

# Chapter 9:

# Freshwaters – Openwaters, Wetlands and Floodplains

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## Key Findings\*

**Rivers, lakes, ponds, groundwaters and wetlands provide major services, but their benefits are inadequately identified and valued<sup>1</sup>.** This has resulted in habitat losses that are among the fastest in the UK. When managed appropriately, Freshwaters should transport water, matter, energy or organisms within and between terrestrial systems, riparian zones, estuaries and near-coastal waters. They provide: consumptive and non-consumptive uses of water; organisms for food, recreation and conservation; and energy. They can regulate flooding, erosion, sedimentation, local climates and water quality, while facilitating the dilution and disposal of pollutants. They support dispersal through, and resilience in, adjacent ecosystems (for example, through water or nutrient supply), and act as a medium for key biogeochemical cycles. They have large cultural value for recreation, tourism, education, heritage and as inspiration for arts and religion. Costs for people include their role in waterborne diseases and their propensity to flood low-lying infrastructure.

<sup>1</sup> well established

**Rivers, lakes and wetlands are present throughout UK landscapes. Historically, they were highly connected to each other and to their catchments, but are now fragmented and disconnected<sup>1</sup>.** There are more than 389,000 km of rivers in the UK, almost 6,000 permanent large lakes covering around 200,000 ha and nearly half a million ponds (covering less than 2 ha); but the true extent of the UK's wetlands is less well defined. Distribution is also uneven, with Scotland holding more than 90% of the volume and 70% of the total surface area of Freshwater in the UK—it has over 30,000 openwater bodies, as well as some 40% of active raised bog. The llynau of North and mid-Wales and the tarns of Cumbria form distinctive clusters of natural lake systems on the west coast. In central and southern England, where natural lakes are rare, artificial reservoirs provide important standing water habitats. Natural, small water bodies are also widespread, such as the pingo ponds of the Norfolk and Suffolk Breckland and the smaller Cheshire and Shropshire meres and pools. There are at least 392,000 ha of fen, reedbed, lowland raised bog and grazing marsh, but the true extent is uncertain. Floodplains are the most widespread (963,700 ha) and productive Freshwater systems and are shaped by the natural dynamics of river flows. However, they have been extensively impacted by engineering, including flood embankments and channel modifications, so that over two-fifths (42% by area) of all floodplains in England and Wales (defined by the 100-year flood envelope) have been separated from their rivers.

<sup>1</sup> well established

**No completely pristine Freshwater ecosystems remain in the UK;** almost all have been affected by human activity, including drainage, changes in land cover and atmospheric deposition, and most are now managed to a lesser or greater extent<sup>1</sup>. Habitat fragmentation and degradation have reduced their service value<sup>2</sup>. **However, while the least damaged are expected to provide the most natural service profile<sup>2</sup>,** some managed Freshwaters and artificial habitats can be locally important, such as chalk rivers, reservoirs, fenlands, water meadows and ponds<sup>2</sup>. More information is still required about ecosystem services provided by Freshwaters under various levels of management or condition.

<sup>1</sup> well established

<sup>2</sup> established but incomplete evidence

**There is considerable uncertainty about how ecosystem services are related to ecosystem structure, functioning, habitat type, size, spatial extent and fragmentation<sup>1</sup>.** The functions Freshwater ecosystems provide depend on their type, size, condition and position within a catchment<sup>2</sup>. Water connects diverse habitat types along gradients through catchments (with interaction in both directions) via exchanges between the atmosphere, uplands and lowlands, terrestrial and aquatic systems, fresh and saline waters, and between surface and groundwater. We lack precise knowledge of the importance of connectivity, and, in particular, the role of the many small wetlands or water bodies whose number remains poorly estimated and location often unrecorded<sup>1</sup>.

<sup>1</sup> well established

<sup>2</sup> established but incomplete evidence

\* Each Key Finding has been assigned a level of scientific certainty, based on a 4-box model and complemented, where possible, with a likelihood scale. Superscript numbers indicate the uncertainty term assigned to each finding. Full details of each term and how they were assigned are presented in Appendix 9.5.

**Despite the multiple benefits of naturally functioning wetlands and floodplains, many have been degraded, lost or converted (for example, by drainage) to other uses designed to deliver specific services incompatible with their original condition (such as crop production)<sup>1</sup>.** Where wetlands are intact, the major reason has been for nature conservation, often due to the important habitat they provide for birds. Wetlands comprise the largest proportion of Sites of Special Scientific Interest (SSSIs), but protection or management for the wide range of other benefits they provide to human well-being is only now beginning to influence policy and decision-making. The past focus on the conservation of species and communities now needs to be complemented with the maintenance of ecosystem functions if services are to be delivered in the future.

<sup>1</sup> well established

**To date, our approach in the classification and mapping of different Freshwaters as 'priority habitats' does not necessarily indicate their actual or potential contribution to ecosystem services<sup>2</sup>.** We have little idea about the actual areas of different Freshwater habitat required to provide a specified quantity and/or combination of services<sup>2</sup>. Evidence-based tools are becoming increasingly available to enable the assessment of the functioning of wetlands, together with their capacity to deliver ecosystem services<sup>1</sup>. New partnership concepts, such as the Association of Rivers Trusts, and the emergence of innovative implementation strategies, including covenants on land use and rewards for providing ecosystem services that serve the public good, offer considerable scope to recover previously impaired benefits, particularly at the local scale<sup>1</sup>.

<sup>1</sup> well established

<sup>2</sup> established but incomplete evidence

**Rivers are among the UK's most extensively monitored habitats; systematic, long-term data are available from over 25,000 km of the channel network in England, Wales and Scotland.** Rivers in urban or intensively farmed areas have significantly lower sanitary quality and elevated nutrients (e.g. nitrate greater than 5 milligrams per litre) than elsewhere. The chemical quality of rivers has been progressively improving since the 1980s, but trends are locally variable<sup>1</sup>. Since 1990, the biological and chemical classification of what were formerly the most polluted rivers in England and Wales has now improved<sup>1</sup>, although the quality of some of the best Welsh rivers has recently declined for reasons that are unclear<sup>2</sup>. More widely, nitrate concentrations have increased and phosphorus is still a problem in some locations<sup>1</sup>. Some upland or western regions are still affected by diffuse agricultural pollutants, while biological recovery from acidification lags behind chemical recovery<sup>1</sup>. More than 50% of English and Welsh rivers have been modified physically<sup>1</sup>. The numbers of ponds are now increasing following losses prior to 1980, but, in many, water quality is poor and declining, possibly due to increasing nutrient concentrations<sup>2</sup>. A similar pattern emerges for lakes, where evidence indicates that pressures from water level regulation and catchment developments are compounding water quality issues resulting from excessive nutrient loads<sup>2</sup>. There has been very limited monitoring of lakes and wetlands (with local exceptions including the Lake District and East Anglian fens). Even where monitoring has taken place, it has generally not been oriented towards the assessment of ecosystem services. In Scotland, a change in the monitoring network in 2006 makes a similar overall trend assessment difficult, but up until that time, rivers and canals showed a gradual, continuous improvement<sup>2</sup>. Again, very little monitoring has been directed towards the assessment of ecosystem services.

<sup>1</sup> well established

<sup>2</sup> established but incomplete evidence

**Freshwater ecosystems appear particularly vulnerable to ‘regime’ shifts that, once incurred, can lead to large service losses which are difficult to restore<sup>2</sup>.**

<sup>1</sup> well established

<sup>2</sup> established but incomplete evidence

Past adverse effects include acidification, impoundment, flow modification, eutrophication, siltation, habitat degradation, fragmentation, loss and drainage, toxic pollution, over-abstraction and invasion by non-native species<sup>1</sup>. New pollutants (e.g. endocrine disrupting substances, personal care products, nanoparticles, the effects of synthetic biology) are emerging issues for Freshwaters<sup>2</sup>. Urbanisation and climate change are likely to lead to increased water demand and lower resource availability, as well as increased pressure from saline intrusion on freshwater coastal habitats<sup>2</sup>. Climate change has also driven biologically significant water temperature increases of 1.5–3°C in many rivers over the past two decades, although the full effects on river biodiversity are, as yet, unclear<sup>2</sup>. In some catchments, juvenile populations of trout (*Salmo trutta*) and salmon (*S. salar*) have declined by about 50–60%, and there are major declines among other species, such as eels<sup>2</sup>. Invasive species of vegetation, fish, crustaceans and other organisms, including those causing diseases of wildlife, are of growing concern<sup>2</sup>.

**Throughout human history, the integrity of Freshwater ecosystems has been traded-off against specific management objectives, with little or no understanding of the true costs<sup>2</sup>.**

<sup>2</sup> established but incomplete evidence

Along with wetland drainage, flood defence and the purposeful and accidental use of Freshwaters for waste disposal have led to degraded ecological quality, loss of asset value and adverse health impacts<sup>2</sup>. The largest potential synergies in the delivery of different Freshwater ecosystem services are likely to arise where surrounding habitats are managed positively to enhance service delivery; indeed, some agri-environment measures now emphasise the importance of protecting the land-water interface<sup>2</sup>.

**Understanding the linkages between physical, biogeochemical and ecological processes (from genes to ecosystems) that regulate the services of Freshwater systems remains a scientific challenge.** Examples include: the role of Freshwaters in element cycles (e.g. carbon, silicon); the importance of microbial processes; the up- and down-scaling effects of modifications to catchments and flow regimes; the identity of critical ecosystem resources that underpin key services; and factors affecting resistance, resilience and critical thresholds to support service delivery. We also lack models predicting how Freshwater ecosystems may be altered by future environmental change and variability.

**Only small proportions of wetlands and less than 1% of the UK’s entire river length are part of formal protection networks<sup>1</sup>. Sustainable freshwater management will depend on better use of existing legislation, improved casework planning and better decision-support tools capturing ecosystem service delivery<sup>2</sup>.**

<sup>2</sup> established but incomplete evidence

Key needs will include ‘slowing-down’ water, avoiding adverse runoff quality, and protecting sensitive ecosystem assets<sup>2</sup>. For wetlands, floodplains and catchments ecosystems, there is a need for improved inventory and assessment, including the ecosystem services and benefits they currently, or could potentially, provide<sup>2</sup>. Enhanced stakeholder and community involvement is an important factor in improved Freshwater valuation. Freshwater science is already highly inter-disciplinary, but further development to encompass socioeconomics will bring extra sustainability gains<sup>2</sup>.

**We need to restore and recreate Freshwater ecosystems in order to maximise and reap the benefits of the ecosystem services they provide<sup>2</sup>.**

<sup>2</sup> established but incomplete evidence

Restoration may provide cost-effective solutions to the enhancement of key services such as flood risk reduction and water quality improvement<sup>2</sup>. There is a growing inventory of practical actions and experience throughout the UK which are improving both the technical knowledge base and our understanding of the operational, policy and governmental actions required to reverse the degradation of our Freshwater ecosystems<sup>2</sup>.



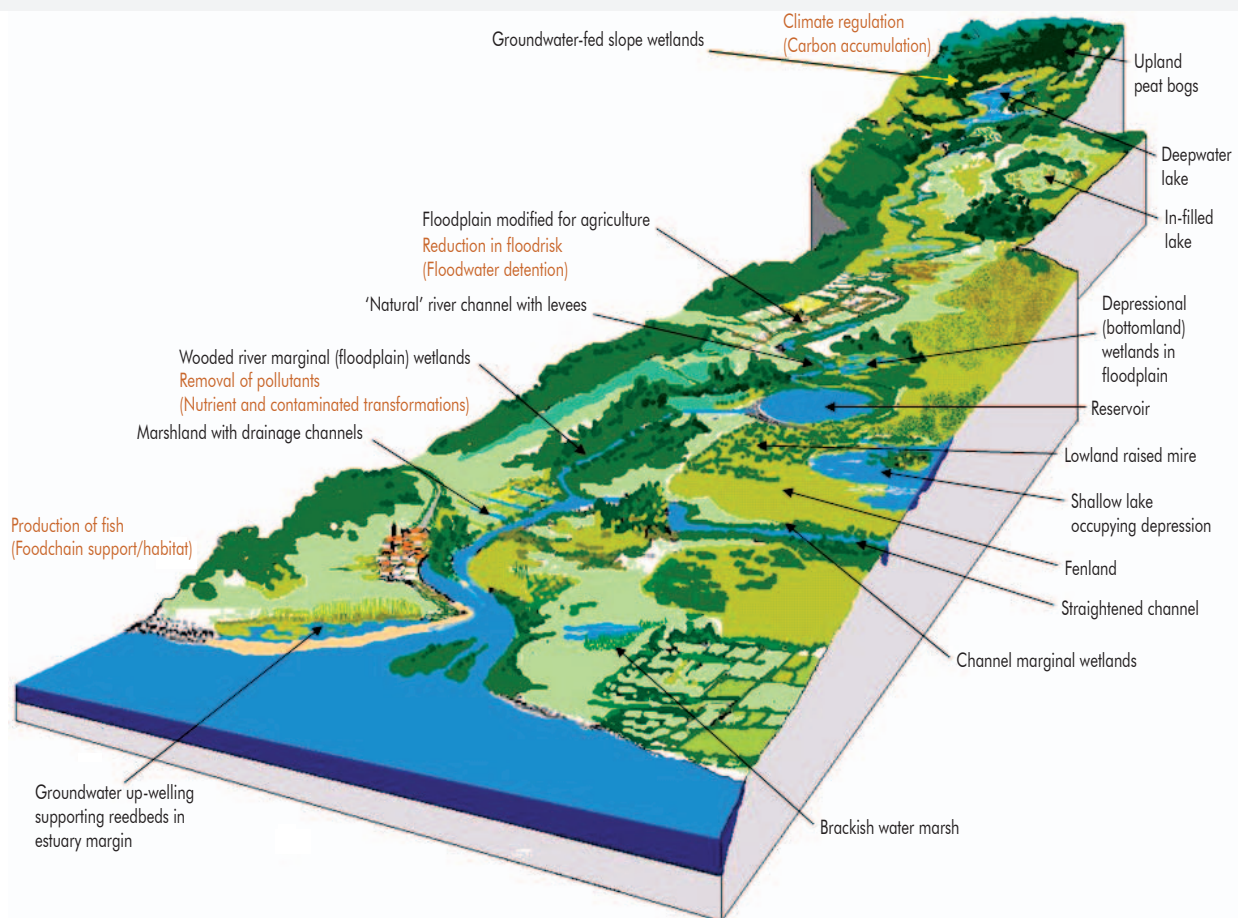
## 9.1 Introduction

The hydrological cycle, along with the rivers, lakes, ponds, wetlands and groundwaters that form its terrestrial phases, provides some of the most critical of all resources for human well-being (Acreman 2001a). These freshwater-based ecosystems are some of the UK's most prominent landscape features and occur wherever rainfall, snowmelt or groundwater collects into flowing channels, standing waters, or associated bogs, fens, grazing marshes and floodplains. In nature, they form a continuum between these habitat types and their wider catchments (Gregory *et al.* 1991; Ward 1998). Not only are these habitats important geographical or management units, but they also control key processes and characteristics that have important ecological influences downstream through the supply of energy, solutes and water (often 'pulsing' during flood conditions) (Junk *et al.* 1989; Tockner *et al.* 2000). Catchment characteristics also influence downstream changes in temperature, hydrology, habitat character and species composition, affecting relative energy sources between litter-fall and in-stream production, and influencing the way nutrients 'spiral' through different organisms (Vannote *et al.* 1980; Newbold *et al.* 1981).

More than 389,000 km of river channels flow across England, Wales and Scotland, while almost 6,000 permanent

large lakes cover a total area of almost 200,000 hectare (ha) (Ordnance Survey data). Scotland alone contains some 70% of all surface waters in the UK by area, and more than 90% by volume (Lyle & Smith 1994). There are about 0.5 million ponds (Carey *et al.* 2008), at least 392,000 ha of fens, reedbed, lowland raised bog and grazing marsh, and floodplains comprise 963,700 ha. It is estimated that there are almost 570 lakes (covering more than 1 ha) in Wales and a much larger number of smaller ponds and wetland pools. Many of these lakes are glacial in origin and are located in the mountains of North and mid-Wales. Over 20 major river systems drain the total surface area of Wales (2,077,000 ha). The UK has major groundwater resources, primarily in rock formations of chalk, Permo-Triassic sandstones, Jurassic limestone and Lower Greensand, which provide significant flow to rivers and wetlands, as well as water for public supply, irrigated agriculture and industry.

Flowing waters vary from headwaters and rivers to estuaries, while standing waters vary in size (i.e. ponds to lakes); the characteristics of both are determined by catchment features such as climate, latitude, altitude, soils, geology and land use. From the uplands to the coast, Wetlands constitute further freshwater diversity as intermediate states between fully terrestrial and permanently inundated habitats. The UK also has numerous artificial Freshwaters, such as reservoirs, gravel pits, canals and sewage lagoons, which often provide key ecosystem services in their own right (**Figure 9.1**).



**Figure 9.1 Links between landscape location and wetland services.** Labels in orange are indicative of the functional gradient in importance of wetland ecosystem services, with text in parentheses providing an indication of the underpinning processes/intermediate services. Source: modified from art work of Aidoud in Maltby (2009a).

Functionally, Freshwaters move water, matter, sediments, solutes, organisms and energy across landscapes, gradients and habitats, linking the atmosphere, terrestrial systems, groundwaters, estuaries and ultimately the marine environment. In particular, Freshwaters control runoff processes from the land to rivers, floodplain inundation, floods and droughts, groundwater recharge (Bullock & Acreman 2003) and water quality (Fisher & Acreman 2004). These processes and movements are vital for the associated ecosystems to which they supply water, nutrients, energy (for example as carbon flux), solutes, sediments and migratory organisms. Freshwater systems also remove and dilute pollutants, store floodwaters and capture carbon. Throughout Freshwater catchments, there is considerable variation in the different ecosystem services provided (**Figure 9.1**), but critical among them are clean waters, flood protection, climate change mitigation, food, recreation, wild species, cultural inspiration and support for other associated systems (**Table 9.1**). However, there are also negative effects when Freshwaters transport undesirable materials such as pollutants from point or diffuse sources in their catchments, excessive loads of sediment, or invasive alien organisms. The flooding of human population centres or infrastructure located in areas which historically would have been inundated represents another negative effect of freshwater movement.

Freshwaters are among the UK's most productive and naturally diverse ecosystems, and are essential in the lifecycles of both freshwater specialists and species that move between Freshwaters and adjacent ecosystems. They have a disproportionately large biological diversity and relative abundance of organisms. This reflects their dynamic and physically varied nature, as well as the natural fragmentation among watersheds that is important for maintaining genetic diversity. Most freshwater species are highly specialised, and important groups include plants (e.g. algae, bryophytes and angiosperms), invertebrates (e.g. protozoa, rotifers, molluscs, micro- and macro-crustaceans, insects), and vertebrates (e.g. fish, amphibians, birds and mammals). Microorganisms, such as bacteria and fungi, are also abundant, and in aggregate drive production, decomposition and nutrient regulation.

In UK Wetlands alone, over 3,500 species of invertebrates, 150 aquatic plants, 22 ducks and 39 wader species occur, while all of the UK's seven native amphibians depend on Wetlands for breeding (Merritt 1994). Ponds, ditches and other small water bodies have also increasingly been recognised over the last 20 years as rich and important habitats in the UK. This follows recognition that, at least in lowland landscapes, ponds contribute disproportionately to the regional biodiversity of aquatic groups such as invertebrates and macrophytes (Williams *et al.* 2004; Oertli *et al.* 2009). While, on average, rivers support more species per location (known as 'alpha richness'), ponds contribute more species across lowland regions ('gamma richness'), and, in particular, hold unique and scarcer species (Davies *et al.* 2008).

The cool, damp microclimate of the often wooded Welsh river corridors supports an exceptional diversity of bryophytes (Hatton-Ellis *et al.* 2009). Aquatic species are

most dominant in the fast-flowing upland headwaters, while additional taxa are associated with a distinct splash and spray zone. Deep gorges and waterfalls provide streamside habitat with especially high humidity, often with a distinctive, local composition of taxa that are of conservation importance.

For Wetlands specifically, this chapter deals with the four UK Biodiversity Action Plan (BAP) priority habitats of grazing marsh, fen, reedbeds and lowland raised bog (**Table 9.2**). Freshwaters also include additional components of the hydrological cycle, notably groundwater, which has its own distinctive ecosystem. Floodplains may contain one or more of the priority habitats, together with other habitats in various combinations resulting from changes in elevation, geomorphology, drainage and other management. Upland Wetlands, especially blanket bog, are dealt with in Chapter 5; rush pasture and Culm grassland is covered in Chapter 6; and wet woodland is covered in Chapter 8. The distinction between different Wetland habitats results from the variation and interaction among natural environmental factors including the magnitude and timing of saturation (waterlogging) and inundation; local topography and connectivity to other water bodies; vegetation cover; substrate and sediment; nutrient status; and management.

The importance of Freshwaters and their organisms means that they are emphasised in major conservation legislation such as the EU Habitats Directive (92/43/EEC) and Birds Directive (74/409/EEC). Rivers and lakes are often recognised as Sites of Special Scientific Interest (SSSIs), reflecting the diversity and naturalness of water bodies in the UK. Freshwaters also figure in specific aquatic policy or legislation, such as the EU Water Framework Directive (2000/60/EC; WFD) which requires the attainment of at least 'Good Ecological Status' (defined as minimal departure from reference (natural) conditions) throughout the UK's water systems. As we discuss later, many highly managed ecosystems in the UK provide important ecosystem services, thus restoration to reference conditions may mean the loss of these services. Wetlands are not explicitly recognised as separate elements in the WFD, but are included as part of the water bodies to which they are connected (lakes or rivers), or as groundwater-dependent terrestrial ecosystems when fed by groundwater (European Commission 2003). The international Ramsar Convention on Wetlands is the only example of an international convention for a specific ecosystem type and achieved a significant turning point in our perception of wetland value (Maltby 1986; Davis 1993) by focusing specifically on delivery of a wide range of ecosystem services. However, Ramsar sites have no legal status. Six priority types of Openwater are also recognised in the UK BAP (**Table 9.2**). In Scotland, 'freshwater and wetlands' forms one of the five ecosystem groups of the new Scottish Biodiversity Strategy, and has some nine UK BAP priority habitats and 75 priority species associated with it. This approach is supported by the Water Environment and Water Services (Scotland) Act 2003 and the Nature Conservation (Scotland) Act 2004. In Wales, work towards the Freshwater BAP is being generated by a similar group consisting of the major environmental bodies including the Environment Agency, Countryside Council for Wales and Forestry Commission.

**Table 9.1 Ecosystem services provided by the Freshwater Broad Habitat.** Component and sub-component habitats potentially delivering ecosystem services are river (R), lake (L), pond (P), grazing marsh (GM), reedbed (RB), fen (F), and lowland raised bog (LRB).

Final services of Freshwater habitat	Habitats potentially delivering services							Conditions or characteristics of habitats required
	R	L	P	GM	RB	F	LRB	
Provisioning								
Fish	•	•	•	•				Commercially significant fisheries (crayfish, salmon, trout) based on rivers, lakes and ponds in suitable conditions.
Dairy and beef				•		•		Wetland grasses provide grazing, silage and hay. Nutrition level depends upon management.
Reeds, osiers and watercress	•	•	•	•	•	•		Reeds grow in saturated soils and slow flowing or still water up to 0.3 m deep. Osiers produce withies for basket making; requiring saturated soil conditions. Cress-beds need swiftly flowing high pH clean water.
Water	•	•	•		•	•		Open water habitats provide a water source for public supply, irrigated crops, power station cooling, industrial processing and fish farming, but high evaporation rates may suppress total water availability.
Peat		•	•	•	•	•	•	Peat provides the basis of some composts for horticulture. Peat needs to be >0.5 m deep to be commercially exploitable due to recent planning guidance.
Navigation	•	•						Navigable waterways need sufficient water depth and low velocity.
Health products	•	•	•			•		Mineral spas, medicinal plants (e.g. bogbean), medical leeches.
Regulating								
Carbon regulation		•	•	•	•	•	•	Carbon accumulates where production of plant litter exceeds decomposition and generally under waterlogged, predominantly anaerobic conditions. Deposition of organic sediments within lakes, ponds and reservoirs is an important component of the carbon budget.
Flood regulation	•	•	•	•	•	•		Flood reduction relies on available water storage. Permanently saturated habitats with no storage may generate or augment floods.
Flow regulation	•	•	•	•	•	•	•	River flow, groundwater recharge influenced by landscape location, water storage characteristics and connection with other water bodies.
Water quality regulation	•	•	•	•	•	•		Freshwater systems can dilute, store and detoxify waste products and pollutants, however there are threshold levels and some systems may accumulate substances to toxic levels.
Local climate regulation	•	•	•	•	•	•	•	Temperature and humidity may be different within the habitat and without; degree depends on size. Important moist microclimates can develop.
Fire regulation	•	•	•	•	•			Open water bodies can act as natural fire breaks.
Human health regulation	•	•	•	•	•	•	•	Natural freshwater systems can increase well-being and quality of life if visually attractive and supportive of physical recreation. Mismanaged freshwaters can be sources of water borne diseases and disease vectors (e.g. mosquitoes), but also sources of biocontrol agents.
Cultural								
Science and education	•	•	•	•	•	•	•	Lake, floodplain and mire sediment sequences contain palaeo-environmental archives and human (pre)history, artefacts that may be lost if disturbed or desiccated. Freshwater ecosystems are important outdoor laboratories.
Religion	•					•		Freshwaters are sites of historical baptism and religious festivals.
Tourism and recreation	•	•	•	•	•	•	•	Extensive recreational fisheries (game species and coarse fisheries depend on good habitat). Tourism depends on landscape appeal and iconic species, such as rare birds, flowers or amphibians. Good water quality and visual appearance required for natural swimming and boating.
Sense of place	•	•	•	•	•	•	•	Water is important in defining specific landscape character and features strongly in art and local culture. Literary and cultural identities embodied in distinctive landscapes such as Snowdonia, the Lake District, the Somerset Levels, Gwent Levels or the Norfolk Broads.
History	•	•	•	•	•	•	•	Freshwaters and especially wetlands have played a key role in human history and settlement since prehistoric times. Water is a recurrent feature at the heart of many historically important places, battlefields, territorial boundaries and many local folklore connections.
Supporting services								
Biodiversity	•	•	•	•	•	•	•	All freshwater habitats with open water: species depend on conditions such as, temperature, oxygen level, depth and velocity of water and area with suitable conditions. Some habitats may provide temporary habitat for fish (e.g. for spawning), such as floodplains.

**Table 9.2 Priority habitats emphasised in the UK Biodiversity Action Plan (UK BAP).** Source: UK Biodiversity Action Plan <http://jncc.defra.gov.uk/>.

Habitat type	Outline attributes	Extent and conservation status
Rivers	Varied, but encompassing all natural and near-natural running waters in the UK, ranging from torrential headwaters through to meandering lowland rivers. Key types are headwaters, <i>Ranunculus</i> -rich rivers, chalk rivers, active shingle rivers, designated Sites of Special Scientific Interest (SSSI)/Areas of Special Scientific Interest (ASSI), those containing UK BAP species (such as salmon and lamprey), or those of high hydromorphological or ecological status.	Recently added to the UK BAP and still being evaluated.
Ponds	Permanent and seasonal waters up to 2 hectares in size with particular conservation importance, i.e. meeting designation criteria under the Habitats Directive, holding UK Red Data Book or BAP species, exhibiting exceptional assemblages of organisms, or having exceptional ecological quality or other special attributes.	About 478,000 in the UK, of which, 20% probably meet these conservation criteria.
Oligotrophic and dystrophic lakes	Mainly greater than 2 hectares, with low nutrient concentrations and productivity. Usually occurring on hard, base-poor, upland rocks, these are among the least disturbed assemblages in the UK. Oligotrophic lakes have very clear water, while dystrophic waters are generally peat-stained.	Recently added to the UK BAP and will comprise examples of known conservation importance, as well as those that are damaged but suitable for remediation.
Mesotrophic lakes	Characterised by a narrow range of nutrients, typically 0.3–0.65 mg nitrogen/litre and 0.01–0.03 mg phosphorus/litre and high macrophyte diversity, often with rare fishes.	Infrequent in the UK and confined to north-west upland margins. Many significant mesotrophic lakes are SSSIs, and some are notified under the Ramsar Convention and/or managed as National Nature Reserves.
Eutrophic standing waters	Highly productive and nutrient rich (>0.035 mg phosphorus/litre and 0.5 mg nitrogen/litre) waters, occurring naturally or as a result of enrichment. Characterised by dense algal populations in mid-summer.	Approximately 178.5 hectares in the UK (including Northern Ireland); about 240 designated as SSSI or ASSI, and around 20 Ramsar sites and 6 Special Areas of Conservation.
Aquifer-fed naturally fluctuating water bodies	Natural water bodies with intrinsic regimes of extreme fluctuation in water level, with natural periods of complete or almost complete drying out. They have no inflow or outflow.	Very rare. Three intact turloughs in County Fermanagh (Northern Ireland) and one in South Wales. At least six fluctuating meres in the Norfolk Breckland. All are designated SSSIs, ASSIs or SACs.
Grazing marsh	Periodically inundated grassland, largely occurring within the flat landscapes of floodplains or coastal plains. Ditches divide the fields and are used to control water levels within the marshland; they can support an extremely diverse aquatic flora and fauna. Grazing marsh is an important habitat for ground-nesting wading birds such as lapwing ( <i>Vanellus vanellus</i> ) and curlew ( <i>Numenius arquata</i> ).	This is by far the most common type of lowland wetland, and is widespread throughout the UK. As a consequence, it comprises a large number of SSSIs, but a relatively small proportion of the overall resource is notified.
Fens	This habitat encompasses a very wide range of wetland types on peat and mineral soil, but all have a water table close to, or above, ground level for much of the year. Fens receive water from groundwater, surface water and rain. They include single-species stands in standing water, species-rich tall fen in floodplains, <i>Sphagnum</i> -dominated vegetation in basins and valley mires, and very species-rich vegetation around calcareous springs.	These are the second most widespread lowland wetland habitat throughout the UK, and the majority of them are subject to notification, e.g. SSSI. About 70% of fen, marsh and swamp SSSIs are considered to be in unfavourable condition.
Reedbed	Wetlands dominated by stands of common reed ( <i>Phragmites australis</i> ), wherein the water table is at or above ground level for most of the year.	These are the rarest lowland wetland habitat considered here. Most of the larger blocks of the resource are notified.
Lowland raised bogs	Exclusively rain-fed, peatland ecosystems which develop primarily, but not exclusively, in lowland areas such as the head of estuaries, along river floodplains and in topographic depressions. The vegetation is dominated by peat-forming <i>Sphagnum</i> mosses and other species such as bog rosemary ( <i>Andromeda polifolia</i> ), cranberry ( <i>Vaccinium oxycoccus</i> ) and cotton-grasses ( <i>Eriophorum vaginatum</i> and <i>E. angustifolium</i> ).	Most of the remaining bogs are found in the wetter northern and western parts of the UK, although bogs were once found in all regions. Only 7% of bog SSSIs are in favourable condition as most of the resource is recovering from peat extraction and drainage.

The long-standing recognition of the importance of water supply, pollutant disposal and other Freshwater goods and services, means that Openwaters are amongst the most intensively monitored of all the UK's environments (Section 9.3.6). Available indicators of change are extensive and include:

- biological features, for example phytobenthos, phytoplankton, macrophytes, invertebrates, fish, microbiological indicators, phyto- and zooplankton and invasive species);
- physical features, for example, flow volume and variability, morphological features, modification and fragmentation;
- physico-chemical indicators of naturally occurring solutes, sanitary discharges, priority substances,

eutrophication, acidification, thermal discharges and inert sediments;

- iv) and energetic measures, such as production, decomposition and heat or light budgets.

Many specific tools have been developed for monitoring, classifying and predicting the biological status of Freshwaters; for example, the WFD emphasises fish, macrophytes, phytobenthos and invertebrates for rivers. For standing waters and wetlands, systematic monitoring has historically been restricted to a few locations without any overall inventory or assessment (Raven & Diamond 2010). However, comprehensive biodiversity surveys of lakes and wetlands have been undertaken in Scotland,



Wales, England and Northern Ireland and used for habitat classification.

Despite increasing knowledge of the significance of Freshwater ecosystems in underpinning a sustainable economy, the services they provide remain generally undervalued. Moreover, few data available on UK Freshwaters specifically offer an ecosystem services context. In this chapter, we outline some of the principal ecosystem services provided by Freshwaters, and exemplify them through case studies. We also appraise trends in the condition of the UK's Freshwaters and provide some insight into possible short-term policy options for their improved management.

