



# **Successes of EU Water Framework Directive implementation**

## **Evidence of river restoration measures improving ecological conditions**

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**Wetlands International – European Association**

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## SECTION 1 – INTRODUCTION

The EU Water Framework Directive (WFD, 2000/60/EC) is the main legislation in the field of water management and protection. The WFD aims at enhancing the status of aquatic ecosystems (i.e. rivers, lakes, transitional and coastal waters and groundwater) and biotic communities in a comprehensive way. Water management is brought beyond water quantity and quality, entailing provisions on land-use and governance. The WFD sets environmental objectives in terms of good status to be met by 2015, or under certain conditions the final deadline of 2027.

The WFD has acted as a driver for several interventions of river restoration aimed at the improvement of streams' ecological conditions across the Member States. In this report, we analyse the **progress in achieving the main objectives of the WFD** based on a non-exhaustive selection of relevant case studies, also looking at specific aspects such as improvement in **governance, public participation** and the **spatial scale** of restoration actions. We will underline factors that have contributed to or stood in the way of achieving the WFD objectives. Moreover, we discuss the **suitability of the monitoring and assessment tools** for detecting improvement of the ecological conditions of rivers.

The results of our analysis will serve as evidence of WFD implementation to the 2018-2019 Fitness Check of the Water Framework Directive and Floods Directive (FD, 2007/60/EC) by the European Commission.

## SECTION 2 – CASE STUDIES

In this section, we present a collection of examples demonstrating the effectiveness of implementation of river restoration measures under the Water Framework Directive. We have looked for case studies that show an improvement in terms of ecological status at water body scale, of at least one quality element or more general improvements at local scale. Links with Floods Directive implementation will be indicated.

The case studies belong to different biogeographic regions and are located in four Member States (Belgium, France, Spain and UK). The category of the interventions carried out and the most significant and innovative elements of the case studies are summarised in table 1 and 2, respectively.

Case study	Member State	Category of restoration intervention		
		Morphological restoration	Hydrological connectivity	Flow regime
1. Eau Blanche and Bocq	Belgium	X	X	
2. Drac	France	X		
3. Cofio	Spain	X	X	X
4. Orbigo	Spain	X	X	
5. Segura	Spain		X	
6. Turia	Spain			X
7. Eddleston Water	UK	X		
8. Glaven	UK	X		

**Table 1** - Category of the interventions carried out in the case studies.

Case study	Improvement in governance	Public participation	Integration with Floods Directive	Monitoring of additional bioindicators and/or backwaters
1. Eau Blanche and Bocq	X			
2. Drac			X	
3. Cofio				X
4. Orbigo		X	X	
5. Segura	X	X		X
6. Turia	X			
7. Eddleston Water	X	X	X	X
8. Glaven			X	X

**Table 2** – Significant and innovative elements of the case studies.

## 1. Rivers Bocq and Eau Blanche (Belgium) – LIFE project “Walphy”

### Project overview

<i>Catchment:</i>	Meuse
<i>Lead organization:</i>	Service Public de Wallonie
<i>Total budget:</i>	€ 2,8 million
<i>Status:</i>	Completed

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<i>Pressures</i>	<i>WFD measures</i>	<i>Impact</i>
<ul style="list-style-type: none"><li>• Channelization</li><li>• Floodplain disconnection</li><li>• Damming and embankment</li></ul>	<ul style="list-style-type: none"><li>• Habitat diversification</li><li>• Passability of barriers</li><li>• Barrier removal</li><li>• Re-meandering</li><li>• Reconnection of backwater</li></ul>	<ul style="list-style-type: none"><li>• Enhanced habitat heterogeneity</li><li>• Improved fish mobility and population size</li><li>• Restored sediment transport</li><li>• Spawning places</li></ul>

### Context

The Eau Blanche and the Bocq are two medium-size catchments of the Meuse basin which were heavily affected by rectification works carried out in the middle of the last century for agricultural development and by the presence of transversal and longitudinal structures. The preparatory assessment showed that the lateral connectivity on the Bocq was not heavily affected, while the longitudinal connectivity was disrupted by numerous obstacles that are difficult or impossible for fish to cross. On the other hand, the longitudinal connectivity on the Eau Blanche was acceptable but the lateral connectivity (the natural connections between the river and the alluvial plain) was very poor.

### Aims

The project focused on the restoration of the longitudinal connectivity on the Bocq through the removal/management of obstacles and on the restoration of lateral continuity on the Eau Blanche. The specific objectives of the project were to:

1. Carry out restoration works on a significant scale on some water bodies at risk of not reaching the good status, based on two axes: longitudinal and lateral continuity.
2. Monitor the restored river system and its ecological status evolution at the local level (site of intervention) and the scale of the whole water body.
3. Develop of a methodology for helping to define the restoration works to be undertaken to improve the hydromorphological quality of water bodies "at risk".
4. Refine the methodology for the development of technical guidelines (decision-making tools) for river stakeholders, in line with the implementation of the WFD.
5. Disseminate these tools and recommendations to the authorities, stakeholders and the public.

### *Timing and location*

The project started in 2009 and was completed by 2013, involving 46 kilometers along the Eau Blanche and the Bocq, close to the city of Namur, in southern Belgium.

