Sustaining our rivers in crisis: setting the international agenda for action

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Abstract The history of streams and rivers is as much a social and technological history as it is a scientific one. Rivers are the lifeblood of nations and the control of their waters has been fundamental to the building of human civilisations. The control or regulation of rivers embodied the advancement of institutions, administration and co-ordination; it was a manifestation of military and economic power.

Yet the history of human development is also characterised by the degradation of the basic resource – polluted water, increased flooding, and the loss of biological diversity. Many early civilisations collapsed in the face of environmental degradation, manifest by flood, drought, famine and plague. The Industrial Revolution upon which modern societies are founded was based upon a short-term vision that has left rivers in crisis, marked by a legacy of pollution, slums, a loss of confidence in civic life, and a loss of ownership of places and spaces – once seen to be at the heart of civilised society.

Within this global or international context of water management, this paper examines the impacts and future of rivers and water within the United Kingdom, establishing some principles for such management in other settings.

Keywords Water; industrial impacts on rivers; United Kingdom water management; solutions to water pollution; river restoration; river recovery

The world of water
The United Nations Conference on Environment and Development in Rio de Janeiro in 1992 established a blueprint for future survival on planet Earth – now known as Agenda 21. The key principles for integrated water management as cited in Agenda 21 are

- water is a scarce resource
- all those who are interested in water allocation and use should be involved in decision making
- water should be managed within a comprehensive framework including water supply and waste management.

For sustainable river management there are three additional principles:

- rivers are influenced by all activities within their drainage basins
- river ecosystems involve longitudinal, lateral and vertical fluxes including important interactions with floodplains and riparian zones during the flood season
- river ecosystems are in large part driven by abiotic factors (hydrological, hydraulic, water quality, and morphological dynamics).

Recognition of these principles is necessary to ensure that what we do today does not undermine the development and environment needs of present and future generations. With foresight, governments, industry, researchers and the public can come together to define this common agenda.

The agenda for sustaining our rivers in crisis, requires promotion of the intimate link between community and ecology. In the developed economies, the agenda focuses on green corridors, clean water, and a diversity of wildlife as potent symbols of prosperity. The emphasis is on “evolving naturalization” where ecological configurations are allowed to evolve in response to changing magnitudes and rates of processes driven by the catchment...
ecosystem. However, small-scale protected areas and *ex situ* conservation measures (gene banks, aquaria, etc.) continue to play important roles. River naturalization is clearly part of wider catchment management plans encompassing social, economic and aesthetic concerns, as well as hydrological and ecological ones. Opportunities for river naturalization are being created by new technology, for example in wastewater treatment and water use, new scientific knowledge, leading to better diagnosis of problems and improved models to evaluate alternative solutions, and by innovative education programmes to help communities to rediscover local resources and environmental values.

In developing and less developed economies, protected areas and *ex situ* conservation measures have a particularly important role in the face of poverty-driven development and natural-resource utilisation. Environmental management is usually, and understandably, driven by water resource demands and public health needs. In many areas of the world, the number of water taps per 100 persons is a better indicator of human health than the number of hospital beds. At the beginning of the third millennium there are 1.3 billion people without safe drinking water and 1.9 billion lacking appropriate sanitation. There are 30 or so major diseases in the developing world and of these 21 are water and sanitation related. Floods too are a major problem in many regions.

A perspective on the United Kingdom

Following the last glacial period, catchments within the UK became dominated by wildwoods with beech, ash, holly, elm, lime, oak, hazel and birch, and valley bottoms were characterised by seasonally flooded woodlands and bogs. Then, about 6,000 years ago the arrival of Neolithic peoples heralded the conversion of the natural wildwood landscape to open countryside dominated by farmland. Deforestation released vast quantities of fine sediments and the resulting accretion of floodplains signified the first identifiable effect of human activity on river systems.

For nearly 2,000 years following the Roman occupation, the rivers of the UK were in balance with the low-intensity agricultural landscape, although progressively problems of overfishing, pollution, and navigation had local but notable impacts. Evidence of overfishing of salmon dates from the 13th century; small urban streams such as the Walbrook in London were reported to be suffering from pollution by the end of the 14th century; and the increasing intensity of river works for navigation followed the 1665 Act “for making divers rivers navigable”.

Once the industrial revolution came in the early nineteenth century, the rapid increase in population led to a huge increase in the demand for water to supply industry and human needs. Demands for food altered agricultural practices, and demands for space by the insatiable urban dweller impacted upon rural landscapes as never before. From this time through to the present, rivers in the UK were dominated by human influences.

Catchments today

In the United Kingdom today, some 70% of the population live in urban areas and nearly 50% live in cities of over 250,000 people. Urban areas cover over 500,000 hectares but the road and rail networks extend the urban influence well beyond the limits of cities and urban conurbations. Despite the general public association of rural environments with natural environments, the modern day catchment bears little resemblance to the natural catchment. The spread of urban development has engulfed vast areas of countryside and the demands of urban populations have induced continuing changes in rural landscapes. Lowland catchments have become dominated by intensive agriculture, upland hillsides have become covered by plantation forests, and valleys have been impounded by dams.