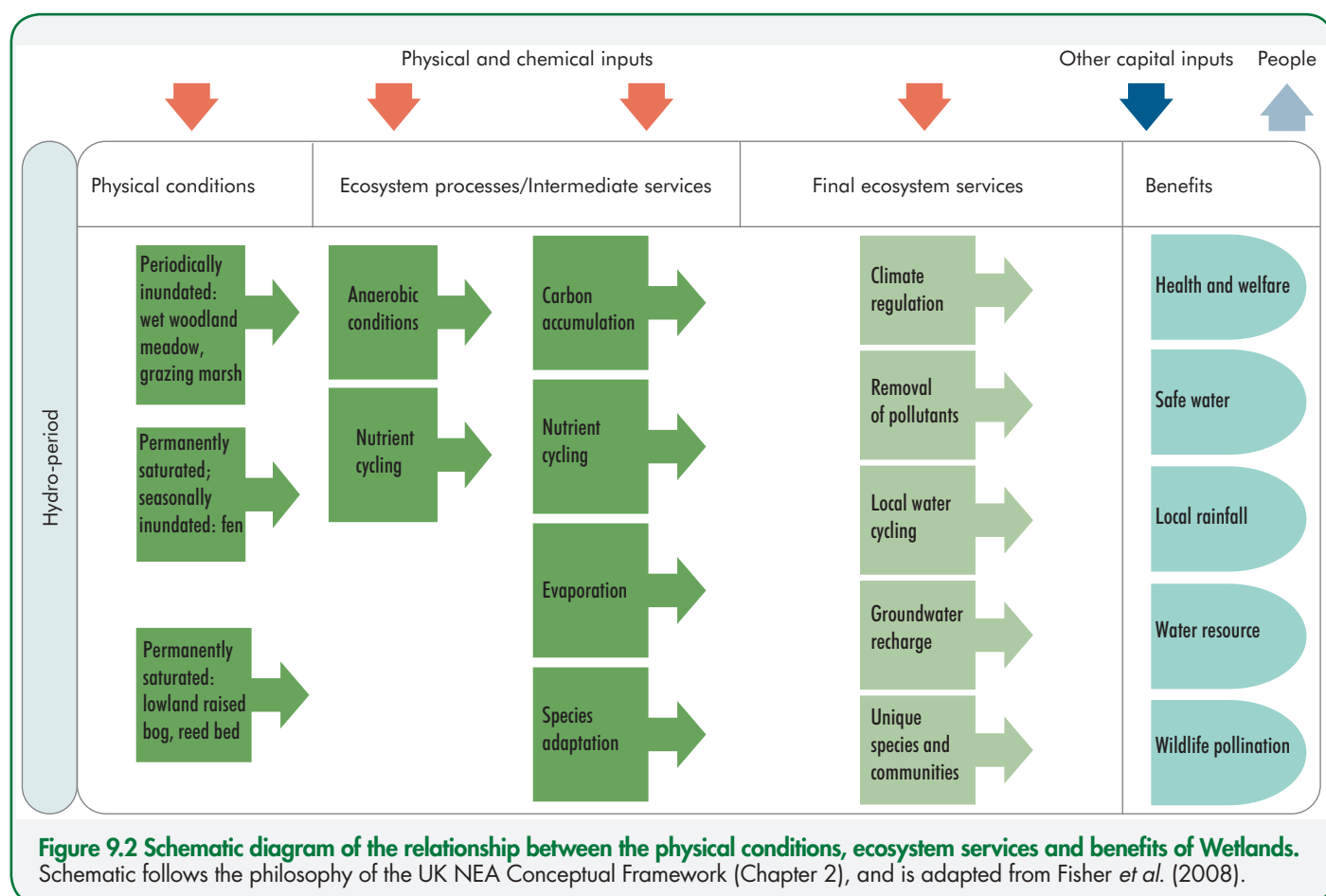
## 9.2 Ecosystem Services from Freshwaters

Freshwaters contribute significantly to the delivery of the entire range of ecosystem services (**Table 9.1**). The concept of goods and services of Freshwaters is well-established for Wetlands (e.g. Maltby 1986; Barbier *et al.*, 1991; Dugan 1993) and was subsequently developed for broader ecosystem services (Turner *et al.* 2008; Fisher *et al.* 2009; Maltby 2009a). The approach taken in the UK National Ecosystem Assessment (UK NEA) defines the link between ecosystem

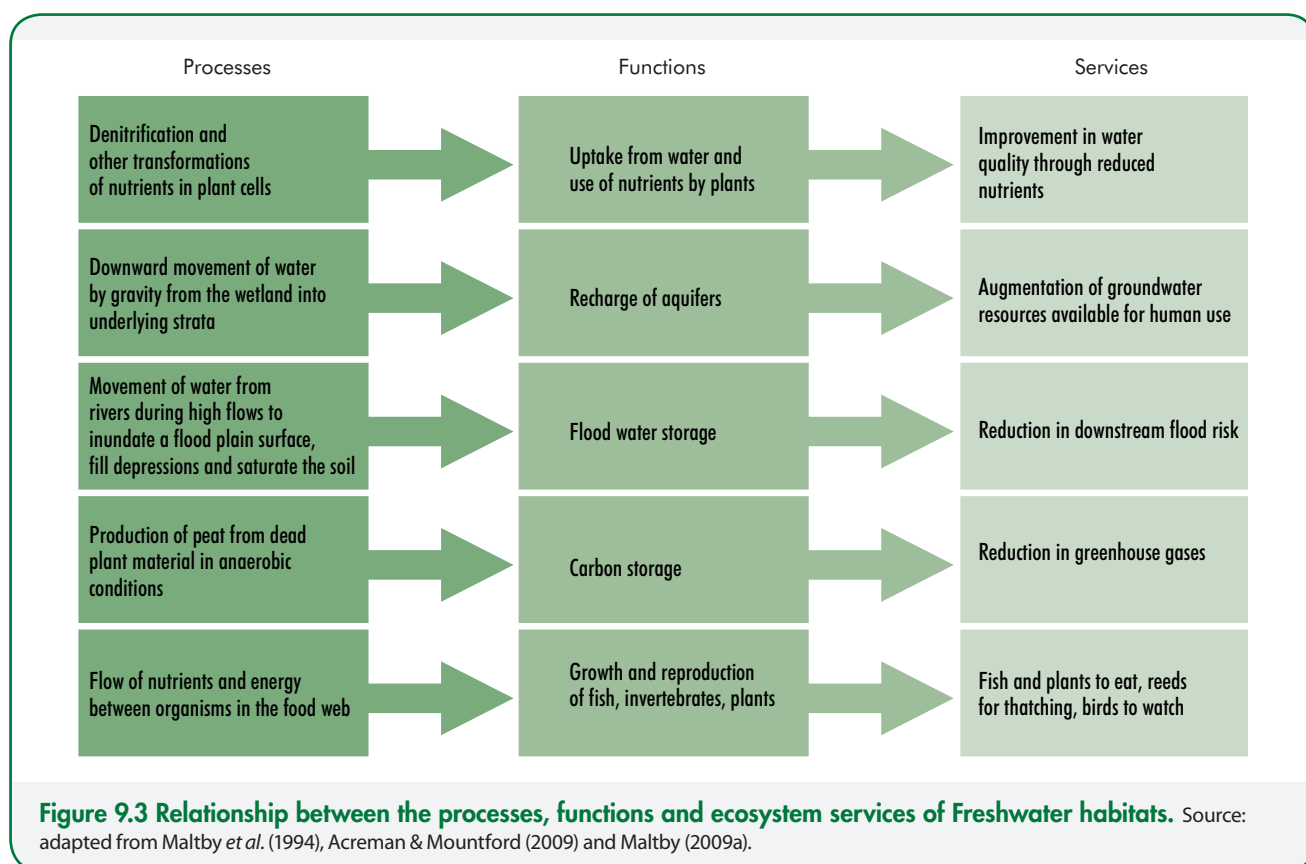
processes into intermediate services first, and then defines final services that form the basis of subsequent assessments (**Figure 9.2**).

Final ecosystem services have important economic benefits, but these are underpinned by physical, chemical and biological processes and functions, many of which remain only partially understood (**Figure 9.3**). Examples include the aggregate role of Freshwater organisms on the diversity, temporal and spatial dynamics of ecosystem functions, and interactions between habitat heterogeneity and Freshwater ecosystem processes. The historical focus on the conservation of species/communities needs to be complemented with the maintenance of ecosystem functions if services are to be delivered in the future.

Not all freshwater habitats perform all processes, functions and services to the same degree (Maltby 1986; Dugan 1993; Maltby *et al.* 1994; Bullock & Acreman 2003), with the production of many services varying according to position in the catchment (**Figure 9.1**). There is increasing recognition of the need to understand better the interactions of various different freshwater and land types within a catchment to assess how their processes and functions combine to deliver ecosystem services. Additionally, individual Wetlands may comprise one or several distinct functional units more or less connected by water flows, which in turn depend on overall catchment dynamics. Functional analysis of such areas through characterisation of these areas as 'hydrogeomorphic units' is well advanced for Wetlands, linking ecosystem structure to the delivery







of services (Maltby 2009a,b; **Figure 9.4**). For rivers the approach of the Riverine Ecosystem Synthesis (Thorp *et al.* 2008) similarly describes the structure and functioning of riverine landscapes via functional process zones.

In addition to spatial heterogeneity, services from Freshwaters depend on catchment and temporal hydrological dynamics. For rivers, broad relationships exist between the flow regime, channel form and habitat provision (Acreman 2001b). For example, flow regimes have essential elements that maintain ecosystem functions and services; large floods maintain channel geometry; low flows allow fish fry to mature; small floods stimulate migration; and high flows allow fish access to spawning grounds (Acreman *et al.* 2009a; **Figure 9.5**).

While many of the final ecosystem services provided by the UK's Freshwaters are well-documented (**Table 9.1**), few studies are available that: i) explicitly quantify the value of the services provided; ii) develop quantitative understanding of interactions among the provision of goods and services, their exploitation and ecological functions; or iii) give an indication of the specific area and/or condition necessary to maintain particular services. These represent major research needs, some examples of which are provided below. Even fewer estimates have been made of Freshwater ecosystem services in aggregate. However, in 2002, estimates were made of the total monetary value of Scotland's natural capital and ecosystem services (Williams *et al.* 2003): within an overall annual figure of around £17 billion, lochs, rivers and estuaries generated more than £3 billion. Many of these ecosystem service benefits are used by industry, becoming incorporated in their final goods and services, while other benefits are spread throughout the wider population or

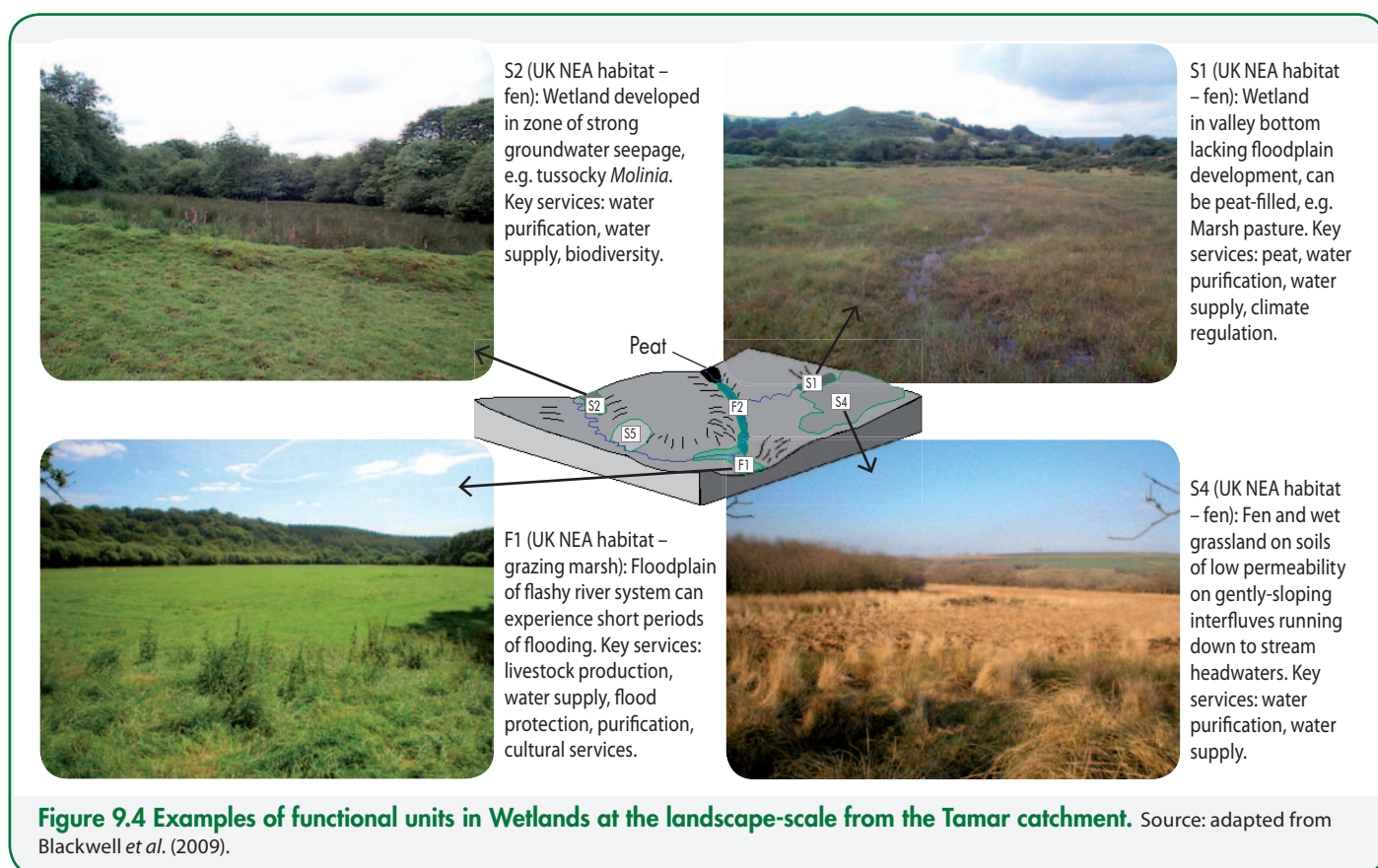
enjoyed by recreational users. An economic analysis of water use in Scotland was undertaken by the Scottish Environment Protection Agency (SEPA) in 2005 and showed links to whisky distilling, hydropower, water supply, recreational angling and agriculture (SEPA 2006). The report also included a number of case studies covering these and other uses including aquaculture, the exploitation of coal, paper and pulp production, canal water supply and leather tanning.

Considerable efforts are being made currently in the UK to identify clearly and value the benefits of Freshwater management. These efforts are being increasingly focused on the identification of strategies that can enhance the realisation of ecosystem services; some examples are presented in **Appendix 9.2**.

## 9.2.1 Provisioning Services

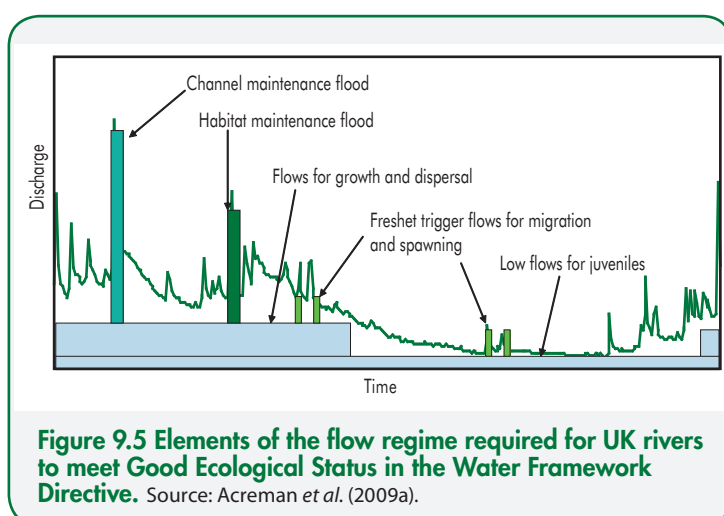
### 9.2.1.1 Direct use of water

The provision of water resources supports agricultural irrigation, public domestic supply and abstraction for industry, but there is substantial variation in rainfall, water supply and abstraction across the UK. Of the 16.8 billion cubic metres (m<sup>3</sup>) of water abstracted annually in the UK, around 40% comes from tidal sources (as cooling water), around 50% comes from surface waters and 10% comes from groundwaters. These abstractions represent about half of the volumes that are actually licensed. The major use of abstracted water is for piped domestic supply (**Figure 9.6**) which is generally provided by water companies, but over 70% of this volume is subsequently returned as treated effluent. Farmers use less than 1% of the total amount of abstracted water for spray irrigation, but this varies regionally and



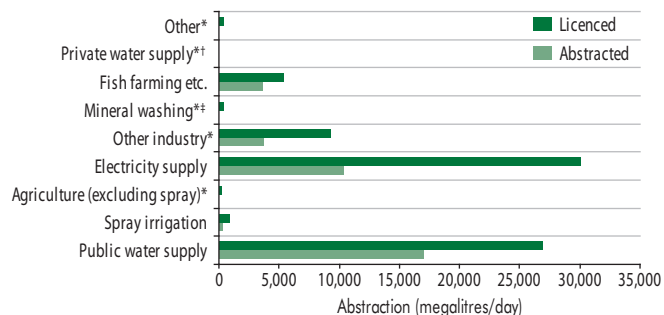
seasonally; for example, in East Anglia, abstraction for irrigation during the summer months can average 20% of the total for all uses of freshwater. The ultimate fate of this water—it is lost through evaporation—means that there are potentially larger environmental consequences associated with the use of abstracted water for irrigation than other uses (Environment Agency 2008a).

Groundwater is an important source of water for the public in the UK, and has a vital role in maintaining supplies during dry summers and prolonged droughts (Acreman *et al.* 2000). The principal aquifers of the UK (**Figure 9.7**) are in the English lowlands and include: chalk, Permo-Triassic sandstones, Jurassic limestone and Lower Greensand. Aquifers also occur in the Devonian and Carboniferous strata of South Wales, northern England, central Scotland and parts of Northern Ireland, but these are much more compact rocks, so are considered to be less important for water supply. The older rocks (Silurian, Ordovician, Cambrian and Precambrian) are regarded as an ‘impermeable basement’, though even these can provide water in significant quantities relative to the scale of individual wells and springs (Groundwater Forum 2002). Groundwater provides 6% of public water supply in Scotland, 8% in Northern Ireland, and 33% across England and Wales (a figure that rises to over 70% when considering the south-east of England alone). Groundwater is also important for rural water supplies in remote parts of the UK. The most productive aquifers in Scotland are in Fife, Strathmore and Moray, as well as south-west Scotland, although surface deposits of alluvium, sands and gravels are also important. Groundwater also plays an important role in sustaining flows in Scottish rivers through the summer months, accounting for up to 30% of total annual flow in 60%

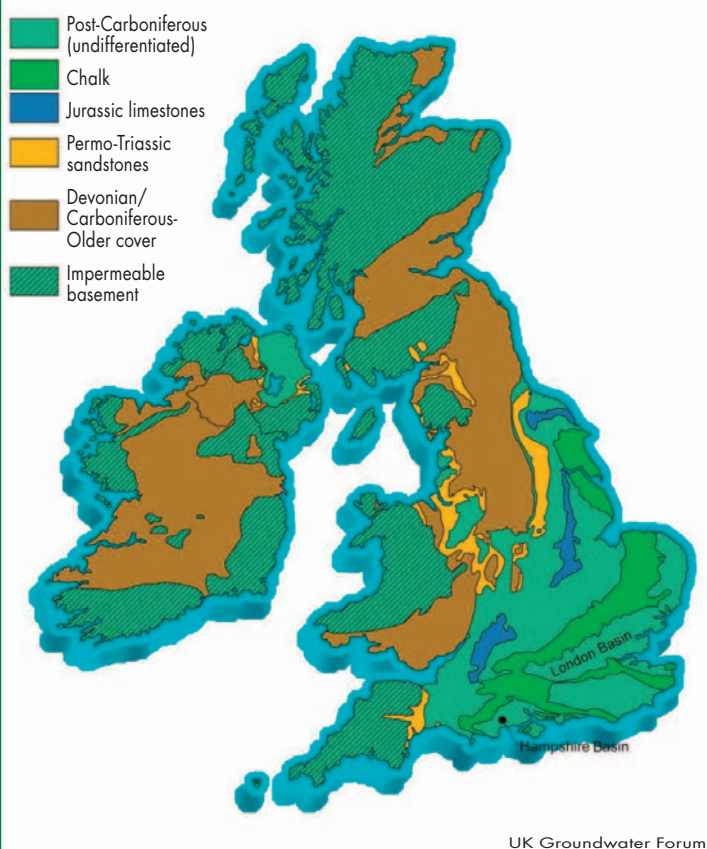


of our rivers; despite this, overabstraction of groundwater is not a widespread problem in Scotland (Spray 2011). Extensive hard bedrock in Wales has limited underwater storage, so the country’s rivers are highly responsive to rainwater runoff or drought (Duigan 2009).

Across England and Wales, water abstraction equates to an average of 10% of total water availability (excluding abstraction to support power production, the water from which is often returned to Openwaters as effluent, although some returns to rivers outside the source catchment). However, this ‘Water Exploitation Index’ (EEA 2003) varies regionally. It exceeds 22% in south-east and eastern England, for example, so these areas are regarded as ‘under stress from water abstraction’ to the same extent as countries that are usually considered drier than UK (e.g. Cyprus, Malta,



**Figure 9.6 Uses of water abstracted from non-tidal sources in England and Wales, 2006–2007.** \*Return requirements were changed from 01/04/2008 whereby licences that abstract under 100 m<sup>3</sup>/day no longer had to send returns back this has mainly affected agricultural, private water supply/other and small industrial licences. †In 1999, mineral washing was not reported as a separate category. Licences for mineral washing are contained in 'Other industry'. ‡Private abstractions for domestic use by individual households. Source: Environment Agency (2008a). © Environment Agency and database right.



**Figure 9.7 Principal aquifers of the British Isles.** Source: map obtained from the UK Groundwater Forum (Downing 1998).

Spain and Italy). Some catchments outside the south-east of England are also considered to be overexploited for both surface and groundwaters, while others are considered to have water available.

In Scotland, water supply has a direct influence on the food and drink sector, especially with regards to its

significant link to the iconic Scottish whisky industry which is of economic importance, supporting over 40,000 jobs. The whisky industry as a whole consumes some 2–3 million m<sup>3</sup> of water per annum, along with 30–40 million litres for cooling which is abstracted and then returned. The Welsh water resource supplies a population of almost 3 million people, with about two thirds concentrated in the south-east around Cardiff. In addition, there are significant cross border demands to supply metropolitan areas of England.

The value of reservoirs often exceeds their role as solely supply features. For example, when evaluated in the early 1990s, Rutland Water had a total annual value of up to £215 million, of which, at least 64% was attributable to ecosystem services (principally recreation) in addition to its primary purpose as a source of potable supply (Gaterell *et al.* 1995). Wetlands may also be locally important in the provision of water supply either directly or through the recharge of aquifers, but there are no national data to indicate the full extent of this service.

The availability of water does not remain fixed over time. Natural interannual meteorological variation has substantial effects on both supply and demand, particularly during droughts (e.g. 1984, 1990–1991, 1995–1996, 2003). Climate change is likely to change flow conditions and availability in the future (e.g. Romanowicz *et al.* 2006; Johnson *et al.* 2009), while also altering demands; although current evidence for trends in low and high flows are equivocal (Hannaford & Marsh 2007, 2008). Water is required for the dilution of pollutants and the consequences of altered flow for organisms and natural ecosystem function are still only partly understood. Many river regimes are now substantially altered from their natural state (Petts 2009). This not only results in ecological effects, but also in consequences for other ecosystem services, particularly where other stressors are involved such as increasing river temperature (Clews *et al.* 2010; Dunbar *et al.* 2010a,b). Subsequently, potential conflicts in use may arise, as exemplified by case studies (Spillett *et al.* 2003).

#### 9.2.1.2 Water for power generation

Water has been used for thousands of years to drive water wheels and watermills. More recently, water has been harnessed to drive turbines for electricity generation. Different configurations exist, but principally consist of schemes where power is generated at a dam or weir, and schemes where water is diverted at a dam or weir and transported via a penstock or leat to generators located some distance away. The UK currently generates more than 1,500 megawatts (MW) of electricity from hydropower sources, which represents a little over 2% of total national energy generation. Most of the large hydropower stations are in Scotland, but the largest of all, Dinorwig (a pumped storage scheme with a capacity of 1.7 gigawatts GW), is in North Wales. Reservoirs held back as part of Scotland's 23 main hydropower schemes cover over 800,000 ha, and affect the ecological status of 117 water bodies. Along with drinking water supply (117 water bodies) and agriculture, abstraction and flow regulation from these activities affect 21% of Scotland's rivers and 25% of its lochs.

The recent large increase in small-scale (<2 MW), run-of-river hydropower schemes is causing severe local impacts



on flow regimes where they involve off-line turbines; they are generating controversy because of possible effects on longitudinal connectivity of rivers. Although hydropower is non-consumptive, it can affect connectivity, and may have additional effects on flows depending on the configuration and operation of the particular scheme—it can deplete flows in bypassed sections of river and cause artificially rapid flow fluctuations. By regulating the Afon Prysor in Wales, Llyn Trawsfynydd was built in 1931 as the storage reservoir for the Maentwrog hydroelectric power station (Whitehouse 2002). It was also used as the source of cooling water for the Trawsfynydd nuclear power station, which has now been decommissioned. Nonetheless, the reservoir water continues to be used for fishing and hydropower generation.

### 9.2.1.3 Crops, plants, livestock and fish

The majority of the UK's permanent, Openwater bodies support fish, whether coarse species, such as carp, bream, roach and pike, which prefer slow-flowing or still lowland waters, or game fish, such as trout, grayling and salmon, which prefer fast-flowing waters. Historically, protein from coarse fish was an important element of human diet, and so, medieval fish ponds were widespread in the UK. Today, coarse fish are far less widely eaten. The capture of migratory salmon has also declined, although a few commercial fishermen have continued to net wild salmon in tidal sections of rivers. The Salmon and Freshwater Fisheries Act (1975) regulates and bans fishing licences, fishing seasons and size limits, and banned obstructing the salmon's migratory paths. As a result, most UK salmon fishing is now undertaken for sport and only 30–40% of the 90,000 salmon caught annually in Scottish rivers are eaten, with the remainder being released. Floodplains and Wetlands also provide fish habitats, especially nurseries for coarse species, such as pike, eel and carp. Consequently, the fishing industry

is reliant upon these habitats for fish recruitment, although these fish may not be harvested commercially within the habitats themselves (provisioning and regulatory services). Again, much of the harvesting or catch-and-release of these fish is related more to the leisure and recreation industries (cultural services) than to provisioning services.

By far the most important Freshwater systems for food and fibre production are Floodplains, which are naturally fertilised by rivers during floods and are, therefore, amenable to seasonal grazing and arable production (**Box 9.1**). Many are used for intensive agriculture (for example, the Humberhead Levels are used for arable root crops and turf production), while the cutting of natural vegetation on Floodplains provides hay crops and on fens provides sedges used in thatching. The harvesting of reedbeds for thatching is also a significant industry of Floodplains, although not as important today as it was historically. In the 1980s, problems of premature decay in another thatching material, long wheat straw, were traced to high nitrogen contents following intensification of their cultivation with nitrogen fertilisers. The same problem was also claimed for reed roofs, but despite high nitrogen levels causing problems for floating mats of reed (Boar *et al.* 1989), which were disappearing rapidly from Floodplains in East Anglia, there was little evidence of problems in the soil-rooted reed of the managed beds (Boar *et al.* 1999). Perception of the problem may have led to greater imports of cheaper reed from the Danube Delta and Poland, and reduced sales of UK reed. Currently, there seems to be no steady trend in supply and demand of UK-grown reed, but this position is determined largely on anecdotal evidence.

Managed Floodplains and grazing marshes are used for the intensive (and sometimes extensive) farming of dairy, beef and sheep products. Agricultural grassland is the most extensive land cover within Welsh Floodplains and, as a

#### Box 9.1 Agriculture on floodplains.

In England, 1.02 million hectares of agricultural land are within the indicative floodplain, that is, they have an annual risk of flooding of 1% or greater from rivers, or 0.5% or greater from coastal waters (**Table 1**). Although the indicative floodplain accounts for only 9% of the total agricultural area of England, it includes some of the most fertile and productive areas, having been 'reclaimed' and 'improved' for agricultural purposes over hundreds of years. Fifty-seven percent of Grade 1 agricultural land falls within the indicative floodplain, and the capital value of agricultural land at risk of flooding has been estimated at £15 billion using 2008 values. The management of hydrological regimes, in the form of flood alleviation and land drainage, has been key to maintaining the agricultural productivity of this land. The cost in terms of loss of other goods and services has yet to be properly assessed.

**Table 1 Classification of agricultural land in indicative floodplains in England, 2002.** Source: Natural England (2011).

Agricultural Land Classification	Typical land use	Total ('000s ha)	Indicative floodplain ('000s ha)	Proportion of total area in indicative floodplain (%)
Grade 1	Intensive arable	355	204	57%
Grade 2	Intensive arable	1,849	239	13%
Grade 3	Extensive arable	6,292	379	6%
Grade 4	Dairy and grazing livestock	1,840	186	10%
Grade 5	Grazing livestock	1,101	11	1%
Total potential agricultural land		11,437	1,019	9%
Non-agricultural land		657	31	5%
Urban areas		952	72	8%
<b>Total</b>		<b>13,046</b>	<b>1,122</b>	<b>9%</b>

consequence, Floodplain semi-natural habitat is scarce, with 60% of the area within just ten river systems (Jones *et al.* 2009, Chapter 6, Chapter 20). Neutral and marshy grassland is the most common component of semi-natural habitat, together with secondary woodland, swamp, fen, bog and standing water.

Wetlands provide habitat for wild game such as woodcock, snipe, ducks and deer, although these are generally now harvested for sporting reasons than for food. This is in sharp contrast to the historic importance of undrained areas, such as The Fens, which supplied London and other urban markets with large quantities of game, eels and other food items (Darby 1983; Maltby 1986).

#### 9.2.1.4 Trees, standing vegetation and peat

Many semi-natural wetlands on Floodplains produce timber that is sustainably managed, while, historically, many grazing marshes produced coppiced and pollarded willow as an important local source of wood for fuel.

Willow has been used for centuries as a construction material, particularly for baskets (Cole 1990), and is prized for its quality in the crafting of cricket bats. Giraldeus Cambrensis provides a 12th Century description of a coracle as a round boat made of willow and covered with raw hides which was used for fishing. Willow is harvested by pollarding: trees are cut back to the main trunk and new shoots, called 'withies', grow out of the trunk and are cut periodically for use. During the 1930s, over 3,600 ha of willow was grown commercially on the Somerset Levels and Moors, but since the 1950s, this industry has declined as packaging has become dominated by plastic and cardboard. By 2000, only around 140 ha of willow was grown commercially in the UK, and only the Somerset Levels and Moors remain today in commercial willow basket production (Acreman *et al.* 2011).

The native black poplar (*Populus nigra* subspecies *betulifolia*) is an attractive, rare and highly valued tree, persisting largely on river floodplains (Jones *et al.* 2009). Many individual trees are now old and in decline. Traditionally, its sturdy timber was used for making carts and stable partitions, in particular, but it had multiple uses in pre-industrial society.

Lowland raised bogs provide peat for the horticultural industry and were historically dug for fuel (**Box 9.2**). However, the pace of peat formation versus its extraction, and the subsequent impacts on biodiversity and hydrology, raise serious questions about its sustainability.

Together with Walton Moss in Cumbria, Cors Caron, which dominates the inland floodplain of the Afon Teifi in Wales, and Cors Fochno, at the mouth of the Dyfi also in Wales, represent the best surviving examples of raised bog landscape in the UK. Yet depressions created by historic peat digging are still visible in these areas. The Fenn's, Whixall, Bettisfield, Wem and Cadney Mosses complex on the Welsh border is the only other surviving relatively large-scale, raised bog, with the remainder of the Welsh resource comprising sites between 1 and 50 ha (Jones 2009). Thorne and Hatfield Moors in England were once among the largest raised bogs, but declined following many years of peat-cutting; they are now being restored. Other natural products from peatlands

include water for whisky production, *Sphagnum* moss for hanging baskets and wild flowers for floristry.

A recent assessment carried out on UK peatlands has examined the full range of services they provide. A summary is given in **Appendix 9.3**.

Fibre, timber and thatch have well-established market values. Other goods may have significant local importance, but most are hard to quantify. In some cases, such as peat extraction or drainage for more intensive agriculture, exploitation may not be consistent with sustainable Wetland or Floodplain management. Other Wetland goods include:

- fibre and fuel including thatch and timber, animal fur, bulb fibre, flax, peat, osiers and withies;
- genetic resources including the grazing of rare breeds and the heritage of the natural diversity of plants which may be used for human benefit (for example, genes for crop resilience);
- biochemicals, natural medicines and pharmaceuticals including known valuable agents such as salicylic acid from willow bark, fungal extracts and local herbal remedies, as well as yet unknown resources;
- and ornamental resources including insectivorous plants, bulrushes and other plants of decorative interest, pebbles, gravel, cobbles and sand.

#### 9.2.1.5 Reedbeds

Reedbed management in the UK supports around 90 direct full-time equivalent jobs and further contract work to a value of up to £4 million per year (GHK 2004). Commercial reed-harvesting provides further direct employment that helps

#### Box 9.2 Peat.

In the UK, peat is still extracted from lowland raised bogs to supply the amateur and commercial horticultural market. In Northern Ireland, Scotland and parts of Wales there is also still peat-cutting for local domestic fuel and export. Extraction continues at around 10 sites in England, covering some 1,300 ha. Consents have been granted on 2,237 ha of peatland and the total area of peatland covered by a current active consent is 520 ha (Lindsay & Immirzi 1996; Brooks 2003; Headley & Dargie 2004; Thomas & Walker 2004; Capita Symonds 2005). Around 77% of raised bogs in Northern Ireland have been cut for fuel, the majority for domestic purposes, but with some relatively limited commercial extraction also. In Scotland, there were 72 extraction sites in 2003: 20 were active, 16 had expired, 3 were pending and 33 were awaiting confirmation (Brooks 2003).

Demand for peat use in horticulture increased in the 1990s, rising by 46% between 1993 and 1999 (ADAS & Enviro 2008). Since 1999, the absolute amount of peat used in the UK has stabilised, and even declined in 2007. Total peat use for horticulture in the UK was 3.01 million m<sup>3</sup> in 2007, of which, around 1.31 million m<sup>3</sup> was derived from UK sources, with 221,000 m<sup>3</sup> from Scotland; extraction of peat for other uses in the UK was around 10,000 m<sup>3</sup>.

Extraction of peat for horticultural uses requires the vegetation to be stripped, thus removing the floral and faunal biodiversity. In addition, site preparation for peat extraction requires drainage by cutting deep arterial drains to take away the water collected in the superficial drains around the cutting areas. It therefore interferes with the existing biodiversity, water quality, carbon storage and nutrient dynamics in an intact bog, as well as with the rates of, or potential for, restoration of degraded bogs.



to support the thatching industry. Major reedbeds such as those at the Royal Society for the Protection of Birds (RSPB) Ham Wall, Titchwell Marsh, Minsmere and Leighton Moss nature reserves in England, together with the Tay Reedbeds in Scotland, are also important for wildlife tourism. In Wales, swamp habitat is widespread, but occurs most frequently and extensively along the coast (Jones 2009). The total extent of all forms of Welsh swamp is around 1,800 ha, of which, about 460 ha are dominated by reed sufficiently extensive to be regarded as reedbed. There is strong demand for quality, UK-produced thatching reed. Along with other fen products, such as biofuel and pet litter, thatching reed can be produced viably while sensitively managing the reedbeds for wildlife. Reedbeds can also provide water management functions (Fisher & Acreman 2004), as well as making significant contributions to improving water quality (Moss *et al.* 1984; 1988).

Some conservation bodies have re-established semi-natural reedbeds, particularly for birds such as bittern (*Botaurus stellaris*), and manage them with minimum cutting (RSPB 1994). Northumberland Wildlife Trust has a target of increasing the reedbed resource by 20 ha/annum within their own reserves. However, many pre-war reedbeds have reverted to scrub and carr, and are unlikely to be recovered. The market for thatch is believed to be buoyant—thatched roofs are considered valuable features and need replacing every few decades.

## 9.2.2 Regulating Services

### 9.2.2.1 Flood regulation

Openwaters are both agents of flood risk and also dissipate floodwaters. Both outcomes have been a key feature of their management. The frequency and magnitude of floods from Openwaters are influenced by human uses of land in their wider catchments including urbanisation, increased drainage and other conversions that alter hydraulic retention, such as embankments that separate rivers from their floodplains. Although these alterations can provide part of the solution to flood risk management, maintenance of such engineered solutions is expensive. Floodwater retention occurs where water is retained in catchment soils or Wetlands, and where flood storage capacity is enhanced by green roofs, permeable surfaces, channels, lakes, Wetlands and Floodplains functioning in natural ways. These notions were expressed partly in the Department for Environment, Food and Rural Affairs (Defra) (2005) report, 'Making Space for Water', and also in the concept and development of Sustainable Urban Drainage Systems (SUDS).

Most flooding occurs from the overspill of rivers or the sea, or from the failure of local drainage. However, groundwater flooding can also occur in areas underlain by aquifers, such as chalk, or in river valleys with thick deposits of alluvium or river gravel. This latter type of flooding typically happens in response to a combination of already high groundwater levels and lengthy rainfall events, and lasts far longer than fluvial flooding (Macdonald *et al.* 2008). There are currently around 380,000 properties at risk of groundwater flooding and the cumulative cost of these events has been estimated at £4–14 million/year.

In Scotland, a new Flood Risk Management (Scotland) Act 2009 has been approved. This Act deliberately focuses attention on the extent to which a reduction in flood risk can be achieved through both structural and non-structural options (Spray *et al.* 2010). It also highlights the importance of assessing whether interventions in the upper catchment could assist in reducing flood risk to communities lower down the valley. It directs relevant authorities (working in partnership) to consider flood risk management in a holistic manner and instructs SEPA to map natural features and artificial structures in terms of their contribution to flood risk management.

In Wales, riverbank reinforcement and embankment for flood control are widespread, especially in urban environments, with almost the entire length of rivers such as the Taff being impacted in this way (Dobson *et al.* 2009). From Environment Agency River Habitat Survey data, there is evidence of slightly more reinforcements at sites in the 2007/2008 baseline survey compared with 1995/1996, particularly in the South Wales Valley area towards Cardiff.

The extensive modifications to river channels and floodplains undertaken in the recent past for flood control and land drainage purposes have had serious consequences for habitats and their inhabitants (Dunbar *et al.* 2010a,b). At the same time, when carried out sensitively and in conjunction with natural processes, flood defence works offer a major potential route for river rehabilitation and restoration, including the restoration of important ecosystem functions. However, to judge whether the overall costs and benefits of flood defence are positive or negative for ecosystem services or functions requires further, careful evaluation of the evidence in order to guide action.

