River Conservation
Challenges and Opportunities

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Chapter 2 Offprint

The Silent River: The Hydrological Basis for River Conservation

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We may conclude that in every respect the valley rules the stream.

HYNES, 1975

From headwaters to mouth, the physical variables within a river system present a continuous gradient of physical conditions. This gradient should elicit a series of responses within the constituent populations resulting in a continuum of biotic adjustments and consistent patterns of loading, transport, utilization, and storage of organic matter along the length of a river.

VANNOTE ET AL., 1980

Rivers, as hydrological systems, have a highly integrated nature: changes anywhere in the catchment can have significant effect further downstream. Rivers differ in their hydrological regimes, following general regional patterns. These regimes are important as they provide a context within which human influence on the river system can be defined. The pathways followed by the water to reach the channel determine its sediment and solute load. Therefore, climate, land use change and channel engineering can impact river hydrology along with the prospects for delivering sustainable water supply.

2.1. The river continuum

People are constantly changing entire landscapes, deeply affecting river ecosystems. Many of the key impacts are linked to water. Some of these changes are deliberate: building dams, diverting water for irrigation, taking water for domestic and industrial use. But some impacts are indirect, and yet equally influential. These include major changes in land use like urbanisation or deforestation, which can change the whole character of the river as well as the surrounding land. Many of these impacts result in reduced flow in the river: there may be fewer flood peaks but also lower flows as well. Water withdrawal results in domesticated, silent rivers where most of the natural functions have disappeared.

The river basin is an open system with outputs from upstream areas (land surface and channels) providing inputs to downstream sections

Today, there is an intuitive assumption that the condition of the river channel and its drainage basin are intimately linked, but this was not always so. A series of research papers in the 1970s encouraged a new approach to aquatic ecology, borrowing concepts from fluvial geomorphology that stressed the drainage basin as the fundamental unit of analysis. This concept is known as the *river continuum* concept (Vannote et al. 1980; see review in Burt et al. 2010). This takes the view that, at any point on the river network, there is a balance between the water moving through the channel and the resulting habitat and species mix. The river is regarded as an open system, with the output from one section providing the input to the next. Hence, the river network can be seen as an integrated system, with a clear connection between upstream and downstream. At any point along the channel, the amount of water flowing in the river, its chemistry and sediment load, all reflect processes operating within the *entire* river basin upstream of that point (i.e. not just in-channel conditions). Moving from source to mouth, the in-stream biological community is constantly adjusting in response to progressive downstream changes in discharge, energy inputs and nutrient availability.

At the same time as the river continuum concept was proposed, another group of researchers developed the *nutrient spiralling* concept (Webster and Patten 1979) which describes how, as organic matter and nutrients flow downstream, they are taken up by plants, and then perhaps eaten by animals. Later, the plants and animals die off and matter is released back into the river water. The nutrients seem to "spiral" along the river, from the water to the biota and *vice versa*, constantly being taken up and released. Together, these two concepts underpin our current understanding of river ecology, emphasising production, cycling and transfer of energy and organic matter along the stream network. We can easily forget just how vital water is to river ecology; we must remember always that any changes to the quantity or quality of river flow are bound to have major consequences.

Another key idea is the importance of temporal variability in discharge for river ecology. Each type of river has its own natural flow regime, to which the local fauna tends to be adapted, and thus, any change of the flow regime is likely to result in changes in the biological communities (Poff et al. 1997). Important points in the natural flow regime are the number of flood events or spates per year, the time the river requires to return to base flow after the spate, and the predictability of spates, this is, the extent to which spates occur at the same time every year. Small streams tend to be very flashy, i.e. discharge increases swiftly following rainfall, and recedes again rapidly to base flow. Large rivers, on the other hand, because they receive the flow from vast drainage basins, tend to have more slowly rising and receding flows, and also more repeatable hydrographs from year to year. In the largest rivers, floods can last for months and flood vast areas of the floodplain; this flood-pulse is a key driver of the ecology of large rivers (Junk et al. 1989). For instance, many fish species breed in flooded terrestrial habitats which get nutrients from the floodwater, nutrients that can later return to the river channel in the form of fruits, leaves, and other organic materials. Additionally, floods are important for many migratory fishes, as features such as small chutes, debris dams or shallow areas, that are impassable barriers during low flows, can be easily traversed during floods. Therefore, the flow regime, the natural alternation of floods and periods of low discharge, is an essential element of river health.

Traditional river engineering provided solutions at a particular site, often with little or no regard being paid to upstream conditions. Today, the drainage basin is viewed as a single, connected system. This requires an integrated approach in which upstream conditions, both in the channel *and* in the catchment area surrounding the channel network, are fully taken into account. This spatially "distributed" approach focuses our attention on the sources of water, sediment and solutes being transported within the river channel. Moreover, the pathways by which water and any material being carried in the water ("load" – a mixture of solid and dissolved material) must also be understood, so that connectivity between "source" and "target" can be fully appreciated.

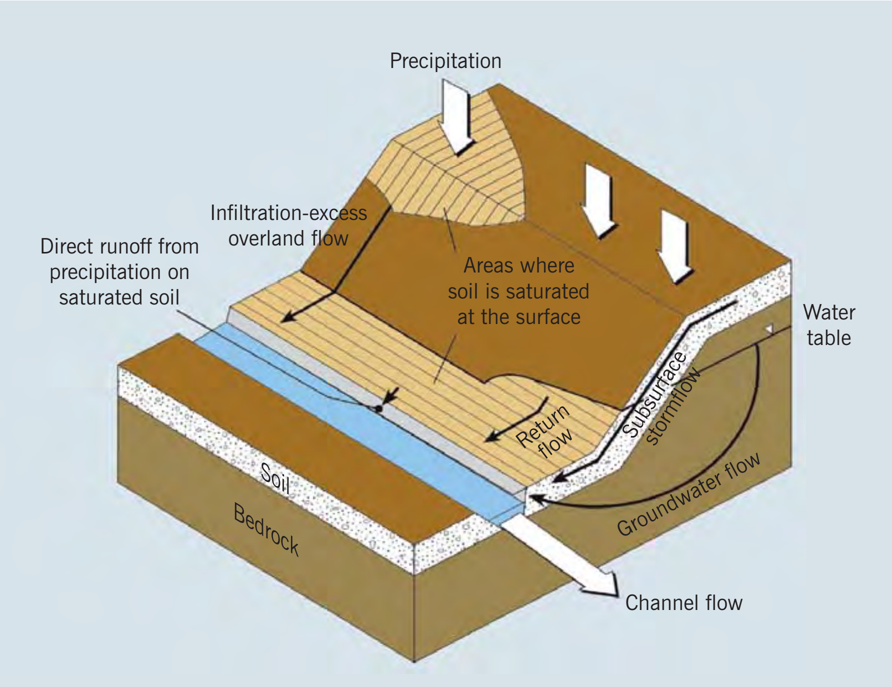
Any changes to the quantity or quality of river flow are bound to have consequences for river ecology

