.

Figure 218



© J.R. Malavoi

The photos above show the variability of grain sizes on the surface of an alluvial bar (point bar). The D50 values vary by a factor of five and the largest sediment is located near the top of the bar. In this case, measurements should be carried out on the zone with the largest sediment

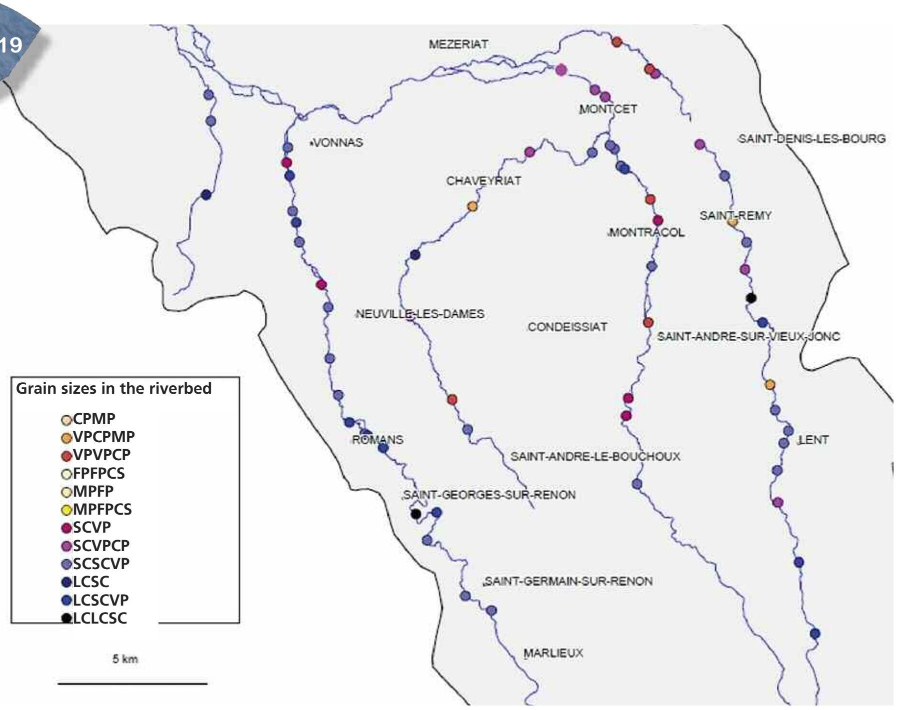
Grain sizes in riffles

In addition to measuring the grain sizes of bedload on the surface of alluvial bars, it is worthwhile to measure the grain sizes in riffles which are, in theory, the **sections of rivers where the largest bedload is deposited.**

This is worth the time and effort for two reasons.

- Typological classification. The river or river reach can be classified according to a "grain-size" type. Examples could be riffles with boulders, riffles with large or small pebbles, etc.
- Knowledge of the processes entraining the alluvial substratum. In conjunction with the unit stream power, the information on grain sizes in riffles informs on the minimum frequency of sediment entrainment in the riverbed.

Figure 219



Map showing visual grain-size measurements in riffle facies of the Veyle River and its tributaries (the darker the colour, the coarser the sediment). In the downstream section, the riffles are no longer visible because they are submerged behind mill dams (Malavoi and Epteau, 2003).

Hydraulic geometry and characteristics of natural banks

The last two additional elements of field data, that were perhaps obtained earlier in the study from existing documents, are the mean hydraulic geometry of the river and the cohesiveness of the banks.

■ Bankfull hydraulic geometry

The bankfull geometric data are factors in the typological classification, including both static (e.g. the width/depth ratio) and dynamic (e.g. bankfull discharge, unit stream power) aspects.

As noted above, the ratio of the average bankfull width to the average bankfull depth is a useful geometric characteristic for a number of reasons.

- In hydromorphological terms, it is a typological parameter i**ndicating the geodynamic activity of the river.** For example, fairly dynamic rivers with significant lateral erosion and high sediment inputs have relatively high w/d ratios of 20 or more. Braided rivers often have w/d ratios near or even greater than 100.
- The w/d ratio also informs on **bank cohesiveness** (see the next section). The more cohesive the banks, the narrower and deeper the river, conversely, if the banks are not very cohesive, rivers tend to be wider and shallower. The trends are identical to those for riparian vegetation in that the two parameters (vegetation and cohesiveness) both encourage vertical erosion and limit lateral erosion.

Finally, these geometric measurements can be used to calculate the bankfull discharges and the corresponding unit stream powers.