The legacy of our urban and industrial heritage is the contaminated sediments, canalised
channels, and culverted streams, which continue to function within derelict corridors for storm water and wastewater drainage. The social response to urban living has been one where people become increasingly alienated from, and disinterested in, the local natural environment. There develops a perception of complete independence from nature. Nature and wild(erness) become associated with remote areas, to be visited when desired, for recreation and leisure.

A review of Local Environment Action Plans (LEAPS) produced by the Environment Agency of England and Wales reveals a suite of common concerns focusing on flow levels in rivers, pollution, ecology and amenity, and widespread uncertainty about the implications of climate change. Common concerns are listed in Table 1 below.

Table 1 Concerns about river catchments, in the UK

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<tr>
<th>Flows</th>
<th>Ecology</th>
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<td>Local flooding due to blocked culverts</td>
<td>Lack of in-stream habitat</td>
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<td>Low flows, saline intrusion and wetland degradation</td>
<td>Loss of wetlands</td>
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<td>Rising groundwater</td>
<td>Loss of floodplain habitats</td>
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<td>Pollution</td>
<td>Conservation of rare species</td>
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<td>Misconnections</td>
<td>Impact of invasive, non-native species</td>
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<td>Storm overflows and CSOs</td>
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<td>Pollution incidents/accidents</td>
<td>Lack of access</td>
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<td>Eutrophication</td>
<td>Derelict sites along river corridor</td>
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<td>Runoff from contaminated land</td>
<td>Litter and illegal tipping</td>
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<td>Persistent chemicals</td>
<td>Algae</td>
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<td>Water abstractions</td>
<td>Drain-like channels</td>
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Growing demands for water supplies by urban centres have been met by increasing abstractions and then by river regulation using dams and reservoirs. Abstractions from groundwaters have severely impacted springs and streams. Important aquifers occur throughout central, southern and eastern regions. Urban water management has exacerbated the problem. Rainfall that is diverted into the storm water drainage system cannot enter the ground. Thus a possible consequence of the urbanisation of a catchment is the reduction of groundwater recharge as a result of the extent of waterproof covering of the ground.

Reduced recharge together with increased groundwater abstraction to meet urban needs resulted in severe decreases in groundwater levels in several major conurbations in the mid 20th century, including Birmingham, Manchester, Liverpool and London. Today, groundwater abstractions account for about 20% of the total abstractions, rising to over 50% in the south-east. Concerns for the decline in springflows from the important Chalk aquifer, because of increasing abstractions, were raised as early as 1850. Below Trafalgar Square, for example, as groundwater levels fell the springs and water-supply boreholes ran dry and the drilling of deeper boreholes became more expensive; salt water intruded the aquifer from the River Thames; and land subsidence of up to 1 m occurred. In 1993, the National Rivers Authority of England and Wales identified 40 rivers that appeared to be suffering from severe low flows; 12 of these drain Chalk catchments.

All the major upland rivers in the UK – Tay, Severn, Tweed, Welsh Wye, Beauly, Tyne, Conon, Towy, Welsh Dee, Usk, Tamar, Tees – are controlled by dams. Even “lowland” rivers such as the Trent, Great Ouse and Medway are heavily regulated. Dams and reservoirs introduce barriers disrupting the upstream-downstream connectivity within river systems. Most obviously they obstruct the passage of migratory fish. However, they also reduce floods and can introduce artificial flow regimes, reduce sediment loads, change channel form and the mosaic of physical habitats, change river temperatures, and alter the
type of organic matter that drives the food chain. The reservoir itself introduces a new type of habitat but unlike natural lakes, many reservoirs suffer from wide variations of water level making the banks inhospitable for many organisms. In some instances the entire course of a river has been altered to some extent, either by abstractions or effluent returns.

Flooding

Flooding is a natural process but landuse change has increased rates of flood runoff in some small catchments. The concrete, tarred, paved or roofed surfaces in urban areas are impervious to water. As a result, rainwater does not infiltrate the ground surface but runs into the urban stormwater system and then directly into the streams. Thus, an urban area generates a large quantity of runoff in a short time, much more so than natural ground.

An example of a recent large flood is that of the River Tay in Scotland which experienced the two largest floods on record in 1990 and 1993! In January 1993, a record flow for the United Kingdom of 2200 m$^3$/s caused £20 million worth of damage to Perth and its surrounding areas. Before the 1993 event, the 1990 flood was perceived as the 1-in-100 year flood. Because the available information was limited to a few decades, in 1990 the 1-in-100 year flood discharge was estimated at 1540 m$^3$/s. After 1993 the 100 year flood was re-evaluated to be 2000 m$^3$/s. This means that there is now a greater area than previously within the 1-in-100 year flood zone!

Plantation forestry

Upland catchments have also been impacted by acidification and in some cases, waters with productive fisheries have become fishless. Acid rain arising from industrial pollution can be at least five times more acid than unpolluted rain. The pH of water measures the degree of acidity. In upland, hard-rock catchments the soils lack buffering capacity and low pH (high acidity) can be associated with elevated concentrations of dissolved aluminium which can be acutely toxic to many forms of aquatic life. In some parts of the UK, the expansion of coniferous plantations has exacerbated the effects of acid rain. Today, some 10% of the UK is covered by forests, most of which are growing non-native species with high productivity. By 1986, some 100 km of upland rivers in Wales were thought to have been degraded by low pH.

