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Figure 1 | The weir at Pulteney Bridge, Bath, UK. Belletti *et al.*[1] estimate that more than 1.2 million artificial constructions, such as weirs, dams and locks, alter the flow of Europe's rivers and streams.

Hydrology

Small barriers are a big deal for Europe's rivers

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An atlas of European river barriers has been made, by curating and correcting existing records, and by surveying 2,700 kilometres of waterways. It reveals that rivers are fragmented by an amazing number of obstructions. **See p.436**

If you asked a child in Europe to draw a river, what would this picture look like? Would it resemble a natural, wild and scenic river, with braided and meandering flow paths in a vast floodplain, fringed by riverine vegetation? Or would it show a modern, well-managed river with houses lined up along the banks and boats passing by on a confined channel? On page 436 Belletti *et al.*[1] report a remarkably detailed survey of river barriers in Europe, which suggests that the second picture would be much more likely.

Free-flowing rivers have become increasingly rare, because centuries of human activities have altered their passage and channels: dams and levees have been built to protect us from floods; weirs have been added (Fig. 1) to abstract water for irrigation or human use; locks and canals have been used to ensure and expand navigable waters; and river flows have been trapped or diverted for power-generating applications ranging from ancient waterwheels to modern hydroelectricity plants. Diverse in-stream structures have been constructed for these purposes, such as large concrete dams, wooden locks, small weirs and partially submerged fords. All of these interventions fragment the rivers and disturb the flow in various ways across different spatial and temporal scales, affecting the transport and delivery of sediments and nutrients[2,3], and the migration and dispersal of aquatic organisms[4].

Researchers and water managers who want to investigate the consequences — both beneficial and harmful — of these modifications must first ask some fundamental questions. How many barriers have been installed, and what types? And, most importantly, where have they been built?

Perhaps surprisingly, the answers are largely unknown. No comprehensive inventory of barriers has been available on a continental scale that includes structures less than 10 metres high, uses consistent, clearly defined terminology and does not under-represent certain barrier sizes and types or geographical regions. This is not least because of the long history of barrier construction and the general lack of documentation. Recent research[5] has compiled global data for the locations of dams, but mostly only those that are larger than 10–15 m in height or visible in space-satellite imagery.

The degree of connectivity of rivers worldwide has also been quantified[6] using records for about 20,000 of the largest dams. The study not only accounted for longitudinal connectivity along the river, but also considered lateral interactions with the floodplain, temporal flow alterations, and vertical exchanges of water with the atmosphere and groundwater; such exchanges are often lost in cities if rivers are lined with concrete or forced into underground channels. According to that study, the main causes of the decline in the number and condition of free-flowing rivers are dam-related effects, such as river fragmentation, flow regulation and sediment entrapment. However, because the data underpinning this research did not take smaller barriers into account, the estimated 63% global loss of very long free-flowing rivers (greater than 1,000 km in length) probably represents only the tip of the iceberg.

This type of knowledge gap motivated Belletti *et al.* to compile a pan-European atlas of river barriers for 36 countries. The primary aim was to quantify the density of artificial barriers (defined as any built structure that can cause longitudinal discontinuity) across the rivers of these countries. The results are a prerequisite for various approaches[7] that analyse the level of river fragmentation.

The authors took on the tedious and challenging task of compiling records from 120 local, regional and national databases. They curated the data, for example to remove duplicates and ensure consistency in the size categories and terminology, and then mapped out all the barriers to the European river network — a system that contains 1.65 million km of rivers.

However, Belletti and co-workers recognized that there will be inherent biases in the source data, such as the omission of small or unusual barriers. They therefore made an impressive effort to test the quality of their data: they surveyed about 2,700 km of the river network in 26 countries by walking along selected river stretches during low-flow conditions. The researchers recorded the characteristics of each barrier observed, such as its location, size and whether it was abandoned or still in use. None of the 147 surveyed rivers was found to be free of obstructions, a concerning observation in itself. The findings from this monumental field trip were used to improve the precision of the calculated barrier density, correcting errors and biases in the existing records.

Finally, Belletti and colleagues extrapolated their data to estimate the barrier density in countries and regions with missing data records, taking into account anthropogenic and environmental factors, such as the degree of urbanization and the amount of agriculture. Although each step of the study has its own shortcomings, as the authors discuss, the combination of approaches strengthens the overall quality of results and reduces uncertainties caused by the variability of the available data across large regions and across several scales in barrier size.

Belletti *et al.* identified almost 630,000 unique barrier records, the majority of which were for ramps and bed sills, weirs and culverts. This is the most comprehensive inventory of river barriers ever created. Nevertheless, it still substantially under-represents reality: the number of barriers observed in the field study was, on average, 2.5 times that reported in the existing inventory. In fact, the authors estimate that there are more than 1.2 million artificial barriers obstructing Europe's rivers and streams, possibly making it the most fragmented river network in the world.

The authors estimate that barrier densities range from 5 barriers per 1,000 km in Montenegro to almost 20 barriers per km in the Netherlands. Their statistical model suggests that the average barrier density across Europe is 0.6 per km, which is similar to the value obtained from the field observations (0.74 per km), confirming the robustness of the modelling results. Central Europe has the highest abundance and density of barriers, whereas rivers in the Balkans in southeastern Europe, in parts of northern Scandinavia and in some remote areas in southern Europe remain relatively free-flowing. The authors point out, however, that these unfragmented rivers face new threats from a boom in hydropower development, which could put the biodiversity and ecosystem health of the rivers at risk[8].

"The authors estimate that more than 1.2 million artificial barriers obstruct Europe's rivers and streams."

Given the challenges of global environmental change, finding sustainable solutions to protect fluvial ecosystems and their associated services to humans will need a combination of actions — for example, measuring the ecological impacts of barriers; developing models of regional hydropower installations to find ways of minimizing the environmental toll on the river system while maximizing electricity production; and examining past and future trends in barrier construction and their effects. All of these require a large knowledge base and data that fit the scale, complexity and resolution of the questions to be asked. For example, some barrier types might interrupt sediment transport but pose no problem for a specific aquatic organism, whereas others might be detrimental to that organism despite not interrupting sediment movement.

Belletti and colleagues' river-barrier atlas for Europe is an excellent accomplishment, but more efforts like this are now needed. After all, river barriers and their effects are not confined to Europe, and data availability tends to be even more restricted in many other parts of the world. A large global network of scientists and stakeholders will need to join forces to compile data and develop tools (such as the Global Dam Watch initiative at http://globaldamwatch.org) before a complete assessment of the impacts of barriers — both large and small — on river ecosystems can be achieved.

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