### *Measures*

In total, the project was able to remove 20 obstacles to improve fish migration (19 on the Bocq and one on the Eau Blanche), with 16,6 km along the Bocq and 28,9 km along the Eau Blanche that are nowadays free of any obstacle. In some cases, the obstacles were destroyed (e.g. the demolition of a dam), however, in many cases such action was not possible. Some dam owners did not consent because they have or are planning to construct mini hydroelectric power plants. In other cases, the role of the dam is important in relation to bridges and other constructions. In those cases, other solutions were implemented solely or in combination, including the creation of bypass channels, fish passes and rock ramps (Castelain et al., 2018).

Furthermore, the lateral connectivity of around 22 kilometers along the Eau Blanche and the Bocq was improved. Different kinds of techniques were implemented. In several sites, the works were limited to the river bed with small-scale meandering and the introduction of various structures to diversify the habitat. In other areas, more ambitious works were implemented such as the restoration of a former meander on the Eau Blanche. A former side river of the Eau Blanche Plain, the Grand Morbi, was also reopened and reconnected with the Eau Blanche (Castelain et al., 2018).

### *Monitoring and evaluation*

Monitoring activities showed that the habitat heterogeneity was enhanced, with a consequent improvement of the ecological conditions in most of the study sites. Significant examples are the weir removal at Spontin and the remeandering in Emptinale along the Bocq. At the Spontin site an improvement was observed of the number of rheophilic species, biomass and number of individuals. In addition, the value of the biotic index of fish integrity (IBIP, indicating the ecological quality based on the attributes of fish communities) moved from 19 to 23, i.e. from good to high quality class. On the other hand, no significant improvements were measured through the sampling of benthic macroinvertebrates. At the remeandered site in Emptinale, a significant improvement was observed of both the benthic macroinvertebrates-based index IBGN (Indice Biologique Global Normalisé, indicating the ecological quality for benthic macroinvertebrates) from moderate to good quality class and the fish-based index IBIP from good to high quality class (Castelain et al., 2018).

### *Conclusion*

LIFE project “Walphy” has been a pilot project to test different techniques of river restoration and could be an example for other interventions in the Walloon Region, as the applied methodology has been summarized in a technical guide. The results of the monitoring showed an improvement of the ecological conditions at different surveyed sites. However, water quality should reach a sufficiently high level to ensure that the benefits of restoration are optimal for the aquatic organisms and ecosystem as a whole. Water conditions are still problematic and act as a limiting factor on the Eau Blanche and the Bocq for the improvement of the ecological conditions. Nevertheless, hydromorphological restoration is an indispensable tool to reach the good ecological status of the water bodies. The monitoring also showed that the removal/management of obstacles is an effective way to improve fish mobility and population size. Furthermore, the removal of obstacles improves bedload transport, resulting in higher quality gravel banks as spawning places (Castelain et al., 2018).





*Figure 1. Works for weir removal at Spontin (source: LIFE project «Walphy» Layman's report).*



*Figure 2. Re-meandering of the Eau Blanche at Boussu-en-Fagne (source: LIFE project «Walphy» Layman's report).*

## 2. River Drac (France)

### Project overview

<i>Catchment:</i>	Rhône
<i>Lead organization:</i>	French Water Agency
<i>Total budget:</i>	€ 5 million
<i>Status:</i>	Completed

<i>Pressures</i>	<i>WFD measures</i>	<i>Impact</i>
<ul style="list-style-type: none"><li>• Riverbed incision due to gravel extraction</li></ul>	<ul style="list-style-type: none"><li>• Restoration of morphological conditions</li><li>• Restoration of sediments continuity</li><li>• Reconnection of tributaries</li><li>• Innovative monitoring method</li></ul>	<ul style="list-style-type: none"><li>• Improved physico-chemical quality</li><li>• Improved habitat conditions</li><li>• Increased presence and abundance of aquatic and flagship species</li></ul>



Figure 3. The Drac in the restored reach (October 2017, picture by Bruno Boz).

### Context

In 2000, a scientific study highlighted a problem of incision in the Drac riverbed, caused by the intense gravel extraction started in 1960, and ended in 2012. The incision reached up to few meters, eventually reaching a clay layer that further accelerated the incision. Along with the riverbed, the water table lowered as well, altering the riparian forest. The new clay substrate substituting the gravel one caused further alteration of the aquatic habitats, allowing an expansion of clay outcrops. Moreover, the stability of the dam at the Champsaur leisure center, a lake used for recreation and fishing, was compromised, causing significant risk.

### *Aims*

The project aimed at reverting the regressive incision that was leading to a destabilization/loss of functionality of protection work and a high risk of collapse of the Champsaur dam. This goal was coupled with the restoration of morphological dynamics of the river, particularly by developing a braided channel morphology similar to the condition of the Drac before the incision phase. Moreover, the project targeted the improvement of sediments continuity and the lateral reconnection of tributaries.

### *Timing and location*

The project started in November 2013, and was completed in June 2014. It is located in southern France, close to the city of Grenoble. The project affected 4 km of river.

### *Measures*

450 000 cubic meters of gravel were recovered, mainly from the terraced alluvial plain of the Drac and added to the river channel. The altimetric profile prior to extraction was in this way reconstructed. A weir was built at the downstream end of the intervention to fix the riverbed height. The weir features a passage for fish and one for canoes.

### *Monitoring and evaluation*

Several elements were considered in the assessments carried out before the intervention, ranging from morphodynamics, to habitats and aquatic fauna. The project established a 10-year monitoring program on morphology and ecology. Innovative monitoring methods are planned for evaluating the evolution of the channel morphology: bedload tracing program using active ultra-high frequency RFID technology, repetitive high-resolution topographic surveys of the restored reach and high-frequency qualitative survey of channel changes using time-lapse cameras. The first morphologically relevant flood (15/11/2015) triggered the development of braided channel morphology.