Agricultural impacts

Today, rural landscapes are dominated by cultivated lands (32%) and managed grasslands (33%). River catchments are impacted by two processes: soil erosion and nutrient losses especially from intensively cultivated areas. Soil is not only essential for food production and an important habitat for many animals and plants, but it also has important functions within a river catchment. The soil can filter, transform and neutralise potentially polluting substances from rainfall or as a result of human activities; and it can act as an important reservoir for water and a sink for carbon. Soil erosion is a natural process but some land management practices can accelerate erosion rates to abnormally high levels. Streams and rivers affected by large volumes of silt derived from accelerated soil erosion often appear desert-like, because they contain so few living organisms.

Harvesting, soil disturbance, drainage and fertiliser applications can all influence nutrient levels in streams. Phosphorus and nitrogen are powerful natural chemicals that are widely used. In balanced aquatic systems, plants such as algae are always present but their growth is limited by the amount of naturally available nutrients. The natural process of nutrient enrichment of a water body is known as eutrophication and is seen, for example, in successional change of an oxbow lake as it develops from open water to marsh. However, human activities can dramatically accelerate this process. In excessive amounts, nutrients cause enormous growths of algae. In severe cases, algae can cover the river bed destroying
the habitat for most bottom-living organisms. When large mats of algae die, rapid decom-
position can also deplete oxygen levels.

The most visible of the effects of human activity on surface waters is in the formation of
“algal blooms”, promoted by the growth of microorganisms such as bacteria, algae and
diatoms. Some of these produce potent toxins, which may enter the food chain through
drinking water or by accumulation in edible shellfish. Cases of human and animal poison-
ing have resulted. Today, high concentrations of phosphate and nitrate tend to be found in
the rivers of the Thames, Midlands and Anglian regions, that is, in highly populated and
intensively farmed areas.

Organic pollution
Faecal and organic pollution are the oldest forms of pollution to impact rivers. Organic mat-
ter, and especially sewage, is a particular problem for urban rivers. A normal end product of
the decomposition of animal protein, faecal matter and urine is ammonia, which is toxic at
high concentrations. Ammonia is oxidised to nitrite then nitrate by nitrifying bacteria, but
this contributes to the oxygen demand. When large volumes of organic matter are involved
so much oxygen may be used that the water may be deprived of oxygen. Under such
anaerobic conditions, a deposit of highly organic mud can form on the bed. Bacteria reduce
the sulphates in the mud to produce hydrogen sulphide, which has a pungent “bad-egg
smell” and turns water black due to the precipitation of insoluble iron sulphide.

Biodiversity
Wildlife is valued for its own sake and because it is part of our natural resource – our natural
capital – which we aim to preserve for future generations. In natural rivers and streams,
communities of animals and plants support a large number of different species with rela-
tively few individuals of each type. Poor water and sediment quality, or habitat reduces the
diversity of animals and plants. An unhealthy community is characterised by a restricted
number of tolerant species, each with a relatively large number of individuals.

Across Europe, 17 of 222 river fishes are globally endangered or vulnerable. Migratory
species such as salmon and sturgeon are directly affected by dams which block their jour-
nets, pollution, and loss of spawning and nursery grounds. Many species of invertebrates,
mammals, amphibia and birds depend on river systems for their survival, and several of
these have become depleted or extinct. The geographic range of the otter has been
drastically reduced this century due to habitat destruction, pollution and hunting.

In the UK, between 10 and 20 per cent of native species are considered threatened.
Urban development, transport development, forestry expansion and intensification of agri-
cultural production are principal causes. In rivers and streams, habitat loss and pollution
have significantly impacted biodiversity. For example, just over half of the dragonfly
species declined in geographical distribution between the early 1970s and late 1980s.

New water quality problems
There has been a recent upsurge of interest from scientists, regulators and the public in
micro-organisms and endocrine-disrupting chemicals, which are widely distributed in the
environment, and may have health implications for humans.

Micro-organisms (parasites, bacteria, fungi and viruses) are part of every ecosystem.
Many are essential to natural processes, others cause disease and there are serious concerns
that human impacts upon surface waters may increase risks to human health. A wide range
of pathogenic organisms (microbes that cause illness in humans or animals) are found in
river water but rarely in sufficient numbers to cause infection. Historically, outbreaks of
typhoid and cholera were caused by contamination of drinking and washing water with
human faeces. Enteric pathogens (ones which infect the gut) may be released directly by animals defaecating close to or in rivers, by accidental run-off of slurry from farms, by treated sewage effluent discharges from sewage works, by untreated sewage discharges from combined sewer overflows, or by contaminated run-off from roads, gulleys, surface water drains, etc. The degree of pollution by animal and human faeces can be measured by tests for faecal coliforms and faecal streptococci for which there are EC Bathing Water Directive standards. Such tests show that most urban streams and rivers will be more contaminated than the worst contaminated bathing waters in the UK. Water purification treatments and sewerage systems have controlled disease outbreaks in the developed world, although they can still be problems in less developed countries. Although conventional water treatment disinfection processes will deal effectively with bacterial and viral pathogens, protozoal parasites such as Cryptosporidium will survive through normal treatment processes. Cryptosporidium has been the cause of several major outbreaks of disease in the UK and is now routinely monitored in drinking water supplies.