2.2. Where does the water go when it rains?

The nature of the soil and bedrock determine the pathways by which runoff from the catchment area will reach a stream channel. These flow paths determine the speed and volume of water travelling to the nearest channel and the load of sediments and dissolved substances acquired by the moving water. Runoff pathways are studied using a hydrograph, a plot of discharge (with units of volume per unit time) against time. For very small basins, it is necessary to plot instantaneous discharge values whereas for larger basins, mean hourly or mean daily discharge values will suffice.

The water falling during a storm can follow different pathways, depending on the local conditions (Figure 2.1). Part of the water is intercepted by the vegetation, part is evaporated again directly to the atmosphere, and part of the water reaches the soil surface, where it tends to infiltrate at a rate that depends on the slope, porosity, and moisture content of the soil. When the rainfall intensity exceeds the infiltration capacity of the soil, water flows over the land surface, where it can cause erosion, especially if the soil is bare (Figure 2.2). When it rains on a ground that is already saturated, all the water must flow overland. Often the water infiltrates the soil, but reaches an area that is already saturated with water or which is less permeable than the topsoil, and thus, water emerges from the ground and flows across the surface. Water flowing through the soil (sometimes called *throughflow)* moves much more slowly than overland flow, but the response can still be quite rapid when newly infiltrated water shunts water that was already in the soil out of it and into the stream, or when the water moves through large cracks in the soil rather than through the soil matrix. Water that percolates into the bedrock moves at much lower velocities by longer flow paths and takes much longer to reach the

Figure 2.1: *Block diagram of hillslope runoff processes showing the main pathways followed by rainfall*



Source: Burt (1992).

Figure 2.2: *Soil erosion on an agricultural field in southern England caused by infiltration-excess overland flow*

stream channel. The long residence time of groundwater usually means that it has a much higher solute concentration than overland flow, simply because this gives longer for rock material to dissolve.

Figure 2.3 shows a hydrograph for a small headwater basin in south-west England; also shown is the solute concentration of the stream water. This flood hydrograph was generated by an intense storm of 25 mm rain in just 15 minutes. Note how the stream water is rapidly diluted by input of overland flow. The storm hydrograph has been divided into “new” and “old” water. The new water – overland flow – reaches the channel quicker than the old water which has to move through the soil. In this case, the flood is quickly over and the stream returns to baseflow conditions – low flow with a higher solute concentration than the storm runoff.

2.3. Water balance

The water balance for a river basin over a selected time period (usually annual) can be evaluated as follows:

$$P - Q - E - C - \Delta S = 0$$

where P is precipitation, Q is river discharge, E is evaporation, C is water consumption (that is, the amount abstracted by the human population and not

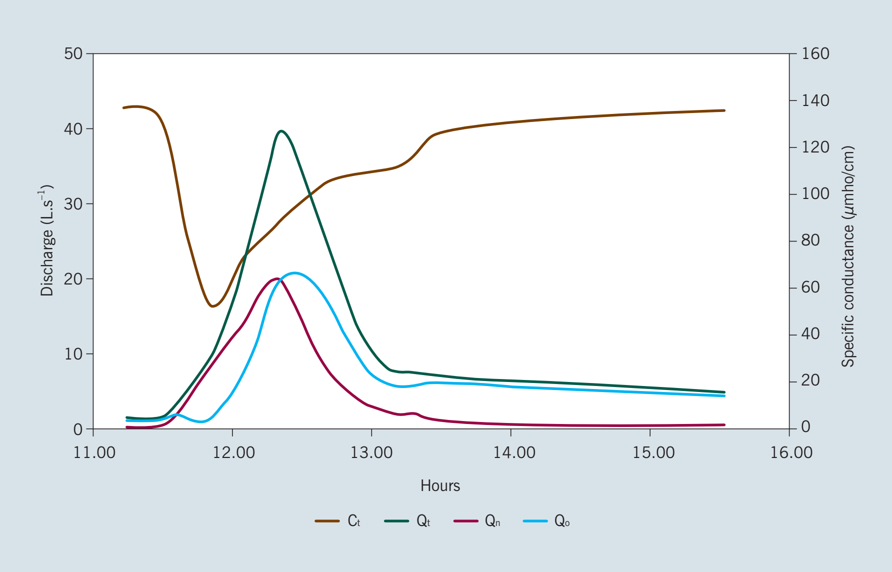


Figure 2.3: *Storm discharge (Q_t) and stream solute concentration (C_t) for the Bicknoller Combe stream. Old (Q_o) and new (Q_n) water contributions estimated using a chemical mixing model (adapted from Burt, 1979). Specific conductance is a proxy for total dissolved solids concentration*

returned to the river; Milliman and Farnsworth 2011), and ΔS is change in storage. In some river basins there may be leakage of groundwater into or out of the basin (as defined using surface topography) but in most cases this can be ignored.

By way of example, the mean water budget for a small catchment in south-west England (Slapton Wood) over a 37-year period was as follows:

$$\begin{aligned} P &= 1066 \text{ mm} \\ Q &= 540 \text{ mm} \\ E &= 524 \text{ mm} \end{aligned}$$

Note that 48% of rainfall was converted into river flow and 52% was lost through evaporation, a very typical result for a lowland basin in a warm temperate climate.

2.4. Global hydrology: Climate and river regimes

The regime of a river may be defined as the seasonal variation in its flow and is usually portrayed by a curve based on monthly mean flow (Burt 1992). Seasonal variations in the natural runoff regime of a drainage basin depend primarily on climate. Of course, vegetation cover plays an important role too, but it is also controlled by climate and so not a truly independent driver. As noted above, soil and bedrock control the rapidity of runoff: impermeable soils encourage rapid storm runoff response; basins with permeable soils and deep aquifers will greatly attenuate the link between rainfall and runoff.

