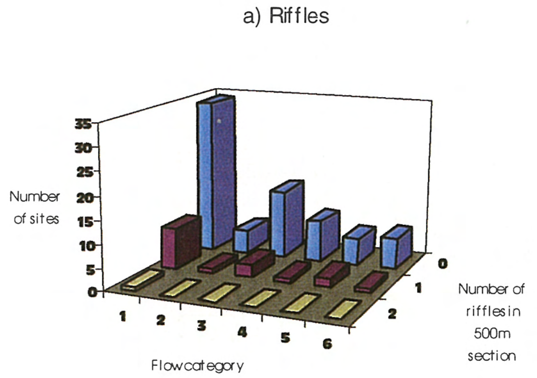


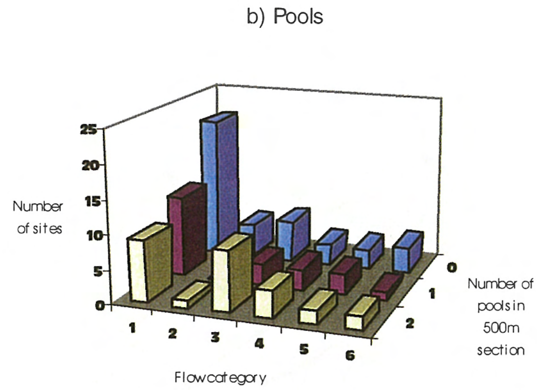


Figure 5.2 Occurrence of riffles at RHS sites in chalk river SSSI catchments.

5.4 Low flows

5.4.1 Ecological effects

The causes and main consequences of low flows in chalk rivers are summarised in Figure 5.3. Effects on the biota are associated with reduced current velocities, the loss of water depth and the drying out of marginal and riffle areas, reduced dilution of effluents, increased water residence times in the river, and reduced reoxygenation from turbulent flow and weirs. Reduced current velocities make conditions less suitable for the many rheophilic (current-loving) species inhabiting chalk rivers, including brook water crowfoot, salmonid species and riffle-dwelling invertebrates, and reduce the ability of the river to maintain the clean gravels required by them (Section 5.5). Decreases in water depth reduce the total habitat resource and concentrate fish and invertebrate populations into smaller areas where competition and predation are enhanced. In the upper reaches, winterbourne habitat effectively shifts downstream and the dry upper reaches become dominated by non-aquatic grasses. Access through instream structures becomes more difficult for migratory species, whilst water quality deteriorates due to a combination of reduced effluent dilution, increased residence times and reduced reoxygenation. Higher residence times and nutrient concentrations in the growing season provide greater scope for the development of algal populations.

Chalk river systems tends to suffer heavily from low flow problems, being concentrated in the heavily populated south and east of England where water demand is high and rainfall is relatively low. Many are therefore on the Environment Agency's list of rivers for priority attention (the Alleviation of Low Flows, or ALF, programme). Although not proven, the Hull, Mimram, Ver, Kennet and Wylye are all examples where natural seasonal declines in *Ranunculus* are likely to have been greatly enhanced by groundwater abstractions. The Ver is a prime example, which confirms both the impacts of abstraction and the recoverability of chalk stream communities once impacts are removed. Cessation of pumping at a major groundwater abstraction site in 1993 soon resulted in the return of perennial flows, and within three years brook water-crowfoot had returned to a site that had been dry for years.

