

An aerial photograph of a river meandering through a vibrant green landscape. The river flows in a series of loops and curves, surrounded by dense vegetation and trees. The water is a dark, calm blue-grey color. The overall scene is lush and natural.

THE POTENTIAL OF BARRIER REMOVAL TO RECONNECT EUROPE'S RIVERS



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EXECUTIVE SUMMARY

European rivers are the most fragmented in the world, leading to the loss of critical biodiversity, and driving fish and other freshwater species towards extinction.

In 2020, the EU-funded AMBER project recorded over 600,000 barriers on rivers and streams across Europe and estimated that the total number of barriers may be more than 1 million. This suggests the necessity of further improvements to the river continuum to overcome the massive fragmentation of rivers.

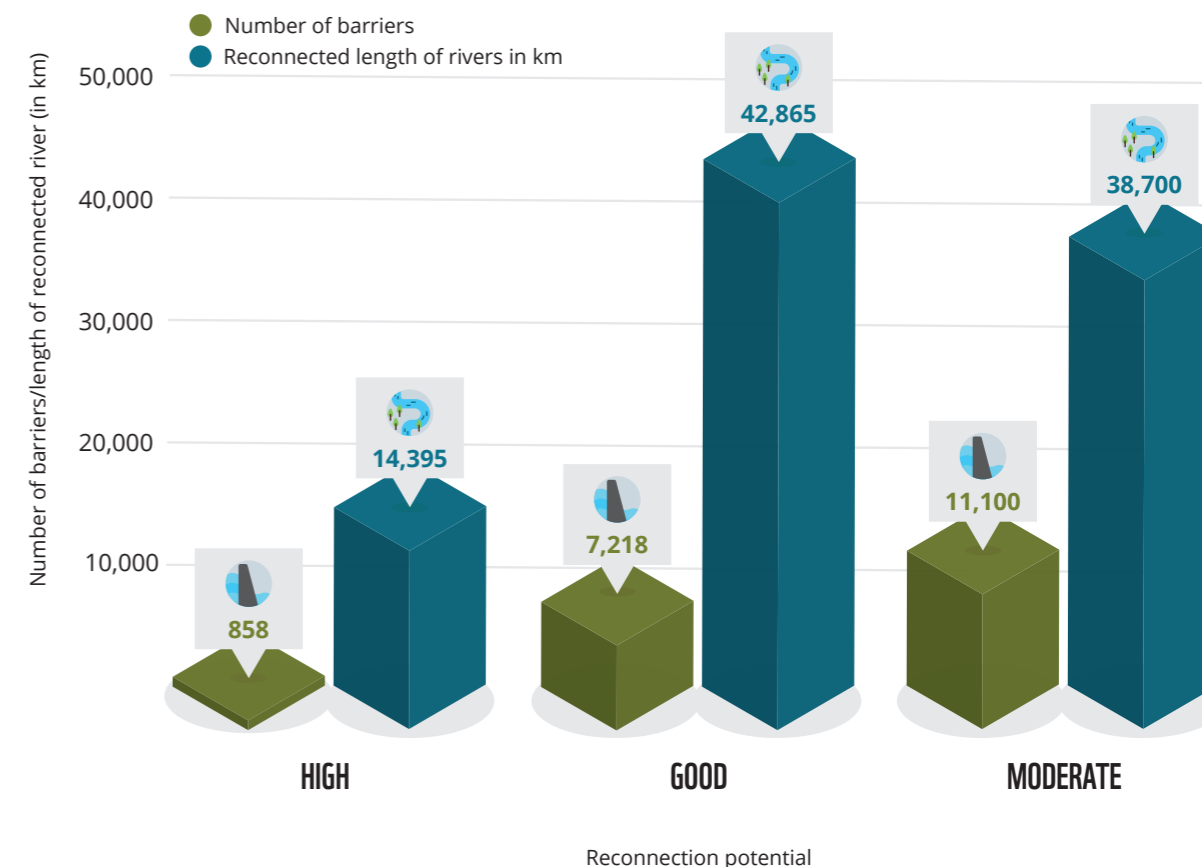
The removal of river barriers—namely ramps, weirs and dams—is a significant and effective measure to restore the river continuum for biota and sediment, as proposed by the EU Biodiversity Strategy for 2030.

This study proposes an initial assessment of the number of river barriers in Europe which could be prioritised for removal and the expected outcome of such removal, based on a sample of 30,000 barriers (less than 3% of the total estimated number of barriers) in large and medium-sized rivers. The report focuses on the reconnection potential, i.e. the length and the ecological quality of reconnected rivers which could be achieved through barrier removal. Some of the barriers with particular uses, such as drinking water reservoirs or hydropower plant of a capacity > 10MW, are excluded where feasible.

Out of over 30,000 assessed barriers along larger rivers across Europe¹, the study identifies 858 barriers with high reconnection potential in large and medium-sized rivers, which would allow to reconnect about 14,400 km of rivers. In the EU27, this figure would amount to 732 barriers with high reconnection potential, allowing to reconnect 11,500 km of rivers.

1. Excluding Russia and Caucasus.

Figure 1: Distribution of barriers with reconnection potential in Europe



In addition, the analysis also identifies another 7,200 barriers in Europe (6,600 in the EU) with at least a good potential which would allow to reconnect some 42,900 km (37,000 in the EU), while another 11,100 barriers have a moderate potential and would allow to reconnect 38,700 km. The other 11,000 barriers were not prioritised, after review, partly due to incomplete data.

The barriers and candidates for removal are not equally distributed across the continent. While in general the barrier density is the highest in Central and Western Europe, with peaks in the mountainous areas of the Alps, less barriers can be found in Eastern Europe, the Balkan region and Scandinavia, which therefore influences the absolute numbers of prioritised barriers. In the Mediterranean region, a lot of reservoirs have been constructed over decades.

The calculation of the reconnection potential is based on a set of criteria including the length of reconnected river, the land use (natural habitats along the rivers which can be reconnected), the riparian zone (floodplain) along the reconnected river stretch, the protection status of the reconnected river stretch, as well as the position of the barrier inside a protected area. Those criteria illustrate how important it is to consider the benefits of barrier removal not only in term of longitudinal continuity, but also

in terms of hydromorphological improvements and restoration of lateral connectivity (e.g. reconnection of floodplains and wetlands).

Removing the barriers identified with high and good potential can therefore offer significant benefits in terms of restoring natural flow, sediment transport and allowing migration for aquatic species, but also in terms of improving freshwater and riparian habitats. Their removal can make a significant contribution to the achievement of the EU nature restoration target, and the achievement of good ecological status or potential (the EU Water Framework Directive's main objectives).

The study delivers a first entry point to bring the discussion of barrier removal to a wider audience and to support European and national authorities in the planning of barrier removal. As most of the European water authorities are already engaged in barrier removal, mainly for small rivers, this study can also shed some light onto larger rivers and structures where removal would bring increased benefits.

This study focuses on one dimension of removal: the reconnection potential. Additional studies are recommended to continue improving the prioritisation, including to consider the functionality of barriers in a more granular way, and to include small rivers which are often critical ecosystems.

1. INTRODUCTION

The removal of dams, weirs and other longitudinal river barriers has progressively emerged in the last two decades in North America and Europe as a valuable tool to restore our critically endangered rivers. This was prompted by three realisations. Firstly, artificial barriers were severely threatening freshwater ecosystems, due to impeded fish migration and the disruption of river flow. Secondly, freshwater ecosystems were found to recover rapidly after a barrier removal.² Thirdly, many dams are getting old and are left abandoned, without any further use.³

With the EU 2030 Biodiversity Strategy commitment to restoring connectivity in at least 25,000 km of rivers in the next decade through the removal of primarily obsolete barriers and the restoration of floodplains and wetlands, the European Commission gained further traction. The issues at stake were high: **barriers in rivers constitute a significant pressure for about 20 % of European surface water bodies (34% regarding hydromorphological alterations in general) and they are one of the main reasons for rivers failing to reach good ecological status.**⁴ They are also among

the main reasons causing the use of article 4(7) exemption to the EU Water Framework Directive and the designation of rivers as Heavily Modified Water Bodies.⁵ According to the *AMBER* Atlas of barriers, an estimated 1 million obstacles – dams, weirs, culverts – disturb the free movement of water, sediments, animals and plants across Europe.

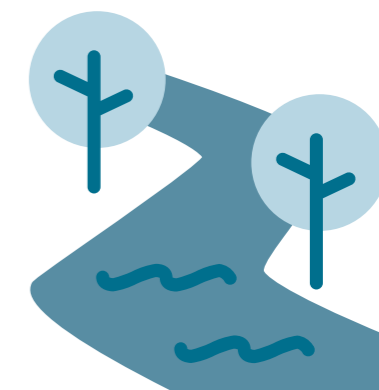
While offering a significant opportunity to reconnect and recover rivers through barrier removal, the EU free-flowing rivers restoration targets opens many questions: How many barriers would have to be removed to reach the target of 25,000 km of free-flowing rivers reconnected in the upcoming decade? Most importantly, how are those barriers to be prioritised?

As hinted by the EU Biodiversity Strategy, abandoned or obsolete barriers – amounting to 100,000 across Europe according to *AMBER* estimates – might offer the most obvious pool of possible candidates for removal. Prioritising obsolete barriers, barriers which could soon become obsolete, or for which the maintenance investments are too high compared with demolition, can indeed ensure that socio-economic trade-offs are minimised and that other

less conflictive and less impacting alternatives can be considered. Those approaches are absolutely essential. **Another – complementary – approach to prioritisation consists in looking at how to maximise the ecological benefits of the restoration.**

The current study looks at the whole of Europe and chooses to focus on the ecological quality of the reconnection which can be achieved through the removal of longitudinal barriers. The length of reconnected river stretch, the hydromorphological conditions as well as the position of the barrier within the drainage network and the location in protected areas are taken into account.