The storage of floodwater on Floodplains can reduce flood magnitude downstream (Bullock & Acreman 2003). A modelling study of the River Cherwell in Oxfordshire (Acreman *et al.* 2003) showed that separation of floodplains from the river by embankments increases the peak flows downstream by up to 150%. The majority of flood storage in Wetlands is above ground; for example, at a flood level of 5 m Above Ordnance Datum (AOD), the floodplains of the Parrett (Currymoor, Northmoor and Haymoor) in Somerset have a combined volume of 6.8 million m<sup>3</sup> through the inundation of 1,710 hectares of land. Saturated soils, with a water table near the surface, occur in many Wetlands and have no, or limited, flood storage capacity (Acreman *et al.* 2007). However, it is important to note that drained agricultural soils may also reach saturation during the heavy rain that precedes a flood. Areas of saturated soils in headwater areas are defined as 'runoff contributing areas' by hydro-geomorphologists (e.g. Hewlett & Hibbert 1966); this relationship forms the basis of rainfall-runoff models used by hydrologists, such as 'TOPMODEL' (Beven & Kirkby 1979; Beven *et al.* 1984). Taken as a whole, the available evidence suggests that the widespread belief that Wetlands act as sponges, storing large quantities of water during times of high rainfall, is misplaced. However, storage is just one factor that determines how floods are generated and transmitted through a catchment. For example, the presence of Wetland vegetation, and particularly wet woodland, can significantly increase the hydraulic roughness of a Floodplain

when compared to alternative land uses (Baker *et al.* 2009). This has the effect of holding up water levels locally during extreme events, slowing the movement of the flood peak downstream, and reducing the height of the peak. This may synchronise or desynchronise flood peaks, thus implications at the catchment-scale are difficult to generalise. Surface roughness can also be a factor in runoff generation in upland catchments; overland flow is slower through vegetation than bare soils (Holden *et al.* 2008). Land drainage can have an additional, significant impact on runoff-generation, but whether it increases or decreases floods depends on the soil type (Robinson 1990).

Objectives for re-wetting Floodplains for biodiversity and for flood risk management are combined in the Great Fen Project in Cambridgeshire. It aims to store winter floodwater for the protection of the Middle Level System and the houses, farms and businesses that depend on it, while also providing water to restore and maintain fenland habitat on previously arable land. Other objectives include improving water quality, increasing recreation and tourism opportunities, and improving quality of life for local people.

The Insh Marshes, an internationally important Wetland in the Spey Valley, provides flood defence benefits to Aviemore and other downstream settlements (Alveres *et al.* 2007). The marshes cover some 1,100 ha of Floodplain and have a role in water storage that has been valued at more than £83,000/annum, were it to be replaced by 7 km of flood defence banks around Aviemore. Alongside their flood defence services, the marshes provide many other functions that add economic, recreational and cultural value to the local community and visitors. Tourists contribute around £132,000 to the local economy each year, while fishing revenue provides a further £35,000. Additional ecosystem services, such as farming, water quality, education, training and conservation management, are also provided by the marshes; their total value, along with that of biodiversity, has not yet been quantified.

Secondary impacts on flood behaviour may result from the experimental reintroduction of the European beaver (*Castor fiber*) into the Scottish landscape. Beaver dams that create ponds on headwater streams may have a role in flood attenuation, while also providing biodiversity benefits. The Scottish Beaver Trial, jointly run by the Scottish Wildlife Trust and Royal Zoological Society of Scotland, is monitoring the effects of their reintroduction on high and low river flows, as well as their effects on the wider habitat and species diversity.

#### 9.2.2.2 Carbon sinks and sources

In global terms, Freshwaters are small in comparison with the marine environment, so have smaller absolute roles in carbon uptake through, for example, algae or macrophytes. However, peat soils can store more carbon than forests and woodland.

Lowland peatlands are often deeper than upland peatlands; their enhanced accumulation is a result of their topography and the higher growth rate of plants in milder, lowland climates, particularly in nutrient-rich systems. As a result, lowland peatlands often store more carbon per unit area than their upland counterparts. Peat deposits exceeding

12 m deep can occur in valleys like Fen Bog in North Yorkshire, and deposits up to 12 m deep occur in the former fenland of the Somerset Levels (Cope & Colborne 1981). Many raised bogs also have peat deposits which exceed 10 m deep in places (Burton & Hodgson 1987). Natural England (2010) estimated that the remaining lowland fen in English peatlands stored 1,004–2,576 tonnes of carbon/ha, and raised bog peats stored 1,575–1,629 tonnes of carbon/ha. However, when peatlands are drained for agriculture, peat-cutting or forestry, their stored carbon is no longer protected from decomposition by waterlogging. Thus the peats begin to degrade, becoming shallower through slumping, compression and erosion, and gradually rot away, releasing carbon dioxide as they decompose. These areas, known as ‘wasted’ peatlands, may still store considerable quantities of carbon (around 850 tonnes/ha) in their remnant peat. However, Natural England (2010) recognises that these calculations are mostly based on data that is 25 to 30 years old, and that loss of peat carbon is likely to have progressed at a greater rate more recently (Holman 2009). The National Peat Depth and Carbon Storage Project, funded by Natural England, is underway to collate more peat depth and carbon storage data, and promote new and coordinated surveys to improve estimates of peatland carbon storage. In addition to the significant store of carbon in the peat deposits, lowland wetland vegetation can be an important store of carbon. Lindsay (2010) estimates that a 15 cm deep *Sphagnum* mat can represent a carbon store of 45 tonnes carbon/ha—a figure comparable to some woodlands.

Peatlands retaining a high water table continue to store new carbon through the build-up of plant material that has captured atmospheric carbon through photosynthesis. While some plant material decomposes in the upper, more aerobic peat layers, a proportion becomes more or less permanently waterlogged and anaerobic, decomposing far more slowly. This very slow anaerobic decomposition is outstripped by the deposition of newer plant material and peat builds up. However, this anaerobic decomposition releases methane, a greenhouse gas much more powerful than carbon dioxide (Immirzi & Maltby 1992). This means that waterlogged peatlands are not only carbon sinks, but may also be overall sources of greenhouse gases. This effect is strongest in the short-term, because the potency of methane as a greenhouse gas declines over time as it is degraded in the atmosphere (Baird *et al.* 2009). However, the carbon dioxide emissions from drained and cultivated peatlands are so large that they are likely to have five to six times the global warming effect of waterlogged peatlands, even allowing for the greater potency of methane. Natural England (2010) used figures generated from a range of European sites (Couwenberg *et al.* 2008) to estimate that drained intensive agricultural peatlands emit the greenhouse gas equivalent of 22–26 tonnes of carbon dioxide/ha/yr.

A major and extensive phenomenon over recent years has been a marked and progressive increase in the export of dissolved organic carbon (DOC) from peatlands discharging through upland rivers, lakes and reservoirs (Worrall *et al.* 2002, 2003). Although the exact cause is debated (Freeman *et al.* 2001, 2004; Monteith *et al.* 2007), observed trends correlate with increasing average summer temperatures

coupled with peat-drying and local land use modification. There are serious concerns about this alteration in carbon dynamics and soil storage, which also have implications for water treatment costs, particularly due to water discolouration.

A series of projects, including the United Utilities' Sustainable Catchment Management Programme (SCaMP) and the Exmoor Mires Project, are now assessing how catchment-scale restoration can help attenuate DOC export, while also meeting the target of returning SSSIs to favourable condition. There is also a focus on sediment load and downstream flooding with the intention to "ensure a sustainable future for the company's agricultural tenants and support United Utilities' Biodiversity Strategy". The measures taken include large-scale drain-blocking, revegetation of extensive bare peat and the introduction of more sustainable grazing regimes. Partnerships are extensive in these projects, including government bodies, universities, water companies and non-governmental organisations (NGOs) such as the RSPB. It is still not clear whether drain-blocking consistently reduces DOC loads and water discolouration once peat has undergone significant physical and chemical change. However, meta-analysis by Armstrong *et al.* (2010), using data from 32 study sites, revealed 28% lower DOC and colour in blocked drains than in unblocked drains. Other conclusions about biodiversity and atmospheric gas exports (e.g. of methane) are still emerging.

In Scotland, SEPA has used long-term monitoring data to investigate recent trends in carbon dynamics, and has shown that 39 out of 58 rivers have significantly increasing Total Organic Carbon (TOC), with rates equal to a doubling of the concentration over 20 years. All of the sites showing an increase were south of the Cromarty Firth, while 11 of the 18 that did not were north of Inverness. Fewer long-term data were available for lochs, but decreasing trends in DOC were found at 23 sites about which more than five years' worth of data had been collected. For both lochs and rivers, increasing TOC concentrations caused darkening of water colour, reducing light and energy levels entering these ecosystems.

Sea-level rise is a specific concern for coastal Welsh peatlands, such as Cors Fochno, which suffers from marginal drainage and is at risk of saltwater flooding if coastal defences fail (Jones 2009).

Wetland restoration, particularly of peat, is often cited as a means of combating climate change and the wider societal benefits of this have been examined by Maltby (2010). Carbon dioxide and methane are the most important components of the peatland carbon budget, although methane is 25 times more potent as a greenhouse gas. The Somerset Levels and Moors is one of the UK's largest Wetlands containing around 10.9 million tonnes of carbon (Brown 2009a); estimates of carbon dioxide and methane available for this Wetland (**Box 9.3**) show it to be broadly carbon neutral, but the balance depends on site management, particularly water level and the grazing/hay-cutting regime.

### 9.2.2.3 Climate regulation

In addition to the above effects on carbon dynamics, Freshwater ecosystems can moderate extreme temperature.

#### Box 9.3 Greenhouse gas fluxes on the Somerset Levels and Moors.

In 2002, the net flux of carbon dioxide was measured at Tadham Moor, a lowland wet grassland on the Somerset Levels and Moors (Lloyd 2006). Carbon assimilated into the wetland during 2002 exceeded the carbon produced by 169 grams carbon/m<sup>2</sup>, making the site an apparent sink for carbon. These measurements, however, include the assimilation of carbon dioxide into the meadow vegetation, but not the loss of carbon dioxide that would have occurred if the vegetation had been left to senesce and decompose in the field. Instead, the hay was harvested and taken away, and some of the new meadow growth was consumed by cattle which also removed the vegetation in the form of their increased body weight. From harvest yields and established relationships between cattle weight gain per kilogram of herbage eaten, it was estimated that 228 grams carbon/m<sup>2</sup> had been removed from the field. Subtracting this from the overall balance turned the site from a carbon sink to a carbon source losing 59 grams carbon/m<sup>2</sup> during the year. By using a model of the site, it was estimated that raising water levels would have reduced carbon losses by 243 grams carbon/m<sup>2</sup> over the year, making the site at least carbon neutral (Acreman *et al.* 2011).

Measurements of soil methane fluxes were made during three campaigns between 2003 and 2004 (Acreman *et al.* 2011). Strong relationships were apparent between water table depth (which varied between -0.81 and +0.18 m) and average methane flux (which ranged from -85 to +19 micrograms/m<sup>2</sup>/hr). The wetland generates methane during high water table levels and consumes methane when water levels are low. The critical water table level at which this switch takes place is around 10 cm below the soil surface.

#### Box 9.4 Microclimate regulation.

Enhanced evaporation over a wetland, compared to dry land, would be expected to increase relative humidity and cool the lower atmosphere with feedback consequences for evaporation in surrounding habitats. There is also the possibility that cloud cover will change over a wetland, linked to the modified evaporation and surface energy fluxes, and to modified rainfall. The magnitude of these influences will depend on the size of the wetland, the contrast with the surrounding region and the overlying weather patterns. The Somerset Levels and Moors is one of the UK's largest wetlands and shows some microclimate alterations. Meteorological data from Yeovilton airstation (25 km to the south-west and outside the Wetland) shows the air over Tadham Moor has higher daytime humidity and slightly lower temperature leading to a substantially lower vapour pressure deficit in the day (Acreman *et al.* 2011). The vapour pressure deficit is one of the primary drivers to evaporation and we would infer that the potential evaporation over the Wetland would be 10–20% lower (Acreman *et al.* 2011).

The supply of water to the atmosphere is also an essential contribution to fundamental climate control at all scales, but can be especially marked at the local level (**Box 9.4**).

### 9.2.2.4 Waste disposal and dilution

Openwaters are used extensively for the disposal and dilution of wastes and pollutants. As with water supply, the financial (not to mention energy, chemical and land take) costs of providing the same service through other methods would be very high. Equally, the costs incurred in treating this material before disposal are a measure of how much value is placed on good quality Freshwater ecosystems: annual water treatment costs across the UK are estimated at around £1.2 billion.

There are an estimated 100,000 consented wastewater discharges across England and Wales. Many are small, domestic sewage discharges (<5 m<sup>3</sup>/day), but around 8,000



are 'significant' sewage or trade effluent discharges. A further 20,000 discharge consents are for intermittent discharges, such as storm overflows, that serve joint purposes of voiding floodwaters and bypassing sewage treatment works that would otherwise be overloaded. Discharges have been a very significant source of ecological impact on river ecosystem quality, illustrating how, in the past, Openwaters were used for pollutant disposal and regulation without full recognition of the environmental costs (Section 9.4). General compliance with consents is high, and has improved through time, but problems remain in some locations. Water quality issues are also increasingly likely to reflect the inadvertent disposal of diffuse pollutants through non-consented routes.

Parallel data for Scotland reveals around 1,250 consented discharges, divided between trade discharge (approximately 370), public sewage (660) and private sewage (165). Compliance with consent requirements across Scotland is in the range of 80–90%. Northern Ireland has about 280 consented sewage outfalls and 655 trade outfalls, with compliance at around 66%.

Waste purification in constructed Wetlands provides a further example of waste regulation services. However, in contrast to the situations described previously, which deal with waste from point sources (usually pipes), these services address the much more challenging issue of diffuse pollution whether from agricultural or urban sources.

The ability of Freshwater ecosystems to trap, breakdown, process and transform pollutants, especially those derived from diffuse agricultural pollution, means they perform the services of waste breakdown, detoxification and purification to a significant degree (Maltby 2009a) and with an associated high societal value that is often overlooked. Key processes occurring in Wetlands that enable delivery of this service include bacterially driven denitrification, nitrification and mineralisation, plant uptake and the trapping or filtering of particulates (Kadlec & Knight 1996). Wetland systems, particularly reedbeds, have combinations of highly oxic and anoxic sites within their soils due to stratification in the sediment or soil profile and/or the release of oxygen from plant roots; these conditions are conducive to the breakdown and transformation of many pollutants including organic and inorganic compounds derived from agriculture and denitrification (a major mechanism for 'cleaning' groundwaters of their nitrogen content). It should be noted, however, that overloading a Wetland's natural capacity to cope with chemical transformations may cause ecological changes resulting in the loss of biodiversity. Consequently, constructed Wetlands are often created to deal with pollutants rather than trying to use natural ecosystems.

Detoxification of polluted waters, such as those containing high concentrations of heavy metals, can occur through the uptake of toxic materials by Wetland plants, such as reeds or bulrushes, or through the deposition of particulate matter. However, there is growing concern that these accumulated nutrients or pollutants may escape from Wetlands into rivers as pulses (Prior & Johnes 2002), resulting in significant pollution events. In addition, many persistent pollutants are stored rather than metabolised, leading to Wetland toxicity in extreme cases. Removal or harvesting of the plant material cannot ensure complete removal of these

pollutants, although excavation and disposal of trapped sediment is more effective.

Welsh Freshwater ecosystems are still suffering from an industrial legacy, but there is evidence of improvement following remediation interventions. The Afon Goch, which drains the currently inactive copper mine on Parys Mountain, Anglesey, has been described as one of the most acid- and metal-contaminated streams in the UK (Boulton *et al.* 1994). Abandoned coal mines are releasing acidic, sulphate-rich water, often with negative effects on biota (Ormerod & Jüttner 2009). The most recent Welsh review identified 90 mine discharges, with around 60 km of Welsh rivers judged to be affected. Within and around those river stretches that were affected, deposits of 22 ha of ochreous pollutants were conspicuously visible, and clearly linked to biological impacts at around 70% of the sites sampled. Despite the fact that Welsh rivers are still polluted, more than 50 metal mine locations have remediation strategies in place (Environment Agency 2002) and there have been some success stories. For instance, the Afon Pelenna Wetlands were constructed between 1995 and 1999 to remediate an acid-mine discharge; regardless of occasional episodes of pollution, the abundances of invertebrates, trout and river birds have recovered (Wiseman *et al.* 2004). Treatment of these discharges have probably aided the wider ecological recovery within the Welsh Valley Rivers, with salmon returning to the Ebbw, the Rhymney, the Taff and the Rhondda (data from the Environment Agency; Holmes & Gough 2009).

The capacity of naturally occurring Wetlands to improve water quality depends on them occupying locations that intercept polluted waters such as agricultural runoff (Blackwell *et al.* 2009). The use of constructed Wetlands for water treatment has seen enormous growth over the past 50 years and, in some cases, they are now seen as a more sustainable and cost-effective solution to the problem of treating various types of polluted water than their engineering counterparts. Appropriate planning and management of the Wetland is necessary to ensure lasting, effective treatment; without this, the Wetland is, at best, ineffective and, at worst, may add to the pollutant load. Constructed treatment Wetlands can also provide a range of secondary benefits such as habitat provision and production of reeds for thatching. However, management for these additional benefits should not compromise the primary objective of water treatment (Stratford *et al.* 2010). There are now more than 1,000 examples of such systems in the UK (Cooper 2007) including: the constructed Wetland at Slimbridge which treats wastewater from the Wildfowl & Wetlands Trust's bird collection; the Wheal Jane Wetland in Cornwall which treats mine wastewater; and the Heathrow Wetland which treats runoff from the airport's runways (Nuttall *et al.* 1997).

South West Water estimates that water treatment costs rise by between 17% and 20% for managing raw river water with heavy sediment loads. In extreme floods, river intakes may be closed for short periods while the turbidity in the raw water declines; during this time, the treated water system relies on stored water. Modelling has shown that a £10 million investment could save £650 million in costs of treating

nutrient- and topsoil-laden water over a 30-year period. South West Water has, therefore, put forward a proposal to OFWAT (the Water Services Regulation Authority) under Price Review 2009 (PRO9) to make payments to farmers to alter the management of their land (i.e. private land, not owned by South West Water) for the benefit of particular ecosystem services (Martin Ross pers. comm.).

Economic choice experiments to estimate the value of improving water quality (as required by the WFD) have been carried out in two Scottish catchments impacted by agricultural non-point source pollution and water abstraction (Hanley *et al.* 2006). Encouragingly, 90% of the respondents interviewed in each catchment expressed a 'willingness to pay' for better river water quality. These benefit estimates are potentially 'transferable' to other sites with similar characteristics. The Scottish Environment Protection Agency has consequently set up a river restoration fund, in part, to help achieve this goal (Gilvear *et al.* 2010).

#### 9.2.2.5 Firebreaks

Freshwater can provide important fire breaks, as in gaps in combustible material that act as a barrier to slow or stop the progress of a bushfire or wildfire.

#### 9.2.2.6 Health and diseases

Freshwaters can be very important for sustaining human health through recreation and quality of life. However, historically, they were often described as unhealthy. For example, in 1794, George Kay (a well known writer of the day on agricultural issues) described Anglesey: "The climate is moist and unhealthy, producing frequent agish complaints. This is imparted to the fogs from the Irish Sea by which it is surrounded. I am however rather inclined to think that it arises from the great number of fens and morasses which, if drained, would not only be a great acquisition to the proprietors but would lend much to the healthiness of the island" (Kay 1794).

Today, Freshwaters remain potential sources of infection (Acreman *et al.* 2011); our current knowledge is very limited, so risks are difficult to calculate, but the issue warrants some reporting. For example, Freshwaters support large numbers of migratory waterbirds, such as ducks, geese and swans, that can be reservoirs for Low Pathogenic Avian Influenza viruses and have also played a role in the transmission of Highly Pathogenic Avian Influenza (HPAI), specifically H5N1 (Gilbert *et al.* 2008) which represents a threat to wildlife, poultry and humans (Snow *et al.* 2007). In 2008, an outbreak of HPAI H5N1 was recorded in a mute swan (*Cygnus olor*) population at Abbotsbury, Dorset (Defra 2008); however, direct contact with such birds would be needed for humans to become infected.

In Wetland systems, the abundance of mosquitoes has been shown to be reduced by the presence of the diverse communities of invertebrate predators (including water beetles such as *Dytiscus*, *Laccornis*, *Hydaticus* and *Hydrophilus* species) that are generally present in mature water bodies (Carlson *et al.* 2009). Key human-biting mosquitoes have been found in UK Wetlands including *Anopheles claviger*, a species capable of transmitting *Plasmodium vivax* (the probable causal agent of historical malaria in the UK), and

*Coquillettidia richiardii*, a species that bites humans and birds and is implicated as a bridge vector involved in the transmission of West Nile Virus in the USA (Medlock *et al.* 2005). Wetlands in the south of England are currently warm enough to support the transmission of *P. vivax* for two to three months per year (Lindsay & Thomas 2001)—a period that is likely to extend with future global warming. However, there is currently no evidence for the existence of insect vector-borne diseases associated with Wetlands in the UK, even though the data suggests that several Wetland-associated UK mosquito and midge species have the potential to vector a range of exotic diseases. While the expansion of Wetland habitats may have the potential to increase the risk of disease transmission, particularly via some mosquito species, it is possible to mitigate against such effects with well-considered Wetland design and management (Zimmer *et al.* 2010). Where Wetlands are reasonably remote from large population centres, mosquitoes produce only limited biting nuisance to people in the foreseeable future. However, stagnant areas of water in urban areas (e.g. water butts and tyre dumps) also provide good mosquito habitat and may pose a risk to humans.

### 9.2.3 Supporting Services

#### 9.2.3.1 Resistance and resilience in surrounding ecosystems

In addition to the support of organisms and internal ecosystem processes, Freshwaters also support other surrounding ecosystems. This includes the export of energy or carbon in the form of emerging insects or exploited fishes which are used as prey by terrestrial organisms; for some birds, bats and spiders, this subsidy can contribute 25–100% of total energy used (Briers *et al.* 2005; Baxter *et al.* 2005). The export of water and sediments into terrestrial zones and Floodplains inundated during flood cycles may also be significant.

The hyporheic zone (the zone beneath and lateral to a stream bed, where mixing of shallow groundwater and surface water takes place) provides a refuge habitat for surface-dwelling taxa during disturbance events such as droughts; thus, it has the capacity to add resilience to the whole river ecosystem (Brunke & Gonser 1997; Robertson & Wood 2010).

#### 9.2.3.2 Wild species diversity including microbes

Wetlands, in particular, are ecologically diverse, and more than a quarter of the Wetland area in England is designated as a SSSI. In some cases, the individual habitat may not appear overly diverse (e.g. reedbeds), but they support specialised species. But often, much of the diversity of Wetlands is hidden in the soil, where varied and sometimes unique microbial communities are found. In these frequently anoxic environments, microbes have developed novel adaptations including the ability to respire anaerobically and to use reduced organic compounds in the soil as energy sources (nitrate, manganese, iron and sulphur). Diverse and unique communities of microorganisms include: nitrifiers such as *Nitrosomonas* species and *Nitrobacter* species which are capable of oxidising ammonium to nitrate; denitrifiers such as *Pseudomonas* species and *Thiobacillus* species,



capable of reducing nitrate to nitrogen gases; methanogens such as *Methanobacterium* species and *Methanococcus* species, capable of removing excess hydrogen from anaerobic environments in the form of methane; and sulphate-reducing bacteria such as *Desulphobacterales* and *Desulphovibrionales* which are capable of reducing sulphates to sulphites. These communities are essential for nutrient cycling and the performance of the water purification and detoxification services operated by Wetlands. Many of these same organisms can occur locally in river environments, and form part of a range of organisms that have been 'domesticated' for use in treating a wide variety of domestic and trade wastes.

### 9.2.3.3 Biogeochemical cycling

In addition to conveying the all-important water cycle, Freshwaters have close links with other cycles, for example, through providing nitrogen, phosphorous, carbon and other trace elements into marine environments and other adjacent systems. These effects are expanded in Chapter 12.

### 9.2.3.4 Contribution to biological and genetic diversity

Freshwater habitats cover less than 1% of the Earth's surface, yet support about 10% of all known species, and around one third of all vertebrate species. Regardless of this, they are also hotspots for human activities that have led to widespread habitat alteration, pollution, flow regulation, abstraction, fish exploitation and alien species introductions. As a consequence, impairments to biodiversity and extinction rates are faster in Freshwaters than in any other ecosystem types (Denny 1994; MA 2005; Strayer & Dudgeon 2010).

The importance of the biodiversity of the UK's Freshwaters is recognised in a range of ways, including:

- in the UK BAP (see **Table 9.2**);
- through the inclusion of UK Freshwater organisms in the Habitats Directive (92/43/EEC) such as fish like brook lamprey (*Lampetra planeri*), river lamprey (*Lampetra fluviatilis*), sea lamprey (*Petromyzon marinus*), Atlantic salmon (*Salmo salar*), bullhead (*Cottus gobio*), twaite shad (*Alosa fallax*) and allis shad (*Alosa alosa*); invertebrates like the snail, *Anisus vorticulus* and the bivalve, *Margaritifera margaritifera*; and *Callitriche-Batrachion* plant communities characteristic of chalk rivers;
- and through additional national and international conservation legislation (e.g. Wildlife and Countryside Act, Ramsar Convention) and the UK statutory designation system.

With regards to statutory designations, using England as an example, there are 28,693 ha of Openwater within SSSIs, of which, 20,458 ha are standing waters (including 10,391 ha designated for their bird interest), 354 ha are canals and 7,881 ha are rivers and streams. Forty-four rivers have at least a part of their length notified as an SSSI, covering just over 2,500 km of river length. Among the most important internationally are England's chalk rivers, which cover a greater length here than any other country in Europe (around 3,900 km). About 2,500 km of river in England and Wales have water-crowfoot (*Ranunculus* species),

recognised as important both in the EU Habitats Directive and UK Biodiversity Action Plan.

Special Areas of Conservation (SACs) cover 9,308 ha of Openwater habitat (**Table 9.3**) including: 33 lakes or groups of lakes totalling 4,628 ha; 17 rivers, which are mainly large, whole-river sites, covering a length of 1,744 km; the Rochdale and Cannock Extension canals; and hundreds of temporary ponds throughout the New Forest and pond complexes on 32 sites around the UK designated specifically for great crested newts (*Triturus cristatus*). Large areas of Openwaters (6,615 ha or more) are also designated as Special Protection Areas (SPAs), mainly for wintering waterbirds (**Table 9.3**) (Natural England 2009).

Fresh water is considered a key biodiversity, landscape and recreational resource in the UK. The Freshwaters and Wetlands of Wales, for example, represent a nationally and internationally important conservation resource. More than 75% of Welsh designated conservation sites (SSSIs/SACs/SPAs) contain freshwater-dependent biological features (data from Countryside Council for Wales). There are designated sites on six major river systems and over 140 lakes (data from Countryside Council for Wales). Approximately 320 Wetland SSSIs depend upon groundwaters (data from Countryside Council for Wales). More than 50% of the land area of Wales is within the catchments of these rivers, lakes and wetlands. Some river stretches have also been recognised as the best examples of fluvial geomorphological features as part of the Geological Conservation Review (Duigan *et al.* 2009). These sites (approximately 20) serve as illustrations of the evolution of the Welsh landscape and cover landforms, processes, channel features, channel change and examples of human impact.

There are 284 SSSIs notified for their 'fen, swamp and mire' habitats in Scotland, 147 notified standing waters and canals, and just 10 notified rivers and streams. In terms of the UK BAP priorities for Freshwaters and Wetlands, Scotland holds 9 priority habitats and 75 priority species including 1 alga, 7 bryophytes, 4 fungi and lichens, 24 invertebrates, 13 vascular plants and 26 vertebrates.

In England, ponds support more UK BAP priority species than lakes, and a similar number to streams, rivers and river floodplains combined (**Figure 9.8**).

This richness of ponds reflects both the intrinsic productivity of this water body type when not degraded and the heterogeneity among pond types, with permanence,

**Table 9.3 Areas (hectares) of Openwater in England under different statutory designations in 2008.**

Source: Natural England (2009).

Designation	Total area (ha)
Sites of Special Scientific Interest	28,693
Special Areas of Conservation	9,308
Special Protected Areas	6,615
Ramsar sites	6,013
National Nature Reserves	1,972
Within National Parks	9,339
Within Areas of Natural Beauty	4,058

depth, flow, altitude, age, surrounding vegetation, underlying geology and chemistry all contributing to marked differences in their ecology and species composition.

Alongside ponds, drainage ditches are also abundant with an estimated 600,000 km in Great Britain (**Table 9.4**). Lowland grazing marsh ditches are among the most species-rich Freshwater habitats (Brown *et al.* 2006). Although ditches in other landscape areas often support fewer species (i.e. alpha richness) (Biggs *et al.* 2007), there is not enough data on the biota of this extensive Freshwater habitat to make a full assessment.

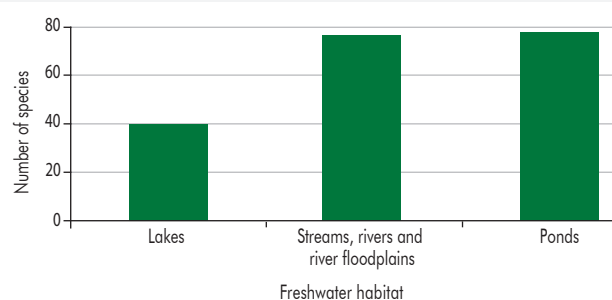
### 9.2.3.5 Hyporheic zones and groundwaters

Water-bearing rocks (aquifers) and stream sediments (the hyporheic zone), where surface water mixes with groundwater, provide habitats for uniquely adapted organisms. These habitats include open and interconnected pore spaces, caves, mines, wells and boreholes which may contain diverse assemblages such as obligate groundwater species (stygobites), species with an affinity for subterranean environments (stygophiles), and those which occur accidentally (stygoxenes) (Gibert *et al.* 1994). In the UK, the composition, distribution and biology of subterranean assemblages is poorly understood (see Proudlove *et al.* 2003; Gilvear *et al.* 2006; Knight 2008; Robertson *et al.* 2009). In mainland UK, 10 stygobitic crustacean species are currently recognised: 6 amphipods, 1 isopod, 1 syncarid, 1 copepod and 1 ostracod. Only one species (*Niphargus glennei*; listed on the UK BAP) is endemic and, so far, has been found in Devon and Cornwall (Knight 2008). Stygophilic assemblages have been collected from groundwaters throughout the UK, but stygobites are largely restricted to areas that were not glaciated (Robertson *et al.* 2009; **Figure 9.9**). Existing records are strongly biased towards chalk geology, although other aquifers, including other fractured carbonate aquifers, have been under-sampled. Systematic studies of invertebrate ecology of groundwater habitats are now taking place in parts of England, but there are no similar surveys of the hyporheic zone in the UK as a whole.

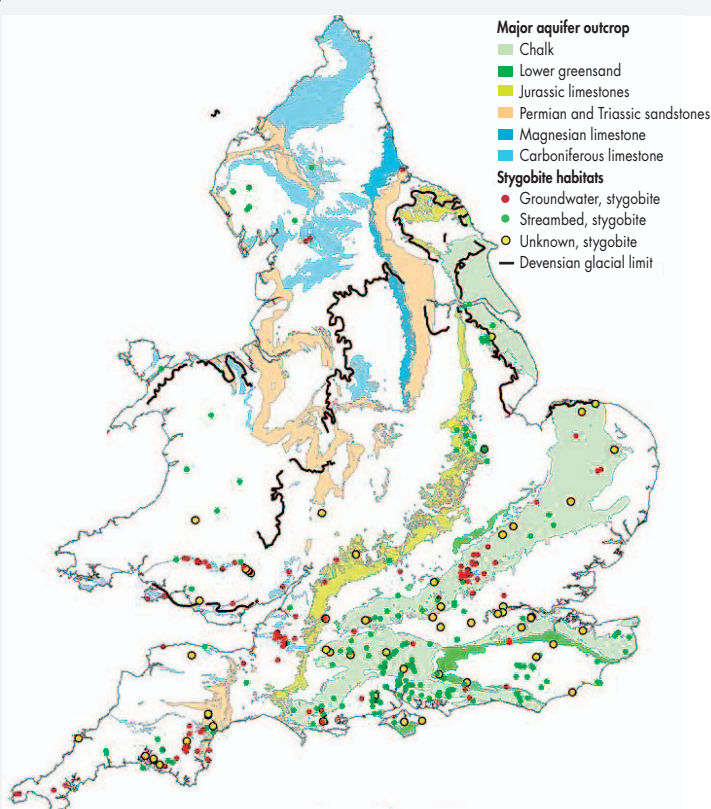
The hyporheic zone is important in biogeochemical filtration which is largely mediated by microbial biofilms (Butterini *et al.* 2000) that fuel rapid biogeochemical cycling of nutrients while retarding their downstream transport (Fischer *et al.* 2005). Intense cycling of nitrogen, phosphorous and carbon occurs in the hyporheic zone; these zones are also locations of denitrification, nitrogen mineralisation and ammonification (Hill *et al.* 1998; Duff & Triska 1990). Porous hyporheic media increase water residence time, thus increasing the opportunities for

**Table 9.4 Linear lengths (km) of rivers, streams and ditches in the ten main Defra agricultural landscape classes in Great Britain.** Source: Brown *et al.* (2006).

Water body type	Total linear length (km)
Rivers	91,499
Streams	175,975
Ditches	604,405



**Figure 9.8 The number of UK Biodiversity Action Plan (UK BAP) priority species recorded in lakes, streams, rivers and river floodplains, and ponds in England.** Source: data from Webb *et al.* (2010).



**Figure 9.9 Hyporheic and groundwater stygobite records in England and Wales overlain on a map indicating the outcrop of principal aquifers.** Source: Robertson *et al.* (2009).

microbial-mediated reactions relative to surface water. The movement of larger invertebrates (e.g. amphipods, isopods, oligochaetes) through sediments may reduce clogging and increase hydraulic conductivity within substrates, thus enabling the penetration of oxygen, nutrients and other bacterial substrates (e.g. Mermillod-Blondin *et al.* 2000). The hyporheic zone can moderate stream discharge by absorbing or releasing water (Environment Agency 2009b), while providing habitat for salmonid eggs (Malcolm *et al.* 2008). Refuge habitat is also available for surface organisms during disturbance events, such as droughts (Wood *et al.* 2001) and spates, and organisms that live in the hyporheic zone may add resilience to whole river ecosystems (Brunke & Gonser 1997; Robertson & Wood 2010).

There is no firm understanding of how groundwater invertebrates influence ecosystem services in aquifers (Boulton *et al.* 2008), although they may assist remediation following organic pollution. However, hyporheic and groundwater assemblages are vulnerable to disturbance, pollution (Danielopol *et al.* 2003), groundwater abstraction and fine sediments (Malcolm *et al.* 2010).

## 9.2.4 Cultural Services

### 9.2.4.1 Heritage goods: history and archaeology

Recently excavated from the peat-infilled, former, post-glacial lake, the Starr Carr House in Pickering, North Yorkshire, has been dated at 8,500 BP and is the oldest known dwelling in the UK. Mesolithic (from 8,500 to 4,000 BP in the UK) communities favoured lake margins for the establishment of villages as they could exploit the Freshwater habitats for food, shelter and security. Following this, Neolithic (from 4,000 to 2,500 BP in the UK) people continued to exploit Wetlands for their natural resources and started to construct wooden trackways. More than 40 different trackways have been discovered in the UK; the best preserved is the Sweet Track, dating from 3,806 BP and crossing nearly 2 km of Wetland that lay between dry land and a mid-marsh island in the Somerset Levels and Moors (Coles 1990). Its single plank walkway was held about 40 cm above the soft ground by pairs and groups of obliquely crossed pegs retained by a ground-level rail.

The most complete representation of the material culture of the Iron Age (from 750 to 300 BP in the UK) is the Glastonbury Lake Village (Adkins & Adkins 1992), England, formerly inhabited by around 200 people living in 14 roundhouses. The Isle of Avalon (the high land around Glastonbury, including the hill of Glastonbury Tor, which is surrounded by Wetlands) is said to be the burial place of King Arthur and Guinevere, although there is no archaeological evidence to support this enduring legend.

The waterlogged peat and clay deposits of the Somerset Levels and Moors also contain a wealth of palaeo-environmental data in the form of plant and animal remains such as pollen, seeds, snails, beetles, diatoms and foraminifera. These provide a unique record of the changing climate, sea-level and landscape during the Holocene (which began about 10,000 years ago), including during the Medieval Warm Period (approximately 950 to 1250 AD) and the Little Ice Age (1350 to 1850 AD) (Lamb 1972). The peat deposits are up to 8.5 m thick and are believed to contain the longest Holocene peat record of any lowland location in the UK.