- Bankfull discharge. It is widely acknowledged that the bankfull discharge of a natural river under steady-state conditions has a recurrence interval close to that of the 1.5 to 2.5-year flood (daily level). Even a rough calculation of the bankfull discharge at a station can theoretically be used to detect any alterations (e.g. recalibration) if its recurrence interval significantly exceeds Q2 (e.g. Q5 or Q10).
- Bankfull unit stream power. NOTE that the bankfull unit stream power is a decisive parameter in river dynamics. The higher the power, the greater the capacity of the river to erode its banks (if they are not cohesive) and to transport the sediment. In conjunction with the substratum characteristics and the river hydrology, this parameter can be used to determine the frequency of sediment entrainment and consequently substratum stability over time, an important factor in the ecological operation of the river.

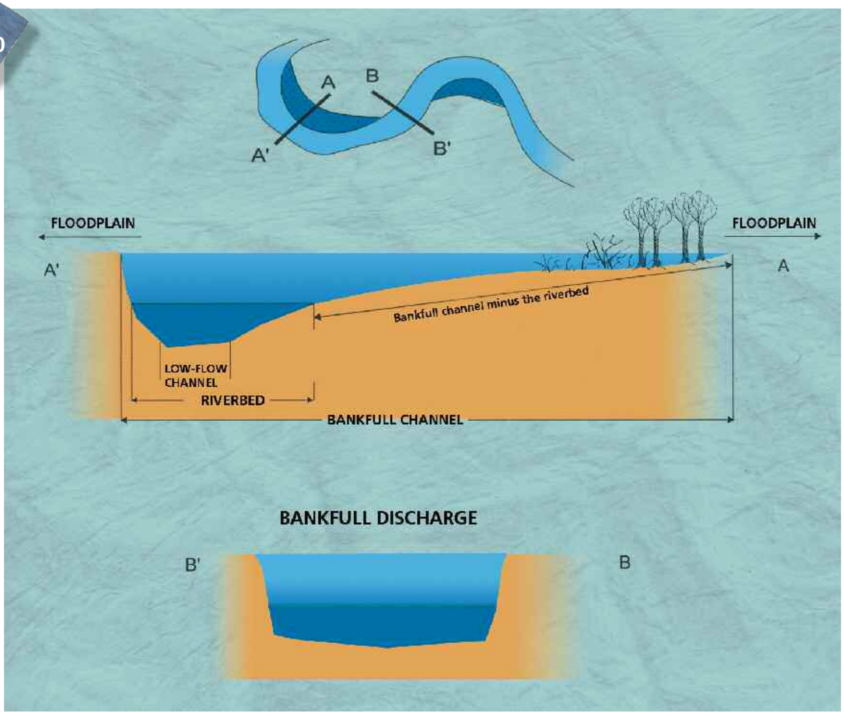
NB These bankfull geometric measurements must theoretically be carried out:

- at the inflection point between two sinuosities;
- or in a straight section of the river.

In theory, it is at the above points in the river pattern that symmetrical cross profiles may be found, whereas they are generally asymmetrical and more complex in the sinuosities (see Figure 220). Note that it is also at the inflection points or in straight sections that the most favourable river facies (riffles and runs) for simple hydraulic calculations, such as the Manning-Strickler[4] equation, may be found. Flows at those points are generally uniform[5].

Cross-profile measurements do not require an exceptionally high degree of accuracy (errors of 15 to 20% are acceptable). The measurements may be carried out using a measuring tape for the widths and a survey rod for the bank heights.