The extensive network of river corridors makes rivers highly vulnerable to colonisation by invasive alien species established through accidental or deliberate introduction. A number of plants have proliferated in this way and many species of non-native plants now live and breed along water courses.

Some, such as Japanese knotweed (*Fallopia japonica* var. *japonica*) and Himalayan balsam (*Impatiens glandulifera*) have adapted particularly well to the difficult and often polluted urban environment and have come to dominate river banks in urban areas. Japanese knotweed is a perennial plant that can grow through concrete and tarmac and forms dense thickets that can displace native plants. Himalayan balsam can also displace native plants, spreading by seeds explosively propelled from ripened pods. Another invasive species, giant hogweed (*Heracleum mantegazzanum*) poses a public health hazard because its sap causes a painful skin rash on contact. In addition, when the plants die down in winter, they leave river banks unvegetated, liable to become unstable and prone to erosion.

It is not just exotic plants that pose a threat for native species. Non-native animals, such as mink and North American crayfish, farmed in the UK, have escaped into the wild or have been deliberately released and now compete with native species for food, space and other natural resources. The White-clawed Crayfish (*Austropotamobius pallipes*) is the only native species of freshwater crayfish in the UK. It is now under competition from alien crayfish species, most notably the American Signal Crayfish, which causes damage to river habitats, spreads a fungal disease deadly to the native species and out-competes the White-clawed Crayfish for food.

Concerns about climate change

The 21st century is likely to witness climate change, but the effects of climate change on weather patterns across the UK, on water resources and on the distributions of animals and plants, is uncertain. Nevertheless, risk and uncertainty are being incorporated into planning frameworks, for example, for large projects such as reservoirs, and for diverting local government planning for housing to areas less prone to flooding.

Surface temperatures are likely to increase. Globally, mean temperatures may increase by 2°C by 2100. Increased surface temperatures are likely to lead to a more vigorous hydrological cycle, with more extreme events – floods and droughts – in many areas. In the UK, average temperatures have increased by around 1°C in the last hundred years. Computer models of the atmosphere predict that a further temperature increase of +1.2 to +3.4°C is likely by 2080. They also predict that warming will cause generally drier summers, especially in the south-east, and wetter winters, especially in the north-west. The unusually hot dry summer of 1995 could become typical. Storms are likely to become more frequent.
Changes of climate have occurred in the past but predictions suggest that this current period of climate change will occur much more rapidly – and too rapidly for many species to adapt in an evolutionary sense to the changing conditions.

There are immediate implications for urban rivers from these changes. Flooding incidents are likely to become more frequent. In the past flood risks were managed by flood warning, defence and emergency response. In the future it will be increasingly important to define the 1 in 100 year flood limit and to improve flood contingency planning. The sustainable approach to flooding is to avoid building on river floodplains. This both avoids damage to property caused by flooding, and permits the floodplain to be used for flood storage, thus offering some protection downstream. Sea levels will also rise, both as a consequence of ice-cap melting and because warmer oceans will expand. The anticipated rise in southern and eastern England is more than half a metre. This rise in sea level affects the water level in the lower reaches of rivers draining to the sea, and will cause river levels to rise also, further increasing the risk of river flooding.

Increasing demand for water in the dry south-east of England may result in frequent summer water shortages and reduce summer river flows below ecologically acceptable amounts. Increased water stress may result from drier, more predictable summers attracting more visitors, increased holiday or second home ownership, and return migration as retirement homes. However, increased irrigation for agriculture may cause the greatest problems. Gardens will evolve with low water requirements and the concept of the zero-water garden may be advanced with grasses, hardy palms and extensive use of gravels and pebbles to prevent evaporation from the soil, and any water will be collected in water butts to collect roof runoff.

Planning for the effects of climate change will need to take into account new information and the increasing rate of information generation. Monitoring of changes in rivers is likely to play an increasingly important role.

Opportunities and challenges for sustainable river management

The adoption of the goals and aspirations of sustainable development remains one of the key challenges for the revival of urban areas. Communities in which people are denied opportunity and face poverty and exclusion, and economies in long-term recession are not sustainable. Actions by governments to secure enhancements which contribute to the short-term improvement in the quality of life are important, but inadequate.

Opportunities for sustaining rivers in crisis are arising because of three developments: new attitudes in governments and by the public; new science and technology; and new management frameworks. New science and technology is needed for the diagnosis and treatment of environmental problems, such as waste treatment, flood control, and ecological degradation. Technological innovation is also needed for efficient water use and recycling. These advances will enable the implementation of new concepts for development. Attractive waterfronts and blue networks are now seen as key elements of successful urban revival manifest by sustainable, clean, river corridors. Clean rivers with a diversity of animals and plants have become symbols of a healthy environment, an attractive city, and a stakeholder society having ownership of its environment and responsibility for the needs of future generations.

Recovery of the River Thames: a cause for optimism

Industrialisation occurred earlier in the United Kingdom than in any other western country. The urban population (defined as those living in towns of more than 5,000 people) rose spectacularly from approximately 3.1 million in 1800 to almost 28 million a century later. This represented both an unprecedented natural increase and a large-scale migration into
towns and cities. Overcrowding resulted from the desire to house as many workers as possible in a small space near to the industrial workplace.