The aesthetic value of Freshwaters has been an inspiration for painters, poets, bards and writers. Charles Dickens was, for example, inspired by the landscape of the North Kent Marshes which he recreated in *Great Expectations*. The development of tourism and the concept of picturesque landscapes are particularly associated with tours of the River Wye in the 1700s: 'Wild Wales' became a place where people could escape the urban landscapes and pollution created by the Industrial Revolution, and pastimes in botanising and fishing evolved. Today, several river valleys feature in the Register of Landscapes of Historic Interest in Wales (Cadw: Welsh Historic Monuments 1998, 2001).

There has always been a close relationship between water resources and the development of Welsh society and the regional economy; for example, the 13th Century native laws of Wales, 'Cyfraith Hywel', set the price for valuable otter (*Lutra lutra*) and beaver skins. Rivers have acted as boundaries, lines of defence and transport and communications routes. Lakes and Wetlands have been shown to hold valuable archaeological deposits and environmental records (Rees 1997). For example, an ancient Celtic fortification (crannog) was built in Llangorse Lake and has been subject to archaeological excavation; the accumulated lake sediment represents an environmental record extending back to the Devensian Late Glacial period (13,000 to 10,000 BP).

### 9.2.4.2 The multiple values of Freshwaters

Cultural services provided by Freshwaters are many and include unique opportunities for recreation, boating, fishing, tourism, education, history, religion, inspiration and art, while also providing a sense of place, physical boundaries and barriers, and the notion of mythical creatures, which are a source of inspiration in their own right. Many Freshwaters are valued for their mere existence, even if people do not necessarily visit them.

Among all the recreational uses of Openwaters, the asset value of the UK's Freshwater fish populations is particularly significant and reflects several key features. From an economic perspective, coarse fisheries alone contribute £850 million to the economy out of a total spend by rod fishermen exceeding £3 billion in England and Wales (Environment Agency 2006). In December 2006, there were 18,250 full-time employees in the angling industry and 5,500 part-time employees. At this time, there were 2,700 angling outlets, with an average annual turnover of £191,000. For migratory salmonids, the capital value of fishing rights alone is estimated at £140 million (Aprahamian *et al.* 2010), and several case studies show how associated angler spending within game fisheries is particularly important to rural economies and job creation (Peirson *et al.* 2001; Butler *et al.* 2009). From a recreational perspective, in excess of 2.6 million Freshwater anglers make this the most widespread participant sport in the UK across all social strata. However, there is also more fundamental ecological importance, with many species key to energy and nutrient transfer through Freshwater food webs (a supporting service).

Salmon fishing is particularly important to the economy of rural Scotland. A study in 2007 estimated it brought in £18 million to the local Borders economy and directly supported 487 jobs. Annually, 35,876 rod days of fishing are let, with 75% of salmon anglers travelling from outside Scotland; these visiting anglers spend an average of £189 per day in the Borders compared to an average of just £56 spent by other, non-fishing visitors. At a national level, Freshwater angling in Scotland is estimated to support around 2,800 jobs and generates nearly £50 million in wages and self-employment, as well as a spend of £100 million during the 1 million angler days involved.

Angling is not the only water sport generating large amounts of income. A study on the River Spey, Scotland, in 2004 estimated the number of water sports days to be over



38,000, contributing about £1.7 million to the local economy and supporting 48 jobs.

Wildlife tourism also plays a vital part in Scotland's rural economy. Since its return to Scotland over 50 years ago, the iconic osprey (*Pandion haliaetus*) has attracted hundreds of thousands of people to Wetland sites such as the Scottish Wildlife Trust nature reserve at Loch of the Lowes. In 2006, it was estimated that 125,000 visitors went to the five osprey viewing sites (nests) across Scotland, spending some £2.2 million, with birdwatching boosting the overall Scottish economy by £5 million (SNH 2008)

A Welsh Assembly sponsored study in 2000 estimated that the contribution of inland recreational fisheries to Wales was around £50 million per year (Anon 2002); but this is thought to be an underestimation by other interested parties. Approximately 60,000 rod licences are sold in Wales each year, while around 700,000 fishing trips to Wales are undertaken, generating a spend of about £75 million. Knowledge of fish and fishing is respected in Welsh communities, where tales of anglers (and poachers) are part of the oral tradition (Evans *et al.* 2009). The art of tying fishing flies has a number of world famous patterns derived in Wales—Coch Y Bonddu, the Diawl Bach, the Welshman's Button—with a correspondingly rich mythology on their use (Gee & Fowles 2009).

In England, the creation of the London Wetland Centre increased the value of adjacent, overlooking property significantly. The Centre supports rare species, such as bittern, employs many local people, supports volunteers, generates income for the Wildfowl & Wetlands Trust, and contributes to local cohesion. It provides a unique education and research facility in the centre of London.

#### 9.2.4.3 Health goods: meaningful places including green and blue space

Wetlands are often associated with nature and provide both green (e.g. forests, meadows) and blue (Openwater, e.g. The Broads) space. Habitats such as rivers and their floodplains and grazing marsh comprise key facets of locally characteristic and valued landscapes, with associated tourism, aesthetic and recreational interest.

In English and Scottish literature, Wetlands have often been symbolic of mystery and the unknown, remoteness, and sometimes the supernatural. Freshwater has also always been an important component of Welsh Celtic heritage. Water was considered a magical substance associated with spirits and legends, and requiring ceremonial offerings. And holy wells are a Christian expression of a religious connection with water.

#### 9.2.4.4 Socially valued landscapes and waterscapes

Wildlife groups, angling clubs, grazing communities and other associations have formed around the services provided by Wetland habitats of multiple types, such as the Somerset Levels and Moors, and East Anglian Fens. The Lake District is England's largest national park and covers 229,200 ha. In 2007, 8.3 million visitors came to enjoy the spectacular landscape and rich cultural heritage in a peaceful setting; Romantic poets found inspiration in the beauty of 'untamed'

countryside, with Wordsworth describing the Lake District as "a sort of national property, in which every man has a right and an interest who has an eye to perceive and a heart to enjoy". Loch Lomond and its landscape were celebrated by Sir Walter Scott in his famous poem, *Lady of the Lake*, two hundred years ago, and later by Gerard Manley Hopkins in his poem, *Inversnaid*, in 1881. Ponds, lakes, waterfalls and other watercourses are an intrinsic part of landscape history and dominant components of estates and parklands, especially from the 18th Century onwards (Rees 1997).

## 9.3 Freshwater Condition and Trends

### 9.3.1 Status of Freshwaters

Despite their functional importance, ecological value and various forms of protection, Freshwaters have been extensively modified physically, chemically and biologically. Human impacts on river flow and sediment regimes, channel size, form and mobility, and the widespread management of riparian and aquatic vegetation, have all affected the entire assemblage of aquatic, wetland and terrestrial habitats (Gurnell & Petts 2010). It is almost certain that there are now no completely pristine Freshwater ecosystems in the UK—almost all have been impacted by human activity and are managed to a lesser or greater extent. Management has increased over the past few centuries, and has progressed from the local enhancement of natural processes, such as natural irrigation of water meadows, to major interventions to prevent natural processes, such as the building of dams. While the least damaged are expected to provide the most natural profile of services, more managed systems and artificial habitats can be very important locally; for instance, chalk rivers, reservoirs, fenlands and ponds and some water management structures have been protected for their cultural heritage.

A key element of change has been the disruption of the natural continuum, such that Freshwater has become highly fragmented over time, resulting in habitat degradation and loss. This is particularly significant with regard to connections among or within Wetlands, Floodplains and rivers, where the movement of water would normally reduce flood magnitude, encourage infiltration to aquifers, and allow the exchange of organisms and nutrients with adjacent habitats. Loss of connectivity has occurred through dams, weirs, land drainage, embankments, channel deepening, straightening and widening (Newson 2002), and infrastructure development adjacent to rivers. For example, the River Habitat Survey (Environment Agency 2003) records the presence of Floodplains, bank-top land use, artificial embankments and features of special interest on the Floodplain including natural open water, water meadow, fen, bog, carr and marsh. Of the 24,000 river sites (along 12,000 km of river) surveyed, 1,705 had a Floodplain on either bank for at least a third of the 500 m survey length. Some

13% of the 1,705 Floodplain sites had embankment close to the watercourse and 6% had embankments set back (**Table 9.1**); in both cases, this prevented water from inundating the 'natural' Floodplain, resulting in fragmentation of the hydrological continuum vital for the maintenance of ecosystem services. Many of these changes occurred before environmental safeguards, such as environmental impact assessments and cost-benefit analyses, and most have gone unrecorded.

### 9.3.2 Changes in River Dynamics

In addition to responses to longer-term climate and land cover changes (e.g. Macklin & Lewin 2008), the dynamics of the UK's rivers have been heavily impacted by centuries of agricultural development and land drainage, as well as management for water supply, flood defence, navigation and other human activities (Newson 2002). Many dynamic rivers, particularly in England, were affected by significant floodplain alluviation with fine sediment during the medieval period following the intensification of agriculture through the use of the open field system (e.g. Brown 2009b). This increased the strength of riverbanks and reduced river lateral dynamics. Since the medieval period, numerous direct and indirect human pressures have modified river flows and their hydrological connectivity, the sediment load available to river systems, and the degree to which river channels, banks and Floodplains are able to respond to changes in flow and sediment supply (e.g. Gregory 2006; Gregory *et al.* 2008).

Human impacts have affected the entire assemblage of habitats that characterise river corridors (Gurnell & Petts 2011), yet the monitoring of these physical changes remains a relatively neglected area (Sear & Newson 2003). The impact of particular types of human activity on river and Floodplain form and dynamics has been evaluated, including: dam

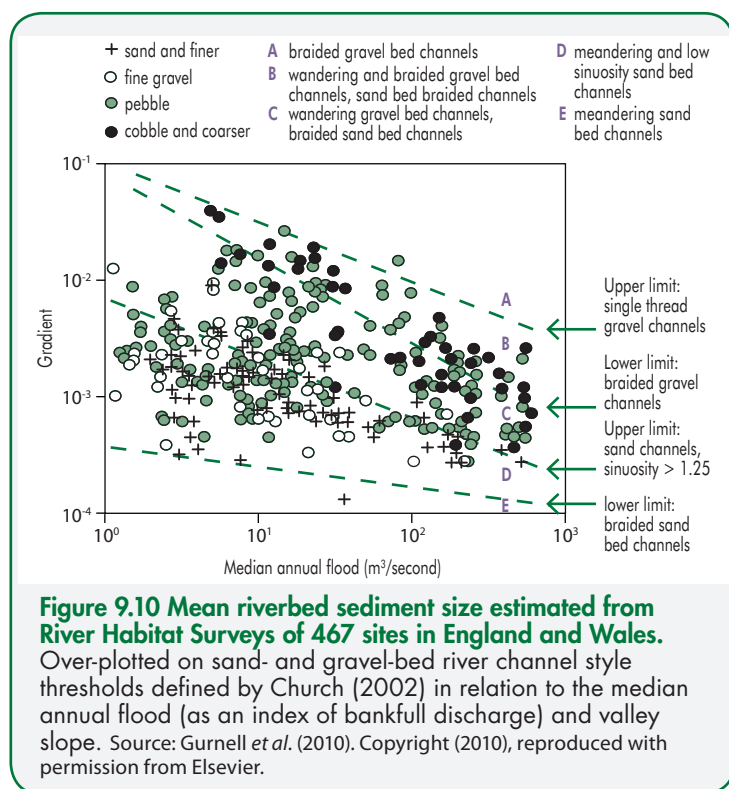
construction (Petts & Gurnell 2005); the realignment, simplification and reinforcement of river channels (Brookes *et al.* 1983); sediment dredging (Sear *et al.* 1995); the cutting and pruning of riparian vegetation; and the removal of wood from river systems (Gregory *et al.* 2003, Gurnell & Petts 2002). Investigations of historical documentary and aerial photography sources, alongside sedimentary and morphological evidence, have illustrated major changes on individual rivers; but these investigations have largely focused on relatively dynamic case studies (e.g. Hooke & Yorke 2010), so the integrated impact of human activities on rivers and their Floodplains remains difficult to quantify. However, as national datasets are assembled, particularly to meet the hydromorphological requirements of the WFD, it is becoming possible to gain some broader insights. For example, over-plotting data (drawn from the Environment Agency's River Habitat Survey) on established relationships between river gradient, discharge and riverbed sediment size for a sample of river reaches in England and Wales suggests that multi-thread rivers should be far more widespread than at present (**Figure 9.10**). The loss of multi-thread rivers is often indicated in Floodplain sedimentological sequences, as well as cultural artefacts such as complex historical bridge structures. Such multi-thread systems supported the side channels, Floodplain ponds and Wetlands whose importance and status as a diminishing resource is described in other sections of this report. Today, we are left in many catchments with a fossilised and more or less fixed arterial drainage system that responds only to large flood events, such as those in Cumbria in 2009.

As noted in a global context by Tockner and Stanford (2002), "there is an urgent need to preserve existing, intact flood plain rivers as strategic global resources and to begin to restore hydrologic dynamics, sediment transport and riparian vegetation to those rivers that retain some level of ecological integrity".

While there is some understanding of the dynamics of Freshwaters, quantitative evidence of the effects on ecosystem services is limited and uncertain, and monitoring remains a relatively neglected area (Sear & Newson 2003). We understand some of the basic processes within relatively unaffected environments, but we need to know more about how different Freshwater systems in various levels of management/condition impact on, or deliver, ecosystem services. This is required to meet hydromorphological objectives under the WFD.

### 9.3.3 Condition of Designated Sites

By area, 18.4% of SSSI rivers in England are in favourable condition and 29.9% are recovering; for standing waters, the figures are 50.5% and 30.5% respectively (statistics provided by Natural England, October 2010). Those standing waters notified for their bird interest are in the best condition, that is 86% favourable or recovering (Natural England 2009). But overall, these values are among the worst for all habitats protected in England's SSSIs, mainly as a consequence of eutrophication from both point and diffuse sources. In general, there is less monitoring in Wetlands and information is based on site condition monitoring for SSSIs to determine trends.





Based on some 559 condition assessments on protected areas in Scotland, by 2009, 61% were judged to be in favourable condition, with 8% recovering and the remaining 31% unfavourable. The main reasons for poor condition were the presence of invasive species and lack of management (Mackey & Mudge 2010).

Of the UK BAP priority habitats associated with Freshwaters and Wetlands in Scotland, 40% were assessed as declining, 20% show no trend, 20% are fluctuating probably stable, and 20% are fluctuating probably increasing (Spray 2011). The comparative picture for the 75 UK BAP priority species showed 42% declining, 11% no clear trend, 31% fluctuating probably stable and 16% fluctuating probably increasing. Some native species, such as otters and Greylag geese (*Anser anser*), have shown major increases, but so have many invasive non-native species including signal crayfish (*Pacifastacus leniusulus*) and Australian swamp stonecrop (*Crassula helmsii*).

Freshwater ecosystems in Wales are undergoing serious environmental degradation from a variety of human induced pressures, including pollution, sedimentation, fisheries management, invasive and non-native species introductions, and water regulation. The majority of Freshwater sites or features within designated sites in Wales are in unfavourable or declining condition.

### 9.3.4 Openwaters and Groundwater Monitoring and Assessment in the UK

Rivers are the UK's most extensively monitored Freshwater habitats. Water quantity is measured through a network of around 1,500 gauging stations located along rivers, and 160 index wells or boreholes that provide details on groundwater (Marsh & Hannaford 2008) in summary reports ([www.ceh.ac.uk/data/nrfa/nhmp/monthly\\_hs.html](http://www.ceh.ac.uk/data/nrfa/nhmp/monthly_hs.html)). The Environment Agency has many more groundwater monitoring sites for chemistry and water level. For the WFD Article 8 report on monitoring, the Environment Agency reported to the European Commission (EC) that, for England, there were 1,217 monitoring points for groundwater level (used for WFD assessment) and 3,373 for groundwater quality (used for groundwater body status and trend assessment). For biological trends, systematic, long-term data are available from over 20,000 sites on 25,000 km of rivers in England, Wales and Scotland. For physical structure (i.e. hydromorphology), in excess of 24,000 locations have been sampled along rivers throughout the UK using River Habitat Survey methods developed by the Environment Agency (Raven *et al.* 1998). These extensive surveys are complemented by the sampling of 300–400 headwaters in 1990, 1998 and 2007 for macrophytes, macroinvertebrates, habitat structure and chemistry, and a similar number of ponds sampled for macrophytes in 2007 as part of the Countryside Survey (Dunbar *et al.* 2010c; Williams *et al.* 2010). Several major river systems have also been the subject of detailed long-term research. This effort to assess status and trends reflects the legislative importance placed on Freshwaters; the importance of water quality to its uses; the array of pressures affecting water; and the indicator value of river organisms in revealing change.

For lakes, trend data are less systematic, but good insights are available from well-known case studies, for example,

Lake Windermere (George & Harris 1985) and the English Lake District in general (Maberly *et al.* 2002; Thackeray *et al.* 2008), Loch Leven, Scotland (Spears & Jones 2010), Lough Neagh, Northern Ireland (Griffiths 2007), the UK Acid Waters Monitoring Network (Monteith & Evans 2005; Kernan *et al.* 2010), the Norfolk Broads (Sayer *et al.* 2010), the Anglesey Lakes (Bennion *et al.* 1996), Llangorse Lake (Duigan *et al.* 1999) and Llyn Tegid in Wales (Gritten *et al.* 2003), and a range of smaller water bodies (Jeffries 2008). New data are also emerging as a consequence of the surveillance monitoring programmes required for implementation of the WFD.

### 9.3.5 Limitations of the Available Trend Data

While trend data for lakes and rivers are numerous, there are some limitations. The most important is that the ecological methods used are based largely on static, structural measures of taxonomic composition, rather than on functional measures linked to ecosystem processes or services. In addition, sampling locations for most purposes are not representative, with headwaters, upland and smaller water bodies often under-represented. Pressures specifically affecting these locations, such as habitat degradation, acidification, metals or sheep dips, are, therefore, overlooked to an extent, but are best identified in specialised studies (e.g. UK Acid Waters Monitoring Network, Countryside Survey). There are also some mismatches in the availability or timing of trend data from different parts of the UK, with England and Wales covered most fully and consistently. By comparison with sanitary aspects of water quality, some sources of ecosystem change in Freshwaters are appraised less effectively in systematic monitoring, such as physical modification, inert sediments and climate change. Quality varies among datasets; for example, some of the most extensive biological monitoring data cover only a limited taxonomy. Finally, Freshwater monitoring throughout the UK has recently been changed radically to support the WFD and this has important bearings on interpretation.

The situation in Scotland is particularly challenging with two recent, major changes in the nature and extent of the water monitoring network. Relative to the rest of the UK, Scotland has an abundance of surface waters. However, up until the requirements of the WFD were enacted through the Water Services Water Environment Act (2003), little attention had been paid to groundwater resources, to the impacts of abstraction (which was largely unregulated) or to hydromorphological alterations of surface waters. Furthermore, while invertebrate monitoring had been undertaken on a systematic basis, there was no systematic fish monitoring, except for salmon catches. With the implementation of the WFD, and following extensive consultation with other bodies, SEPA introduced a new Scottish aquatic monitoring strategy that addressed these shortcomings by developing a groundwater monitoring network, for example, as well as introducing new controls on abstraction and flow regulation (The Controlled Activities Regulations).

Across the whole of the UK, WFD developments include augmenting the array of indicators used for ecological quality assessment (fish, macrophytes, and invertebrates,

plus phytobenthos in rivers and phytoplankton in lakes) as well as assessment of hydromorphology and chemistry. These and other changes have increased the sensitivity of assessment for some effects, notably eutrophication through the stronger inclusion of diatoms and macrophytes. Nevertheless, differences remain between the constituent countries of the UK, for example Scotland's measurement of hydromorphological change uses a different tool (MIMAS) to that elsewhere and to date Scotland still has limited fish monitoring. Recently, the extent of the Scottish recently-introduced freshwater monitoring network and frequency parameters have been severely cut back as a response to financial pressures, with many sites previously monitored annually being dropped or reduced to less frequent sampling.

### 9.3.6 Trends for Openwater

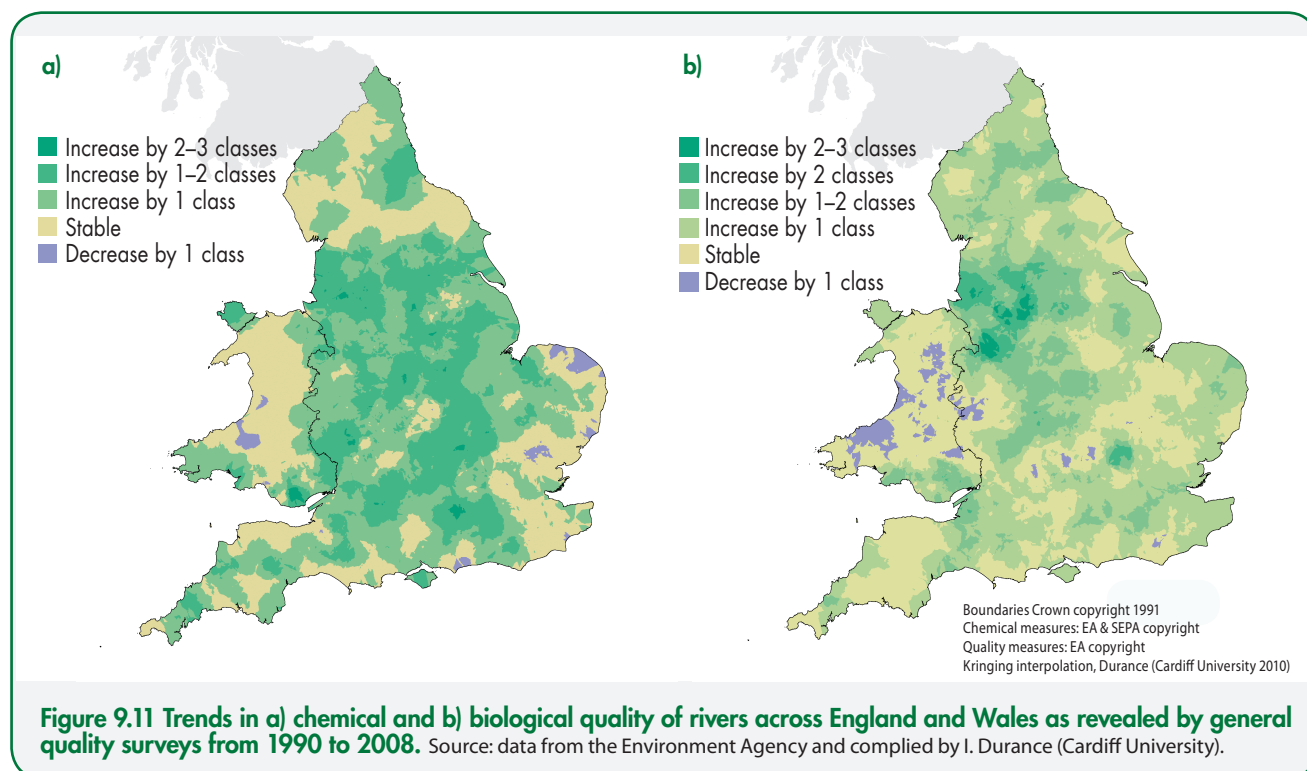
Trends in water quality in the UK's Freshwater habitats have been determined from extensive, systematic surveys of rivers, case studies in lakes and Wetlands, and recent systematic surveys of ponds. These data provide a valuable indication of: i) how the uses of the UK's Freshwaters for flood defence or waste disposal have affected their quality; ii) how Freshwater trends reflect catchment use for fibre production, agriculture or urban land; iii) how Freshwater quality can limit the uses of water for final goods and services, for example, abstraction, fisheries, recreation and aesthetics; and iv) the potential costs of degrading Freshwaters, either assessed through the costs of restoring quality or through the loss of services that occur where Freshwater ecological functions are degraded. These issues also illustrate a long-standing trade-off in which terrestrial goods and services have often been exploited without recognition of the full cost of ecological consequences downstream.

In general, several aspects of long-term monitoring data illustrate a major improvement in the quality of many UK

rivers as a result of actions over the last two decades. In England and Wales, the biological and chemical classification of 7,000 km and 12,000 km of rivers, respectively, improved significantly from 1990 to 2008. Although still short of full recovery, effects have been most marked across formerly polluted catchments with extensive urbanised land, particularly those in central England, northern and southern England and South Wales (**Figure 9.11**). Measured in terms of sanitary quality (such as biochemical oxygen demand, dissolved oxygen, ammonia and associated biological indicators), these improvements reflect investments in wastewater treatment and other point source discharges.

Against this generally improving trend, recovery patterns are much more variable at a local level. For example, biological quality declined by one or more classes in 2,500 km of the best hill-rivers in Wales and the Welsh borders for reasons that are unclear (**Figure 9.11**). This trend was corroborated in the Countryside Survey at the locations originally sampled (**Figure 9.12**). Whereas, across 168 headwaters in Scotland and 132 in England there was a general gain in taxa and significantly improved index values over the period 1990 to 2007. By contrast, 46 headwaters in Wales have not sustained the same improvement, with a tendency for richness to fall against expectations between 1998 and 2007 (**Figure 9.12**). The most likely explanations are continuing problems with diffuse pollutants. Declines have also been observed in macroinvertebrate status in the Scottish Highlands which had the highest proportion of sites at good or high status in 1998; by 2007, this proportion has dropped to a level comparable to that of the rest of Scotland and upland England but it is not currently possible to pinpoint causes of this decline.

Nitrate concentrations increased in almost 4,000 km of English and Welsh rivers between 1995 and 2008, mostly in the lowlands (**Figure 9.13**). Other eutrophication indicators, such as phosphorus concentrations, also remain

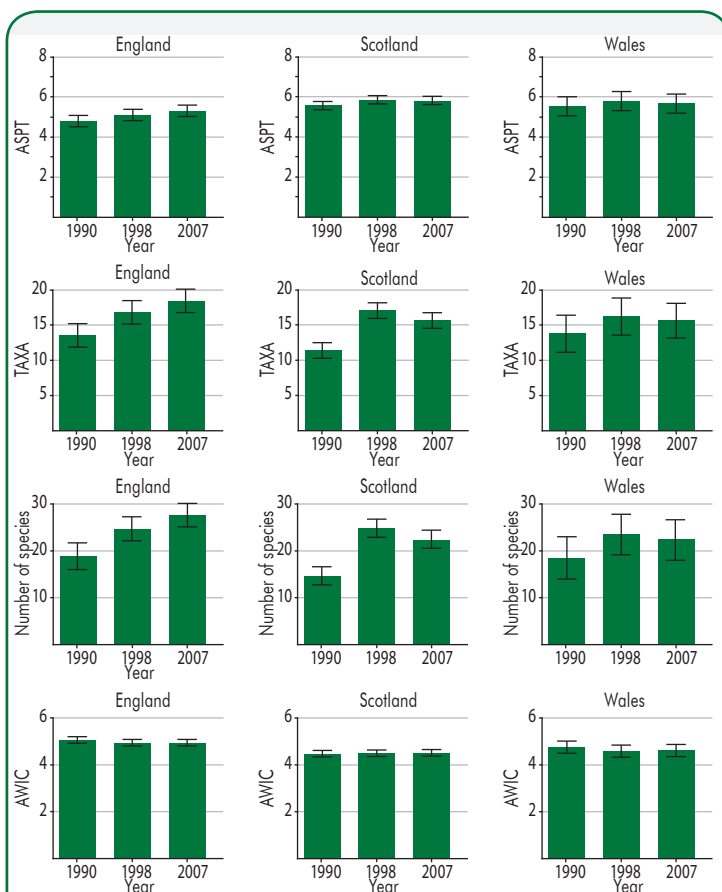


elevated in many locations despite some stabilisation or reversal of long-term increase (e.g. Mainstone *et al.* 2008; Neal *et al.* 2010; **Figure 9.14**). Sources probably reflect continued discharge from wastewater treatment, with more modest contributions from agriculture (e.g. Jarvie *et al.* 2010), although the importance of contributions from minor, unconsented point sources, such as septic tanks, is increasingly recognised (May *et al.* 2010). Implications for ecosystem services arise from the costs of remediating damaged systems, from the costs of sewage treatment, and from increased risks of cyanobacteria in receiving waters. Lost recreational opportunity, as well as increased human and livestock health risks, can be substantial.

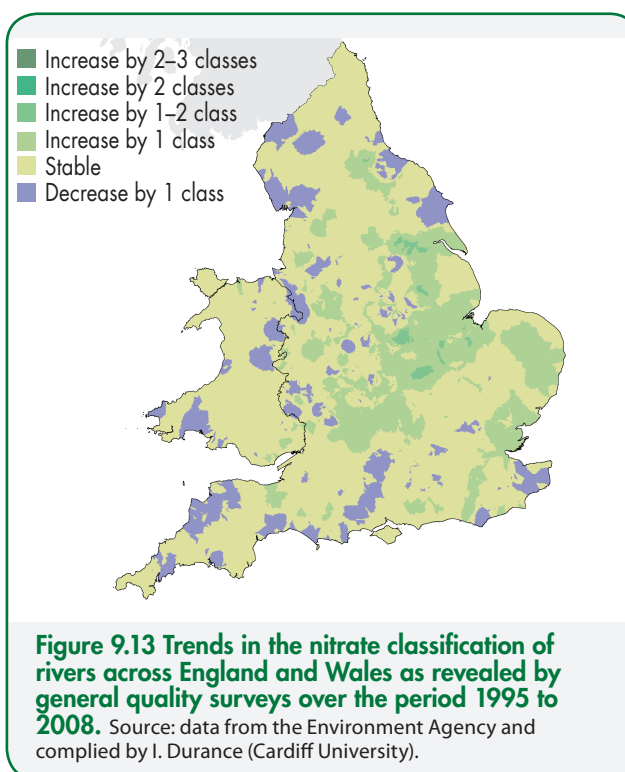
In upland locations, data on acidification caused by acid rain show that chemical recovery continues to track reductions in acidifying emissions (Davies *et al.* 2005). However, associated biological recovery is more modest, probably because of continuing acid episodes (Kowalik *et al.* 2007; Ormerod & Durance 2009). Ore-bearing regions in some acid-sensitive locations still produce local problems through metal-rich drainage, while more extensive background metal loadings also occur from atmospheric deposition (Lawlor & Tipping 2003). Out of 7,815 water bodies across England and Wales, 465 appear to be impacted by pollution from non-coal mines, with around half of these likely to affect in-stream pollution (Mayes *et al.* 2009).

There is widespread regulation of priority substances under the WFD (WFD Annex VIII). Monitoring shows limited exceedence of Environmental Quality Standards (EQS) for pesticides in most surface waters. However, breaches of EQS values, or standards set by the EU for drinking water supply, do still occur and, in some cases (e.g. metaldehyde used as slug pellets), this requires targeted action to minimise entry to water. General population recovery across the whole of the UK among sensitive organisms, such as otters (listed on the Habitats Directive 92/43/EEC), illustrates how previous pesticide effects, notably from organochlorine compounds, such as dieldrin, have diminished. On the other hand, EQS over the last decade were exceeded on scores of occasions in sheep-rearing areas by two active ingredients in sheep dips: the synthetic pyrethroid, cypermethrin, and the organophosphate, diazinon (Sinclair *et al.* 2007). However, licensing changes have now reduced, if not fully eliminated, these risks.

Agricultural developments and increased livestock density across Wales have probably more than doubled catchment phosphorus loadings to rivers and trebled nitrogen loadings (Johnes *et al.* 2007). Based on an analysis of Welsh Local Environment Agency Plans (Ormerod & Jüttner 2009), agricultural runoff is identified as a particular problem in mid-Wales, with sheep dip an issue throughout the region, and especially in west Wales. Tens of major or significant pollution incidents involving sheep dip have occurred annually across England and Wales, with the increased numbers recently reflecting targeted investigations. Wales contributes strongly to the Environment Agency sheep dip statistics. In 2000/01, sheep dip residues were found at 86–92% of Welsh survey sites, with cypermethrin responsible for most EQS failures; the cypermethrin marketing licence has now been suspended (Ormerod and Jüttner 2009).



**Figure 9.12 Trends in quality measures from a stratified random sample of headwaters in Great Britain as shown by the Countryside Survey in 1990, 1998 and 2007.** Means ( $\pm$  95% CI) of four macroinvertebrate indices: Average Score Per Taxon (ASPT); number of BMWP (Biological Monitoring Working Party) scoring taxa (TAXA); number of species; and Acid Waters Indicator Community (AWIC). Source: Dunbar *et al.* (2010c). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.



**Figure 9.13 Trends in the nitrate classification of rivers across England and Wales as revealed by general quality surveys over the period 1995 to 2008.** Source: data from the Environment Agency and compiled by I. Durance (Cardiff University).



Inert and nutrient-bearing sediments are thought to be increasingly problematic, and possibly widespread, but there is insufficient monitoring, and trends through time vary among locations. Patterns reflect changes in key sources such as agriculture or forestry, and climate variability (Owens & Walling 2002; Orr & Carling 2006; **Figure 9.14**). The most intensively used catchments have often had amplified sediment fluxes over the last 40 to 100 years (Walling *et al.* 2003; Small *et al.* 2005; Hatfield & Maher

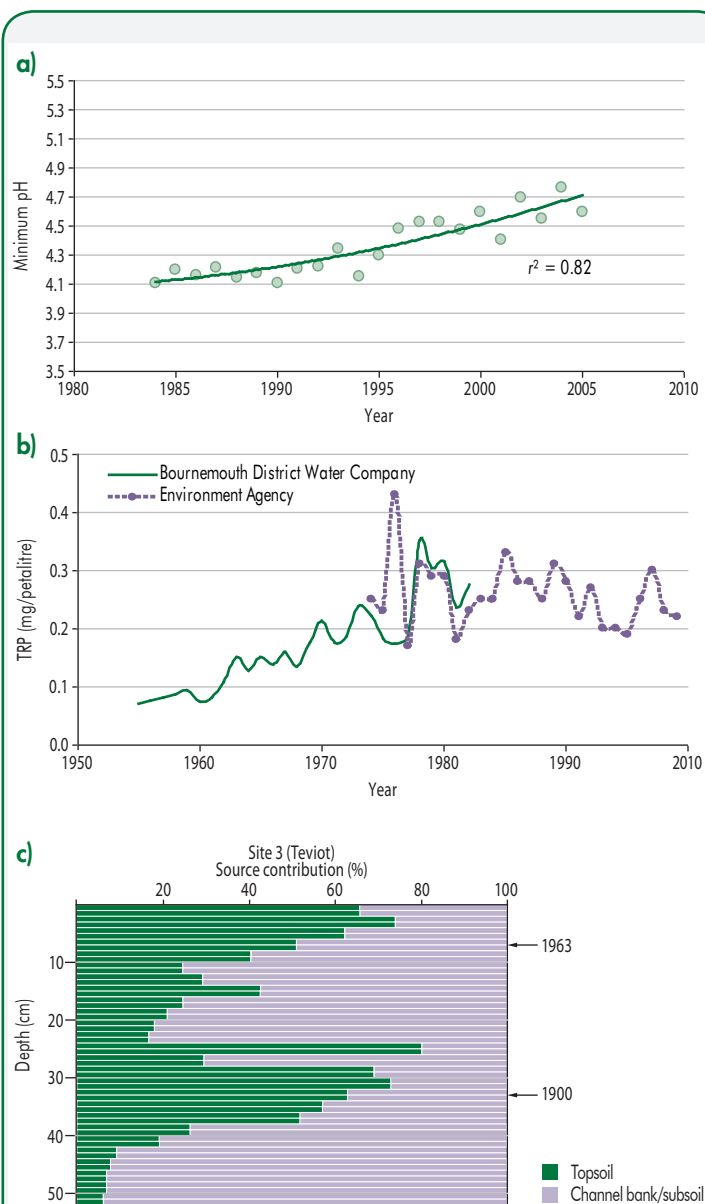
2009). Increasing evidence shows how river organisms and ecosystem processes can be sensitive to such effects at surprisingly low levels, particularly in upland regions (e.g. Larsen & Ormerod 2010). Several species of importance to nature conservation are affected, notably the freshwater pearl mussel (*Margaritifera margaritifera*) (Hastie *et al.* 2003; Geist & Auerswald 2007) and white-clawed crayfish (*Austropotamobius pallipes*); salmon spawning success has also been impacted upon. There are also problems for public water supply or regulating reservoirs as a result of treatment costs and reduced capacity (e.g. Holliday *et al.* 2008). In addition to their physical effects, sediments are also a vector for pollutants such as phosphorus (Neal *et al.* 2010). Sediment loads to some rivers, particularly chalk streams, are now exacerbating anoxia in bed sediments to the extent that methane exports to the atmosphere have increased (Sanders *et al.* 2007). Absolute emissions are small, but this illustrates how unexpected changes in ecosystem function can arise from poor catchment management. The understanding of the role of nanoparticles (produced by the cosmetics industry, for example) in Freshwaters is increasing, and solutions to treat them are evolving (Jarvie & King 2010).