After the intervention, the physico-chemical quality of the water improved thanks to the diminished input of organic matter, partly linked to the improved wastewater treatment in the upstream catchment. As regard the ecological conditions, an increase was observed of the value of the index based on the benthic macroinvertebrates (IBG) from 11,8 (i.e class good) to 15,8 (i.e. class high), as well as the presence of sensitive taxa. The number of fish species increased from 2 to 4, with a significant increase of the abundance of the brown trout (*Salmo trutta*), an indicator species in the Alpine context, that indicates an improvement of the in-channel habitat conditions. Moreover, flagship species such as the Common kingfisher (*Alcedo atthis*), were rapidly seen to come back to the area.



*Figure 4. On the left panel, aerial view on the single channel Drac prior the 2013 intervention; the Champsaur dam can be recognized in the bottom right corner. The river flows towards the top of the picture. On the right panel, the same reach after the intervention (source: French geoportal).*

### *Conclusion*

The ecological conditions of the restored reach showed a clear improvement after the intervention and it is worth to underline that the increase of the values of the biotic metrics considered can be attributed to the improvement of both the in-stream channel condition as well as to the physico-chemical quality of the water. The regressive incision of the riverbed has been reverted and thus it has been reduced the risk of collapse of the Champsaur dam and of other protection structures. The physical restoration of the Drac required a huge amount of resources and means at a very high cost. The project would have been much smaller and less expensive if measures had been taken when riverbed incision was first observed.

### 3. River Cofio (Spain)

#### Project overview

<i>Catchment:</i>	Tagus
<i>Lead organization:</i>	Tagus River Basin Authority
<i>Total budget:</i>	€ 280k
<i>Status:</i>	Completed

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<i>Pressures</i>	<i>WFD measures</i>	<i>Impact</i>
<ul style="list-style-type: none"><li>• Damming</li><li>• Water pollution</li></ul>	<ul style="list-style-type: none"><li>• Dam removal</li><li>• Sediment extraction</li><li>• Reforestation</li></ul>	<ul style="list-style-type: none"><li>• Improved fluvial habitats and riparian forests</li><li>• Recovery of riverine communities</li></ul>

#### Context

This study is part of the river restoration project of the Cofio River (Madrid) after the demolition of the dam of Robledo de Chavela. This dam was built in the 1960s for the supply of potable water for the municipality, coming into operation in 1968. In 1990, due to problems of water quality, derived from discharges of livestock of upstream origin, it was decided to change the supply of the municipality and the dam was in disuse. In 2004, the Tajo Hydrographic Confederation recovered the ownership of the dam due to the expiration of the use and its state of evident abandonment. In the spring of 2012, leaks began to occur in the bottom drainage of the dam and, as a matter of urgency, a series of measures were implemented to prevent water contamination and to alleviate the effects on the river ecosystem. Finally, in September 2014, the dam wall was removed.

#### Aims

The project aims at the restoration of the longitudinal river continuity and at the re-naturalization of the riverbanks.

#### Timing and location

Cofio River is located in the western portion of Madrid Province and the intervention was carried out in September 2014.

#### Measure

The works carried out, apart from the elimination of the dam wall, consisted of the extraction and relocation of sediments, and re-profiling and reforestation of the riverbanks.

#### Monitoring and evaluation

A complete monitoring programme was established to monitor physico-chemical, hydromorphological and biological indicators to test the effectiveness of the interventions. The evaluation of the fluvial habitat and the quality of the riparian forest shows high values of the indices IHF (Índice de hábitat fluvial) and QBR (Índice de calidad del bosque de ribera) in all the monitored stations. The stretch occupied by the dam, although still showing signs of alteration is recovering satisfactorily.

The biological parameters analyzed in 2018 regarding the community of aquatic macroinvertebrates show a High Ecological Status of the waters of the Cofio River. In addition, the improvement in all biological parameters analyzed, such as richness, indices and different percentages, is evident. The

differences between the stations located outside and inside the old reservoir continue to be reduced. Downstream of the dam, the recovery was faster and the values of most of the biological parameters remain stable or are higher. The recovery of the fish community in the stretches of the old reservoir and downstream of it is remarkable. The fish community is already well defined and the values of density and biomass continue to increase with respect to the first surveys carried out in 2016. The improvement of fish populations of all the species is linked to the higher fluvial heterogeneity and the greater coverage of the riparian forests. Therefore, after four years since the demolition of the Robledo de Chavela dam, there is an evident recovery of fluvial habitats and related riverine communities.

### Conclusion

This intervention demonstrate that the removal of medium to large-sized dam can be an appropriate and efficient measure to restore river continuity and the in-channel and riparian conditions. It is also worth to highlight that the monitoring of the conditions of the riparian vegetation, through the application of a specific index (i.e. QBR; Munné et al., 2003), is a key-element of the evaluation plan that can thus offer a holistic description of the river corridor (i.e. the channel and the adjacent floodplain). On the other hand, the presence of some invasive species (i.e. *Procambarus clarkii* and *Potamopyrgus antipodarum*) could be a negative for further improvements of the riverine communities and it is an element that should be carefully considered for future management actions.



Figure 5. The Robledo de Chavela dam (source: Tajo River Basin Authority – Confederación Hidrográfica del Tajo).



Figure 6. Riparian vegetation inside the old reservoir in 2018 (source: Tajo River Basin Authority – Confederación Hidrográfica del Tajo).