Beckinsale (1969) noted that river regimes in most parts of the world reflect the regional climatic rhythm. Therefore, he modified the classical classification of world climates made by the German climatologist, Köppen, and so was able to produce a generalized delineation of hydrological regions (Figure 2.4). These are the main types of hydrological climate according to Beckinsale:

A = tropical rainy climates
B = dry climates with an excess of potential evaporation over precipitation
C = warm, temperate rainy climates
D = seasonally cold, snowy climates

Beckinsale applied the rainfall symbols of Köppen to provide the second capital letter in the code:

F = appreciable runoff all year
W = marked winter low flow
S = marked summer low flow
M = moderate low-water season

Beckinsale added a further class to take into account regimes that occur in the snow and ice environments of high mountains (H) outside the polar ice caps: HN and HG, denoting nival (N, dominated by spring snowmelt) and glacial (G, dominated by summer glacier melt) regimes respectively.

Generalized classifications like that of Beckinsale (1969) remain useful as a context for more local analysis. Recently, Milliman and Farnsworth (2011) have used temperature, total annual runoff and season of *maximum* runoff as the basis for their classification of global river regimes. Maximum runoff is more meaningful for considerations of stream sediment transport to the oceans, as most sediments are transported during floods (Chapter 3). On the other hand, minimum flow is relevant to river ecology because in-stream biota are stressed by low flows, which is why the Beckinsale scheme is retained here. Not surprisingly, the data base of river discharge now available is very much more extensive than it was in the 1960s. On the other hand, many more rivers are affected by abstractions so that far fewer regimes remain “natural” and river biota must adapt accordingly to the modified flow regime.

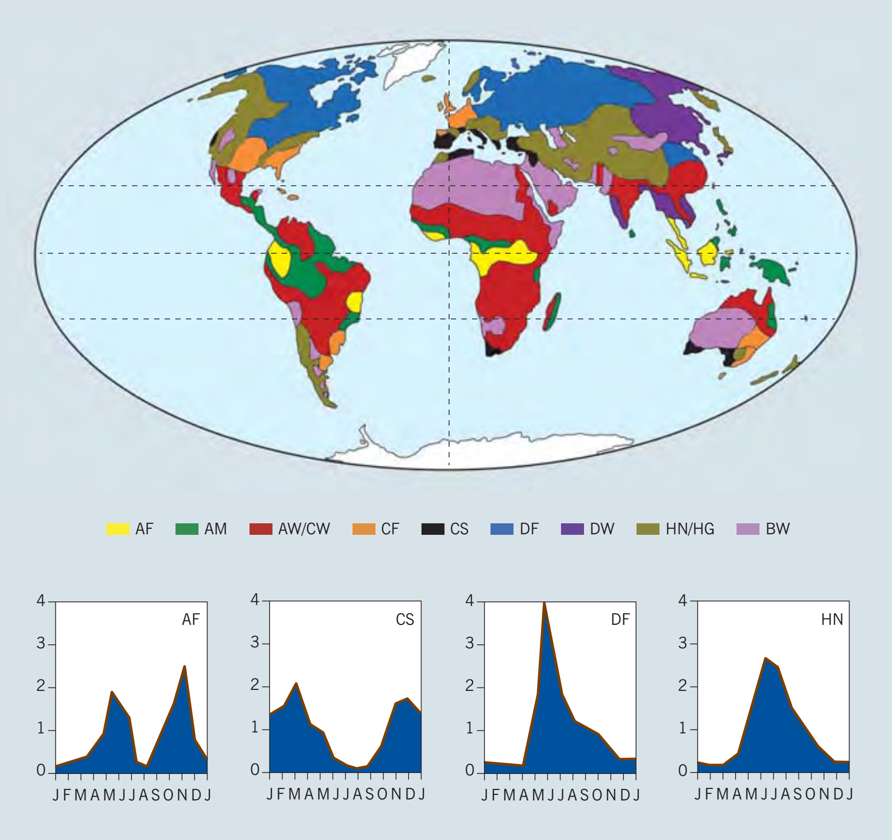


Figure 2.4: *The world distribution of characteristic river regimes with type examples from four regions. Letters are specified in the text. The four rivers shown are: Lobaye, Congo (AF); Volga (DF); Arno (CS), Rheus, Switzerland (HN). Data plotted for the four rivers show the ratio of mean monthly flow to mean annual flow*

Source: Adapted from Beckinsale (1969).

2.5. Flow regimes at the regional scale

Once we begin to examine river regimes at the regional scale, the relative importance of climatic variation diminishes somewhat and other drivers increase in significance. Figure 2.5 shows regimes for two of the largest UK rivers: the Tay and the Thames. The headwaters of the Tay are in the rainy Scottish mountains so the Tay has much higher absolute flows in every month of the year, compared to the Thames. The regimes shown confirm Beckinsale's classification (CS) for UK rivers: a warm, temperate rainy climate with a marked summer low flow.

Drainage basins dominated by surface runoff respond rapidly to precipitation or snowmelt, whereas groundwater-dominated basins have a dampened response, with a greater delay between input and output. This tends to result

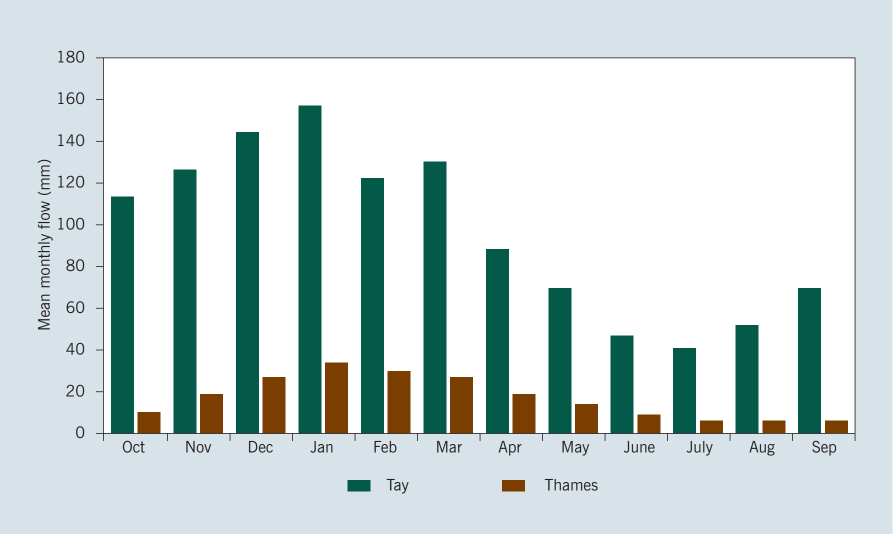


Figure 2.5:
Mean monthly runoff (mm) for the rivers Tay and Thames, UK

Note: Data from UK National River Flow Archive (station numbers 15006 and 39001).

