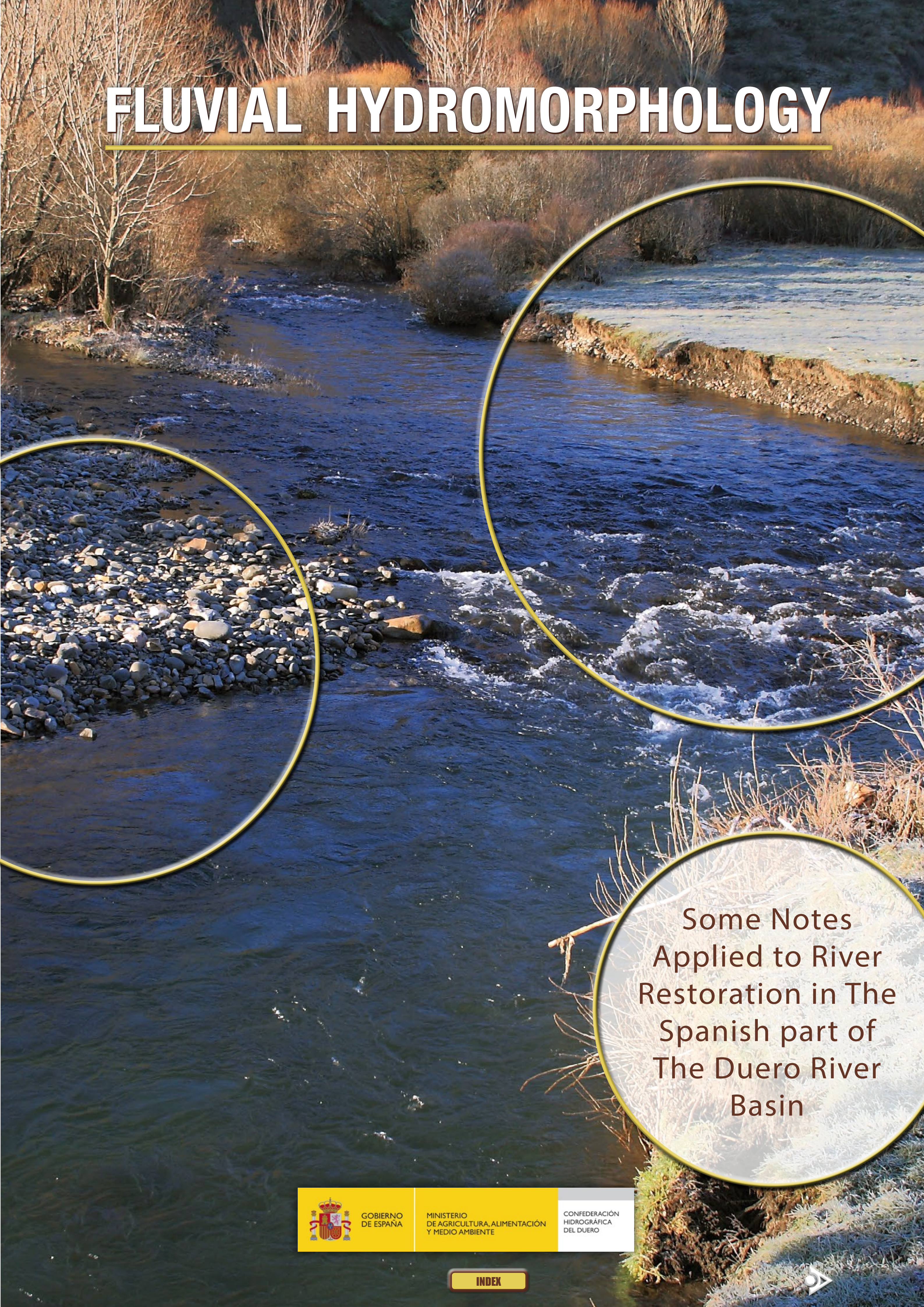
FLUVIAL HYDROMORPHOLOGY



Some Notes Applied to River Restoration in The Spanish part of The Duero River Basin

GOBIERNO DE ESPAÑA
MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE
CONFEDERACIÓN HIDROGRÁFICA DEL DUERO

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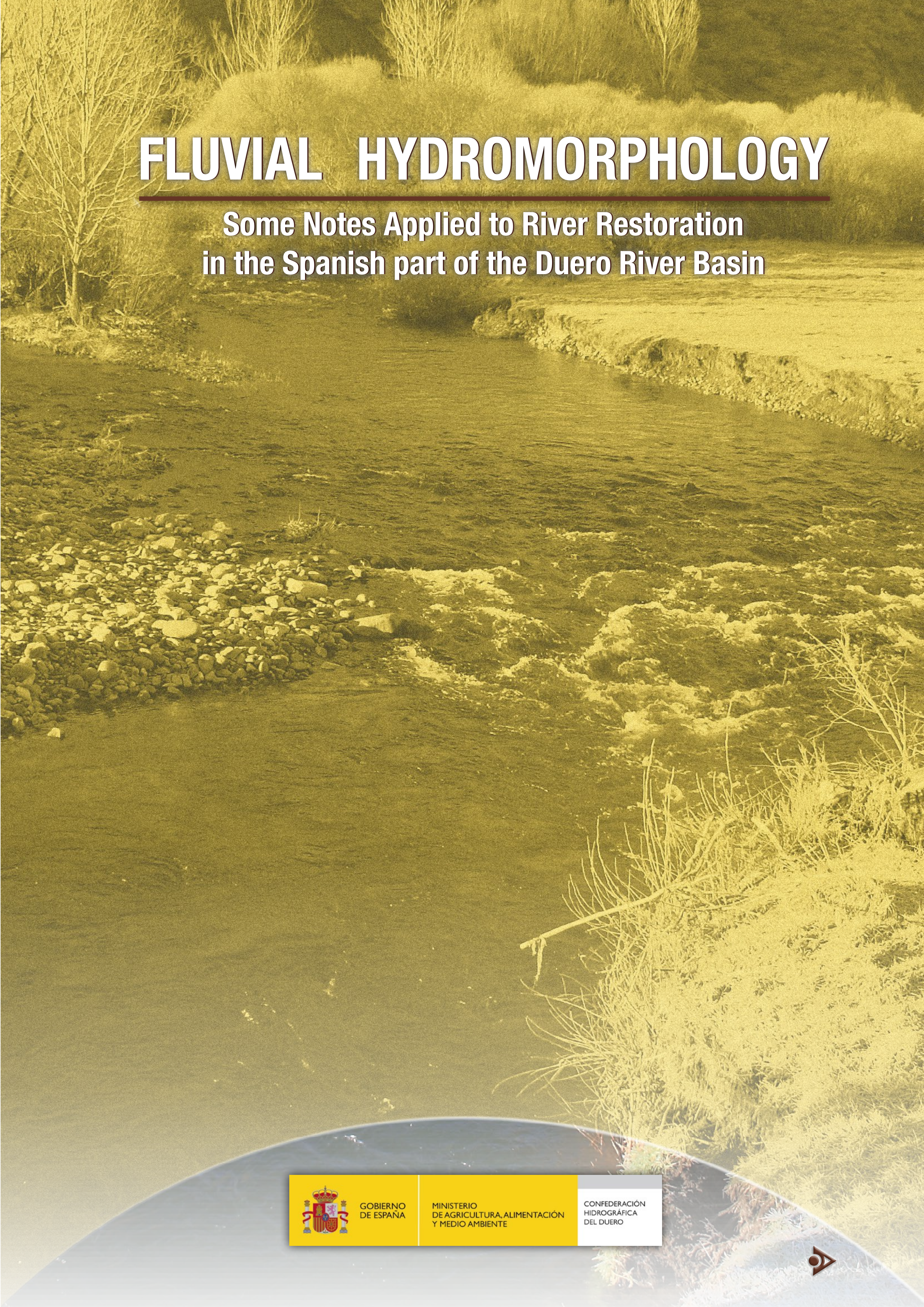

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Valladolid, 2016

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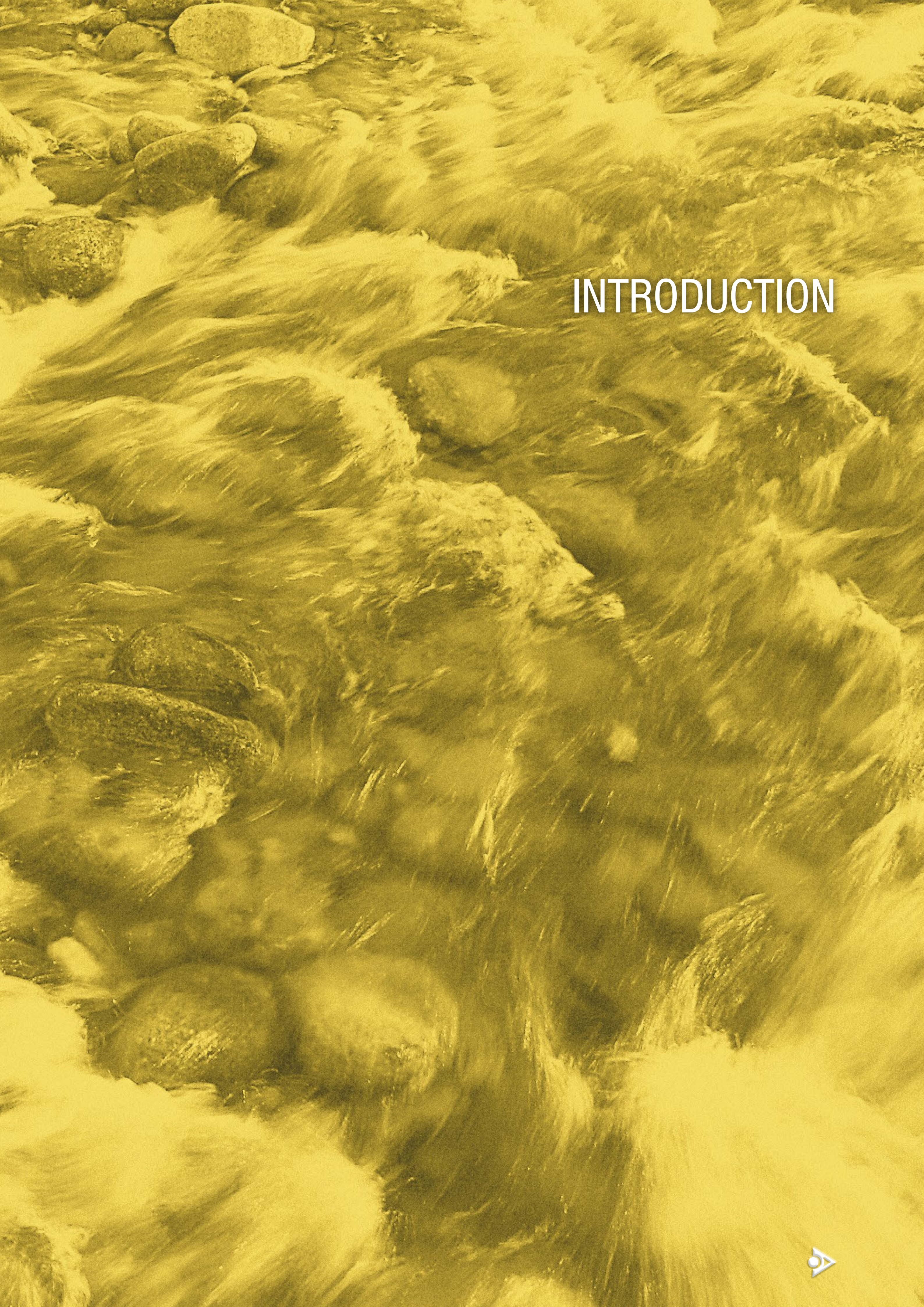
INTRODUCTION



Rivers are the main connection between lands and oceans. They are an essential element in the water cycle, as well as in biogeochemical cycles and continental weathering and erosion processes, which drive the functioning of the biosphere.

Furthermore, they are extremely complex and diverse natural systems, due to the large number of variables involved in their functioning.

These variables are continuously changing in space and time, giving rise to a broad diversity of responses. To this huge natural variability, we must add the variability generated by human activity, forcing rivers to complex adjustment processes and different speeds of response.

Those who work with rivers are aware of this diverse and complex 'fluvial realm'; different approaches and plenty of models and formulas which approximate reality have been developed for it. It is, however, impossible to control and measure every variable, and, above all, it is impossible to predict accurately all the potential responses.

Many scientists continue to look in greater depth at these aspects, but others, showing equal common sense, start making efforts to simplify the analysis methods used, and accept the broad margin of unpredictability within fluvial responses. When approaching rivers, a vision that is based on experience, based on the senses and on the field must prevail over a ra-

Curueño river. León.
Group of students and teachers doing granulometric measurements on a sediment bar.

tionalist one. An expert in rivers must be able to identify the situation and assess the status of a river based on a good visual inspection and some essential measurements.

Who is, however, that expert in rivers? Or, in other words, to whom is this publication addressed? It would be pretentious on our side to imply that anyone who reads this document and approaches a river becomes an expert. That is not our intention at all. However, this publication pretends to be equally useful for those with a professional background that relates directly to water courses and river restoration, as for those who would like to get to know this field.

For the first ones, maybe their professional development has led them to certain inertias that, with the passage of time, have shown to be undesirable. For this group, this document could possibly be an invitation to further thinking and then acting accordingly. And thus the first of the two objectives set for this document will have been achieved.

In terms of the second target group, those who are not specialists in the subject, they could discover a whole universe of technical aspects as well as sensory aspects related to water courses, which can serve as the basis for further learning later on, based on their own interests.

With this double objective in mind, of providing a first approach to rivers and also further thinking about them, we have set out a simple structure for this publication, in order to facilitate understanding those aspects that have a certain degree of technical difficulty. The images and illustrations are simple, presenting many of the phenomena and the consequences described; they are used liberally in order to improve the readers' understanding of the explanations in the text. Although we have deliberately chosen examples from the Duero river basin, most of the facts and the issues that the images present are universal in nature, applicable to other river basins.

Rivers are, as we already said, natural systems whose functioning is complex and dynamic. Human interventions give rise to pressures on rivers that should be reduced to a minimum and corrected. River restoration actions should seek reverting water courses to a natural state, through the recovery of the hydrological regime and the space for the river to move freely, eliminating as much as possible any excess anthropogenic presence in our rivers, such as all sorts of hydraulic devices or other type of artefacts. The first two chapters of this publication deal with these aspects.

The hydrological regime of a river, as well as its topography and the materials it runs through, have an influence on the shape it will have. As such, the study of hydromorphological indicators is key to determine the ecological status. This issue is currently not well understood, and we should insist upon it: the biotope base of river ecosystems is the matter; the regime and

Fluvial system

A complex system integrated in the water, solid matter and biogeochemical cycles, as a result of a complex climatic, hydrological, geomorphological and ecological mechanism of surface movement or conveyance of continental waters, together with the materials they transport, sediments, nutrients and living organisms or parts of them, following a downhill gradient, sometimes against the current, until they reach oceans, lakes, or inland seas. They have an enormous capacity to transport mass and energy. They are open systems, acting as corridors to communicate ecosystems, are extremely dynamic in space and time, and considerably complex, in such a way that the relationships among elements are countless.

its consequences, the form. Without adequate knowledge of river dynamics it is very difficult to do an accurate analysis and assessment of the status of a river, as it is sometimes done based on biological indicators which are entirely inappropriate, due to a mistaken application of the Water Framework Directive. To this effect, chapter 3 outlines the basic hydromorphological indicators that ought to be considered in a river restoration process.

Linking to earlier contents, chapter 4 focuses on establishing a system to monitor river restoration actions, in order to validate data, as part of a continuous learning process.

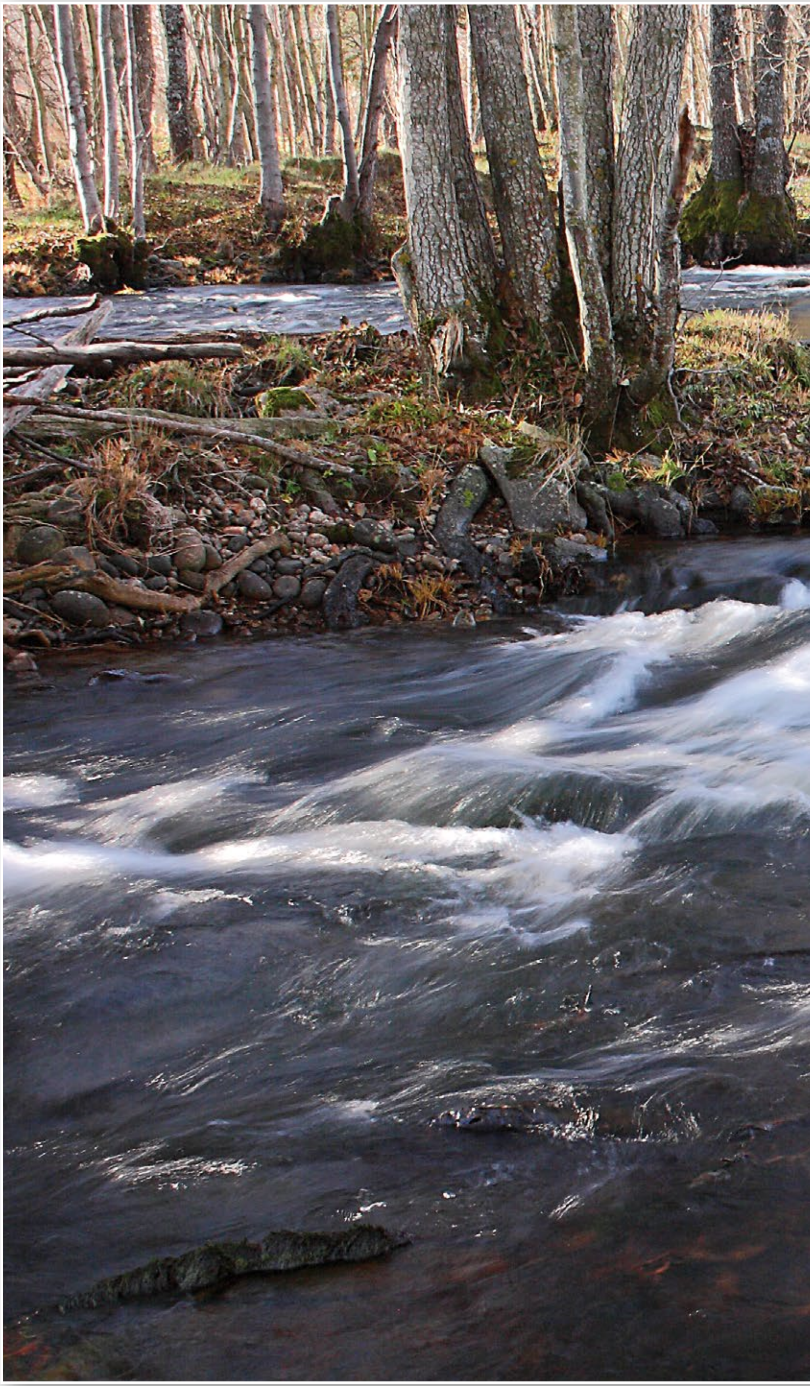
Being aware of the complexity of some of the content this work deals with, we provide some monitoring worksheets to facilitate data collection.

Finally, as we pointed out at the beginning of this introduction, for some readers this document will be enough to satisfy their information needs; however, others will require in depth knowledge about certain aspects. The last section is addressed to the latter, providing bibliographic references, interesting web pages available on line and references within current legislation, which might be useful whenever we need to refer to legal matters.

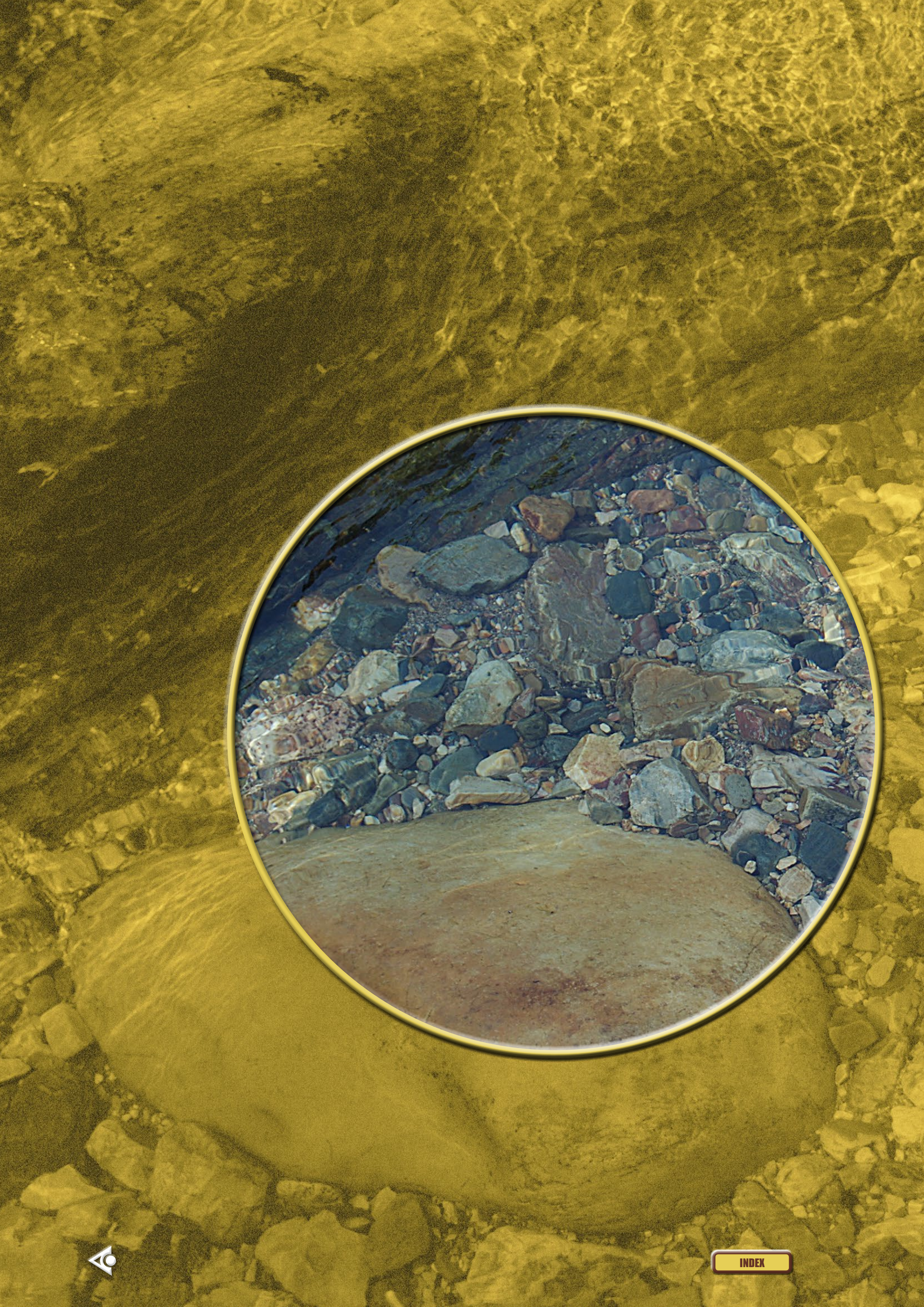
We trust that this publication will be essentially useful when it comes to making decisions about our rivers, and will also contribute to further thinking of a more general nature on the role we play in such a complex system as our biosphere.

As a conclusion we present this quote from Aldo Leopold, a North American ecologist and environmentalist, father of the also renowned hydrologist Luna B. Leopold, who developed a fundamental line of thinking based on the way to preserve our environment, and which summarises with certainty the essence of this work:

'The real substance of conservation lies not in the physical projects of government, but in the mental processes of citizens'.

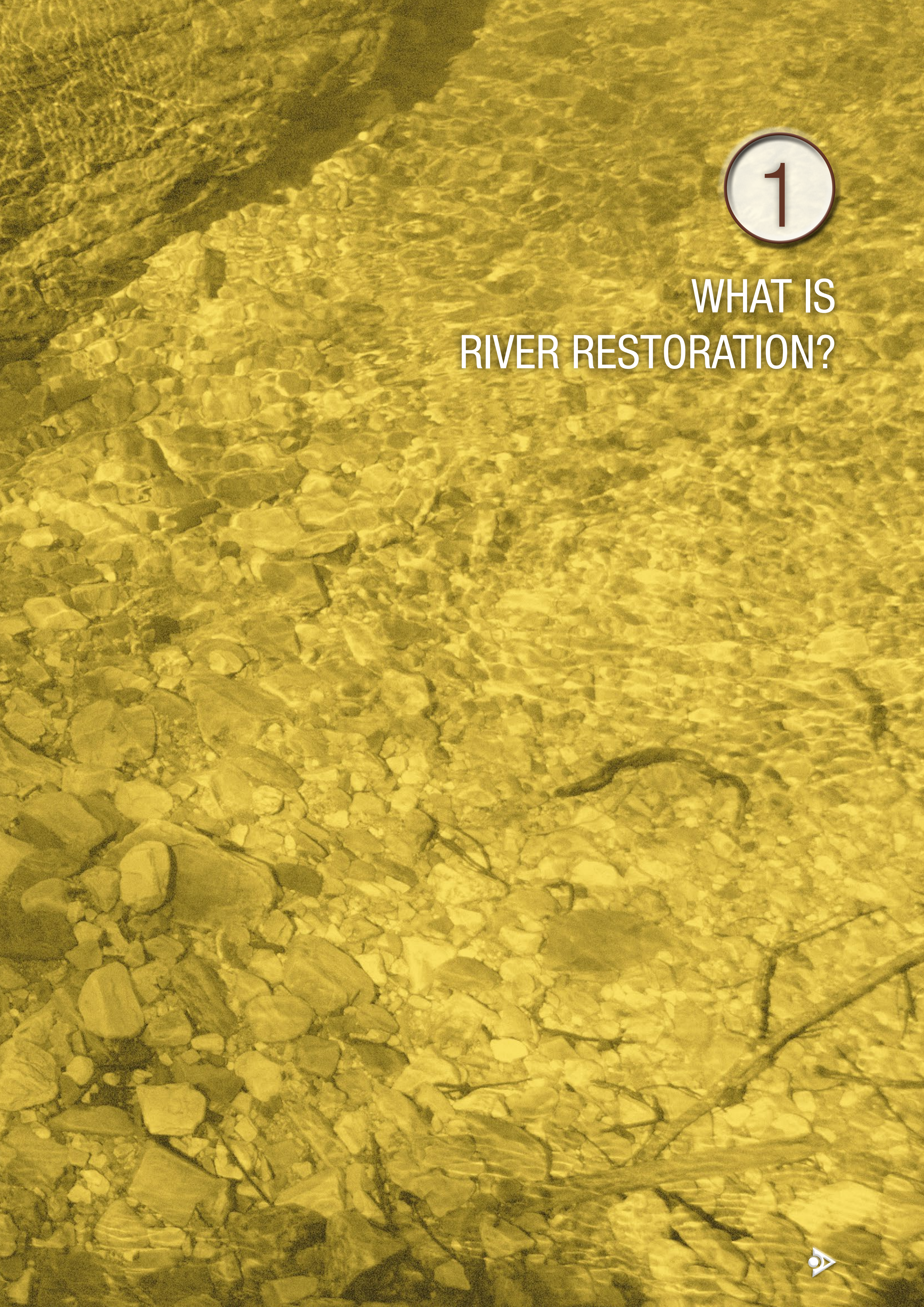


Aravalle river. Ávila.



1

WHAT IS RIVER RESTORATION?



River restoration is a set of management and intervention measures that aim to achieve very simple objectives: a hydrological regime and a river morphology that are as close as possible to those under natural conditions.

Nowadays the need for it is not questioned. Few ecosystems have undergone a greater degree of transformation, with the subsequent loss of environmental goods and services. Moreover, when we analyse them at length, we can see that many of those transformations have been counterproductive, unnecessary and even unsustainable from a hydraulic as well as an economic point of view.

Many actions taking place in our rivers are defined as river restoration; however, this concept should not be used so loosely, and sometimes carelessly. It is necessary to identify as accurately as possible what river restoration is and what it is not. As well, we should categorize those actions that lead to enhancements or the rehabilitation of rivers, but do not have the extent of restoration.

True river restoration is self-restoration (passive or with minimal intervention), and mainly addresses hydromorphological aspects; it deals with the two essential variables of the river system, which do the all the work: water flow and sediments. If the natural hydromorphological function is recovered, so will the biotope, and that will favour the recovery of the collection of living organisms, what ecologists call biocenosis, which make up the habitat or ecosystem.

In short, restoring means re-establishing or recovering a natural system, in this case a river system, by eliminating the impacts that contribute to its degradation as part of a process that extends in time, until a more natural and self-sustainable functioning is achieved.

What do rivers provide us?

The scientific literature talks about 'environmental services of river ecosystems', maybe due to a distorted economical perspective of nature. In any event, this expression refers to a set of natural functions which are very useful and indispensable for the functioning of the biosphere, and, therefore, the economic sub-system.

According to the classification of ecosystem services in the millennium ecosystem assessment, we can outline the following ones:

Provision services

- Fresh water for drinking, irrigation and industrial processes
- Food: fish, game, fruits...
- Formation of floodplains
- Fertilization of floodplains with inputs of fine particles, organic matter and nutrients
- Timber and fiber from riparian vegetation
- Aggregates for construction
- Hydraulic and hydroelectric power
- Medicines, genes and ornamental species

Regulation services

- Recharge and discharge of groundwater
- Flood attenuation
- Water treatment
- Carbon sinks
- Local climate regulation
- Regulation of marine salinity in transitional waters

.../

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Cultural services

- Aesthetic
- Spiritual
- Educational
- Recreational

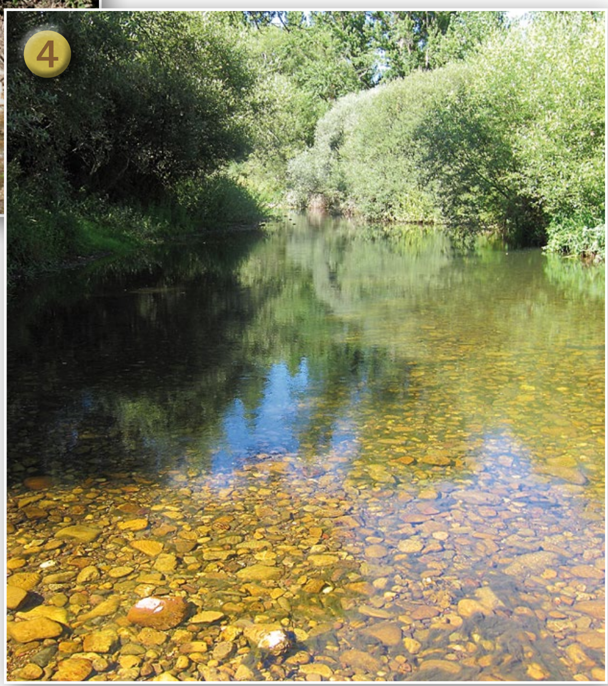
Supporting services

- Main agent of continental denudation through processes of erosion, transport, and sedimentation
- Nutrient cycling
- Biological corridors to link different habitats and ecosystems
- High diversity habitats
- Edge or ecotone effect between aquatic and terrestrial ecosystems

All of these functions alternate through time in the same location, and are very efficient in terms of the exchange of matter and energy.