## 4. River Orbigo (Spain)

### Project overview

<i>Catchment:</i>	Duero
<i>Lead organization:</i>	Ministry of Environment and Rural and Marine Affairs
<i>Total budget:</i>	€ 3 million
<i>Status:</i>	Completed

<i>Pressures</i>	<i>WFD / FD measures</i>	<i>Impact</i>
<ul style="list-style-type: none"><li>• Embankment and erosion control structures</li><li>• In-channel obstacles</li><li>• Channelization</li></ul>	<ul style="list-style-type: none"><li>• Removal and adjustment of weirs, embankments and rock armour</li><li>• Reconnection of floodplains</li><li>• Active public participation</li><li>• Innovative monitoring method</li></ul>	<ul style="list-style-type: none"><li>• Improved flood risk mitigation</li><li>• Habitat diversification</li></ul>

### Context

Increased agricultural activities, mainly poplar plantations, over the last fifty years altered and impoverished the river Orbigo, resulting in the occupation of approximately 80% of the river corridor, the modification of the channel morphology (i.e. from multiple to single-thread), poor lateral connectivity, loss of longitudinal continuity as well as vegetation simplification and fragmentation. Embankments and channelization did not prevent floods that put housing in small urban stretches under risk, despite their expensive maintenance.

### Aims

The project aimed at mitigating flood risk, by recovering the connectivity with the floodplain. It also targeted the improvement of the ecological status of the river in the embanked stretch. The project was part of the Spanish National Strategy for River Restoration.

### Timing and location

The project was carried out between 2011 and 2012. It is located in northern Spain, close to the city of Leon. Overall, it affected 24 kilometers of river.

### Measures

Rock armoring of river banks and earth embankments were removed from more than 13 kilometers of river channels. Some earth embankments were set-back along 5 kilometers of river channels, and other barriers such as groynes were lowered. 10 kilometers of secondary arms were reconnected and/or directly restored. Moreover, a riverbank vegetation buffer was created along 7.2 hectares that were reconnected to the river. Other in-channel obstacles, namely weirs, were modified to restore continuity for fish fauna and sediments. The project approach was very different from the experience of the local stakeholders, who were initially reluctant, especially towards expropriation. However, an active public participation process was set in place, involving stakeholders in 50 meetings during 3

years and including environmental river restoration volunteering by NGOs, eventually facilitating a successful implementation.



*Figure 7. An artificial levee is lowered to recover lateral connectivity (source: Duero River Basin Authority – Confederación Hidrográfica del Duero).*

Source: Duero River Basin Authority (Confederación Hidrográfica del Duero, CHD)



*Figure 8. River bank protections were also removed along the river: on the left, the situation before the project; on the right, the river is reconnected to its floodplain (source: Duero River Basin Authority – Confederación Hidrográfica del Duero).*

### *Monitoring and evaluation*

Aerial images were collected with an innovative monitoring method (i.e. drones) to compare the river morphology before and after floods. Stakeholders were interviewed and provided qualitative assessments of the functioning of the floodplains. A quantitative assessment compared the floods of winter 2013 (160 m<sup>3</sup>/s) and spring 2014 (250 m<sup>3</sup>/s) to those of comparable magnitude of 1995 and 2000. The comparison showed the flood waters were successfully contained within the new river configuration, whereas in the old situation they caused serious damages.

The water quality was already good to high before the project, according to the physico-chemical indicators and the biotic indices based on diatoms and benthic macroinvertebrates. However, first evaluation results show that the ecological status of this water body has been improved. Morphological changes are also subject to monitoring and evaluation through hydromorphological indicators.



## *Conclusion*

This restoration project led to several significant results. First of all in terms of flood protection, i.e. material damage reduction, as well as in terms of improvement of the ecological conditions, due to the habitat diversification. In addition, the reforestation allowed to save about 7,500 tons/year of CO<sub>2</sub> and 3 hm<sup>3</sup>/year of water. Moreover, the project was finalist of the 2013 IRF European Riverprize and can be considered a positive reference for the following aspects: integrated water management and land use policies, implementation of innovative concepts (i.e. “green infrastructures”), integrated approach of WFD and FD, relevance of public involvement during the whole process and impact on the media.

## 5. River Segura (Spain)

### Project overview

<i>Catchment:</i>	Segura
<i>Lead organization:</i>	Segura River Basin Authority
<i>Total budget:</i>	€ 3,4 million
<i>Status:</i>	Completed

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<i>Pressures</i>	<i>WFD measures</i>	<i>Impact</i>
<ul style="list-style-type: none"><li>• Damming</li></ul>	<ul style="list-style-type: none"><li>• Weir removal</li><li>• Fish passage construction</li><li>• Vegetation management</li><li>• Stakeholder and public participation</li></ul>	<ul style="list-style-type: none"><li>• Increased fish migration</li><li>• Improved condition of riparian forest</li><li>• Improved governance</li></ul>

### *Context*

The Segura River is heavily affected by the presence of transversal structures. These obstacles, such as dams and weirs, break up the natural flow of the water and constitute physical barriers to the natural movement of fish (migration, dispersal and colonisation) upstream and downstream, resulting in serious environmental problems and worsening the ecological status of the river.

### *Aims*

The project aims to improve and strengthen longitudinal connectivity along the river channel.

### *Timing and location*

The project started in 2013, and was completed by 2017, and it is a LIFE+ project (called SEGURA RIVERLINK). It involves the river segment between Cañaverosa and Abarán (i.e. 54 kilometers), and the terminal reach of Moratalla River, up to its confluence into Segura River.