in a more uniform runoff response compared to the more "flashy" response where surface runoff dominates. The influence of geology on the different water regimes can be exemplified by the Ock and Dun rivers, two tributaries of the River Thames in southern England that, despite having almost identical annual runoff (Ock 211 mm; Dun 222 mm), have very different hydrographs (Figure 2.6). In the Ock, a basin with impermeable clay soils and a dense network of ditches and drains, there is a rapid response of the river to rainfall, with intense, short-lived flood peaks, but very low baseflow in rain-free periods. In the Dun basin, the substrate is permeable limestone, and thus, little storm runoff is produced despite the steeper terrain, and groundwater provides almost all the streamflow. Note that these hydrographs include the severe drought of 1975-76; the complete lack of storm runoff during the very dry winter of 1975-76 is starkly evident.

2.6. Climate change and long-term change in river flow response

The natural flow regime is by no means constant from year to year. We expect catchment hydrology to vary as a direct result of climatic variability (e.g. Figure 2.5). But what if there is long-term climate change? This must gradually affect the response of the river basin. In terms of temperature change, if rain tends to fall instead of snow, this might alter the timing of runoff, with more winter floods and lower runoff from snowmelt in the early spring.

Figure 2.6: *Hydrograph for two contrasting English rivers: River Ock and River Dun. The rain-fed Ock is flashier, has more peak flows and lower base flow than the groundwater-fed Dun*

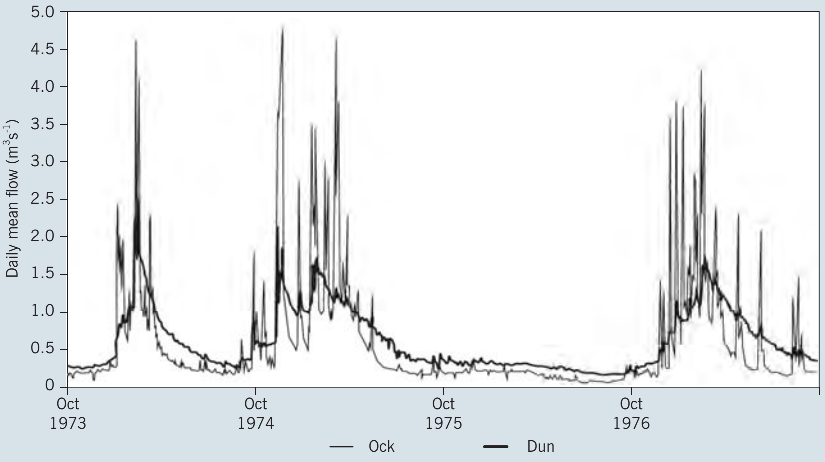


Figure 2.7 shows the relationship between the North Atlantic Oscillation Index (NAOI) and seasonal river flow totals for two UK rivers. The NAOI is a measure of the strength of the North Atlantic circulation. A highly positive NAOI means strong winds and many rain-bearing weather systems crossing north-west Europe. In the River Tay there is a strong positive correlation with the wintertime value of NAOI and it is clear that when atmospheric circulation in the North Atlantic is at its strongest (highest values of NAOI), the winter is likely to be very wet, with implications for flooding. On the other hand, when the NAOI is highly negative, Scotland is likely to be dominated by "blocking" high pressure systems over Scandinavia and winter rainfall will be very low. On the other hand, in the River Derwent, in north-eastern England, there is a negative correlation with the summertime value of NAOI. In this case, when NAOI is highly positive, river flows will be very low, with drought threatening in-stream biota, especially in rivers where there are large water abstractions for domestic supply or irrigation. If the climate were to change so that, for example, the NAO becomes more positive, this would have long-term implications for river ecology: increased winter flooding could destabilize channel systems but low flows would become more common in summer, threatening the viability of some species and ecosystems. Given the tendency of the NAO to fluctuate considerably in just a few months, the most worrying sequence as far as low flows are concerned are two dry summers separated by a dry winter. This happened across England and Wales in 1975-76, producing extreme drought conditions (see Figure 2.5). Box 2.1 provides another example of changes in water resources related to inter-annual climatic variation.