The study explains the methodology used for the prioritisation and the steps of the analysis (part 2) and presents the results for Europe, the EU27 countries, as well as the main geographical regions (part 3). Final conclusions are drawn to sort results, show technical limitations and to give further recommendations (part 4).



THE CURRENT STUDY LOOKS AT THE WHOLE OF EUROPE AND CHOOSES TO FOCUS ON THE ECOLOGICAL QUALITY OF THE RECONNECTION WHICH CAN BE ACHIEVED THROUGH THE REMOVAL OF LONGITUDINAL BARRIERS.

² Hermoso et al (2021), An accessible optimisation method for barrier removal planning in stream networks, *Science of the Total Environment*. Volume 752, 141943.

³ Perera, D., Smakhtin, V., Williams, S., North, T., Curry, A., 2021. Ageing Water Storage Infrastructure: An Emerging Global Risk. *UNU-INWEH Report Series*, Issue 11. United Nations University Institute for Water, Environment and Health, Hamilton, Canada.

⁴ European Environmental Agency, briefing Tracking barriers and their impacts on European river ecosystems, February 2021. *Comment*: Out of 34 % of surface water bodies where hydromorphological pressures are a significant pressure, 20 % failed to reach good ecological status because of the presence of barriers.

⁵ The first three categories of projects causing the highest number of article 4.7 exemptions to the WFD environmental objectives are somehow linked to barriers: impoundments for drinking water supply, flood protection schemes, and hydropower. Similarly, two of the first three activities for which water bodies are being designated as Heavily Modified Water Bodies (allowing them to only reach "good ecological potential" instead of "good ecological status") are linked to barriers (flood protection and hydropower). Source: European Commission, SWD, "European Overview – River Basin Management Plans", 2019

2. METHODOLOGY AND ASSESSMENT

2.1 A FOCUS ON THE RECONNECTION POTENTIAL

The prioritisation of barriers to be removed is primarily based on the reconnection potential more than on any other factors, and in particular, on data on the barriers themselves. The reconnection potential, as detailed in the table below – was preferred for several reasons.

A first reason is that prioritising the reconnection potential gives an indication of the efforts needed to achieve the 25,000 km target set at European level, and brings clarification on what this commitment should entail.

It makes it clear that when considering barrier removal, not only the length of the reconnected river should be considered, but also the ecological quality of the reconnection, including the restoration of connected floodplains, wetlands and riverbanks. It also serves as a complementary approach to the prioritisation of the removal of “obsolete” structures.

Another reason is linked to feasibility: concise data availability on barriers is still low and uneven at European level and must be improved for a further prioritisation.

PRIORITISING THE RECONNECTION POTENTIAL GIVES AN INDICATION OF THE EFFORTS NEEDED TO ACHIEVE THE 25,000 KM TARGET SET AT EUROPEAN LEVEL, AND BRINGS CLARIFICATION ON WHAT THIS COMMITMENT SHOULD ENTAIL.



Table 1: Main criteria used for the prioritisation of barriers in this study

PRIORITISATION CRITERIA	DESCRIPTION AND REASONS FOR SELECTION
Length of reconnected river	Gives the measured length of continuously free flowing river stretch upstream ⁶ , important for fish migration and sediment transport.
Share of natural habitat coverage in the reconnected river stretch	Measured within a buffer around the reconnected river stretch, provides an indicator for hydromorphology or in general the intactness of the river.
Share of riparian zone (floodplain ⁷) in the reconnected river stretch	Additional indicator for the importance of upstream river stretch regarding floodplain reconnection (which is vital for fish spawning, habitat restoration, and sediment retention/remobilisation). Also measured within a buffer around the reconnected river stretch.
Share of the reconnected stretch included in a protected area	Another indicator for the intactness and ecological importance of the upstream river stretch to be reconnected, also measured within a buffer around the reconnected river stretch.
Position of the barrier in a protected area	Prioritises barrier removal within a protected area.

⁶ Considering only the length of the river section upstream of the removed barrier seemed to provide the most accurate estimate of the effects of barrier removal, especially in the case of removal of several successive barriers.
⁷ Floodplain and riparian zones are used here as synonymous.



Although the function of the barriers is a very important factor in the decision of removing a barrier, for feasibility reasons this parameter could only be addressed to a limited extent in this study, through the following filters:

- Hydropower plants of a capacity of >10 MW are excluded in a vast majority of cases;
- Drinking and irrigation barrages are also mostly excluded;
- The general conditions, estimation of structures (good, moderate, poor) were only considered in the initial assessment and for the final screening of the candidates in the highest class.

2.2 SCOPE OF THE STUDY: ABOVE-WATER BARRIERS IN LARGER EUROPEAN RIVERS

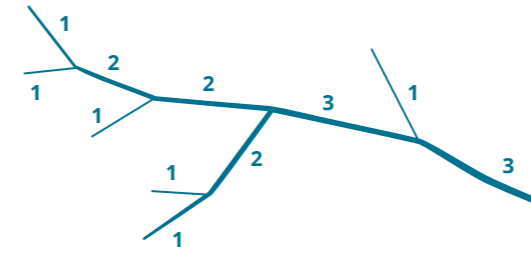
Geographical scope: The study covers the entire Europe (excluding Caucasus and Russia). It includes several climatic zones and numerous bioregions, and is comprised of a large variety of river types and sizes.

To provide a better overview of the results, 6 subregions were defined (an analysis by country is included in section 3):

1. Iberian Peninsula (Andorra, Portugal, Spain)
2. Central Western European region (Belgium, France, Germany, Ireland, Italy, Luxembourg, Malta, Monaco, the Netherlands, San Marino, Switzerland, United Kingdom)
3. Northern European region, Scandinavia (Denmark, Finland, Iceland, Norway, Sweden)
4. Central Eastern Europe, Danube region (Austria, Czech Republic, Hungary, Romania, Slovakia)
5. Eastern European region with Baltic countries (Belarus, Estonia, Latvia, Lithuania, Moldova, Poland, Ukraine)
6. Balkan and Eastern Mediterranean region (Albania, Bosnia & Herzegovina, Bulgaria, Croatia, Greece, Kosovo, Macedonia, Montenegro, Serbia, Slovenia, Turkey)

Size of rivers: The study focuses on large and medium-sized rivers resulting from several successive confluences since the headwater tributaries (hydrological Strahler order > 3, as shown by the figure below). The smallest assessed rivers are of approximately 30 km length but most of them are much longer.

Figure 2: Strahler stream order. For the present study, only rivers of order 3 and more are considered.



The focus of this study on large and medium-sized rivers does not mean that small rivers are not important. On the contrary, small rivers are critical ecosystems which provide some of the most abundant and diverse aquatic habitats.

Type of barriers considered: 30,000 barriers are addressed in this study. This corresponds to less than 3% of all river barriers in Europe⁸, although it covers a majority of the barriers in large and medium size rivers. The study started

⁸ AMBER project, <https://amber.international/>

with a screening of hydropower plants mapped in the 2019 hydropower inventory (Schwarz 2019a), from the river mouth towards upstream, and also includes most of the major barriers serving for other purposes than hydropower such as weirs, ramps, sills or sluices along navigable rivers (no culverts and fords at bridges and road crossings), as further described in section 2.3.

In general, all barriers above 50 cm in height are included (some smaller ones in coastal areas). Medium-sized and large hydropower plants⁹ (with a few exceptions as proposed by partners) and drinking water reservoirs (as far as possible) have been excluded at this first stage to ease the comparison between different EU Member States. Also, as these infrastructures are usually sensitive to public opinion and decision-makers, we consider that they are less prone to be removed at this first stage, and we decided to prioritise other more feasible barriers currently. Barriers equipped with operational fish passes are not entirely excluded as in most cases coarse sediment (bed load) cannot pass those structures and the functionality of fish passages is always much lower than a free flowing stretch.

⁹ For this study, the following definitions are used:
 - Small hydropower plants: capacity < 10 MW
 - Medium-sized hydropower plants: capacity 10-50 MW
 - Large hydropower plants: capacity > 50 MW

Table 2: Type of barriers included in the analysis

THE STUDY INCLUDES	THE STUDY DOES NOT INCLUDE
<ul style="list-style-type: none"> ⊕ Longitudinal barriers, built for various purposes, namely ramps, weirs and dams ⊕ Barriers > 0,5 meters in height¹⁰ ⊕ Some barriers equipped with fish passes 	<ul style="list-style-type: none"> ⊖ Hydropower plants above 10MW ⊖ Drinking water reservoirs ⊖ Culverts and fords (mostly bridges and road crossings) ⊖ Lateral barriers such as flood dykes ⊖ Barriers < 0,5 meters height

¹⁰ Where specific information was available, some barriers < 50 cm were included for coastal areas and lowlands.

Even for some of the 30,000 barriers included in this study, some limitations were encountered as data on barrier type and height or even age is very heterogeneous, including in the AMBER data set. The assessment is therefore based on the most important conditions of river stretch upstream to be reconnected, in combination with a final visual interpretation of the barriers (see section 2.3). We recommend expanding the analysis at national and basin level.

For instance, the condition (age and shape) of barriers could only be estimated for some 1,000 barriers (as “good”, “moderate” or “poor”) as based on visual impression out of the high resolution satellite images and available ground images in Google Earth. It was therefore not included as a criteria for the prioritisation, but only used at the end of the assessment for the individual check of the barriers with high reconnection potential. Likewise, the functionality of the barriers (whether they are obsolete or not; or the level of siltation in reservoirs) could not be estimated. The type of barrier (ramp, weir, dam) was only available for some 40% of all 30,000 barriers assessed in this study, and their purpose (e.g. hydropower, navigation, irrigation, erosion control) for only some 25% of the barriers, so this information was not considered for the prioritisation.

2.3 INVENTORY AND ASSESSMENT OF POTENTIAL CANDIDATES FOR BARRIER REMOVAL

Methodology, step 1: Inventory and assessment of potential candidates for barrier removal

The study follows a two-step approach. For the first step, an initial assessment was prepared, mainly based on visual interpretation of high resolution images and expert judgment as well as a first qualitative assessment made by the WWF network, which also provides additional candidates.