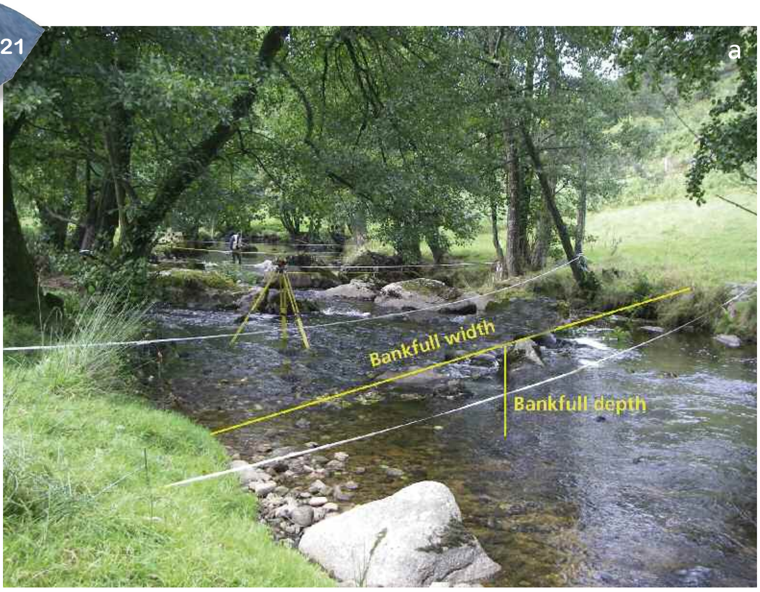
Figure 220



Examples of cross profiles depending on the position in the river pattern. It is preferable to measure the geometric values (widths and depths/heights) on river sections such as that marked B-B'.

[4] Manning-Strickler equation. $V = K \cdot R^{2/3} J^{1/2}$ and $Q = V S$ where V is the velocity (m/s), R the hydraulic radius (m), J the slope (m/m), S the wetted cross section (m²).
[5] A uniform flow occurs in a river if:
- the riverbed slope is constant;
- the geometry (wetted cross section) is virtually constant;
- roughness is constant;
- discharge is constant (stationary flow).

Figure 221



a- b- © J.R. Malavoi

Examples of bankfull geometry measurements.
N.B. For both width and depth measurements, the lowest bank is always used.

■ Degree of bank cohesiveness

As noted above, the cohesiveness of the bank sediment is one of the main control factors in geodynamic processes.

With the exception of stone banks where it is not an issue, a rough evaluation of bank cohesiveness and consequently of potential bank erodibility can be carried out by determining the proportion of cohesive sediment in the bank (silt and clay) and its stratigraphic position (top of bank, foot of bank, etc.).

NB The goal is to evaluate the **potential** erodibility of banks. If protection systems are installed, it is necessary to find a non-protected sector. Note that, depending on the geomorphological history of the valley, the type, height and stratigraphic structure of the banks can vary significantly. A single observation is not sufficient to evaluate the banks for an entire river reach.

The various steps in determining the cohesiveness of the banks are presented below.

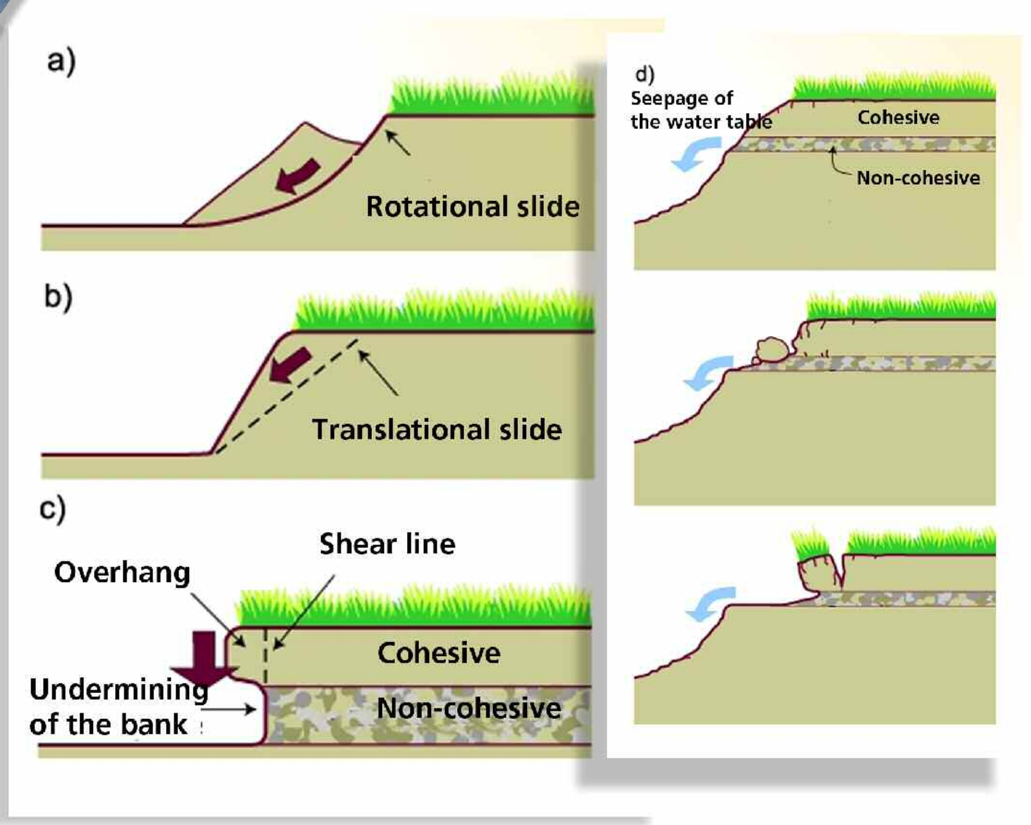
- Look for an unprotected section of bank with no vegetation, if possible in a sector where the foot of the bank is close to the mean bottom of the riverbed or even the talweg.