### *Measures*

The measures of the project consisted in the removal of one weir, the construction of 8 fish passages, the removal of 65 hectares covered by invasive plant species and the plantation of 2.200 trees and 4.800 shrubs along the river corridor. Moreover, 10 custody agreements with local farmers were signed and 7.000 students were volunteering in restoration activities and environmental education.

### *Monitoring and evaluation*

A full monitoring programme has been established to monitor physico-chemical, hydromorphological and biological indicators to test the effectiveness of the interventions. The classification of the ecological status of 9 out of 18 sampling stations improved of one quality class between 2015 and 2016. One of them improved from poor to moderate status, while eight stations moved from moderate to good ecological status. Fish passes demonstrated to be effective, as about 10.000 fishes have been fished in them, and the condition of riparian forest is improving too, according to the application of the QBR index (Índice de calidad del bosque de ribera) that increased from 3 to 5 stations in class high between 2015 and 2017. Nevertheless, it is necessary to monitor and control invasive species, such as Giant reed (*Arundo donax*), and these activities are quite tricky and expensive.



*Figure 9. Azud Archena weir, on the left, and lateral fish bypass for Archena weir, on the right (source: Segura River Basin Authority – Confederación Hidrográfica del Segura).*

### *Conclusion*

The LIFE+ SEGURA RIVERLINK project lead to an improvement of the longitudinal connectivity, fish passability and riparian vegetation conditions and structure. This positive results depended also on the improvement of the river governance (i.e. the custody network), as the sites that reached a good ecological status are those where administration and local farmers are working together. Other significant aspects of this project are the evaluation of the riparian vegetation in the monitoring plan and the participation and education of the public.

## 6. River Turia (Spain)

### Project overview

<i>Catchment:</i>	Júcar
<i>Lead organization:</i>	Júcar River Basin Authority
<i>Total budget:</i>	n/a
<i>Status:</i>	Completed

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<i>Pressures</i>	<i>WFD measures</i>	<i>Impact</i>
<ul style="list-style-type: none"><li>• Damming</li></ul>	<ul style="list-style-type: none"><li>• Establishment of environmental flow</li></ul>	<ul style="list-style-type: none"><li>• Restored spawning places and diversified habitats</li><li>• Recovery of aquatic species</li><li>• Improved riparian forest</li></ul>

### Context

The Benagéber dam was built in the 1950s for water supply and significantly altered the hydrological regime of the Turia River downstream. The low flow rates resulted in consequent stress of water temperature - up to 24°C in summer. This condition affected the ecological integrity of the riverine communities and caused the almost total disappearance of the brown trout (*Salmo trutta*) throughout the water body.

### Aims

The project focused on the increase of the minimum environmental flow below the dam. The effort aimed to improve one of the four aspects of environmental flows (following Spanish regulation) in the River Basin Management Plan with the overall objective to contribute to improvement of the ecological status of the water body.

### Timing and location

The restored reach is located between the reservoirs of Benagéber and Loriguilla (17 kilometers in length), in the Júcar River Basin District, West of Valencia. The measure was implemented in 2014 by the Confederación Hidrográfica del Júcar (Júcar River Basin Authority).

### Measures

The measure established a minimum ecological flow of 1.20 m<sup>3</sup> to allow the recovery of the hydrological conditions and riverine communities.

### Monitoring and evaluation

The increase of the minimum flow had positive consequences on macrophytes, benthic macroinvertebrates and fish. The populations of brown trout (*Salmo trutta*) are recovering thanks to the newly created areas with loose gravel that are of fundamental importance for spawning. The abundance and diversity of benthic macroinvertebrates improved due to in-channel habitat diversification. Moreover, the condition of the riparian forest is also improving.



*Figure 10. Restored flow along the Turia River (source: Pedro Merino Monzonis /RÍOS CON VIDA - Comunidad Valenciana).*

### *Conclusion*

The most innovative aspect of this restoration project is the establishment of environmental flows, a kind of restoration measure that have been shown to be important to the ecological and geomorphological dynamics of regulated rivers, with significant implications in terms of environmental services provided (Davies et al., 2014). The establishment of environmental flows can also be considered as a measure of improved river governance.

## 7. River Eddleston Water (United Kingdom)

### Project overview

<i>Catchment:</i>	Tweed
<i>Lead organization:</i>	Tweed Forum
<i>Total budget:</i>	£1.4 million
<i>Status:</i>	In progress

<i>Pressures</i>	<i>WFD / FD measures</i>	<i>Impact</i>
<ul style="list-style-type: none"> <li>• River straightening</li> <li>• Embankment</li> </ul>	<ul style="list-style-type: none"> <li>• Re-meandering</li> <li>• Removal of embankments</li> <li>• Natural flood management measures</li> <li>• Vegetation management</li> <li>• Creation of water storage</li> <li>• Public participation</li> </ul>	<ul style="list-style-type: none"> <li>• Habitat creation</li> <li>• Recovery of fish and other species (otter)</li> <li>• Improved flood risk management</li> </ul>

### Context

The river was severely straightened at the start of 19<sup>th</sup> century to enable the building of a toll road to Edinburgh, which, together with agricultural intensification, led to improved agricultural production. However, in combination with the subsequent building of a railway embankment and further changes in land use and forestry, this resulted in habitat loss/degradation and increased flood risk downstream. The river was classified by the Scottish Environmental Protection Agency (SEPA) as at 'bad' ecological status in 2009, largely due to the historical impacts on the physical structure of the channel and a loss of aquatic plant cover. Currently, SEPA's flood risk assessment shows some 582 properties at risk of flooding in the villages of Eddleston and Peebles under a 1:200 year scenario; the most recent floods being in 2016.