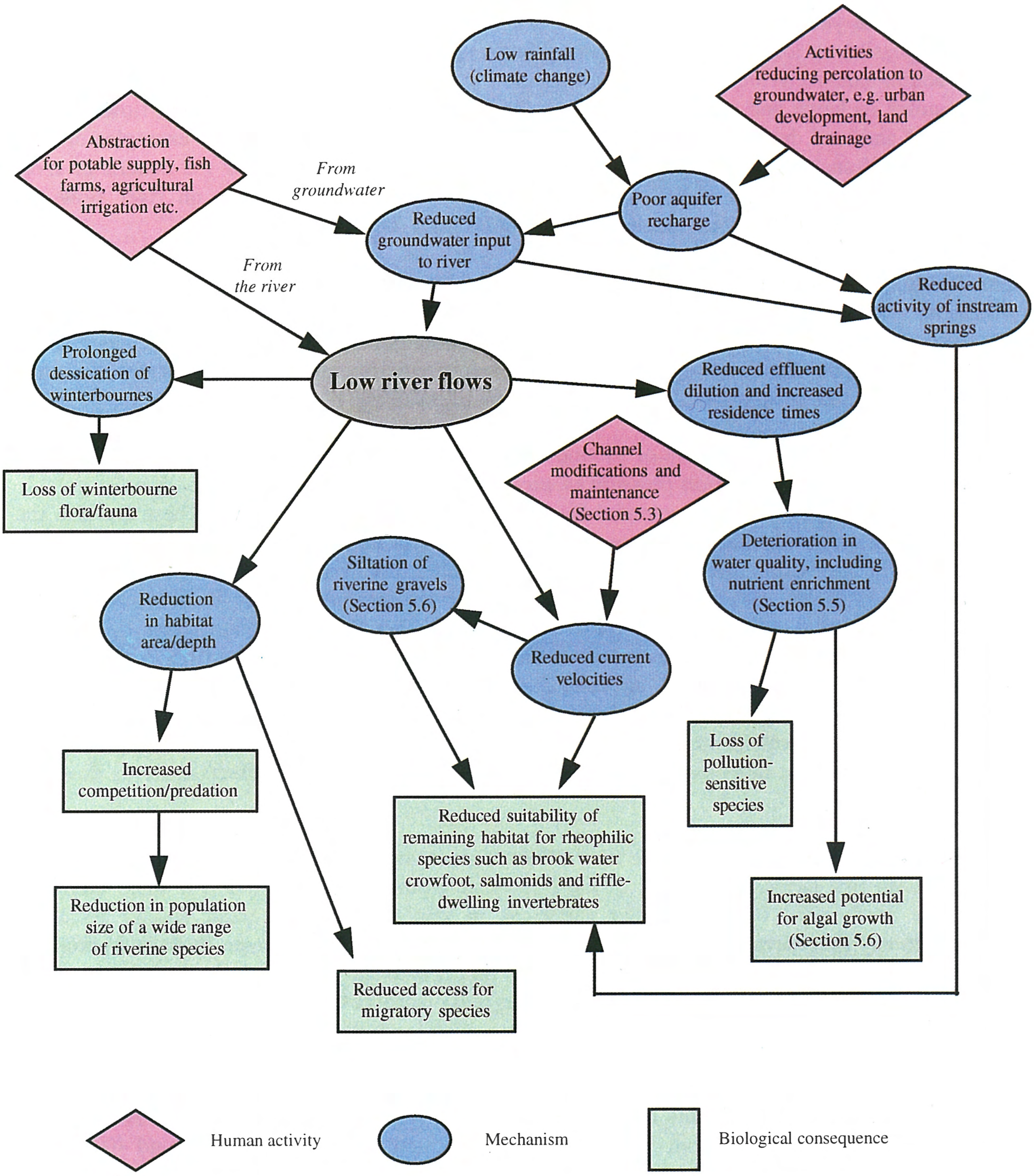


Figure 5.3 **Causes and consequences of low flows in chalk river systems.**

5.4.2 Sources of impact

Year-to-year variations in rainfall, including long-term climate change, are fundamental factors in generating low flow conditions in chalk rivers; however, climatic influences are beyond the control of local management. Man-induced alterations to hydrological pathways within the catchment represent a second-tier of influence on river flows, heightening the impact of drought years and creating low-flow problems in years of normal rainfall. Unlike the impact of drought years, where ecological recovery is possible as long as other environment factors permit, the influence of abstractions on river flows is continuous. Activities that reduce percolation to groundwater and catchment water retention reduce aquifer recharge and erode the ability of the river network to sustain summer flows. Urban development and land drainage for agricultural improvement are the most obvious examples of this, but the effect of such activity is greatly dispersed and difficult to manage for the benefit of river flows. The most individually significant and controllable artificial influences on river flow are abstractions, and it is on these that management attention must focus.

Abstractions of most concern are those that divert water out of a catchment, so-called 'consumptive' abstractions. These represent a permanent loss to the river network that affects all reaches downstream of the abstraction point. The majority of abstractions are non-consumptive, where water is generally not lost to the river network as a whole, but is redistributed within it such that shortfalls can occur between the point of abstraction and the point of discharge back to the river.

Owing to the generally high quality of groundwater in chalk catchments (a statement that is being strained by the increased pollution pressure of recent decades), groundwater abstraction for potable supply is common and has a high potential for ecological impact in chalk rivers. These are also the abstractions that are most likely to be consumptive. Fish farms are an important influence on chalk rivers, generally abstracting directly from the river and often taking large volumes of water. Farms with 'licences of right' can be legally entitled to abstract far more water than is ecologically sustainable, in extreme cases equating to the entire dry weather flow. Although water is generally returned within a few kilometres of river length, the combined effect of a series of fish farms along a river can be significant. In addition, any one farm may reduce river flows to a point where free passage of migratory species along the river is affected. Spray irrigation for agriculture adds a further stress at a time when river flows are already low. It should also be noted that initiatives to restore water meadows represent non-consumptive abstractions that have potential effects on river flow and ecology.

Whilst it is straightforward to assess the local effect of river abstractions on river flow, such as those associated with fish farms, assessment of the effects of groundwater abstraction is more complex. Impacts are confounded by year-to-year variations in rainfall and subsequent aquifer recharge, together with any long-term trends in recharge rate generated by climate change. In order to properly understand the situation, a sophisticated hydrological model is usually required. Once such a model is calibrated against real data on river flow, abstractions and discharges can be hypothetically 'switched off' to simulate 'naturalised' river flow. Results of a model simulation on the River Wye, a chalk stream tributary of the Thames, are shown in Figure 5.4. The river was once renowned for its vigour and supported 29 water mills along its short length, but is now much reduced in strength. The model simulation indicates an approximate 80% reduction in dry weather flow through the town of High Wycombe as a result of abstractions, together with a reduction in peak flows of around 40 to 70%. Using such models, abstraction rates at different boreholes can be hypothetically altered and other alleviation options can be simulated in order to identify a suitable programme of mitigation measures (see Section 6.2).

5.4.3 Evaluating ecological flow requirements

A proper assessment of the flow requirements of riverine communities involves constructing relationships between habitat conditions and river discharge, requiring a knowledge of the hydraulics and geomorphology of the channel, including any significant obstructions to the passage of migratory species. Habitat conditions are typically expressed in terms of factors such as depth and current velocity, and the habitat resource can be expressed as 'usable area' in relation to defined parameter thresholds (such as above 30 cm depth). This information can be used to assess how conditions appropriate to particular target species (or life stage thereof) change with river discharge, as long as the requirements of target species are known. Comparison of current river discharges with historical discharge rates gives an indication of how available habitat has changed over time.

The model PHABSIM (Dunbar *et al.* 1996) enshrines the current understanding of the habitat requirements of key species (and life stages thereof) within Habitat Suitability Curves, describing changes in habitat suitability with changes in individual physical factors or combinations of factors. Such curves have now been defined for a range of UK species, derived from expert opinion, information in the literature, and field observations as necessary. These are used to estimate the usable area of a watercourse for a particular species or life stage under different rates of river discharge. Combining this output with a time series of flows yields a habitat duration curve, which estimates the percentage of time a specified habitat condition is equalled or exceeded. PHABSIM has been used on a range of UK chalk rivers, including the Allen (Johnson *et al,* 1995), Piddle (Johnson and Elliott, 1997), Wylye, Babbingley (Petts *et al,* 1996) and Wissey (Petts, 1996).

In chalk streams and many other river types, brown trout is the typical target species chosen, exhibiting a range of habitat requirements at different life stages. Many rheophilic species will have similar basic requirements and so will be reasonably well served by the use of brown trout as a target species. However, species of particular conservation importance in chalk rivers can have very different requirements to brown trout, and so it is important that such species are considered separately. Unfortunately, there is a lack of understanding and/or quantification of the requirements of many endangered species.