The initial assessment of the study is based on the following datasets:

- Data from the 2019 hydropower inventory (existing plants and those under construction) of about 23,000 barriers, amended by:
 - o Individual survey/satellite analysis for 1,150 barriers,
 - o improved in particular for Mediterranean (reservoirs for other purposes than HPP) by GOODD and GRanD data sets¹¹ (some 500 additional)

¹¹ <http://globaldamwatch.org/data/>

- “Validated” AMBER data¹²
- Detailed data provided by WWF partner organisations for Austria, Germany, the Netherlands, Romania, Slovakia, Spain and Switzerland for some 100 priority projects.

Due to data availability or heterogeneity of data, some choices had to be made. Only the categories “dams” (about 61,000) and “weirs” (125,000) of the AMBER dataset were used, even though many “others” could be also relevant. Those barriers were further reduced to larger rivers (above Strahler 3 level) to some 11,000 barriers. The quality of AMBER data is very heterogeneous, and the country-specific definitions of categories “dams, weirs and others” can differ significantly. In addition, only for 50% of the structures listed in the AMBER atlas the height of structure is known. Finally, the AMBER dataset was cleaned up (as far as possible and as far as it is relevant for the reduced set of barriers of this study) to avoid having different barriers identified for one obstacle (for instance in the case of a dam and a weir located at the same place).

All together the entry raw barrier dataset contains some 30,000 barriers.

Methodology, step 2: Extended GIS analysis including reconnection, riparian zones and land use

In a second step, an extended GIS analysis was conducted based on the datasets of drainage network, riparian zones, land use and protected areas provided by the EU Copernicus land data system, and on complimentary datasets (if available) for countries outside the EU.

As comparable hydromorphological data is missing for the whole of Europe, a very general approach has been applied to characterize the potentially reconnected river stretch.

The following core data sets were used:

- As base drainage/river datasets, European hydrological data¹³ (plus some complementary data for Eastern Europe) was used.
- Corine¹⁴ land use classes served to estimate the hydromorphological status and natural habitat coverage of reconnected river stretches. If any kind of forests or grasslands prevail for the stretch (>50% cutting area of a 600 m buffer around the rivers), it can be assumed to have better conditions. The following Corine classes are covered:

¹² Originally the database includes 630,000 barriers. Due to field testing and calibration the Amber project expects > 1 million barriers in Europe (Belletti et al. 2020).

¹³ <https://land.copernicus.eu/imagery-in-situ/eu-hydro/eu-hydro-river-network-database>

¹⁴ <https://land.copernicus.eu/pan-european/corine-land-cover>

- o All kind of forests (CLC 311-324), sparsely vegetated areas, namely sand and gravel river beds (braided rivers)
- o rock faces (CLC 331-335, excluding 334 for burned areas)
- o all kind of wetlands (CLC 411-423)
- o waters, but excluding “standing water/lakes (including many dam reservoirs)” with exception for Scandinavia where lakes are very frequent naturally within the river continuum (CLC 511-522)
- o For the non-EU and “non-Corine” countries Belarus, Ukraine and Moldova the complementary older land use classification Pelcom¹⁵ was used. While the resolution is strongly limited with 1 km², but sufficient to allow a general estimation. The classes 11-20 represent all kind of forests and natural grasslands while 80 and 91 cover wetlands and inland waters respectively.
- Riparian zones¹⁶ data were served to estimate the occurrence of potential floodplains as general indicator for the ecological importance of the river reach upstream.
- Protected areas data: The Natura 2000¹⁷ datasets and World Database on Protection Areas (WDPA)¹⁸ as well as other categories such as national parks, Ramsar sites, World Heritage sites and Biosphere reserves were used. For a given barrier or river stretch, the highest applicable category of protection was retained.

¹⁵ <http://www.geo-informatie.nl/projects/pelcom/public/index.htm>

¹⁶ <https://land.copernicus.eu/local/riparian-zones/riparian-zones-delineation>

¹⁷ <https://www.eea.europa.eu/data-and-maps/data/natura-11>

¹⁸ <https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA>

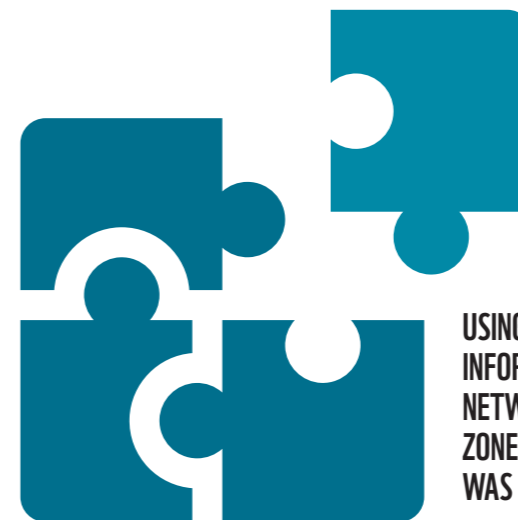
- Elevation, slope and erodability¹⁹ data allow a very general estimation if sediment transport plays a significant role for the respective barrier.

The 30,000 barriers identified at the end of step 1 were subdivided into the six geographical regions (Iberia, CWE, Scandinavia, Baltic and Eastern Europe, CEE/Danube region, Balkan and Eastern Mediterranean).

Using the datasets indicated above, information related to the drainage network, protected areas, riparian zones, land use, and sediment transport was matched to each barrier. River buffer polygon segments of a total width of 600 meters (300 meters on each bank) were defined to cover riparian zones, land use, and protected areas.

For each of the prioritisation criteria, scores were attributed based on the reconnection potential as well as the ecological quality of reconnection lengths, the position of barriers in a protected area, and finally the more detailed proposals of step one and qualitative assessment made by the WWF network, as detailed in the table below.

¹⁹ https://esdac.jrc.ec.europa.eu/events/Conferences/2015/SoilErosion_EGU2015.pdf



USING THE DATASETS INDICATED ABOVE, INFORMATION RELATED TO THE DRAINAGE NETWORK, PROTECTED AREAS, RIPARIAN ZONES, LAND USE, AND SEDIMENT TRANSPORT WAS MATCHED TO EACH BARRIER.

Table 3: How each individual barrier was scored based on the prioritisation criteria

PRIORITISATION CRITERIA	RANGES	SCORES	CALC 1	CALC 2	CALC 3
1 – Length of reconnected river	0.5-<10 km	3	Arithmetic mean of all three reconnection stretch parameters (2a, 2b, 2c)	Arithmetic mean of length (1) and Calc 1	In case barrier is NOT inside a PA (3): Calc 3 = Calc 2 In case barrier is inside a PA (3): Calc 3 = Calc 2 minus 0.1*
	10-<20 km	2			
	> 20 km	1			
2a – Share of natural habitat coverage of reconnected river stretch as indicator for hydromorphological intactness within buffer	0-<30 percent coverage	3			
	30-<70 %	2			
	70-100%	1			
2b – Share of potential riparian zone within buffer	0-<30 percent coverage	3			
	30-<70 %	2			
	70-100%	1			
2c – Share of the reconnected stretch included in a protected area within buffer	0-<30 percent coverage	3			
	30-<70 %	2			
	70-100%	1			
3 Position of the barrier in a protected area	If inside of protected area: bonus of -0.1				

*if Calc 2=1 (1-0.1=0.9) the bonus is omitted (=1)

After the calculation of length in three classes (1), in a first step (Calc 1) the values for the buffer of reconnection stretches (2a, 2b, 2c) are calculated and summarized as arithmetic mean value (calculation includes only available parameters). In a second step (calc 2) the arithmetic mean is built out of the length (1) and buffer (2a-c) to have the score for the reconnection stretch.

Finally in a third step (calc 3), the result can get a bonus of “-0.1” if the barrier itself is located inside a protected area (which might be facilitating the removal). The final score is between 1 (best result) and 3. Based on the scoring results, barriers were finally put into three assessment categories according to table 4 below.

Table 4: Final classification of barriers depending on scoring results

ASSESSMENT CATEGORIES	SCORING RESULTS
Barriers with high reconnection potential	scores 1-<1,7
Barriers with good reconnection potential	scores 1,7-<2,3
Barriers with moderate reconnection potential	scores 2,3-3

11,000 barriers were excluded from the prioritization into high, good or moderate potential, because of their size (too big/too small/feasibility check after final review) for approximately half of the excluded barriers, and because of missing data for the other half, as the barriers were too close to each other (mainly small barriers coming from AMBER). This does not mean that those barriers have no reconnection potential, just that their potential was not assessed.

Finally the additional indications by the WWF network, as well as those based on the first initial visual assessment were applied to the respective barriers (about 500) and overrule the assessment, but in most cases the assessment matches the proposals.

Methodology, step 3: Final review of barriers with high reconnection potential

The barriers with high reconnection potential were finally checked individually by high resolution images. Large dams (> 10 m height), sluices and huge multipurpose barriers on the one side, but also very small barriers (small sills and shallow ramps which are partly passable) were either excluded from the prioritisation (when they obviously were too big/massive or too small/passable) or downgraded to “good reconnection potential” or “moderate reconnection potential” (when their reconnected stretch upstream receives a high evaluation, but the structure seemed to be more difficult to remove).

3. RESULTS

The results are organised in four sections. First the overall results for Europe as a whole, secondly for the EU, and thirdly in six geographical regions. Results are discussed in a fourth section.

3.1 EUROPE AS A WHOLE

Out of over 30,000 barriers across Europe analysed for this study, nearly 860 barriers are identified with high reconnection potential, which would allow to reconnect 14,400 km of rivers.

Another 7,200 barriers with at least a modelled good potential which would allow to reconnect 42,900 km of rivers were identified. Finally, another 11,100 of the analysed barriers have a moderate potential, with 38,700 km.