Dissolved organic carbon has relevance to both water supply and climate, and extensive data now reveal widespread increasing trends (Evans *et al.* 2005; Worrall & Burt 2007; Dawson *et al.* 2009). Exact causes are debated (see section 9.2.2.1), but there is growing evidence that underlying increases may be driven by the greater mobilisation of Soil Organic Matter as a result of recovery from acidification (Monteith *et al.* 2007); short-term peaks and interannual variations, on the other hand, are linked to climatic factors, such as temperature, droughts and high flows (e.g. Clark *et al.* 2005; Erlandsson *et al.* 2008), or land management, such as moorland drainage ditches ('grips'). There are potential costs for freshwater organisms, potable supply and carbon balances.

### 9.3.7 Changes in River Flow Since 1950

Annual mean precipitation over England and Wales has not changed significantly since records began in 1766. Seasonal rainfall is highly variable, but appears to have decreased in summer and increased in winter; although there has been little change in the latter over the last 50 years. All UK regions have seen an increase over the past 45 years in the contribution of heavy precipitation events to winter rainfall; in summer, all regions, except north-east England and north Scotland, show decreases in rainfall. Between 1961 and 2006, all regions have also experienced an increase in average annual and seasonal temperatures, which suggests increases in evaporation.

Examination of flow timeseries data for 15 rivers across England and Wales revealed positive trends in both winter and summer flows in some rivers since 1940 (Wilby 2006); however, the majority of summer flow trends were not significant. Autumn and winter flows increased in 95 'benchmark' natural catchments during the period between 1969 and 2008 (Hannaford & Harvey 2010). The strongest winter increases were generally found in the north and west of the UK, whereas autumn trends were most prevalent in



**Figure 9.14 Three examples of trends in diffuse effects on British rivers. a) Trends in minimum pH in an upland stream at Lyn Brianne, Wales, recovering from acidification over the period 1981 to 2005.** Source: Ormerod & Durand (2009). Copyright © 2009 Journal of Applied Ecology. Reproduced with permission of Blackwell Publishing Ltd. **b) Long-term trends in total reactive phosphorus (TRP) in the Hampshire Avon River, England.** Source: Mainstone *et al.* (2008). Copyright (2008), reproduced with permission from Elsevier. **c) Core-derived trends in Floodplain deposition at a site on the River Tweed, Scotland, illustrating the delivery of sediments from different catchment sources.** Source: Owens & Walling (2002). Copyright © 2002 Earth Processes and Landforms. Reproduced with permission of Blackwell Publishing Ltd.



south-west and central England. Trends in summer and spring flows were weaker and regional patterns were very mixed, although spring flows have decreased in some areas during the last 40 years. The winter and autumn trends observed were resilient to changes in the study period, whereas the decline in spring flows seen in recent records is not apparent over longer periods.

Based on 34 benchmark catchments across the UK, there is little evidence for trends in low flows over the period 1963 to 2002 (Hannaford & Marsh 2006). Certain positive trends seen during 1973 to 2002 were influenced by a sequence of notably dry years at the start of the period, but were not evident over a 40-year time period. Furthermore, these authors found little compelling evidence for low flow trends in longer hydrometric records; there is some evidence for an increase in naturalised 30-day minimum flows on the Thames since 1880, but this is likely to be influenced by a lack of homogeneity in the long Thames record. Lane (2008) has identified flood-rich and flood-poor periods.

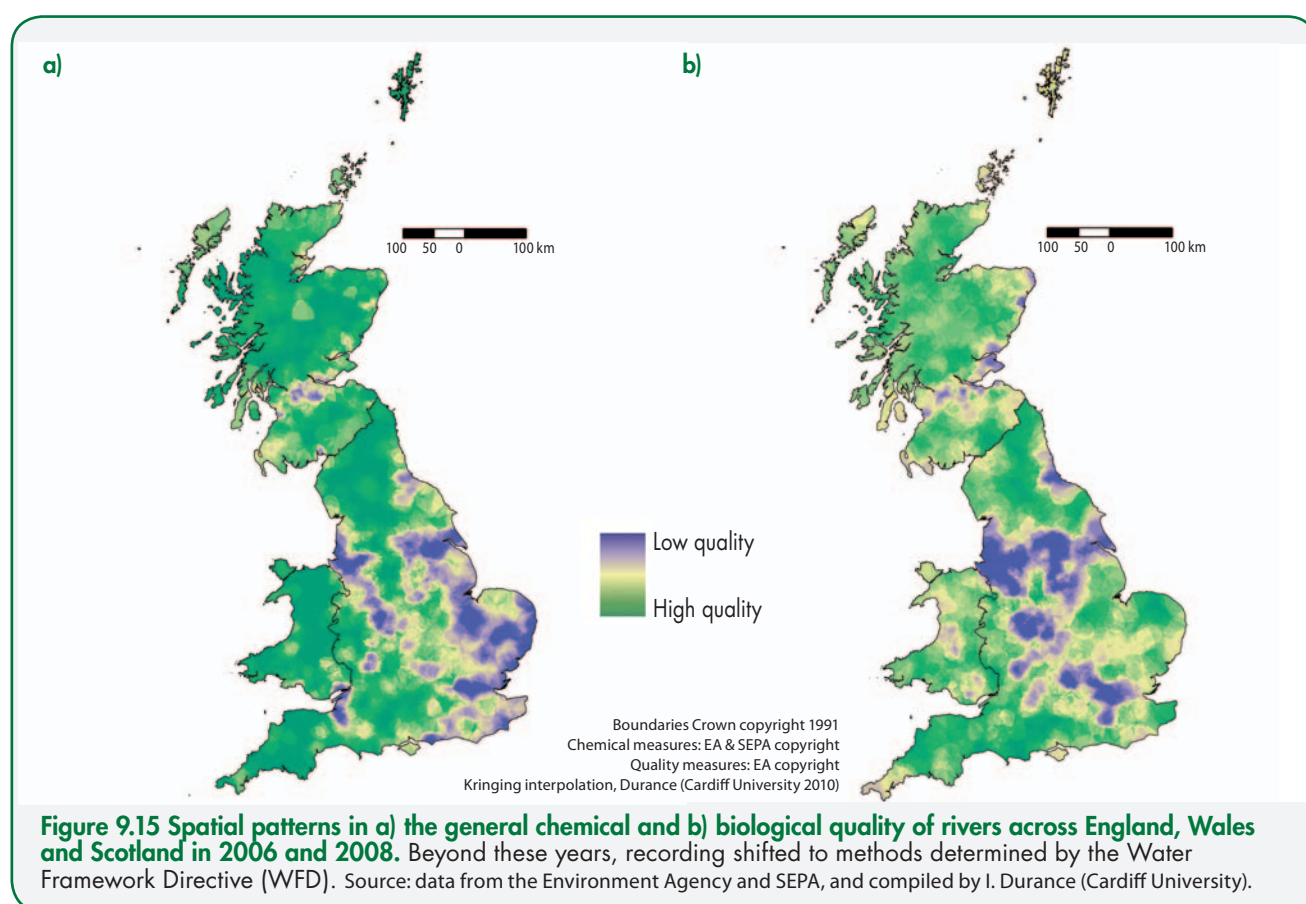
Significant trends in high flows and floods were found across upland, maritime northern, and western areas of the UK in a study of 87 benchmark catchments (Hannaford & Marsh 2007). In western Scotland, there are some dramatic examples of a flood-rich period post-1990: eight out of the ten largest floods gauged since 1973 on the River Forth at Stirling have occurred post-1990, with six of these since 2000. However, there was little conclusive evidence for trends in the occurrence of high flows in English lowland rivers. From the late 1980s onwards, flood peaks on the River Avon at Amesbury are more pronounced than before

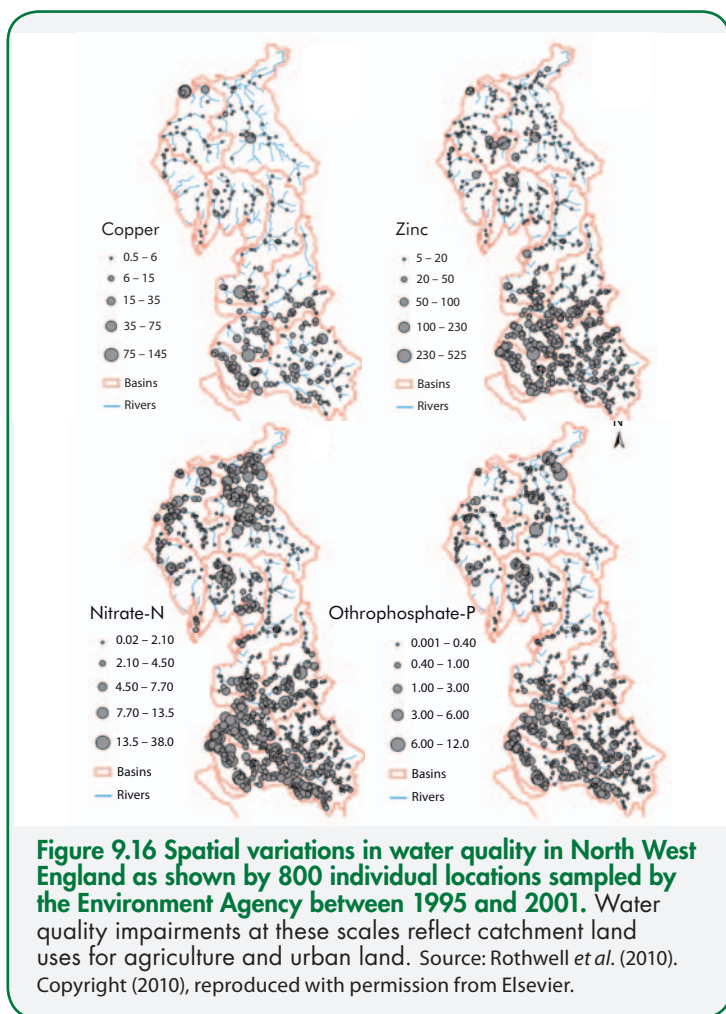
1988/1989, with similar changes to varying degrees on other chalk rivers (Solomon & Lightfoot 2007). Groundwater records from Chilgrove House, Chichester, show a similar pattern, with more extreme levels (especially low autumn and high winter levels) since 1989 compared with the more stable period between 1962 and 1988. It is not clear, however, whether this is part of cyclic or persistent behaviour, a long-term trend, or a step change.

### 9.3.8 Current General Quality in Rivers

Despite improvements, the current quality of rivers across the UK is still uneven. Rivers in the urban regions of England, Wales and Scotland still have the poorest quality (**Figure 9.15**), and reflect a range of factors including: elevated organic loadings (often from storm overflows); elevated metal loadings from industrial or combustion sources (**Figure 9.16**); and enhanced indicator values for waterborne pathogens. Relatively new urban pollutants, such as endocrine-disrupting substances, are giving rise to increasing concern with regards to their effects on fish. The risk of these effects occurring is greatest in locations where the contribution of treated sewage to river flow is largest (Williams *et al.* 2009).

Chemical indicators reveal continued problems in the extensively cultivated lands to the south and east of the Severn-Humber line. Here, and in south-west Wales and eastern Scotland, elevated nutrient concentrations (e.g. nitrate >5 milligrams per litre) contrast markedly with the UK's upland areas in Exmoor, Dartmoor, Wales, the Pennines and large parts of Scotland (**Figure 9.17**). The intensive





agricultural areas of Scotland, such as the Ythan Valley and eastern seaboard, also show continuing problems with nutrient enrichment and impacts from nitrates and other diffuse pollutants. The Scottish Environment Protection Agency is tackling the issue through the identification of priority catchments for remediation (e.g. Lunan Water, Angus).

Impaired quality in both urban and agriculturally intensified locations is reflected in the recent water body classification for the WFD (**Figure 9.18**). Newly added WFD tools for assessing the physical modification of rivers provided by River Habitat Surveys, (which are based on stratified random sampling) reveal that more than 50% of English and Welsh rivers have been modified physically (**Figure 9.19**). Rivers in urban or central English regions are most affected by bank reinforcement, where artificial materials are used to strengthen bank or bed structures, and re-sectioning, where the banks or bed are mechanically reprofiled for flood defence purposes (Boitsidies *et al.* 2006). Similar data from Scotland show that hydromorphological alterations are one of the most widespread causes of the failure of the country's water bodies to reach good ecological status, with 17% suffering from modifications to channels and banks, and 16% having barriers to fish migration. Trend data from the Countryside Survey 2007 (Carey *et al.* 2008) suggest a tendency towards increasing modification in Scotland, although this may reflect improved recording (Dunbar *et al.* 2010c). The effects of modification on total ecosystem services have not been

quantified, but the effects on biota are likely to be negative, decreasing habitat heterogeneity, for example, and rendering biota more sensitive to low flows (Dunbar *et al.* 2010a,b).

### 9.3.9 Microbiology and Microbial Quality

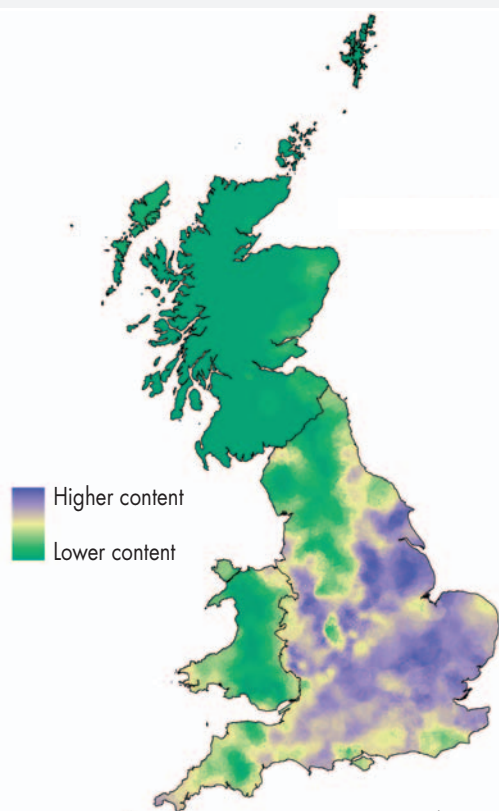
In terms of their microbiology, the UK's inland waters have improved during the past 30 to 50 years, reflecting investment in wastewater treatment and disposal. However, significant problems remain where poorly performing sewage treatment works and sewer overflows, along with livestock, are sources of pathogens. Some pathogens, such as *Cryptosporidium* species, can still lead to reservoir closures, while other organisms can affect potable supply, bathing waters or shellfisheries downstream (e.g. Pickup *et al.* 2006; Kay *et al.* 2008). Fluxes of faecal indicator organisms, such as coliform bacteria, increase at high flow compared with base flow, and are greater in summer than in winter. Catchments also vary widely in export, with urban areas and lowland improved pastures most likely to be key sources (Kay *et al.* 2008). In the northern English Ribble system, for example, more than 90% of the total coliform load to the estuary arises from sewage-related sources during high flow events (Stapleton *et al.* 2008; **Figure 9.20**).

*Mycobacterium avium* subspecies *paratuberculosis* has been discovered in the Afon Taff, Cardiff, and has been implicated in chronic inflammation of the intestine in humans. The increased occurrence of such illness in the area appears to be related to how close the affected residents live to the rivers where they may be exposed to aerosols bearing this pathogen (Pickup *et al.* 2005).

### 9.3.10 Groundwater Status and Trends

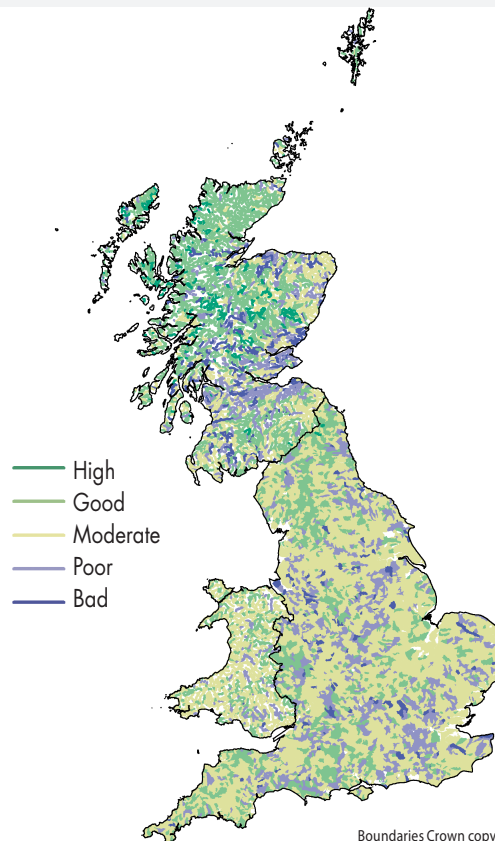
Groundwater contributes significantly to our water resource needs and is essential to maintain a healthy natural environment. Although groundwater occurs everywhere, it is not always accessible due to the properties of the subsurface. Where it is accessible, and not contaminated by pollutants, it can provide clean, fresh water for a range of human uses, as well as meeting the needs of the environment (surface waters and wetlands). To aid the protection and management of groundwater, aquifers have been divided into 'groundwater bodies' for the purposes of the WFD. There are 714 groundwater bodies in the UK: 304 in England and Wales, 343 in Scotland and 67 in Northern Ireland. The status of each groundwater body was assessed for the first time as part of the implementation of the WFD (**Table 9.5**). This comprised an assessment of the quantitative (flow rate) status and the chemical (water quality) status. It should be noted that groundwater status is based only on chemical quality, and not on biological quality as is applied to other water bodies. However, there is a biological test for groundwater-dependent terrestrial ecosystems under the WFD; and if the terrestrial ecosystem is not considered to be in good status, then neither is the aquifer.

For each assessment, a number of tests (four quantitative and five chemical) were applied to check whether the groundwater body was meeting the criteria for good status as set in the WFD. In addition, a review of environmentally significant trends in pollutant concentrations in groundwater was undertaken as there is a specific objective in the WFD



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EA and SEPA copyright for quality measures  
Kriging interpolation, Durance (Cardiff University 2010)

**Figure 9.17 Spatial patterns in nitrate concentrations of rivers across England, Wales and Scotland in 2006 and 2008.** Source: data from Environment Agency and SEPA and compiled by I. Durance (Cardiff University).



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EA and SEPA for WFD data 2008

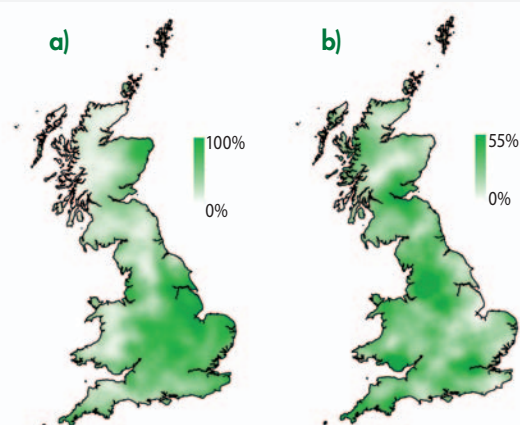
**Figure 9.18 Ecological status classes for rivers and river basins in England, Wales and Scotland as determined by the Environment Agency and Scottish Environment Protection Agency (SEPA) in 2008 for the purposes of the Water Framework Directive (WFD).** The classes reflect the most sensitive indicator element in each location relative to the prevailing risks. Source: data from Environment Agency and SEPA and compiled by I. Durance (Cardiff University).

**Table 9.5 Status of groundwater bodies across the UK.** Source: data derived from River Basement Management Plans produced by the Environment Agency, Northern Ireland Environment Agency and Natural Scotland.

Country	Overall Status		Chemical Status		Quantitative Status		Ground-water bodies with upward trend
	Good	Poor	Good	Poor	Good	Poor	
England & Wales	180	124	194	110	130	174	81
Northern Ireland	65	2	63	4	63	4	Not assessed
Scotland	271	72	318	25	259	84	Not assessed

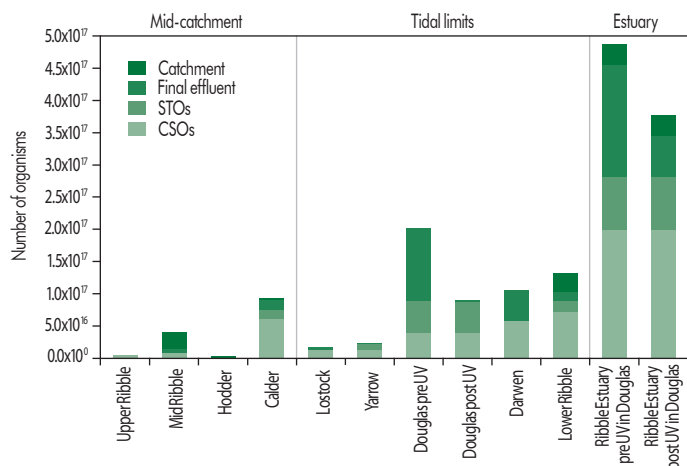
to reverse such trends. For this purpose, an environmentally significant trend was defined as one where concentrations are showing a statistically significant upward trend in pollutant concentrations and this trend has led/will lead to a failure of one or more environmental objectives.

The most significant cause of groundwater bodies not meeting the good quantitative status was the impact of groundwater abstraction on the flow of surface waters and groundwater-dependent terrestrial ecosystems. The largest



**Figure 9.19 The extent (percentage of channel length) of two major physical modifications to rivers: a) re-sectioning of the channel and b) reinforcement of the bed and/or banks.** Source: data derived from the Environment Agency baseline River Habitat Survey of England and Wales (2006 to 2008) and the Scottish Environment Protection Agency/Environment Agency baseline survey of Scotland (1995 to 1996). Both sets of data derive from randomly selected locations, stratified by 10 km grid squares. Data compiled by I. Vaughan (Cardiff University).





**Figure 9.20 Estimated high flow faecal coliform loads discharged to the Ribble Estuary and selected sub-catchments from diffuse catchment sources and sewage effluents.** Source: Stapleton *et al.* (2008). Copyright (2008), reproduced with permission from Elsevier.

contributors to a poor chemical status were failure to achieve drinking water protected area objectives and groundwater pollution contributing significantly to surface water bodies (rivers and lakes).

For the 81 groundwater bodies (27%) in England and Wales with environmentally significant upward trends, the main pollutant was agriculturally derived nitrate; this was followed by pesticides and industrial solvents. Due to the paucity of data, however, it is likely that the number of groundwater bodies with upwards trends in pollutant concentrations has been underestimated. Insufficient monitoring data were available in Scotland and Northern Ireland to undertake a trend assessment.

### 9.3.11 Fish Populations

Freshwater fish populations in Openwaters reflect natural habitat character as well as the effects of pollution, eutrophication, acidification, afforestation, channel engineering and exploitation, which have driven some stocks to local extinction (Maitland *et al.* 2007). Fragmentation, introgression from hatchery releases, climate change and the effects of exploitation at sea on Freshwaters are also issues (Ormerod 2003; Clews *et al.* 2010). Non-native species, such as Asian topmouth gudgeon (*Pseudorasbora parva*), are also a potentially growing threat to nature conservation value and some native fish (Britton *et al.* 2007). Stock movements threaten the stability or viability of local species; for example, the relatively recent extinction of vendace (*Coregonus albula*) in Bassenthwaite Lake, Cumbria, was largely due to the introduction of coarse fish species.

Native populations of fish that require clean water, such as Atlantic salmon, have reappeared or re-established and increased (though not necessarily bred) in formerly polluted rivers, such as the Thames, Clyde and Taff, commensurate with general improvements in water quality (e.g. Doughty *et al.* 2003; Evans *et al.* 2009). However, there are areas of concern. For example, the demographic structure of Atlantic salmon populations in many rivers suggests a shift from multiple sea-winter fish to one sea-winter fish

(known as grilse) because exploitation effects have been disproportionately large on those fish with longer lifecycles (e.g. Welton *et al.* 1999; Youngson *et al.* 2003). Additionally, rod catches have followed similar declining trends during recent years over geographically extensive areas from Scotland to Wales and the south-west of England (Figure 9.21), but the extent to which rod catches reflect population trends is still debated (e.g. Thorley *et al.* 2005; Hendry *et al.* 2007). Changes in marine temperature and survival and exploitation at sea are implicated, although diffuse effects in river catchments also appear to be involved because non-migrant salmonids have declined too (Figure 9.21). Climate is an emerging factor, with hot, dry summers apparently reducing juvenile populations of both brown trout and salmon (Clews *et al.* 2010).

Trends in populations of European eels (*Anguilla anguilla*) are now a cause for major concern. This is the most valuable commercial inland fishery in England and Wales, but declared catches of glass eel have fallen from 10–70 tonnes/yr in the 1970s and 1980s, to less than 1–2 tonnes/yr today. Declared catches for yellow and silver eels have fallen from 280 tonnes/yr in the mid-1990s to 28 tonnes/yr. Overall, glass eel recruitment in the western UK is now thought to be around 30% of what it was before 1980, while yellow and silver eel stocks are at 20% of their late 1980s levels (Aprahamian & Walker 2008). Adverse feeding conditions in the Sargasso Sea appear to have had large effects on recruitment (Friedland *et al.* 2007).

### 9.3.12 Lakes and Standing Waters

There are around 8,818 permanent large (>2 ha) lakes in the UK covering over 196,700 ha. The vast majority by number, volume and surface area are in Scotland, with English lakes being focused in Cumbria and Welsh lakes in Snowdonia and mid-Wales. In central and southern England, where natural lakes are rare, artificial reservoirs provide important standing water habitats. Many UK lakes are oligotrophic, although others, such as the Machair lochs of the Western Isles, are calcareous in nature. However, they do exhibit a very wide range of ecological diversity and have been classified in the UK into 11 distinct lake groups mainly based on their aquatic plant assemblages (Duigan *et al.* 2006; 2007). Together, these different lakes hold a range of important plant species, such as slender naiad (*Najas flexilis*) and Shetland pondweed (*Potamogeton rutilus*), as well as many algae; associated wetland flora includes locally distributed species such as Irish ladies' tresses (*Spiranthes romanzoffiana*) and marsh saxifrage (*Saxifraga hirculus*).

The nature conservation agencies in England, Scotland and Wales have surveyed over 3,400 lakes, but, with local exceptions like the Lake District, there has been very limited systematic monitoring of lakes in the UK. Even where monitoring has taken place, it has generally not been oriented towards the assessment of ecosystem services.

Trends in the UK's Openwaters are more difficult to appraise systematically, although many trends are consistent with river data. For example, at upland, acid-sensitive lake sites in the Acid Waters Monitoring Network, sulphate, hydrogen ion and aluminium concentrations have declined progressively over the last 20 years (Davies *et al.*



**Table 9.6 The ecological status of lakes in the UK under the terms of the Water Framework Directive (WFD).** Source: data derived from the Environment Agency, Northern Ireland Environment Agency and Natural Scotland.

Country	Number of lakes (>50 ha)	Proportion (%) achieving good ecological status or better
England & Wales*	762	36
Northern Ireland	22	33
Scotland	309	66

\* In England and Wales, there are 433 lakes of more than 50 hectares in size, most of which are reservoirs or excavated pits. The figure given here of 762 includes smaller water bodies where they are deemed to be of significance for conservation.

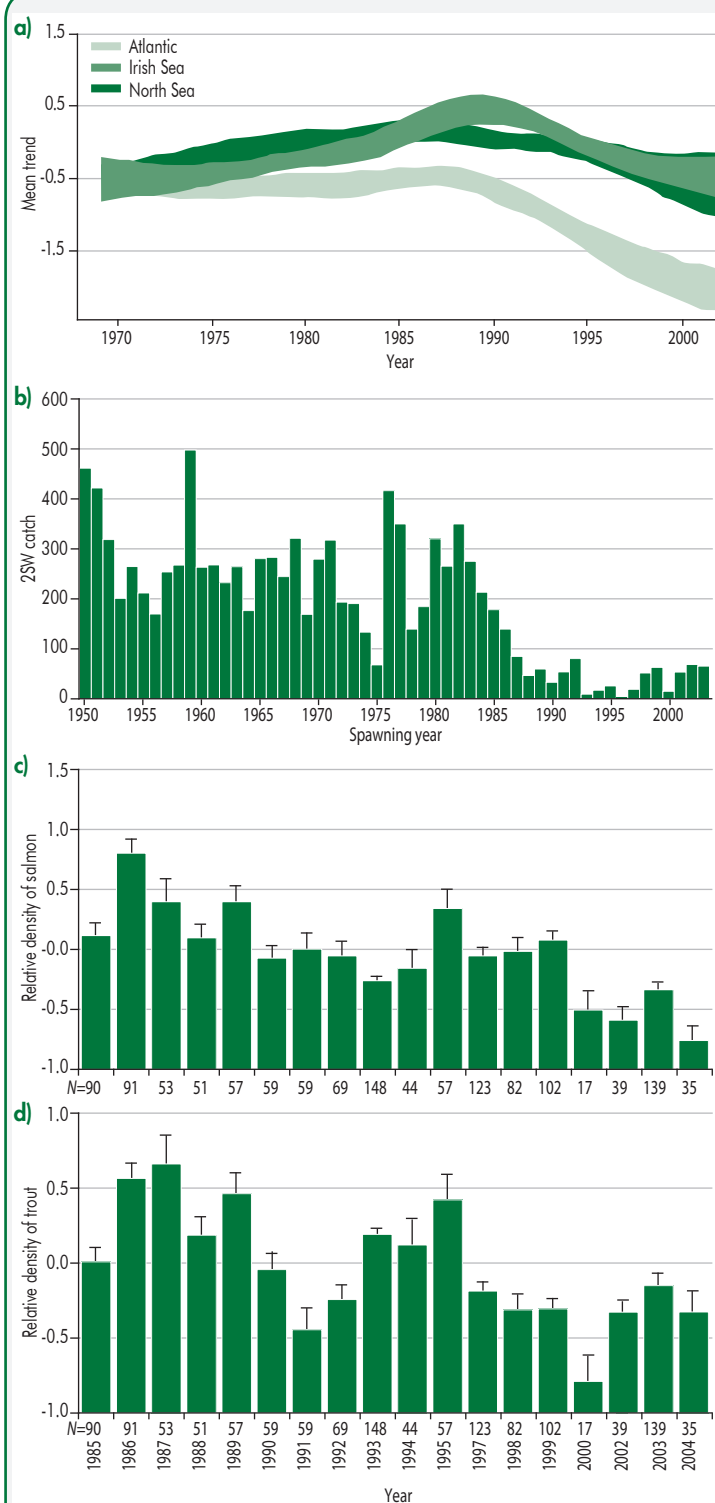
2005). Modest biological recovery among macrophytes and invertebrates is also now underway (Monteith *et al.* 2005). In contrast, but in keeping with trends in streams, DOC concentrations have increased which has consequences for water supply.

**Table 9.6** provides a summary of the overall ecological status of the UK's lakes as reported by the environmental agencies of England, Wales, Northern Ireland and Scotland. Currently, 66% of Scotland's 309 lochs reach good ecological status, while 36% of England and Wales' and 33% of Northern Ireland's lakes achieve the same status. This reflects the much higher proportion of reservoirs and excavated pits in the countries, and more widespread hydromorphological and water quality pressures. At Loch Leven, Kinross, nutrient loads have been controlled progressively by active catchment management. As a result, the ecological quality of the lake has improved. In particular, macrophytes have returned to deeper areas of the lake in response to increased water clarity, and this has resulted from the lowering of phosphorus inputs (**Figure 9.22**). Although macrophyte communities have not yet reached the lake's former condition, which included characteristic soft water species (Salgado *et al.* 2010), their overall abundance and species composition have improved considerably. This is an important sign of sustainable recovery, because macrophytes play a critical role in nutrient cycling, sediment stability and community composition across multiple trophic levels. The lake provides an important lesson on the requirements for restoring openwaters and the benefits that can be gained (D'Arcy *et al.* 2006).

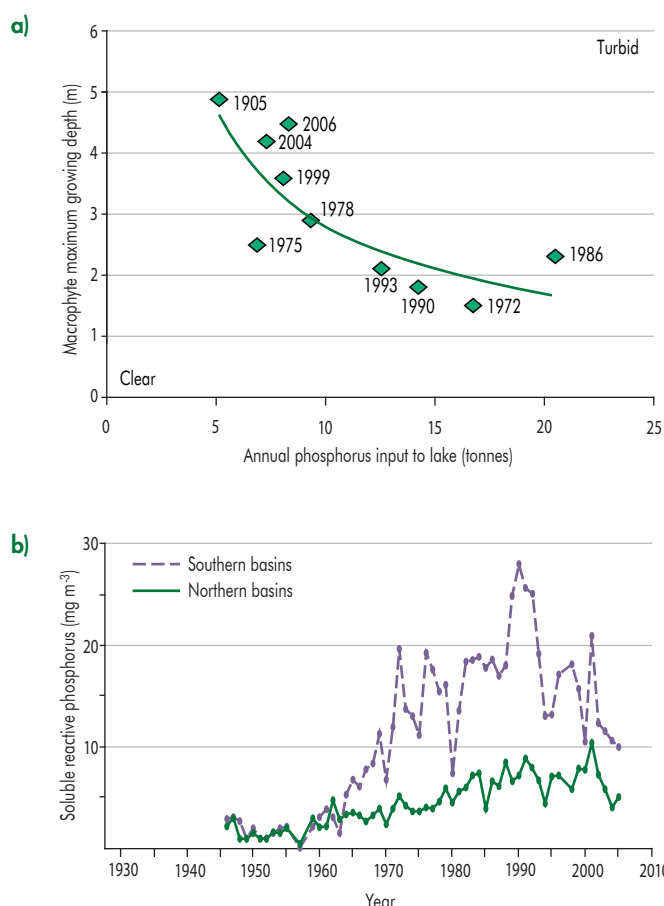
### 9.3.13 Status and Trends in Ponds

Ponds are defined as bodies of standing water 0.0025–2 ha in size and containing water for more than four months of the year. They have been counted in the Countryside Survey since 1984, and most recently in 2007. For the first time, however, the 2007 Countryside Survey also appraised pond physico-chemical condition and biological quality throughout GB, with trends also assessed in a lowland subset (Williams *et al.* 2010).

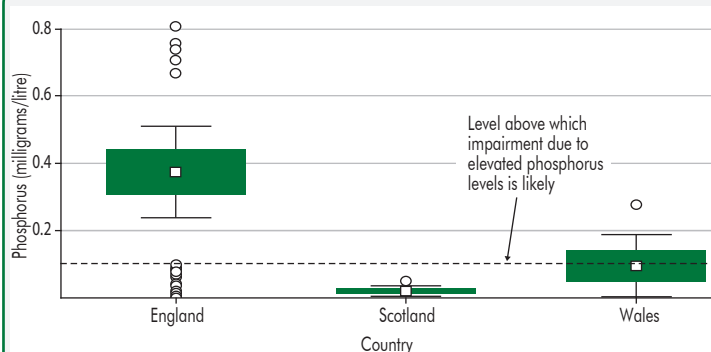
In 2007, there were around 478,000 ponds in GB at densities of roughly 1.8/km<sup>2</sup> (in England) to 250/km<sup>2</sup> (in



**Figure 9.21 Examples of recent trend data for salmonids in the UK:** **a)** Scottish rod catches (with 95% confidence envelopes) of Atlantic salmon (pale green line, Atlantic; medium green line, Irish Sea; darkest green line, North Sea). Source: Vøllestad *et al.* (2009). **b)** rod catches in May and June of Atlantic salmon in the River Avon Hampshire four years after the spawning year shown. Source: Solomon & Lightfoot (2007). Contains Environment Agency information © Environment Agency and database right. **c) & d)** standardised densities (± SE) of juvenile (> 0+) salmon and trout averaged across tributaries of the Welsh River Wye, from 1985 to 2004 (N indicates the number of rivers contributing to mean annual density in each year). Source: Clews *et al.* (2010). Copyright © 2010 Global Change Biology. Reproduced with permission of Blackwell Publishing Ltd.