The inevitable result of such rapid, unplanned expansion was insanitary and unhealthy housing in the inner cities and the emergence of slums. Open ditches and streams had long been receptacles for disposing of domestic sewage and trade refuse, as well as rubbish from street surfaces. Flowing water provided a simple means of waste disposal. With growing populations the ability of streams to disperse, dilute and assimilate organic wastes became limited. Channels often became blocked. The expense of cleaning and maintenance led to widespread neglect. Plague and cholera were the inevitable cost.

In medieval London wherever there was running water, latrines were built over it as the easiest method of disposal. In Ben Johnson’s *On the Famous Voyage* published in 1616, he describes the foulness of a voyage up the Fleet: “When each privies seate is fill’d with buttoc? And the walls doe sweate urine and plaisters?” “when their oares did once stirre, belch’d forth an ayre as hot as at the muster of all your night-tubs”. The river was not only unsightly and unbearably smelly, but it also became a source of epidemic disease. The plague of 1665 destroyed every parish along the lower river.

By 1771 when Tobias Smollett wrote *Humphrey Clinker* the river was in rapid decline:

“the river Thames, impregnated by all the filth of London and Westminster. Human excrement is the least offensive part of the concrete which is composed of all the drugs, minerals, and poisons, used in mechanics and manufacture, enriched with the putrefying carcasses of beasts and men; and mixed with the scourings of all wash-tubs, kennels, and common sewers”

In 1846 the polluted river Fleet, which had become covered over by development “– quite literally – blew up, its rancid and foetid gases bursting out into the street above […]. in Clerkenwell three poorhouses were swept away in a tidal wave of sewage”. Finally, the river was lost beneath the expanding urban infrastructure. The Fleet had been turned into a large underground sewer of 5.6 m by 3.7 m section at its mouth carrying an estimated 8 million cubic metres of sewage water each year!

Ironically, the widespread “improvement” in wastewater management with the use of the water closet from the 1820s and the construction of sewer systems had dramatic impacts on inland waterways, creating large point sources of sewage discharge directly into streams and rivers. The ecological consequences were disastrous!

The control of nature and exploitation of natural resources was at the heart of the industrialisation process and of advances in the co-ordination and effective administration of water- and land-management schemes. Great river regulation and wetland reclamation schemes in 17th and 18th century Europe were not simply the result of technological advances. They were symbols of power: the power of the emerging centralised state that was able to underwrite developments legislatively and financially; the power of a capitalist land market to realise the financial gains of improvement in increased land values.

The political will to finance major new waste disposal schemes was slow to be realised for two reasons. First, there was a lack of scientific proof of the link between waste water and public health. Secondly, the problem had not reached crisis proportions! It took the hot summer of 1858 – the year of the Great Stink! – to persuade politicians of the need for action. *The Times* of 3rd July 1858 reported that the Thames stank so badly that parliament was nearly closed and members of a committee led by the Chancellor of the Exchequer were observed to rush from the “pestilential odour”. By 1865 the Bazalgette scheme comprised a total of about 2000 km of sewers in London and 132 km of intercepting sewers – the main drainage works had cost over £4 million. The main drainage of London was cited at the time as “a magnificent instance of successful drainage”.

10
Before the spread of London and the Industrial Revolution, the inner estuary of the River Thames between London Bridge and Thurrock was a wilderness of marshes and reedbeds with a diversity of wildlife. Birds such as bitterns, bearded reedlings, spoonbills and Montagu’s harrier were probably common. Fish including smelt, salmon, lampern, shad, flounder eel and whitebait, together with cultured mussels and oysters, formed the basis of important fisheries. The virtual destruction of the River Thames as an ecological entity between 1800 and 1850 was caused both by pollution and by the “reclamation” of huge areas of riverside marsh. The decline in the river continued until the mid 20th century, when the whole section of the Thames was virtually lifeless and anaerobic in summer. Studies in the early 1960s showed that the Bazalgette scheme actually focused untreated sewage discharge which, because of the enclosed, tidal nature of the river, became trapped only about 5 km below the discharge point!

New scientific understanding of the flow within the upper tidal river led to improvements and within ten years there was clear evidence of the return of fishes and birds to the tidal Thames. The 40 km reach between London Bridge and Tilbury benefited most. Between 1967 and 1973 a total of 72 species of fish were captured on the river. Six migratory species, including smelt, penetrated upstream to at least 10 km above London Bridge. In 1974, a few salmon were reported to have returned to the lower tidal river. Signs of change in the bird population along the upper tidal river were noted during the mild winter of 1968 with the arrival of two large flocks of pochard with numbers of shelduck, pintail, and tufted duck – all relatively unknown so far up river. Once again the upper tidal river became a refuge for many species of water birds including a wintering population of up to 10,000 wildfowl and 12,000 waders. The foundation for regenerating London’s waterfront had been established at last.