5.5 Siltation

Clean gravel substrates are a key habitat requirement of a range of riverine species typical of chalk rivers (Section 4), and their maintenance is therefore vital to the proper functioning of characteristic chalk river communities. Brook water-crowfoot thrives in this habitat, with germination rates and establishment from shoot fragments likely to be much poorer as silt content increases. Seeds of the species appear to rarely germinate in soft silt, and any that do so have restricted initial root development that provides no firm anchorage against river flow. *Ranunculus peltatus*, the characteristic crowfoot of winterbournes, has similar difficulties in submerged silt but can utilise consolidated silt after a period of drying (see Section 4.2). Established *Ranunculus* plants reduce their root length in response to siltation, making them more vulnerable to untimely wash-out and replacement by species more suited to fine substrates. The inability of the species to adjust its rooting level in the face of high siltation rates puts it at an additional disadvantage compared to more flexible species such as water-cress.

A range of benthic macroinvertebrate species are also dependent upon gravel habitat, and in winterbourne sections clean gravels with abundant interstices are a crucial refuge for specialist organisms during periods of no flow. Fish species with an intra-gravel spawning habitat, including brown trout, salmon, the three lamprey species and dace, are all dependent upon gravels with a low silt content. As silt accumulates in spawning substrates, egg and alevin survival drops due to lack of interstitial water flow and consequent reductions in dissolved oxygen. This effect is more acute if the silt carries a high proportion of degradable organic material.

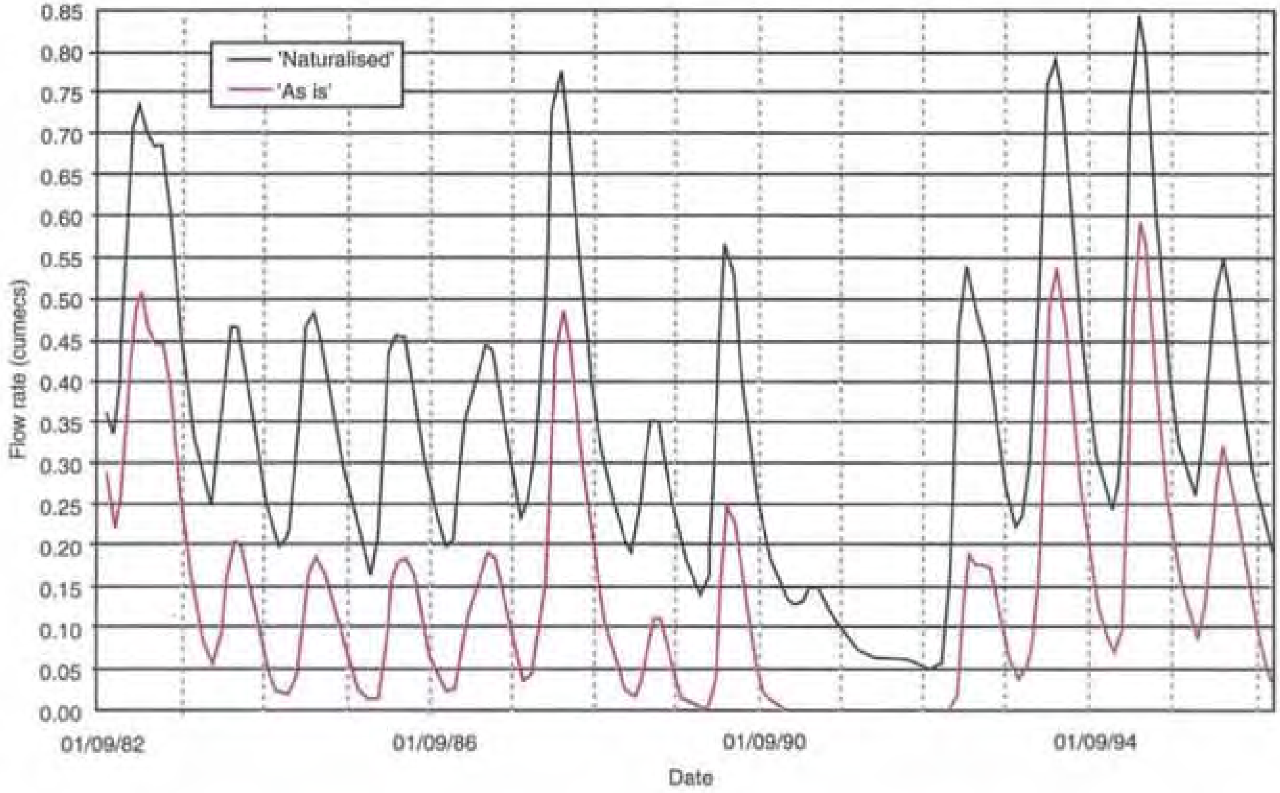
This said, silt is a crucial component of the habitat matrix so typical of chalk river systems and it is important that a proper perspective is maintained when discussing the problems of siltation and planning mitigation measures. Many chalk river species are dependent upon silt for all or part of their life cycle (Section 4). The larvae of all three species of lamprey reside exclusively in silt beds, as does the characteristic plant whorl-grass. Beds of starwort, a typical feature of the chalk river habitat mosaic, require high silt levels to compete effectively with other submerged species. Invertebrate species such as the burrowing mayfly *Ephemera danica* also require silty habitats. The key point is that clean mid-channel gravels have to be maintained *as part of a habitat mosaic that includes silt banks and silted coarse substrates*.