The calculated average length of reconnected rivers per barrier removal drops after the full assessment, from the highest class with 17 km, over the good with 6 km, and then down to the moderate class at 3 km, showing impressively the extremely dense and adverse fragmentation of European rivers.

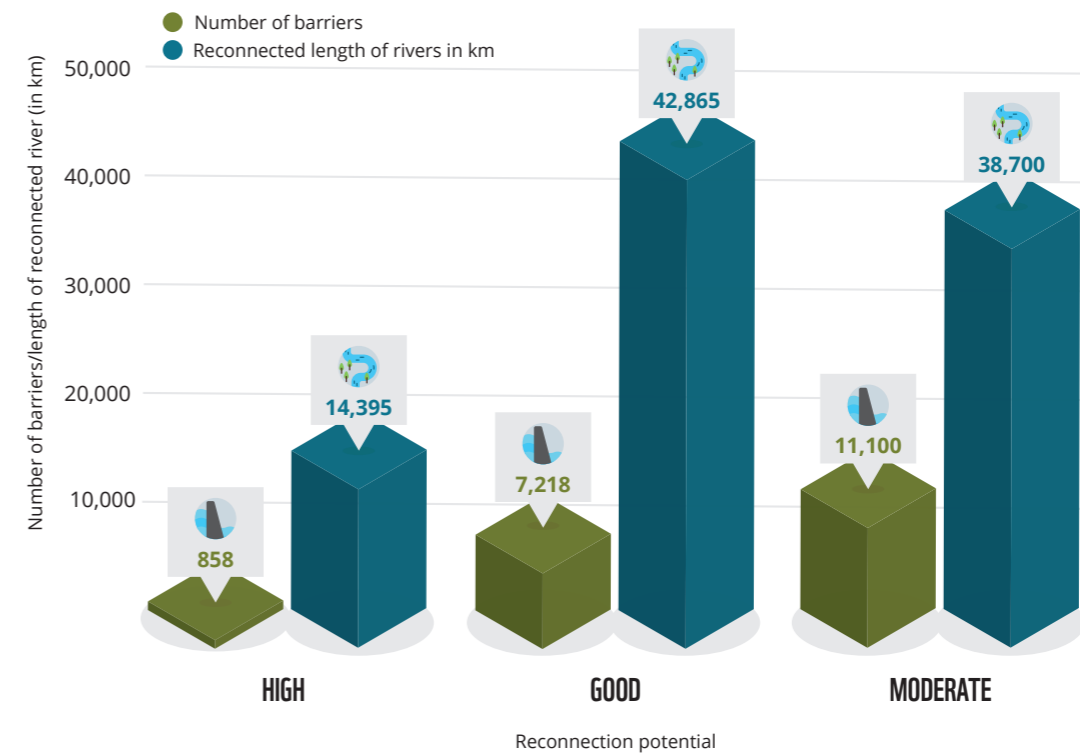
OUT OF OVER

30,000

BARRIERS ACROSS EUROPE ANALYSED FOR THIS STUDY, NEARLY 860 BARRIERS ARE IDENTIFIED WITH HIGH RECONNECTION POTENTIAL, WHICH WOULD ALLOW TO RECONNECT 14,400 KM OF RIVERS.



Figure 3: Total distribution of barriers with removal potential covered in the analysis



The following tables summarize the distribution of potential candidates and reconnection length per country. Unsurprisingly, in western European countries, the density and therefore the removal

potential by number is the highest. In Eastern and some northern and south-eastern Europe, rivers are still less interrupted and a lower number of barriers would reconnect often longer river stretches.

Table 5: Number of barriers with removal potential per country

	HIGH	GOOD	MODERATE	TOTAL
Albania	2	49	78	129
Andorra			13	13
Austria	13	438	1685	2136
Belarus	1	3	3	7
Belgium	3	24	51	78
Bosnia & Herzegovina	2	27	64	93
Bulgaria	14	95	62	171
Croatia	2	15	17	34
Czech Republic	6	197	364	567
Denmark	2	7	15	24
Estonia	1	1	1	3
Finland	18	22	14	54
France	103	832	981	1916
Germany	54	974	2276	3304
Greece	8	26	16	50
Hungary	11	62	31	104
Iceland			1	1
Ireland	10	20	11	41
Italia	25	428	939	1392
Kosovo	1	21	13	35
Latvia	4	7	7	18
Lithuania	6	7	10	23
Luxembourg	2	2	1	5
Moldova		1	6	7
Montenegro		5	9	14
Netherlands	4	5	10	19
North Macedonia	1	23	24	48
Norway	24	86	76	186
Poland	57	376	253	686
Portugal	31	152	132	315
Romania	28	116	137	281
Serbia	5	31	39	75
Slovakia	13	44	47	104
Slovenia	3	47	107	157
Spain	239	2209	2975	5423
Sweden	75	522	182	779
Switzerland	15	52	155	222
Turkey	17	36	10	63
Ukraine	20	52	49	121
United Kingdom	38	204	236	478
	858	7218	11100	19176

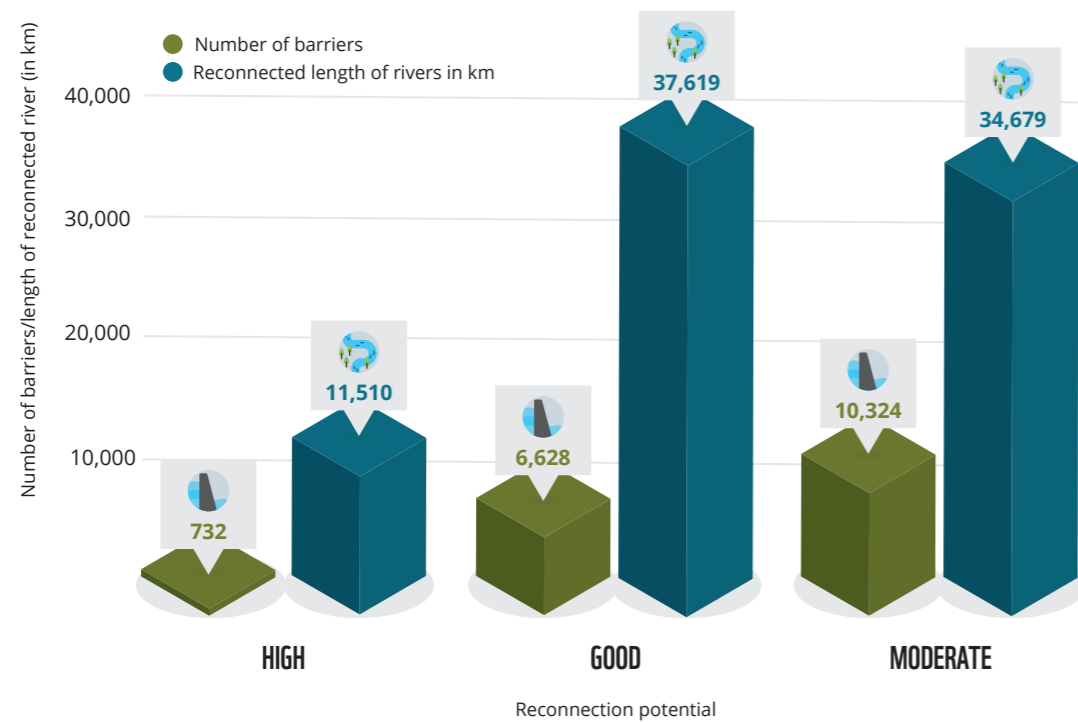
Table 6: River reconnection potential per country (in km)

	HIGH	GOOD	MODERATE	TOTAL
Albania	62	201	289	552
Andorra			24	24
Austria	65	1421	4138	5624
Belarus	44	51	22	117
Belgium	35	216	240	491
Bosnia & Herzegovina	51	236	250	537
Bulgaria	279	714	330	1324
Croatia	37	154	132	322
Czech Republic	129	1305	1400	2834
Denmark	34	45	87	165
Estonia	41	64	2	107
Finland	393	320	162	875
France	1885	6243	4591	12719
Germany	476	5037	7799	13312
Greece	75	192	83	349
Hungary	312	741	292	1345
Iceland			3	3
Ireland	180	230	45	456
Italia	540	3113	2884	6537
Kosovo	20	118	41	179
Latvia	231	88	92	411
Lithuania	232	148	96	476
Luxembourg	8	5	1	13
Moldova		28	80	108
Montenegro		30	46	76
Netherlands	77	60	58	194
North Macedonia	12	129	104	244
Norway	489	663	503	1655
Poland	1459	3506	1321	6286
Portugal	433	830	478	1741
Romania	727	978	582	2288
Serbia	142	287	166	595
Slovakia	143	481	250	873
Slovenia	80	197	333	610
Spain	2261	7544	8101	17906
Sweden	1379	3988	1182	6549
Switzerland	134	281	619	1035
Turkey	619	426	105	1150
Ukraine	595	865	537	1998
United Kingdom	718	1932	1231	3881
	14395	42865	38700	95961

3.2 THE EU27 COUNTRIES

In the EU27, this figure would amount to 732 barriers with high reconnection potential, allowing to reconnect 11,500 km of larger rivers. The good and moderate groups of barriers based on the modelling should be understood as a pool for further potential candidates, namely out of the good group with 6,628 candidates and 37,600 km reconnection potential.