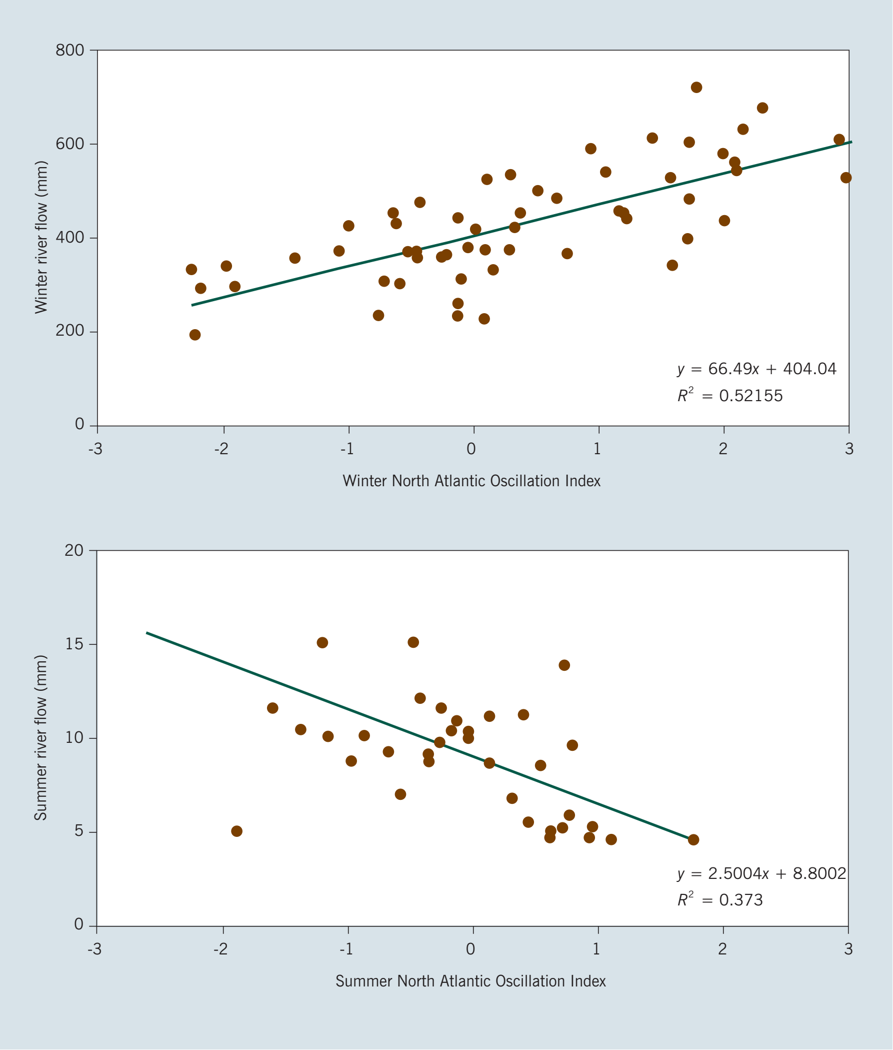


Figure 2.7: *Relationship between wintertime NAOI and flow in UK rivers.* (Up) *River Tay, Scotland.* (Down) *River Derwent, England*

Note: Data from UK National River Flow Archive (station numbers 15006 and 27041).

2.7. Impacts of human actions on river flows

In addition to those caused by climatic variation, human impacts also have long-term effects in river flows. As mentioned above, human impacts may be either *direct*, such as those derived from reservoir construction or water abstraction, and *indirect,* produced by changes in flow pathways across the drainage basin, for instance, because of impacts related to the condition of the land surface are probably more important: these include agricultural practices, deforestation or urbanisation.

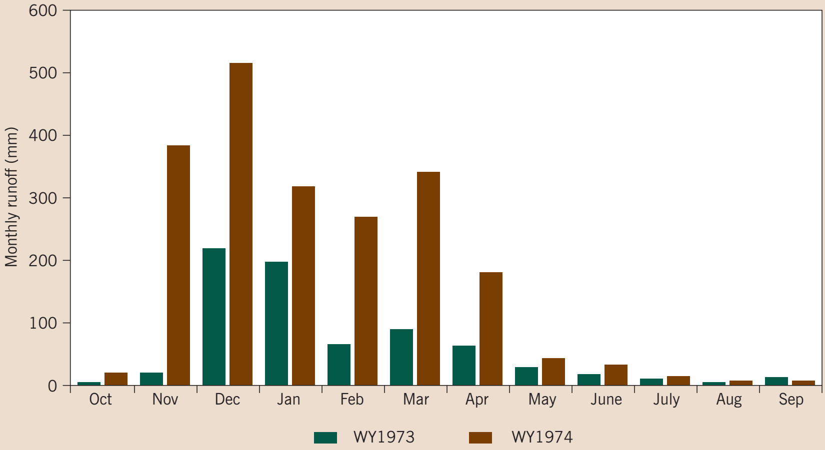
Box 2.1

River regimes and climatic variability

The river regimes presented in sections 2 and 3 are calculated for mean conditions; thus, climatic variability is disregarded. In most places, this simply means ignoring modest differences between wet and dry years, but in some places, variations in ocean-atmosphere coupling can result in very large changes in the pattern of river flow. The figure 2.8 shows the runoff regime at Watershed 2 at the H J Andrews Experimental Forest, Oregon, USA. The water year (WY) runs from 1st October the previous calendar year to 30th September. This basin has a highly seasonal climate with winter snow and a marked summer minimum: Beckinsale maps this region as HN.

First, a brief explanation of the El Niño Southern Oscillation (ENSO) is needed. El Niño (EN) conditions in the Pacific Ocean are characterized by a large-scale weakening of the trade winds and warming of the surface layers in the eastern and central equatorial Pacific Ocean. El Niño events are accompanied by swings in the Southern Oscillation (SO): the pressure gradient along the Equator reverses which in turn reverses wind direction. Instead of cold, deep water upwelling off the coast of Ecuador and Northern Peru, warmer surface water is blown from the west, causing an increase in rainfall in the otherwise arid eastern Pacific. Meanwhile, there is drought in the western Pacific over Indonesia. La Niña, the reverse phenomenon, is associated with a larger than normal pressure difference between the western and eastern Pacific, resulting in stronger than normal trade winds so that upwelling is significantly enhanced off the coast of South America. It is very wet in the western Pacific. These shifts in the condition of the Pacific Ocean, which happen typically every 2-7 years, exert strong control on the climate of the continents surrounding the Pacific Ocean.

Figure 2.8:
Monthly flows (mm) for WS2 at the H J Andrews Experimental Forest, Oregon



Source: CLIMDB/HYDROBD Database.

At H J Andrews, the very wet year (WY 1974) was affected by La Niña conditions whereas the previous year (WY 1973) experienced a drought as a result of an El Niño event. Whilst the overall pattern of runoff remains the same, the largest differences are seen at the beginning and end of the wet season, November in particular. Although the increase in low flows is relatively small (+31% in July, +68% in August), these have considerable implications for river ecology since headwater tributaries may dry up in El Niño events.

The first recorded dam was constructed in Egypt some 5,000 years ago. Since then, they have been built everywhere except Antarctica as people seek to improve crop yields, prevent floods, generate power and provide a reliable source of water. There are, for example, some 750,000 dams in the USA alone; paradoxically, most are small, but just 3% of the total account for 63% of the total storage volume (Goudie 2006). The main period of construction was during the second half of the twentieth century, and whilst there are still plans to build more large dams, for example along the Mekong River in China, in some places dams are being removed, in recognition of their adverse impact on river ecology (see, for example, http://or.water.usgs.gov/projs_dir/marmot/index.html). Whilst the river continuum continuity is a valid paradigm for river systems (see section 2.1), few rivers in the world are completely unaffected by the presence of dams. Dams completely truncate the channel network, and introduce the so-called *serial discontinuity* (Ward and Stanford 1979), that is the disruption of the channel continuum in hydrological, geomorphological, biological and biogeochemical terms. The disruption relates both to the interruption of the movement of water and the associated load, as well as to the replacement of shallow, flowing water *(lotic)* by relatively still, deep water *(lentic)*. The impact of the dam on the river downstream of the impoundment depends on the size of the dam and the extent to which unaffected tributaries join the affected river. Sediment retention behind a dam is a particular problem, reducing the amount of flood-deposited nutrients on floodplains and causing clear-water erosion of the channel downstream of the dam (Chapter 3).