As mentioned previously, chalk river systems have limited natural flushing capacity and are therefore highly susceptible to siltation of gravels. It has been estimated that natural freshets in chalk rivers only scour the top few centimetres, and extensive silt deposits have been found in gravels down to a depth of at least 50 cm. Considering that salmonids generally cut redds down to a depth of 20 or 30 cm (average of 12-15 cm), the situation is highly precarious for salmonid species and other lithophilous spawners in chalk rivers. Surveys by IFE (Beaumont *et al.* 1995) have revealed that many salmonid rivers in southern England have silt contents lying close to the threshold value for salmonid survival (taken as 20% fines). However, the occurrence of upwelling flows from in-channel springs within chalk rivers is likely to reduce the effects of fines relative to other lowland river types, an alleviating factor that can be impaired by low flows (see Section 5.4). It is also important to note that a thriving salmonid population can greatly influence the quality of its spawning gravels through the action of redd-cutting, which can dislodge large amounts of interstitial silt. Impacts upon salmonid populations due to siltation and other factors affect spawning activity and reduce the efficacy of this self-cleaning process, introducing a negative feedback loop into the siltation process.

An outline of the causes and consequences of siltation in chalk rivers is given in Figure 5.5. Whilst increased particulate inputs to the system and low flows appear to be the main culprits, the situation is exacerbated by the reduction in river/floodplain interactions, the development of oversized channels, the presence of in-river structures, heavy weed-cutting programmes (these last three factors reduce current velocities and therefore scouring forces), and additional factors contributing to salmonid population decline (reducing redd-cutting activity). Importantly, whilst the deposition of fine silts results in deep infiltration of gravels, the deposition of coarser sands and fragments of tufa (a product of the precipitation of calcium out of solution) can result in the development of a consolidated layer (or 'armour' layer) just below the gravel surface that is resistant to scour during high flows. This effect makes the self-cleaning of silted gravels through natural processes very difficult and necessitates some artificial interference. Gravel cleaning has been practised for centuries by river keepers to improve chalk streams for salmonid spawning (Plate 24), well before any post-war agricultural intensification or recognised low-flow problems. The need for such cleaning has increased in post-war decades, due to enhanced sediment loads and reduced scouring, at the same time the practice has declined.

Given the natural lack of energetic flushing flows, chalk rivers must rely heavily on receiving low inputs of solids and the maintenance of these inputs in suspension over bare gravel. Where significant accumulation occurs, physical disturbance is likely to be required in addition to hydraulic scour to remove material, either through redd-cutting, the ripping out of plant root masses under high flows, or artificial gravel cleaning. The physical filtration of the majority of stream flow through the chalk aquifer means that solids levels are naturally low throughout the year, but loads are greatly enhanced by a range of human activities (see Box 1). Even under high flows, the deposition of suspended material can be high in bare gravel, where water forces its way into the permeable gravel layer and leaves its silt load behind in the gravel interstices. This is particularly noticeable in recently cut salmonid redds, where in-filling has been observed during high winter flows (Acornley and Sear in press). This means that even if gravels are clean at the onset of spawning (typically autumn), they can become inhospitable to eggs and fry during the incubation phase, thereby placing a heavy emphasis on effective control of solids inputs (and particularly diffuse inputs) to the system.

Figure 5.4 **Model simulation of the effect of abstractions on the flow of the River Wye through High Wycombe (after Buckland *et al*. 1998).**



Box 1. Sources of particulate loads to chalk river systems.

The relative contribution to the solids budget from near- and far-field diffuse sources is a subject of great debate. Bank erosion generated by intensive livestock grazing can contribute large loads (for instance, Rabeni and Smale 1995) and is an obvious target for mitigation measures, but the contribution from the wider catchment is also highly important. Chalk downland naturally generates relatively little overland flow to the river (the principal pathway for particulate inputs), owing to the high permeability of the geology and the low drainage density of the river network. Even during winter rainfall events the majority of run-off entering the river is derived from shallow aquifers and sub-surface drainage. However, overland flow can be greatly enhanced by artificial hard surfaces, such as farm tracks of compacted soil (particularly if located in the bottom of dry valleys), rural roads and urban areas, and also by the presence of superficial deposits of impermeable clay overlying the chalk.

Widespread ploughing and intensified grazing of downland over recent decades has rendered the thin, inorganic soils characteristic of chalk downland highly vulnerable to erosion, and artificially created run-off pathways have provided improved access for particulate run-off to the river network. In the floodplain, intensive arable cultivation up to the bank edge has been a feature of agricultural intensification over the past few decades and represents a high risk, in terms of both particulate run-off during rainfall and soil loss during occasional flooding events. The change in arable cultivation practices from spring sowing of cereals to autumn sowing of cereals and fodder crops has resulted in bare and unstable soils over the winter period of high run-off, creating greatly enhanced scope for particulate delivery to the river network. The permanently bare soils associated with increasing areas of free range pig production are also of concern, as well as an observed trend towards potato cultivation (which provides poor binding of the soil matrix).

The activities of the Ministry of Defence (MOD) are worthy of mention, since they have large landholdings in a number of chalk river catchments (such as the Hampshire Avon). Whilst most of their land is given over to rough grassland for training purposes, soil disturbance and the creation of highly compacted tracks by to heavy vehicles create the potential for enhanced delivery of particulate loads that should be considered. Particularly high risk situations occur when tank tracks run across a river or stream, generating a concentrated run-off pathway with rapid access to the river network.

Where arable cultivation is widespread, the role of the floodplain in sediment cycling is effectively reversed, since it now acts as a source of silt instead of the sink it has historically been, particularly during occasional overbank flooding episodes. The role of riparian meadows as a sediment sink was greatly enhanced during the days of water meadow operation, when overbank flooding was not necessary to carry river water over adjacent pastures and deposit silt prior to returning to the river. Under-drainage of floodplain land may lead to enhanced solids loads if the soil is cracked or contains macropores that allow easy access to tile drains.

Point source inputs can be substantial, particularly from fish farms and commercial cress beds without physical treatment. Whilst sewage treatment works can generate significant loads, secondary treatment is the norm and they therefore carry comparatively low solids loads. It has been estimated that a large cress farm without any form of sediment trapping can deliver 100 tonnes of particulates per year (Casey and Smith 1994), whilst a sizeable fish farm (say 40 tonnes annual production) without effluent treatment can generate 54 tonnes (derived from figures given by Solbe 1982), equivalent to sewage treatment works with secondary treatment serving 34,000 and 63,000 population equivalents respectively. Many fish and cress farms now remove solids using settlement lagoons, but their proper maintenance is vital to high removal efficiency. The presence of fish in settlement lagoons disrupts the laminar flow necessary to generate sedimentation, whilst failure to clean lagoons out at regular intervals reduces residence time and therefore solids removal. Keeping lagoons on line whilst they are emptied can result in large pulses of solids entering the river.