**Figure 9.22 a) Maximum growing depth of macrophytes in relation to historical changes in phosphorus input to Loch Leven, Scotland, 1905 to 2006.** Source: May & Carvalho (2010). Reproduced with kind permission from Springer Science+Business Media. © Springer Science+Business Media B.V. 2010. **b) Mean concentrations of soluble reactive phosphorus during the first 4 weeks of the year for the north (closed symbols, continuous line) and south (open symbols, broken line) basins of Windermere from 1945 to 2005.** Source: Winfield *et al.* 2008. Reproduced with kind permission from Springer Science+Business Media. © Springer Science+Business Media B.V. 2008.



**Figure 9.23 Soluble reactive phosphorus in ponds across Great Britain in 2007.** All values are means with standard errors (green) and 95% CIs (lines). Source: reproduced from Williams *et al.* (2010). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

Scotland). Between 1998 and 2007, more ponds were created (almost 71,000) than were lost (18,000), so pond numbers in GB are probably now increasing by about 1.4% per year after sustaining losses up to and during the 1980s (**Table 9.7**).

The 2007 Countryside Survey Ponds Report (Williams *et al.* 2010) showed that Scottish ponds appeared to be in a better state than those in England and Wales (**Figure 9.23**). In these latter countries, ponds were often degraded (80% poor or very poor) and, on average, supported only a third of the expected total number of wetland plants and one fifth of the expected uncommon plants. Where trend data were available for lowland England and Wales, quality fell between 1996 and 2007 as plant species richness decreased by 20% and the proportion of poor or very poor quality ponds increased by 17%. Pollution by nutrients was probably a major cause of poor status and deterioration (**Figure 9.23**), this is of particular significance given the current increase of nitrate concentrations across England and Wales. Ponds on arable land or under shade from trees were also of lower quality, while climate variability was largely responsible for the increased tendency of ponds to dry out during more arid years. In contrast, ponds near or connected to other Wetlands fared better, while newly created ponds also appeared to be of better quality.

The protection of ponds in the UK appears to depend on the management of surrounding landscapes rather than specific statutes. The Habitats Directive (92/43/EEC) lists eight 'habitats of high conservation importance' that either partly or wholly include ponds, while a range of species listed on Annex II of this Directive are also pond species. However, except for incorporating ponds and ditches within larger designated areas, SACs created by the Directive mostly involve water bodies larger than the UK's typical pond area (generally <0.4 ha). The WFD overwhelmingly emphasises standing waters of more than 50 ha in size. By contrast, the UK BAP has now given specific emphasis to high quality ponds, with national targets and action plans for those that have conservation importance or particular ecological characteristics (Williams *et al.* 2010).

The current poor condition of the pond stock, and the scarcity of unpolluted freshwater throughout the landscape, is being partially addressed through the multi-partner Million Ponds Project, led by the NGO Pond Conservation. Phase 1 of the project (2008 to 2012) is creating 5,000 new clean water ponds in England and Wales, with 1,000 specifically targeted towards the 80 or so pond-associated UK BAP species. In the long-term, the aim is to double pond numbers over the next 50 years and reinstate clean water widely in the landscape. Specifically, the project is using the creation of new, clean water ponds as a tool for Freshwater biodiversity protection.

### 9.3.14 Status and Trends of Ditches

The Defra aquatic habitats study assessed the extent of ditch and stream habitats, and patterns in biological diversity. The Countryside Survey (2007) also assessed ditch quality to a limited extent (Carey *et al.* 2008). However, no systematic national data on ditch quality trends are available despite the fact that ditches are part of the condition assessment for specific Wetland SSSIs such as the Somerset Levels and Moors.

### 9.3.15 Invasive, Non-Native Species

Non-native species that become invasive and problematic are a growing issue in both running and standing Freshwaters (Strayer 2010). Examples include many groups of organisms in the riparian zones or shorelines of Freshwaters, as well as some beneath the water line. Adverse effects from the spread of such species have emerged rapidly in UK lakes and rivers over the last 20 to 30 years, some of which are outlined below for particular fishes and molluscs.

In England and Wales, at least 24 Freshwater fish species occur in lakes and rivers as a result of introduction, of which, 15 have established self-sustaining populations in at least one location. Among these, five long-standing introductions now occur in over 100 water bodies and have a high risk of further expansion; these are: common carp (*Cyprinus carpio*), European catfish (*Silurus glanis*), goldfish (*Carassius auratus*), ide (*Leuciscus idus*), European pikeperch (*Sander lucioperca*) and rainbow trout (*Oncorhynchus mykiss*). These and other more recent introductions could pose significant risks to ecological function, particularly if climate change progresses as expected. Among them, common carp is an interesting example as it is favoured by some anglers, but can have significant impacts on habitats, macrophyte communities, nutrient dynamics and turbidity where it is introduced (Britton *et al.* 2010a). Such instances illustrate tensions between the exploitation of some ecosystem services (such as for food, fisheries, sport or ornamentation) and other fundamental ecological processes in Freshwaters. Other effects of introduced fish include vectoring pathogens, competition with native species, impairing recruitment in native species, altering food web structure, and enhancing natural enemies that prey on scarce species (Britton *et al.* 2007, 2010b; Inger *et al.* 2010).

Few non-native species have such marked effects as the zebra mussel (*Dreissena polymorpha*). Initially recorded in the UK in the 19th Century, the incidence of this species in the UK has increased dramatically in lowland lakes and rivers across extensive areas since the 1980s. It has even recently been recorded in the Scottish canal system on the hull of a boat. On hard surfaces, zebra mussels can reach densities as high as 100,000/m<sup>3</sup>. The consequences of such invasions include: effects on oxygen dynamics, both through direct uptake and effects on primary producers; effects on turbidity, sediment and nutrient dynamics; and competition for resources with native species. In the newly formed Cardiff Bay, closed by impoundment in 2001, zebra mussel larvae have become one of the most abundant zooplanktonic organisms, settling in densities of 3,000–5,000/m<sup>2</sup> on all hard surfaces, including the Bay's aeration system (M. Alix unpublished thesis). At this site, zebra mussels also harbour large populations of the recently arrived invasive crustacean, *Dikrogammarus villosus*. There are also problems at water treatment installations, where they occlude flow, but, so far, there is no safe method of control other than physical removal (**Figure 9.24**).

The recent occurrence of the invasive, non-native gammarid shrimp (*Dikrogammarus villosus*) at Grafham water in Cambridgeshire, Cardiff Bay and one other Welsh site, illustrates the need for vigilance over the movement of such species, which often pose major risks for Wetland

**Table 9.7 Change in the estimated number of ponds ('000s) and pond density (per km<sup>2</sup>) across Great Britain between 1998 and 2007.** Arrows denote significant change ( $p < 0.05$ ) in the direction shown. Source: reproduced from Williams *et al.* (2010). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology. Williams *et al.* (2010).

	Density (per km <sup>2</sup> )		Number of ponds ('000s)		% change	Direction of significant changes 1998–2007
	1998 (95% CIs)	2007 (95% CIs)	1998 (95% CIs)	2007 (95% CIs)		
<b>GB</b>	1.86 (1.41, 2.54)	2.1 (1.64, 2.78)	425 (321, 580)	478 (374, 634)	12.5	↑
<b>England</b>	1.55 (1.30, 1.81)	1.83 (1.53, 2.14)	197 (165, 230)	234 (195, 272)	18.3	↑
<b>Scotland</b>	2.35 (1.25, 4.14)	2.48 (1.37, 4.30)	187 (100, 330)	198 (110, 344)	5.5	↑
<b>Wales</b>	1.91 (0.85, 3.31)	2.24 (1.23, 3.70)	40 (18, 70)	47 (26, 78)	16.9	↑

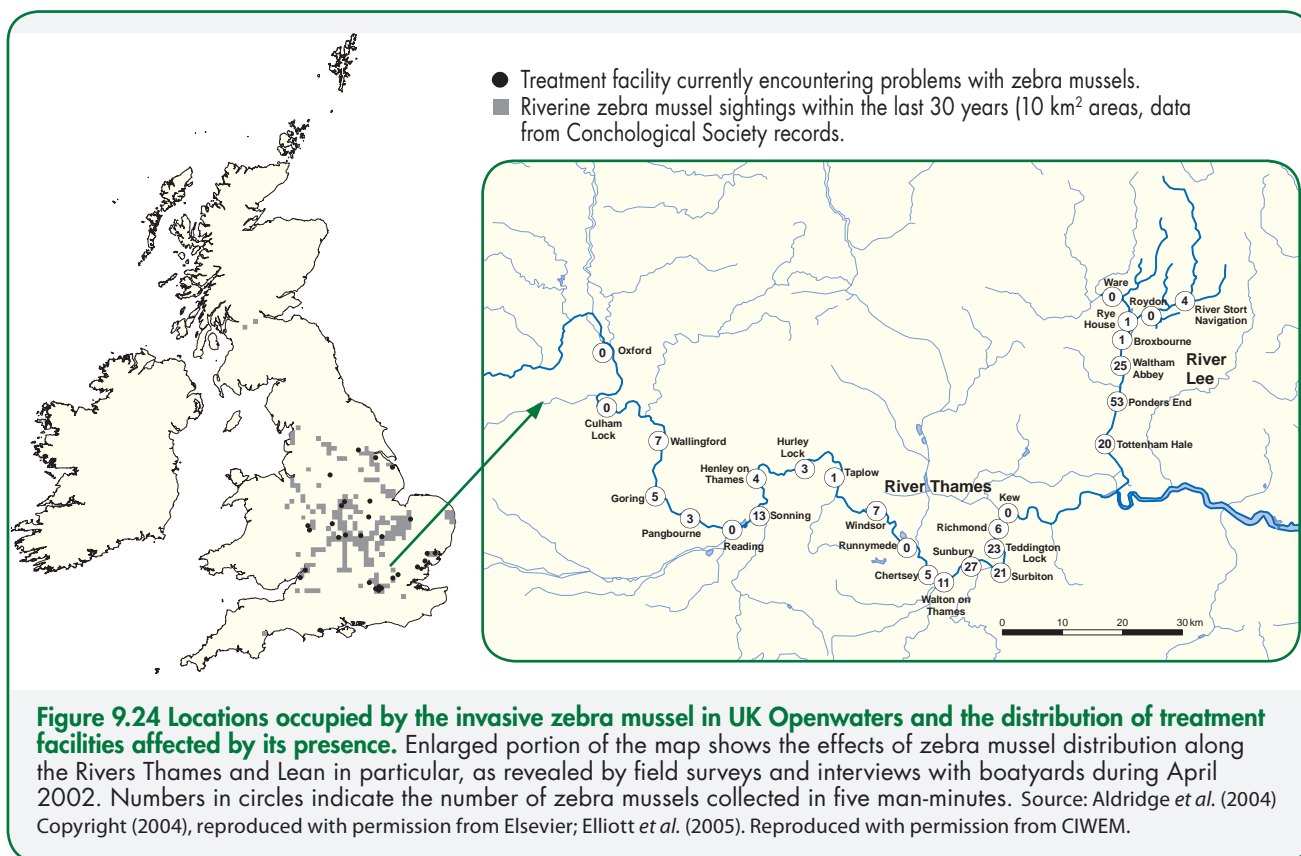
biodiversity, into and around the UK. The prevention of further spread of this species is reliant on voluntary cooperation between landowners and recreational water users (Natural England & Environment Agency 2010). There are expectations that similar problems will increase in future as environmental change progressively favours non-native species, but the consequences for ecosystem services have yet to be fully evaluated.

Other examples of the damaging effects of invasive, non-native species are already well-known, such of the impact of introduced crayfish species on the UK's native white-clawed crayfish (Freeman *et al.* 2010). The likely ecosystem service impacts of the introduced signal crayfish (*Pacifastacus leniusculus*) have been explored by Everard *et al.* (2010). There are also concerns about the risks of new arrivals, such as the potentially highly damaging ectoparasite of salmon, *Gyrodactylus salaris* (Johnsen & Jensen 1991; Peeler & Thrush 2009).

The spread of non-native plant species in, and alongside, watercourses has been due to supply by the horticultural industry and the increase in water gardening since the 1960s. Non-native aquatic species and their date of introduction into the UK include: New Zealand swamp stonecrop, *Crassula helmsii* (1911); parrot feather, *Myriophyllum aquaticum* (1964); water pennywort, *Hydrocotyle ranunculoides* (1989); and water primrose, *Ludwigia grandiflora* (1991). The particularly invasive Canadian pondweed (*Elodea canadensis*) was introduced into the UK towards the end of 19th Century. One of the earliest colonisations took place at Bosherton, Pembrokeshire, and is recorded in correspondence by Lord Cawdor who remarked that, prior to 1895, it was a favoured food for the large mute swan population (Duigan & Haycock 1995). Today, it is widespread in lowland lakes in Wales and can be found across the UK in streams, ditches and ponds, often choking the waters with its rapid growth.

Other species of concern are Himalayan balsam (*Impatiens glandulifera*), Japanese knotweed (*Fallopia japonica*) and giant hogweed (*Heracleum mantegazzianum*). Catchment-wide control programmes for giant hogweed in





the Tweed and the Medway have proved very successful in terms of the local eradication of this species. *Ad hoc* control programmes without coordinated action tend to be less successful as reintroduction from untreated areas in the same catchment often occurs.

Aquatic ecosystem function is usually impaired by the presence of non-native plant species with a high resource demand, resulting in the loss of native species by simple competition, loss of habitat space, and sometimes allelopathic interactions (the production of biochemicals by a species that either positively or negatively affect another species; e.g. New Zealand swamp stonecrop). The absence of suitable control techniques (e.g. loss of appropriate herbicides due to Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market) and the relatively high cost of mechanical and manual vegetation management in water means that control programmes are limited to areas where the expense of control costs can be justified against the economic use of water (such as income from recreation), or the flood defence risk from not controlling these species. This inevitably leads to the presence of these species in areas where control costs cannot be justified, resulting in a permanent pool for reintroduction to other areas. The recent introduction of biological control for Japanese knotweed could be a good model, both economically and effectively, to follow for other non-native weed species, provided sufficient risk assessment is undertaken.

### 9.3.16 Climate Change

Lakes, rivers and other wetlands are likely to be among the most sensitive of all habitats to climate change. Temperature and precipitation affect fundamental attributes of aquatic

systems, such as discharge, thermal regimes, stratification, oxygen and solute concentrations. In turn, these effects interact with existing pressures, such as acidification and eutrophication, while also having major consequences for Freshwater organisms that are predominantly cold-blooded (Moss *et al.* 2003; Wilby *et al.* 2006; Ormerod & Durance 2009). As in other parts of the world, temperatures in British Openwaters have increased by about 0.1°C per year over the last 25 years, although trends are winter-biased (Kaushal *et al.* 2010). Trends in discharge are more equivocal because interannual variations are already large (Wilby 2006). Nevertheless, either alone or in combination with natural interannual variations in discharge, temperature changes have already been sufficient to alter species composition in headwaters and alter the abundances of important organisms, including salmonids (Durance & Ormerod 2007; Clews *et al.* 2010). Evidence is also emerging regarding the effects of climate change on water quality (Whitehead *et al.* 2009; Orr *et al.* 2010).

Analysis of the impacts of climate change on Wetlands across Britain (Acreman *et al.* 2009b) suggests that reduced summer rainfall and increased summer evaporation will put stress on Wetland plant communities in late summer and autumn. Bigger impacts are likely to be seen in the south and east of Britain and will be greater on rain-fed Wetlands than on those dominated by river inflows and groundwater. The consequences for ecosystem services, such as water supply, fisheries and energy subsidies for associated ecosystems, have yet to be appraised.

Changes in river flow and in water chemistry associated with the impacts of climate change have been studied by SEPA. These studies provide evidence of major increases in winter peak flows in many rivers since 1961, especially in the

west (SEPA 2006). They also show greater flow variability, although less impact has been observed on summer flows.

### 9.3.17 Wetland Extent

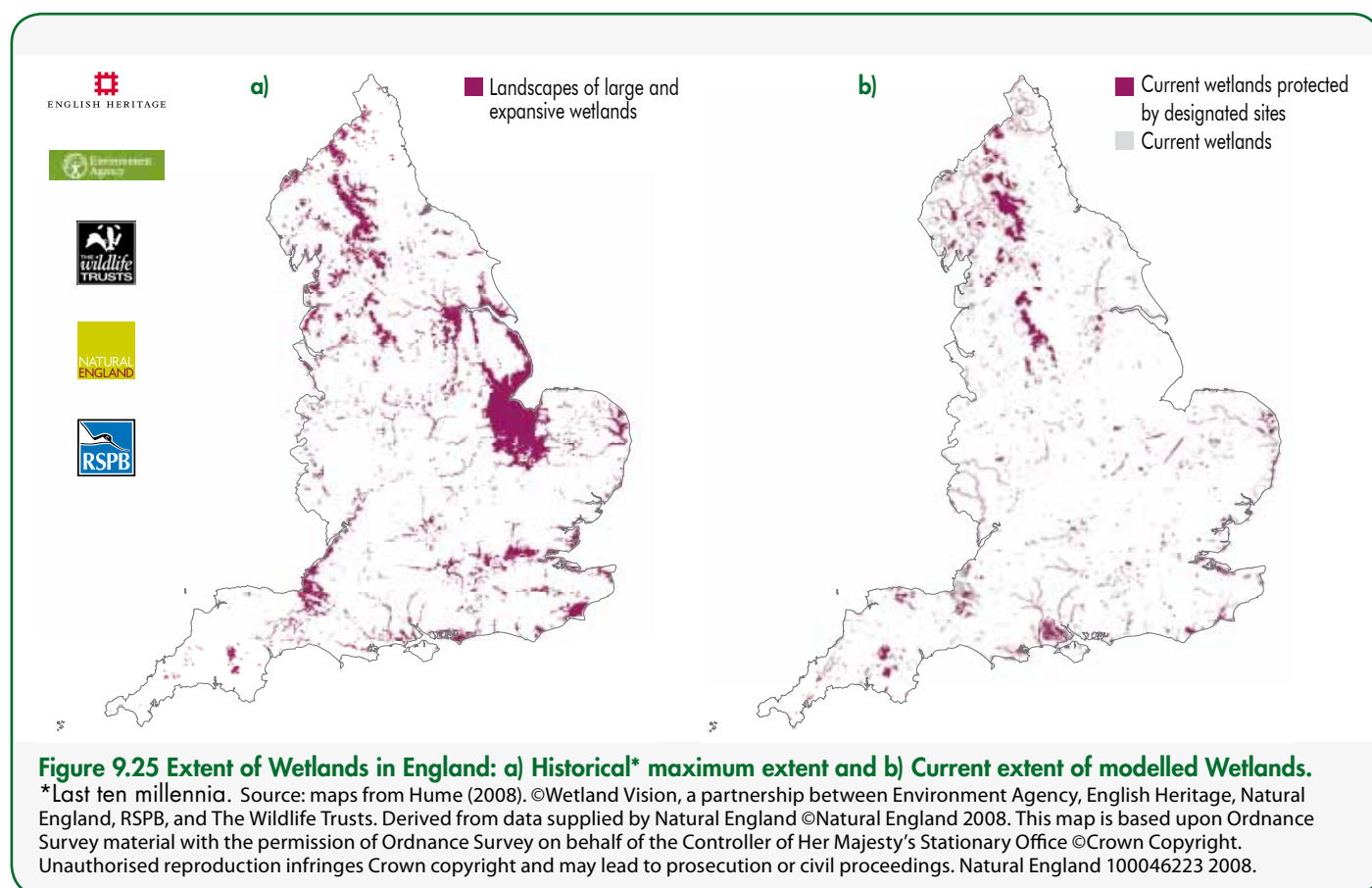
Precise figures for the current extent of the UK's Wetlands are difficult to calculate. According to Natural England's State of the Natural Environment Report (2009), there are an estimated 273,600 ha of coastal and floodplain grazing marsh, fen, lowland raised bog and reedbed in England, making up approximately 2% of England's land area. The majority of this is coastal and floodplain grazing marsh (**Figure 9.25**).

The importance of Wetland habitats is reflected in the fact that they comprise a large proportion of SSSIs in England. Despite this, only 26% of the Wetlands we are considering here are afforded protection by this designation. And while the majority of fen, lowland raised bog and reedbed are designated as SSSIs, only 16% of the coastal and floodplain grazing marsh has been notified (**Table 9.8**). For SSSIs in England, 81% of lowland raised bogs, 87% of fen, marsh and swamp, and 89% of lowland neutral grasslands are in favourable or recovering condition (by area) (statistics provided by Natural England, October 2010). A sample survey of undesignated coastal and floodplain grazing marsh estimated that a similar amount of land (approximately 80%) was in good condition (Dutt 2004). Approximately two-thirds of undesignated fens were not in favourable condition, largely as a result of scrub development, drainage and nutrient enrichment (NWT 2006). It is, therefore, thought that non-statutory Wetlands are generally more likely to be in a poorer condition than SSSIs.

Blanket bog is the most extensive mire habitat in Wales (56,000 ha) and is mainly found in the uplands, although there are significant examples in the lowlands of Gwynedd, Ceredigion and Pembrokeshire (Jones 2009). The relatively small area of lowland blanket bog (1,700 ha) is thought to be a reflection of historic modification and degradation, with current areas of acidic, marshy grassland and wet heath representing former blanket bog. In contrast to the extensive nature of blanket bog, lowland raised bog is confined to just twenty or so scattered sites, including Cors Caron and Cors Fochno, both in mid-Wales. Soligenous (rainwater-fed) fen is widespread and most abundant in the Welsh uplands, while topogeneous (groundwater-fed) fen has a more western

**Table 9.8 Wetland Site of Special Scientific Interest (SSSI) designations in England.** Source: Natural England (2009).

Wetland habitat	Total resource (hectares)	Area designated SSSI (hectares)	% resources notified
Coastal & floodplain grazing marsh	235,046	37,288	16
Fen	21,927	19,515	89
Lowland raised bog	10,227	8,949	88
Reedbed	6,378	5,388	85
<b>Total</b>	<b>273,578</b>	<b>71,140</b>	<b>26</b>



lowland distribution; Anglesey is a stronghold for calcareous-rich fen in Wales. Swamp habitat is widespread in Wales (about 1,800 ha in total), but occurs most frequently and extensively along the coast, where reedbeds (about 460 ha) are concentrated (Tyler 1993). The lowland bog inventory of Britain (Lindsay & Immirzi 1996) estimates that the original extent of Welsh lowland bog was around 4,000 ha, but only 1,840 ha have been mapped as such in the more recent field survey of the habitats of Wales (Blackstock *et al.* 2009). The lost Wetland area is concealed by heavily drained, low-lying grassland, with a significant proportion adjacent to extant raised bog near to the Dyfi Estuary. A similar scenario of loss is described for fen habitat: the Welsh Lowland Peatland Survey (Ratcliffe & Hattey 1982) identified 646 probable lowland wetland sites from their analysis of 1,910 maps, but only 289 supported Wetlands in 1978.

Floodplains do not constitute a single habitat type, but may be composed of wet woodland, wet grassland or other habitats, and is, in many cases, a mosaic of habitat types. The River Habitat Survey includes an assessment of Floodplains along with the river channel itself. The data show that, of the UK Floodplains surveyed, around a third are rough pasture and a third improved grassland, with tall herbs (24%), woodland (23%) and scrub (11%) being the next most widespread types (**Table 9.9**). Few Floodplains are reported to have typical Wetland special interest features, with only 0.3% having Openwater (at the time of the survey), 2% having water meadows and 2% supporting fen vegetation.

Statutory agencies, such as Natural England, Scottish Natural Heritage and the Department of the Environment Northern Ireland, compile statistics about Freshwater habitats. However, many statistics are derived for broad habitats, within which, certain Wetlands form a subclass; for example, grazing marsh is included within 'improved grassland' and wet woodland within 'broadleaved mixed and yew woodland'. **Table 9.10** provides a summary of data on Wetland extent from various sources. Estimates vary; for example, the extent of wet woodland is around 50–75,000 ha, while reedbeds cover 6–8,000 ha and grazing marsh 230–300,000 ha. England currently has about 500 ha of intact lowland raised bog, Scotland 2,500 ha, Wales 800 ha and Northern Ireland 2,000 ha. England has about two-thirds of the total area of grazing marsh. The area given for fen in England is likely to be an overestimate since the total habitat area includes other habitats (openwater, woodland habitat) comprising the mosaic within which the fen sits.

In 1996, the Institute of Hydrology calculated the total area of Floodplain land inundated on average once every 100 years. However, the resulting figure of 1,068,000 ha was an estimate of natural Floodplain extent as it did not include any embankments that might separate rivers from their Floodplains. The Environment Agency's ongoing National Flood Risk Assessment includes two datasets related to the 100-year flood zone. The first includes undefended areas (without embankments) and is 963,700 ha, thus defining the actual area of inundated land. The second is a total of both defended and undefended areas and equals 1,658,000 ha. The difference between the two figures provides an estimate of the Floodplain area lost by flood defence embankments. This equates to 694,000 ha or 42% of the former Floodplain extent.

Some idea of the original extent of land naturally and originally affected by waterlogging can be obtained by interpretation of published soil maps. Floodplains associated with alluvial soils occupy long, narrow strips in valley bottoms, most commonly along stream order 4<sup>2</sup> or higher. These sites have been maintained by high groundwater levels, augmented from time to time by periods of flooding from river channels. Unfortunately, soil maps are published at a scale unlikely to show the full extent of these sites. Even at 1:25,000 scale (Harrod 1978), alluvial soils can only be depicted to about a 50 m width margin due to cartographic limitations.

Thus, defining the extent of Wetlands is partly a scale issue, because we lack a systematic inventory. At a national scale, Wetlands can be interpreted from broad soil type, topography and catchment hydrology (flood maps) as was achieved for the Wetland Vision for England (Hume 2008). However, at a local scale, micro-topography, specific soil characteristics and drainage history control precise Wetland extent.

### 9.3.18 Wetland Condition and Trends

Wetlands are very sensitive to subtle changes in water supply and quality, including acidity, nutrient levels and water table fluctuations (Wheeler & Shaw 2001); they range in acidity from acid (often rain-fed) to base-rich (fed by a chalk aquifer). The requirements of many Wetland plant

**Table 9.9 Characteristics of Floodplains in the UK from River Habitat Survey (RHS) data.** Figures are expressed as a percentage (%) of 1,705 river sites surveyed where the feature is present on at least a third of the right or left bank. Source: Compiled for the UK NEA by the Environment Agency from raw RHS data.

Survey categories	Physical or botanical classes	% site
Banktop land use within 50 m of banktop	Broadleaf/mixed woodland	23.2
	Moorland/heath	9.0
	Scrub	11.3
	Tall herbs	23.7
	Rough pasture	35.9
	Improved grassland	36.0
	Wetland	4.2
Bank profile	Embankments	13.1
	Set-back embankments	6.2
Special interest features of the floodplain	Natural open water	0.3
	Water meadow	0.2
	Fen	0.2
	Bog	0.1
	Carr	0.0
	Marsh	1.0

2 Stream order is a numerical measure of the branching structure of a river network. At a river's source, the stream has order 1. When two order 1 streams come together, they form an order 2 stream and so on.



**Table 9.10 Extent of UK Wetlands.** Source: \*Natural England 2009; †2008 UK BAP Biodiversity Action Reporting System (BARS 2011); ‡UK BAP priority habitat descriptions; §Hume (2008); ¶Carey *et al.* (2008); \*\*Dutt (2004).

Component habitats	Countryside Survey ('000 ha)§		Priority habitats	UK Historical ('000 ha)	UK Current ('000 ha)	In semi-natural condition ('000 ha)	Trend†
	2007	1990–2007 % change					
Broadleaved mixed/yew woodland			Wet woodland		50–70‡ 62§ (1998) 75§ (2007)		
Semi-natural grassland			Lowland meadow	6,600‡	200‡ (1984)	15‡	
Improved grassland			Grazing marsh	1,200¶ (England)	231‡ 300‡ (England 235*)	7 (England**)	No clear trend
Fen, marsh, swamp	392	-0.2	Reedbeds	10¶	7.8‡ 5‡ 6‡ (England 6.4*)		Declining slowly
			Fen	310¶ (England)	25.8‡ (England 21.9*)		
Bog	2,232	8.4	Blanket bog		1,234		
			Lowland raised bog	95‡ 37¶ (England)	37.1‡ (England 17.4, Northern Ireland 8.9, Scotland 8.9, Wales 2.0)	12.9‡ (England 3.7, Northern Ireland 4.5, Scotland 3.3, Wales 1.4)	Fluctuating (probably declining)

communities have been defined along these gradients (Wheeler *et al.* 2002, 2004; **Figure 9.26**).

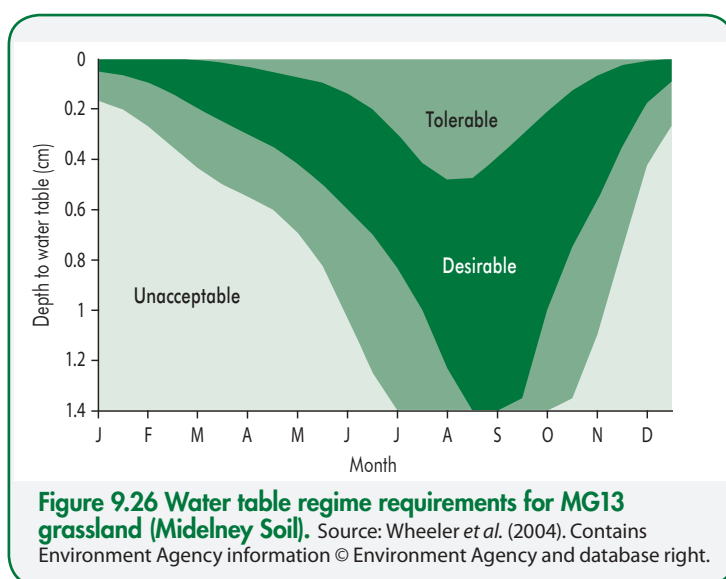
These distinctions and effects are important as the level of the water table at different times of year determines the viability of different Wetland functions. For example, **Figure 9.26** shows the water table requirements for a mesotrophic wet grassland vegetation community in NVC category MG13. Water levels in the dark green zone are desirable for this community, water levels in the mid-green zone are tolerable for short periods, but water levels in the light green zone are unacceptable and will lead to the loss of this community.

For most natural and semi-natural UK Wetlands, water tables are above, at or near the land surface during the winter, frequently falling to 40–80 cm in the summer, except where there is emerging groundwater. The seasonal water regime provides a cycle of multiple benefits including wildlife habitat, traditional summer grazing and hay-making. **Figure 9.27** shows the seasonal water table requirements for conservation objectives in the Parrett catchment in Somerset, which would provide a compatible mixture of habitat and agricultural opportunities. If the water table is altered, for example, to enable agricultural use throughout the year, this will be incompatible with some ecosystem services; for instance, it may be too dry in winter for waterbirds and too wet in summer for flood meadow plant communities.

It is even more difficult to estimate the changes in Wetland extent. Various estimates suggest that as much as 90% of the national resource of Wetlands has been lost since Roman times, with 13% of the Floodplain resource degraded or completely disconnected from river channels. In the case of lowland raised bog, the area retaining a largely undisturbed surface has declined by 94% (**Table 9.10**). This national trend is mirrored globally: more than 50% of specific types of Wetlands in parts of North America, Europe, Australia and New Zealand were destroyed during the 20th Century,

and many others in many other parts of the world have been degraded. **Table 9.10** suggests that lowland meadows have declined in the UK from 6,600,000 ha to 200,000 ha, and fens have declined from 310,000 ha to 26,000 ha. On the other hand, reedbeds have only declined from 10,000 ha to 6–8,000 ha as a result of recent restoration efforts; Countryside Survey data from a sample of 591 1x1 km squares, show a small decrease in reedbeds since 1990 (Haines-Young *et al.* 2000). A comprehensive assessment (Hume 2008) has been made of the theoretical historical extent of Wetlands (**Figure 9.25a**) and the current extent (**Figure 9.25b**) in England.

The areal extent of Wetlands is only part of the story since the delivery of their ecosystem services depends on their ecological condition and actual location in the landscape. For designated sites (SSSIs, SPAs, SACs), the statutory authorities maintain information on condition and status, although this is generally not in a form directly



related to ecosystem services. Much more technical data are required for this purpose, which have yet to be collated and applied (Maltby 2009a). Furthermore, we only have limited distributional information for those Wetlands that have been legally designated, and no, or very little, information on undesignated sites; however, most Local Records Centres have some electronic data, and Natural England is currently improving the Wetland habitat inventories. These updated inventories will provide more comprehensive information on the distribution and extent of different Wetland types, and will also provide a baseline from which to monitor changes in the condition of the wider Wetland resource.

Plant species within Wetlands provide one measure of condition; the strongest changes in species recorded by the Countryside Survey between 1990 and 2007 are shown in **Table 9.11** (increases and decreases), together with implications for ecosystem services. In general, UK lowland wetlands are quite small, so are not necessarily well represented by the sampling of 591 grid squares. Although a few species may display trends as a result of altered precision in taxonomic recording, for the majority of species, trends will reflect changes in the habitats that are being monitored. When all the individual trends reported above are assessed together, general trends in Wetland habitats seem to reflect:

- Higher nutrient levels, with a general increase in nutrient-loving plants and a related decline in species requiring nutrient-poor situations.
- A coarsening of the vegetation due to the general eutrophication of the habitats, with lower-growing species declining, especially those which prefer nutrient-poor conditions.
- Increased atmospheric deposition of nitrogen, making soils both more fertile and more acid.

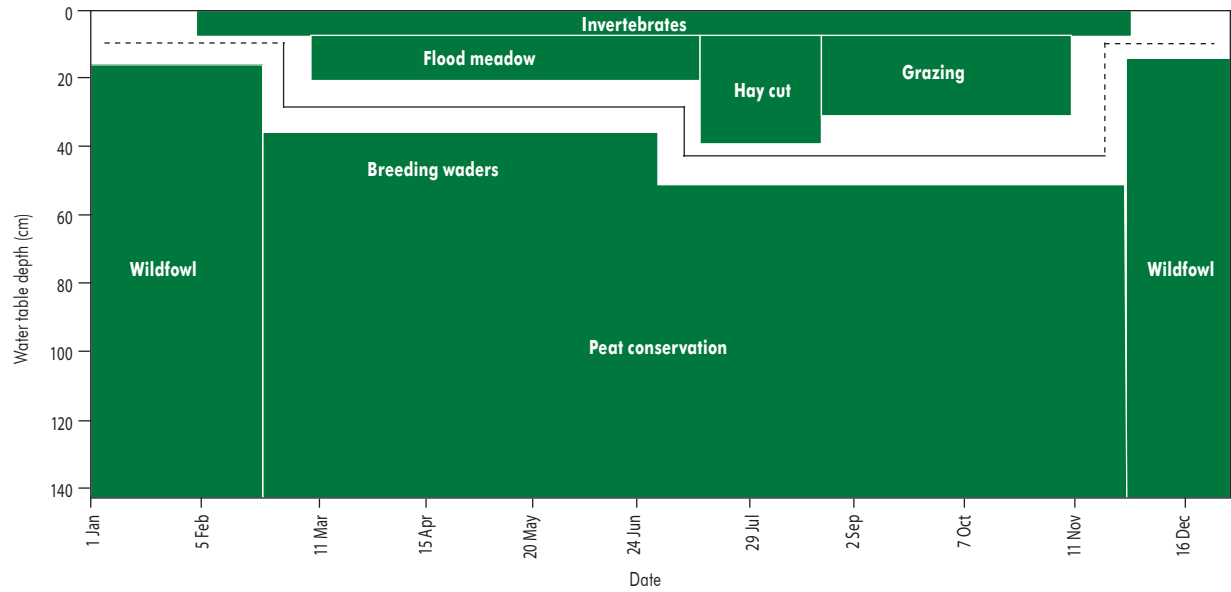
- An expansion of alder and willow, reflecting the abandonment/lack of cutting or grazing (as sites no longer fit within conventional agricultural systems), increased planting, or more accurate recording of species.
- Altered grazing pressure in parts of the UK—reduced grazing pressure is indexed by a decline in common yellow sedge (*Carex viridula*) and red fescue (*Festuca rubra*), and an increase in creeping willow (*Salix repens*).
- Localised effects, with species such as heath rush (*Juncus squarrosus*) and deer-grass (*Trichophorum cespitosum* agg.) declining in the lowlands, as (wet) heaths and bogs have been drained, enriched or abandoned, but increasing their range in the uplands.
- A large increase in vigorous coarse sedges in Floodplain meadows as a result of increased inundation.