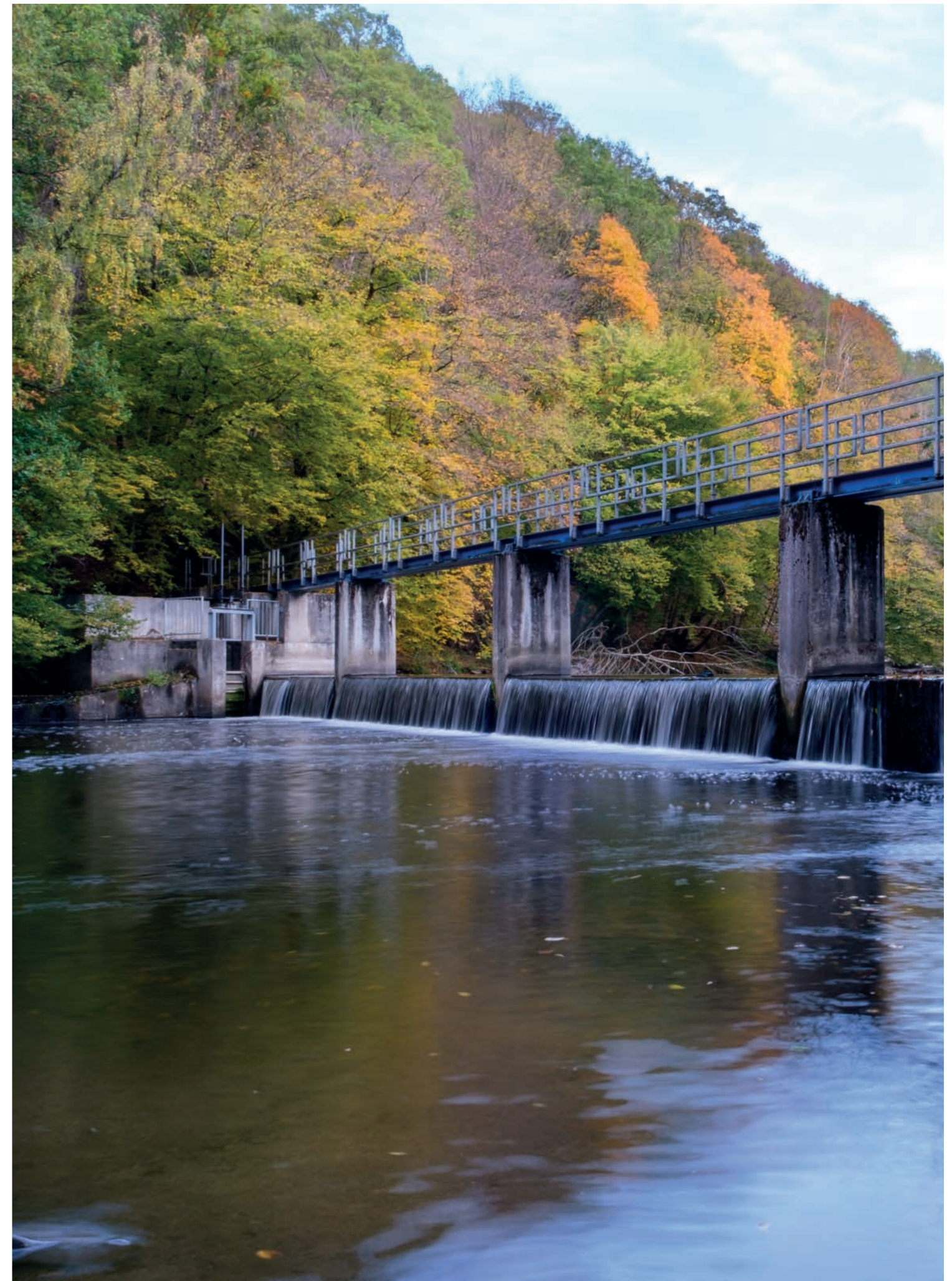
Figure 4: Distribution of barriers with removal potential in the EU27



3.3 REGIONAL RESULTS

The results are sorted into six geographical regions (from west to east) with a final overall analysis for each one:

1. Iberian Peninsula (AD, PT, ES)
2. Central Western European region (BE, FR, DE, IE, IT, LU, MT, MC, NL, SM, CH, UK)
3. Northern European region, Scandinavia (DK, FI, IS, NO, SE)
4. Eastern European region with Baltic countries (BV, EE, LV, LT, MD, PL, UA)
5. Central Eastern Europe, Danube basin (AT, CZ, HU, RO, SK)
6. Balkan and Eastern Mediterranean region (AL, BA, BG, HR, GR, MK, RS, SL, TR, XK)



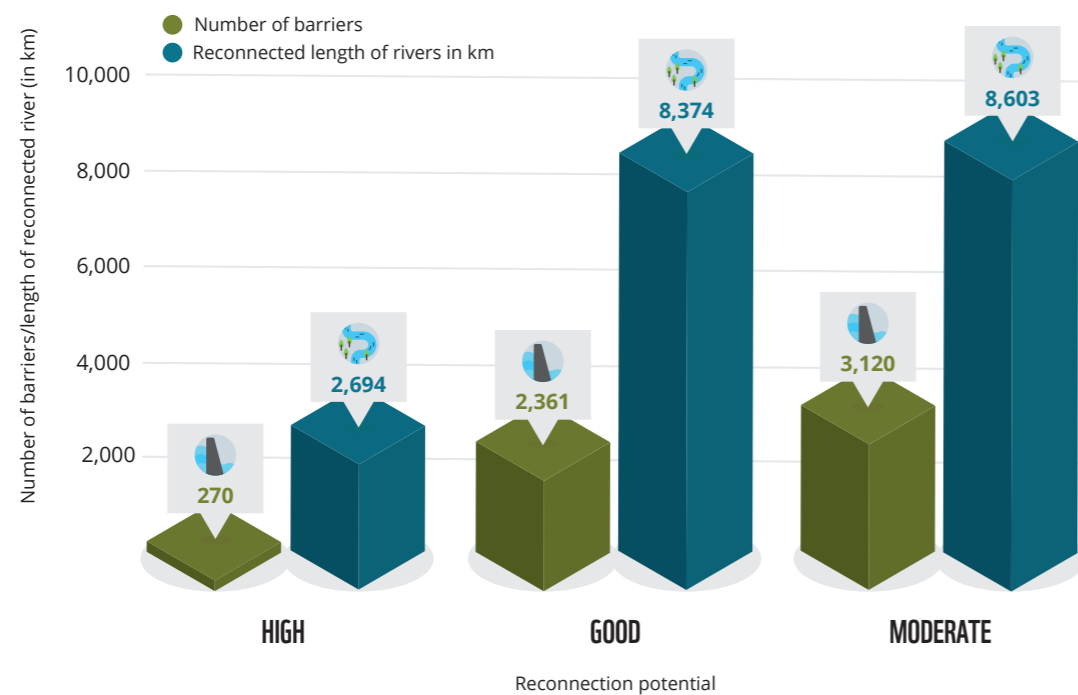
3.3.1 IBERIAN PENINSULA

Countries included: Andorra, Portugal and Spain

In the Iberian Peninsula, a massive number of large river barriers are located on the major rivers. In particular, many reservoirs and barrages in the uplands alter almost all larger rivers.

Many obsolete barriers with removal potential can be found in the remote and sparsely settled uplands, including some of the many reservoirs and barrages. Several dams were already removed in the past and new removal projects are in the pipeline (see example below).

Figure 5: Distribution of prioritised barriers for the Iberian peninsula



MANY OBSOLETE BARRIERS WITH REMOVAL POTENTIAL CAN BE FOUND IN THE REMOTE AND SPARSELY SETTLED UPLANDS, INCLUDING SOME OF THE MANY RESERVOIRS AND BARRAGES.

BARRIER REMOVAL FOCUS: THE HOZSECA DAM ON THE TAGUS RIVER, SPAIN



The Hozseca dam (in the upper Tagus basin) is an example of ecological fragmentation by an impassable transverse barrier (more than 5 meters high) resulting from the exploitation of a mini hydropower plant (< 1MW capacity). The impoundment is heavily clogged with sediment and the water right is currently under expiration.

In a natural way, there is an important influx of fine sediments to the channels from streams and ravines, which when deposited fill and compact the river bed, causing the decrease of the benthic habitat. The problem has been increasing in recent years due to the reduction and changes in the patterns of rainfall and temperatures caused by climate change. Human activities in the area, especially two kaolin mines that contribute to the influx of sediments from nearby tributary courses, have also worsened the situation.

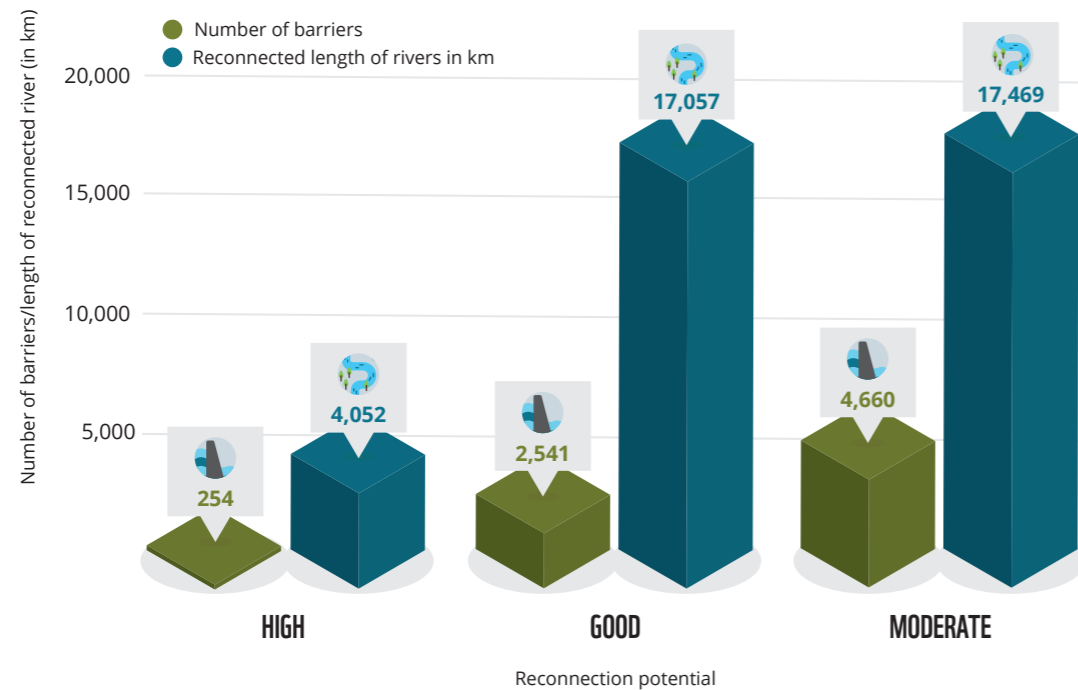
Restoring this river section requires the removal of the dam and the implementation of nature-based solutions for the conservation and protection of the Hozseca river, which is an important tributary of the Upper Taju. The recovery of the ecological connectivity (more than 30 km of free-flowing river upstream and downstream) and environmental value of the area through the removal of this dam and hydroelectric facilities will benefit the natural flow of the Hozseca river. Its removal will also contribute to offset erosion and sedimentation associated from nearby mining activities, such as the protection and restoration of vegetation cover on the banks of streams and tributaries.