It is important to note that the organic content of accumulated silt will vary depending upon the importance of different sources: point sources are typically organic in nature (particularly sewage treatment works, fish farms and cress farms), whilst diffuse sources generally produce inorganic soil particles. This is reflected in seasonal variations in the organic content of suspended solids in the river: summer flows are dominated by point sources and carry suspended solids with high organic content; winter flows carry particulate run-off from the catchment and carry solids with low organic content. *This means that years of poor aquifer recharge produce greatly increased scope for siltation from organically enriched point sources, through increased summer sedimentation and reduced winter flushing, whilst years of normal or high rainfall provide more scope for siltation from inorganic particulates in diffuse run-off.*

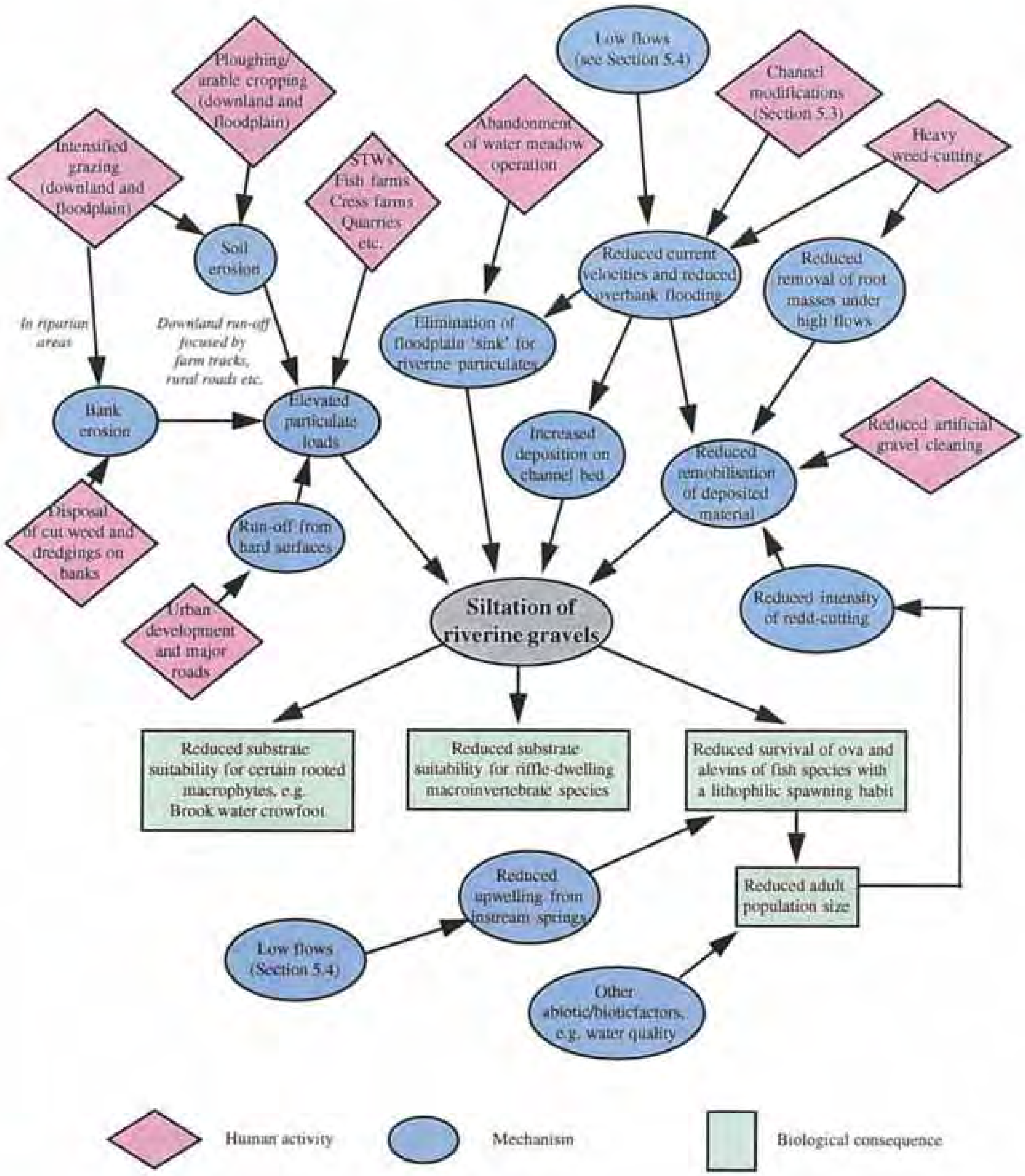


Figure 5.5 Causes and consequences of siltation in chalk river systems.

Plate 23 Resectioning on the River Lark, leaving a straightened and over-deep channel with greatly reduced habitat diversity

Plate 24 A recent attempt to revive traditional methods of gravel cleaning in chalk streams.

5.6 Nutrient enrichment

5.6.1 Mechanisms of effect

Concern over elevated nutrient levels in rivers is focused on the direct effects on plant populations, with secondary effects on other components of the biological community dependent upon plants for shelter, reproduction and food. In addition to nutrients, riverine plants are strongly affected by a wide range of environmental factors, including substrate type, current velocity, catchment geology and resulting water chemistry and the level of shading. It is often difficult to disentangle the effect of these different influences, thereby obscuring the impact of nutrient enrichment. Figure 5.6 summarises the causes and consequences of enrichment in chalk rivers.