While Scotland, like England, has seen decreases in the extent of important Wetland species and habitats, there are still examples of large areas of key habitats such as the 410 ha of the inner Tay reedbeds (6% of the UK total), and the Insh marshes (300 ha of base-poor fen in the floodplain of the River Spey), as well as concentrations of internationally important smaller fens in the Borders (Magee & Badenoch 2010).

Major restoration and creation efforts have been focused on reedbeds in order to create habitat for rare birds such as bittern and bearded tit (*Panurus biarmicus*). For example, the RSPB has created 190 ha of reed at Ham Wall in Somerset in worked-out peat diggings and 300 ha at Lakenheath in Norfolk on previously arable farmland.

### 9.3.19 Trends in Bird Populations

A further indicator of Wetland condition is provided by the revised 'Water and Wetland Birds Indicator' for different



**Figure 9.27 Water table requirements for environmental characteristics in the Parrett catchment.** The shaded zones represent ranges of water table depth which could potentially be detrimental to the named interest. The uncoloured zone represents an optimal soil-water regime to integrate the requirements of all the objectives at a site. Source: Morris *et al.* (2008a). Copyright (2008), reproduced with permission from Elsevier.

habitat types (Smithers *et al.* 2008). Overall, the index comprises an 'All Freshwater Habitats Indicator' covering 26 birds (of which, four are generalists within the wetland environment), backed up by separate indicators for 'Fast-flowing Waters' (four species), 'Slow/standing Waters' (six species), 'Reed Beds' (four species) and 'Wet Meadows' (eight species).

It should be stressed that these indicators do not necessarily provide good information on Wetland habitats and condition in the UK, as the majority of Wetland bird species are migratory and their population levels can be heavily influenced by external factors (Noble *et al.* 2008). For example, the extent and quality of the summer breeding grounds for many waterfowl (often in the Arctic) will influence annual productivity; similarly, the habitat condition of key migration routes will influence survival. The generally more stable All Freshwater Habitats Indicator masks considerable variability among the species making up the indicator. For example, the Fast-moving Waters index has fluctuated at levels about 20% below the 1975 baseline. Despite an initial increase, the Wet Meadows index has shown a marked and steady decline since the early 1980s. The birds of Reed Beds declined from 1975 through to the 1990s, and then increased almost back to the 1975 index (perhaps due to targeted habitat creation work). The trend for birds of Slow/standing Waters has increased to almost double its 1975 baseline.

Migratory Wetland birds, such as yellow wagtail (*Motacilla flava*) and reed and sedge warblers (*Acrocephalus scirpaceus* and *Acrocephalus schoenobaenus*), are affected by factors beyond the UK. Increasing effects of climate change will also influence the future trend of the Index, and an increase in the distribution of several relatively recent arrivals has already been noted (e.g. little egret, *Egretta garzetta*, Cetti's warbler, *Cettia cetti*).

In terms of breeding birds, redshank (*Tringa totanus*), snipe (*Gallinago gallinago*), curlew (*Numenius arquata*) and lapwing (*Vanellus vanellus*) are the most relevant for determining the condition of lowland Wetlands due to their dependence on this habitat, although these species also breed in coastal, upland and arable locations. Breeding populations for all UK Wetland birds have declined since 1982, with increasing severity in recent years (Table 9.12). This decline is consistent with estimates of breeding pairs of waders for wet meadows in England and Wales. Many of these species are now concentrated on just a few sites in lowland England, most of which are managed as nature reserves.

The recent decline in redshank numbers has been related to the drainage of farmland (Gibbons *et al.* 1993). Lowland breeding snipe numbers have also declined, with most of the remaining birds becoming highly aggregated on a very small number of nature reserves. Lapwings have also decreased in number, possibly because changes in agricultural practice

**Table 9.11 Changes in plant species between 1990 and 2007.** Source: derived from results of the Countryside Survey.

Habitat type	Wetland species increasing	Wetland species declining	Possible implications
General	<i>Alnus glutinosa</i> (Alder); <i>Calystegia sepium</i> (Great Bindweed); <i>Epilobium parviflorum</i> (Hoary Willow-herb); <i>Salix cinerea</i> (Grey Willow)	<i>Alopecurus pratensis</i> (Meadow Foxtail); <i>Carex dioica</i> (Dioecious Sedge); <i>Carex pallescens</i> (Pale Sedge); <i>Drosera anglica</i> (Great Sundew); <i>Glyceria fluitans</i> (Floating Sweet-grass); <i>Juncus bulbosus</i> (Bulbous Rush); <i>Pinguicula vulgaris</i> (Common Butterwort); <i>Myosotis scorpioides</i> (Water Forget-me-not); <i>Salix aurita</i> (Eared Willow); <i>Valeriana dioica</i> (Marsh Valerian)	More nutrient-rich Wetlands  Some changes may reflect mechanical disturbance to Wetlands, including planting or abandonment/lack of cutting or grazing as sites no longer fit within conventional agricultural systems.
Neutral grasslands	<i>Cirsium palustre</i> (Marsh Thistle); <i>Glyceria fluitans</i> (Floating Sweet-grass); <i>Juncus bulbosus</i> (Bulbous Rush); <i>Molinia caerulea</i> (Purple Moor-grass); <i>Ranunculus acris</i> (Meadow Buttercup)	<i>Alopecurus geniculatus</i> (Marsh Foxtail); <i>Leontodon (Scorzoneroideis) autumnalis</i> (Autumnal Hawkbit)	More nutrient-rich Wetlands that are coarser (greater productivity), including some evidence of increased atmospheric deposition of nitrogen resulting in elevated nutrient levels and some soil acidification.
Acid grasslands	<i>Eriophorum angustifolium</i> (Common Cotton-grass); <i>Juncus squarrosus</i> (Heath Rush); <i>Trichophorum cespitosum</i> (Deergrass)	<i>Carex nigra</i> (Common Sedge); <i>Carex pulicaris</i> (Flea Sedge); <i>Carex viridula</i> (Yellow Sedge); <i>Luzula campestris/multiflora</i> (Woodrushes); <i>Juncus bulbosus</i> (Bulbous Rush)	More nutrient-rich Wetlands that are coarser (greater productivity), including some evidence of increase atmospheric deposition of nitrogen resulting in elevated nutrient levels and some soil acidification.
Woodland	<i>Cirsium palustre</i> (Marsh Thistle); <i>Rumex conglomeratus</i> (Clustered Dock)	<i>Agrostis stolonifera</i> (Creeping Bent); <i>Luzula campestris/multiflora</i> ; (Woodrushes)	More nutrient-rich Wetlands with coarser growth.
Dwarf shrub heaths	<i>Carex binervis</i> (Green-ribbed Sedge); <i>Carex echinata</i> (Star Sedge); <i>Juncus effusus</i> (Soft Rush); <i>Salix repens</i> (Creeping Willow)	<i>Carex nigra</i> (Common Sedge); <i>Carex flacca</i> (Glaucous Sedge); <i>Carex viridula</i> (Yellow Sedge); <i>Festuca rubra</i> (Red Fescue)	Further acidification of the Wetland soil, together with some increased fertility.
Bogs	<i>Agrostis canina</i> (Velvet Bent); <i>Epilobium palustre</i> (Marsh Willow Herb); <i>Rhynchospora alba</i> (White Beak-Sedge); <i>Salix repens</i> (Creeping Willow)	<i>Agrostis stolonifera</i> (Creeping Bent); <i>Drosera intermedia</i> (Oblong-leaved Sundew); <i>Festuca rubra</i> (Red Fescue); <i>Triglochin palustre</i> (Common Arrow-grass)	Further acidification of the Wetland soil (possibly with some increased fertility).



**Table 9.12 Trends in breeding populations of selected Wetland birds.** Source: \*BTO (2009a); †Wilson *et al.* (2005); ‡Henderson *et al.* (2002).

	All habitats UK*			All habitats England*		Wet meadows England and Wales†	Northern Ireland All habitats‡
	1982–2007	1997–2007	2002–2007	1982–2007	1997–2007	1982–2002	1985–1999
Redshank	-54%	-41%	-27%			-29%	
Curlew	-11%	-31%	-21%			-39%	-60%
Lapwing	-38%	-29%	-21%	-42%	+12%	-36%	-50%
Snipe						-62%	-30%

have led to their breeding productivity dropping below a sustainable level (Galbraith 1988; Hudson *et al.* 1994; Siriwardena *et al.* 2000a; Besbeas *et al.* 2002; Milsom 2005); however, lapwing data for England do show an increase in numbers between 1997 and 2007.

In winter, the UK holds internationally important populations of swans, geese, ducks and wading birds. The Wintering Waterbird Indicator (**Figure 9.28**) shows that numbers rose steadily from the mid-1970s to the late 1990s, stabilised in 2000, but have declined in recent winters (BTO 2009b). Trends in recent colonists due to climate change are evident: breeding by little egrets, for example, was first confirmed in 1996 and, by 2006, there were 600 pairs. Targeted conservation efforts have also had an effect on bird populations and have, for example, led to a rise in the number of bittern from 19 males (heard booming) in 1999 to 75 in 2008.

Development work on Scottish wintering waterbird indicators (by the British Trust for Ornithology for Scottish Natural Heritage) determined that 1975/1976 provided the most reliable baseline for trend analyses (Austin *et al.* 2007). In contrast to England, the overall index has shown no decline up to the end of 2008, but this masks a persisting decrease in wader numbers which is counterbalanced by large increases in most geese species. Scotland is particularly important for wintering geese, most of which have shown marked increases since the mid-1970s. The population of native Greylag geese has also increased. Of the other waterfowl, whooper (*Cygnus Cygnus*) and mute swans, teal (*Anas*

*crecca*), widgeon (*Anas penelope*) and pintail (*Anas acuta*) have all increased, whereas mallard (*Anas platyrhynchos*), shelduck (*Tadorna tadorna*), pochard (*Aythya farina*) and goosander (*Mergus merganser*) are among those that have declined. The dipper (*Cinclus cinclus*) can be considered an iconic Welsh riverine bird, but the population has declined due to acidification (Lovegrove *et al.* 2009).

### 9.3.20 Land Ownership

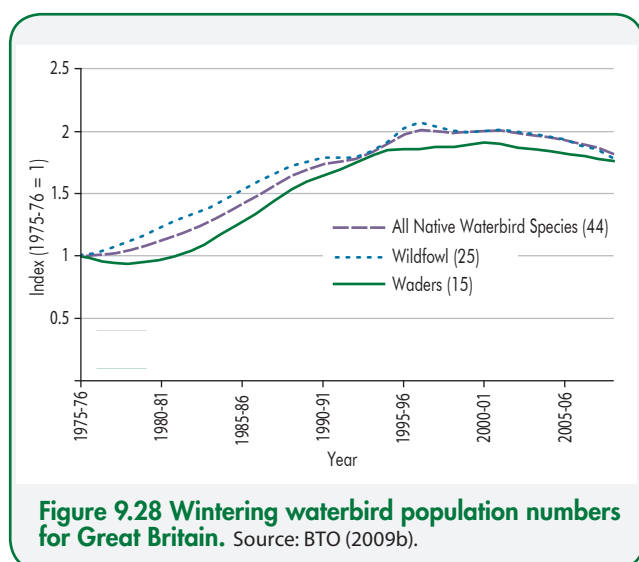
An additional broad-scale assessment of the condition of, and land management objectives for, Wetlands can be made by analysing ownership. Traditionally, many of the UK's Wetlands were owned or rented by farmers as part of their wider landholding with the aim to maximise their food production function. However, increasingly, land has been acquired by local authorities and NGOs such as The Wildlife Trusts, Wildfowl & Wetlands Trust, The National Trust and the RSPB. These organisations tend to focus on the biodiversity and recreation services of Wetlands. For example, parts of the Floodplain of the Thames between Oxford and Reading are owned by South Oxfordshire District Council. From 2004 to 2009, Wetland land purchases made by the RSPB equalled 4,200 ha in England, 2,345 ha in Scotland, 247 ha in Wales and 45 ha in Northern Ireland for bird reserves.

### 9.3.21 Environmental Archaeology

Van de Noort (2001) determined the rate of Wetland heritage loss for England between 1950 and 2000 in three broad Wetland types: upland wetlands (predominantly blanket mires), lowland peatlands, and lowland alleviated wetlands. They concluded that the peatlands had suffered the most in the second half of the 20th Century, especially the upland peats, and that up to 50% of the archaeological sites that existed in these areas in 1950 were lost by 2000; the rate of loss of heritage in lowland alleviated wetlands was much less, and also less visible. Assessment of the quality of nine archaeological sites in the Somerset Levels and Moors showed that those in soils with a low pH, and where a significant overburden of peat and/or clay is present, were best preserved (Bunning 2001).

### 9.3.22 Trends in Ecosystem Services Delivered by Lowland Wetland Priority Habitat Types

The degree of importance of individual ecosystem services delivered by key lowland wetland types, along with the direction of change in the degree to which these services are effectively delivered, is summarised in **Table A9.4.1**



(Appendix 9.4). Also shown is the confidence behind this data, based on the amount of evidence in published literature and the extent to which that literature is in agreement. The degree of importance of each service varies among the different Wetland types, with managed Floodplains clearly providing services to a lesser degree overall than any of the other Wetland types. However, this does not necessarily mean that this Wetland type is less valuable and may, in fact, demonstrate the potential for restoring Floodplains to regenerate lost or degraded services. Moreover, across all Wetland types, the degree to which most services are being delivered has deteriorated.

## 9.4 Drivers of Change

Freshwater habitats—Openwaters, Wetlands and Floodplains—have been affected by a range of drivers that reflect changes in economic development, social preferences, technology and systems governance. Indeed, many of the responses to pressures on the water environment, such as the WFD, have themselves become drivers of change.

### 9.4.1 Openwaters

The drivers of environmental change for Freshwaters are identified elsewhere in this assessment (Chapter 3). Other past or emerging drivers of change in Freshwaters include: economic development associated with increased abstractions from, and discharges to, the water environment which lead to specific pollution pressures; low flows or groundwater levels; channel modifications; and ecological impacts. Technological development has generated new contamination issues. The changing use of chemicals in domestic and industrial settings is shifting the spectrum of important pollutants from sanitary wastes to emerging contaminants including: endocrine-disrupting chemicals, flame retardants, nanoparticles, personal care products, synthetic biological components, and microelectronics. The drive to achieve 20% of the UK's energy from renewable sources has led to the development of wind turbines, which have an indirect impact on Freshwaters, for example, through peat erosion. In particular, small-scale hydroelectric power generation may have more direct impacts when associated with weirs, diversions and small dams.

These drivers have led to responses to alleviate pressures on Freshwater habitats that have, in turn, become drivers of change themselves. For example, the WFD is the overarching policy regime for freshwater quality in the UK, driving targets for water quality improvement. It subsumes a host of EU directives (and related national laws) such as the Drinking Water Directive, Nitrates Directive, and Habitats Directive. The WFD seeks to achieve good ecological water quality status using cost-effective intervention measures, such as investment in water treatment works or limitations on the use of agrichemicals. The WFD has forced a better understanding of water demand and supply at the catchment-scale, and of the implications for water ecology.

The WFD has also nudged water users with different interests to join together to take collaborative actions. For example, campaigns to use water wisely and a genuine willingness to invest in clean-up and wastewater treatment have led to substantial improvements in some aspects of water quality and quantity (e.g. organic pollution, acid deposition, flows). New approaches by water companies (e.g. United Utilities, Dwr Cymru, Northumbrian Water, South West Water) are progressively leading to considerations of asset protection or upstream thinking. Treatment costs of water supply are being reduced by developments in catchment management that protect supply and deliver other service benefits (reviewed by Everard 2009).

### 9.4.2 Wetlands

The main drivers of change for Wetlands have been economic factors associated with population growth, economic prosperity, and increased demand for land for intensive agriculture; these drivers have been influenced by actions to protect remaining Wetland sites. The increase in demand for peat in horticulture and gardening since the 1970s is just one driver which has impacted lowland bogs in particular. Wetlands have been strongly influenced by interactions between agricultural and environmental policies (Morris *et al.* 2008b, 2009; Posthumus & Morris 2010).

The period since the Second World War has seen a succession of policy shifts that reflect a changing balance of priorities given to farming and other countryside services, including biodiversity. For example, the post-war period between 1945 and 1980 was characterised by agricultural growth (Chapter 7). Publicly funded flood defence and improved land drainage for agriculture became major features of support for farming in the UK (Robinson & Armstrong 1988; Morris 1992; Johnson *et al.* 2005), and included the reclamation of wet land for agriculture.

The period from 1980 to 2000 marked a transition in agricultural policy from a focus on production to one that addressed growing concerns about agricultural subsidies and the environmental impacts of intensive farming. International agreements (e.g. the Ramsar Convention on Wetlands, 1971) and European legislation (e.g. the EU Birds Directive, 1979) ran parallel with national initiatives such as the UK Wildlife and Countryside Act (1981) (Hodge & McNally 2000). This gave public agencies a duty to consider nature conservation, to designate some Wetlands as SSSIs, and to allow Floodplain and river restoration to begin (Adams *et al.* 2004).

The mid-1980s witnessed the introduction of production quotas and agri-environment schemes. Agricultural and environmental policies were integrated with the designation of Environmentally Sensitive Areas (ESAs) in 1987. This was followed in 1991 by the wider Countryside Stewardship Scheme (CSS). Both of these schemes included options for Wetland and Floodplain sites. They implicitly recognised the publicly valued ecosystem services provided by managed landscapes, even if they were not framed in these terms (Everard & Appleby 2009). However, these payments were voluntary and cooperative action between landowners was not encouraged, so they were not very effective at reducing habitat losses or reversing the decline of Wetlands. About the same time, the Common Agricultural Policy reform partially

decoupled subsidies from farm income support and introduced 'set-aside' to take land out of production, unintentionally providing opportunities for environmental benefits.

The period since 2000 has been one of reform, driven by further realignment of agricultural and environmental policy. These include the European Union Common Agricultural Policy (CAP) reform of 2003 and, in 2005, the introduction of the Single (Farm) Payments Scheme whereby income support is no longer linked to production. A new Environmental Stewardship scheme, with options for Wetland habitats and 'inundation grassland', was also introduced at this time. Options currently under consideration for the future of the CAP through to 2020 vary in terms of the type and extent of interventions, and the balance of agricultural, environmental and other priorities (EU 2010).

### 9.4.3 Floodplains and Flood Risk Management

It is apparent that a combination of extreme rainfall events and changes in land use has made flooding more problematic in the UK, resulting in very significant social, economic and environmental costs (Foresight 2004; Pitt 2008). About six million properties are exposed to some degree of flood risk, mostly from river and coastal flooding (Foresight 2004; Environment Agency 2009a,c). Critical infrastructure and public services can also be affected by flooding, as was demonstrated by the summer floods of 2007 in England (Chatterton *et al.* 2010). For these reasons, the management of flood risks has become an increasing concern for government at both local and national levels, and there has been a three-fold increase in expenditure on flood risk in England since 2004 (Environment Agency 2009d).

During the last decade, however, emphasis has switched from flood defence to flood risk management. Strategies such as the Defra's Making Space for Water (Defra 2005) advocate the creation of wetlands and washlands, river corridor widening and river restoration to alleviate flood risk in downstream urban areas, as well as providing other benefits at the same time (Environment Agency 2003; Morris *et al.* 2004; Defra 2005). However, the emphasis is on appraising, managing and reducing risk not necessarily avoiding Floodplain development.

Thus, rural land use in some Floodplain areas has shifted from intensive farming to uses that need less protection against flooding and can deliver multiple benefits, including flood storage. In this respect, as the name suggests, Catchment Flood Management Plans (Environment Agency 2008b) take a landscape-scale approach to managing flood risk, identifying where increased catchment storage might help. Alongside this, in some areas, the Catchment Sensitive Farming Programme aims to join flood risk management with other objectives such as the control of diffuse pollution from farmland (Defra 2008). Other actions have also promoted this integration of policy areas, such as regulatory measures like habitat protection or limits on nitrogen fertiliser to protect water quality. Economic mechanisms such as agri-environment payments for Wetland management, and/or voluntary arrangements undertaken by landowners in collaboration with NGOs, such as the Farm and Wildlife Advisory Group (FWAG) and Linking Environment and

Farming (LEAF), are other examples. Yet incentives are still piecemeal, and there are no mechanisms for requiring changes to land use or management when and where they are needed in order to achieve other objectives such as those of the WFD. Appraisals of public investment in flood alleviation now recognise the benefits of creating Wetland areas (Defra 2007), and landowners may be paid for the retention and/or storage of floodwater on their land (Defra 2005; JNCC 2008).

In broad terms, the various administrations in the UK now explicitly include conservation objectives in their flood risk management strategies (Werritty *et al.* 2010), seeking the protection of nationally important wildlife sites and the achievement of biodiversity targets (Defra 2005; Environment Agency 2009d). Furthermore, guidance aims to avoid the development of Floodplain land wherever possible, and to provide storage and pathways for floodwaters in urban areas. The Flood Risk Management (Scotland) Act (2009), for example, is leading to a complete shift in the sustainable management of whole catchments and the restoration of Wetlands (Spray *et al.* 2010). This is clear recognition of the role of Floodplains in providing a range of ecosystem services (CLG 2009).

Although priorities appear to have switched in favour of environmental enhancement, there remains a requirement for farmers to maintain land in 'Good Agricultural and Environmental Condition' (Defra 2008). The food shortages and price spikes of 2007/2008, exacerbated by international demand for bioenergy, confirm the relevance of maintaining capacity in reserve. Indeed, in the UK, much of this capacity exists in lowland areas that are almost universally dependent on managed land drainage and, in many cases, on some degree of flood protection. This is endorsed by resurging UK government concerns about food security (Defra 2010). In this respect, it will be increasingly important to achieve the sustainable management of agricultural floodplains, balancing the demand for food and fibre with the protection and enhancement of floodplain landscapes and wildlife (Foresight 2010; 2011), particularly in lowland peatland areas. (Morris *et al.* 2010).

## 9.5 Trade-offs and Synergies

The quality of Freshwater ecosystems has always been traded-off against the aims of wider landscape management, usually for purposes unconnected with water, but which lead to effects downstream. Examples include using water for wastewater disposal or the inadvertent runoff of agricultural chemicals, both of which affect other services and water users, such as fisheries and anglers. In many cases, ecosystem modifications have been undertaken in order to boost production of one or a few favoured services, while wholly overlooking the implications for other ecosystem services and overall ecosystem integrity. For example, widespread drainage has permitted increased crop yields, but has simultaneously led to



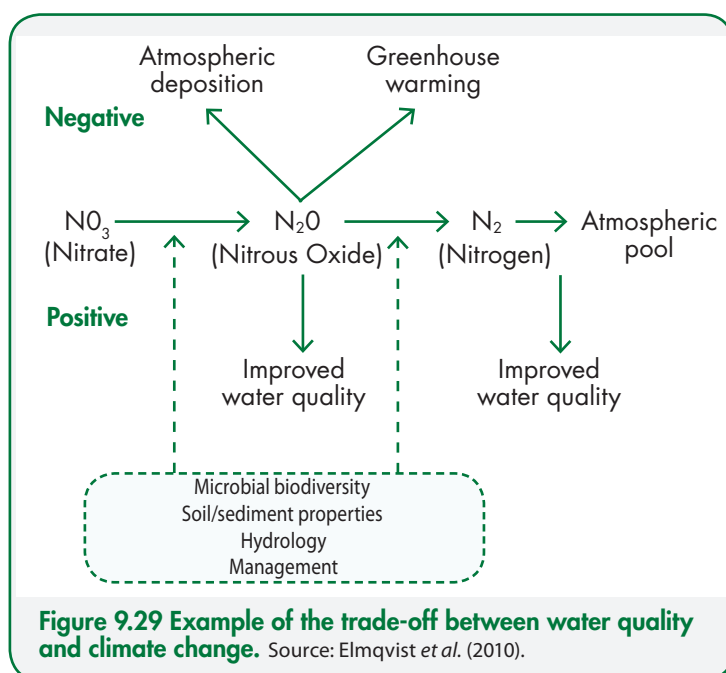
the loss or degradation of other ecosystem services ranging from water regulation and soil erosion, to changes in valued landscapes and the loss of habitats for biodiversity. Draining peatlands for agriculture also releases soil carbon to the atmosphere, potentially contributing to global warming.

The key message in the matrix in **Table A9.4.1 (Appendix 9.4)** is that the only lowland wetland ecosystem that is showing any form of improvement in the degree to which ecosystem services are delivered is managed floodplains. In these, the delivery of provisioning services is increasing, while in all other ecosystems considered, the levels of services are either declining or are unchanged. The degree of knowledge supporting these conclusions is only consistently high for Floodplains, which are the most studied of our Wetlands systems; our knowledge of other systems is generally poor, demonstrating key gaps in our understanding about how other Wetland ecosystems function. It is also apparent that the majority of functions in most lowland wetland ecosystems are considered important, but despite this, they are still deteriorating.

**Table A9.4.2 (Appendix 9.4)** is a trade-off matrix for a 'natural' Floodplain, showing how optimising one ecosystem service affects the delivery of other ecosystem services. The key point demonstrated in this table is that optimisation of the provisioning service of crops, plants and animals results in large decreases in the delivery of all other ecosystem services. This supports the finding of Pilgrim *et al.* (2010) who also identified that maximising agricultural production is one of the most damaging activities to ecosystem services that can be carried out.

Matrices such as **Table A9.4.2**, can assist in the better assessment of scenarios required for meeting desired policy and management objectives. One emerging challenge will be to quantify these potential synergies and trade-offs in economic terms, such as the maintenance of high water table levels for conservation versus flood storage and flood risk reduction. **Figure 9.29** illustrates one such potential management dilemma, where Wetlands may reduce the levels of nitrate flowing from agricultural land into rivers and lakes through denitrification, but if these processes generate nitrous oxide (a highly potent greenhouse gas) rather than nitrogen gas, the result is a contribution to global warming.

The ecosystem approach (Maltby 2006, 2009b; Defra 2007) has done much to promote an appreciation of the value of Wetlands, Freshwater and Floodplains for human welfare (Chapter 22), but also the trade-off and synergies among different ecosystem services. Recent examples include applications in Floodplain management (Everard 2009; Posthumus *et al.* 2010), peat and Wetland management (Turner *et al.* 2008; Bonn *et al.* 2010, Maltby 2010) and the wider countryside (Eigenbrod *et al.* 2009). The ecosystems framework typically uses sets of biophysical and socioeconomic indicators to assess the relative performance of alternative land and water management strategies such as the creation of Wetlands and the ecological restoration of agricultural Floodplains. For example, **Figure 9.30** shows the synergies and trade-offs among ecosystem indicators for alternative land use scenarios that aim to meet different objectives in

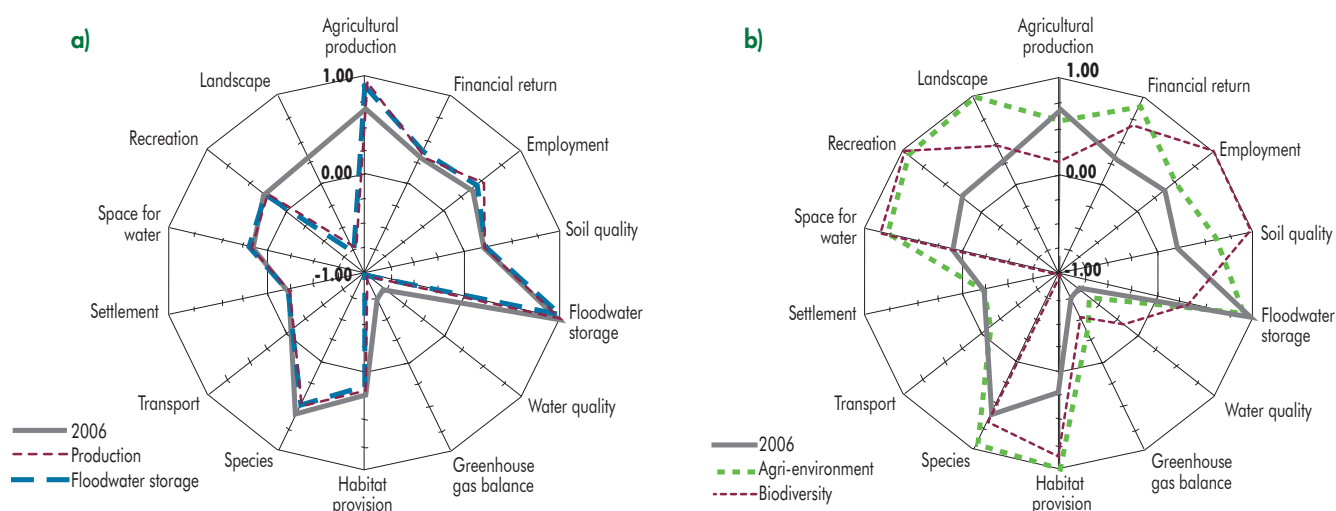


Beckingham Marshes—900 ha of Floodplain by the River Trent in Nottinghamshire (Posthumus *et al.* 2010).

For this case, the existing (2006) agricultural land use, maximum flood storage and maximum agricultural production scenarios show similarity and convergence in values for ecosystem indicators. These scenarios score high on agricultural production and floodwater storage, but low on environmental services such as water quality, greenhouse gas balance, habitats and space for water recreation and landscape. By comparison, the agri-environment and biodiversity scenarios show relatively higher values for indicators relating to soil quality, habitats, space for water, recreation and landscape. Controlled flood storage is more compatible with the agricultural land use scenario than the biodiversity scenario for this site. The scores shown here are unweighted, so all the ecosystem services are considered of equal importance; expressing them in monetary terms provides a basis for comparison.

Similar synergies and trade-offs almost certainly vary according to local conditions. Some trade-offs are more obvious than others, such as the draining of peatlands for agriculture and resultant loss of carbon and biodiversity (Bonn *et al.* 2010; Natural England 2010), or the intensification of agriculture and the resultant loss of biodiversity (Eigenbrod *et al.* 2009). But in some situations, the use of Floodplains for storage may be more compatible with agricultural land uses than some types of biodiversity conservation (Posthumus *et al.* 2010). From a management viewpoint, it is critical to understand the potentially diverse impact on ecosystems services associated with interventions, including unintended consequences.

Across Europe, there are many examples (e.g. Skjern catchment in Denmark) of engineers draining the land for intensive agriculture, knowing the gains would be short-term, but without realising the ramifications of what they were doing. This resulted in a decline in the condition of habitats designated as SAC and their dependent species, impacts on water quality and fisheries, and the loss of landscape value. Ultimately, it led to the government



**Figure 9.30 Synergies and trade-offs among land use scenarios in the Beckingham Marshes, Nottinghamshire.** **a)** Shows the convergence of existing (2006) agricultural production and flood storage scenarios; **b)** Shows how environmentally oriented scenarios diverge from existing land use. P=production; R=regulation; H=habitat; C=carrier; I=information service. Scale: from -1 (worst performance) to 1 (best performance). Source: Posthumus *et al.* (2010). Copyright (2010), reproduced with permission from Elsevier.

purchasing land for restoration and producing what is now a very popular local amenity and tourism resource.

Qualitative assessments of the ecosystem service outcomes from river habitat enhancement (Everard 2009; 2010) has concluded that the restoration of ecosystem functioning is likely to deliver generally positive benefits to the full range of provisioning, regulatory, cultural and supporting ecosystem services, whereas ‘heavy engineering’ solutions to optimise only specific benefits were likely to degrade most other ecosystem services (Everard & Kataria 2010).

Tools to appraise the optimisation of such trade-offs and synergies in Freshwaters, particularly in operational forms relevant to day-to-day support for management decisions, require further development.

## 9.6 Sustainable Management

The sustainable management of all Freshwaters should derive from the recognition of the importance catchment-scale management and the potentially large cost savings that can result from it. Some of the instruments are already available, and involve using existing directives and legislation better (such as the Habitats Directive, WFD, Floods Directive, Water Act, Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA)) to deliver appropriate management measures for good ecological status, beneficial ecosystem services and key species. In Scotland, the requirements of the Flood Risk Management (Scotland) Act (2009) and the provisions in the earlier Water Environment Water Services Act (2003) provide a direct stimulus to progress in this area. Better

focus will require competent authorities to identify sensitive features in Freshwater systems and initiate management to protect them more adequately than they have done before. In smaller water bodies, such as headwaters and ponds, the UK BAP could have greater purchase, although this has, until recently, been a weak driver for improvements and has no linkage to ecosystem services. The England Biodiversity Group has developed a series of Integrated Biodiversity Delivery Areas within which landscape-scale approaches to the delivery of UK BAP objectives for species and habitats will be trialled; this makes a more explicit reference to the need to consider a broader range of ecosystem services. The joint Wetland Vision for England, a partnership project involving statutory agencies and voluntary wildlife groups, is already developing this approach in a number of key regions of Wetland importance across England ([www.wetlandvision.org.uk](http://www.wetlandvision.org.uk)).

More visionary delivery is liable to derive from strengthening links between management of the terrestrial and Freshwater environments through, for example: catchment sensitive farming; agri-environment schemes that link water, carbon and biodiversity (e.g. Glastir) (Cook 2010); integrated ‘upstream thinking’ rather than paying increased treatment costs; and ‘slowing water down’ by more sustainable catchment drainage. The reform of the CAP is likely to stimulate more payments for maintaining ecosystem services. Considering both land and water protection at a landscape-scale could hold major benefits in terms of safeguarding water-related ecosystem services and biodiversity simultaneously, while allowing the integrated management of catchments, riparian zones and Floodplains at a reduced cost. Enhancing stakeholder and community involvement, for example, through the current Government’s ‘Big Society’ thinking, are key to this approach, and a range of stakeholder groups are already expressing interest in taking on these roles (e.g. the Association of Rivers Trusts which is now operating throughout the UK).

The dissemination of 'ecosystem services' thinking will be key to valuing Freshwater ecosystems more fully, communicating more clearly their importance to broader sets of stakeholders, and appropriately costing the pressures arising from catchment land use and Freshwater modification. Major synergies could accrue from simultaneous and more cost-effective management for biodiversity, water quality, flood risk and security of supply.