### Aims

The Eddleston Water Project aims to reduce flood risk and restore the Eddleston Water for the benefit of the local community and wildlife. The project has three main objectives:

1. To investigate the potential to reduce the risk of flooding to downstream communities through the utilisation of Natural Flood risk Management (NFM) measures.
2. To improve habitats for wildlife and fish, and raise the ecological status of the river, according to the Water Framework Directive classification.
3. To work with landowners and farmers in the local community to maximise the benefits of the work, whilst sustaining farming livelihoods and practices.

The Eddleston Water project is mentioned in the Tweed River Basin Management Plan as a multiple benefit project which aims to deliver biodiversity targets, improved fisheries, natural flood management, improved water quality and the mitigation of the effects of climate change in upland catchments.

### *Timing and location*

The Eddleston Water is a tributary of the River Tweed in the Scottish Borders and flows through the towns of Eddleston and then Peebles for around 20 km, where it joins the main river. This heavily altered upland catchment has a surface of about 70km<sup>2</sup>. The restoration project started in 2009 and many interventions were completed in in autumn 2016. Further interventions are under negotiation.

### *Measures*

To date, three river reaches with a total length of 2 km have been re-meandered with an increase in river length, a reduction of the slope and speed of the water flow. Re-meandering provided more space for flood waters, as well as creating new habitats and improving the landscape. Moreover, 2.9 km of flood embankments were removed and 101 flow-restricting log-jams have been installed in strategic locations in the upper catchment, to encourage out-of-bank flow and hold back water in the headwaters. Lastly, 66 hectares of native riparian woodland (i.e. some 200,000 native trees) has been planted, to increase rainfall interception and soil infiltration, and 22 stormwater ponds were created to store water during intense rainfall events. Stakeholders helped identify key ecosystem services in the catchment. All measures were carried out together with local farmers and landowners, who were key partners to the project, as was the Eddleston community.

### *Monitoring and evaluation*

Despite still being at a relatively early stage, the project has shown an improvement in river ecology and it is on track to restore the river from Bad to Good Ecological Status. Further significant progress relies on landowners being willing to change current land use and management practices. As regards the monitoring activities, salmonid surveys were carried out before the project began and a new set of surveys will be conducted in the near future to determine the effect the works have had on fish populations. Surveys in 2014 to 2016 showed the presence of salmon redds and Eurasian otter (*Lutra lutra*) in the remeandered river reaches. Although a quantified account of ecological improvement on the Eddleston Water will require further work, it is clear from site visits that the new habitats created are being occupied by salmonids. Moreover, preliminary results show that different NFM measures can reduce flood risk through both temporarily storing surface waters and delaying the flood peaks, as well as through increased surface roughness and groundwater connectivity.



*Figure 11. Construction of new ponds in the upper catchment (source: Eddleston Water Interreg Project Report 2016).*



Figure 12. Re-meandered section of Lake Wood, with the old channel on the left (source: Eddleston Water Interreg Project Report 2016).

### Conclusion

This project provides evidence that the restoration of the catchment can be undertaken alongside the continuation of sustainable farming and livelihoods and that the public participation is crucial to reach the objectives. Moreover, the NFM integrated measures to reduce flood risk and habitat enhancement measures to improve ecological condition provide a wide range of additional benefits and ecosystem services. Lastly, surveys of a flagship species, such as the Eurasian otter (*Lutra lutra*), were carried out beside to the monitoring of fish populations.



## 8. River Glaven (United Kingdom)

### Project overview

<i>Catchment:</i>	Glaven
<i>Lead organization:</i>	Environment Agency
<i>Total budget:</i>	n/a
<i>Status:</i>	Completed

<i>Pressures</i>	<i>WFD / FD measures</i>	<i>Impact</i>
<ul style="list-style-type: none"> <li>• Canalization</li> <li>• Floodplain disconnection</li> <li>• Damming and embankment</li> <li>• Floodplain drainage</li> </ul>	<ul style="list-style-type: none"> <li>• Floodplain reconnection</li> <li>• Removal of embankment</li> <li>• Restoration of channel morphology</li> </ul>	<ul style="list-style-type: none"> <li>• Enhanced habitat connectivity and heterogeneity</li> <li>• Increased vegetation richness</li> <li>• Increased invertebrate diversity in backwaters</li> <li>• Increased density of brown trout</li> </ul>

### Context

The River Glaven has historically been modified for industrial purposes through the creation of water mills. With the exception of Letheringsett Mill, these mills are no longer in use. However, water control structures such as weirs and sluices remain, and these impede the natural river flow. The River Glaven has been severely modified with canalisation and embankments were historically created to protect the adjacent floodplain farmland. Therefore a large area of floodplain is disconnected from the main river system. Coupled with this, some floodplains have been drained to further improve agricultural productivity. The dredging that occurred throughout the 1970s to 1980s in many parts of the channel resulted in the lowering of the channel bed and further disconnections between the river and its floodplain.

### Aims

The aim of this restoration project was to increase hydrological connectivity between the overdeepened, embanked river and its long abandoned floodplain to improve ecological diversity within the river and floodplain. Improvements in river and floodplain biodiversity were thus the primary driver, however, flood peak attenuation was also a goal within the overall objective to improve natural river–floodplain connectivity and associated ecosystem services.