The impact of reservoirs on the water balance includes abstraction of water for domestic and industrial purposes; some of this water may be returned to the river, but large quantities may be piped out of the basin altogether. Mean annual water balance calculations assume that there is no long-term change in the average amount of water stored in the soil and bedrock, additions in wet years being balanced by losses in dry years. However, this may not always be the case. In many countries, groundwater is being “mined” in unsustainable quantities, resulting in

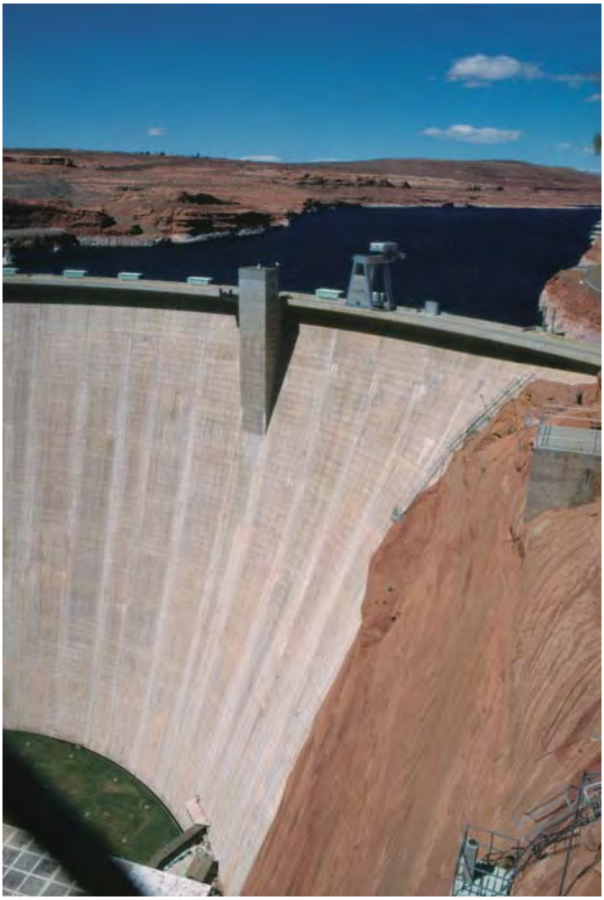


Figure 2.9: *The Glen Canyon Dam on the Colorado River provides a good example of problems that arise when a river is completely blocked, including alterations to the flow and thermal regime of the river downstream of the dam, threats to endemic fish species, and drowning of scenic landscape. Benefits were overvalued and costs underestimated. It is ironic that the Lake Powell is named after the man who first drew up recommendations for the sustainable use of water resources in the arid southwest USA*

falling water tables and headwater tributaries drying up (Pearce 2007). For example, groundwater tables have fallen by up to 100 m in the Las Vegas area since the early twentieth century, in response to increasing demand. Note that water abstracted for irrigation is mainly lost through evaporation and does not return to the river therefore. The most devastating impact of irrigation has been the demise of the Aral Sea, which covered over 68,000 km^2 in 1960, and was reduced to a mere 10% of its original size by 2007. The demise of the mighty Aral resulted in huge impacts both on biodiversity and on human populations. The case of Moynaq in Uzbekistan, formerly a flourishing fishing port which now lies miles from the sea shore, is but one example. The net effect of all these abstractions is reduction in river flows, with resultant impact on in-stream biota and habitats.

Regarding indirect impacts, replacement of permeable, vegetated soil with impermeable surfaces of concrete and tarmac is the most extreme indirect change: in simple terms, perhaps only 5% of rainfall forms floods in a rural basin whereas 60% of rainfall may be converted into stormflow in an urbanized catchment. The implications are obvious: a much more flashy regime with greatly increased potential for erosion during flood events. This can destabilise in-stream and riparian habitats by creating a much more extreme flow regime, and also impact human dwellings near the banks during times of flood.

The influence of small changes, even if dramatically changing the local hydrological response (e.g. urbanisation), tends to be undetectable within the flow regime of a large river basin. However, where changes to land cover are sufficiently widespread, then regimes of even large rivers can be significantly altered, with implications for all those dependent on the river, including in-stream biota. Box 2.2 describes how hydrologists conduct "paired catchment experiments" to investigate the effect of land use change on the water balance. Figure 2.10 shows the difference in annual runoff for a treated catchment Watershed (WS)1 compared to its control, WS2. The control period ran from 1953 to 1962 and then the cover of mature Douglas fir trees was logged. From 1967, vegetation cover on WS1 has been allowed to re-grow naturally, but even after more than 40 years, it is clear that there is still more than 100 mm extra runoff each year from WS1 compared to WS2. This is because the vegetation cover on WS2 is old-growth forest: the canopy intercepts large quantities of rain and snow which is then evaporated without ever reaching the ground. The new trees, even when thirty or forty years old, still intercept less water than the fully mature tress, so it may be several decades more before there is no difference between

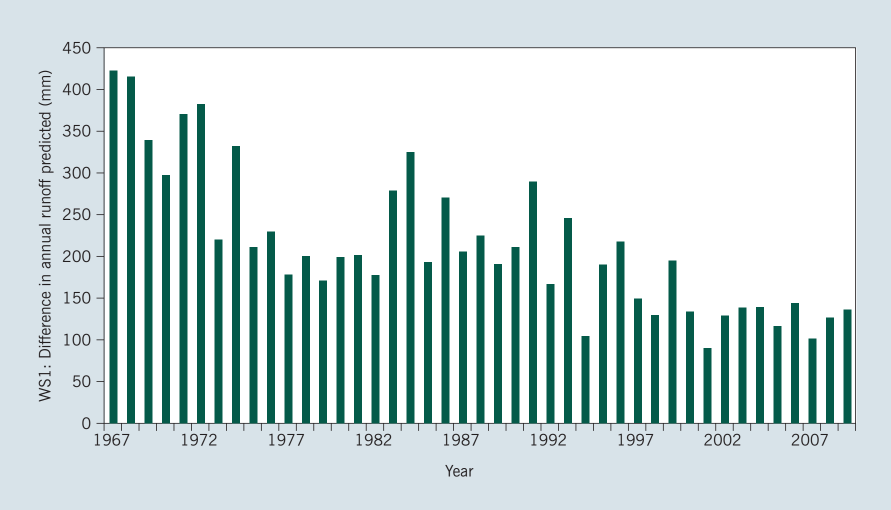


Figure 2.10: *Difference between predicted and actual annual water yield from WS1, H J Andrews Experimental Forest, Oregon*

Source: CLIMDB/HYDRODB database. The prediction method is explained in Box 2.2.