Waterfront regeneration
Urban river corridors have been used as a catalyst for the regeneration of the wider urban area in a number of cases. The scope for redevelopment is immense. The decline of the major river ports and associated industries of shipbuilding and engineering left their parent cities with increasing amounts of derelict, polluted land at the heart of the urban area. This land can, however, be successfully reclaimed. One celebrated example is that of the Docklands regeneration in London, and in particular the flagship scheme at Canary Wharf.

Another is the 121 ha Greenwich Peninsula. Here one of Europe’s biggest regeneration projects, with £180 million invested in site cleaning and preparation and infrastructure works, includes the Millenium Village at the heart of which is a new artificial ecology park. A network of green corridors connect the village to the Thames riverfront. The scheme includes 1.2 ha of created lakes and wetlands and innovative ecological flood barriers comprising newly planted terraces with reed beds and salt marshes. The scheme claims to have restored the stretch of the river close to the Thames Barrier to its past environmental glory with the re-introduction of a wide range of natural habitats lost by the industrialisation of the site. Wildlife such as shelduck, lapwings, ringed plovers, dunlin and redshank are expected to return.

The Greenwich Peninsula is designed as a model for a society of the future. It rejects the single function neighbourhood model and creates a new community consisting of a mixed use, residential and commercial area with leisure, shopping and recreational facilities all linked by a series of parks, corridors and transport links.

Alternative planning strategies
How can urban river corridors best be used? It is clear that a co-ordinated strategy is necessary for the successful planning of urban rivers. Rivers now have a place in many urban...
development and regeneration plans. Norwich is one example where progress is being made; the river corridor is now viewed as a precious public asset, a resource for relaxation and recreation, a valued haven for wildlife, and a wonderful landscape setting for the historic city.

At a larger scale, recent initiatives in the Thames Corridor are significant in focusing specifically on the river as a basis for urban planning policy. The river is now covered by Strategic Planning Guidance issued in 1997, with riparian authorities responsible for delimiting a “Thames Policy Area”. There is an additional sub-regional planning framework for the Thames Gateway area, where environmental concerns have to be balanced with development pressure in growth areas along the estuary. The principal objectives of the Strategic Planning Guidance are defined as being to:

• maintain and improve the quality of the built environment
• restore and promote the vitality of the riverside in areas of development opportunity
• conserve and enhance the character of the natural and historic environments
• encourage and facilitate the use of the River and riverside for transport and recreational purposes

However, this document has not been without its critics. The London Rivers Authority report Putting Rivers on the Map (2000) considers it to be overly concerned with riverfront land, rather than with the water space of the river itself. As an alternative, the LRA propose that Blue Belts should be designated as a water-based equivalent to green belts. This would allow the planning of urban rivers under a single management strategy. They would be viewed more holistically, as an ecological and cultural resource, capable of supporting sustainable tourism, recreation and transport, with the natural environment given the highest priority. Dynamic and diverse bluespace strategies would, the LRA contend, provide a much more sophisticated means of planning the river. Potential development sites would be classified as bluefield and be subject to review. For example, all development proposals would be the subject of a river impact assessment to establish their ecological, economic and social impact upon the river.

New developments in science and technology

New advances in science and technology will offer new opportunities for the redevelopment of rivers. Advances in water collection systems and sewage effluent treatment are creating opportunities for water reuse, reducing water stress in dry areas and improving the quality of rivers enhancing opportunities for wildlife and recreation. New ecological research is also advancing designs for restoring wildlife and fish habitat.

Collecting rain. Rainfall collection systems and the storage of filtered rainwater in tanks beneath houses can supply many purposes apart from cooking and drinking. Such schemes can provide essential storage of water in winter, when excess roof drainage can cause flooding, for supply during the summer when the water is a valuable resource. The Millenium Village on the Greenwich Peninsula aims to minimize water use not only through water saving devices such as efficient showers and toilets but also water collection facilities for roof runoff for irrigation and recycling. In addition to the 1377 homes, the Dome is designed to collect the millions of gallons of rainwater that falls on it every year for use in the 650 visitor toilets and washrooms. Also the distinctive roof of Sainsbury’s Superstore has been designed to collect water which is treated and used to water a nature area, lawns and gardens within the development.

Wastewater treatment. The development of biological processes to remove the nutrients nitrogen and phosphorus from treated wastewater introduced biochemical pathways that
were previously unknown to sewage treatment scientists and engineers. It also opened the doors to the development of significantly more economical and stable activated sludge systems, minimised secondary environmental impacts and reduced the cost of implementation. By using nitrate contained in the sewage to oxidise some of the pollutants present in the sewage, the energy costs of mixing air into the sewage are reduced and the volume of sludge produced is also smaller.

However, the process is slow and therefore the reactor vessels are larger than the usual process. Size matters for a large works and the trend is towards high rate technologies that enable the works to take as little land area as possible, and to operate with very low manning levels. In some cases the works are totally enclosed because of proximity to other development, and sophisticated ventilation systems are needed to prevent odour nuisance and to ensure a safe working environment for the operators.

Treatment plants can be made more compact by increasing the concentration of suspended bacteria – the more there are, the faster the job is done. Using standard techniques, at a certain concentration (around 5,000 mg/l) it becomes increasingly difficult to settle them out of the treated water. The latest idea is to use membrane filters to separate the sludge out, permitting operating bacteria concentrations of 15,000 mg/l producing extremely high quality effluents and significantly reduced sludge volumes for treatment. Significant costs are involved in installing and cleaning the filters and this technology, developed in Japan, is currently more expensive to operate than conventional plant. However, plants are running in Wales and Ireland and improved designs are likely to become economically attractive.