3.3.2 CENTRAL WESTERN EUROPEAN REGION

Countries included: Belgium, France, Germany, Ireland, Italy, Luxembourg, Malta, Monaco, The Netherlands, San Marino, Switzerland, United Kingdom

In Central Western Europe, the density of barriers is the highest across Europe, home to many old weirs of mills, which could be removed. Many barriers are associated with navigable rivers and canals with sluices (often only for touristic purposes) making the restoration more difficult. In the Alps, a lot of erosion control and hydropower barriers can be found, which are more difficult to remove. The examples below show small hydropower plants out of order, which should be removed first.

Figure 6: Distribution of barriers for Central Western Europe



BARRIER REMOVAL FOCUS: THE WURZEN AND PAUSCHWITZ WEIRS ON THE MULDE RIVER, GERMANY



On the Mulde river, a major left wing tributary of the Elbe in Germany, two weirs equipped with hydropower turbines are out of function (Wehr Wurzen and Wehr Pauschwitz). Removal of the Wurzen weir would reconnect some 12 km of river. While these weirs would have a great potential to undergo a complete removal, plans are being made for resuming hydropower generation. In order to reintroduce Atlantic salmon, installing properly functioning fish passes will not be sufficient, and the restoration of river habitats will be required.

The Mulde river receives a lot of attention because of the research and protection of remaining free flowing streams. In the future, it is necessary to develop regional initiatives and to gather citizens' support for other emblematic rivers like the Lippe in North Rhine-Westphalia, where already entire weirs were removed and are planned to be removed.

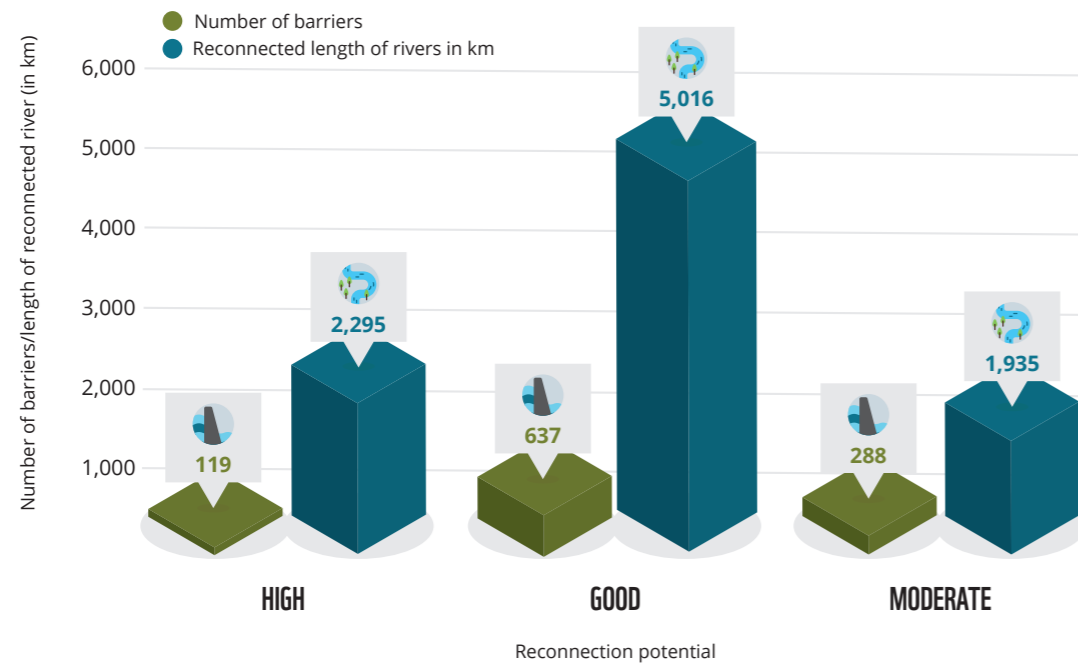
3.3.3 NORTHERN EUROPEAN REGION, SCANDINAVIA

Countries included: Denmark, Finland, Iceland, Norway, Sweden

Scandinavia is very rich in water resources, namely lakes and rivers, resulting in a

long tradition of hydropower usage. In the mountainous regions, rivers are naturally intersected, often by cataracts. In the lowlands, rivers often flow through natural postglacial lakes and depressions, making those rivers unique across the continent. Several old facilities, along with those in the lower, more densely settled courses close to the Baltic sea confluences, could be candidates for removal.

Figure 7: Distribution of barriers for Northern Europe-Scandinavia region

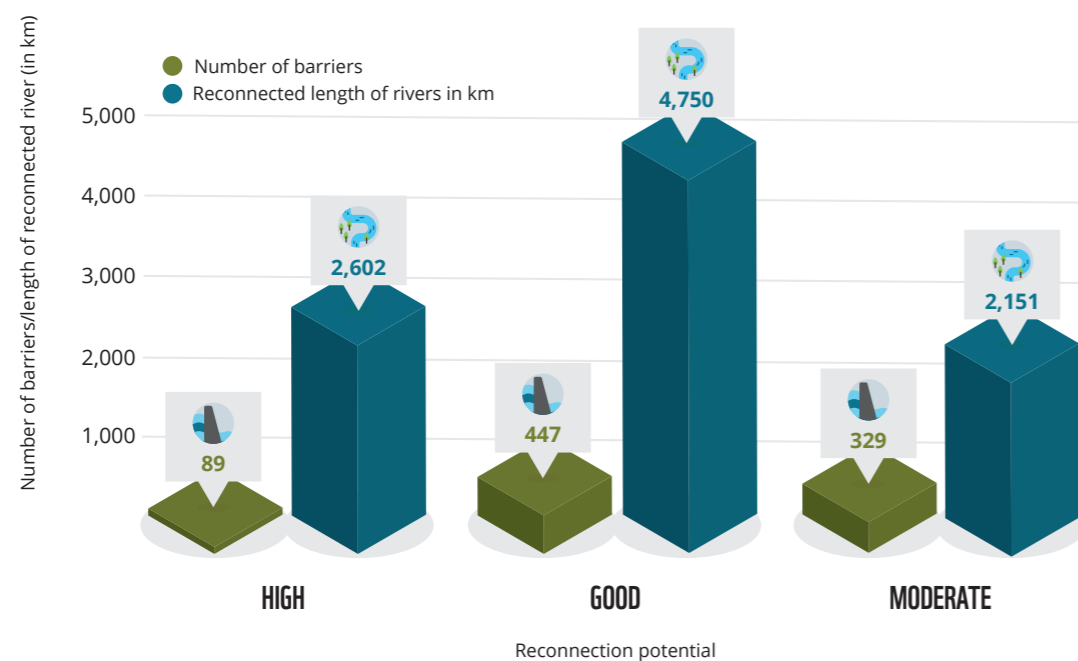


3.3.4 EASTERN EUROPEAN REGION WITH BALTIC COUNTRIES

Countries included: Belarus, Estonia, Latvia, Lithuania, Moldova, Poland, Ukraine

As many rivers in Eastern Europe still have long free-flowing reaches with near natural sections, barriers cause the interruption of long and slowly flowing river systems. Therefore obsolete structures should be removed as a priority.

Figure 8: Distribution of barriers for Eastern Europe



BARRIER REMOVAL FOCUS: WEIR IN ULANÓW ON THE TANEW RIVER, POLAND



© Piotr Bednarek 2019

This 1,5 meter high weir in Ulanów is the only barrier for fish migration located on the lower Tanev river, located 3 km upstream from river mouth. It was built in the 1970s for recreational purposes and did not have any other function. The weir restricted the movement of all migratory fish, such as the European nase. Before the 1970s, the Tanev watershed was important for diadromous fish such as trout, eel and vimba, until their ability to migrate into the Tanev was impaired by several barriers, including the major Włocławek dam on the lower Vistula. The only fish species hypothetically able to pass this weir now are trout and salmon (Bednarek 2020).

The removal of the weir would open up over 100 km of the highly valuable Tanev river stretch and up to ca. 450 km of rivers in the catchment (tributaries) according to a national inventory of barriers and data collected by Barrier Tracker users. As there are many natural habitats and spawning grounds in the upper Tanev watershed, migratory fish would have many kilometers of river habitats suitable to spawn and live. It is one of the most effective weir removal opportunities in Poland in terms of restoration.

The weir is privately owned. The owner is planning to keep it and although there are plans for restoring some kind of recreational area, he is currently not in favour of the removal.

Source: Bednarek P., 2020, Fragmentacja rzek w północnej części Kotliny Sandomierskiej. Uniwersytet Jagielloński. <https://doi.org/10.13140/RG.2.2.26410.64968>.