### Timing and location

The restored reach is located in Hunworth Meadows, northern Norfolk, UK. A 400 m reach of river was restored and the works were conducted between 2009 and 2010.

### Measures

Restoration took place at locations that were severely modified and disconnected from the floodplain, therefore measures that improved the form of the river and connectivity to the floodplain were considered. Restoration at Hunworth Meadows took place in 2 phases: during the first phase in 2009, around 400 m of embankments were removed resulting in a 40–80 m wide floodplain area (3 hectares). A second phase of work was conducted in 2010 to improve the river morphology. The

intervention created a narrower and geomorphologically more diverse and meandering channel, with an associated increase of river sinuosity by 16%.

### *Monitoring and evaluation*

Embankment removal and remeandering alongside the River Glaven at Hunworth has created a more natural flood-pulsed hydrological regime, characterised by regular, short duration inundation of the floodplain meadow, with consequent positive effects for river–floodplain ecosystem functioning (e.g. enhanced habitat connectivity and heterogeneity). Before and after control intervention (BACI) surveys of floodplain plants, aquatic macrophytes, benthic invertebrates and fish were carried out, but some results are still to be published. Vegetation surveys recorded a significant increase in macrophytes' richness following the 2 phases of restoration. Remeandering at Hunworth Meadows had no significant impact on stream invertebrate biodiversity, but when invertebrates in backwaters along the floodplain were included, a significant increase in invertebrate diversity was detected, due to the addition of several 'pond-associated' species (Sayer 2014). The backwaters were also colonised by amphibians and these observations demonstrate that the presence of these standing waters significantly enhanced biodiversity in the river–floodplain system. Restoration interventions increased the density and biomass of brown trout (*Salmo trutta*), but had no significant short-term impact on other fish populations (Champkin et al., 2018).

The restoration work had a moderate but detectable effect on flood peak attenuation, owing to the limited length of restoration (Clilverd et al., 2016), and improved free drainage into the river. A coupled hydrological/hydraulic model was utilised to analyse the impact of the floodplain reconnection before and after restoration. Using data from 2007 to 2010, the study found that the removal of the embankment resulted in widespread inundation of the floodplain at high-level flows ( $>1.7\text{m}^3\text{s}^{-1}$ ). Restoration also promoted regular inundation of the immediate riparian area during lower magnitude flood extents. In addition, groundwater levels were slightly higher and subsurface storage was greater.



*Figure 13. Re-meandered reach of the River Glaven at Hunworth: (a) In January 2009, prior to the rehabilitation project, on the left, and in December 2010, after re-creation of meanders in August on the right (source: modified by Champkin et al., 2018).*

### *Conclusion*

A significant aspect of this project is the inclusion of 6 backwaters in the monitoring plan that allow a more appropriate and detailed evaluation of the ecological conditions of the whole river corridor. On the other hand, the results in terms of ecological improvement considering in-channel bioindicators (i.e. benthic macroinvertebrates and fish) were quite limited. The results of this small-scale restoration project are not an isolated case and stress the need for catchment scale combination of measures. Numerous studies have shown that stream rehabilitation does not necessarily translate into significant

improvements in biotic communities, at least in the short term, and this may be attributable to a combination of factors that cannot be addressed by localized river rehabilitation work (e.g. Palmer et al., 2010). One factor that is not addressed by reach-scale rehabilitation is the influence of catchment-scale pressures on rivers (Champkin et al., 2018). River rehabilitation efforts may be more effective if they also concentrate on improving water quality within the upper stretches of small rivers in agricultural catchments to reduce stresses placed on downstream biological communities (Palmer et al., 2010). The spatial scale of the rehabilitation work should thus be proportional to system size (Schmutz et al., 2014).

## SECTION 3 – FINDINGS AND DISCUSSIONS

### 3.1 – Effects of restoration measures

The case studies analysed in the previous sections describe river restoration projects carried out with the aim to meet the objectives of the Water Framework Directive and, in some cases, the Floods Directive. The case studies demonstrate **positive results in the improvement of the ecological conditions of the restored river reaches**. These improvements include for example the abundance, diversity and population structure of specific bioindicators and improvements of hydromorphological conditions or flow regime.

Some of the case studies highlight relevant **improvement in river governance** (i.e. Segura, Turia, Eddleston Water and Eau Blanche and Bocq) or the crucial role of **public participation** (i.e. Orbigo, Segura and Eddleston Water). These provisions of the WFD prove to be key elements for successful river restoration interventions (Morandi et al., 2014).

### 3.2 – Implementation gap

The case studies also point out that an **implementation gap still remains between current restoration measures and the actions required to improve ecological conditions at water body scale**. This gap can be attributed to the:

- **Limited scale of interventions** (half of the case studies being not more than a few kilometres in length), very short with respect to the mean length of the water bodies, most of them being more than 10 or 20 kilometres and up to 30 or 40 kilometres (Champkin et al., 2018).
- **Spatial scale of the water bodies**: too long to catch the results of site-scale interventions.
- **Persistence of pressures** (e.g. water quality, alteration of flow regime and/or sediment and wood flux) in the **upstream catchment** (e.g. the case study of the Eau Blanche and Bocq rivers) (Palmer et al., 2010; Schmutz et al., 2014; Champkin et al., 2018).
- **Lack of funding for large scale interventions**. Half of the case studies are carried out in relatively short river reaches (i.e. less than 5 kilometres), while the median length of the restoration case studies is 10.3 kilometres. It is also worth to underline that the projects that were carried out on longer reaches consisted in the removal of some

transversal structures, as the main measure, and in the establishment of environmental flows, not in the complete morphological restoration of the river reaches. Orbigo case study is the only notable exception.