Figure 222

Even if the bank is covered with natural vegetation, it is often possible to distinguish at least part of the bank and notably the base. That is also the case when bank-protection systems are damaged or intermittent.

■ Clear the slope of the bank down to the bottom, which is the most vulnerable to erosion. Even if the upper part of the bank is cohesive, but the foot non-cohesive, lateral erosion can be significant.

Figure 223



Types of erosion depending on the type and stratigraphy of the bank.

■ Determine bank erodibility. This can be done directly in the field or later after having photographed the entire slope of the bank, if possible with an item for scale in each photograph. The degree of bank erodibility is divided into four classes (see the section on "Geodynamic ranking"), namely zero, low, moderate and high.

- **Zero erodibility.** This class concerns stone banks or banks with alluvial deposits, often very old, that are too large to be entrained by the available stream power.

Figure 224

a- b- © J.R. Malavoi

Examples of banks with zero erodibility.

● **Low erodibility.** This class concerns banks made up of clay (extremely cohesive) or clay-silt sediment (very cohesive) from top to bottom. In spite of the high degree of cohesiveness, these banks can be eroded, notably following a dry period resulting in "mud cracks". The latter constitute weak zones that facilitate the fall of sediment down the bank.

NB The presence of vegetation on all or part of the bank slope may be an indicator of low erodibility.

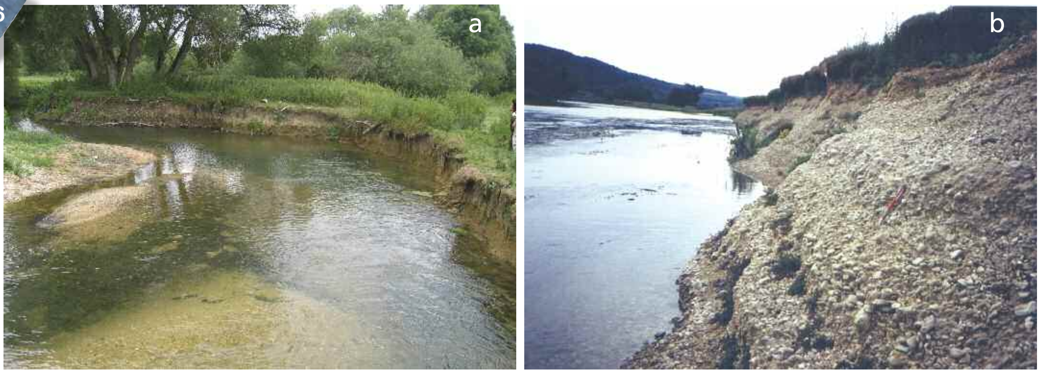
Figure 225

a- b- © J.R. Malavoi

Examples of banks with low erodibility.

● **Moderate erodibility.** This class concerns banks where silt is dominant in the sediment texture (sandy silt or silty sand) or in the stratigraphy (over 80% of the bank height is comprised of silt). It is also the case for banks with initially non-cohesive grain sizes, but that are made more cohesive due to precipitation of calcium carbonate which "cements" the bank surface.

Figure 226



a- b- © J.R. Malavoi

Examples of banks with moderate erodibility. (a) Silt bank. (b) Gravel bank made more cohesive due to precipitation of calcium carbonate which "cements" the bank surface.

- **High erodibility.** This class concerns banks where coarse sediment (sand and pebbles up to cobbles and boulders in mountain torrents) dominates over at least the bottom quarter of the bank (high erodibility) or over the entire height of the bank (very high erodibility).

Figure 227

a- b- c- d- © J.R. Malavoi

Examples of banks with high erodibility.

- **Determine the grain-size distribution.** It may be useful to indicate the dominant grain size or that of the two dominant strata, if possible with stratigraphic indications, e.g. 0 to -2 metres = silt, -2 to -3 metres = gravel and sand, or MPFPCS if the method discussed above is used. This rough approximation may be carried out later using photographs.