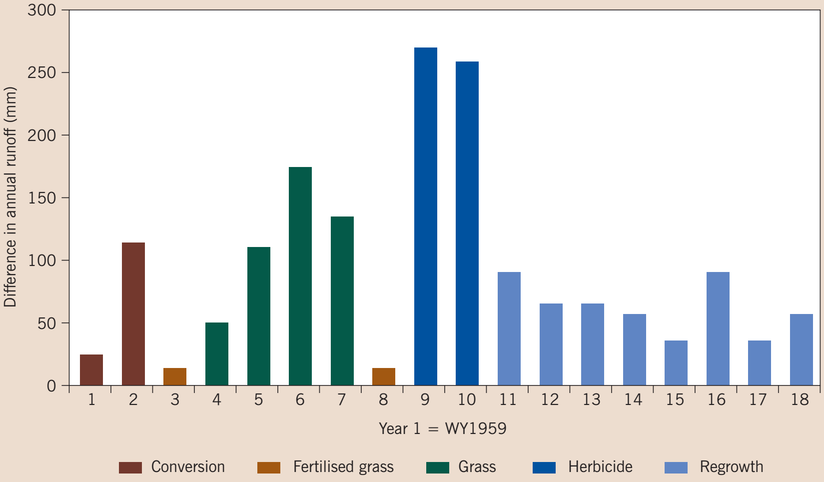
Box 2.2

Water or wood? Experimental investigations in forest hydrology

To investigate the impact of land use change on the water balance, the traditional approach in hydrology has been to conduct "paired catchment" experiments. Two adjacent basins, otherwise as similar as possible in all respects, are studied together. First, there is a period of calibration (ideally several years), during which a regression equation is established to show the relationship between runoff from the two basins. Then, land cover is changed in one basin ("treatment") whilst the other remains unchanged ("control"). The impact of the land use change is shown by calculating the difference between the actual response and that predicted using data from the control catchment.

Paired catchment studies in forest hydrology were pioneered in the USA. Figure 2.11 shows results from a series of treatments at the Coweeta Hydrologic Laboratory, North Carolina, USA (Burt and Swank 1992). Following clearance of the hardwood forest, to be replaced with grass, water yields increase, but the exact amount depends on the vigour of grass growth. When the grass is fertilized and dense, the overall effect is little different from the original forest, but as the grass productivity declines, because it was no longer receiving fertiliser, water yields rise. This is because there was a less dense leaf canopy so less rain was intercepted and lost through evaporation. When herbicide was applied to kill the grass, water yields increase dramatically, since there was no transpiration and the dead grass intercepts little of the rainfall. Finally, as the natural forest is allowed to regenerate naturally, water yields gradually decline towards the expected level. Such changes would, of course, impact on in-stream conditions, especially in headwater reaches where riparian shading is lost when the tress are cut down.

Figure 2.11: *Changes in annual water yield on WS6 at the Coweeta Hydrologic Laboratory, North Carolina, following forest clearing and application of different treatments. (See text for details)*



Source: Adapted from Burt and Swank (1992).

the water balance of the two basins. Thus, the impact of deforestation can be very long-lasting, even when the forest cover is allowed to recover. Of course, deforestation affects not just the amount of runoff: shading of the channel is lost, runoff pathways are significantly altered, and the river's sediment and solute load both change too. There are dramatic implications for the channel biota and their habitats therefore.

Goudie (2006) has reviewed the scale and extent of global environmental change. Some changes are *systemic*, affecting the whole world, such as the impact of global climate change resulting from emissions of greenhouse gases. Other changes are *cumulative*, indicating the substantial and significant accumulation of localized changes. It is these latter changes that characterize the human impact on rivers and river basins. The scale of cumulative land use change since pre-historic times is dramatic: Goudie (2006) shows that the area of forest has declined from 46.8 M km^2 to 39.3 M km^2 today, a reduction of 16%. Loss of grassland (19%) is larger in percentage terms but involves a smaller land area (from 34 M km^2 down to 27.4 M km^2). At the same time, the area of cultivation has increased from nothing to 17.6 M km^2 and the combined size of the global urban area is thought to be around 2 M km^2. As a result of all these various changes, relatively few large rivers can remain in pristine condition, and any assessment of future change must be judged against the uncertain baseline of "recent" condition.

2.8. Future projections

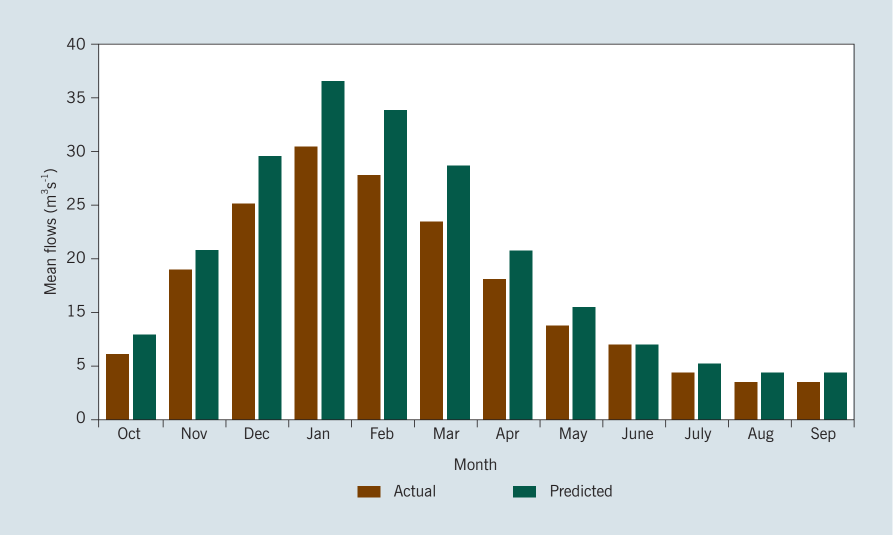
The main drivers of long-term changes in rover flow are climate change and human impact

We have already noted that the main drivers of long-term variations in river flow are climate and human impact. What does the future hold for our river basins? It seems all too likely that people will continue to have significant impact on basin hydrology (Pearce 2007), especially in the developing world, as ever more food is needed for growing populations.