- **Lack of sensitivity of the monitoring and assessment tools** (i.e. the biotic indices based on the BQEs) to the improved conditions (Friberg et al., 2011; Friberg, 2014; Golfieri et al., 2018). See a detailed analysis of this aspect in paragraph 3.3.

### **3.3 – Monitoring and assessment tools**

The WFD requires the assessment of different organism groups (i.e. benthic macroinvertebrates, benthic diatoms, aquatic macrophytes and fish) called Biological Quality Elements (BQEs) to define the ecological status of rivers. These organisms were selected because they are widely considered good indicators of water quality, the alteration of which was the main pressure acting on rivers in developed countries in the last decades (Armitage et al., 1983; Friberg, 2014).

Recent studies showed that BQE-based metrics and indices that were developed for the implementation of the WFD and that are used for standard assessment and monitoring are sensitive to water quality alteration and general habitat degradation. Conversely, their response to hydromorphological degradation is generally weak or absent (Hering et al., 2006; Friberg et al., 2009; Marzin et al., 2012; Dahm et al., 2013). Moreover, the effects of river restoration actions showed contrasting results on the BQEs richness and abundance (Kail et al., 2015). The other significant shortcoming of the WFD-compliant biotic indices is that their standard application is limited to flowing channels, i.e., sampling sites are generally located along the main channel, and side channels and lentic sites within the river corridor are not considered within the sampling protocols (Golfieri et al., 2018).

The **need for an appropriate assessment of the entire fluvial corridor** that also considers the lateral dimension of the river system, has become a priority for both the scientific community and water managers in recent years (Reyjol et al., 2014). It is evident that relying exclusively on the BQE-based indices and metrics does not allow a comprehensive assessment of the ecological conditions of the whole river corridor, in particular in large multiple-thread river systems (Golfieri et al., 2018), but also in smaller systems (e.g. chalk fed River Glaven case study). An incomplete evaluation could lead to incorrect planning in

river management and restoration actions. The application of promising biotic evaluation tools based on functional traits or indicators of ecosystem functioning might provide deeper insights into the assessment of river conditions, particularly in the context of multiple pressures (Carvalho et al., 2019).

In addition to BQEs, other bioindicators have been used to evaluate the condition of riparian areas and floodplains, such as amphibians, ground beetles, riparian vegetation and dragonflies (Munné et al., 2003; Jähnig et al., 2009; Gumiero et al., 2015, Sayer, 2014; Simaika and Samways, 2009). The latter taxon is of particular interest as in recent years several dragonfly-based indices were developed across Europe to assess the condition of streams and wetlands according to the WFD requirements and classification scheme.<sup>1</sup>

In this report, half of the considered restoration case studies included in their monitoring plan the assessment of additional bioindicators and/or considered also the backwaters but only in two case studies (i.e. Cofio and Segura) the assessment was carried through the application of a WFD-compliant index (i.e. the QBR, Índice de calidad del bosque de ribera) which is also considered in Spanish national legislation. The two other case studies based the additional monitoring activity on the presence of a flagship species (the otter, Eddleston Water) and the sampling of different bioindicators (i.e. aquatic macrophytes, benthic macroinvertebrates, dragonflies and amphibians) in backwaters in Glaven case study.

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<sup>1</sup> The Dragonfly Association Index in Austria (Chovanec et al., 2015), the “Odonata Community Index – Corsica” in France (Berquier et al., 2016) and the Odonate River Index in Italy (Golfieri et al., 2016).

## SECTION 4 – INFORMATION SOURCES

The screening of the case studies is mainly based on the following sources. Some of the documents are not available in English.

Eau Blanche and Bocq (Belgium): LIFE Project Number LIFE07 ENV/B/000038 “Walphy” FINAL Report.

Drac (France): Technical note about the monitoring of hydromorphological restoration of the Upper Drac River (Hautes-Alpes, France). Report of the INTERREG “Alpine Space” project HyMoCARES. Irstea and Conseil Départemental des Hautes-Alpes.

Cofio (Spain): Seguimiento del Estado Ecológico del Río Cofio tras la demolición de la presa de Robledo de Chavela. Confederación Hidrográfica del Tajo. Years 2016, 2017, 2018.

Orbigo (Spain): Natural Water Retention Measures – Case study: Órbigo River ecological status improvement (Stretch I): Duero River Basin.

Segura (Spain): Departamento Inspección y Control Ambiental, Área de Control de Vertidos y Calidad de Aguas. Informe Final 2015-2017. Programa de Monitoreo del Estado Ecológico y Análisis de Sedimentos en el ámbito de actuación del Proyecto Europeo LIFE+ “Segura Riverlink”(LIFE12 ENV/ES/1140).

Turia (Spain): Andreu J., Ferrer-Polo J., Pérez M.A., Solera A., 2009. Decision Support System for Drought Planning and Management in the Jucar River Basin, Spain. 18th World IMACS / MODSIM Congress, Cairns, Australia.

Eddleston Water (United Kingdom): Case study 9. Eddleston Water Project. Working with natural processes to reduce flood risk by the UK Environmental Agency.

Glaven (United Kingdom): Case study 5. River Glaven, North Norfolk. Working with natural processes to reduce flood risk by the UK Environmental Agency.

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