Wastewater reuse. Essex is the driest county in the UK and half of its water is imported from other areas. Continuing growth in household numbers and uncertainty about impacts of climate change are raising increasing concerns over the reliability of existing resources. An attractive new supply option is the reuse of Chelmsford’s sewage effluent boosting local resources for 1.4 million people by 10%. The plans involve intercepting a sewer and providing additional treatment before discharging the treated water into the River Chelmer to support an abstraction about 4 km downstream.

The consent to discharge to the Chelmer requires the removal of phosphorus and nitrogen from the effluent, as required by the EC Directive, plus an additional UV disinfection stage to secure a microbiological quality to protect recreational users of the river – mainly canoeists and anglers. The final stage is not a regulatory requirement. Concerns about oestrogenic properties of the mainly domestic effluent were overcome when research demonstrated that the compounds involved are broken down during treatment by ozone and activated carbon at the water treatment works.

On a larger scale, water resources derived from outside a region – and used and reused several times before being discharged via a river or by direct pipeline to the sea – can also support growing demands. Today, about 1.3 million people live in Birmingham and the Black Country and their main supply of water is water-supply reservoirs in mid-Wales. The river Tame provides the primary vehicle for wastewater disposal. The formation of the Upper Tame Main Drainage Authority in 1966, with regional responsibility for sewage treatment throughout the urban upper catchment, paved the way for major environmental improvements. Trade effluents were diverted to sewers, the production of highly polluting coal gas ceased, local wastewater treatment was improved at two works in the upper catchment, and the remaining flows were transferred by a new trunk sewer – the Black Country Trunk Sewer – to a major plant at Minworth. The impact of all these activities on the water quality of the Tame was dramatic: average BOD fell from over 30 to less than 10 mg/l, DO increased from about 3 to over 8 mg/l, and ammonia levels declined from over 15 to less than 5 mg/l. This has
allowed for the development of a coarse fish population in the river downstream.

Today, discharges of treated sewage effluent from Minworth and the nearby Coleshill works produce a combined dry weather flow of about 500,000 m$^3$/d and 80% of the flow in the river in summer may be made up of treated sewage effluent. As the Tame enters the River Trent, these discharges have more than doubled the dry-weather flow in the main river! Improved treatment has created opportunities for the reuse of the water after it has passed downstream and been subject to natural self-purification processes.

The Trent-Witham-Ancholme scheme was established in the 1970s and is licensed to transfer up to 182 Ml/d from the lower Trent at Torksey to meet water demands for agriculture, industry and public water supply in North Lincolnshire. More recently the Trent has been identified as a source to meet future supply needs in the East Midlands with a new abstraction on the middle river near Shardlow incorporating worked-out gravel pits to provide bankside storage. To protect existing uses of the Trent, such as navigation and effluent dilution, new licences are subject to a prescribed flow below which abstractions are required to reduce or cease.

Advanced modelling capability

One of the primary aims of scientific research is to create models – these days usually computer programs – to help decision-makers evaluate the benefits and costs or impacts of different management scenarios. These are especially important to help understand complex systems such as river catchments.

In the River Tame catchment, the Minworth Sewage Treatment Works is the biggest single pollution source and the river is the largest contributor to pollution in the River Trent. However, there are over 600 combined sewer overflows in the Tame catchment and pollution from storm water runoff is also a significant problem. Wet weather pollution can result in total oxygen depletion extending downstream into the River Trent! Artificial purification lakes were constructed on the River Tame in the early 1980s and these trap some 9,000 tonnes of fine sediments and 9,000 m$^3$ of other debris each year, acting as effective sedimentation basins for particulate metals and BOD. During sustained wet-weather flows, however, the efficiency of the lakes declines due to decreased settling and a gain in total ammonia due to disturbance of anoxic bed sediments in the lakes. A localised thunderstorm on 10th July 1995, following a period of 6 weeks of dry hot weather, caused rapid reduction of DO in the Tame and downstream in the Trent killing 97% of the fish having a weight of over 1000 kg.

Advances in modelling have enabled impacts of various management scenarios to be assessed. Eight water quality management scenarios have been assessed using a catchment-scale water quality model and a model to relate episodic flow and water quality. The scenarios considered the river with and without the lakes; with current and future waste-water consent conditions; and with estimated effluent quality of discharges associated with ongoing and planned sewerage and sewage treatment investments in the catchment. The modelling showed that:

- significant losses of BOD (6.3 t d$^{-1}$) and total ammonia (3.0 t d$^{-1}$) occur in the rivers due to self-purification;
- the lakes reduce BOD by about 2 t d$^{-1}$ but increase ammonia by about 0.5 t d$^{-1}$;
- the lakes protect the River Trent fisheries against fish kills caused by pollution episodes of a return period of up to 1 in 1 year.

When integrated with an economic model, a cost-benefit analysis of the water quality scenarios showed the present additional costs of continuing to operate the lakes is £16.7 million. The analyses also showed that significant improvements in water quality
can be anticipated to arise from the current wastewater capital expenditure but the full environmental benefits of these improvements will only be obtained if the lakes continue to operate to protect downstream water quality from wet weather pollution loads.