Two examples will serve to illustrate these long-term changes. In Figure 2.12, a comparison is made between actual flows in the River Thames, England, using actual flow data from a gauging station in the middle of the basin, and a predicted flow series derived from rainfall data. Actual flows are significantly below predicted right across the flow range. For example, the mean summer flow (June – August inclusive) is actually 5.4 m^{3}s^{-1} but is 6.4 m^{3}s^{-1} for the reconstructed series. The mean monthly flow exceeded in 95% of months is 1.37 m^{3}s^{-1} for the actual series but is 2.18 m^{3}s^{-1} for the reconstructed series.

The second example of human impact comes from the Ebro River in north-east Spain. The Ebro River basin contains 187 dams, with a total capacity equivalent

Figure 2.12: *Mean monthly flows for the Thames at Eynsham (NRFA station number 39008) and for the reconstructed flow series*



Source: http://www.cru.uea.ac.uk/cru/data/riverflow/

to 57% of the total mean annual runoff (Batalla et al. 2004). The diverted water is used mainly for hydro-electric power production and for irrigation. Virtually all the dams were constructed during the 20th century, two thirds in the period 1950-1975. Figure 2.13 shows the highly significant decline in annual mean flow since 1954; the Tortosa gauging station is close to the Mediterranean Sea and therefore integrates the response for the entire basin. For the period 1917-1931 i.e. prior to the Spanish Civil War, the mean flow was 567 m^3s^{-1}. For the period 1954-1975, the mean flow was 493 m^3s^{-1} and only 309 m^3s^{-1} for the period 1976-2007. This is clear evidence therefore that the Ebro basin has been significantly impacted by the construction of reservoirs. It is worth adding that some head-water basins draining the southern Pyrenees have seen a considerable increase in forest cover due to both land abandonment and afforestation (Gallart and Llorens 2004). This will have contributed to the decline in flow as there are higher evaporation losses from forest than low crops (see also Box 2.2).

2.9. Is our glass half full or half empty?

The global population has now reached 7 billion, half of whom live in cities; the global population is expected to reach between 7.5 and 10.5 billion by 2050. Given an extra 0.5-3.5 billion mouths to feed, plus the rising expectations of a developing world, we can anticipate continued pressure on the world's resources, water most especially. At the same time, there is growing recognition of the

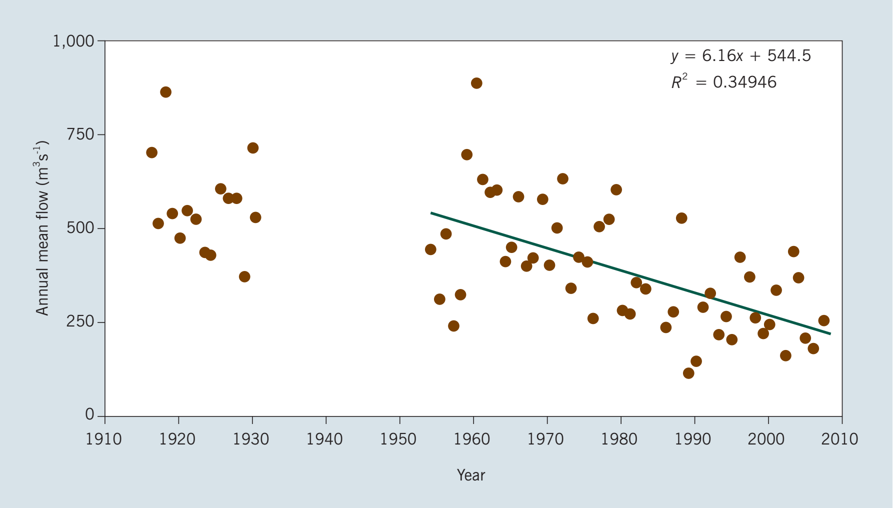


Figure 2.13: *Annual mean flow (m^3s^{-1}) at Tortosa, Ebro River, Spain (The base year was 1954)*

Source: Data from the River Ebro Authority (Confederación Hidrográfica del Ebro).

need to create sustainable water use, not threatening the opportunities for future generations by excessive exploitation today.

Should we be optimistic or pessimistic about the future of our rivers? In the near future, we can expect to see greater pressure on water resources in the developing world, with more dams being built, for example along the Mekong River, and more water being abstracted for irrigation. This will have serious consequences for river conservation. Meanwhile, in the developed world, there are likely to be efforts to reverse some of the worst effects of river engineering, with some dams being removed. Wiser use of water may even lead to a slight fall in consumer demand. Under these circumstances, we might speculate that climate will become a relatively more important driver of long-term change in river systems.

Gradually, we may see some rivers becoming noisy again, as the flow regime is returned to its natural state. This certainly means higher flood peaks. It may mean higher baseflow too, if water abstractions are reduced, but it might mean lower – but more natural – baseflow when dams are removed since "compensation water" is often released from reservoirs to maintain a more even flow regime. However, in most river basins, particularly in the arid regions as well as in the poorest countries, as we struggle to provide drinking water and to grow crops, rivers will become silent. Not only will there be deterioration of physical habitat; other problems will include decreased dilution capacity, reduced possibilities for fish migration and much less frequent flooding of riparian areas. Fred Pearce advocates a more sensitive use of water resources, giving up the notion of the "technological fix" and learning to treat nature as the ultimate provider of water, not a wasteful withholder. We cannot keep turning to irrigation when the climate gets drier or build more levees to prevent flooding in wetter periods. Treating water as a precious resource will allow us to better protect our rivers as well as deal with human needs. We need to give water back to nature, to protect our wetlands and conserve our freshwater ecosystems. This approach is reflected in modern legislation, such as the European *Water Framework Directive* (WFD: 2000/60/EC). With its holistic approach focusing on the achievement of "good ecological status", the WFD will help deliver water quality that favours the health of aquatic habitats as well as the quality of drinking water. Protecting and improving the riverine environment is an important part of achieving sustainable development and is vital for our long-term health, well-being and prosperity as well as for the river basin in which we live.

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