Therefore, human activity in river restoration should consist solely of eliminating the impacts that prevent river self-restoration. Ultimately, restoring a river is allowing it to recover its freedom, liberating it from the pressures and impacts it is subject to. And this is very complicated, because it would imply modifying many water and land uses and banishing quite a few preconceived notions.

Gamo stream. La Lurda. Salamanca.
Orthophoto where we can clearly see the sharp transition from a stretch that has been channelized, where the floodplain is occupied by cropland, and another stretch with the original morphology, in this case with meanders, and a floodplain with little modification. (Source: Google-Earth).



Cea river. Villamorisca. León.
This series of images shows the initial state (1) and current state (4) of the Cea river after the demolition of a weir. The images in between (2 and 3) show the progress of the demolition works and the removal of rubble from the river bed.

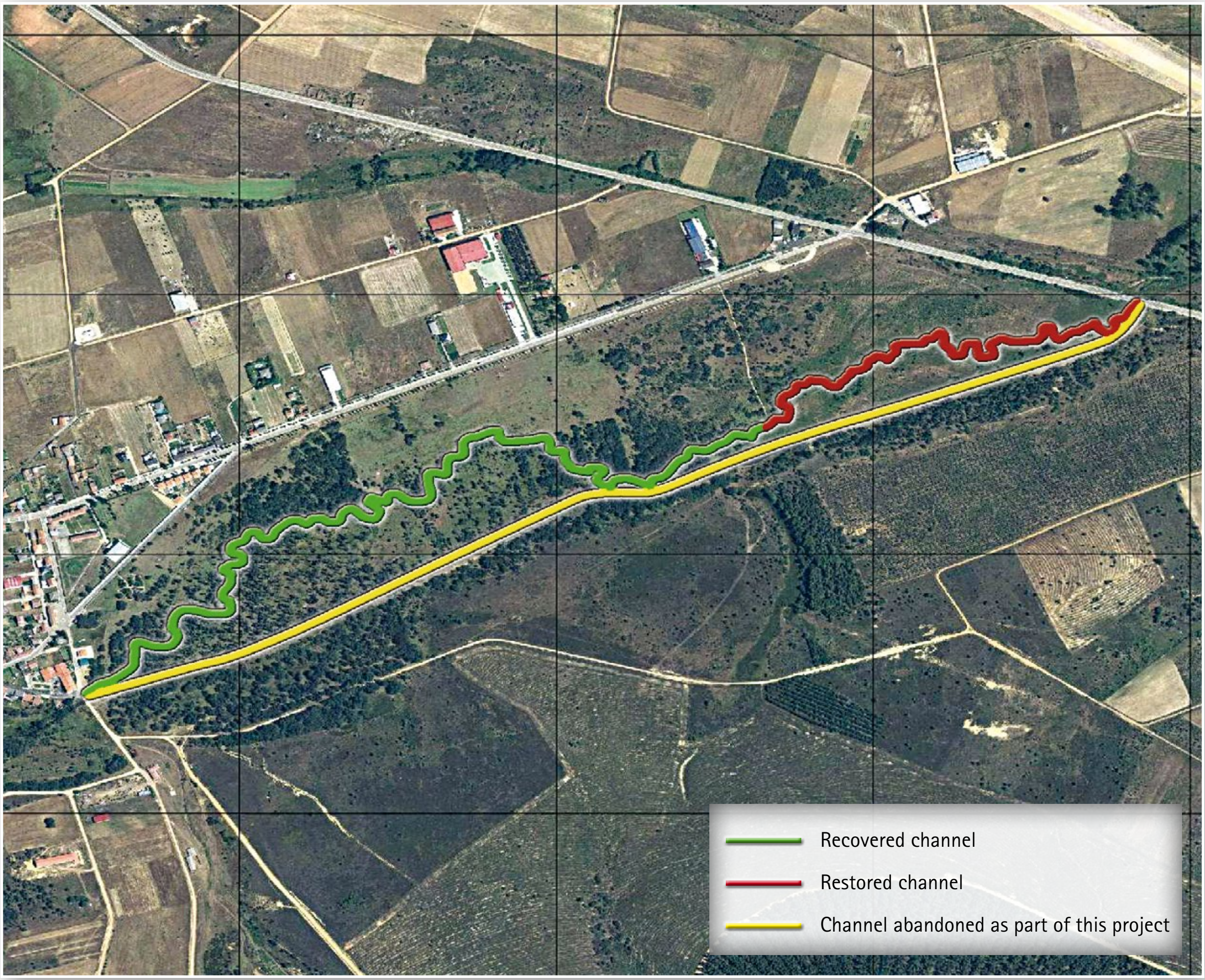
If we cannot eliminate all the impacts, we will never be able to achieve authentic restoration. Thus, river restoration is, in most cases, an idealistic objective. Nonetheless, it should not be dismissed. Restoration should be tried if at all possible, and if it is not, we should help the river function better. We should not call this restoration, so as not to misrepresent it; instead, it should be called **rehabilitation or enhancement**.

And in order to practice rehabilitation we have to think about restoration, helping the river while bearing in mind the essential principles of restoration, bringing it closer to the best situation so that it can recover itself to the greatest extent possible.

In the next chapter we will see that helping the river is, for example, removing transversal obstacles in the water course (dams, weirs, wading areas, bridges, etc.), removal of channelisation structures, dikes, levees, rip-raps and lateral obstacles, widening the space for the river to move, etc. Many other actions take place quite frequently in our rivers which go by the name of restoration incorrectly and misleadlingly.

In many cases they only pretend to be promotional, justify investments of funds allocated to environmental actions or avoid environmental assessment procedures.

Thus, channel stabilisation, regardless of the technique used, is never restoration, and it is



Castrón river. Ferreras de Abajo. Zamora.
Aerial photo showing the recovery of the Castrón river after a process of removal of channelisation structures. In yellow we can see the layout of the straightened channel, which has been filled in and rendered inactive in terms of hydraulics. The yellow channel measured 1850 metres in length, whereas the channel recovered is over 3000 metres in length (Source: Iberpix. National Geographic Institute of Spain).

Castrón river. Ferreras de Abajo. Zamora.
Current image of one of the many meanders that have been recovered and function again as such, almost 30 years after the channel was straightened as part of a land consolidation process.

completely against its principles. Along the same lines, preventing bank erosion or flooding, or enlarging the discharge section of a channel is never restoration, quite the contrary. Re-vegetation, tree planting, cultivation of poplars, landscaping, or the whitewash, cover-up or decoration of stabilisation or urban development actions, or building meanders where they never existed are not restoration actions either. Likewise, we cannot talk about restoration when the objectives of the action are aesthetic or recreational in nature. Altering water courses to benefit certain species, or just treating the water is not restoration either. All of those actions are not river restoration, and in many cases it is not even rehabilitation or an enhancement, even though the intervention may be presented as such. Demolition works to take down weirs and other obstacles which are no longer in use are quite dramatic and it may seem that, instead of improving things, they will have a negative impact on the river. But that is far from being true. Once the works have been finished off and the demolition waste has been removed, the river recovers its natural condition very fast, thanks to its resilience. A small flood always helps mobilize and redistribute downstream the accumulated sediments. Sometimes there are changes in morphology, as a result of the readjustment of the river gradient.

In the particular case of channel stabilisation, a measure frequently used, especially in urban environments, and generally perceived as something positive, we must be aware that it is a very detrimental action for river dynamics. It contributes to simplifying, confining and narrowing the river and, by preventing bank erosion from occurring, it stops sediment input to the bed in the vicinity, which may lead to incision processes and reduces habitat diversity, limiting drastically their renovation. As a consequence, the river undergoes a gradual 'fossilization' process and a false sense of safety is generated, which is very dangerous. Hence, this type of measures should be reduced to the absolutely necessary minimum, wherever urban development processes are not reversible, and must not extend to areas around or outside the urban core.

The principles of river restoration conflict to a great extent with social demands for stability, safety, urban development, leisure, etc., as well as with various economic and corporate interests, and a series of aesthetic preconceptions. If we want the state of our rivers to improve, and river restoration to be less idealistic and more viable, we need to change our mentality.

Cea river. Soto de Valderrueda. León.
Demolition of a weir.

Carrión river. Monzón de Campos. Palencia.
Demolition of a weir.

It is essential to **'unlearn'** some stereotypes which are wrong and obsolete. We need to consolidate, through education and appropriate training programs, the basic principles of restoration and the benefits that are derived from the good functioning of the biosphere, and, therefore, the benefits human beings derive being part of the biosphere.

River restoration is not simple. And even if the objectives are partial ones, as it happens with rehabilitation or enhancement works, the process is still long and complex, and the results may take time to reveal themselves. A river restoration or rehabilitation process encompasses the phases and tasks in the following outline.

River restoration or rehabilitation

What is it?

It is the process of recovering a river system until it reaches natural and self-sustainable functioning. It is not a single action, but a long process that the river itself undertakes, if possible, with little human intervention.

How is it achieved?

- **Eliminating all the impacts or pressures that cause the degradation** of the river system in the basin, the floodplain and the water course.
- Having **natural flows, sediments** that can be mobilized, **high flows** that can speed up processes and **low flows** that can limit the expansion of exotic species.
- Having a **space** for the river that is continuous and wide, with no obstacles.
- **Work is done by the river itself** (self-restoration or passive restoration) as part of a process that extends in **time.**

.../

/...

¿What will a river system recover at the end of a river restoration process?

- Its natural **processes** and all the **interactions** between its elements and with other systems.
- Its **structure**, that is, all of its components and flows, with all their complexity and diversity.
- Its **functions** in the Earth system: transport, regulation, habitat, biogeochemical cycles, etc.
- Its **territory**, that is, its own continuous space that it should occupy so that its processes and functions can take place.
- Its **natural dynamics** (mobility, changes, adjustments) in space and through time.
- Its **resilience** or strength to face future impacts, its capacity to self-regulate and to self-recover.
- The remaining environmental benefits that it provides to society: flood attenuation, carbon sink, landscape, natural resources, groundwater recharge, etc.

Phases in the process of river restoration

a) Preliminary phase

1: **Study** what the river system is like and how it works, and **identify** its problems.
2: Reach a **consensus** and decide what should be the **objective** and the scope of the restoration or rehabilitation efforts.
3: **Disseminate** information and **raise awareness**, explaining to society the problems of the river system and the planned solutions.

b) Initial phase

4: **Eliminate** the impacts and obstacles entirely (in the case of restoration) or to the extent possible (in the case of rehabilitation).
5: **Ensure** the availability of matter and energy necessary for the functioning of the river system: FLOWS (INCLUDING HIGH FLOWS AND LOW FLOWS) + SEDIMENTS.
6: Ensure the availability of the space or **territory** necessary for the recovery of the river system.

c) Restoration or rehabilitation process

7: It involves **self-recovery**, it is done by the river system and needs time.
8: **Monitoring** of processes and ongoing observation and assessment, where volunteering can play a significant role.
9: Ensuing **intervention** modifying some parameters in order to speed up or correct some processes (it is not advisable, only to be done exceptionally as part of rehabilitation efforts, but not as part of a restoration process).

INDEX

2

HYDROGEOMORPHOLOGICAL PRESSURES

2.1 Identification of pressures

2.2 Elements, practices and uses leading to those pressures

2.3 The effect of pressures: hydromorphological impacts

Pressures are all those human activities and uses that may have a negative effect on rivers and fluvial systems, altering and modifying their natural behaviour. These negative effects or impacts affect not only the channel and the floodplain, but also their associated ecosystems.

This is a term coined by the Water Framework Directive (WFD 2000/60/CE), comprising those actions that have a negative environmental impact. European Union Member States have to describe the pressures in the river basin management plans, or 'basin hydrological plans' as they are known in Spain.

2.1 IDENTIFICATION OF PRESSURES

There is a wide range of pressures that may be detected in river systems, although some of them are difficult to identify, since they are so common that we have grown used to them and do not consider them to be pressures. Still, there are other cases where pressures are not so obvious, and thus it is necessary to make an effort to raise social awareness about them. The most important ones are as follows:

Pollution

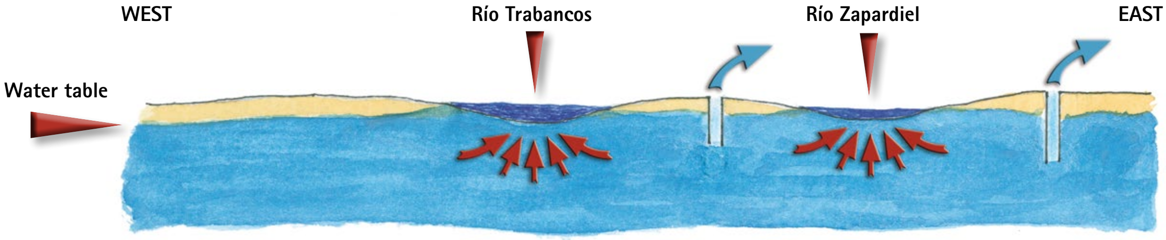
It may be point source pollution, when the source is clearly known, or diffuse source pollution, when it comes from numerous sources but without a specific point of discharge. The main sources of pollutants are urban and industrial discharges, whereas most of the diffuse source pollution comes from agricultural sources (fertilizers and phytosanitary products). Water retention by weirs and dams encourages nutrient sedimentation, and these nutrients lead to eutrophication processes, which in turn may result in the proliferation of algae that pose a threat to human and ecosystem health.

Water abstraction

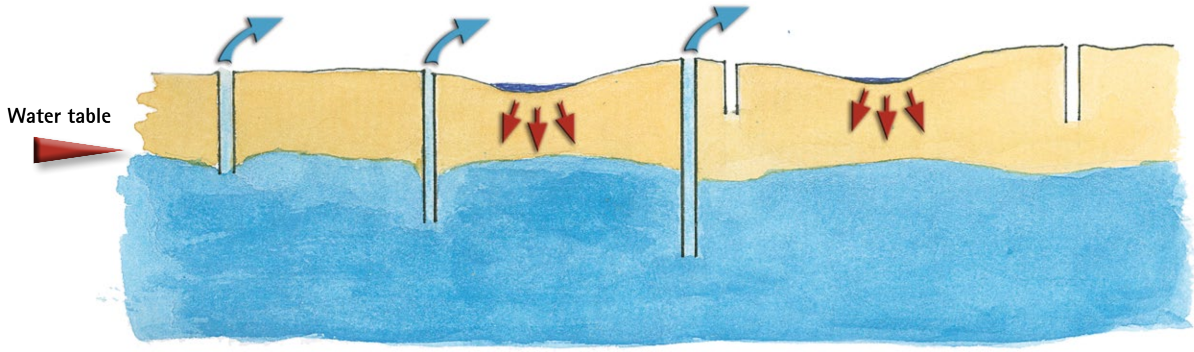
Excessive water abstraction may result in a decrease in water flows. During periods of low

Tormes river. Almendra reservoir. Salamanca-Zamora.
Cyanobacterial bloom (also known as blue-green algae). This type of blooms may have a health impact, since some of the species of cyanobacteria produce very poisonous toxins known as microcystins.

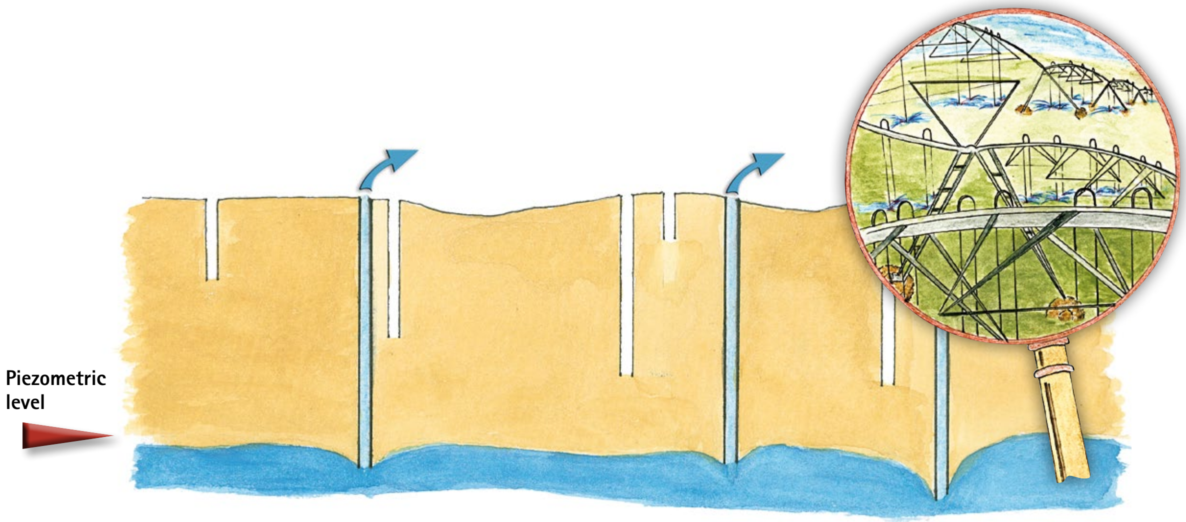
Diagram of the evolution of the water table in the sub-basins of the Zapardiel and Trabancos streams in the past 30 years



At a first stage, groundwater abstraction is minor and limited to not very deep wells, thus the permanent flow regime of the streams is maintained. The streams receive part of their water input from groundwater. They are streams which 'gain' flows.



An increase in the land area under irrigation leads to increased irrigation using groundwater sources. This situation causes a lowering of the water table, and consequently, water abstraction is done with deeper wells. A portion of the stream discharge infiltrates and we may refer to these streams as stream which 'lose' flows, since their discharge decreases very noticeably.



Currently, aquifer overexploitation is a reality which has modified the permanent regime of the Zapardiel and Trabancos streams, which have become occasional and ephemeral, depending exclusively from surface water inputs. The development of more sophisticated technology, which allows increasing the depth of wells, has contributed significantly to this situation flows, when water is scarce, the impact may be very negative. It is not necessary for the abstraction to be done directly from surface waters to notice a decrease in water flows. The overexploitation of aquifers results in a decrease in water inputs, since rivers which used to 'gain' flows, that is, those whose water flows increased due to groundwater discharges, become rivers which 'lose' flows, because a sizeable portion of their flows infiltrate into the terrain to compensate the lower water table and piezometric level. A typical example in our country occurs in the upper Guadiana river, but in the Duero basin we also have our 'Guadiana' like cases, streams such as the Zapardiel or the Trabancos, which have practically disappeared due to groundwater overexploitation.

Retention of sediment

In the case of large dams, the retention of bottom sediment transport could be absolute. The issue of sediment flows is very much neglected in terms of understanding the hydraulic and environmental problems of our rivers, even though it is crucial. Sediment flows, that is, the sediment input to the river by the drainage basin and transported by water flows, configure the channel or channels and, ultimately, the shape of the river and its floodplain. In addition, they are the substrate of life, since a sizeable portion of the biota (algae, macroinvertebrates*, etc.) that make up the base of the river's trophic system gets established on them, aside from their role as a breeding area for fish species, amphibians, and other associated fauna.

Water flow regulation

The presence of infrastructure that regulates water flow in rivers, such as reservoirs or ponds, may have an impact on river systems, changing the flow regime of the river. It is common to see the disappearance of channel forming winter high flows, whereas naturally occurring

Duero channel. Valladolid.

The withdrawal of water flows from the river may be greater than the discharge flowing downstream form the abstraction point; sometimes it can amount to practically the entire river discharge, having very negative effects on the river..

* *Macroinvertebrates. Invertebrates larger than 0.5 mm in size, usually found on the bottom of streams. For the most part they are insect larvae or nymphs, although there are also crustaceans and molluscs. They are indicators of the biological quality of water courses and very sensitive to the hydromorphological, physical and/or chemical variations that aquatic environments may be subject to in general.*

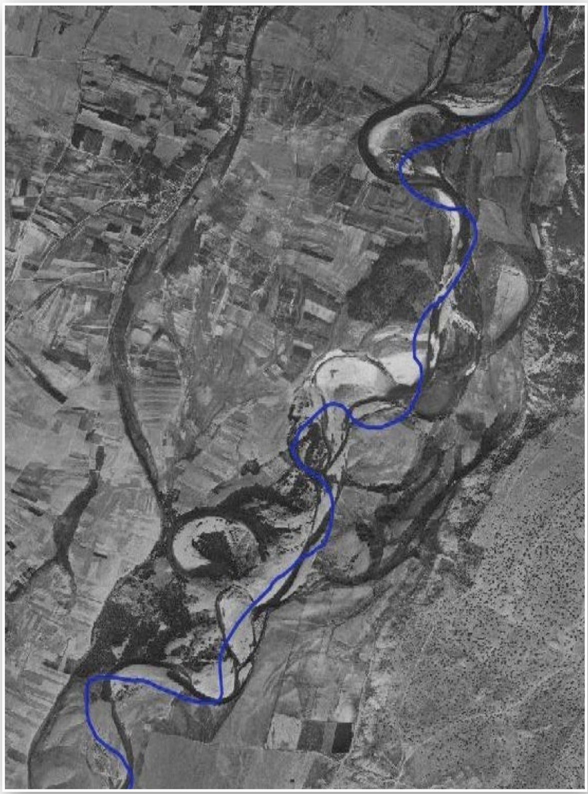
summer low flows disappear, having instead unusually high water flows, inverting the regime and causing drastic changes in ecosystems.

Morphological alterations

These are alterations of the shape of the river. They mean a total or partial modification of river systems. They would comprise activities such as flood protection infrastructure, dredging, aggregate mining, channel straightening, channelisations, urban development and building of infrastructures in the margins, etc.

Floodplain occupation

Having access to water, together with the fact that the land adjacent to rivers is most productive, have led to a universal trend towards the occupation of floodplains and exposure to flooding by high waters. Of course, there are different degrees of occupation: it is not the same to have housing developments exposed to floods, than having infrastructure or cultivated land exposed to floods. As a result of this occupation, very often river channels undergo morphological alterations that intend to encourage drainage, and increase water velocity. Water regulation is also increased through the use of reservoirs, leading to a series of negative synergies. The truth is that modern urban development efforts, instead of focusing on protection from river floods, encourage the exposure of assets and people to a flood risk, sometimes very serious, and in many cases unnecessary and not justified. And this happens under the deceptive catchphrase 'we are going to live facing the river' or something similar.



Esla river. Santa Colomba de las Carabias. Zamora.

Comparative images, where the orthophoto on the left is current (2009), whereas the orthophoto on the right is from the American flight of 1956, where the current water course has been drawn in blue. The simplification of river forms and adjacent areas, reduced to a single, narrower channel, and the occupation of the riparian zone by herbaceous and poplar crops in flood prone areas are evident, and reflect a great loss of habitat and hydraulic capacity. (Sources: Iberpix, National Geographic Institute of Spain, IGN; MÍRAME Information System, Duero River Basin Authority).

Tormes river. Ávila.

Azolla filiculoides in a secondary arm of the Tormes river (Ávila). This is a water fern, originally from tropical America, used in aquiarium keeping and garden ponds as an ornamental species, or to control the growth of other algae. Its growth capacity is huge; it can cover even large water bodies, as it used to do in the geological past, during the Eocene epoch, when what is known as the 'Azolla event' took place.

Proliferation of invasive species

The introduction of exotic species, whether animal or plant species, can become a serious problem. This issue can be encouraged, in many cases, by the pressures described above, since exotic species can find modified river ecosystems where they have greater opportunities to adapt, leading to the displacement and decline of native species.

2.2 ELEMENTS, PRACTICES AND USES LEADING TO THOSE PRESSURES

Pressures on water courses are very diverse in nature, as we have seen. All of them are ultimately caused by human activity; whether to improve our usage of water courses or to improve transport links, infrastructure has been put in place which drastically disrupts the normal functioning of the river regime. In other cases, pressures are a result of land use changes or new needs that have emerged from a poorly understood (urban/rural) development. This section deals with all of those elements and practices, identifying, explaining and illustrating each one of them.

Weir

Small dam or barrier located across a water course with the purpose of raising and regulating the water level and collecting water, thus facilitating water conveyance through a canal, to be used for water supply, irrigation or hydropower (in the past, it was used as a source of power for watermills to produce flour, textiles, and other hydraulic artefacts). Water usually flows over the crest, and the sediment retention capacity is limited. The movement of living organisms or parts of them is not completely hampered, although, if they reach a certain height, they become an impassable barrier for many species trying to move upstream. They may be of great importance in terms of nutrient retention; when there are many of them in the middle and lower stretches of rivers, they turn the water course into a series of water ponds, thus contributing notably to the eutrophication of rivers. The increase in channel width means more sunlight reaches the water surface; this, together with nutrient availability and the disappearance of rapids, encourages algal blooms, sometimes with a high production by certain species of toxic proteins known as microcystins.

Duero river. San Román de los Infantes. Zamora.

San Roman weir

Duero river. Villaralbo. Zamora.

Water impoundment in the Duero river as a result of the weir of a mini power station. In some rivers, water damming using weirs reaches such an extent that it is not possible to find stretches where water flows freely and which maintain their original riffle and pool structure. As well as involving a loss of habitat, a weir acts as a decanter and nutrient trap, encouraging eutrophication processes, hence the greenish look of the waters in the summer, which leads to potability problems.

Tormes river. Almendra. Salamanca.

The Almendra dam, in the lower Tormes, is the largest dam with the largest reservoir in the Duero basin. Since it started operating, in the 70s of the past century, the Tormes river, from that point until it meets the Duero river is no longer a river due to the withdrawal of practically its entire discharge.

Dam

It differs from a weir in terms of size and reservoir capacity, much larger in the case of dams. This gives them regulation capacity, that is, the capacity to alter the downstream flow regime. They are impermeable to bottom sediment transport, retain suspended solids and nutrients and do not allow the movement of living organisms or their parts upstream, limiting their movement to a downstream direction. As a result of the dam, the water course is replaced by a reservoir of waters used for the irrigation of large land areas, water supply to population centres, electricity production, recreational uses, etc.

Wading area

A shallow area of a stream or an area with an artificial structure that facilitates the crossing of vehicles, animals or people. Usually this type of infrastructure can be found in minor water courses.

Eresma river. Navas de Oro. Segovia.

The wading area built on the stream is a poor hydraulic solution. Besides having a very negative effect, it is a huge hazard for road traffic.

Aliste river. Dómez. Zamora.
Accumulation of plant residues and raised water level due to the poor hydraulic design of the bridge.

Cea river. Castrobol. Valladolid.
Accumulation of plant residues against the piers of a bridge.

Bridge

A construction that allows passage over the water course using a platform suspended over the channel. There are many different types of bridges. Their main effects on river systems are due to hydraulic insufficiency to allow the passage of high water flows and to the constriction of the channel. Piers, and in particularly culverts, are obstacles which may retain floating debris, become blocked and act like a dam. If the bridge has an apron, it may lead to incision downstream from it, the same as any other transversal works. The lack of maintenance of wading areas and bridges worsens the problems mentioned.

Water diversions and transfers

The diversion of water flows to use them for other activities (agricultural uses, water

Map of the water transfer from the Curueño stream to the Porma stream.
(Source: Iberpix. National Geographic Institute of Spain).

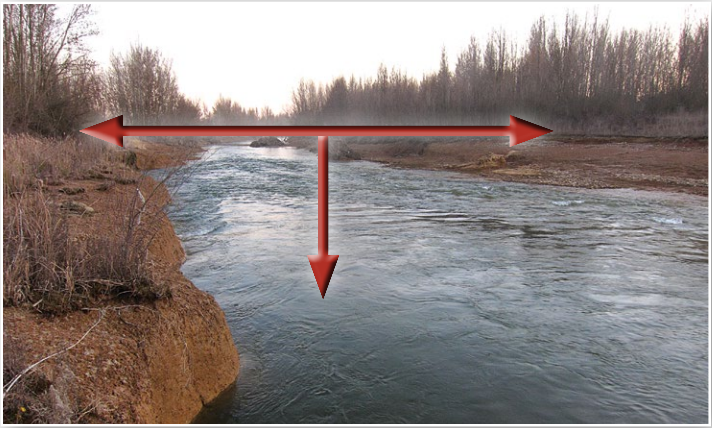
supply, industrial uses, etc.) leads to a decrease in river flows, even to the point of withdrawing the entire flow of the river system, leaving a dry channel. Water diversion channels usually have a water inlet at dams and weirs, although sometimes water can be diverted from a current deflector or a submerged weir, reducing to a minimum the pressures on the water course.

Discharges and water returns

These are water flow inputs to the river system in areas which are not the natural ones. They do not have to be necessarily direct polluting discharges, they may consist of left over water from irrigations ditches or channels, water released from tanks, or water returned from hydropower channels once it has gone through the turbines.

Example of a direct discharge into the water course.

Urban discharges are very abundant and usually they have been subject to a minor degree of treatment.



Bernesga river. León.

Incision downstream from the city of León. The channelisation of the urban stretch, together with extensive and indiscriminate aggregate mining, have led to the worse incision event in the Duero basin. On the left photo we can see the clays where the stream has become lodged, after the entire gravel and pebble bed has disappeared, with an average incision of some 4 metres. The horizontal arrow shows the level of the original bed, which now is the bankfull level.
The image on the right shows a perched old gabion indicating where the bed used to be some 40 years ago.

Aggregate mining

Removal of mine materials which usually affects areas with an accumulation of sediment in the banks or on the river bed itself. Usually aggregate mining is done for commercial purposes, obtaining materials of various sizes that are then used in activities such as construction.