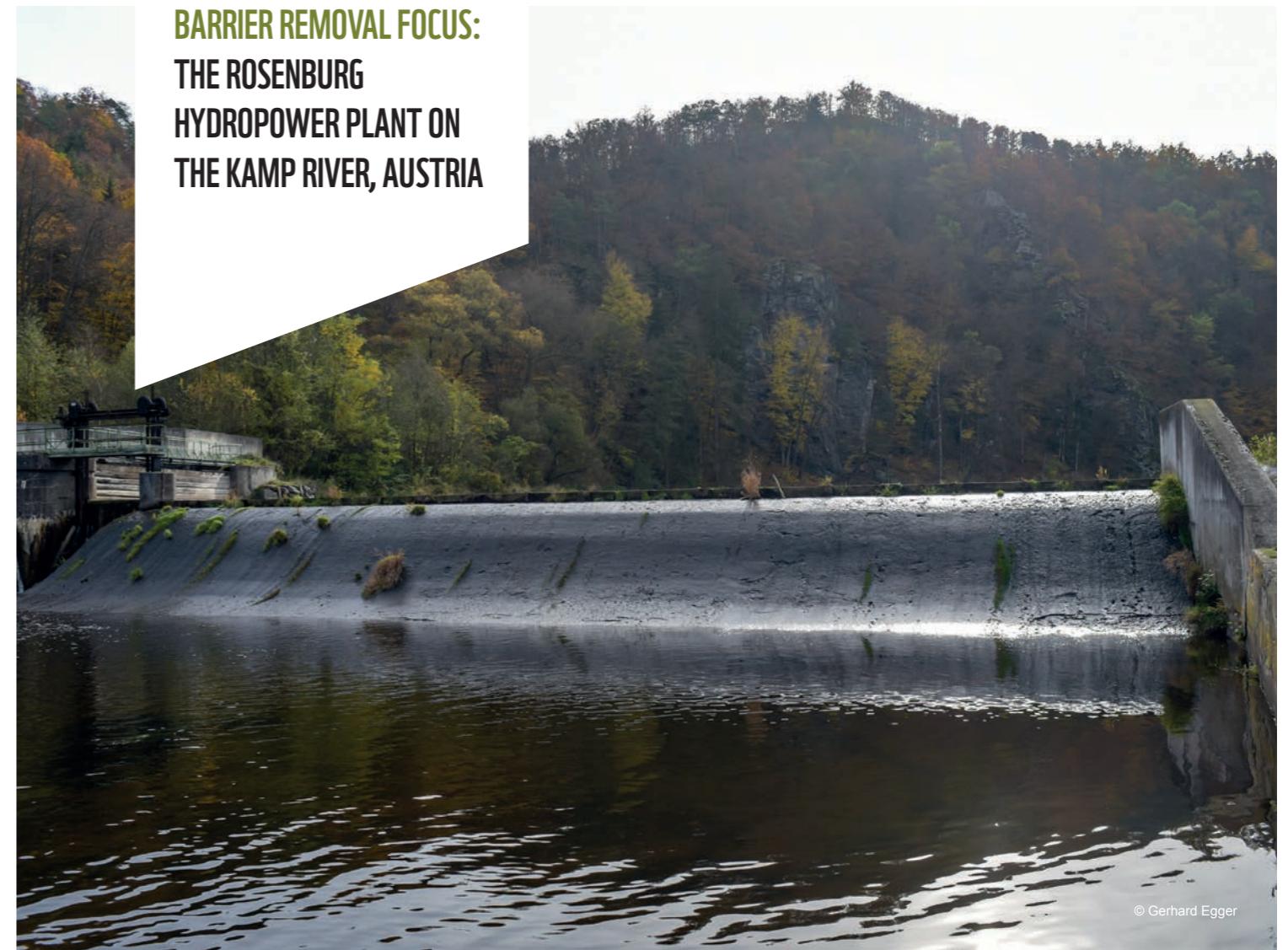
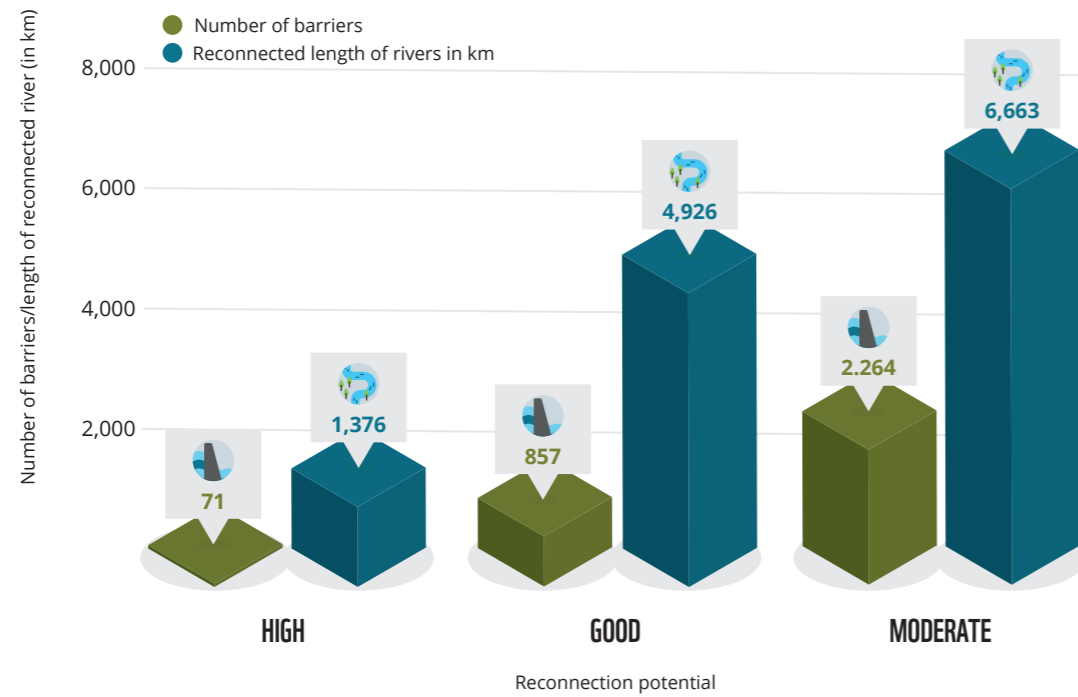
3.3.5 CENTRAL EASTERN EUROPE, DANUBE REGION

Countries included: Austria, Czech Republic, Hungary, Romania, Slovakia

The western part of the region, with countries like Austria, Czech Republic and Slovakia has numerous existing barriers, mostly for small

hydropower production, but also for natural hazard control in the mountains or for the former timber floating. Several old ramps and weirs could be removed. While the Hungarian lowlands include many canals for water regulation with limited removal potential on the larger rivers, Romania with the Carpathian mountains and numerous Danube tributaries has more barriers, several with high removal potential.

Figure 9: Distribution of barriers for Central Eastern Europe-Danube region



The small hydropower plant of Rosenberg on Kamp river (< 1 MW capacity), a left wing tributary of the Danube in Austria cuts through a valley meander, leading to a 3 km residual river reach downstream and disconnects some 16 km of river upstream. Due to its soon expiring license (2027), its old age (it was built in 1908) and the high costs required to refurbish it, the plant would be a consensual candidate for removal, but the decision has still not been made.

Other plans by the energy company exploiting the plant foresee the removal of several old small hydropower plants, and the construction of a smaller number of more efficient new plants. Investment costs will be a critical deciding factor.

3.3.6 BALKAN AND EASTERN MEDITERRANEAN REGION

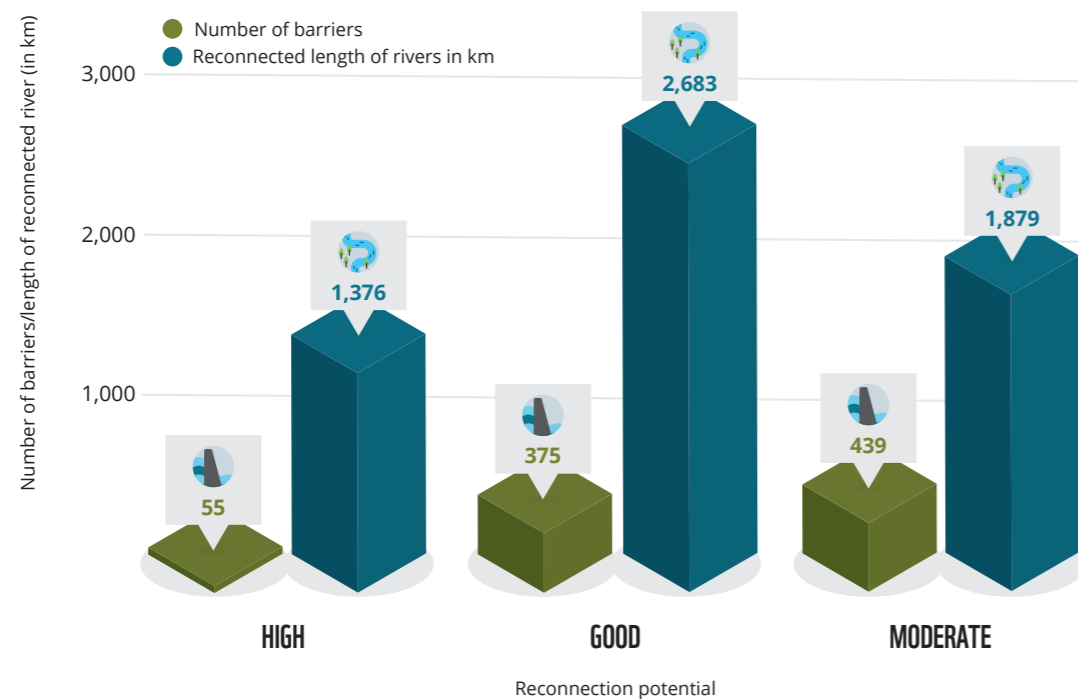
Countries included: Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Greece, Kosovo, Macedonia, Montenegro, Serbia, Slovenia, Turkey

Similarly to Eastern Europe, the density of barriers for this region is rather low (though with an upwards tendency) in comparison with Western Europe. There are however several

obsolete structures to be removed, that could reconnect long river stretches. Therefore, the number of barriers with a high reconnection potential is very low compared to other regions, but would allow the reconnection of larger stretches.