Other key needs include:

- i) To better understand the trade-offs between different ecosystem services, as well as the synergies that may arise from novel management approaches. This would support decisions on how to optimise the balance of ecosystem services, taking into account embedded costs (e.g. carbon costs of importing reed from abroad) and wider sustainability, as well as local economics. Where ecosystem-based solutions can be applied to problems, such as Sustainable Urban Drainage Systems (SUDS), Wetland treatment and buffer zoning, it is more likely that win-win outcomes may arise than through traditional, engineered, single-benefit, management solutions.
- ii) To improve our understanding of how best to optimise Wetland and Freshwater management to maximise the range of ecosystem services. Sustainable management with minimum intervention often requires a large-scale perspective to enable natural processes to operate as far as possible, and to enable a range of different and, perhaps otherwise, incompatible ecosystem services to be delivered. At the smaller-scale, it is often possible to adopt management approaches which enable more than one outcome to be delivered; for example, increasing the variation in topography in a floodplain grazing marsh to allow for a range of degrees of wetness alongside a flood defence function.
- iii) To strengthen the drivers for sustainable Freshwater management incentive payments under agri-environment schemes. These payments are a major potential mechanism for delivering ecosystem objectives and are currently mainly targeted at biodiversity and resource protection (with a significant focus on landscape and access as well). Incentive payments have an increasing future role to play in other areas such as flood risk management and mitigating greenhouse gas production. For some Freshwaters, however (e.g. Wetlands), particular problems with Higher Level Stewardship schemes include:
  - a) incentive payments that are not sufficient to promote restoration or the reversion of land to Wetlands along river corridors for biodiversity and flood risk management; and
  - b) the scale of Freshwater systems requiring farms to coordinate their activities to deliver benefits across a catchment or along a Floodplain. Future constraints are likely to arise from the scale of agri-environment funding under the next revision of the CAP and EU budget post-2013. Nevertheless, recognition of the breadth of benefits arising from sensitive ecosystem management may open up opportunities for 'paying for ecosystem services' (PES) including for benefits such as improvements in local air quality and health through habitat regeneration.
- iv) To develop effective monitoring to evaluate sustainable Freshwater and Wetland management and restoration

at large scales (while recognising that action at smaller scales may also be important to account for local effects). All major Freshwater and Wetland management or restoration must be accompanied by appropriate monitoring to evaluate success and to guide future steps; hence, it will properly quantify the range of benefits achieved by operating at a large scale and across a range of ecosystem services. Though there are good examples, particularly at plot-scale, there is no consistent approach to monitoring the full range of benefits at a landscape-scale over the long-term.

- v) To link land and water management more explicitly to 'slow water down', enhance quality, reduce flood risk and increase security of supply. The water industry is a key stakeholder in land and water management. An essential part of managing Freshwaters is that water be progressively released from catchments, urban areas and Wetlands in ways that overcome tendencies for over-rapid drainage. Gentler and more consistent flows make water easier to treat, protect minimum flows in droughts and allow reservoir water releases to be reduced. South West Water is promoting £10 million worth of capital works for Wetland restoration and farm pollution reduction from 2010 to 2015 on moorland and farmland, none of which is owned by the company. The aim is to achieve "savings on operating costs for water treatment and deferral or avoidance of future costly treatment systems upgrading to meet deteriorating water quality in feeder rivers" (M. Ross *pers comm.*). The cost of this work is met as a levy to customers of about 60p per annum by 2015, compared to a customers' 'willingness to pay' assessment for price setting of £2.50 per annum for environmental enhancements; approval from Ofwat was secured for this more holistic catchment-based approach which has a cost-benefit score of 1:65. The company is working with Defra, Natural England and many other organisations on a 'proof of concept' to identify a 'reward system' for landowners and managers who consistently produce the best quality and quantity of water, thereby reducing the risks to the business and management of extreme events or diffuse pollution.
- vi) To engage with all legitimate stakeholders. Valuation of ecosystem services must take into account the range of stakeholder interests in Freshwater ecosystems, and the way ecosystems services are distributed among them (**Table 9.13**) (Rawlins & Morris 2009; Reed *et al.* 2009). Dominant stakeholders pursue their interests through control over property rights, such as farmers holding agricultural tenure for the purpose of agriculture production. Many non-market 'goods' such as flood regulation, carbon sequestration, biodiversity and landscape, and conversely, non-market 'bads', are not the subject of clearly defined entitlements. Valuation and an understanding of distributional aspects can help inform policies to correct for these market failures, including the potential to create 'markets' in ecosystem services.
- vii) To develop an integrated policy for Wetland resources. Wetlands are considered only partially within our most comprehensive piece of water policy: the WFD. Sustainable management will require both a policy and



**Table 9.13 Links between ecosystems and stakeholder interests in Floodplains and Wetlands.** Source: Morris *et al.* (2009).

Function and service	Goods	Stakeholder	Values
Production	Crops, fuel	Farmers, Defra	Economic gains from crop and livestock production
Regulation	Floodwater storage, drainage	Environment Agency-Flood Risk Management, Internal Drainage Boards, farmers, local industry, carbon traders	Avoid damage due to flooding, tradable services
Habitat	Maintenance and enhancement of biodiversity	RSPB, Environment Agency, Natural England, local residents	Contribution to UK BAP targets, Willingness To Pay
Carrier	Transport and settlements	Local residents, local industry, farmers, local authority	Location for housing, roads, local industry. Property and service values, costs of alternatives
Information	Amenity, landscape, recreation, history	RSPB, local residents, local authority	Enjoyment of the countryside and related benefits, Willingness To Pay

legislative framework which recognises the importance of linkages among the diversity of Wetlands, Openwaters and other habitats. Unlike some countries, notably the USA, there is no unifying wetland policy which would strengthen the recognition and perception of the resource as a whole as a priority.

in Freshwater ecosystems in the face of use and development to deliver services;

- determine the area and distribution patterns of those habitats necessary to provide the appropriate balance of regulatory and productive services in order to meet specified policy objectives;
- model links across Freshwater ecosystems and their functions to enable the reliable assessment of possible future environmental or management changes;
- identify robust, measureable and verifiable indicators of ecosystem changes which lead to alterations in ecosystem service delivery.

## 9.7 Knowledge Gaps

Some Freshwaters are well monitored and understood, and provide obvious targets for developing integrated indicators of the delivery of ecosystem services at a catchment-scale. There are, nevertheless, generic gaps in understanding that cross all Freshwater systems. Some of the largest gaps include quantitative links between service provision and ecosystem structure or function, and valuation of those ecosystem services that generate benefits for which there is no obvious market price, such as the value of species whose functional contribution is small (Tallis & Polasky 2009). There is also a major need to improve understanding of how to manage Freshwater sustainably through the ecosystem services paradigm to ensure that shorter-term use does not degrade longer-term capacity. The past focus on the conservation of species and communities needs to be complemented with the maintenance of ecosystem functions if services are to be delivered in the future. We also need to understand the interactions of various different Freshwater and land types within a catchment in order to assess how their processes and functions combine to deliver ecosystem services (Maltby 2009a).

Other specific issues that may arise include how to:

- uncouple the use of Freshwater catchments for food production from negative impacts downstream;
- optimise catchment management effectively as the climate changes to ensure both biodiversity protection and service delivery;
- value the aggregate role of all organisms, including microbes, in ecosystem processes;
- restore processes and functions in degraded catchment ecosystems to optimise service benefits;
- identify factors that maintain resilience and resistance

In all these respects, there is a pressing need for pilot studies and projects that demonstrate how best to manage Freshwater catchments, and how to guide management operationally.

## 9.8 Conclusions

This assessment reveals a need to reappraise our view of the importance of Freshwater ecosystems and their critical position in policy, management and a sustainable economy. This involves recognising the multiple benefits, potential cost-benefits and wide range of public and private interests which can be supported simultaneously by Freshwaters through a more holistic approach linked to their pivotal role in delivering ecosystem services. In turn, this recognition will arise from a more practical implementation of the ecosystem approach to integrate the sustainable management of land, water and living resources. Above all other ecosystems, and because of their many linkages through their catchments with terrestrial and marine environments, Freshwaters demonstrate the need for more joined-up thinking across the whole ecological continuum through which ecosystem services are supplied. Of particular significance is the need for integrated policy to bolster the current emphasis on individual priority habitats, which represent often arbitrary and artificial separations of land and water, upland and lowland landscapes, rivers and wetlands, and different segments of the hydrological

cycle. We suggest that such approaches would improve the valuation of Freshwaters, while simultaneously improving their integrated management and offering a more effective means for overall conservation.

The wide-ranging benefits derived from Freshwater ecosystems have been largely taken for granted, gone unnoticed, got lost in preference for overriding, single-sector objectives, or at worst, been wilfully abused. Reversing such inadequacies requires better understanding and explanation from the scientific community of how Freshwater condition and management translates into economic, social and conservation benefits through ecosystem service delivery. At the same time, it is essential to recognise that the management of ecosystem services in Freshwaters will increasingly be taking place under highly dynamic and uncertain circumstances—despite recent improvements in quality, Freshwaters will be extremely sensitive to future changes in climate, land use, demographics and water demand. Therefore, a key management aim will be to ensure that Freshwater ecosystems are sufficiently resilient to deliver their most valuable benefits over the longer-term. The associated uncertainties also imply the need to ensure that key functions are maintained even under extreme scenarios. Furthermore, the development and implementation of monitoring, assessment and modelling procedures, which evaluate ecosystem service delivery through time and under different future trajectories, will be immensely important.

Within these broader objectives, a range of more specific needs and near-term policy goals have emerged from this assessment. These include:

1. Strengthening public awareness of the 'ecosystem service perspective' of Freshwaters. There is a need to address concerns in some sectors that this does not replace existing conservation and legislative approaches to Freshwater management, but adds value through the recognition of functions and benefits.
2. Improving understanding of the links between ecosystem structure, species composition, ecosystem functioning, ecosystem services, and economic and non-economic values throughout catchment systems to better inform management and appraise management outcomes. This study has shown the need for improved understanding of the current extent and state of Wetlands across the UK. An improved Wetland inventory will be key to better planning for a range of ecosystem services, especially as the climate changes.
3. Highlighting the practicalities of the 'ecosystem approach' in meeting the combined challenges of climate change, and secure and sustainable food and water supplies. Increasing food production from Freshwater catchments implies an ability to offset or minimise the effects downstream by catchment management actions. Buffer zones and habitat networks (Lawton *et al.* 2010) are one such mechanism, but others will be required to balance productive and protective ecosystem services.
4. Adapting policy and legislation, especially within agri-environment measures, to more fully recognise the links between catchment activities and Freshwaters. Analysis of existing legislation (the WFD, Habitats Directive, Flood and Water Management Act, etc.), strategies (BAPs, the

Natural Value Programme in England and the Natural Environment Framework in Wales) and tools (SEA, EIA) to identify how the ecosystem approach can be used more effectively to deliver ecosystem services (e.g. through various WFD 'programmes of measures') will be required.

5. Stimulation of markets and stronger engagement with business and other stakeholders to ensure that: i) opportunities for the 'green economy' are maximised; and ii) those benefiting from the use of catchment services pay appropriate costs to support or protect ecosystems and services that are affected negatively by their actions. This will require exploring the institutional aspects of property rights and entitlements that recognise the support and provision of multiple benefits from Freshwater ecosystems. New collaborative arrangements might include rewards for the provision of ecosystem services by land and water managers where these serve the public good.
6. Partnering with, strengthening and informing local actors (e.g. local authorities, landowners and Rivers Trusts) to consider wider ecosystems (i.e. whole catchments and beyond) in local decisions. Actions need to be supported with the best available guidance, evidence and evaluation to achieve optimal mutual outcomes beneficial to a wide range of stakeholders. A key outcome will be more participatory decision-making.

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## 2. BAP matrix

UK BAP Biodiversity Action Reporting System (BARS) report for 2008. Source: [www.ukbap-reporting.org.uk/status/species\\_habitat.asp](http://www.ukbap-reporting.org.uk/status/species_habitat.asp)

This website provides access to information collated from the UK's four countries charting progress towards UK BAP targets under the quinquennial reporting review in 2008. It includes information on current status (extent and habitat condition) and trends in those characteristics. It contains important caveats over the quality and reliability of data used in the assessment; in particular, habitat inventory information is very unreliable for several priority UK BAP wetland habitats.

## 3. UK BAP priority habitat descriptions

The species and habitats were selected through the application of criteria based on international importance, rapid decline and high risk. These criteria and their application were then further developed separately for marine biodiversity, terrestrial/freshwater species and terrestrial/freshwater habitats in recognition of the very different forms of information and knowledge available for these three groupings.

## 4. Wetland Vision for England

Data was defined in three stages: i) Basic conditions that support the current range and extent of wetlands, such as the suitability of soils, topography and relationship to the fluvial or tidal floodplain, generated a baseline for wetland potential; ii) Factors that could support landscape-scale wetlands were summarised by sub-catchment and then weighted; they included: the presence of indicator species, existing priority habitat, statutorily designated wetlands, nature reserves, low extent of urbanisation within floodplains, the grade of agricultural land, and the presence of large contiguous areas; and iii) The Technical Advisory Group (TAG) and stakeholders defined the areas of greatest potential across the country, based on comparing information analysed per sub-catchment (Hume 2008).

## 5. Countryside Survey 2007

The Countryside Survey is made up of two main parts: a) the Field Survey which focuses on habitats, vegetation, soils (0–15 cm) and freshwater; and b) the Land Cover Map which is a digital map using satellite data from space. The Field Survey covered a total of 591 1x1 km sample squares spread across England, Scotland and Wales, which were representative of the variations in the climate and geology of the three countries. Where appropriate, data are also included from a separate survey of 0.5x0.5 km squares undertaken in Northern Ireland. Not all Field Survey squares contain a suitable stream or pond. Streams and ponds are not surveyed in detail in Northern Ireland. Areas of habitat were mapped within each square and more detailed samples were made of vegetation in a series of plots. Soil (0–15 cm) samples were also collected from five plots in each square, and a stream and a pond were also sampled in many of the squares. The UK Results from the 2007 Report (Carey *et al.* 2008) provide further details of the survey methodology and key results, while the country reports (Countryside Survey

# Appendix 9.1 Description of Sources of Data

## 1. State of the Natural Environment Report (Natural England)

This report covers the natural environment (landscapes, flora and fauna, freshwater and marine environments, geology and soils) using existing data.

2009; Norton *et al.* 2009; Smart *et al.* 2009) provide results for each country surveyed. Freshwater results are contained in Dunbar *et al.* 2010c (headwater streams) and Williams *et al.* 2010 (ponds).

#### **6. Scottish Environment Protection Agency (SEPA) State of the Environment Report 2006**

This report brings together existing information from a variety of sources covering the state of Scotland's air, land and water environments. It also covers key environmental issues: waste and resources, radioactivity, hazardous chemicals, nutrient enrichment and acidification; and three main environmental challenges: human health, biodiversity and climate change.

#### **7. Scotland's Biodiversity: An assessment of biodiversity in 2010. Mackey, E.C. & Mudge, G. (2010) Scottish Natural Heritage**

This report, coincident with the start of the International Year of Biodiversity (2010), provides an initial commentary on progress with Scotland's biodiversity targets. It uses data from the 2008 UK assessment biodiversity reporting round, Scotland's biodiversity indicators, protected site condition monitoring outcomes, and progress with Scotland's 2010 targets.

## **Appendix 9.2 Current Initiatives**

In 2008, the Scottish Government commissioned a study to develop the ecosystem approach into a workable methodology, with the development of an outline guidance framework and a model ecosystem framework for a pilot area in Aberdeenshire a key goal (Macaulay report March 2010). There is also particular interest in developing pilot catchment studies, with work being initiated in the Cairngorms National Park (SEPA and Cairngorms National Park Authority) and Eddleston Water in the Borders (SEPA, Tweed Forum & Dundee University) (Werritty *et al.* 2010). This latter project links in to the earlier work done in the Borders by the Tweed Forum to produce the Tweed Wetland Strategy, and focuses on ecosystem services delivered through natural flood management, alongside habitat restoration. Similar examples are now emerging in England (e.g. SCaMP; 'Upstream thinking') and Wales (e.g. Lake Vyrnwy, Pont Bren), and involve partnerships across several sectors.

1. **The WATER Project** (Wetted Land Assessment and Techniques for Restoration) is developing a market-based catchment restoration scheme that will be built on a Payments for Ecosystem Services (PES) model and aims to identify both delivery and funding mechanisms to lever private investment for catchment restoration by:

- Developing a substantive Northern European cooperation network that identifies our shared common

identities and problems and can deliver environmental restoration of wetted land within a river catchment in a cost-effective way.

- Developing a set of five robust cost-benefit guides that demonstrate how investment from private companies in catchment restoration can make a long-term impact on their profitability and competitiveness.

Simply put, the people and businesses that benefit from good ecosystem function will pay the people who deliver good ecosystem functions directly. They will do this because they have a clear understanding of the economic, social and environmental benefits, as demonstrated by the WATER Project.

2. **Natural England** is undertaking studies in three upland catchments to evaluate the ecosystem approach (and benefits from ecosystem services) in practice. The project aims:

- To use the ecosystem approach to define land and water management.
- To demonstrate that investment in the natural environment can result in multiple benefits (carbon, water, biodiversity, recreational and health benefits).
- To work in partnership to deliver a range of ecosystem services in a cost-effective way and link these services to the beneficiaries.

The study is being undertaken in three pilot areas:

- Bassenthwaite Lake catchment, Cumbria
- South Pennines National Character Area, Yorkshire
- Dartmoor and Exmoor, South West England.

Each is being run by stakeholder groups at a regional level, with technical aspects being coordinated nationally.

3. The **West Country Rivers Trust** is heading a project (Wetland Example of Payments for Ecosystem Services) that is part-funded by the Natural England Wetland Vision Fund, and based on a section of historic Floodplain on the River Fal in West Cornwall. The project aims to:

- Reconnect and re-wet 21 ha of extensively grazed and cultivated, disconnected Floodplain, reinstating it as a series of lowland wetland UK BAP habitats.
- Economically evaluate the direct and indirect ecosystem services benefits including carbon sequestration, flood mitigation, nutrient stripping, biodiversity and extensive management (limited grazing, shooting, fishing).
- Identify and sell the most economically beneficial services to local investors.
- Establish with the landowner, and pay for, mechanisms to remove land from long-term intensive production to light-touch extensive management agreements or 1,000-year covenants.
- Evaluate the project's applicability in terms of developing a PES based scheme that ensures long-term protection of other hydrologically important areas within the rest of the Fal catchment.

## Appendix 9.3 Summary of Recent Assessments of UK Peatlands

**Table A9.3.1** Comparison of the ecosystem service values of different lowland peatland management practices using active non-impacted peatland systems as a baseline. The table indicates how different management practices, when applied to an active lowland peatland, affect delivery of these services\*. ↓ shows a decrease in ecosystem service function; ↑ shows an increase in ecosystem service function; ≈ shows no change in ecosystem function. The table is adapted from JNCC (2011); it is based on expert judgement and on review versions of UK NEA chapters reflecting the current state of understanding and is not a definitive assessment of process interactions. Note that even this qualitative analysis is subject to some uncertainties, not least because the scale and direction of ecosystem service delivery is heavily context dependent.

		Afforestation	Abandonment	Peat cutting (fuel)	Peat cutting (horticulture)	Agricultural improvement	Cultivation
	<b>Vegetation produced</b>	Coniferous forestry	Scrub/Woodland	Wet/Dry Heath	Bare	Improved grassland, Grazing marsh	Cropland
	<b>Peatland type most affected</b>	Shallow peat, Raised bog	Raised bog, Fens	Raised bog	Raised bog	Shallow peat, Raised bog, Fen	Raised bog, Fens
	<b>Peat condition</b>	Degraded/Archaic	Degraded	Degraded	Bare	Archaic	Archaic
<b>Provisioning</b>	Crops, livestock & fisheries	↓	↓	≈	≈	↑	↑
	Fuel or horticultural peat	≈	≈	↑	↑	≈	≈
	Timber or building material	↑	↑	≈	≈	≈	≈
	Genetic resources	↓	↑ / ↓	↓	↓	↓	↓
	Drinking water supply	↓	≈	≈	≈	≈	≈
<b>Regulating</b>	Carbon storage	↓ / ≈	↓	↓	↓	↓	↓
	Preventing GHG emissions	↑ / ↓	↓	↓ / ≈	↓	↓	↓
	Flood prevention	↓ / ↑	↑	↓ / ≈	↓	↓	↓
	Disease prevention	≈	≈	≈	↑ ?	↑	↑
	Detoxification and purification	↓	≈	≈	↓	↓	↓
	Pollination	↓	↑	↓	↓	↓	↓
<b>Cultural</b>	Religion and spirituality	↑	↑	≈	≈	↑ ?	↑ ?
	Cultural heritage	↑	↓	↑	↑	↑	↑
	Aesthetics	↓	↓ / ↑	↑	↓	↓ / ↑	↓ ?
	Social Cohesion	≈	↓	↑	↑ ?	≈ / ↑	≈ / ↓
	Tourism and recreation	↑	↓	↑	↓	≈	≈
	Education	↑	↑	↑	↓	↑	↑
<b>Supporting</b>	Soil formation	↓	↓	↓	↓	↓	↓
	Nutrient cycling	≈	↑	↑	↑	↑	↑
	Biodiversity	↓	↑	↓	↓	↓	↓

\* An increase or decrease of any given ecosystem service function does not necessarily equate to an improvement or deterioration of the system overall.



# Appendix 9.4 Ecosystem Service Delivery for Lowland Wetlands and Trade-off Matrices for Floodplains and Reedbeds

Table A9.4.1 Ecosystem service delivery by key lowland wetland types.


	Service	Floodplains		Fens	Reedbeds	Grazing marsh	Lowland raised bogs	Headwater wetlands
		Natural	Managed					
Provisioning services	Crops, plants, livestock, fish, etc. (wild and domesticated)	Light grazing, wild game, sedge for thatching ↘2	Intense grazing of livestock (meat and wool) and crop production ↗1	Grazing of livestock, sedge for thatching ↓1	Grazing of livestock, reeds for thatching etc. ↓1	Potentially intense grazing of livestock ↓1	Bulb fibre, sphagnum for hanging baskets ↓1	Managed grouse moors, extensive grazing ↓1
	Trees, standing vegetation and peat	Timber, some peat, other vegetation ↘2	Short-term vegetation for agricultural production ↗1	Natural vegetation, peat ↘4	Some standing vegetation and organic soils ↓1	Maybe some peat/organic soil horizons ↓1	Peat accumulation ↓1	Peatlands ↓1
Provisioning and regulatory services	Water quantity	Natural buffer zone, flood defence by natural flooding regime ↘1	Often embanked to prevent flooding, promotes flooding downstream. Fertiliser inputs etc. degrade water quality ↘2	Provides clean water ↘2	Flood protection, water purification potential ↓2	Flood protection, aquifer recharge ↓1	Provides clean water ↓1	Major source/shallow aquifer ↘4
	Wild species diversity including microbes	High biodiversity ↘1	Low biodiversity ↘1	Rare and some degree of diverse habitat ↘1	Rare but not particularly diverse habitats ↓1	Grazing restrictions (e.g. July onwards) promotes increased plant diversity ↓1	Rare but not particularly diverse habitats ↓1	Rare habitats ↔4
Regulatory services	Climate regulation	High carbon sequestration ↘1	Low carbon sequestration ↓1	Carbon sequestration (peat soils) ↓1	Carbon sequestration in soils ↓2	Local temperature and humidity regulation ↓2	Carbon sequestration (peat soils) ↓1	Carbon sequestration (peat soils) ↓1
	Hazard regulation: vegetation and other habitats	Natural flooding regime helps prevent downstream flooding ↘1	Does little to prevent flooding or climate stress ↘1	Prevent flooding if on floodplain ↔2	Some erosion protection potential, little flood prevention, some carbon sequestration ↓2	Flood protection potential, aquifer recharge ↓1	Some erosion protection potential, little flood prevention, high carbon sequestration ↓2	Flood protection potential, aquifer recharge ↓4
	Waste breakdown and detoxification	Natural processes can break down wastes ↘1	More likely a source than a sink ↘1	Natural buffer zone system ↘1	Natural buffer zone system ↓2	Breakdown of animal wastes and of contaminants in runoff ↓2	Natural buffer zone system ↓2	Natural buffer zone system ↘4
	Purification	Natural buffer zone ↘1	Buffer zone qualities lost due to intensification/embankment ↓1	Natural buffer zone system ↘1	Natural buffer zone system ↓2	Breakdown of animal wastes and of contaminants in runoff ↓2	Natural buffer zone system ↓2	Natural buffer zone system ↘4
Cultural services	Meaningful places including green and blue space	Integral components of evolving river systems, diversity of processes, spawning areas for fish species, art, folklore ↘1	Development pressures have been intense due to high productivity, flat topography, proximity to navigable routes and potable water. Biological degradation and isolation of habitats ↓1	Unique self-supporting landscapes created by alliances of humans and nature, 'sense of place', religious significance; folklore and mythology, art, language, place-names, family histories ↘2	Landscape that regularly flood, coastal reedbeds act as natural buffers ↓2	A once common feature, species-rich habitat, support for wide variety of insects and birds; aesthetic and spiritual value ↓2	Unique self-generated landscapes, 'sense of place', religious significance; folklore and mythology, art, language, place-names, family histories ↓2	Unique self-generated landscapes, 'sense of place', religious significance; folklore and mythology, art, language, place-names, family histories ↘4
	Socially valued landscapes and waterscapes	Traditional landscape uses (wet meadows, osier beds, mill leats, fisheries); 'living landscape'—mosaic of habitat created at a landscape scale ↘1	Natural landscape-scale rhythms lost; fragmented habitats, species isolation, increased flood risk due to enhanced 'flashiness' ↓1	Artefacts of the past, traditional water and land-use, traditional medicine and ethno-botany, educational resource ↘2	One of the forgotten crops of the British countryside thatching industry, sedge, constructed reedbeds as environmentally-sensitive water treatment systems' bird habitat (e.g. the bitter) ↓2	Traditional agricultural practices evolved over centuries, flood alleviation, rich source of biodiversity ↓2	Rare but not particularly species-diverse habitats; artefact preservation (trackways, bog people) palaeontological records of environmental and climate change ↓2	Rare but not particularly species-diverse habitats; artefact preservation (trackways, bog people) palaeontological records of environmental and climate change ↘4

Degree of importance of ecosystem service: ■ High level ■ Medium level ■ Low level

Direction of change: ↑ Improving ↗ Some improvement ↔ Equivocal changes ↘ Some deterioration ↓ Deteriorating

Confidence: 1 – High agreement, high evidence 2 – High agreement, low evidence 3 – Low agreement, high evidence 4 – Low agreement, low evidence

**Table A9.4.2 Trade-off matrix for natural Floodplains.** The assumption is that the Floodplain is pristine, that is, it is predominantly diverse mixed woodland. This means that for many of the services they are being optimally performed and can not be improved; therefore, the trade-off is neutral as nothing would change. The trade-off is determined by considering how optimisation of the policy lever would affect the responding factor.

		Responding factor 										
		Crops, plants, animals	Trees, standing vegetation, peat	Water quantity	Climate regulation	Hazard regulation	Waste break-down	Wild species diversity	Purification	Meaningful places	Valued landscapes	
Policy lever	Crops, plants, animals		↓ ***	↓ ***	↓ ***	↓ ***	↓ ***	↓ ***	↓ ***	↓ ***	↓ ***	1
	Trees, standing vegetation, peat	↔		↑ *	↔	↔	↔	↓ *	↓ *	↓ *	↓ *	2
	Water quantity	↔	↔		↔	↔	↔	↔	↔	↔	↔	3
	Climate regulation	↔	↑ *	↔		↔	↔	↓ *	↓ *	↓ *	↓ *	4
	Hazard regulation	↔	↔	↔	↔		↔	↔	↔	↔	↔	5
	Waste breakdown	↓ *	↓ *	↑ *	↓ *	↔		↓ **	↑ *	↓ *	↓ *	6
	Wild species diversity	↑ *	↓ *	↔	↔	↔	↔		↔	↑ *	↑ *	7
	Purification	↓ *	↓ *	↑ *	↓ *	↔	↑ *	↓ **		↓ *	↓ *	8
	Meaningful places	↔	↔	↔	↔	↔	↔	↔	↔		↔	9
	Valued landscapes	↔	↔	↔	↔	↔	↔	↔	↔	↔		10

Direction of change: ↑ Increase ↓ Decrease ↔ No change

Degree to which change would occur: \* Low \*\* Medium \*\*\* High

#### Interpretation:

1. To increase crops etc. natural Floodplain would need to be converted to agriculture, thereby degrading most of the natural functions it is performing.
2. To increase timber production, the natural Floodplain would require afforestation, thereby removing natural habitat, although more carbon may be sequestered.
3. Nothing could really be done to enhance this service—it is already optimally provided (natural buffer zone).
4. Enhancement of climate regulation would probably arise through afforestation, which would increase trees and timber, but have negative effects on some other services.
5. Erosion protection and flood protection are already provided, so no action is required to enhance service delivery. (There is some debate about function of Floodplain woodland, so one possibility is the removal of woodland, but this option is not considered here due to uncertainty).
6. If the Floodplain is used to enhance waste breakdown and detoxification, it is likely to reduce some services due to habitat degradation, but would enhance the provision of potable water. However, this may lead to production of more greenhouse gases.
7. This would probably involve the creation of mixed habitat involving felling of some natural woodland.
8. Same as 6.
9. & 10. It is undetermined as to how these services can be enhanced—natural Floodplains are usually valued and meaningful.

**Table A9.4.3** refers to managed reedbeds, used for the production of reed (*Phragmites australis*). Sedge (*Cladium mariscus*) is cut from sedge beds and is also used for roofing. Natural reedbeds and sedge beds are more diverse components of natural Floodplains, where they are successional to carr woodland. Managed reedbeds will succeed to carr woodland if they are not cut regularly and are kept at high water level during summer, but drained down to make cutting (usually every two years) easier in winter, when the dead stems are cut for thatch. Sedge beds are managed much more lightly and kept at high water level throughout the year; the sedge is cut green in summer, usually once every few years. Thus, sedge beds have higher nature conservation value than reedbeds, which are closer to monocultures, and are mainly only valued alongside fen vegetation and natural Floodplains in terms of conservation.

The intention to increase crop production is not relevant as managed reedbeds are already looked after for maximal reed production. Intention to produce timber would mean the complete loss of reed production (indicated in **Table A9.4.3** as ---). Reduced management for reed production will tend to moderately increase the values of other services (indicated in **Table A9.4.3** as ++) because it will mean maintaining water levels higher for longer and less removal of biomass as reed. The most common useful change is to cease cutting for up to a decade or only to cut small areas in a large reed marsh. This, with inevitably increased water levels, will favour characteristic birds like bittern, but essentially means abandonment of crop production and allowing the area to revert to semi-natural Wetland conditions. Complete abandonment of reed production would increase the values of these services even more and result in conversion to a semi-natural reed swamp.

**Table A9.4.3 Trade-off matrix for reedbeds.**

Intention to increase these services		Will have the indicated consequences for these other services							
		Crops	Timber and wood	Water quantity	Climate regulation	Hazard regulation	Waste breakdown and water purification	Wild species diversity	Meaningful places and valued landscapes
	1. Crops	Not relevant as the prime intention is already crop production							
	2. Timber and wood	---	++						
	3. Water quantity		++						
	4. Climate regulation			++					
	5. Hazard regulation				++				
	6. Waste breakdown and Water purification					++			
	7. Wild species diversity						++		
	8 Meaningful places and Valued landscapes								

**Value of ecosystem service:**

High Medium Low

Loss of service --- Gain in service ++

**Interpretation:**

- Managed reedbeds are specifically managed to produce a crop of reed.
- Regular cutting precludes succession to scrub then carr, so the habitat would move to the fen category if there was intention to allow it to succeed to woodland.
- Storage of water in summer may alleviate summer flooding elsewhere. Managed reedbeds are always located on Floodplains, which are then inevitably no longer natural as the water levels are manipulated for reed production. Reedbed management reduces the overall capacity of the Floodplain to store water, while potentially preserving the Floodplain from complete drainage.
- Carbon storage is minimal under management conditions as the potentially stored carbon is removed to roofs. The half-life of the carbon compounds will be long (decades), but still shorter than if they had been stored as waterlogged peats (millennia).
- See 3.
- Reedbeds will denitrify nitrate in summer; indeed, specifically managed, constructed Wetlands are currently used to do this. They may retain heavy metals and other pollutants temporarily, but as the peat builds up, they dry out and cease to function as reedbeds. Digging out or burning to reduce the soil level will obviate this storage.
- Managed reedbeds provide very little diversity because they are maintained as near monocultures. Cleaning reed of other species to create bundles of thatch is expensive and to be avoided. Birds like bittern (*Botaurus stellaris*), Cetti's warbler (*Cettia cetti*) and bearded tit (*Panurus biarmicus*) are associated with reedbeds, but less so with the commercially managed ones than with those that are components of natural Floodplains.
- The noise of wind in the reeds, the visual appeal of rural industries, the great swathes of beige-yellow reed stems, and the attractiveness of thatched roofs all contribute to the importance of reedbeds in the landscape to recreational users of these habitats, such as walkers and boaters. Countless calendars and boxes of biscuits and chocolates use photographs on these themes. Tourist Boards in Eastern England regularly use pictures of wind pumps, sailing boats and sunsets within the settings of common reed. Reed areas, however, have declined since the Second World War as reed production demands expensive labour, traditional crafts are declining, and cheaper reed imports come from Eastern Europe. Much of the former managed reedbed resource has succeeded to scrub and alder woodland.

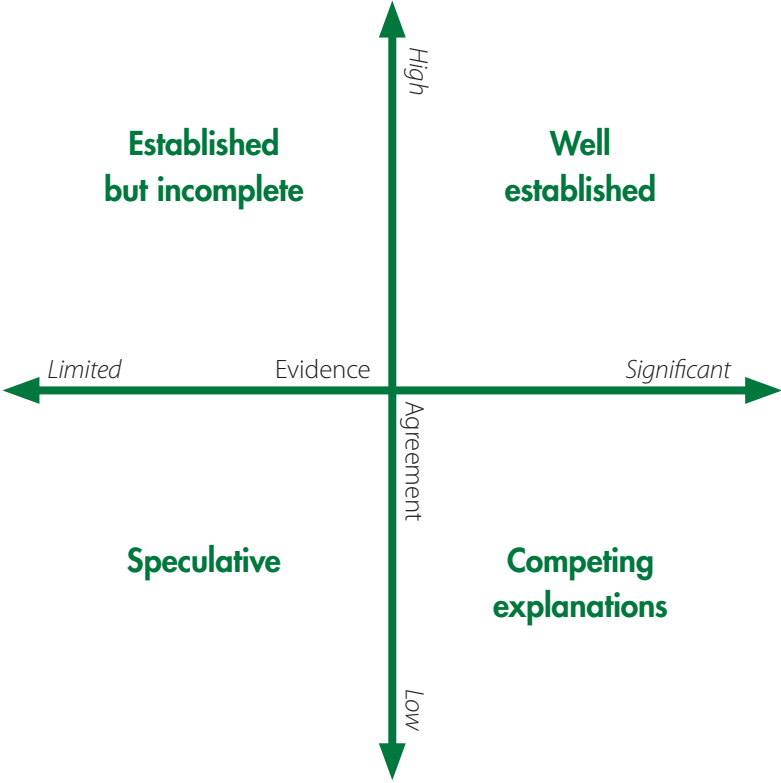


# Appendix 9.5 Approach Used to Assign Certainty Terms to Chapter Key Findings

This chapter began with a set of Key Findings. Adopting the approach and terminology used by the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Assessment (MA), these Key Findings also include an indication of the level of scientific certainty. The ‘uncertainty approach’ of the UK NEA consists of a set of qualitative uncertainty terms derived from a 4-box model and complemented, where possible, with a likelihood scale (see below). Estimates of certainty are derived from the collective judgement of authors, observational evidence, modelling results and/or theory examined for this assessment.

Throughout the Key Findings presented at the start of this chapter, superscript numbers and letters indicate the estimated level of certainty for a particular key finding:

- |  |   |
|--|---|
| 1. <i>Well established:</i>                    | high agreement based on significant evidence    |
| 2. <i>Established but incomplete evidence:</i> | high agreement based on limited evidence        |
| 3. <i>Competing explanations:</i>              | low agreement, albeit with significant evidence |
| 4. <i>Speculative:</i>                         | low agreement based on limited evidence         |



- |                                   |                                |
|-----------------------------------|--------------------------------|
| a. <i>Virtually certain:</i>      | >99% probability of occurrence |
| b. <i>Very likely:</i>            | >90% probability               |
| c. <i>Likely:</i>                 | >66% probability               |
| d. <i>About as likely as not:</i> | >33–66% probability            |
| e. <i>Unlikely:</i>               | <33% probability               |
| f. <i>Very unlikely:</i>          | <10% probability               |
| g. <i>Exceptionally unlikely:</i> | <1% probability                |

Certainty terms 1 to 4 constitute the 4-box model, while a to g constitute the likelihood scale.