Dredging

Extraction of material from the bed itself or from side bars, as well as removal of mid-channel bars, with the purpose of increasing the discharge capacity of the channel. It is a protection system that works the opposite way as the usual ones (levees, rip-rap), since instead of narrowing the channel, dredging tries to widen or deepen the channel. The materials resulting from dredging processes are sometimes used to reinforce the margins, or sometimes are commercialized as if they came from aggregate mining. Aside from the severe geomorphological and ecological impacts, a typical problem with dredging is that the dredged areas can fill up again with sediment very rapidly, as a result of a high water event, so it is particularly unsustainable both from a hydraulic and an economic perspective.

Eria river. Castrocontrigo. León.

Dredging of the channel and construction of rip-rap.

Torío river. Garrafe de Torío. León.
Rip-rap with live stakes.

Rip-rap

A very common margin protection system, with different types (natural stones, blocks or rubble), resistant and easily adaptable to the topography of the river bank. In the past, artificial rip-rap, made up of concrete cubes, was preferable; however, nowadays we use natural rip-rap, which is more useful because the stones get lodged with each other better. Aside from using it by itself, rip-rap can be used as a foundation for other containment works or as a reinforcement for dikes in the stretches where they are close to the margin. If the rip-rap is not grouted, vegetation can colonize de gaps between the stones; in this case, it is advisable to plant live stakes to accelerate the integration process.

Gabion

This is another margin protection system consisting of a steel cage filled with stones or gravel located on the bank. Gabions usually allow plant species to grow since the substrate is more porous.

Levee

A longitudinal dike, elevated between the water course and the floodplain; it represents the oldest existing protection system. It does not work against the erosion of river margins, instead it contains high water flows; its height prevents water from overflowing the banks.

Valdeginate stream. Mazariegos. Palencia.
Levee on the right margin of the stream. The material used to build the levee came from dredging the stream, which has been converted into a canal with a trapezoidal cross-section (blue line), invaded by macrophytes (red arrow). The dredging was part of the works done in the 50s to drain the Nava de Campos lake, a wetland which could reach up to 6,000 ha, resulting from the overflowing of three streams at the point where they met: Valdeginate, Retortillo and Salón.

Esla river. Valencia de Don Juan. León.

Deflectors on the right margin of the Esla river. As an outcome of the occupation of the floodplain in this area, it was necessary to build costly protection infrastructure.

Usually they have a trapezoidal cross section and in many cases they are used as paths; they may also have a drainage ditch alongside. They are built with compacted earthen materials, which can also be covered with gravel on the surface, or reinforced with gabions, concrete, rip-rap, etc.

Current deflector

A margin protection system consisting of concrete walls, rip-rap or stone gabions placed in the channel perpendicular to the banks or almost so, to slow down the current of the river, preventing it from hitting directly the banks and altering the hydrodynamics, which may thus change the pattern of erosion-sedimentation.

Channelisation

A protection or channelling system which completely modifies the channel or channels (in rivers that have more than one). It involves excavation; as well, continuous structures may be built along both banks (dikes, rip-rap, gabions, concrete walls, etc.); in some cases a whole section may be lined with concrete. The river system becomes an artificial canal. In many cases, channelisation means also modifying the course of the river, commonly reducing the length of the channel, that is, the channel becomes straight, instead of following a winding course; this sometimes involves cutting off meanders. This is known as straightening.

Channel cut off may occur as a natural process, when meanders are cut off from the rest of the channel. One consequence of river dynamics is that a channel or channels may migrate laterally in the floodplain; this process is known as avulsion.

This can be observed in many areas of our basin. Old river channels are known by different names in Spanish, and as oxbow lakes in English. They are what is left from old channels which formed alluvial wetlands of great importance and singularity; they have been systematically eliminated during processes of agricultural transformation. Man-made cut off processes are usually unsustainable in the medium and long term, having very negative hydraulic, ecological and economic implications.

Eresma river. Coca. Segovia.

Natural meander cutoff (in red) in the Eresma river, after the Voltoya flows into it.

(Source: Iberpix. National Geographic Institute of Spain).

When channel modification is not very obvious, it is often known as channel management or a series of 'soft' measures. If channelisation takes place in a wet alluvial zone, that is, a very flat area where a wetland is formed as a result of the overflowing of one or more rivers, then we talk about drainage. Often it involves deepening the channel to 'clean up' the land. This is the case of channelisation in the Valdeginate, Retortillo and Salón streams, in the area known as 'Tierra de Campos', in the province of Palencia. They used to meet at the Nava de Campos lake, which no longer exists. Or the case of the channelisation of the Salado stream, upstream from Villarrín de Campos, in the province of Zamora; the inland salt marsh, part of the Villafáfila wetland complex, was partially drained.

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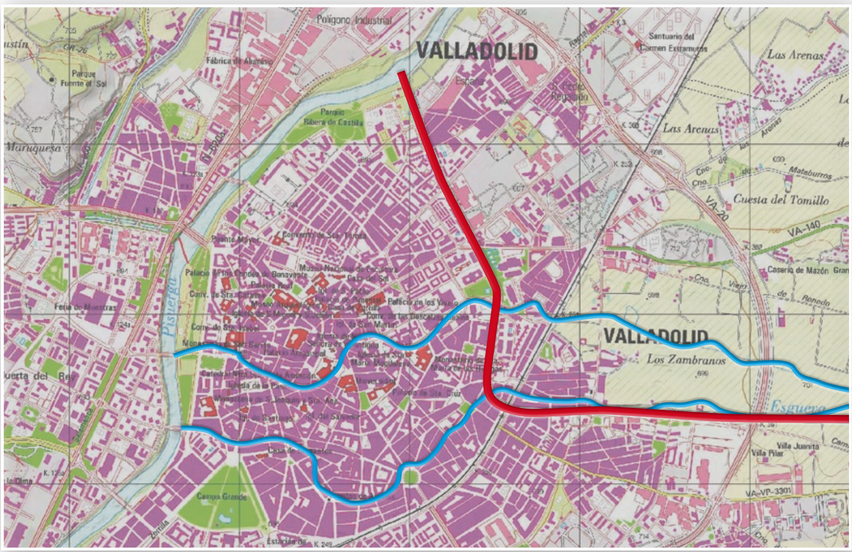
Channel diversions

Activities carried out either at specific zones or along longer stretches of river which involve diverting or simplifying the course of the river system. Generally, and in theory, they are done to prevent flood risks, such as in the case of the diversion of the Esgueva river in Valladolid. This stream used to flow into the left margin of the Pisuerga river, separating into two and even three distributary channels, and forming a large inland delta. The settlement of the city of Valladolid on the left margin of the Pisuerga, between the Esgueva channels, meant that whenever the high flows of the Esgueva met with flows also high in the Pisuerga, they flooded a sizeable portion of the city.



Esgueva river. Valladolid.

Diversion of the Esgueva river as it passes through Valladolid, to the Northeast. In the past, the Esgueva river separated into two distributary channels that would flow through or bordering the medieval urban centre, flowing afterwards into the Pisuerga river.

(Source: Iberpix. National Geographic Institute of Spain).

Arlanza river. Lerma. Burgos.

Urban development on the right margin of the Arlanza river. Among the possible land uses occupying floodplains, residential development is the most hazardous one, as it results in the exposure to flood risks of real estate assets of high value, and, above all, of people.

Urban development

The progressive occupation of floodplains throughout the years due to the expansion of urban areas is a change with an impact on factors such as surface runoff, flood attenuation, infiltration, sediment input, etc.

Grazing

The pressure of livestock on river systems can be observed mainly in the loss of vegetation in riparian zones, as animals trample and nibble on plants. This leads to a lack of vegetation which, during high water periods, serves as an obstacle to flowing water, decreasing its velo-

Sequillo river. San Pedro de Latarce. Valladolid.

Sheep herd drinking water on the right margin of the stream.

city and facilitating the sedimentation of solid material. In addition, the presence of large numbers of livestock in the margins of rivers impacts the banks at the points where animals access the river to drink, modifying the shape of the bank due to trampling by herds.

Plantation

Tree cultivation for industrial use, generally poplars, takes place mainly on the margins of rivers, eliminating the natural riparian vegetation that may exist in those areas.

The preparation of the terrain, which involves land levelling and filling has destroyed many areas adjacent to rivers. In some cases, plantations are protected with lateral barriers along the river, sometimes levees, to the point where the effort is illogical: we try to isolate a floodplain crop from floods. This implies losing the capacity to attenuate floods, infiltration capacity, the capacity to recharge the alluvial aquifer, and the sedimentation capacity of suspended solids which contribute to fertilizing the land.

Esla river. Palanquinos. León.

The occupation of the river, the modification of the channel and the floodplain, and the removal of naturally occurring riparian vegetation are activities linked to this type of crops when they are cultivated without proper management. (Source: Iberpix. National Geographic Institute of Spain).

Example of rubble dump beside the river.

The presence of waste in the margins of our water courses is a common sight, which should make us reflect about this dumping practice.

Landfill/rubble dumping

The margins of rivers and riparian areas are dumping sites where wastes and rubble accumulate. Sometimes these materials are used as filling for levees or lateral protection barriers, so that they surface when the river system erodes the banks.

Transport routes

They cause pressures on river systems because they are often built along the same corridor where rivers flow, especially in mountain areas or narrow valleys, where it is easier to fill in the channel and build the road on it than to build it on the hillside. The closer they are to

Eria river. Villanueva de Azoague. Zamora.

Flooded road on the right margin of the Eria river (Zamora), at a site near its outlet into the Órbigo river. The occupation of the floodplain has led to its vulnerability to flooding.

Main hydromorphological pressures		
Elements	Practices	Uses
Weir	Water diversions and transfers	Urban development
Dam	Discharges and water returns	Plantations
Wading areas	Aggregate mining	Landfill/rubble dumping
Bridge	Dredging	Transport routes
Rip-rap	Current deflector	Grazing
Gabion	Channelisation	
Levee	Channel diversions	

the water course, the more directly transport routes affect the geomorphology of the river. Embankments built on floodplains may be an obstacle to water flow when the river overflows its banks, facilitating the retention of water and preventing normal drainage.

2.3 THE EFFECT OF PRESSURES: HYDROMORPHOLOGICAL IMPACTS

Many of our water courses are very deteriorated due to human activities. All the elements of the river system suffer from the effects of pressures, but hydromorphological elements are also subject to a widespread lack of knowledge, awareness and appreciation by society and by technicians and land managers themselves, making them even more vulnerable.

It is a fact that water and sediments, as simple elements, are not equally valued as living organisms, so that quite often we act indiscriminately to their detriment without any concerns. This is a very serious error, not only because of the unquestionable intrinsic value of water and sediments, but because water and sediments are key variables for river function, and any other variables, and particularly living

Torío river. Vegacervera. León.

The fish pass in the background was the first one to be built in the Duero basin. It is useless because of a faulty design.

organisms, depend on them and on their good status. Sediment and water flows are the engine of our rivers, and shape the morphology of the river. Both flows and morphology are the physical basis of the river ecosystem, what ecologists call the biotope. The biota or set of living organisms depends on them.

As a summary of the pressures mentioned, we may conclude that the hydromorphological alterations of rivers originate in a socio-economic development model that involves activities that consume water, sediments ('aggregates'), and land (space for the river), and a society that prefers to live in a riverfront location with a flood risk, and when faced with river dynamics it demands safety from floods and stability. A society that is also immersed in urban models and fashions that pull it away from natural values. As an example, there is a significant social disdain for open areas with gravel, which are considered dirty, or for dry channels; or how pools are valued whereas white water or rapids are not. This implies a continuous and growing demand for certain actions on water courses, usually 'hard' options, as they are thought to be faster and more efficient, implemented without any concern for the river functions and the hydromorphological and ecological functioning of the river. The result is the increased deterioration of these natural systems, which is irreversible in many stretches.

Hydromorphological impacts on our rivers modify water and sediment flows, and alter processes as well as forms, and sometimes are only evident later in time. The main alterations can be classified into five large groups:

a) **Impacts caused by the alteration of the natural river hydrology.** Reservoirs produce serious alterations of the river regime and a net loss of flows due to increased evaporation. Modifying the regime alters the distribution of flows, sometimes leading to a real inversion, with maximum flows in summer and minimum flows in winter in the case of reservoirs used for irrigation purposes. It also eliminates or reduces to a minimum the peak flows downstream from it, reducing the number of bankfull events and attenuating low water periods. When you modify water flows and intercept a sizeable portion of the sediment load, you change the stream power and competence, and therefore the processes of erosion, transport and sedimentation, which adapt to the new morphology and dimensions of the channel. The more extreme cases correspond to water shortcuts used for hydropower generation, where river stretches are left practically dry, thus losing their hydromorphological dynamics and becoming fossil channels, incapable of sediment transport.

Stream power and competence

These are two closely linked concepts. Stream power (Ω) is the amount of work done by the current and is given in watts per metre (W/m), multiplying the volumetric mass density of water (1.000 kg/m^3), by the acceleration due to gravity (9,8 m/s^2), by the discharge (m^3/s), and by the channel slope (m/m), as per the equation: $\Omega = \rho\ g\ Q\ S$. Competence, given by stream power, is the capacity of the current to transport sediment, and is defined based on the grain size of the sediments. River studies often use a simple parameter to compare fluvial stretches and provide an idea of the competence and of geomorphological processes in each of them: the specific stream power, which divides stream power per unit of channel width in metres: $\omega = \rho\ g\ Q\ S / w$ (the result is given in W/m^2).

Castañón channel. León.

Castañón canal on the left margin of the Órbigo river..

Pisuerga river.
Venta de Baños. Palencia.

Water 'shortcut' used for hydropower generation in the Pisuerga river, upstream from Venta de Baños. The meander channel has lost its geomorphological dynamics due to a decrease in water flows, encouraging greater colonisation by vegetation. The arrow is parallel to the diversion channel causing the water 'shortcut'. (Source: Iberpix. National Geographic Institute of Spain).

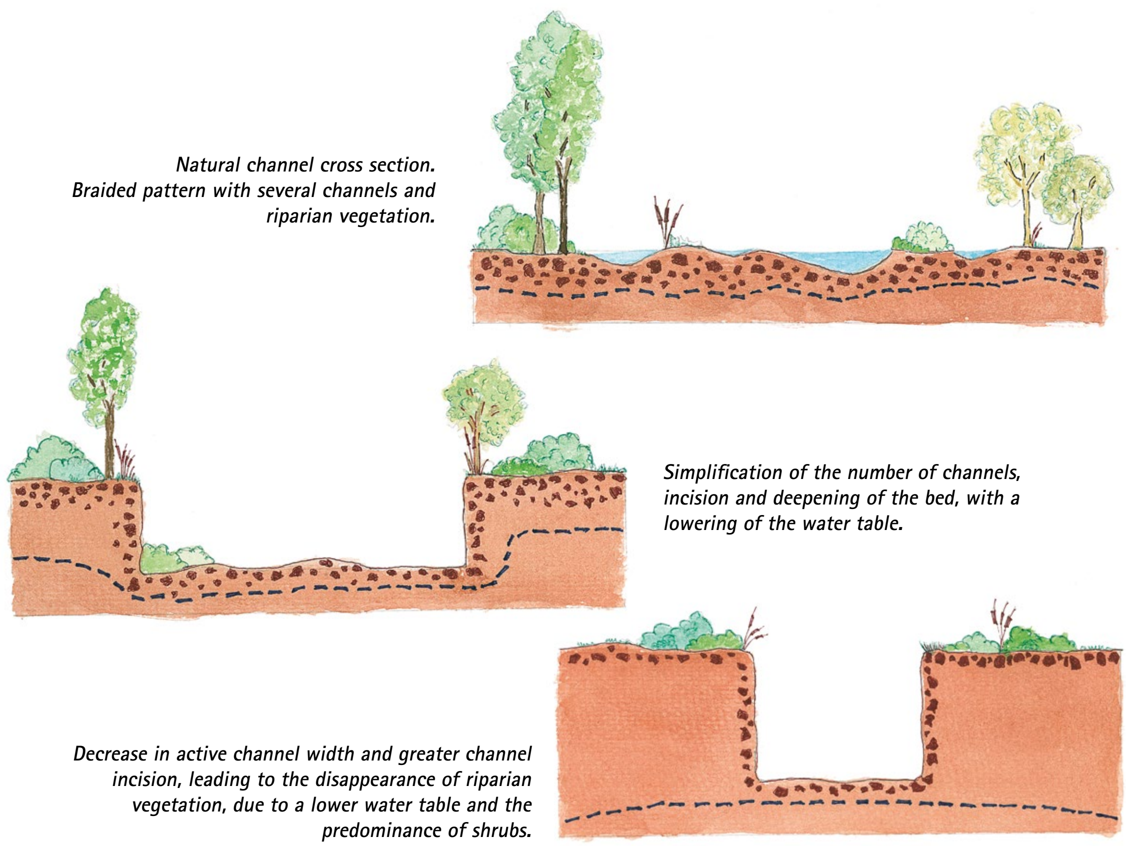
b) **Impacts caused by a decrease in sediment load,** which is retained mostly by large dams, but also by weirs, wading areas, transport infrastructure, etc. The sediment deficit leads essentially to incision processes, as well as changes in the shape of the channel, being responsible for such trends as the disappearance of braided channels and their replacement by single channels. In winding rivers with meanders, the sediment deficit also leads to incision, but together with an increased winding pattern, which can be explained mainly by the colonisation and development of vegetation in the meander lobes. In this manner, sediment bars no longer move, whereas the vegetation that colonizes them drives the flow against the concave margins, increasing their erosion.

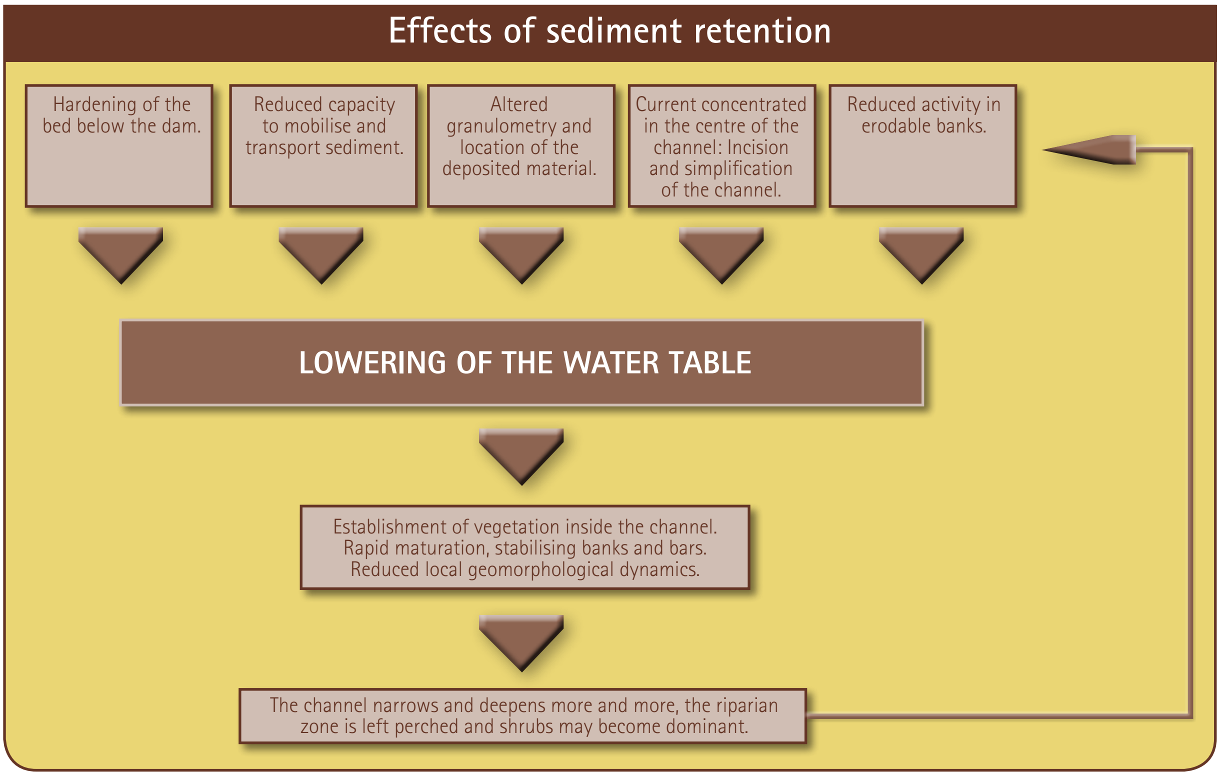
In the Duero basin, whether because there are fewer reservoirs, or because not

Duerna river. Destriana. León.

Streams with large amounts of gravel and pebbles are known as mobile bed streams, since flooding can move them quite frequently. In the province of León there are good examples, such as the Duerna, shown in the picture.

Diagram of the change in a river cross section as a consequence of the retention of sediment





enough time has lapsed to reach that third stage, the second stage predominates. The combined effect of regulation with the use of water flows for irrigation in spring and summer inverts the regime. Thus, when under natural conditions there would be a period of evident low flows, the river has a much greater discharge, as it is used as a canal to convey water for irrigation purposes. This circumstance, in the middle of

Duero river. Castronuño. Valladolid.

An old meander in the Duero river with water impounded as a result of the San José reservoir. Regardless of its artificial nature and the fact that the river dynamics have been lost, this area is recognized under the Natura 2000 Network as a Site of Community Interest and also as a Natural Reserve within the Network of Protected Areas in the Region of Castilla and León.

the growing season, promotes the development of tree-like riparian vegetation adjacent to the main channel. Also, the attenuation of floods and the decrease in the occurrence of channel forming discharges facilitates the stabilisation of margins and riparian zones and the development of a mature riparian forest which increases such stability as part of a feedback process. It just so happens that, puzzlingly, since it is highly artificial, this is the river ecosystem with the highest degree of protection under the Sites of Community Importance (SCI) of the Natura 2000 network in the Duero basin, and possibly in the remaining Spanish basins.

c) **Impacts due to a functional reduction of the floodplain:** infrastructure and land uses that modify the morphology and functionality of the floodplain disrupt its flood attenuation and energy dissipation functions. Dikes or levees partially prevent the river from overflowing, but increase the velocity of the current, accelerating linear and lateral erosion processes. They also increase hazards downstream and in the opposite margin or wherever the high flows may break the protection barrier. As well, they facilitate a rapid transmission of the high flows through the phreatic layer, flooding areas far removed from the low water channel. During the phase when the discharge decreases, sediments accumulate in the channel itself, since by preventing the river from overflowing its banks, sediments are not allowed to settle on the floodplain. As a consequence, there are modifications to the form, granulometry and distribution of sediment deposits, both on the river bed and on the margins. At points where the protection barrier has given way, breaking, the sudden rush of water into the floodplain will create gullies, as well as small chaotic sediment fans.

Pisuerga river. Tariego de Cerrato. Palencia.

Bankfull stage of the Pisuerga river, filling the channel in its middle stretch. A river channel does not correspond with the low water canal that we are used to see most of the year: it is much larger. The floodplain starts from the bankfull stage, which is where the picture was taken.

This type of processes can also happen downstream, wherever the current arrives to a sector without protection structures.

d) **Impacts caused by direct actions (channelisations, protection structures, dredging, extractions) on the shape of the channel, the bed and the margins.** Their effects are very intense locally, with important repercussions also downstream, which become apparent without much delay. Dredging and extraction processes also have consequences upstream, due to headward erosion. The loss of the natural attributes of the water course represents a loss of natural and geodiversity heritage, threatening the river dynamics and the good ecological status. In general, there is a tendency to reduce the natural complexity of the course, transforming the channel into a simple discharge canal. This implies an increase in slope and incision processes on the bed. Sediments are easily transported through the centre of the canal, but there may be lateral deposits left behind. There could be important changes in the location of the rifle and pool sequence. In general, limiting the lateral dynamics leads to increased longitudinal and vertical dynamics, with incision processes. However, in river stretches tending towards accretion or siltation, this trend has been observed to increase when the river is limited by protection structures, because the current tends to deposit sediment and it is forced to do so in a smaller space, rising the river bed.

Eria river. Felechares de la Valdería. León.
Breakage of a levee-rip-rap built inside the channel after a high flow event.

There are two types of incision processes:

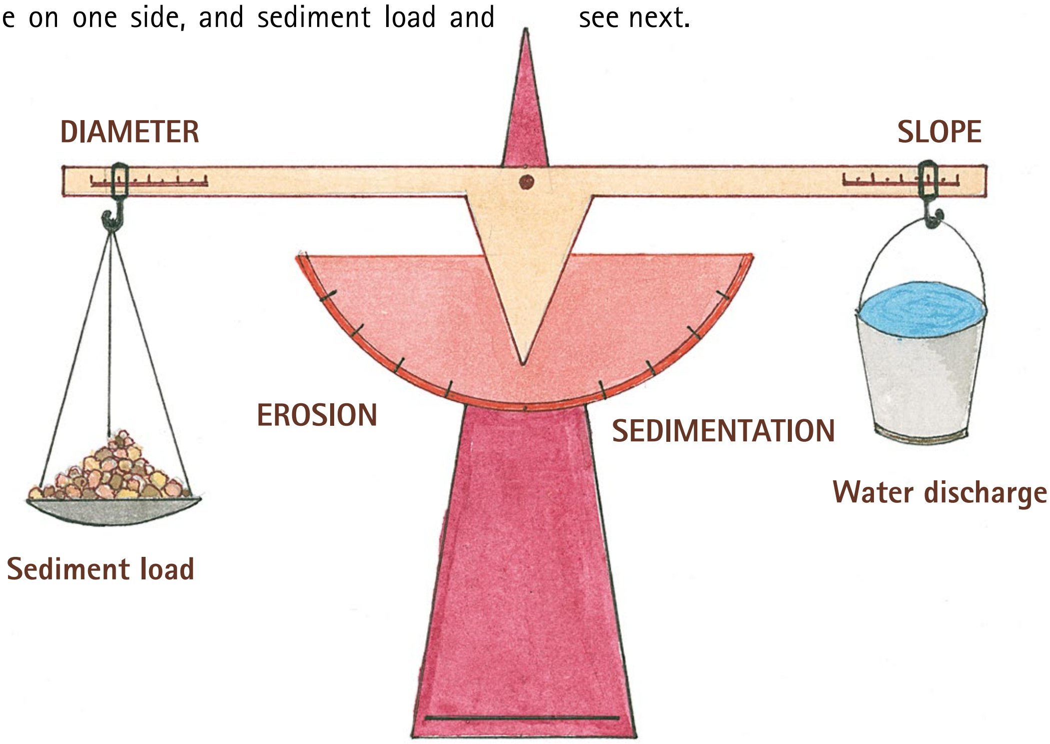
- Headward incision: caused by aggregate mining, dredging or a reduction of the channel cross section due to channel management (see the equation of specific stream power), channelisation or straightening. (Please see page 95).

- Downward incision: produced by damming and retention of sediment, specially bed load, by dams.

In the first case, modifying the hydraulic parameters leads to an increase in water velocity and bottom traction which sweep the bed, causing an increase in bottom sediment transport and a lower bed level. In the second case, the reservoir acts as a sediment trap, so effective concerning bottom sediment, that the river balances out downstream by changing the slope. This implies lowering the bed level to reach a new balance between stream discharge and slope on one side, and sediment load and average particle size on the other, a balance known as Lane's balance.

e) Impacts caused by the deterioration of continuity, width, structure, natural attributes, and connectivity of the riparian corridor. In general, hydromorphological dynamics increase as riparian vegetation deteriorates. Overflowing waters penetrate more easily, opening flood channels and generating coarse material deposits and crevasses within the corridor. Without vegetation, fine materials are not so easily deposited, thus the turbidity of the water current increases. Erosion processes are accelerated at the banks. As a result of the deterioration of vegetation, trunks and branches may get into the current and take part in sedimentation processes.

These alterations may be assessed and evaluated, and we may monitor their effects through the use of hydromorphological observation protocols and indexes, as we will see next.



Lane's balance (1955).

This is a graphical representation that intends to show, in a simple way, the dynamics of a river or a stretch of river. To do that, it proposes a relationship between the four essential variables of a river, namely the sediment load, the water discharge, the slope and the diameter of sediment particles. A greater dominance by one or several of these factors combined will lead to erosion or sedimentation processes in the river or the stretch of river under study.

3

HYDROMORPHOLOGICAL INDICATORS AND RIVER RESTORATION

3.1 Flow

3.2 Channel

3.3 Lonfitudinal continuity

3.4 Lateral dynamics at the banks

3.5 Vertical dynamics

3.6 Sediment transport

3.7 Sediment arrangement

3.8 Riparian vegetation

As we mentioned earlier, river restoration should aim to achieve natural conditions in river systems. When it comes to assessing and analysing the different water courses, there are plenty of indicators: some are biological in nature, others are related to the physico-chemical conditions of the water, and a third group are known as hydromorphological indicators.

The Water Framework Directive (WFD) establishes the variables and parameters to monitor and control in water bodies, as part of what is known as **monitoring**. Within monitoring, the most important part corresponds to hydromorphological aspects, which form the basis of the river ecosystem, what ecologists call the biotope. However, due to an inappropriate interpretation of the Water Framework Directive, these aspects have been pushed into the background and do not have the weight they deserve. In fact, there are no established solid methodological proposals to carry out the hydromorphological control and monitoring of water bodies as part of the assessment of the status of water bodies. This deficiency when it comes to do an assessment of the ecological status of water bodies has been made up for with an incorrect use of biological indicators.

To do an analysis focused on parameters of a hydromorphological nature, we have considered several important indicators that will allow us to study and assess the different water courses. When these indicators approach a natural condition, the water course functions with fewer alterations, thus implying a better hydromorphological status of the stretches analysed and better river functionality.

3.1 FLOW

What is it?

This is the first question that should be answered correctly. When we talk about flow, we can discern three types:

- **Water flow**
  Water flow or discharge is the amount or volume of water that passes through a specific cross-sectional area of a channel in a given time. It is measured in m^3/unit of time, which results from multiplying flow velocity (m/unit of time) by the cross-sectional area occupied by the flow (in m^2). The time units most frequently used are: seconds (instantaneous flow), hours, days (24 hours), months and years; in the case of the latter we talk about annual discharge, and it is measured in cubic metres and millions of cubic meters or Hm^3. In addition to mean flows, extreme flows are very important, both during high water periods and during low water periods, because they drive channel changing processes and they limit the development of certain species, in particular invasive spe-

Hydromorphological indicators proposed in the WFD		
Hydrological regime	**River continuity**	**Morphological conditions**
- quantity and dynamics of water flow - connection to groundwater bodies	- longitudinal - transversal - vertical	- river depth and width variation - structure and substrate of the river bed - structure of the riparian zone

Lucio stream. Villallano. Palencia.