Planning for wildlife

A “healthy” river is widely accepted as socially desirable; a reflection of the quality of life, and the quality of “the city”. The urban process has led to the degradation of urban water courses and their rehabilitation is central to the regeneration of the urban environment. Economic and social benefits will arise through environmental enhancement, improved public health, greater amenity and recreational opportunities, and increased competitiveness. However, river corridor restoration can be a major problem because of the wide range of factors causing ecological damage. Runoff from diffuse and point sources has introduced a cocktail of pollutants into urban waterways. Many are associated with fine sediments. River rehabilitation usually begins with programmes to improve the quality of effluents entering the river from point sources. Then, efforts often focus on managing runoff from diffuse sources and contaminated land. As inputs to rivers are cleaned up, the relative importance of other damaging factors becomes increasingly apparent: pollutant release from contaminated stream sediments, highly flashy flood-runoff from urban surfaces, high flow velocities in artificially straightened and often concrete-lined flood channels, and the lack of connectivity between isolated patches of wildlife habitat are four issues of current concern.

An international dimension

The springs of groundwater-dominated streams can have considerable ecological interest but many have been lost or severely degraded by urban development, others are highly vulnerable to future groundwater abstraction. The Babingley on the Chalk aquifer of north Norfolk is one example of a healthy springhead. The variety of habitats includes temporary and permanent ponds, reedbeds, wet meadow and wet woodland. A diverse invertebrate fauna includes over 100 species of Cleoptera (beetles) and at least 55 species of Diptera (true flies) with several rare species and many taxa are dependent upon wet or damp habitats. The area is managed to conserve its conservation value for water vole, breeding wetland birds, migrant wetland birds including significant numbers of geese and duck, amphibia, and at least 40 species of wetland and aquatic plants including common spotted orchids and early marsh orchids.

The headwaters of upland rivers, shaded by riparian trees, oak, ash and alder, have fast cool flows and well oxygenated, silt-free water that provide suitable habitat for trout and spawning grounds for salmon. This is the home of the dipper, a bird which has become totally dependent on the stream and almost all its feeding on aquatic insects is done below the surface. Another common bird of upland streams, the grey wagtail, feeds mainly on emerging adult insects.

Along the wandering middle river, grayling and minnow characterise the faster reaches with chub and gudgeon. Open grassy areas of gravel bars provide summer habitat for nesting lapwings and common sandpiper. The areas of exposed sediments provide important habitat for a wide diversity of flies, beetles and spiders.

The sluggish lower river, with its network of backwaters, provides a wide range of habitats for bream, dace, perch, pike, tench and carp. Seasonal floods connect the river channel to a variety of wetland and still-water habitats across the floodplain, providing nursery areas for fish and feeding grounds for migratory birds. Floodplains also provide habitats for a diversity of wetland plants and animals that depend upon regular flooding to bring nutrients or to protect them from competition with terrestrial species.
In winter, shallow, flooded washlands attract a wide variety of wildfowl, drawn by rich grazing and secure roosting sites. The water meadows on the great fenland rivers Ouse and Nene still attract vast numbers of winter visitors: more than 30,000 wigeon, 3,000 Bewick’s swans, 4,000 teal. . . . The summer water meadows are also full of breeding birds such as the common snipe. The banks of oxbows provide favoured habitat for reed buntings, attracted by the abundant cover for nesting and the prolific crop of seeds and fruits. The shallow margins of the large lowland river, its backwaters, floodplain pools and oxbow lakes all create the ideal home for the grey heron. Under low water levels in summer, exposed patches of mud attract waders returning from their northern breeding grounds, such as ruff and spotted redshank.

The estuary receives all the runoff from the catchment and contains a thick soup of nutrients. This resource is the food base for millions of small organisms (worms, snails and shrimps) in every square metre of mud! In turn, these organisms provide a rich source of food for fish and birds. Almost 90 species of fish have been recorded from the upper parts of the Severn estuary. Oystercatchers are characteristic of the estuarine tide line and specialists in exploiting shellfish for food. Like floodplains, estuarine marshes offer rich habitat for flocks of wildfowl and waders escaping the harsh winter conditions of the Arctic. The grasslands and marshes of the River Severn, for example, make it particularly attractive to overwintering geese and swans from as far afield as Siberia.

Conclusion
Cultural differences as well as biogeographical contrasts mean that Western models for conservation and natural resource management are often inappropriate. Difficulties are often compounded by a lack of ecological information and scientific expertise to aid decision making. The desire to maintain national sovereignty constrains the potential benefits of globalisation of trade for natural resource utilisation. Nevertheless, many river systems remain in good condition and opportunities exist for these countries to achieve economic and social development within a framework of appropriate environmental management. The success of some rehabilitation programmes in the developed countries must not be allowed to create the illusion that future rehabilitation will be a viable option in the face of environmental change driven by 21st-century technology and population pressures. The agenda must focus on long-term development rather than short-term economic growth based upon locally and regionally advanced solutions. What is clear is that sustainable solutions will require institutions and individuals to work collectively through local, national and international strategies.