Of the major plant nutrients, phosphorus is typically in shortest supply in freshwaters and so has the greatest potential to limit plant growth. Increasing phosphorus availability can affect plant growth rates and standing crop and consequently the competitive balance within riverine plant communities. In addition to affecting the physical habitat afforded to the aquatic fauna, such changes can lead to severe nocturnal sags in dissolved oxygen (due to plant respiration) that stress the more sensitive animal species and may result in reduced survival rates. There are four principal ways in which elevated phosphorus levels can affect riverine plant communities in chalk rivers:

1. by increasing growth rates and thereby creating a large standing crop that regrows rapidly following management;
2. by the encouragement of rooted plant species whose growth rates are geared to higher nutrient levels, thereby altering species composition/balance;
3. by increasing growth rates of epiphytic and filamentous algae, thereby reducing the amount of light reaching rooted plants and shifting community balance towards shade-tolerant species and ultimately algal dominance;
4. by reducing rooting depth and thereby making plants more susceptible to being ripped out of the substrate.

For any of these mechanisms to operate in response to artificially enhanced phosphorus concentrations, background levels of phosphorus in the river have to lie below the threshold concentration that triggers an effect. If this is not the case, no effect of increasing phosphorus levels above background concentrations can be expected. The threshold concentration will vary between mechanisms and also environment compartments (i.e. the water column and the substrate).

Mechanisms (1), (2) and (4) are probably dependent upon phosphorus levels in both the sediment and the water column (Mainstone *et al.* 1998), whilst mechanism (3) acts largely through phosphorus uptake from the water column (although benthic forms of algae will probably receive phosphorus from the sediment as well, whilst epiphytes can derive at least some of their requirements from the host plant). Little detailed work has been undertaken on the identification of critical levels of sedimentary phosphorus that shift the balance between different rooted plant species, but somewhat more is known about the risks from mechanism (3) due to extensive work on algal growth rates at varying levels of ambient SRP (see Box 2). The main point from such work is that phosphorus has the potential to greatly affect the growth rate of individual algae at concentrations up to 200-300 $\mu g\ l^{-1}$ and probably beyond. Increases in riverine concentrations from likely background concentrations of less than 0.04 $mg\ l^{-1}$ (see Section 2.3) to such levels are therefore potentially extremely important to the ecology of the river.

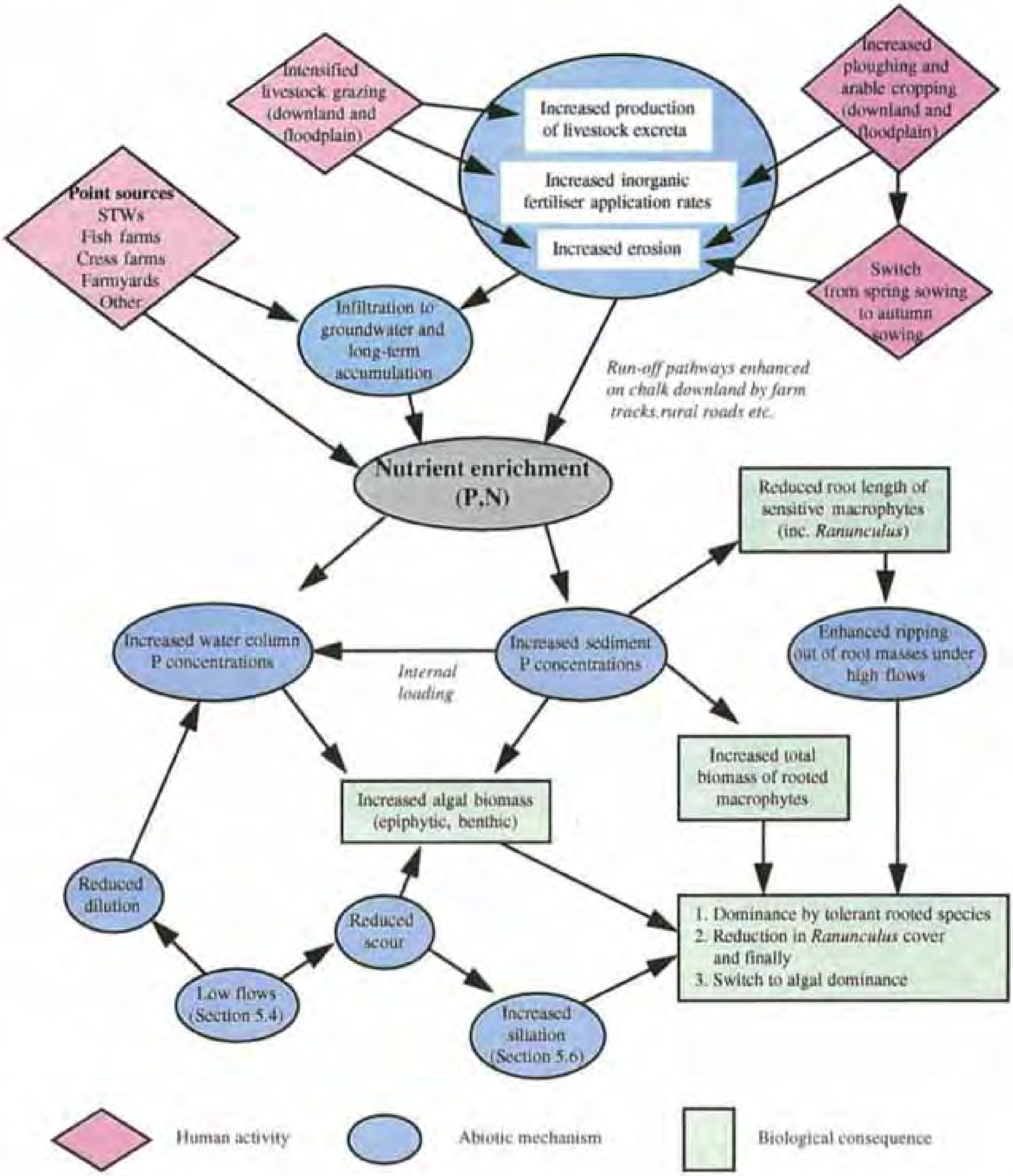
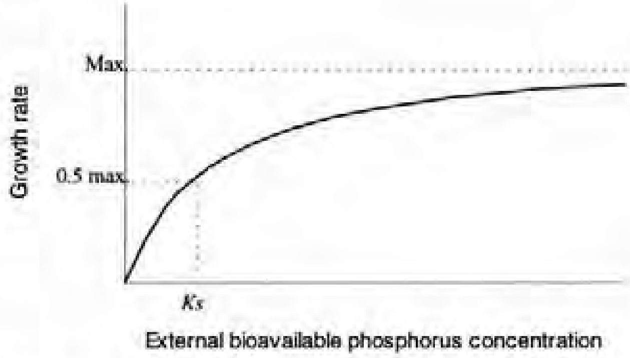


Figure 5.6 Causes and consequences of nutrient enrichment in chalk river systems.