Direct stream gauging during a high flow event to calibrate the gauging station with the green measuring rods in the foreground, that is, to adapt the rating curve between discharge and stage for the gauging station. In the enlargement we can see the current meter.

cies. The integration of all these components is known as the hydrological regime.

- **Sediment load**

  A water course is an environment with a three-phase flow of water, sediments, and living organisms or their parts. This is something we usually disregard, paying attention exclusively to liquid flows, since most studies are done from the perspective of water use. The flow of sediments or the collection of solid materials transported (including parts of living organisms, such as branches, trunks, leaves, seeds, spores, etc.) make up the solid flow, which can be measured with different techniques and can be expressed in a similar way as liquid flow, in m^3/s or in units of mass/s. The sediment flow plays an essential role in the river processes of transport and sedimentation.

Esla river. Bretó. Zamora.

High flow event at the point where a bridge joins Bretó and Bretocino, over the Esla river after the outlet of the Tera river. The transport of suspended load is huge during this type of events; that explains the colour of the water. It is due to the input from surface runoff waters which carry soil solid particles. When the water level goes down, the predominant runoff is sub-surface runoff, from the terrain and aquifers, so the water becomes clearer.

If rivers did not transport an enormous sediment load which is deposited in alluvial areas, these areas would not have characteristics so favourable for agriculture and livestock activities.

- **Geomorphic, dominant or forming flow**
  It consists of a liquid portion (water flow) and a solid portion (sediment load). This is the discharge responsible for the shape and the dimensions of the channel, necessary for changes to take place in water courses, that is, to have a functional system. Usually it corresponds with the discharge during high flow events, flowing at maximum velocity and occupying the whole channel (bankfull discharge); beyond it, water overflows into the floodplain.

Omañas river. Riello. León.

Why is flow important?

Generally speaking, during extreme events, during high flow events, is when the most important changes take place in rivers, because the processes of erosion, transport and sedimentation are very active. During high flow events the river performs most effectively its geomorphological functions; this is why it is so important to have a good natural hydrological function, and thus it is important that in highly regulated rivers there are flow releases which reproduce at least the bankfull flow, according to the timing and the frequency that correspond in that particular stretch. There are many types of water courses (torrents, rivers, ephemeral streams, etc.) and they are different in terms of their hydrological functioning, but high water flows are relevant in all of them, and they all need to have a natural hydrological behaviour.

- **River**
  A fluvial system that almost always has surface water flow, except during low water periods when water flows in the hyporheic zone. It has longitudinal continuity, although it can be divided into stretches or functional sectors which are homogeneous internally, but different from each other in terms of their hydromorphological characteristics. It has a complex cross section: if the valley allows for it, it can be comprised by a channel, riparian zones and a flood prone area or floodplain, where other fluvial forms can be found, such as abandoned channels, alluvial lakes or oxbow lakes.

- **Ephemeral stream**
  A type of water course with an ephemeral flow, that is, dry most of the year. It is characteristic of arid or semiarid environments, without aquifers of enough magnitude to compensate for low water periods or periods without precipitation with their discharge. The bed is usually wide and comprised of poorly classified alluvium, as a result of intermittent transport which is activated during the rare torrential events. Instead of having a V shape, like ravines, ephemeral streams usually have steep banks, almost

Milano creek. Maello. Ávila.

This is a tributary of the Voltoya river on its right margin; an ephemeral stream, the bed morphology is flat and wide, resembling Mediterranean ephemeral streams.

vertical, easily eroded by river action. Ephemeral streams usually have complex drainage networks, flows that concentrate fast, and powerful flash discharges of water and sediment.

- **Torrent**

  A water course with a steep slope (more than 6%) which flows down mountainous or abrupt terrain, fed mainly by intense rainfall or snowmelt, which can be dry temporarily, sometimes for long periods of time. As a fluvial system with a lot of energy, it has competence to transport a large sediment load, and the bed is usually rocky or comprised of alluvial sediment (from the channel itself) and colluvial sediment (directly from the hillsides) of considerable size. The steep slope also implies that the dominant geomorphological process is incision or deepening

Portillos creek. Villaviciosa. Ávila.

A torrent on granitic material.

Barranca creek. Villaflor. Ávila.

A torrent deeply set in Tertiary fill materials from the basin, currently undergoing an incision process, partly due to deforestation done to clear the land for crop cultivation..

of the bed, which in turn can result in destabilisation processes in the unstable hillsides that are connected to the channel.

The absence of water flow at certain times of the year does not mean that a stream has worse quality, quite the contrary. Interesting ecosystems are not those which are stable, but those where changes, which are the drivers of biodiversity, occur. It is not uncommon to hear colloquial discussions about ecological flows, and, when we do not have a clear idea of how a fluvial ecosystem should be and how it should function, we may make wrong interpretations such as: this stream used to dry up in the summer and now, thanks to a regulation dam, it has an 'ecological flow' year round.

From a scientific point of view, and if we are precise in terms of its true meaning, an ecological flow would be the flow that the stream would have according to its regime, and not a stable flow which resembles a man-made channel.

When ephemeral streams dry up, it is not a symptom of flow modification and loss of natural conditions, since that type of channels usually lack a liquid flow most of the year. This can also happen in certain seasonal courses, where usually there is a water flow, but it is not uncommon either for them to be dry at certain moments, for example in the summer, during a lengthy summer drought.

What are the main problems?

The flow of a water course may be insufficient to generate geomorphological processes. That is, a regulated or modified flow (with water abstractions for other purposes, such as crop irrigation or industrial activities) will not have the capacity to shape, to design the channel of the river, ravine, or ephemeral stream. The presence of water retention, diversion and abstraction infrastructure (reservoirs or dams, weirs, ponds, diversion channels, wells, etc.) in the basin or in upstream stretches can alter noticeably the hydrology and, in particular, the geomorphic flow. Each type of infrastructure will lead to a different degree of impact. Thus, a large dam can be considered a maximum impact, given that during high flow periods, the retention of water and sediment flows may be absolute. However, water and sediments may flow over smaller size weirs during high flow events, thus they cause a smaller impact, although the impact is more intense during low or medium flow periods.

How do we measure flow?

Flow measurement is an activity of great interest to get to know our rivers. It is done either through direct or indirect measurements at established control points or gauging stations. These must be designed in such a way that they do not compromise the free flow of water, sediment and living organisms. A type of gauging station that unfortunately has become popular in our country are flat V* stations, which present a problem for river dynamics because they alter the longitudinal continuity and raise the upstream water level. As well, they require constant maintenance and cannot measure high flows, because as the flow approaches the bankfull stage, water overtops them.

When carrying out river restoration work, direct flow measurements in the field are not very useful to describe the river, since the flow varies very quickly depending on whether it has rained recently (hours or days before), or whether water has been released from a dam, or is being withdrawn for crop irrigation, etc. Also, river conditions, in particular depth, and access to it, can make measurement quite difficult.

Flat V station on the Arlanza river. Burgos.

Flat V station on the Duerna river. León.

Flat V type equipment to control flow measurements..

* *The channel is truncated with small weirs, between 0.5 and 1 m high, and with the shape of a 'v' that opens at the top located on the bed, to measure flow at a given point..*

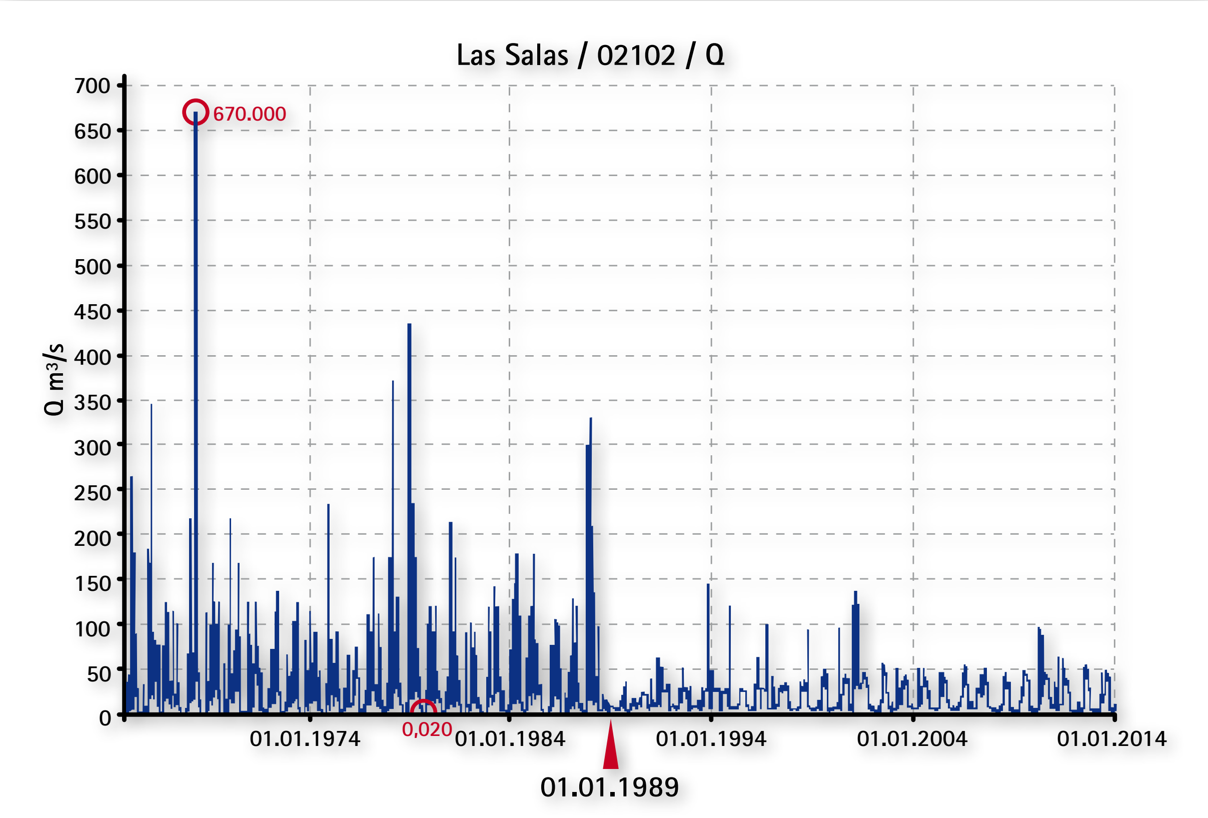
It is preferable to use data from nearby gauging stations (if we are dealing with a water course that is part of the main river network), which are sometimes available in the internet, to know the flow at the time when field work is carried out. If that is not the case, then we have to resort to indirect methods, such as modelling, although this is a very controversial field because of the many models and formulations that are available.

A common way to approximate flow at a certain point in the river network is to use empirical formulas such as the Manning equation, which allows us to know the velocity of a current based on the roughness of the wetted perimeter, the slope, and the hydraulic radius. Once we have determined the velocity, and knowing the cross section, we can determine the flow. It is most interesting to know the regime, that is, how do flows change through time. Data series, in particular when they cover time periods greater than 20 years, will be used to identify the general behaviour of the river and its seasonal regime, and to be able to check for any anomalies that may point to some type of regulation or artificial modification of flows.

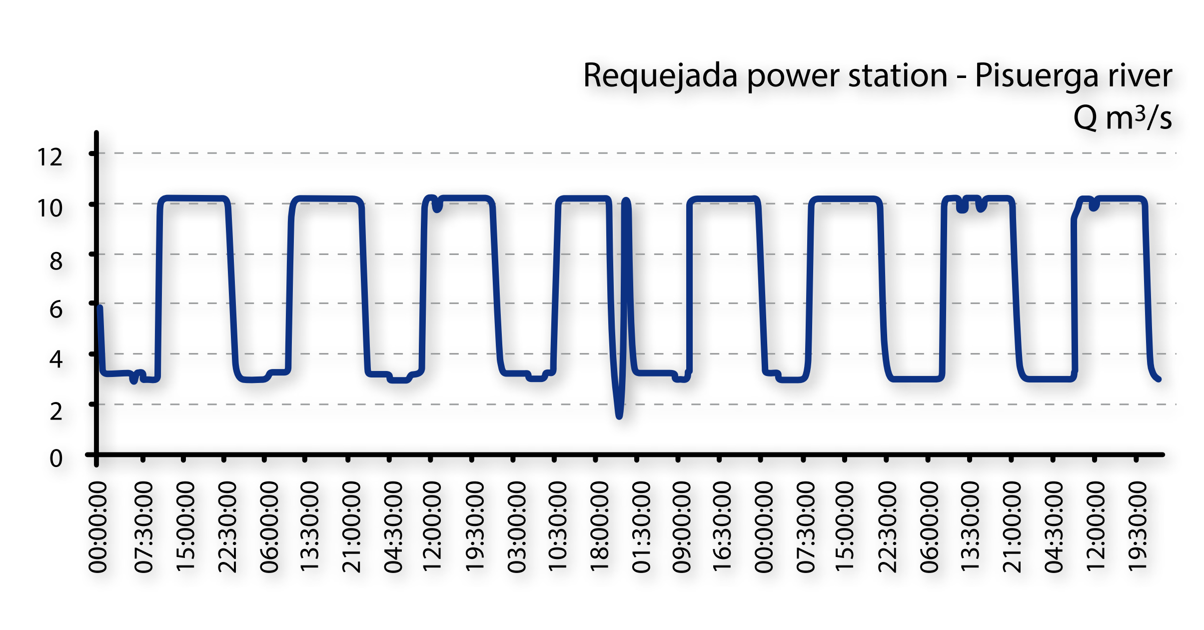
The most common changes are those due to water abstractions, inputs and returns, with or without regulation, that take place randomly or with a daily, weekly or seasonal regularity.

Interpretation of results

To learn about the possible modifications in the flow we have to take into account the



Modified flow regime in the Esla river at Salas (León), downstream from the Riaño dam. The red arrow indicates the moment when the dam starts operating in 1989. The decrease in peak flows as a consequence of flow attenuation is evident, and therefore there is a decrease in the geomorphic capacity. On the other hand, if we were to analyse the hydrograph throughout an average hydrological year, we would see that average flows decrease considerably in winter, sometimes below the summer low flow level, due to the retention of flows by the reservoir. In summer, the river functions as a channel to convey water to the inlets of irrigation channels, so low flows disappear and we find flows that are unusually high. All of these changes translate into a radical change in the ecological conditions of the river.



Example of hydropeaking (sharp fluctuations in flow) downstream from regulation reservoirs. Weekly registry from a gauging station located downstream from a hydropower station located at the foot of the La Requejada dam, in the Pisuerga river, at Cervera de Pisuerga (Palencia). It is a result of alternating periods when the station is operating (peaks) or not (minimum values) throughout the day, to produce energy to satisfy peaks in electricity demand. This is another modification of the flow regime which leads to severe changes in the ecological conditions of the river, and so fast that the rate of change may be very high.*

presence of water impoundments (reservoirs, ponds, weirs) throughout the basin, which lead to alterations in the natural flow and may cause geomorphic processes not to occur properly. In a similar manner, aside from the presence of reservoirs, we have to try to know about potential water diversions, returns and uses that take place upstream and which, at any given point, may lead to alterations in the regime or in the volume of natural flows. When a river has a natural geomorphic flow, some elements may be observed that indicate a good functioning and a correct condition. Some of those elements are:

- **Presence of deposits (bars) without much colonisation by vegetation. If the river is dynamic, during high flow events, those plant species that grow rapidly on the bars are eliminated by the river. In some cases, if bars have large size trees and abundant vegetation (both herbaceous and/or shrub vegetation), this is a symptom showing that water does not flow as naturally as it should. Puzzlingly, some systems to asses river quality based on riparian vegetation assign a higher score when riparian vegetation within the active channel or channels is more developed and mature, which happens in rivers with highly modified flows and which, from an ecological point of view, are much poorer.**

- **Mobilisation of deposits (bars).** During consecutive field visits, we may observe how these deposits 'move', relocating downstream; they can grow 'larger' (accretion) due to sediment input, or 'smaller' (erosion) as the river transports the materials downstream.

* *Rate of change, defined as the maximum difference in flow between two consecutive values in a hydrological series per unit of time, both when flow is increasing or decreasing. Hydrological planning instruction, section 3.4.1.4.1.3 (ORDER ARM/2656/2008, of September 10, Spanish Official Gazette (BOE) of 22 of September, 2008)*

Bar

A fluvial sedimentary deposit that may occur totally or partially submerged in the channel, or shaping the bank. There are different types: side bars (narrow, attached to the margins), point bars (with crescent shape, forming the convex bank or inside of the bend), longitudinal bars (in the middle of the channel, forming an island which, downstream, ends in an arrow point), transverse bars (actually they are diagonal to the current, rhomboid in shape, typical of braided channels), etc. Under normal conditions, the sediments in the bar are arranged from larger size upstream to smaller size downstream, the same as in deltas; this is known as progradation. In the bars, pebbles and gravel are imbricated, that is, they are superimposed in order as shingles in a roof, and they are aligned with the principal axis parallel to the direction of flow. If a selective transport process takes place on the bed surface, carrying away the finer material and leaving behind the coarser material, this leads to bed armouring. Sandy rivers, with hydraulic characteristics which show certain peculiarities, have bars which are predominantly sandy.

Tormes river. Ávila.

Point bar in the inside of a bend, partially colonised by riparian vegetation, in the upper stretch of the river.

Corneja river. Villar de Corneja. Ávila.

The point bar on the right (the river flows towards the background on the photo) is more stable and is covered by pasture, whereas the middle bar on the left is more mobile and is not covered by vegetation.

Eria river. Pobladura de Yuso. León.
Side and mid channel bars with large grain size sediment.

3.2 CHANNEL

What is it?

Once again, it is advisable to reach an agreement from the start. **The channel, from a physical point of view, is the planform, cross-section and profile of a water course. Usually their three dimensions are curved; channels with a straight planform are rare, generally due to the tectonic structure.** The definition of a channel from the legal or regulatory point of view is something else, as we can see in the box.

Channel

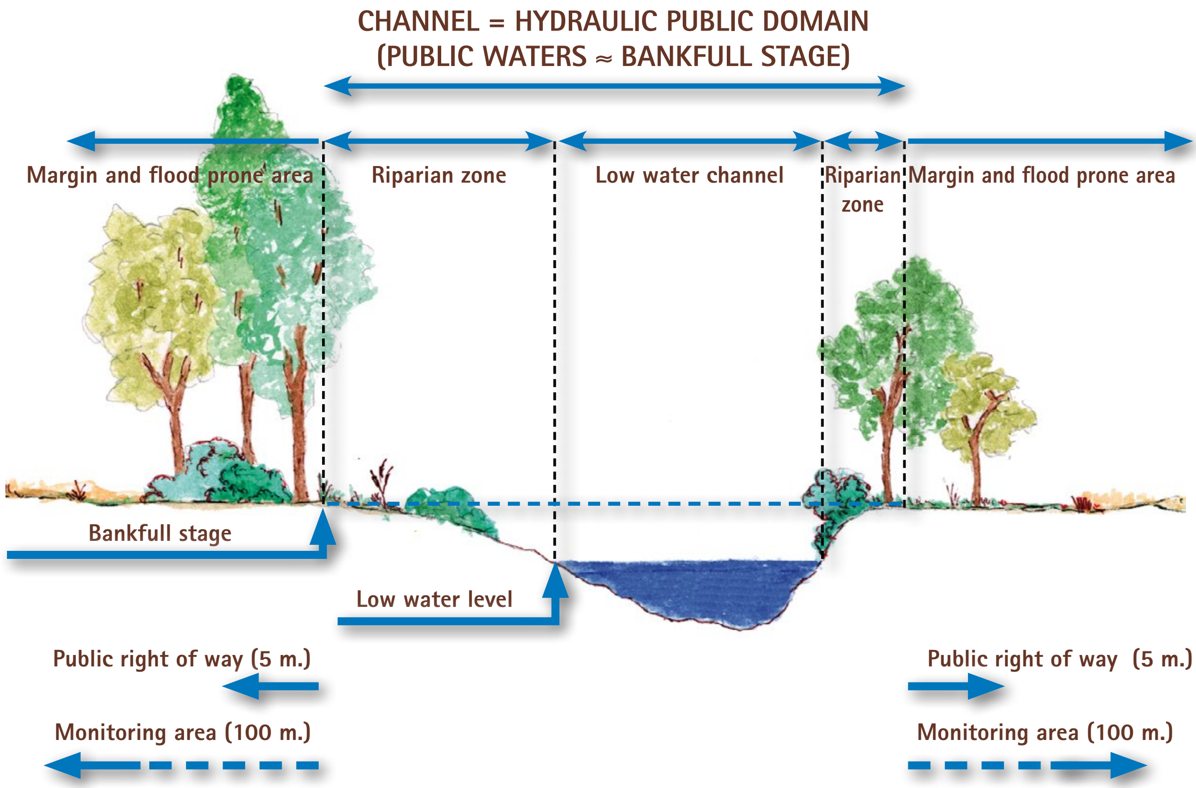
From a regulatory point of view

In Spain there is a legal definition of a channel, as per Article 4 of the Regulation on the 'Hydraulic Public Domain' (a figure in Spanish legislation which refers to public waters)

1. The natural channel of a continuous or discontinuous current is the land covered by water during bankfull events. This land will be determined taking into account its geomorphological and ecological characteristics, and considering information from hydrological, hydraulic, photographic, and cartographic sources, as well as any available historical references.
2. The ordinary bankfull flow will be considered as the average of the maximum annual flows, under a natural regime over ten consecutive years, representative of the hydraulic behaviour of the current, and taking into account what is said in section 1.

From a physical point of view

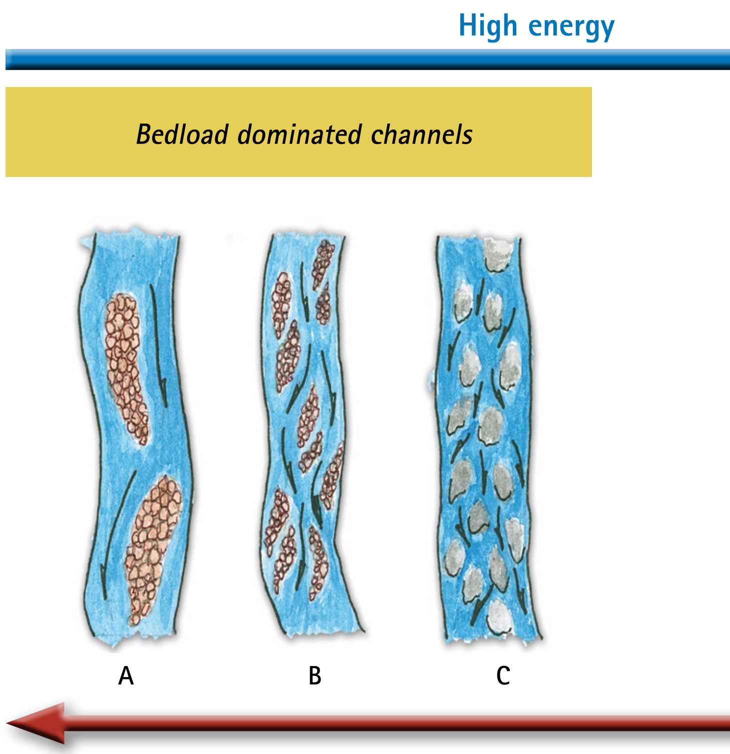
A landform built and dimensioned by the fluvial system for the efficient transport of water and sediment flows. It can be simple or multiple (braided, anastomosed), a straight line, or winding, with a greater or lesser tendency to form meanders. It presents a certain degree of confinement that allows us to delimit it and the flow circulates most of the year through this confined area. Its attributes (cross-section, depth, number of arms, morphology of the bed and the banks, texture, etc.) is the result of the interaction between the geomorphological conditions of the specific terrain it flows through (lithology, slope, etc.) and the characteristics of the flow (flows, regime, extreme processes, sediment load, etc.).



Channel form

Each water course has a different form. There are rivers deeply set in canyons, in narrow valleys (usually in mountain areas and headwaters), rivers with a meandering course (with numerous 'bends' or meanders), braided rivers with several channels and many sediments and bars, anastomosed rivers, also with several connected channels, but with finer sediments than braided rivers, etc. When it comes to do an assessment, it is important to check whether the current form is a result of the natural action of the river system, and has not been modified by human activity. The pressures on the river system affect the channel as well, either directly or indirectly, and may lead to a change in morphology.

Among the many channel form classification schemes, we choose here the one by R. Charlton (2008), which we think is very concise and can be applied universally:



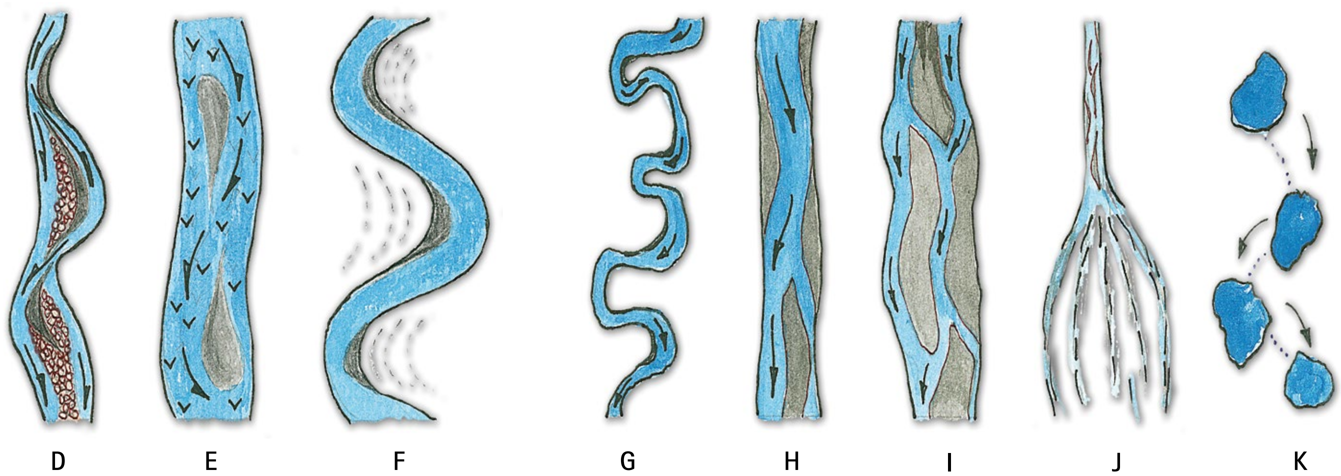
A. Boulder bed
B. Gravel bed braided
C. Sand bed braided

Morphological classification of alluvial channels

Source: Fundamentals of fluvial geomorphology. R. Charlton, 2008

Medium energy | **Low energy**

Mixed load dominated channels | *Suspended load dominated channels*



INCREASING STREAM POWER
INCREASING SEDIMENT CALIBRE
INCREASING CHANNEL GRADIENT
DECREASING CHANNEL STABILITY

D. Wandering gravel bed
E. Wandering sand bed
F. Sand bed meandering
G. Fine-grained meandering
H. Low sinuosity fine-grained
I. Anastomosing fine-grained
J. Floodout
K. Chain-of-ponds

Corneja river. Ávila.

Wandering type E channel, according to the Morphological classification of alluvial channels. (Source: Iberpix. National Geographic Institute of Spain).

Tuerto stream. Campo Azálvaro. Ávila.

Meandering stretch (type G channel, according to the Morphological classification of alluvial channels) of the Tuerto stream, a tributary of the Voltoya on the left margin. Tuerto is a common name for rivers, which in this context means tortuous. (Source: Iberpix. National Geographic Institute of Spain).

What is it important for?

It is important to know the type of water course, because each one has its own characteristics and a different behaviour. For example, deeply set rivers usually have a steeper gradient, a higher number of riffles and pools, minor banks (or non-existent), and larger size sediments, such as boulders and large rocks. Braided rivers, however, usually have a gentler gradient, a riparian zone that is not so much developed, but is adapted to gravel channels, and a channel bed with smaller size sediments (gravel, pebbles, sand, etc.). The form of the water course will be different, but we have to analyse and assess whether that form is natural or not.

What are the main problems?

One of the most important aspects in this section is the definition and analysis of the *bankfull* width or full channel. This is a concept that often poses difficulties when we define it in the field. A small incline with an abrupt change in slope at each bank can determine that level, or else the presence of permanent vegetation above it, or a change in the colour of the rock in deeply set rivers, due to the growth of lichens above the bankfull level. In deeply set rivers or in valleys without a space for floods, the occurrence of accumulated wood carried by high flows can give an idea of where the bankfull level is located.

Duero river. Fresno de la Ribera. Zamora.

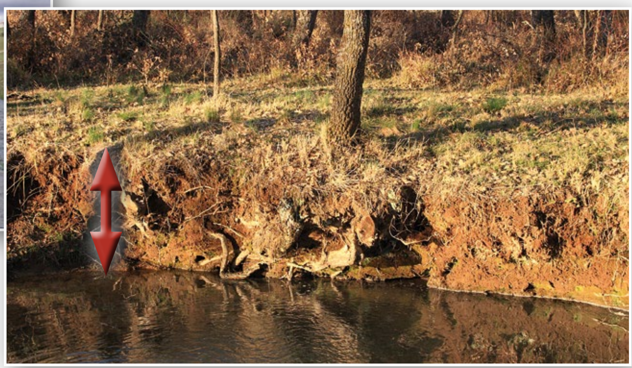
The arrow indicates the bankfull level on the left margin, which appears here as a very sharp incline.

Castrón river. Ferreras de Arriba. Zamora.

Representation of the normal or low water channel, and the bankfull level.

Almar stream. Ávila.

Bankfull level on the right margin of the Almar stream. The accumulation of deposits indicates that the level was almost surpassed during a recent high flow event.