Unfortunately the numerous new hydropower plants constructed in the last 20 years in Albania and Turkey have caused the fragmentation of almost all larger rivers.

Figure 10: Distribution of barriers for the eastern Mediterranean region and Turkey



UNFORTUNATELY THE NUMEROUS NEW HYDROPOWER PLANTS CONSTRUCTED IN THE LAST **20 YEARS** IN ALBANIA AND TURKEY HAVE CAUSED THE FRAGMENTATION OF ALMOST ALL LARGER RIVERS.

BARRIER REMOVAL FOCUS: THE BABA CVETA HYDROPOWER PLANT ON THE ELOVISTA RIVER, BULGARIA

The 0.6 MW Baba Cveta hydropower plant on the Elovista river, a tributary to the Struma river in Bulgaria, had to be removed due to missing building licences. While this is a special case, it is rather important to show the need to limit the impacts of new hydropower in many upper reaches of still near-natural rivers of the Balkans. Those small and ineffective plants depend directly on the subsidies regime of each country, which are also driven by the European public financing policies.

In the rather young EU countries along the Balkans, like Bulgaria, Croatia and Slovenia, the booming development of hydropower seems to slow down with many rivers joining the Natura 2000 network and with the implementation of more stringent environmental policies. But still many new projects are planned (even in Natura 2000 areas) and counteract the attempts to reconnect rivers in Europe.



3.4 ANALYSIS OF THE RESULTS

Since the first river basin management plans were developed in 2009, many measures have been taken by water management authorities to improve the river continuum. In some countries like France and Spain, the de-damming already started in the early 2000s and has accelerated since 2009. Since 2015, de-damming has also expanded to Central Europe (Germany, Austria), although it mostly occurs in small rivers. This slow but steady increase in barrier removal could not be fully reflected in this study, which does not take stock of the barriers already removed but focuses on the potential to remove more.

In the large and medium-sized rivers considered in this study, the current measures to improve the river continuum mainly focus on the management and adaptation of existing barriers, through constructing fish passes or adapting ramps. **This study suggests going beyond the adaptation of barriers in order to guaranty the full biota and sediment continuum, which can be realised in most cases only by entire removal of the obstacle.**

For a vast majority of the river barriers with the highest potential, the entire removal should be considered, with very limited exceptions (flood protection purposes for instance), or adaptations (buffer zones on riparian areas in the case of intensive land-use). Barrier removal is a nature-based solution for river restoration with fast²⁰ and large²¹ effects on ecosystems.

In addition, the removal or at least modification of steep ramps and sills just downstream of bridges or infrastructure should be considered. In some cases a partial removal might be a solution to improve connectivity. Very often, the critical situation of bridge fundamentals and subsequently the construction of sills and ramps is a direct consequence of sediment deficit and incision of river channels downstream of dams. Therefore the restoration of sediment transport in combination with the removal of barrier might be an option to be considered as well.

While the present study prioritises barriers based on their reconnection potential and the ecological quality of the reconnection, it does not deny the fact that the various purposes of barriers might raise some social, economic and

political challenges for their removal. Excluding hydropower plants of a capacity above 10 MW and drinking water reservoirs from this assessment has been a way to integrate this parameter in this study.

Still, **those results should be complemented with an analysis (mostly at national or local level) of the usability of the barriers, to complement this prioritisation with a focus on the removal of the barriers which provide no further or limited services.**

Europe (together with North America) is known to have the highest median age of large dams globally (between 50 and 100 years).²² This suggests that many of the largest barriers will soon be obsolete. Some of those may be already covered by the present study, but others, such as ageing large hydropower plants or dams for irrigation, may not be.

According to the AMBER Atlas of barriers, more than 10% of the 1 million barriers recorded in Europe are abandoned or obsolete. This means that there may be over 100,000 obsolete barriers (even though mostly small ones) that could be removed to help reconnect Europe's rivers. AMBER estimates that by simply acting on the removal of 2.5% of these, 25,000 km of rivers could be freed, helping to meet the current goals of the new EU Biodiversity Strategy for 2030.²³ **By compiling the results obtained by AMBER with the barriers identified in this study, there is potential to go much beyond the EU target of restoring 25,000 km of free flowing rivers.**

More free-flowing rivers in Europe will have multiple benefits. It will not only support the goals set by the EU Biodiversity Strategy, but also enhance the achievement of the objectives of the EU Water Framework Directive, as well as the Sustainable Development Goals (in particular target 6.6 "Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes").

22 Perera, D., Smakhtin, V., Williams, S., North, T., Curry, A., 2021. Ageing Water Storage Infrastructure: An Emerging Global Risk. UNU-INWEH Report Series, Issue 11. United Nations University Institute for Water, Environment and Health, Hamilton, Canada
23 AMBER Atlas of barriers, "river fragmentation", <https://amber.international/european-barrier-atlas/>

20 O'Connor et al, (2015). 1000 dams down and counting. Science, 01 May 2015: Vol. 348 Issue 6234, pp. 496-497.

21 Harby, A, David, L, Adeva-Bustos, A, Hansen, BT, Rutkowski, T, (2019) https://www.fithydro.eu/wp-content/uploads/2020/03/D4.2_Functional_application_matrix_for_identification_of_potential_combinations_of_improvement_measures.pdf

ACCORDING TO THE AMBER ATLAS OF BARRIERS, MORE THAN **10%** OF THE 1 MILLION BARRIERS RECORDED IN EUROPE ARE ABANDONED OR OBSOLETE.



4. CONCLUSIONS AND RECOMMENDATIONS

- Out of a sample of 30,000 river barriers, this report identifies 858 barriers across larger European rivers including 732 in the EU whose complete removal can offer the greatest benefits in terms of reconnection of ecosystems (“high reconnection potential”). Removing those barriers would allow to achieve nearly half of the target set by the EU Biodiversity Strategy by reconnecting 14,400 km (11,500 km in the EU). Removing barriers with both high and good reconnection potential would allow to double the EU target by reconnecting 57,000 km of rivers (49,000 in the EU).

The results of this study, based on a sample of 3% of existing barriers in Europe, show that the 25,000 km target set by the EU Biodiversity Strategy is a conservative one and that there is potential to go much further by looking at smaller rivers (excluded from the current study) and at a broader range of barriers. It would bring substantial benefits in terms of restoring freshwater and riparian habitats.

- Following the release of the EU Biodiversity Strategy, EU national authorities have started setting national targets for reconnection, sometimes in relation with their third River Basin Management Plans under the EU Water Framework Directive for the period 2022-2027. This inventory shows that **assessing the reconnection potential of ecologically valuable river stretches is a major prerequisite to prioritise barrier removal.**

- The restoration of free-flowing rivers requires the complete removal of physical, longitudinal barriers. **By no means should equipping a barrier with a fish pass be considered sufficient to restore connectivity.**
- This study presents some limitations as it concentrates on large and medium-size rivers, and excludes a significant number of specific barriers, such as medium-size and large hydropower plants, drinking water reservoirs, and many, often small barriers for which data was not available. Much higher results could be achieved by increasing the scope of this study.

- This study focuses on longitudinal continuity, which is probably the easiest connectivity to achieve. However, **the restoration of free flowing and thus functional rivers also implies transversal (between the main channel, the floodplain and riparian areas), vertical (between the groundwater, the river and the atmosphere) and temporal (seasonality of flows) connectivity.**

- The removal of barriers is strongly bound to country authorities from national to local level, but also to the usage licences and the life expectation for barriers.

In many cases licenses expire without companies or public authorities setting up any plan for the decommissioning of the barriers. Barriers are often seen as inevitable and nobody is responsible for the removal after the regular usage. In general, at least

the largest barriers should have an agenda and budget for final removal after their life span. We encourage national authorities to take the opportunity of the third cycle of River Basin Management plans to address this issue of accountability for the lifecycle of existing barriers.

- **While barrier removal is one important step towards the restoration of free-flowing rivers, it also requires concerted action to avoid constructing new obstacles.** It is important to create a culture that values the importance of river connectivity.
- This study is an initial step towards a prioritisation of barriers for removal. Technically this quick analysis could be expanded and improved using a full GIS network analysis environment, including also catchment analysis.
- The results of the present study should stimulate further work and studies on barrier removal across the continent and at national level. The lists and the prioritisation must be sharpened (and will have to be prepared by the competent authorities in the countries and on catchment level to fulfil reconnection tasks).
- We recommend that EU and national water management authorities complement this study with additional ecological data (based on the WFD reporting data, on migratory fish species, on key freshwater biodiversity areas and on sediment balance and hydromorphology). Any prioritisation effort should also consider

the functionality of barriers, and small rivers, which are critical ecosystems.

- Free-flowing rivers have immense value for biodiversity, climate, and people, and their restoration can help achieve multiple policy goals, improve well-being, and get critical freshwater ecosystems back on track. Actions to remove river barriers at EU, national and local levels should be significantly accelerated without further delay.

REMOVING BARRIERS WITH BOTH HIGH AND GOOD RECONNECTION POTENTIAL WOULD ALLOW TO DOUBLE THE EU TARGET BY RECONNECTING 57,000 KM OF RIVERS -

49,000
IN THE EU.

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This report is part of the collaborative work undertaken by WWF offices within the Living European Rivers Initiative. Living European Rivers is a WWF-led initiative to bring life back to Europe's waters for the benefit of people and nature. Involving other civil society organizations, governments, investors, businesses and communities, the initiative aims to protect rivers, lakes and wetlands that are still in good health and restore the ones that have been degraded. To achieve this ambitious goal by 2030, the initiative works to improve water governance, redirect financial flows towards nature-based solutions, remove dams, fight unsustainable hydropower, and raise awareness about the values of freshwater ecosystems.

WWF is part of the Dam Removal Europe Coalition, working together with other international NGOs to restore rivers in Europe that have high natural or cultural importance by removing obsolete barriers and ensure healthy free-flowing rivers.

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TO BUILD A FUTURE IN WHICH
HUMANS LIVE IN HARMONY
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