Box 2. The effect of phosphorus on algal growth rates (from Mainstone *et al.* 1998).

Two basic equations can be used to describe nutrient-limited growth by algae. The Monod equation relates growth rate to external nutrient concentrations, while the Droop equation relates growth rate to intracellular nutrient stores (Kilham and Hecky 1988). The Monod model describes simple Michaelis-Menten kinetics, and includes a half saturation coefficient, *Ks*, the external nutrient concentration at which half of the maximum growth rate is achieved (see figure below). *Ks* values are often cited to support the idea that the growth rate of the algal community as a whole is only limited at P concentrations of <10 μg l^{-1}. Reported *Ks* values for individual species range between 1 and 364 μg l^{-1} (Reynolds 1984), such that at any concentration within this range some species will be growing at their maximal rate. However, it is self-evident that the growth of individual species may be limited at concentrations substantially greater than 10 μg l^{-1}. Substantial increases in growth are possible even above the *Ks* value of a species, as is evident from the figure below.

The Monod model of plant growth kinetics



Algae, which dominate at high phosphorus concentrations, appear to have high *Ks* values and are out-competed at lower concentrations by algae with low *Ks* values. They are sometimes, but not always, faster growing than those, which dominate at lower concentrations. In any case, higher algal standing crops may be achieved by such algae by a number of different methods, such as:

- being less pallatable, so grazing losses are lower;
- being physically stronger or more streamlined, so scouring losses during high flows are lower; or
- being adapted to photosynthesise at lower light intensities, so self-shading does not become limiting until higher standing crops are reached.

All of these mechanisms can work to produce greater algal problems in rivers as phosphorus concentrations increase from natural/background levels to 200-300 μg l^{-1}.

While emphasis is often placed on the Monod equation, the Droop equation often better describes algal growth rates in culture and natural systems (e.g. Hecky and Kilham 1988), since algae are able to accumulate nutrients internally when external nutrient levels are higher than those strictly required for spontaneous growth. This intracellular nutrient store can then be utilised when external nutrient availability becomes growth-limiting. This is an important issue, since this 'luxury uptake' increases the importance of phosphorus at times in the year when concentrations are too high to be limiting the growth of any algal species. If concentrations subsequently decline to levels that are potentially growth limiting (perhaps due to increased spring flows), algal species with high *Ks* values can produce and maintain high standing crops despite low external phosphorus availability.

For algae such as *Cladophora*, both intracellular and extracellular nutrient concentrations are critical to understanding growth (Auer and Canale 1982a, b Auer *et al* 1982). Canale *et al* (1982) and Canale and Auer (1982) discuss the seasonal and spatial variations in growth kinetics, and the development of a model for studying growth control strategies. Despite the fact that intracellular P concentrations are critical to understanding the growth dynamics of *Cladophora*, there is often a close relationship between extracellular and intracellular phosphorus concentration. For instance, Wong and Clark (1976) reported a correlation coefficient (r^2) of 0.76 between the two concentrations. Thus, Painter and Jackson (1989) were able to simplify the *Cladophora* model of Auer and co-workers (*ibid.*) by simulating internal phosphorus concentrations using temperature, Secchi depth and SRP concentration.

Maximum standing crops of *Cladophora* have been reported at water column concentrations of between 60 and >1000 μg SRP l^{-1} (e.g. see Cartwright *et al* 1993), but peak growth rates appear to be reached at a concentration between 60 and 200 μg SRP l^{-1} (see Woodrow *et al* 1994).

The overall effect of these four mechanisms as phosphorus concentrations are sequentially elevated is to firstly increase plant biomass, then to shift community balance towards those species most tolerant of high nutrient status (with subsequent declines in diversity), and finally to induce a switch to an algal-dominated community. The process can be rapid if phosphorus loads are increased quickly, or more insidious as phosphorus accumulates in the catchment and in riverine sediments. Secondary consequences are more violent diurnal fluctuations in dissolved oxygen levels and consequent stress on aquatic fauna, and ultimately loss of vital vegetative habitats as the diverse plant assemblage is depleted and then effectively eliminated by algae. Table 5.3 lists those rooted species inhabiting chalk rivers that are thought to be most influenced by nutrient enrichment and siltation, the two being dealt with together as their effects are difficult to disentangle. Brook water-crowfoot is the greatest victim of nutrient enrichment, although at modest levels of enrichment standing crop is likely to be boosted before pollution-tolerant species assume dominance.

Table 5.3 Plant species particularly affected by nutrient enrichment and siltation in chalk rivers

Species	Nutrient enrichment			Siltation
	Slight	Mod./High	Very high	
Ranunculus pen. subsp. pseudofluitans	↗	↘	↘↘	↘
Catabrosa aquatica				↗
Veronica anagallis-aquatica				↗
Callitriche stagnalis				↗
Elodea nuttallii		↗	↗	↗
Callitriche obtusangula				↗
Berula erecta				↘
Zannichellia palustris	↗	↗↗	↘	↗
Potamogeton pectinatus	↗	↗↗	↘	↗
Lemna minor	↗	↗↗	↘	
Amblystegium riparium	↗	↗↗	↘	
Vaucheria agg.		↗	↗↗	↗
Cladophora glomerata		↗	↗↗	
Enteromorpha		↗	↗↗	

↗ Beneficial; ↘ Adversely affected.