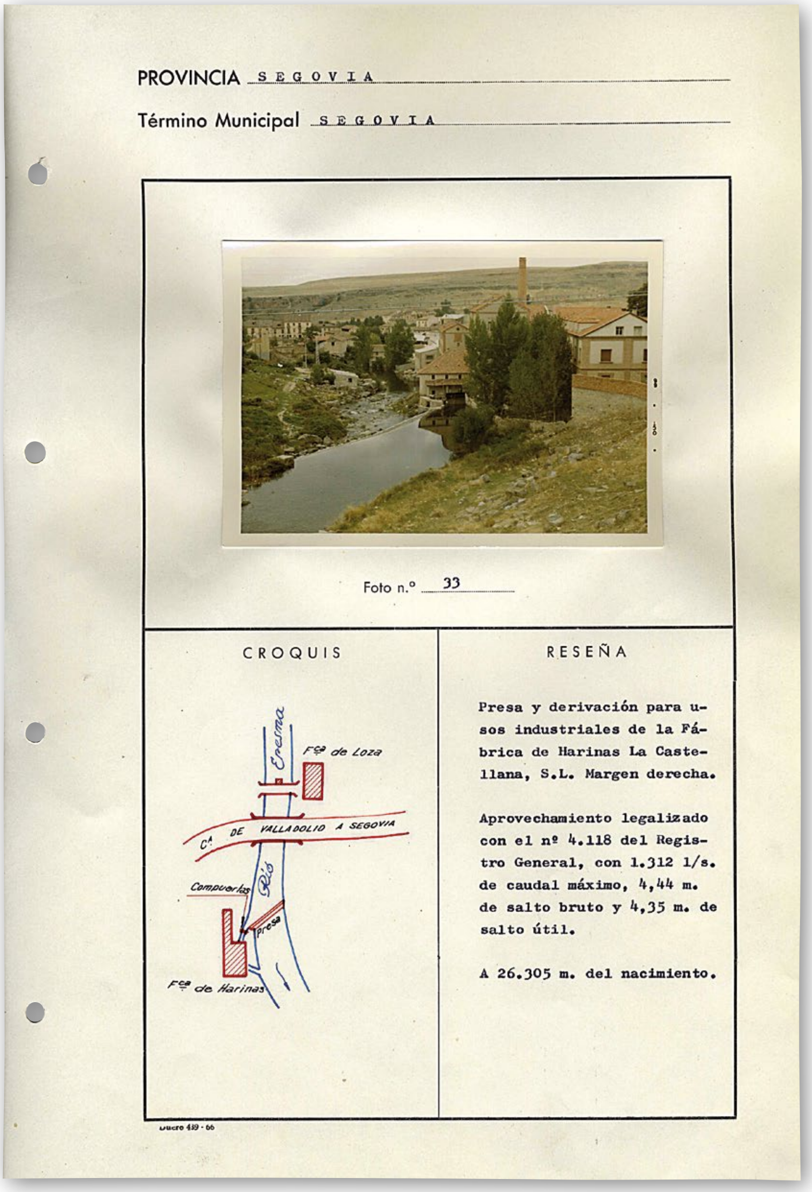
Bankfull

It means ‘full banks’. It is a term very much used by hydrologists and geomorphologists in the United States. The bankfull level of a river marks a change in the slope of the bank, as the point at which water overtops the banks, defining the total width of the channel or channels and other hydraulic and hydrological parameters. The bankfull level can usually be identified in the field, both in the topography of the banks as well as observing the vegetation. The bankfull discharge at each point of the river is the threshold flow that will overtop the banks (thus it can be used to differentiate high waters from flood events). It is a channel forming discharge, the one with highest geomorphological efficiency, since at bankfull level, with no dissipation by overtopping the banks, the current has maximum velocity and energy. The average return period of the bankfull discharge is about 2.3 years, although in our country, very Mediterranean, and with pronounced differences between years and within the same year, it can be highly variable, with return periods ranging from one and a half year and seven years, depending on the area.

How do we measure channel form?

It is interesting to analyse the form of the channel and see if it has been modified naturally or not. To do that, we can go to the field and observe the area, looking for impacts (construction works, dredging, mining operations in the channel, any sort of movement of material in the bed or the banks, activities in the margins, etc.). Sometimes the area has become naturalised and it is very difficult to appreciate the changes, and an inexperienced observer may consider natural a heavily modified channel just because it has very well developed riparian vegetation. It could be that the observer is looking at a single channel stabilised due to channelisation and regulation by a reservoir, with a well-developed riparian forest, whereas the reference conditions included a braided morphology, with riparian vegetation that did not have time to reach a mature stage because the flood regime and the transport of sediment were very active.

To see whether the river has been modified, we can do periodic measurements of the cross-section of the water course, and compare the profiles thus obtained. To do these analyses correctly, we should look for a permanent point in both margins, and, with the


PROVINCIA SEGOVIA

Término Municipal SEGOVIA

Foto n.º 33

CROQUIS

RESEÑA

Presa y derivación para usos industriales de la Fábrica de Harinas La Castellana, S.L. Margen derecha.

Aprovechamiento legalizado con el nº 4.118 del Registro General, con 1.312 l/s. de caudal máximo, 4,44 m. de salto bruto y 4,35 m. de salto útil.

A 26.305 m. del nacimiento.

Duero 419 - 66

Field study of pressures with an impact on flow, carried out in the Eresma river, 1967. Source: general archives of the Duero River Basin Authority.

These studies done by the Duero River Basin Authority in the 60s and 70s involved in depth field studies of many water courses. They include plans, descriptive worksheets, and images identifying the location of the pressures detected.

help of an automatic optical level, do a cross-section, taking measures regularly or in areas where the slope changes. We should be able to identify the chosen site in subsequent field visits, to do the measurements at the same point, trying to repeat the same control areas. If possible, it is highly advisable to do a direct streamflow measurement, as well as determine the texture of the materials that make up the bed and the banks.

Another very important source of data are historical records, especially those of the River Basin Authorities, since in them we can find project designs and files relating to construction works and water uses that take place in the channel. In some cases, the documents may contain land surveys which could be very useful to compare heights. This is the case of past field studies of allocation pressures that had an impact on the river flow, known as *modulaciones* in Spanish.

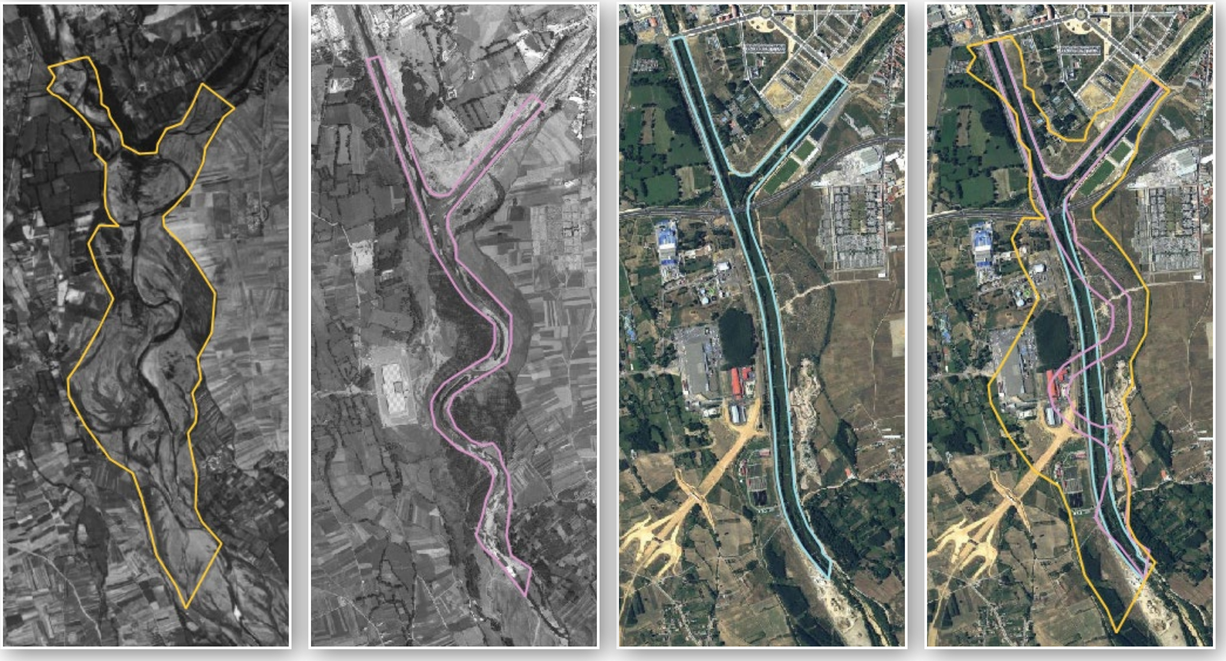
Another analysis can be done, at a different scale, to see if there have been any changes in channel form. To do it, we need to compare aerial photographs from several different years. Nowadays, River Basin Authorities have current images of the land under their management and, in some cases, they also have older photographs that can be used to compare the water courses in them. Currently there is greater access to aerial photos and images. The use of drones can be a very useful tool. For example, we may be able to see changes at a large scale, such as channel straightening, channelisation, meander cutoffs, etc., whereas at a local scale it may be difficult to analyse the changes in channel form.

Interpretation of results

Natural water courses are dynamic: they evolve through time, faster or slower, depending on the type of river. Assessments are done to discover whether the changes in river form are due to natural factors or, on the contrary, are caused by human activities.

The form of the river is very much linked to the circulating flow; the presence of reservoirs

Negro river. Otero de Centenos. Zamora.
Process to measure a cross-section.



Bernesga river. León.

Changes in the morphology of the Bernesga river downstream from León, after the Torio flows into it. In yellow, the original space that the river occupied in 1956-1957 (American flight), where we can appreciate the original braided morphology. In pink, the year 1972 (flight of the Instituto de reforma y desarrollo agrario, IRYDA [Institute for Agricultural Reform and Development]). In light blue we can see the current channelisation. The fourth image is a composite of the three situations overlaid on a current orthophoto (2009), where we can see the huge loss of space for the river to move.

and dams upstream from the area of study may entail a loss of flows (water and sediments), and as a result braided and dynamic rivers end up being more stable, single channel rivers. In these cases, we may speak of a change in form caused by factors that are not natural or anthropogenic factors.

Channelisations, another type of artificial activity, involve the greatest degree of alteration of river form, since the entire geomorphological structure is lost and the new form is completely altered. The most severe modifications are those affecting the planform (cutoffs), the profile and the cross-section of the river.

Channelisation of a river stretch.

The channelisation and construction on what used to be a river bed, now a slab of concrete, puzzlingly imitates a natural low water channel, 'winding' and with 'bars.'

3.3 LONGITUDINAL CONTINUITY

What is it?

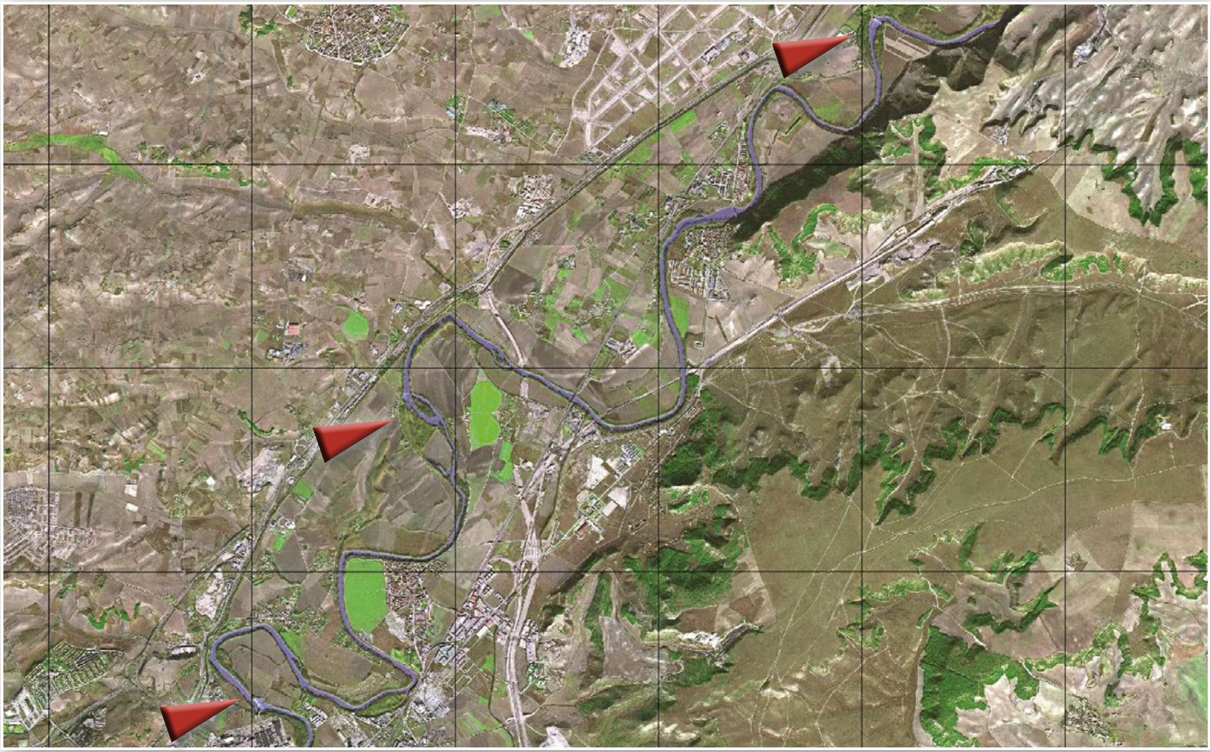
This is the continuity along the axis of the river gradient. A natural water course without transversal barriers (weirs, dams, wading areas, etc.) that artificially modify its functioning and cause changes in the associated ecosystems is, from this point of view, a healthy fluvial system, without any impacts to its longitudinal continuity.

What is it important for?

Longitudinal continuity is important because it ensures the free flow of water, sediments and biota. Under ideal conditions, there should not be any impermeable barriers in a water course, both for water and sediment flows and for living organisms, except for, of course, any natural ones in the landscape, such us vertical grade changes with waterfalls. Continuity along the course is a factor that indicates a correct interaction between the headwaters, the middle stretches, the lower course and the mouth.

What are the main problems?

Transversal barriers, especially those that are totally impermeable, entail a very noticeable loss of hydromorphological quality and habitat fragmentation. The main problem is caused by dams, impermeable barriers of considerable height that totally destroy longitudinal continuity, retaining, for example, most of the sediments.



Pisuerga river. Valladolid.

Stretch of the Pisuerga river upstream from the city of Valladolid. The arrows indicate three weirs with consecutive mini hydropower stations. The length of the stretch is 21.7 km, and the average gradient is 0.03%. The pool and riffle sequence has disappeared, leading to a significant loss of habitat; nutrient retention brings about the eutrophication of stretches, with characteristics more typical of lentic systems than of fluvial systems. In general, the occupation of middle and lower stretches of rivers has reached such an extent that from a limnological point of view, the river, before a lotic system, has been replaced by a series of ponds, becoming more like a lentic** system. (Source: Iberpix. National Geographic Institute of Spain).*

* *Lotic. A system with flowing water, such as rivers and creeks.*

** *Lentic. A system with slow or relatively still water flow, such as lakes and reservoirs, where vertical water movement dominates.*

Other types of barriers, smaller in size, such as weirs or wading areas, may involve a temporary loss of continuity, given that the water flow overtops the barrier during high flow events.

How do we measure the longitudinal continuity of the system?

In order to measure the longitudinal continuity of a system, we have to analyse the **number** and **type** of transversal elements found along the river system or the area of study. The number of elements can be analysed using aerial photographs. If the photos are recent, the data will be up to date. In case the data are old, an initial assessment can be done, then it can be verified with ground truth field observations.

Some other elements, occurring at certain points and smaller in size, such as wading areas, are more complicated to identify in aerial photographs, although the presence of trails, paths or roads in the margins of rivers can help locate them.

If we are working with small water courses, with very dense riparian vegetation or areas with a severe land relief, the use of aerial photos will hardly help and we will have to resort to field work to a greater extent.

It is always advisable to do field work to solve any doubts that might have come up during the assessment of the number of transversal elements, and to **typify** the elements detected in the aerial photos.

Not all the transversal elements occurring in rivers have the same impact. The presence of dams will be assessed as more negative, whereas smaller size weirs, large wading areas or bridges with piers in the channel may cause a medium impact.

Another type of structures, such as small wading areas or bridges without piers may only affect the banks and not the channel, hence the impact on the river system is quite smaller.

Interpretation of results

To assess the longitudinal continuity we have to analyse the existing permeability, both in terms of biological elements (fish fauna) and in terms of sediments. An impermeable barrier, such as a dam or a weir without a fish ladder or sediment bypass, does not have the same importance as an infrastructure of these same characteristics but which does have elements to make it permeable.

As well, the impact of a wading area is not the same as the impact of a bridge, since the second one, depending on the type, may function as a barrier, whereas water can easily get around the first one during high flow periods.

Once the number of elements in the area of study has been obtained, and knowing the length of the river in that area, a simple calculation can be done dividing the length (in km) into the number of transversal elements. This way, we obtain an **index of alteration due to impacts of transversal elements.** If the value obtained is lower than 1, this means that, as far as this aspect is concerned, the impact is important. The greater the value obtained, the more diffused and less localised will be the impact as far as this aspect is concerned.

For example, if a river stretch is 12 km long and 17 transversal elements are detected:

$$12 / 17 = 0.70$$

However, if in the same 12 km stretch there are only 3 elements:

$$12 / 3 = 4$$

The second example shows a case with better longitudinal continuity than the first example. In the Duero basin, we have used an indicator of longitudinal continuity that is more complex, since it takes into account the extent to which fish fauna can get through each of the obstacles, both going upstream and downstream. In this way, a weight is assigned to the index, since not all obstacles pose the same degree of impact. Additionally, it has been prepared for five types of fish, based on their swimming ability, so that we can discriminate even more.

The number of obstacles identified in the Spanish portion of the Duero basin is surprising: more than 3,500. Oddly enough, many of them are not currently in use; this is the case of many weirs used as part of watermills to produce flour or textiles in the past, or obsolete hydropower stations. Most of these obstacles, now in ruins due to a lack of maintenance and with serious safety issues in the case of the larger ones, should be demolished; this would result in greater safety and the recovery of longitudinal continuity.

Aravalle river. Umbrías. Ávila.

Demolition works (images 1 and 2) of a large dam built in the 70s of the past century, for the water supply to an urban development that was never built. For over 30 years it has been an obstacle for river dynamics and a safety threat due to the lack of maintenance and operation. Its demolition has meant the recovery of one of the best stretches for trout spawning in the Tormes river. In image 3, taken two months after the demolition, the double arrow shows where the abutments used to be. On the right margin (left side of the image), we can see that exactly where a portion of the body of the dam used to be, a sediment point bar has been deposited. The mobilisation of sand and silt accumulated upstream is also quite obvious.

3.4 LATERAL DYNAMICS AT THE BANKS

What is it?

The lateral dynamics of river systems comprise those interactions that occur inside the channel, and between the channel and adjacent spaces (margins and floodplain), that is, the processes that are also known as lateral connectivity processes.

What is it important for?

It is important within the channel because it ensures the transport of materials as part of a continuous erosion process in the outer (concave) side of bends and a continuous deposition process in the inside (convex side) of bends. Moreover, the connections with the spaces adjacent to the channel are an essential part of the functioning of the river system, and, therefore, should be as natural as possible, in such a way that lateral processes are facilitated. The modifications that can be seen in the banks of water courses entail a loss, sometimes total, of lateral connectivity, and have the effect of decreasing the ecological quality of the riparian area.

During high flow events, appropriate lateral dynamics will let the areas adjacent to the river interact directly: dissipating energy, attenuating the high flow, infiltrating part of the flow and thereby allowing the recharge of aquifers, and also allowing the input of sediments, which contribute to improving the substrate and fertilise it. Similarly, good lateral connectivity allows flood pulses (overbank flows and their return to the channel or attenuation) to function as ecological exchanges of nutrients and organic matter between the channel and the floodplain, greatly enriching both spaces.

Furthermore, the natural lateral dynamics of a river lets the fluvial system itself design its course and morphology, generating new meanders, new secondary channels, and alluvial wetlands.

Flood prone areas

From a regulatory point of view

There is a definition in the Spanish legislation, under Article 14 of the Regulation on the Hydraulic Public Domain. Flood prone areas are demarcated by the theoretical levels that waters would reach during flooding, the statistical recurrence interval for which would be 500 years, according to geomorphological, hydrological and hydraulic studies, as well as time series of historical flood data and documents or historical evidence of them, unless the Ministry of Environment, following the proposal of a river basin authority, sets the specific boundaries that are most appropriate for the behaviour of flows in each case. The designation as flood prone areas does not affect the legal designation or the ownership of the land.

From a physical point of view

It would be the area of land adjacent to a river beyond the banks of its channel that experiences flooding during periods of high flows; it is also known as the orthofluvial zone and is flanked by the last terraces. The topography is basically flat (and thus it is usually called a flood-plain), and generally has a slight tendency towards concavity, although some have a convex cross-section. During high flow periods, they function as a space where overbank flows can dissipate energy and be stored, having a flood attenuation effect. They are also areas where suspended fine material transported with the current settles; this settling process is responsible for the vertical growth of deposits and their fertility. In rivers deeply set in a canyon, the flood prone space is narrower, and, sometimes, does not exist.

Arlanza river. Tordómar. Burgos.

During high flow events, the suspended solids transported by the river are deposited on the alluvial areas, fertilising them.

What are the main problems?

The main problems associated with a lack of lateral mobility is the confinement of the river bed, leading to an increase in flow velocity, proportional to the height; in turn, this implies an increase in bottom traction. The most common problems that may result are incision or undermining.

Eria river. Felechares de la Valdería. León.

The undermining of the central pier of this bridge could be a result of the river flowing very deeply set into the main channel, reaching very high water velocity.

Órbigo river. Bridge at Veguellina. León.

Addition of aggregates from the dismantling of a levee to fill a large incision pool downstream from a bridge.

Órbigo river. Carrizo de la Ribera. León.

The base of the piers of this bridge joining Carrizo de la Ribera and Villanueva de Carrizo shows also an incision process, but in this case it is probably caused by the channelisation of the river.

Támega river. Verín. Ourense.
Channelised stretch.

How do we measure lateral dynamics in the banks?

In order to measure the lateral dynamics in the banks it is necessary to do several field visits, taking measures at each one of them to compare the data. To check for erosion in the banks, we may drive markers (nails, wood stakes, etc.) into the ground and measure the distance from them to the slope or edge of the bank.

During consecutive visits, we can see if the slope has been eroded or not, based on the data obtained. The location of the markers must be chosen taking into account that the banks may be eroded, so it is advisable to place more than one marker in order to prevent the loss of data if erosion is very severe.

As well, channel form measurements (cross-section) can be used for the same purpose. There could be problems in areas where there is no access to the river to do the cross-sectional measurements; in these cases, the option of using markers can be more useful and safer.

Lateral dynamics do not only include erosion processes, but also sedimentation processes. In these cases, we may analyse the bars that occur in the channel and take photos during the different field visits, to analyse them later as part of desk work. Locating fixed markers on the bars is more complicated because of the materials bars are made of (pebbles, gravel, etc.), which make more difficult the analysis of measurements.

The natural dynamics can also be assessed using aerial photos taken on different dates, checking for the progress of erosion or else the formation of sedimentary deposits.

Urumea river. Arano. Navarra.

Measurement with markers at a bank with lateral erosion processes.

Omañas river. León.

Active erosion bank at the right margin of the lower Omañas river in León. On the left we can see the accretion zone, with a point bar on the inside of the bend (the current flows towards the background of the photo). This is a universal hydraulic pattern, and the mass balance approaches zero, with erosion compensating accretion in the same section. The net transport is due to the fact that what is eroded is not deposited in the same bend, but in the following one, in such a way that there is a wave of net downstream transport.

Interpretation of results

When analysing the lateral dynamics of banks, we must take into account that the existence of erosion or sedimentation processes is negative only if caused by human activity. We should analyse whether these processes are taking place at a faster rate than usual, and, in that case, look for possible causes, which sometimes can be found outside the channel, in the basin.

As we have seen earlier, the removal of weirs is a very good example of restoration. In these cases, most often the banks that were adjacent to the weir lose the support from the water, so that lateral erosion processes occur at a faster rate. These areas are susceptible to monitoring to see the extent of lateral erosion they present, as well as to analyse the margin stabilisation process that will take place over time.

3.5 VERTICAL DYNAMICS

What is it?

The vertical dynamics of river systems comprise all those interactions that take place on the bed, mainly erosion (incision) and sedimentation (accretion) processes, which lead to bed relief features (such as the sequence of rifles and pools) and continuity with hyporheic environments (the contact zone between the water and the substrate) and underground environments (aquifers with an alluvial connection). In rivers flowing over bedrock, contact with the substrate is clearer, but in alluvial courses water flows also through the sediments which make up the river bed, that is, the hyporheic zone, and the channel is in contact with the alluvial aquifer, that is, with groundwater.

The longitudinal profile of the river is also part of vertical dynamics, since it is the line of contact of the channel, and there could be headward erosion or accumulation processes depending on changes in the final base level (the sea) or changes in local base levels of a tectonic nature, and sometimes due to anthropogenic activities. To this effect, transversal barriers may alter vertical dynamics as well as continuity.

What is it important for?

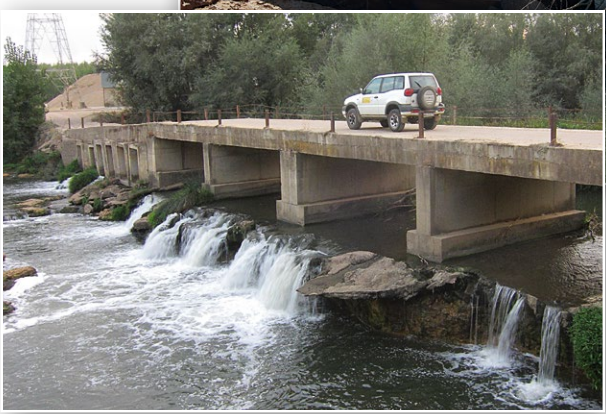
Appropriate local vertical dynamics ensure that the habitats in water courses are distributed naturally and that there is adequate biodiversity in the water and on the bed. At the scale of the river stretch, the activities and infrastructure that modify the natural longitudinal profile of the river lead to modifications of these dynamics. In this manner, activities such as channelisations or dredging will contribute to increasing the velocity of the flow, leading to changes in the bed and in the longitudinal profile, likely with incision as an outcome.

What are the main problems?

The main problems that may be linked to altered vertical dynamics are incision and undermining processes in the middle of the bed and in the areas where the bed is in contact with the banks.

Incision and undermining issues are particularly worrisome with regards to infrastructure located in river systems, because they may pose an additional risk for people, causing the breakage or fall of those structures. In certain cases, adding aggregates to the river, for example those obtained from the removal of levees, is a very suitable measure to solve localised problems. It can even be considered at a large scale, but taking into account that it is a very unpopular measure, it has to be very well explained if it is done in populated areas. Furthermore, it should be noted that, if the causes are not addressed, the result will be palliative, but the problem will not be corrected.

Incision also affects the adjacent riparian areas. If there is excessive vertical incision in



Bernesga river. León.

Besides the channelisation of the river in León, and massive aggregate mining in the bed, we have to add local processes such as the one on the left image, a bridge that has collapsed after a high flow event.

Incision

Erosion downward through the channel bed, due to the action of water and sediment flows. It is a natural phenomenon that at the meso-scale is responsible for the creation of pools that we find on the outer edge and coming out of the bends. At a macro-scale or at the basin scale, it causes the deepening of valleys and the creation of ravines and gorges.

Human activities notably encourage incision processes. Incision can be encouraged by extractions activities (dredging), channelisation (headward incision), and by damming and the resulting retention of bed load (downward incision).

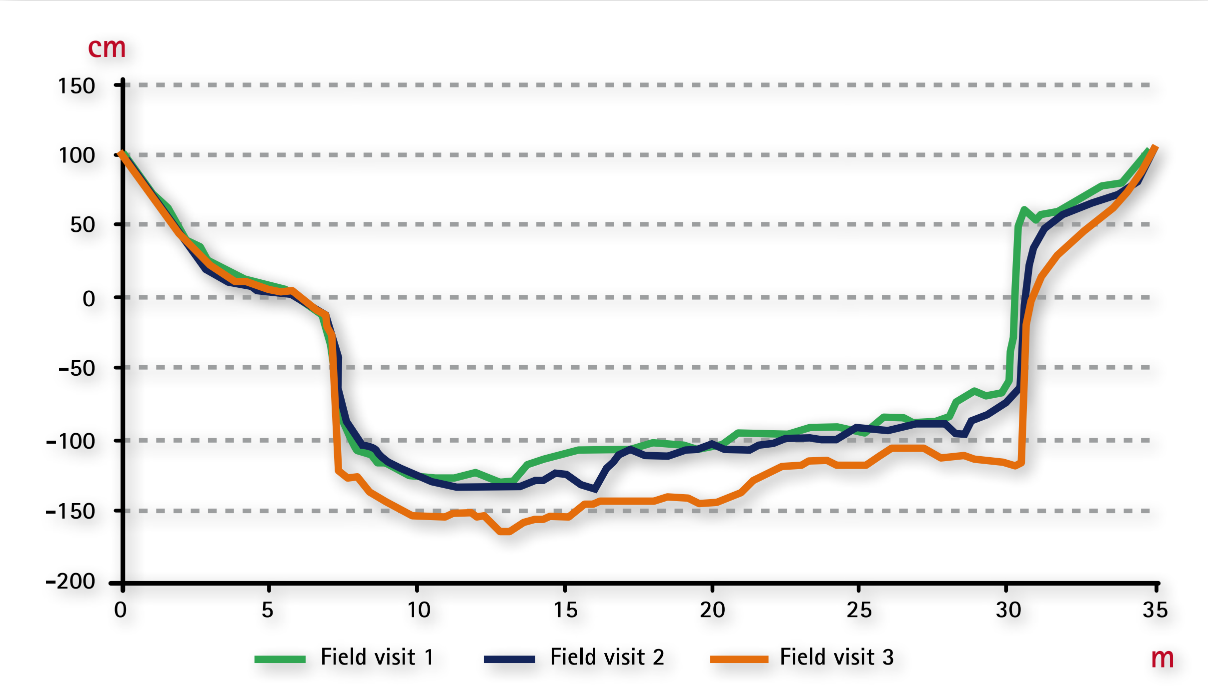
a river system, the banks will be left high up, perched over the bed; the level of surface waters and groundwater (the water table) will decrease and result in the disappearance of riparian vegetation.

How do we measure vertical dynamics?

Vertical dynamics are complicated to analyse when doing field work, because it would entail doing very precise measurements of the bed; these measurements will have to be repeated periodically at the same site, and this may pose access difficulties and even risk to the observer if the depth of the channel is significant. In channels that cannot be waded across, it is necessary to use a boat.

The replication of cross-sectional measurements at the same site will allow their analysis at a later time, measuring any changes that might have occurred, as long as it has been done carefully so that the data are valid.

Incision can also be analysed through a visual assessment of the elements of the channel that present problems, such as the undermining of bridge piers (see page 73) or protection structures in the margins. In these cases, markers can be installed in the infrastructures, to allow eva-



Comparison of the river cross-section at three field visits. We can observe that a pronounced incision has taken place between visit 2 and visit 3.

luating at a later date if the extent of bed incision has increased or not.

Interpretation of results

The same as it happens with lateral dynamics in the banks, vertical dynamics comprise natural processes in river systems, which can be altered by human pressures that modify the channel, increasing the rate at which these processes occur. Changes in vertical dynamics should be interpreted taking into consideration that the impacts may not be necessarily located in the same area where we are doing the analysis, but upstream from it (as it happens with dams, whose effects move progressively downstream), and with dredging activities (in this case we talk about headward incision).

The effects of incision and undermining that can be seen in infrastructures as well as in the river margins are signs that should be interpreted and analysed.

Another sign that indicates excessive incision is the presence of dead or dry vegetation in the banks. A sharp lowering of the river bed has an impact on the water table, because it drains the alluvial aquifer, leaving the adjacent areas at a higher level, with no water input, so that vegetation dries up and dies, or else it is replaced by invasive species or climax species*, better adapted to arid conditions.

Sometimes the vertical dynamics translates into a loss of the connection river-aquifer, not due to incision, but to the interruption of the hydraulic connection with the aquifer. When groundwater is overexploited, there is a decrease in the water table level (alluvial or free aquifers) and in the piezometric level (deep or confined aquifers); as a result, rivers that used to 'gain' flows, with a portion of their flow coming from groundwater, become rivers that 'lose' flows, because a portion of their flow or their entire flow infiltrates into the terrain (see the diagram on page 27).

Trabancos stream. Pollos. Valladolid.

Dead riparian vegetation in the dry bed of the Trabancos stream. This is one of the streams that 'loses' flows in the Duero basin, together with the Zapardiel and the Guareña; the three of them are located in the central area of the left margin. The overexploitation of groundwater that has taken place in the aquifers found in the 'los Arenales' area has caused streams which used to be permanent to become ephemeral.

* *The term climax is used here with the meaning used in geobotany, comprising species which are dependent on rainwater. It is used as opposite to riparian species which are aquatic or edapho-hygrophytes, dependent on surface, subsurface or edaphic water inputs, and therefore not dependent on water from precipitation.*

3.6 SEDIMENT TRANSPORT

What is it?

Sediment transport is one of the main functions of river systems. It consists of the mobilisation of solid material (alluvium or alluvial material) from the headwaters towards areas at the outlet, at the same time as that same material is eroded and rounded during transport.

Sediment transport also includes the movement of material that comes from the hillsides (colluvium or colluvial material) and that the river must move out from its channel.

What is it important for?

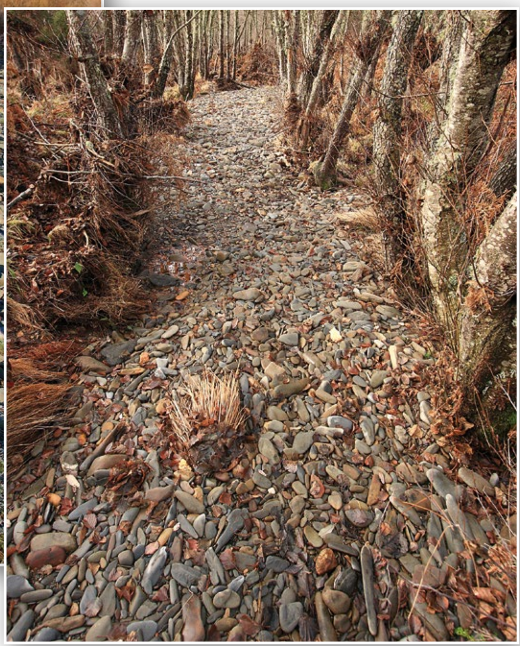
Sediment transport is important because it is a function of river systems that contributes to the shaping, the design of a different relief, typical of that landscape. Erosion and sedimentation processes need correct sediment transport to distribute the material along the river system, generating a series of storage features (terraces, cones, riparian areas, sediment bars, deltas, etc.) that represent valuable habitat.

We should not forget that the final objective of all those materials coming from continental erosion and transported by rivers is to reach the sea, where they are redistributed by coastal dynamics, forming beaches, deltas, providing nutrients to marine sedimentary basins and producing very productive algal blooms, essential for the maintenance of marine fisheries.

What are the main problems?

Sediment transport along the river system will be natural if there are no retention structures in the channel, such as dams or weirs, and if the connection with the margins is natural, without structures that retain lateral inputs. To the negative effect of dams we should add the effects of aggregate mining, dredging or artificial mobilisation of bed materials.

Bernesga river. Cármenes. León.
Accumulation of sediment (gravel, pebbles and cobbles).



Mayas or Malavao stream. Descargamaría. Cáceres.
High flow channel with rounded slates in the headwaters of the Mayas stream, a tributary of the Águeda river.

The presence of lateral elements in the areas adjacent to water courses, such as transport routes, entails an additional retention of sediment inputs from hillsides, so that such input will be reduced or eliminated.

In extreme cases with maximum retention, as it occurs with large dams, the water course will suffer from an important lack of material; the result will be increased transport and reduced sedimentation processes downstream, an effect that will be transmitted all the way to the sea or until the next reservoir, in a progressive manner.

How do we measure sediment transport?

To measure bed load transport we can use sediment traps, which are costly to install. The best way to measure the transport of suspended solids is to take manual or automatic samples, and analyse their concentration in the lab. This task has to be done systematically and for long periods of time, in such a way that we 'catch' the high flows that transport the largest portion the suspended load. Turbidity meters are highly inappropriate for this type of measurements, because algal blooms are interpreted as the river transporting a high sediment load.

During field visits, we can analyse the global status of sediments and determine whether there are any impacts affecting them, such as dredging, aggregate mining, mobilisation, etc. These impacts would entail a clear alteration of the natural condition of sediments and of the processes that are related to them.

A simple observation may involve checking directly in the bars or sediment deposits if the material is loose, or else presents compaction problems, or suffers from excessive colonisation by vegetation which is making it stable.

Interpretation of results

In the case of dredging and aggregate mining, the loss of sediments will be the main impact to assess, analysing its magnitude. In any event, keeping in mind that an activity of this kind causes a severe impact on the river system, there could be more aggressive activities, such as aggregate mining in margins and bars, which usually are more extensive that dredging, which usually is more localised.

A sediment deficit seriously alters the morphology of the bed and can have consequences, particularly downstream, due to an increase in water velocity (dredging increases the slope), leading to increased incision, and maybe causing problems in the margins, where the flow hits with greater velocity. On the other hand, we cannot forget that the sedimentary material of a river is the substrate of life in the river.

3.7 SEDIMENT ARRANGEMENT

What is it?

The sediments generated and transported by rivers are deposited and structured in a stratified manner, thanks to the current: they are sorted by grain size as a function of current velocity at each point, and they are also imbricated, that is, they overlap each other, pointing downstream. An irregular arrangement of sediments could be a consequence of deficiencies in the functioning of the system.

What is it important for?

The correct arrangement of sediments in a river system has a direct influence on the good functioning of the river, generating natural habitats and placing solid material correctly and in order for its transport during high flow events. If the material is laid out in a different way, it may not be mobilised when necessary, leading to a stability which is not appropriate for the river system, and encouraging the armouring of bars.

What are the main problems?

The main problems originate when the bed sediments or the morphology of the bars are modified, often as a consequence of dredging operations or channel alterations, or when the material accumulates on the margins, in the shape of a levee or protection structure. In these cases, there is an alteration of the channel, of the sediments (transport and deposition) and of the banks (margins and riparian zones). The stabilisation of these areas is very negative for the natural hydromorphological dynamics of rivers and their floodplains. The opposite can also occur, that is, the accumulation of material in riparian zones, the discharge and accumulation of material which the river, by itself, is not capable of moving. The final effects are the same ones, a stabilisation process which is not natural, and a loss of river dynamics.

How do we analyse the arrangement pattern of sediments?

The arrangement of sediments can be observed directly in those cases where material extracted from the bed and the riparian zones has accumulated, as well as in cases where a discharge, an exceptional input of material, has occurred.

In addition, a granulometric analysis of the size of materials can be done. To do this, we have to take measurements in the surface portion of the bars (weight and grain size of the material) and then do a subsurface analysis, below the most superficial layer of the bar. To do this, the upper layer or armour of the bar is removed, and samples are taken of the inside portion. The analysis of the lower portion of the bar has to be done in the lab, with sieves that allow se-

Curueño river. Barrio de Nuestra Señora. León.
Protection structure like a levee with pebbles and cobbles from the dredging of the Curueño river, on its right margin.

Classification of river sediments according to grain diameter (D) in mm:

- Clay: D<0.004
- Silt: 0.004-0.062
- Fine sand: 0.062-0.25
- Medium sand: 0.25-0.5
- Coarse sand: 0.5-2
- Gravel: 2-16
- Pebbles: 16-64
- Cobbles: 64-256
- Boulders: D>256

gregating the types of material in the bar once the material has dried up.

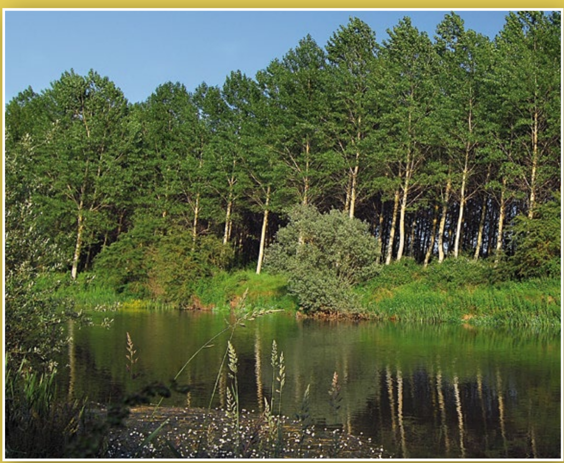
3.8 RIPARIAN VEGETATION

Whats is it?

Vegetation is the collection of plants at a certain site. In this case, it is the vegetation that grows in the river environment, in the banks, in the bars (they may grow in the channel), and in flooded areas. In large riparian areas, riparian vegetation may be far from the river, even kilometres away. This is possible as long as there is a phreatic zone close to the surface. In these cases, these plants are also known as phreatophytes. They would comprise ashes, poplars and elms, among others; these are the vegetation types usually most impacted, because they grow on the best soils from an agricultu-

Alien vegetation

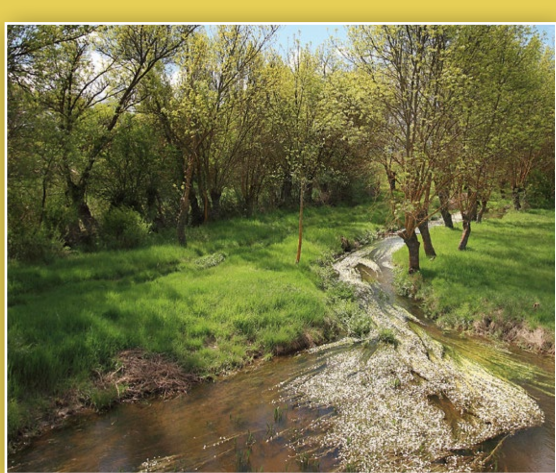
Vegetation which is not native from the place where it grows. During reforestation efforts done in the margins of rivers, sometimes plant species which are not typical of riparian zones are used; usually they are hybrid clones which lead to the impoverishment and displacement of natural vegetation.



Pisuerga river. Olleros de Pisuerga. Palencia.

Native vegetation

In contrast to alien vegetation, this type of species are native from the site where they are found. When it comes to vegetation restoration efforts, it is advisable to use native species, which are adapted to the local environment.



Gemiguel creek. El Fresno. Ávila.

ral point of view. There are many other species adapted to riparian areas, such as a large number of willows, tamarisks, alders, etc.

Among several existing classifications of riparian vegetation, we will use here the following one, from the *Guía de plantas de los ríos y riberas de la cuenca* del Duero [Guide to plant of the rivers and riparian zones of the Duero basin; see bibliographic references]:

- **Trees, woody plants more than 5 m in height**
- **Shrubs, woody plants between 2 to 5 m in height**
- **Climbing plants, vines or lianas**
- **Herbaceous plants, with non woody stems or roots**
- **Helophytes, partially submerged aquatic plants**
- **Hydrophytes, strictly aquatic plants, which may be floating or rooted in the bed**
- **Invasive plants, alien species that have the capacity to expand and compete with natural vegetation.**

What is it important for?

Riparian vegetation has an essential role when it comes to slowing down the river current, especially during high flow events. As well as slowing down the water flow, vegetation contributes to the sedimentation of the suspended load carried by the river, generating a substrate that is very rich in nutrients, and creating habitats of particular interest for the different animal and plant species that are associated to river environments. This function as a green corridor ensures a better interaction between the river and the adjacent environment, and green corridors are very rich areas.

What are the main problems?

The intense occupation of areas adjacent to rivers, as well as the presence of population

Gemiguel creek. El Fresno. Ávila.

Mediterranean ashes with a characteristic pruned shape. The lowland area corresponds to a secondary channel that functions during high flow events.

Curueño river. Nocedo de Curueño. León.
Autumn riparian vegetation in the upper stretch of the river.

centres in the margins of river systems, puts a great pressure on riparian areas.

The continuity, width and structure of riparian vegetation have been modified in a sizeable portion of river systems, in particular the stronger the presence of human activities in the drainage basin and the valley.

In rivers that are heavily regulated, the lack of high flow events encourages the growth of plant species inside the channel, limiting river dynamics and artificially stabilising the channel and the banks. This slows down the water flow even further and reduces the transportation capacity of the river.

Riparian zone

From a regulatory point of view

The same as it happened with 'channel' and 'flood prone areas' there is a legal definition of a riparian zone, as per Article 6 of the Regulation on the Hydraulic Public Domain. Riparian zones are the lateral strips of land adjacent to public channels located above the low water level. That is, the riparian zone is the portion of the channel between the low water and the ordinary high water level. The riparian zone ends where the margin begins.

From a physical point of view

It comprises the land adjacent to the low water channel; together with the channel, they make up the riparian corridor, which in alluvial areas could expand into the whole floodplain, considered as the area between the most recent terraces. Riparian zones are a mosaic of land defined by the type of sediment, the relative height with respect to the channel, and the age or successional stage of vegetation. They may also be defined as ecotones or rich transitional ecosystems at the interface between the aquatic ecosystem of the river current and the terrestrial ecosystem at the most external sector of the valley bottom. The riparian land area, with an irregular relief carved by overbank flows, is directly influenced by the groundwater flow, controlled by the surface current and the high water table, which is responsible for vegetation growth.

How do we analyse riparian vegetation?

The riparian vegetation cover can be analysed using aerial photographs, in particular by comparing several dates. In this manner, you can see how it has evolved, and whether it has been subject to impacts, such as changes in width or land use changes which reduce the extension of the riparian area. The composition (determining the taxa occurring in the riparian zone, the stratification, the vegetation status, mature and dead individuals, etc.) has to be studied doing detailed field work.

Interpretation of results

Vegetation linked to rivers and their channels has and important value in terms of river dynamics, contributing to attenuating and slowing down high flow events; additionally, it fulfils an important role as a natural biological corridor. The presence of colonising vegetation in riparian zones is usually a good symptom, but abundant plant colonisation, very mature forests with no regeneration, or excessive plant presence in the channel may mean a deficit in the dynamic functioning of the river, resulting in difficulties to mobilise sediment.

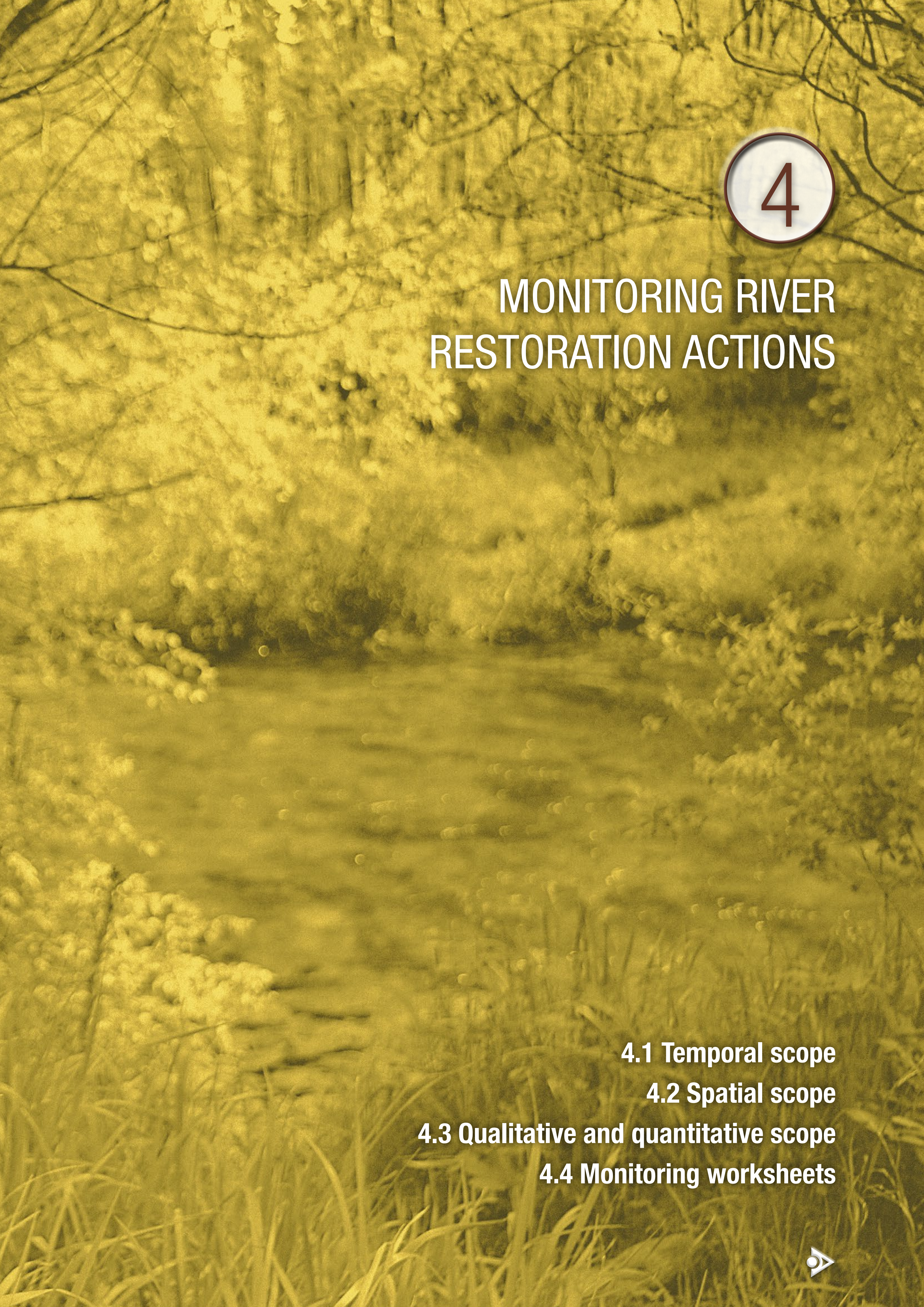
In general, the presence of vegetation in river banks and riparian zones will be assessed as positive, but it will be considered a negative indicator if vegetation has become established in the channel or in the most active sediment bars. Also, the presence of mature vegetation with little renovation will be considered as something negative, a consequence of channel stabilisation due to regulation, channelisation, or both.

The most important thing for rivers, what gives them a high ecosystem value, is having dynamics that are as close as possible to their reference conditions.

In recent years a term has been coined: a 'shifting habitat mosaic', applicable to alluvial stretches of rivers. These habitat arrangements which change seasonally, according to the regime, and throughout the years, with the movement of channels along and across the floodplain and the resulting fluvial forms adjacent to the channel, create perfect conditions to become areas with a high diversity.

Órbigo river. León.

Poplar plantations. This type of crops, and the land stabilisation, filling, levelling and preparation that they imply, have been responsible for the destruction of thousands of hectares of river and adjacent fluvial forms in the Duero basin.



4

MONITORING RIVER RESTORATION ACTIONS

4.1 Temporal scope
4.2 Spatial scope
4.3 Qualitative and quantitative scope
4.4 Monitoring worksheets

When it comes to carrying out river restoration actions, it is advisable to establish a monitoring protocol that comprises the whole process related to the action, including prior and subsequent activities. Appropriate planning is important because monitoring will help analyse and evaluate the extent to which the restoration action has met the objectives of the project, and will provide feedback for future projects.

A river restoration action is a measure, that is, an action adopted under the framework of a Basin Hydrological Plan to improve a 'bad ecological quality' situation previously detected. This type of actions have to be **monitored**, a term that is used in the WFD. According to this, any type of river restoration action should include a complete monitoring protocol, considering at least the following:

1. **Geomorphological monitoring,** which must include an analysis of changes done in the channel, the margins and the riparian zones.

2. **Biological monitoring,** taking into account a series of groups which make up the biota and can work as indicators: macroinvertebrates, diatoms, macrophytes, fish, etc.

3. **Monitoring of physico-chemical parameters** in the project area.

4. **Historical mapping** (first editions of maps, old aerial photography, aerial photos from different years, etc.).

5 **Historical references** (large floods, avulsions, etc.).

Aravalle river. Umbrías. Ávila.
Monitoring the demolition of a dam using a camera configured to take one image per minute.

Esla river. Valdepolo. León.

Rivers move; sometimes it is undetectable, and sometimes the changes are abrupt; these are known as avulsions and usually coincide with extreme high flow events. This bridge was built in the XVIII century and was never used, because a flood of the Esla river caused the avulsion of the main channel.

In addition to the points above, we must take into account another type of monitoring related to the **perception and evaluation of the restoration actions by society,** including residents in the area as well as users. This is a very important point, because, ultimately, river **users** will be the ones in direct contact with the area modified.

4.1 TEMPORAL SCOPE

The control and monitoring of restoration actions must comprise a period of time that starts with the initial phases, before carrying out any type of action (removal of a levee, riprap, elimination of transversal obstacles, etc.) until the later phases, for a length of time that varies depending on the type of action and its effects. Monitoring could involve a shorter or longer period of time, depending on the type of action and the river where it is done.

When transversal elements, such as weirs or dams, are removed from the channel, the conditions before and after the elimination of the obstacle are completely different, and therefore monitoring over time is very important in order to identify and assess the consequences of the action. The existing conditions in the impoundments of weirs or reservoirs have nothing to do with the situation generated after the removal of the transversal obstacle.

When carrying out actions to remove lateral protection structures, there could be changes in flows that modify the habitats in the river, in particular when the channel and/or floodplain area is recovered. River restoration actions aimed to enhance riparian vegetation communities, eliminating alien species and planting native species, also have to be monitored.

Tormes River. Ledesma. Salamanca.

Demolition of the Purísima Concepción weir. The building in the background is a watermill which still has part of the old mechanism. Its maintenance is very much compatible with the demolition project, and thus an element which may have a high heritage value is preserved.

A good approach to monitoring river restoration actions over time should include a planned schedule of visits. The following box describes a proposed monitoring schedule.

Schedule of field visits to monitor a river restoration action

Preliminary visit. Before the action takes place, the initial situation or starting point is analysed, observing geomorphological process and analysing physico-chemical and biological conditions.

Monitoring during project implementation. The works must be supervised, to prevent them from causing a greater impact than necessary, and ensure that the process takes place as planned.

Short term post-restoration monitoring. It is advisable to go back to the site over the weeks following completion of the restoration project to do an assessment of any changes that take place quickly. In cases where transversal obstacles have been removed, those changes take place very quickly during the days, or even hours that follow the removal of weirs or dams, making even more essential this monitoring phase.

Medium term monitoring, approximately 6 months after completing the project. This allows observing changes that lag in response to restoration activities, as the water course adapts to the new circumstances and configures a new morphology.

Long term monitoring, which could range between 1 and 5 years after completion, depending on the project and its effects. This monitoring can be more useful for riparian restoration projects, where we would assess the adaptation of the new plants and their degree of survival. In the case of in-channel projects, geomorphological processes will have modified the river conditions, establishing new flows and searching for a dynamic balance different from the previously existing one. This long term monitoring can also be adapted to the project objectives and tailored to information needs.

Monitoring extreme conditions. To evaluate the suitability or the effects of river restoration actions mentioned up to now, it is necessary to monitor the river system after a extreme high flow event, when hydromorphological processes are faster and it can be very useful to analyse the changes that take place, or after a long drought, in the case of revegetation projects.

4.2 SPATIAL SCOPE

When it comes to analysing river restoration actions, it is important to consider the spatial extent of the effects they generate, both upstream and downstream from them. In the case of elimination of lateral barriers, such as rip-rap, erosion could be more prominent in the margins, causing an increase in sediment downstream; or, on the contrary, there could be an increase in sedimentation in the margin, in cases where we have eliminated a levee, because we give back the river its capacity to attenuate high flows. Taking away transversal barriers involves changes in the bed, modifications in the local gradient which may lead to headward erosion, as well as an increase in sedimentary processes downstream (in the short term), favoured by the presence of sediments in the impounded waters of weirs or reservoirs. Whenever riparian vegetation is eliminated, sediment input may increase due to a loss of the plant cover that was protecting the soil; as well, the capacity to retain sediment during high flow events may decrease.

We should check that geomorphological processes resulting from restoration actions are completely covered by monitoring efforts, taking into account that the spatial extent may vary substantially depending on the type of project.

Therefore, in most cases the extent of monitoring cannot be limited only to the restored stretch; instead, it would be wise to analyse the river system upstream and downstream from it. As time passes after the project has been completed, the spatial scope of monitoring efforts should be expanded, because the effects may spread to adjacent stretches, particularly downstream. This has to be considered when it comes to defining the limits of the monitoring work.

4.3 QUALITATIVE AND QUANTITATIVE SCOPE

There is also another way of approaching monitoring river restoration projects, based on the quality and the quantity of the modified elements in the channel. From this perspective,

Eria river. Torneros de la Valdería. León.

Flood resulting from the explosive cyclogenesis which occurred at the end of February of 2010, affecting mainly the north-west of Spain. Monitoring high flow events and their effects in situ is very important. It allows first hand contact with the river, and nothing else can make up for that. Reference data and photography are very helpful tools to carry out monitoring work.

we may differentiate, simplifying, two types of monitoring:

- **Qualitative monitoring**

- **Quantitative monitoring**

Qualitative monitoring focuses on visual aspects that can be assessed during field visits. It is faster, but not as precise, and has been conceived for instances when there are limitations (time, accessibility, budget) and for people without specific training on restoration issues, although it is necessary to have a basic knowledge of river functioning and be a good observer. The objective of this type of monitoring is analysing on the ground the effects brought about by the removal of infrastructure in the channel, such as weirs or protection works. It can also involve observing any impacts during project implementation, such as impacts on the margins or on riparian vegetation, or before the removal takes place.

On the other hand, quantitative monitoring involves an assessment through specific measurements in the study area, starting before the project takes place, so that, applying indexes and indicators that may be analysed again after the river restoration project is completed, we may quantify the extent of the impact, and, if applicable, of the enhancement of the system, that the project has contributed to. In this manner, the comparison between the different time periods can be used to do a more precise and quantitative analysis of the hydromorphological changes produced.

4.4 MONITORING WORKSHEETS

In this publication we present three types of worksheets: one for each type of river restoration action. In each of them there are some basic data which are the same for the three worksheets. The second part of each of them comprises 8 closed-ended questions, but including a section to describe field observations in detail. It is also advisable to provide graphical documents to complement the information, which may also solve any potential doubts that may come up at a later date when the actions are evaluated. The worksheets include the following information:

Worksheet: removal of transversal obstacles in the channel (weirs, wading areas, dams)

The questions involved in the analysis are as follows:

Are there any remains of the structure in the channel or in the banks?

Yes / No
It is important to look at the project area and look for remains of the infrastructure, such as concrete blocks, stones or iron rods and slabs, found inside the channel or in the banks. These materials are considered as construction and demolition waste and should be treated as such. This is not the case with the sediments accumulated upstream form the weir, which should be left as is, so the river can mobilise and deposit them. Only when sediments are polluted is their removal justified.

Why is it important not to have any remains?
Given the nature of the action, which entails the elimination of transversal elements so that the river system can recover its natural condition, the presence of material that is not natural is an impact. If the obstacle is removed, any remains of it should be eliminated to achieve a better restoration outcome.

Basic data

Water course: Name of the river or creek.
Basin: Drainage basin where the water course is located. If it is a creek or a smaller tributary, it is advisable to locate it in a sub-basin defined by a tributary of a certain magnitude in the drainage basin where we are.
Coordinates: Geographic location.
Municipality/town: Information about the name of the site may also be included.
Date of field visit
Date of action: It is important to know the date the project was implemented to establish the timing when completing the worksheet.
Name of the action: Project title or brief description.
Data entry done by: It could be an individual or an association.
Flow: High; normal; low; no flow (at the moment of the observation). If a direct flow measurement is done, record the data. If it is known through a hydrometric network, record it as well.
Use of the area: Leisure/recreational; Urban; Agricultural; No defined use.
Length and height of the obstacle
Construction materials
Degree of siltation
Nature of the sediments

How do we quantify the presence of remains of the structure?

We can count the number of elements present, as well as their size. If we can get close to them, we may take measurements. During subsequent field visits, we could see whether the elements have been removed, or even if the river itself has mobilised them downstream.

Valdavia river. Polvorosa de Valdavia. Palencia.

Remains of a weir which has been partially destroyed due to a lack of maintenance. As a consequence of the partial breakage, the longitudinal continuity of the channel is partially recovered; however, the portion of the weir still in place (black arrow) acts as a current deflector, increasing the rate of erosion in the opposite margin (red arrow). It has to be removed due to hydraulic reasons. The blue arrow indicates the direction of the current.

Valdavia river. Polvorosa de Valdavia. Palencia.
Demolition of the weir. The eroded left margin can be clearly seen in the background.

Do we observe any lateral erosion process or undermining of the banks?

Yes, in one margin / Yes, in both margins / No

Lateral erosion processes occur normally in dynamic water courses. However, if these processes occur at a faster rate than they used to, or they are excessive, they could be a consequence of modified river dynamics. After the removal of transversal elements which functioned as a water reservoir, usually, as the pressure of the impounded water on the banks is lost, and as the materials deposited in the impounded waters due to the retention of the sediment load are carried off by the current, lateral erosion processes increase. Furthermore, there could be erosion processes at the base of the banks, causing undermining.

How can we quantify these processes?

Taking photographs or drawing diagrams of the areas that are most dynamic can help compare the processes. If you can visit the area again at a later date, you can set some fixed markers (nails, stakes, etc.) and take measurements from them to the bank slope, to compare lateral erosion.

Do we observe incision in the channel?

Yes / No

Incision is another process that takes place naturally in water courses. It is important to analyse incision to see is this process has increased excessively.

How can we quantify these processes?

The assessment of channel elements upstream and downstream from the eliminated obstacle may allow seeing whether there are any incision processes under way. Areas downstream from bridge piers or from sectors with protection structures are susceptible to have points with more erosion due to incision processes. If you can visit the area again at a later date, you can do cross-sections from the same area (you should mark appropriately the points at the banks, to do a profile which is as similar as possible at subsequent visits, and be able to compare the data) and analyse the changes that have occurred between field visits, to see if they are related to the removal of the transversal obstacle.

Do we observe changes in the structure of the sedimentation or the sediments, which are not consistent with those located upstream and downstream from the project site?

Yes / No

Sedimentation is a natural process done by the water current in water courses, the same as the transport of materials. Alterations to the sedimentation structure could mean an increase or a deficit of sedimentary material due to non-natural causes. If there are sediments which are not consistent with the the natural water course, they could be due to inputs from quarries, rubble dumps, construction works, etc.

Why is it important to have a good structure?

When it comes to mobilising sedimentary material through fluvial transport processes, it is important for that material to have a good structure. If sediments are not arranged correctly, this may cause either their stabilisation (when larger size sediments hinder transport because the water course does not have enough energy to move them) or severe incision processes (when the material is very fine and is readily mobilised; the channel can then be eroded down to the bedrock).

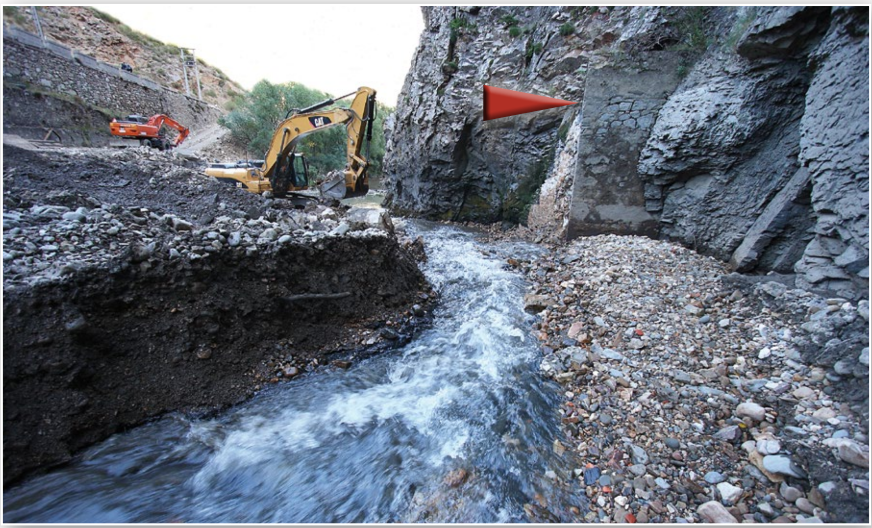
How do we analyse the structure of sediments?

A visual analysis would allow us to see whether there are any materials that do not come from the river system (they could have a different colour, there could be 'strange' accumulations, such as large boulders in areas where there should not be any, etc.). On the other hand, we can carry out a more technical assessment of the bars and deposits in the channel, analysing the texture and composition of the upper layer (superficial analysis), and also the inside through an in-depth analysis (subsurface analysis). To do this last analysis, we have to obtain samples from a certain depth, so if we have equipment available, for example a backhoe, it can be very handy to obtain a sample that is representative enough.

Do we see, downstream from the weir/obstacle that has been removed, a large amount of sedimentary material coming, for the most part, from the old water impoundment?

Yes / No

When we eliminate a barrier of these characteristics, it is quite normal for the ma-



Bernesga river.
La Pola de Gordón. León.

Incision in the sediments after the demolition of the La Gotera weir, in the Bernesga river. The arrows points to the remaining right abutment of the weir. Sediments are mobilised in the early phases of the demolition, even if flows are low, because the materials are not very consolidated.

Bernesga river. Villasimpliz. La Pola de Gordón. León.

A minor high flow event in the Bernesga river, a month after the demolition of the La Gotera weir in the Bernesga river (La Pola de Gordón-León), resulted in peak flows slightly above 22 m^3/s (see the hydrograph in the following page); this led to the mobilisation of some 20,000 m^3 of sediment which were deposited downstream based on the grain size. The photo was taken after such event, and we can appreciate the stream power of the mobilised sediments. This type of materials are unstable, and this explains why water flows well below the geomorphic flows (in this case the ordinary high water flow at the site would be over 60 m^3/s) result in considerable mobilisation of sediments, helping restore the original morphology of the river.

terial deposited over years in the impoundment to be mobilised downstream.

Why is it important to analyse this indicator?

We have to take into account the time elapsed between the removal of the weir and the field visits. If we visit the site shortly after the removal, it is normal to find material from the impoundment in the downstream areas, forming deposits of a certain magnitude. If the river system functions correctly, these deposits will decrease in size as the river mobilises the sediments. If the river system does not work appropriately, those deposits will not be mobilised, leading to a stability which is not natural. One way of monitoring the transport of material is to mark it *in situ* at the project site; this will help us recognise it when it is transported and deposited downstream. This requires painting a large number of stones, so that we may recognise some of them when we find them downstream, and it is used with rocks of a certain size, from gravel to larger grain sizes.

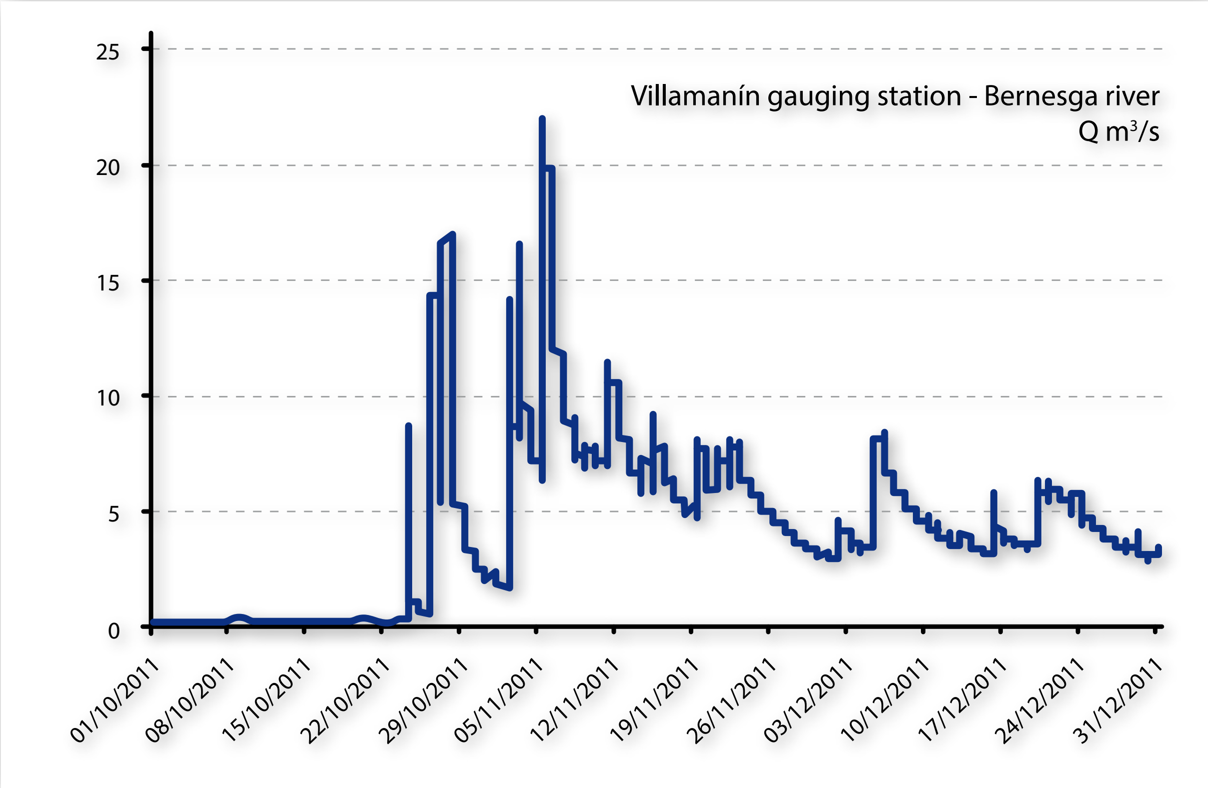
How do we quantify sedimentary material?

Ideally we would analyse the site prior to removing the obstacle, collecting plenty of graphical information on existing deposits (if any). Afterwards, once the action has been completed, it is advisable to do several field visits to collect graphical material again, so that we can compare them to previously compiled information and study the movement of deposits during desk work. If it is possible to have aerial photographs from different dates, the surfaces involved can be calculated, and knowing the average stream power, we can calculate the total volume of sediment.

Is there excess vegetation in the channel?

Yes / No

Most fluvial systems have vegetation in the channel. The presence of excess vegetation in the channel could be due to stable flow conditions (absence of high flow events) or



the occupation of the channel by crops, for example poplar stands, leading to a stationary channel and margins, which are not natural.

Why is it important to analyse this indicator?
As we have already mentioned, the presence of abundant vegetation in the channel modifies the natural behaviour of the river. It can lead to a stability which is not characteristic of the system under natural conditions, encouraging the development of vegetation communities which, additionally, will slow down water flow. As part of the vegetation to be analysed, we should consider algae and macrophytes.

How do we quantify the vegetation in the channel?
Graphical material is very important when it comes to analysing the development of vegetation. Usually transversal barriers which impound water lead to more dense vegetation in the banks; this is favoured by the stability of the water pool formed and the absence of sharp fluctuations in water level. It is also frequent to see species growing inside the water impoundment created by the weir or similar infrastructure. We can try to measure the surface coverage, expressed as a percentage point, and the existing stratification. Identifying species is very useful during this phase.

Have access ways to the area been upgraded after removing the heavy machinery used in the river restoration project?

Yes, completely / Yes, partially / No
When river enhancement and restoration actions are carried out, it is important that the site not be altered afterwards due to the access of heavy machinery. It is very difficult to go back to the initial conditions, because the equipment usually needs appropriate access ways, but we should try to reduce to a minimum any impacts as far as this aspect is concerned.

Why is it important to analyse this indicator?
Given that the project intends to return the river system to more natural conditions, it is counterproductive to attain a positive impact on one area (channel and riparian zone) while causing a negative impact on other areas (margins, floodplain, etc.).

How can we analyse this parameter?
The basic analysis involves observing the access ways built to access the project site and check whether they have been restored afterwards. For example, if paths or trails have been built with materials from the works, it is advisable to remove them after the project has been completed. Any leftover waste or abandoned material are also examples of elements that should be removed to upgrade the area.

Worksheet: removal of levees / lateral protection structures

The questions involved in the analysis are as follows:

Has the levee / lateral protection structure been completely eliminated?

Yes, it has been completely eliminated / No, but it has been partially eliminated / No, but it has been replaced by 'soft' measures
If at all possible, the total elimination of lateral protection structures is the best option in terms of returning the river system to natural conditions. In some cases, the elimination is not total, but partial. Yet other times, protection structures known as 'hard' (concrete, cement, boulders, large stones, etc.) are replaced by 'soft' protection measures (bioengineering).

Why is it important to analyse this parameter?
Lateral protection structures limit the mobility of water courses, thus in certain areas the river cannot move laterally. This stabilisation is not suitable for good river functioning, thus the removal of levees and lateral protection elements entails, in principle, a quality improvement.

Basic data
Water course: Name of the river or creek.
Basin: Drainage basin where the water course is located. If it is a creek or a smaller tributary, it is advisable to locate it in a sub-basin defined by a tributary of a certain magnitude in the drainage basin where we are.
Coordinates: Geographic location.
Municipality/town: Information about the name of the site may also be included.
Date of field visit.
Date of action: It is important to know the date the project was implemented to establish the timing when completing the worksheet.
Name of the action: Project title or brief description.
Data entry done by: It could be an individual or an association.
Flow: High; normal; low; no flow (at the moment of the observation). If a direct flow measurement is done, record the data. If it is known through a hydrometric network, record it as well.
Use of the area: Leisure/recreational; Urban; Agricultural; No defined use.
Length of the protection structures
Distance to the channel
Height over the floodplain of protection structures
Materials they are made of

Recovery of the lateral connectivity of a river

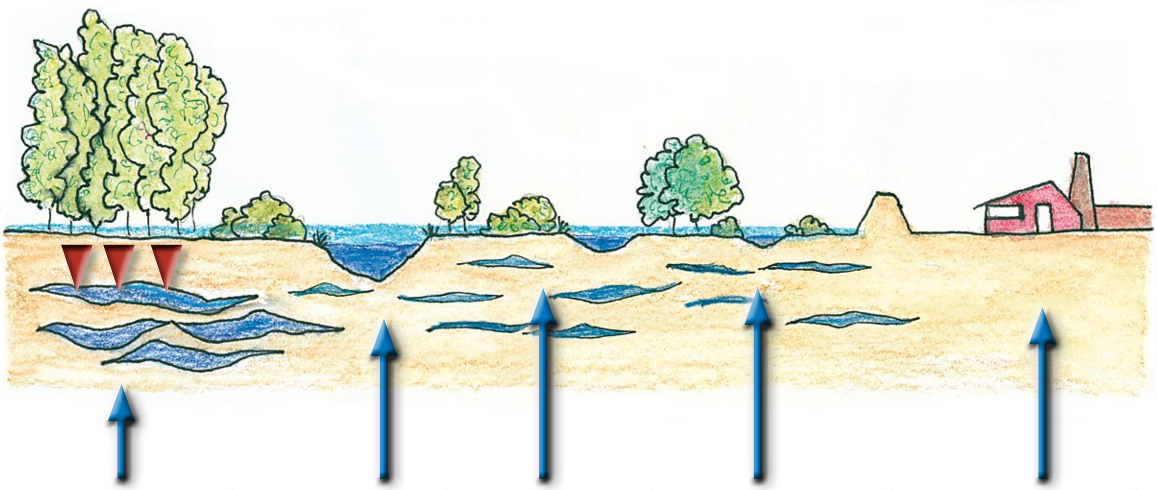
Artificially raised land to protect from floods (levee). The material usually comes from dredging the water course.

During high flow events, the discharge is confined, increasing its velocity, as well as its capacity to carry sediment and erode. The specific stream power increases and that leads to incision.

The floodplain does not function as such, and when it does so, the levees themselves prevent natural drainage from occurring, waterlogging adjacent land. Sometimes flooding takes place due to water infiltration from the channel to the adjacent land.

ELIMINATION

SET BACK FROM THE CHANNEL



Water floods the areas close to the riparian zone, favouring aquifer recharge and depositing silt which fertilises the land.

During high flow events, the discharge is distributed over the floodplain, and thus its velocity, depth and erosive capacity decreases.

Vegetation increases due to the input of nutrients and the higher water table.

The network of secondary channels and associated fluvial ecosystems is recovered, including alluvial wetlands.

We maintain an acceptable level of protection of people and assets, which, in many cases, are illegally located on the Hydraulic Public Domain or on floodplains, with a high exposure to flood risks.

On the other hand, if these elements are raised over the land level such as in the case of levees, the system loses some capacity to attenuate high flows, with a subsequent increase in flows and velocity, which may relocate the flooding problem downstream. Recovering flood prone areas is a basic river management operation which results in increased safety and natural conditions.

How do we quantify the removal of lateral protection structures?
The simplest thing to do is to take measurements of the length of the elements removed, as well as their basic characteristics, such as height, type of structure, etc. Any graphical material obtained in the field will help illustrate the data.

Are there any remains of the structure in the channel?

Yes / No
It is important to look at the project area and look for remains of the infrastructure, such as concrete blocks or iron rods and slabs, found inside the channel.

Why is it important not to have any remains?
Given the nature of the action, which entails the elimination of lateral elements so that the river system can recover its natural condition, the presence of material that is not natural is an impact. If the obstacle is removed, any remains of it left in the channel should be eliminated to achieve a better restoration outcome.
If the materials come from the channel bed itself, which is quite frequent, because often the river is dredged and the resulting material is piled up to form a levee, then the best solution is to return them back to the river, especially if incision issues have been detected. This type of projects can be socially controversial, thus they require a large degree of public involvement.

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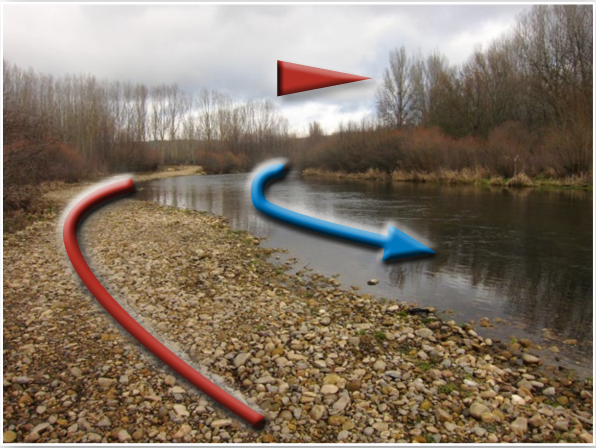
How do we quantify the presence of remains of the structure?
We can count the number of elements present, as well as their size. If we can get close to them, we may take measurements. During subsequent field visits, we could see whether the elements have been removed, or even if the river itself has mobilised them downstream.



Órbigo river. Quintanilla de Sollamas. León.

These photographs have been taken approximately at the same location (use as a reference the poplar that the red arrow points to). The image on the left was taken a few months after the removal of a levee (red line), as part of a restoration project in the Órbigo river. The image on the right was taken one and a half year later. The river's low water channel is moving to the left of the photo (right margin) and has occupied the space where the levee was. In the opposite margin, in the inside of the bend, a point bar is being deposited (green arrow), following a universal hydraulic pattern.

Órbigo river. Cimanes del Tejar. León.

The use of vegetation as an element to stabilise the riparian zone can be an alternative to the use of rip-rap, gabions or concrete structures. The photo shows the left margin of the Órbigo river as it flows through the periphery of an urban area: closely packed live stakes have been planted, including several willow species from the area, collected in situ.

Are there any remains of the structure in the banks?

Yes, in one margin / Yes, in both margins / No

It is important to look at the project area and look for remains of the infrastructure, such as concrete blocks or iron rods and slabs, found in the banks of the water course.

Why is it important not to have any remains?

Given the nature of the action, which entails the elimination of lateral elements so that the river system can recover its natural condition, the presence of material that is not natural is an impact. If the obstacle is removed, any remains of it should be removed from the banks, because they modify the channel profile and act as lateral barriers.

How do we quantify the presence of remains of the structure?

The same as with elements in the channel, we can count the number of elements present, as well as their size. If we can get close to them, we may take measurements.

Do we observe any lateral erosion process or undermining of the banks?

Yes, in one margin / Yes, in both margins / No

Lateral erosion processes occur normally in dynamic water courses. However, if these processes occur at a faster rate than they used to, or they are excessive, they could be a consequence of modified river dynamics. After the removal of lateral elements which were protecting the margin, usually lateral erosion processes increase. Furthermore, the channel could erode the base of the banks, causing undermining.

How can we quantify these processes?

Taking photographs or drawing diagrams of the areas that are most dynamic can help compare the processes. If you can visit the area again at a later date, you can set some fixed markers (nails, stakes, etc.) and take measurements from them to the bank slope, to compare lateral erosion.

Do we observe incision in the channel?

Yes / No

Incision is another process that takes place naturally in water courses. It is important to analyse incision and see if this process has increased excessively, in particular after the removal of the lateral element. As mentioned earlier, it can be advisable to return to the river any materials that had been previously dredged and piled up to form levees.

How can we quantify this process?

The assessment of channel elements upstream and downstream from the eliminated obstacle may allow seeing whether there are any incision processes under way. Areas downstream from bridge piers or from sectors with protection structures are susceptible to have points with more erosion due to incision processes. If you can visit the area again at a later date, you can do cross-sections from the same area (you should mark appropriately the points at the banks, to do a profile which is as similar as possible at subsequent visits, and be able to compare the data) and analyse the changes that have occurred between field visits, to see if they are related to the removal of the transversal obstacle.

Do we observe any damage in the channel?

Yes, severe / Yes, slight / No

The use of heavy machinery to remove lateral protection structures can affect the river channel. These effects can be more or less severe depending on the intensity of the impact.

Why is it important to analyse the impact on the channel?

The use of heavy machinery, as mentioned above, can affect the channel modifying it permanently, such as when there is excavation in the bed, close to the lateral protection structure. However, sometimes the effects are minor and the river will return by itself to a natural condition.

How can we analyse this process?

It is advisable to visit the site before the project takes place and do a visual analysis of the

Órbigo river. Santa Coloma de las Monjas. Zamora.

High flow event in the Órbigo river, as it approaches its outlet into the Esla. A protection levee is right next to the population centre. This type of protection is more effective the closer it is to whatever it intends to protect. This way, the floodplain is undisturbed and so is its capacity to attenuate high flows. On the other hand, the construction works are cheaper, because the height and size of the levee is much smaller than when it is built right next to the bank.

Órbigo river. Carrizo de la Ribera. León.

In this aerial photo taken from a drone, we can see on the right of the image that the protection levee set back right next to the population centre allows the flood to occur and be attenuated during the high flow event, without interfering with river dynamics.

area, taking plenty of photographs. It would also be suitable to visit the entire stretch of river while the project is under way, to observe the procedures and check whether the work is done from the banks, or also from the channel. Finally, we can visit the project area on different dates after completion to see how it evolves, putting a special effort on the visual analysis of the affected area, to compare it with the graphical information obtained before the project was carried out.

Has the restored slope been colonised by vegetation?

Yes, by native vegetation species / Yes, by alien vegetation species / No

After lateral protection structures are eliminated, the process of colonisation by vegetation starts with species from the adjacent area. It is important to study whether there is an active colonisation process under way or whether, on the contrary, there is no colonisation, or the colonisation taking place is not appropriate.

Why is the process of colonisation by vegetation important?

In ecology, this process is known as secondary succession. Once it starts, this means that the fluvial dynamics are recovering. The development of vegetation over time configures a mosaic that shifts and moves with high flow events (shifting habitat mosaic), and provides two characteristics linked to great biodiversity: change (dynamic nature) and edge effect (mosaic pattern). In fact, riparian vegetation or vegetation associated to river dynamics could amount for up to 70% of the vegetation species occurring in a certain landscape. The more diverse the riparian vegetation, the more diverse will be the fauna linked to riparian habitats. On the other hand, the presence of vegetation in the margins slows down the water during high flow events, attenuating flows and depositing sediment.

How can we analyse colonisation by vegetation?

We have to go to the field after the removal of the protection structure, allowing a certain time interval so that vegetation can begin colonising the area. During subsequent visits to the field, we should analyse the composition and structure of vegetation to check that the species growing are appropriate ones and that no invasive species show up; the latter generally grow faster but displace the native species. The analysis can be enhanced by taking images that will help study the data during desk work. If there are any doubts concerning the species, you can always ask an expert or determine the species using guides and identification keys.

Have access ways to the area been upgraded after removing the heavy machinery used in the river restoration project?

Yes, completely / Yes, partially / No

When river enhancement and restoration actions are carried out, it is important that the site not be altered afterwards due to the access of heavy machinery. It is very difficult to go back to the initial conditions, because the equipment usually needs appropriate access ways, but we should try to reduce to a minimum any impacts as far as this aspect is concerned.

Why is it important to analyse this parameter?

Given that the project intends to return the river system to more natural conditions, it is counterproductive to attain a positive impact on one area (channel and margins) while causing a negative impact on other areas (riparian zone, riparian forests, etc.).

How can we analyse this parameter?

The basic analysis involves observing the access ways built to access the project site and check whether they have been restored afterwards. For example, if paths or trails have been built with materials from the works, it is advisable to remove them after the project has been completed. Any leftover waste or abandoned material are also examples of elements that should be removed to upgrade the area.

Worksheet: riparian vegetation restoration projects

The questions involved in the analysis are as follows:

Is the riparian vegetation restoration project absolutely necessary?

Yes / No

The question may be surprising, but it is very relevant. The brief history of river restoration shows us that, in many cases, river restoration is mistaken with 'river landscaping'. In fact, many people who are unfamiliar with this field of work think that river restoration involves planting riparian trees. Furthermore, many technicians and 'experts' tackle this type of projects with little training and lots of preconceived notions; among them stands out the belief that the best river restoration action is planting trees to 'recover the riparian forest'.

We have to qualify this, since it is more correct to talk about riparian vegetation, than to talk about riparian forest. In many riparian areas, because of strong fluvial dynamics, vegetation cannot grow to become a 'forest', comprising instead smaller size plants, that is, herbaceous and shrub successional stages, or else a thin forest develops, but does not reach maturity because of the high frequency of high flow events.

Puzzlingly, many riparian forests have developed in stretches of river that are heavily modified. Quite frequently, downstream from large reservoirs, when these have enough capacity to attenuate peak flows, the stabilisation of the channel encourages the development of tree-like riparian vegetation which would not grow under normal conditions, and which may even occupy

Basic data

Water course: Name of the river or creek.
Basin: Drainage basin where the water course is located. If it is a creek or a smaller tributary, it is advisable to locate it in a sub-basin defined by a tributary of a certain magnitude in the drainage basin where we are.
Coordinates: Geographic location.
Municipality/town: Information about the name of the site may also be included.
Date of field visit
Date of action: It is important to know the date the project was implemented to establish the timing when completing the worksheet.
Name of the action: Project title or brief description.
Data entry done by: It could be an individual or an association.
Flow: High; normal; low; no flow (at the moment of the observation). If a direct flow measurement is done, record the data. If it is known through a hydrometric network, record it as well.
Use of the area: Leisure/recreational; Urban; Agricultural; No defined use.
Type of riparian vegetation: taxa, richness and abundance
Riparian plant community structure: stratification
Riparian vegetation cover

Moros river. Valdeprados. Segovia.

In canyons of rivers which are not regulated or are only slightly regulated, such as the Guijasalvas canyon, riparian vegetation does not reach a large size nor much coverage, because water velocity during high flow events prevents it.

a sizeable portion of the channel. On the other hand, when the river is used to convey water for irrigation purposes in the summer, flows are higher than usual and riparian vegetation can take advantage of the availability of water in the phreatic zone during the growing season. Something similar occurs in stretches with many weirs and stable water pools in summer. Nevertheless, although they are a product of the drastic modification of a lotic ecosystem, many of those riparian forests have been included in the Natura 2000 Network under the designation of riparian Sites of Community Interest. When true river restoration projects are proposed that involve going back to a flow regime as similar as possible to the natural one, or recovering space for the river to move laterally, those responsible for their environmental impact assessment and the Natura 2000 Network raise objections in the name of 'protecting the riparian forest'.

Has the morphology of the area been altered?

Yes / No

The riparian zone and the margins are very dynamic landscapes, subject to different pressures. Recovering the riparian zone and the margins, through the removal of transversal obstacles, land use changes or freeing up channel forming flows, is the best restoration option. Once the area has been recovered, secondary succession processes will take place naturally with the involvement of riparian vegetation, as we saw earlier in section 7 of the previous worksheet. Sometimes temporary fencing may be necessary to avoid excess grazing or trampling by livestock.

Duero river. Pereruela. Zamora.

Incised or entrenched meander at the start of the Arribes area, between the municipalities of Almaraz de Duero and Pereruela. Vegetation has colonised a point bar on the left margin of the Duero river. The look of the area indicates that it is frequently swept by high flows; in fact, it is the high flow channel, with predominance of barren soil with gravel and sand, and sparse vegetation, among them some tamarisk shrubs (Tamarix sp.). In the foreground, on the terrace, there are some broom bushes (Retama sp.), non riparian climax vegetation.

Why is it important to analyse modifications in morphology?

Because the recovery of riparian zones should not alter the morphology of the banks, given that the restoration of one element should not be done to the detriment of other elements in the river system. Riparian vegetation planting projects are never acceptable if they alter channel morphology.

How can we quantify this parameter?

The best approach is to visit the site before the project is implemented, to see the general condition of the area, and take photographs. It can also be visited when vegetation is being removed, to see the impact of machinery on the area. If there is an impact, you can take measurements of the length of the affected area and the degree of deterioration.

Have native species been used in the restoration project?

Yes / No

It is important to restore riparian areas with natural, native species, avoiding the use of ornamental species or any other species that do not grow naturally in the area. Avoiding commercial plant nurseries is a good idea, unless they ensure through adequate traceability that the plants they offer are suitable for the area (that is, identical taxa as those occurring in the project site and coming from locations which are ecologically similar). The cheapest and most practical option is to use live stakes, although not all species can be propagated using this method. Willows and plants from the rose family grow well from live stakes, whereas white poplars, ashes and alders do not. It could be a good idea to set up a small nursery in the project area, to grow plants from seeds and then transplant them.

Why is it important to use native species?

It is important because they are better adapted to the conditions in the project site. On the other hand, certain alien species or genetically modified clones used in riparian plantations may compete with native plants and displace them, and thus riparian vegetation loses its species richness.

How can we quantify this parameter?

This can been done through good quality control of the plants or seeds used. If the live stakes are obtained *in situ*, we have to be very careful when dealing with willow, because the genus has many species and subspecies that hybridise, and we could be propagating taxa that we are not interested in. Identification keys can be helpful with these issues, and consulting with an expert is always a good idea.

Cea river. Cea. León.

Riparian vegetation is commonly pruned and cleared, although as a practice it makes little sense economically, because it decreases roughness for a very short period of time. This type of vegetation has a very high capacity to regenerate itself, and does not take long to grow back to the original state. This practice should be considered a lesser evil, since it has gradually replaced clearcutting, done in the past using heavy machinery; it used to entail destroying the morphology of the riparian zone and the elimination of all shrubs and trees.

Has any work been done to connect the banks with the channel?

Yes / No, because they are already connected / No

Connecting the riparian areas with the channel is essential to maintain the exchange of sediments, nutrients and seeds between these two spaces. Any works or modification in these spaces may limit the connection, leading to a decline of the quality of the river system.

Why is the connection of the banks with the channel important?

As said above, a good connection encourages an appropriate input of sediments, seeds and nutrients from the channel to the margins during high flow events, and the other way around, from the margins to the channel as part of natural erosion processes taking place in the landscape. Furthermore, a good connection is also important to facilitate the movement of fauna.

How do we analyse any actions to connect the banks with the channel?

If any action does exist, we should analyse the type of project, what does it involve, its purpose, and its main function.

Are there any dry or dead plants indicating a poor connection with the water table?

Yes, many / Yes, some / No, none

If the areas where vegetation is planted are not suitable, or the planting year is

Dry channel of the Arevalillo stream and microbial mat. Arévalo. Ávila.

Algae should be highlighted among other types of vegetation in rivers, although they are not really plants, and comprise a group that phylogenetically is quite heterogeneous. They are tremendously important because a sizeable portion of the primary production of the river ecosystem depends on them; on the other hand, they have value as a bioindicator of the physico-chemical quality of the water. In the image we can see an algae layer, which resembles certain types of geotextiles. They are interwoven filamentous algae remains which are left over after wetlands or streams dry up. In many cases, these filamentous layers may indicate a eutrophication problem.

Sequillo stream. San Pedro de Latarce. Valladolid.

If channelised rivers cannot be restored removing the channelisation structures, it is advisable to carry out revegetation projects. Supposedly, when vegetation develops and provides shade, a canopy, there would be a decrease in the coverage of macrophytes in the channel, cattails in this case (Typha sp.), although the truth is that this is the theory and in practice it takes a lot of work to obtain results. The image shows planted white poplars and willows.

exceptionally dry, plant mortality can be quite high. Obviously, depending on the vegetation used in the restoration project, access to the water table will be easier or more difficult. Live stakes have to be planted in the riparian zone itself, close to the low water level, whereas if using the plant itself and equipment is available, deep-planting can be used to facilitate plant access to the water table. Irrigation may be used, although it increases the costs. In any event, it is not a bad idea to schedule planting work in the medium/long term, as consecutive campaigns which can replace any plants lost in the previous years.

Why is it important to analyse the connection with the water table?

If the banks are left appreciably raised over the channel level, the water table would hardly reach a high enough level to be available for the roots of riparian vegetation, so that water input will be poor. This will lead to individual plants dying out and to colonisation by species adapted to water scarcity.

How do we analyse the connection with the water table?

We have to check in the field whether there has been severe incision in the bed, resulting in sharp inclines or terraces that are left hanging high above (several meters); this usually leads to a decrease in the water table in riparian zones. Furthermore, we can analyse the internal structure of riparian forests to see if there are any dry and dead individual plants, counting how many there are, so that, at subsequent visits, we can check if the number has increased.

Can we observe an improvement in the riparian structure, with new layers (herbaceous plants, low and high shrubs, climbing plants, trees)?

Yes, in the entire area / Yes, in some areas / No

Riparian vegetation comprises more than just tree species. The richness of riparian zones lies in the presence of a mosaic that shifts over time, with a different stratification in each case, which will be reduced to a minimum in areas swept by high flows and will be maximum in more consolidated areas.

Why is the presence of different layers important?

The richness of the riparian ecosystem lies in the different layers, because they provide diversity in terms of community structure. Furthermore, the existence of herbaceous or shrub layers will have an important function attenuating high waters and reducing the impacts of high flow events. Another very important function of these lower layers is to provide shelter and generate new habitats for the fauna living in riparian areas.

Tormes river. La Angostura. Ávila.

An example of good quality riparian vegetation in a stretch of river not regulated and very dynamic. The combination of barren bars and vegetation layers of different sizes, without a dominant vegetation type or excess maturity, is a symptom of the ecological quality of riparian river ecosystems.

How can we analyse this parameter?
We should visit the site after the restoration action, allowing enough time for vegetation to develop, analysing the presence of different layers in the riparian zone subject to restoration work. In order to assess the extent of plant development, the site should be compared to a naturalised riparian forest, because it could be the case that the natural conditions of the restored area do not allow the growth of a dense understory.

Is there a wide variety of species?

Yes / No
Natural riparian zones are characterised by the presence of a wide variety of species, which provide a special richness to these areas.

Why is the presence of a variety of species important?
When carrying out projects to restore riparian vegetation, it is important to preserve the richness of plant communities; thus, it is advisable to include, if new individuals are planted, plants from several native species.

How do we analyse the variety of species?
We can do vegetation inventories in the newly restored areas and compare them with inventories from forests without any intervention. This way, we can compare the results and check whether diversity is high or not.

Has restoration been done following a geometric (linear) pattern, or a random pattern?

Geometric (grid) pattern / Random pattern / Both
Riparian restoration should follow a random pattern, placing the species in a random, irregular fashion. Linear or simple geometric patterns should be avoided.

Why is the planting pattern important?
It is important to do the planting in a random fashion, because it implies more natural conditions. Following a certain alignment is unavoidable, given that the projects are linear, but it should be reduced to a minimum.

Have access ways to the area been upgraded after removing the heavy machinery used in the river restoration project?

Yes, completely / Yes, partially / No
When river enhancement and restoration actions are carried out, it is important that the site not be altered afterwards due to the access of heavy machinery. It is very difficult to go back to the initial conditions, because the equipment usually needs appropriate access ways given their large size, but we should try to reduce to a minimum any impacts as far as this aspect is concerned.

Why is it important to analyse this parameter?
Given that the project intends to return the river system to more natural conditions, it is counterproductive to attain a positive impact on one area (channel and riparian zone) while causing a negative impact on other areas (margins, floodplain, etc.).

How can we analyse this parameter?
The basic analysis involves observing the access ways built to access the project site and check whether they have been restored afterwards. For example, if paths or trails have been built with materials from the works, it is advisable to remove them after the project has been completed. Any leftover waste or abandoned material are also examples of elements that should be removed to upgrade the area.

Valderaduey river. Becilla de Valderaduey. Valladolid.

Channelised rivers quite frequently have vegetation which has nothing to do with the vegetation that was present in the river under original conditions. The simplification of channel form, meaning a straight channel planform, cross-section and profile, leads to a uniform environment, occupied by a single type of vegetation, in this case pond vegetation, with reeds as the dominant species (Phragmites australis) In some cases, invasive species colonise the area; this is happening with the giant reed (Arundo donax) and the water hyacinth (Eichhornia crassipes) in basins in the centre and south of Spain.

WORKSHEET: REMOVAL OF TRANSVERSAL ELEMENTS IN THE CHANNEL (WEIRS, WADING AREAS, DAMS)

Water course:		**Basin/sub-basin**	
Coordinates		**Municipality/town/toponym**	
Date of field visit		**Date of action**	
Name of the action			
Flow		**Use of the area**	
Data entry done by			

Are there any remains of the structure in the channel?		YES	NO
Observations:			
Are there any remains of the structure in the banks?	YES, IN ONE MARGIN	YES, IN BOTH MARGINS	NO
Observations:			
Do we observe any lateral erosion processes or undermining of the banks?	YES, IN ONE MARGIN	YES, IN BOTH MÁRGINS	NO
Observations:		If it can be quantified, indicate cm or m of erosion	
Do we observe incision in the channel?		YES	NO
Observations:		If it can be quantified, indicate cm or m of erosion	
Do we observe changes in the structure of the sedimentation or the sediments, which are not consistent with those located upstream and downstream from the project site?		YES	NO
Observations:		If it can be quantified, indicate the approximate surface	
Do we see, downstream from the weir that has been removed, a large amount of sedimentary material coming, for the most , part, from the old water impoundment?		YES	NO
Observations:		If it can be quantified, indicate the approximate surface	
Is there excess vegetation in the channel?		YES	NO
Observaciones:		If it can be quantified, indicate the approximate surface	
Have access ways to the area been upgraded after removing the heavy machinery used in the river restoration project?	YES, COMPLETELY	YES, PARTIALLY	NO
Observations:			

WORKSHEET: REMOVAL OF LEVEES / LATERAL PROTECTION STRUCTURES

Water course:		**Basin/sub-basin**	
Coordinates		**Municipality/town/toponym**	
Date of field visit		**Date of action**	
Name of the action			
Flow		**Use of the area**	
Data entry done by			

Has the levee / lateral protection structure been completely eliminated?	YES, COMPLETELY REMOVED	NO, ONLY PARTIALLY	NO, BUT IT HAS BEEN REPLACED BY SOFT MEASURES
Observations:			
Are there any remains of the structure in the channel?	YES	NO	
Observaciones:			
Are there any remains of the structure in the banks?	YES, IN ONE MARGIN	YES, IN BOTH MARGINS	NO
Observations:			
Do we observe any lateral erosion process or undermining of the banks?	YES, IN ONE MARGIN	YES, IN BOTH MARGINS	NO
Observations:		If it can be quantified, indicate cm or m of erosion	
Do we observe incision in the channel?		YES	NO
Observations:		If it can be quantified, indicate the approximate surface	
Has the channel been altered when removing the levee/lateral protection structure?	YES, SEVERELY	YES, SLIGHTLY	NO
Observations:			
Has the restored slope been colonised by vegetation?	YES, BY NATIVE SPECIES	YES, BY ALIEN SPECIES	NO
		If it can be quantified, indicate the approximate surface	
Have access ways to the area been upgraded after removing the heavy machinery used in the river restoration project?	YES, COMPLETELY	YES, PARTIALLY	NO
Observations:			

WORKSHEET: RIPARIAN VEGETATION RESTORATION PROJECTS

Water course:		**Basin/sub-basin**	
Coordinates		**Municipality/town/toponym**	
Date of field visit		**Date of action**	
Name of the action			
Flow		**Use of the area**	
Data entry done by			

Has the morphology of the area been altered?		YES	NO
Observations:		If it can be quantified, indicate the approximate surface	
Have native species been used in the restoration project?		YES	NO
Observations:		Indicate de approximate surface	
Has any work been done to connect the margins with the channel?	YES	NO, BECAUSE THEY ARE ALREADY CONNECTED	NO
Observations:		If any work has been done, what did it involve?	
Are there any dry or dead plants indicating a poor connection with the water table?	YES, MANY	YES, SOME	NO, NONE
Observations:		If it can be quantified, indicate the approximate surface or number	
Can we observe an improvement in the riparian structure, with new layers (herbaceous plants, low and high shrubs, climbing plants, trees)?	YES, IN THE ENTIRE AREA	YES, IN SOME SECTIONS	NO
Observations:			
Is there a wide variety of species?	YES, MORE THAN 5	YES, BUT LESS THAN 5	NO
Observations:		Determination of species/taxa	
Has restoration been done following a geometric (linear) pattern, or a random pattern?	GEOMETRIC	RANDOM	**BOTH**
Observations:		If it can be quantified, indicate the approximate surface	
Have access ways to the area been upgraded after removing the heavy machinery used in the river restoration project?	YES, COMPLETELY	YES, PARTIALLY	NO
Observations:			

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2. Internet references
3. Legal references

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2. INTERNET REFERENCES

In order to complete document type references, we cannot pass by the opportunity to include some overviews on the topic at hand which are available in the Internet. They facilitate learning about water resources and ecosystems, their pressures and impacts, and assorted management tools. They may be useful for those who approach this publication, as an introduction to river conservation and restoration in general. Of course, there are many more, but the pages shown, in turn, contain links to websites which are more specific on the subject. As well, we include the addresses of some geographical information systems, always interesting when carrying out field work. Given the informative nature of this publication, we have considered suitable to include as well some environmental education references, offering tools for environmental educators who wish to provide information on river functioning.

Institutional Websites

- Confederación Hidrográfica del Duero [Duero River Basin Authority, Spain]
  http://www.chduero.es/
- Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA) – apartado restauración fluvial (Estrategia Nacional de Restauración de Ríos) [Ministry of Agriculture, Food and Environment of Spain, section on river restoration (National Strategy for River Restoration)]
  http://www.magrama.gob.es/es/agua/temas/delimitacion-y-restauracion-del-dominio-publico-hidraulico/estrategia-nacional-restauracion-rios/
- Centro de Estudios y Experimentación de Obras Públicas (CEDEX) [Centre for Studies and Experimentation on Public Works, Spain]
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- European Environment Agency
  http://www.eea.europa.eu/es
- Restore Rivers
  http://www.restorerivers.eu/
- UN-Water
  http://www.unwater.org/
- Ramsar Convention
  http://www.ramsar.org/

Fluvial Restoration Centres

- Centro ibérico de restauración fluvial (CIREF) [Iberian Fluvial Restoration Centre]
  http://www.cirefluvial.com/
- European Centre for River Restoration (ECRR)
  http://www.ecrr.org/
- Centro italiano per la riqualificazione fluviale (CRIF) [Italian Centre for River Restoration]
  http://www.cirf.org/italian/home.html
- The River Restoration Centre
  http://www.therrc.co.uk/
- Australian River Restoration Centre (ARRC)
  http://arrc.com.au/

Other Organizations: Environment Agencies, Water Institutes, etc.

- International River Foundation
  http://www.riverfoundation.org.au/index.php
- Wetlands International
  http://www.wetlands.org/
- Environment Agency, United Kingdom
  http://www.environment-agency.gov.uk/
- Institute of Water, United Kingdom
  https://www.instituteofwater.org.uk/
- French National Agency for Water and Aquatic Environments
  http://www.onema.fr/IMG/EV/index.html
- The Rhone-Mediterranean and Corsica Water Agency
  http://www.eaurmc.fr/index.php?version-anglaise

- United States Environmental Protection Agency (EPA)
  http://www.epa.gov/learn-issues/learn-about-water
- Institute for Water Resources, United States
  http://www.iwr.usace.army.mil/
- American Rivers, United States
  http://www.americanrivers.org/
- Victoria State Department, Australia
  http://www.depi.vic.gov.au/water

Information and Educational Websites

- Water websites in Spain
  http://www.iagua.es/
- Environmental Sciences Institute, University of Zaragoza, Spain (IUCA)
  http://iuca.unizar.es/
- Duero Volunteers
  http://voluntaduero.blogspot.com.es/
- National Geographic
  http://environment.nationalgeographic.com/environment/freshwater
- United States Geological Survey
  http://www.usgs.gov/
- International Rivers, United States
  http://www.internationalrivers.org/

GIS Map viewers

- MÍRAME - Confederación Hidrográfica del Duero [Duero River Basin Authority, Spain]
  http://www.mirame.chduero.es/DMADuero_09/index.faces
- IBERPIX - Instituto Geográfico Nacional [National Geographic Institute, Spain]
  http://www.ign.es/iberpix2/visor/
- GOOGLE Maps
  https://www.google.es/maps

Environmental Education

- Centro Nacional de Educación Ambiental (CENEAM) [National Environmental Education Centre, Spain]
  http://www.magrama.gob.es/es/ceneam/
  Ecomilenio – Educational Materials

  http://www.ecomilenio.es/comunicacion/materiales-educativos
- Water and Environmental Education, University of Salamanca, Spain
  http://cidta.usal.es/cursos/agua/modulos/principal/principal.htm
- Water and its different states, UNICEF Educational Programme
  http://www.enredate.org/actividades
- Water cycle, United States Geological Survey
  http://water.usgs.gov/edu/watercycle-kids.html

3. LEGAL REFERENCES

In the past few years, Spanish water legislation has undergone several modifications which have brought it closer to the principles inspiring the Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy, Official Journal of the European Union 22.12.2000), and some other spinoff Directives, also called daughter Directives, like those about Floods and Groundwater, with the ultimate purpose of achieving a good status of all water bodies.

Many of the indications included in this guide concerning the way we act on fluvial spaces, whether to prevent their degradation or to attain their restoration, are based on these legal norms. This provides the authorities responsible for water resources with a legal basis for reports as well as for resolutions on authorisations and concessions, when faced with initiatives promoted by individuals as well as by public entities. It also helps individuals and entities make allegations as part of public information and participation procedures. All of this is to the benefit of transparency and legal certainty.

We should also note that other environmental regulations offer additional arguments or reinforce the ones mentioned. To this effect, the regulations of the Autonomous Communities concerning fishing and fluvial ecosystems can be very valuable, as well as Law 42/2007, on Natural Heritage and Biodiversity, and the Strategic Plan on Natural Heritage and Biodiversity approved by Royal Decree 1274/2011, of 16 September.

Surely doing a detailed analysis of these norms is not the purpose of this publication. However, we write out next some of the articles included in Spanish water legislation which are most interesting in terms of providing a basis for the importance of values such as the longitudinal and lateral continuity of water courses, their natural morphology and hydrodynamics, sediment flows, or native riparian vegetation.

CONSOLIDATED SPANISH WATER LAW, APPROVED BY ROYAL LEGISLATIVE DECREE 1/2001, OF 20 JULY

Article 98. Environmental limitations to authorisations and concessions.

River basin authorities, in those concessions and authorisations that they issue, will adopt the necessary measures to make use compatible with environmental protection, and ensure the ecological flows or environmental demands envisaged in water resource planning.

When processing concessions and authorizations affecting the public hydraulic domain which may entail environmental risks, it will be mandatory to present a report on the potential harmful effects for the environment. This report will be sent to the competent environmental authorities so they can make known any corrective measures that, in their opinion, should be introduced as a result of the report presented. Without prejudice of the instances when it is mandatory, as per current legislation, in those cases when the basin authority presumes there is a serious risk for the environment, it will likewise refer the matter to the competent environmental authorities, so that they may consider the advisability of initiating an environmental assessment procedure.

LAW 10/2001, OF 5 OF JULY, CONCERNING THE NATIONAL HYDROLOGICAL PLAN

Article 28. Protection of the public hydraulic domain and actions in flood prone areas.

1. Any necessary measures to correct the situations affecting the protection of the public hydraulic domain, including the elimination of built infrastructures and other facilities located within it, shall be taken.

The Ministry of Environment will promote the processing of any files dealing with the delineation of the boundaries of the public hydraulic domain in those stretches of rivers, creeks and ephemeral streams where deemed necessary to prevent, control and protect the domain.

3. The Ministry of Environment will encourage collaboration agreements with regional and local authorities with the purpose of eliminating any built infrastructures and other facilities located in the public hydraulic domain and flood prone areas which may entail a serious risk for people and assets, and protecting the domain.

REGULATION ON THE PUBLIC HYDRAULIC DOMAIN, APPROVED BY ROYAL DECREE 849/1986, OF 11 APRIL

Article 72.

1. The use or exploitation of water courses or the assets located in them by individuals will require prior administrative authorisation.

2. When issuing authorisations for the exploitation of aggregates, tree or shrub vegetation, or the establishment of bridges or footbridges, piers and public toilet facilities, any potential adverse ecological impacts will be considered, and adequate guarantee to ensure that the environment will be restored will be required.

3. Authorisations for sowing and plantation undertakings will be issued for a period of time at the most equal to the growing cycle of the species under consideration.

4. In no case can earth removal that alters the cross section or configuration of the water course take place under these authorisations.

Article 74.

3 bis. Authorisations for sowing, plantations, or tree felling will establish the authorisation holder's obligation to restore the land to its former state, which may include, among others, removal of tree stumps, plantation of native riparian vegetation, and removal of protection works, unless a new authorisation is obtained to continue cultivating during the following growing period.

4. In no case can earth removal that alters the cross section or configuration of the water course take place under these authorisations.

Article 126 bis. Conditions to ensure fluvial continuity.

1. The river basin authority will encourage the protection of the longitudinal and lateral continuity of water courses, harmonising it with current water uses and the hydraulic infrastructure included in water planning.

2. In the terms of any new concessions and authorisations, or the modification or review of existing ones, which include transversal infrastructure works in the channel, the basin authority will require putting in place devices to ensure that native fish fauna can get through, and their adequate maintenance. The same requirement will apply to any such infrastructure already existing, linked to concessions and authorisations which include this obligation in their terms and conditions, or that should include such devices in order to conform to current legislation. These devices could be dispensed with in an interim basis due to environmental criteria or lack of technical feasibility, to be duly justified in each case. The basin authority may demand the devices be put in place based on the environmental evolution of the stretch, or improvements in techniques, whenever the conditions make it advisable.

3. Concerning construction works and the processing of authorisations and concessions dealing with flood protection works, the basin authority will consider any potential effects on the status of water bodies. Protection in-

frastructure raised over the land level on the sides of the channel in the preferential flow area (approximately equivalent to the floodway) can only be built to protect existing towns and public infrastructure, barring exceptional cases.

4. The basin authority will encourage the elimination of infrastructures within the public hydraulic domain that have been abandoned and have no function linked to water use, taking into consideration the safety of people and assets, and assessing the environmental and economic effect in each case.

5. When issuing new authorisations or concessions for transversal infrastructure works in the channel, which because of their nature and dimensions, may have a significantly effect on sediment transport, an assessment of the impact of such infrastructure on the sediment transport regime of the water course will be required. The exploitation of such infrastructure will comprise measures to reduce their impact to a minimum.

REGULATIONS OF THE HYDROLOGICAL PLAN FOR THE SPANISH PART OF THE DUERO RIVER BASIN, APPROVED BY ROYAL DECREE 478/2013, OF 21 OF JUNE, REVIEWED AND UPDATED BY ROYAL DECREE 1/2016, OF 8 OF JANUARY.

Article 17. Protection perimeters and buffers.

2. Buffers around water courses to protect fluvial morphology:

a) In order to improve the protection of fluvial morphology, faced with the adverse ecological impact of aggregate mining operations, grazing and tree and shrub use, the establishment of bridges and footbridges, piers and public toilet facilities, and in particular, in terms of their authorisation and concession, the rivers and streams of the Duero basin are classified, based on their importance and magnitude, as:

- Class 1: Main rivers in the basin, with long courses, important discharges and extensive riparian formations. The protection buffer for these rivers is set as 15 m on each margin.

- Class 2: Medium size rivers, with an important discharge and length, and, where appropriate, good riparian formations in a portion of their course. The protection buffer for these rivers is set as 10 m on each margin.

- Class 3: The rest of the streams, brooks and other water courses in the basin, of smaller dimensions and sometimes realigned, channelised and without natural riparian vegetation. The protection buffer in these cases is set as 5 m on each margin, the same as the public right of way. The fluvial stretches assigned to classes 1 and 2 are listed in Annex 10.1; the remaining streams are included in class 3.

b) Plantations may take place in channel protection buffers, using native riparian vegetation, following an irregular pattern, structured into different age classes, and using tree and shrub species which do not compromise the genetic richness of the species and populations typical of the Duero basin. In the protection buffers corresponding to classes 1 and 2 mentioned under a), other tree crop plantations may take place as per the provisions specified in Article 74 of the Regulation on the Hydraulic Public Domain, when the required environmental report by the competent authority establishes so, always respecting the five metre width of the public right of way.

3. Buffers to protect wetland morphology: According to the provisions under Article 243 of the Regulation on the Hydraulic Public Domain, without prejudice of the public right of way and monitoring areas stipulated in Article 96 of the Consolidated Spanish Water Law, the

margins of lakes, reservoirs and ponds that comprise the wetland inventory of the Spanish portion of the Duero river basin, listed in Appendix 10.2, have a 15 m protection buffer around their ordinary high water mark, with the same effects as those of the fluvial protection buffers established in section 2.

Article 22. Disruption of channel continuity.

1. The longitudinal continuity and lateral connectivity of channels is a value that must be protected. In particular, it cannot be limited when it implies the deterioration of the status of the water body involved; without prejudice of what is established under Article 21, concerning new modifications or alterations.

2. As per Article 126 bis of the Regulation on The Public Hydraulic Domain, any uses taking place in the channel, regardless of their purpose, whether they are weirs, water abstractions, diversions, gauging facilities, or any other action, must be carried out ensuring that native fish fauna present in the affected stretch, or which could potentially live in it, can move downstream and upstream. To this effect, the said works and facilities will contain passes with a flow of water and sediments suitable for the desired purpose, and which must be included in the terms and conditions of any new concessions, or any concessions which are reviewed or modified.

3. Ensuring fauna can get through new infrastructures will be included in the terms and conditions of any new concessions, as well as any concessions which are reviewed or modified. The remaining infrastructures which are less than 10 m high over the low water channel, and do not allow the movement of fauna, must be adapted to ensure the continuity of water courses. Actions involving infrastructures whose modification allows improving the status of the water body at one or more different levels will be a priority.

4. The Duero River Basin Authority, as per Article 28 of the National Hydrological Plan, and Article 126 bis.4 of the Regulation on the Public Hydraulic Domain, assessing the environmental and economic impact in each case, may promote the demolition of any infrastructures which have no function linked to water use with the applicable authorisation or concession and thus, are abandoned, once the procedure to terminate or modify the characteristics initiated ex officio has been processed.

5. The assessment of whether fauna can get through will be done as per the hydromorphological indicators of continuity to evaluate the status of water bodies in the river class specified in Appendix 3.

6. Outside urban stretches, the lateral continuity between the channel and the floodplain area must be protected. In particular, protection structures raised over the land level (levees) which isolate the channel from its floodplain cannot be built without a prior evaluation of their environmental impact. The Duero River Basin Authority will study, with the due safety guarantees for people and assets, the feasibility of eliminating, setting back or lowering the height of existing levees and any other protection infrastructures raised over the land level that limit the natural movement of the channel. Actions involving infrastructures whose modification allows improving the status of the water body at one or more different levels will be a priority.

Article 23. Sediment flow.

1. Natural transport of solid sedimentary material, through suspension, saltation, or rolling, is recognised as an integral part of natural river flow, essential for their evolution and morphological development.

2. The assessment of the impacts of infrastructures located across the channel planned in

Article 126 bis.5 of the Regulation on the Public Hydraulic Domain will ensure that they are not an obstacle to solid flow under normal or pre-alert conditions, defined according to the indicator system adopted in the Drought Special Plan in the Duero river basin.

Article 24. Terms and conditions for aggregate mining.

1. Aggregate mining operations must respect the natural morphological conditions and hydrodynamics of the channel, without introducing any modifications in them. The minimum distance from the exploitation to the channel will be determined on a case by case basis, depending on the characteristics of the channel and the land area. The protections buffers indicated in Article 17.2 and 3 will be taken into consideration.

2. The depth of the excavation within monitoring areas must be defined with a safety margin of at least half a metre above the water table or the water level in the channel. The safety margin can be greater, in order to avoid affecting groundwater hydrology, the connections between groundwater and surface water, and the rights of third parties. The lowest level of the aggregate mining shall not be below the lowest level of the river channel. The concession holder must have an observation pit or piezometer to monitor groundwater hydrology in the area close to the exploitation.

3. Aggregate mining operations will be carried out according to the following requirements:

a) There will be no discharges that increase water turbidity.

b) Measures shall be taken to prevent accidental discharges of fuel, oils or any other substances that may deteriorate the status of surface or ground waters in the exploitation area. Therefore, leak proof containers should be set up for the temporary storage of these potential contaminants, until they are relocated to an authorised waste collection facility.

c) Water recirculation systems shall be implemented in order to decrease consumption and reduce discharges.

d) Perimeter ditches shall be built encircling the exploitation, in order to prevent the flow of stormwater that may lead to unwanted runoff and discharges.

e) During the exploitation period, precise measures to avoid altering the natural morphology of the channel shall be taken. Once the exploitation has ended, the morphology of the floodplain affected by the mining operation must be returned to normal.

4. Whenever the Duero River Basin Authority considers that, based on their own studies or documents facilitated by any other competent authority, and due to safety considerations given a conjunctural flood risk, or to improve the morphology of a river that has been artificially deteriorated, aggregate removal is required in a certain stretch of a water course, it shall take place according to the project and technical specifications stipulated for each particular case; the use of the aggregates may be subject to public tender, as per Article 137 of the Regulation on the Hydraulic Public Domain.

5. The materials accumulated naturally upstream behind dams, weirs or sills shall not be used as aggregates. Moving them will require an explicit authorisation from the basin authority, establishing the technical conditions to do so, and which, generally, unless there is a technical justification advising against it, will lead to depositing the sediments downstream from the obstacle in order not to alter sediment flows, as per Article 23.

Article 32. General regulations on authorisations for construction works and other uses of the public hydraulic domain.

1. Terms and conditions for works to be done in the channel, the public right of way and the monitoring area (5 m and 100 m on the sides of the channel, respectively): The works done in the channel, the public right of way and the monitoring area, as well as the applicable authorisations, will take into account the following criteria:

a) Channelisations in rural land: As a general rule, any actions to straighten the planform and profile of channels, reducing their cross-section, and raising the land level using levees or walls, which may alter the flooding conditions, will not be admitted. Any exceptions to this rule will be studied on a case by case basis, according to Article 126 of the Regulation on the Hydraulic Public Domain.

b) Diversion of a water course into a pipe or a channel below ground, in rural land: As a general rule, diverting a water course into a pipe or a channel below ground will not be admitted in rural land, unless the alternative was economically out of proportion; if the latter is the case, the application will include a study justifying the new modification, completing the different matters included in the 'Template to justify new modifications or alterations' specified in Article 21.

c) Wading areas: To build wading areas that enable transport routes to cross the channel, the cross-section of the channel occupied shall not be covered with materials which reduce it, or which limit the movement of native fauna species, particularly fish, present in the affected stretch, or which could potentially live in it.

d) Bridges, footbridges: The construction of bridges or footbridges shall not decrease the discharge capacity of the channel itself, nor shall it limit the movement of native species present in the affected stretch, or which could potentially live in it.

e) Deep test wells: The construction of deep test wells in the monitoring area will be done cementing the first metres, where the alluvial aquifer of the river is, in order to ensure that water is abstracted from the deep horizon.

2. Terms and conditions for tree crops.

a) No plantations of tree crops shall take place in the channel or the public right of way. In addition, plantations in the channel protection buffers as well as in the wetland protection buffers can be done according to the conditions specified in Article 17.

b) Protection structures to prevent erosion and detachment in private property lands, as well as works to protect poplar or comparable crops, consisting of embankments, shall be authorised as long as they do not involve raising the land level, unless they protect existing towns and public infrastructures, and providing that such works do not have an adverse effect on water bodies or the discharge capacity of the channel, as per Article 126 bis of the Regulation on the Hydraulic Public Domain.

c) Authorisations to cut trees will stipulate the authorisation holder's obligation to restore the land to its former state, which may include the removal of tree stumps, plantation of riparian vegetation, and removal of protection works built to protect the plantation, unless a new authorisation is obtained to continue cultivating during the following growing period.

d) Clear cutting will be limited to production plantations, and must be avoided when clearing natural vegetation, which, if at all possible, should be done using a selection cutting method, cutting down a maximum of 50% of the trees.

e) No new concessions shall be authorised for the irrigation of traditional poplar plantations located in the monitoring area of water courses if the water input can be obtained through deep planting. Nevertheless, if water resources are available, interim flow diversions may be authorised. The gross water needs to irrigate such traditional tree plantations of phreatophytes are limited to a maximum allocation of 800 m^3/ha/year, applicable only during the first two years of the plantation.

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