Effects are highly confounded by other environmental factors (Box 3), so it is vital to understand the role of phosphorus enrichment in setting the underlying potential for impact. Studies where the role of phosphorus has been unequivocally demonstrated in the field are rare. The scope for increased algal growth in chalk rivers has been demonstrated in the River Hull (Carr and Goulder 1990), where *ex situ* growth assays of phytoplankton and periphyton in waters upstream and downstream of a fish farm discharge demonstrated substantially increased growth potential in downstream waters. Detailed analysis of the distribution of plant species and relationships with riverine conditions can also provide insights, as long as the effects of confounding environmental factors are minimised through the judicious selection of study sites. Such work on selected chalk streams in France (Robach *et al.* 1996 and described in Mainstone *et al.* 1998), has identified plant groupings with strong relationships to water column phosphorus concentrations. These French study rivers are under less human pressure than English examples and are therefore of considerably lower nutrient status, with mean SRP concentrations at most study sites ranging from less than 10 μg l^{-1} to 40 μg l^{-1} (up to 150 μg l^{-1} at the most enriched sites).

It is important to recognise that phosphorus concentrations in the water column can exert an effect on the balance between plant and algal populations even though observations can be made of large algal populations in chalk streams where water column phosphorus concentrations are relatively low. Algal populations will eventually reach high densities at a wide range of phosphorus concentrations, as long as other factors remain conducive to their survival and growth. However, concentrations of up to 0.3 mg l^{-1} SRP can allow populations to reach high densities much quicker than likely background concentrations in chalk rivers. Elevated levels of phosphorus can therefore bestow on algal populations an increased capacity to respond quickly to suitable environmental conditions and achieve dominance over rooted plants. It should also be noted that algal cells have the ability to store phosphorus during periods of high availability, to be used when it is in short supply. This means that growth rates can be much higher than ambient SRP levels for up to 5 cell divisions (Maestrini and Kossut 1981), further obscuring links between algal problems and ambient phosphorus concentrations (see also Box 2).

5.6.2 Nutrient sources and their significance

Principal sources and routes of entry into the river system are outlined in Figure 5.6 and are discussed in detail in Box 4. The relative importance of diffuse and point source loads will vary from catchment to catchment and reach to reach depending on the intensity of different human activities. Annual nutrient budgets can be constructed through the use of export coefficients and information on land use and populations served by different treatment works. It should be stressed, however, that the confidence associated with the use of export coefficients is low and that any such budget should be calibrated against load data calculated from river flow and concentration data. It is important to note that although such annual budgets can provide a reasonable apportionment of the load entering the river system, they are potentially misleading in assessing the relative importance of sources to instream nutrient concentrations.

The seasonality of loads from diffuse and point sources is the most important issue to consider. The majority of the diffuse load enters the chalk river system via overland flow or shallow sub-surface drainage over the winter months when soils are saturated and rainfall is at a maximum. The only way in which this load can make an important contribution to plant (macrophyte or algal) uptake of phosphorus through the growing season is if there is significant retention of phosphorus-rich particulates within the river channel until the following spring. Given the relatively low flushing flows generated by chalk rivers in winter and the widespread observations of siltation (see Section 5.5), this is likely to be an important mechanism for sediment eutrophication.

Owing to the low dilution afforded to continuous point sources during low flow conditions in the growing season, and the tendency for much of the non-point source load to be carried immediately out of the catchment under high winter flows, point sources can be considerably more important ecologically than their contribution to the annual budget suggests. The typical seasonality in SRP concentrations exhibited by many chalk rivers (Mainstone *et al.* 1998) is peak concentrations through the growing season, in spite of this being the most intense period of biological uptake. The implication is that point sources, and in particular sewage treatment works effluents (which form the majority of the point source load), typically constitute the main nutrient source for enhanced algal growth rates in the water column through the growing season. An alternative explanation is that release rates from the sediment are high during the summer months and therefore contribute substantially to observed water column concentrations. However, available measurements of release rates suggest that the effect of sediment release on water column concentrations during the growing season is low (Mainstone *et al.* 1996). In any case, it is possible that point sources play a significant role in sediment enrichment, through particulate deposition, chemical precipitation and biological uptake through the growing season (Mainstone *et al.* 1998).

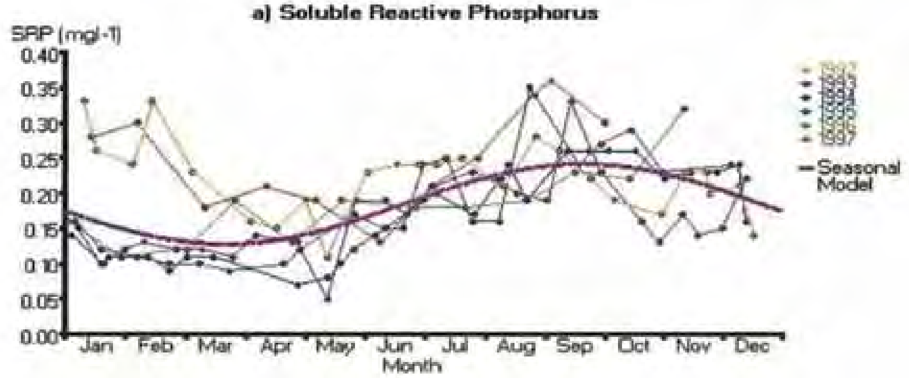
Guidance on the construction of nutrient budgets for rivers and information on phosphorus behaviour in the soil and riverine environments is given in Mainstone *et al.* (1996). Such budgets can be used as a starting point in considering appropriate targeting of control measures, followed by more detailed modelling of riverine phosphorus concentrations as necessary (also described in Mainstone *et al. ibid.*). The account of phosphorus behaviour given in Mainstone *et al.* (*ibid.*) addresses in detail the dynamic relationship between SRP and Total Phosphorus and the adsorption/desorption processes dictating phosphorus uptake and release to/from suspended solids and bed sediments. Ultimately, a knowledge of the concentrations of both SRP and Total Phosphorus in the water column, and the tendency of bed sediments to release phosphorus to rooted plants or the water column (given by the Equilibrium Phosphate Concentration or EPC), is a necessary precursor to a proper understanding of phosphorus behaviour within any given river. At present, only water column concentrations of SRP are generally available.

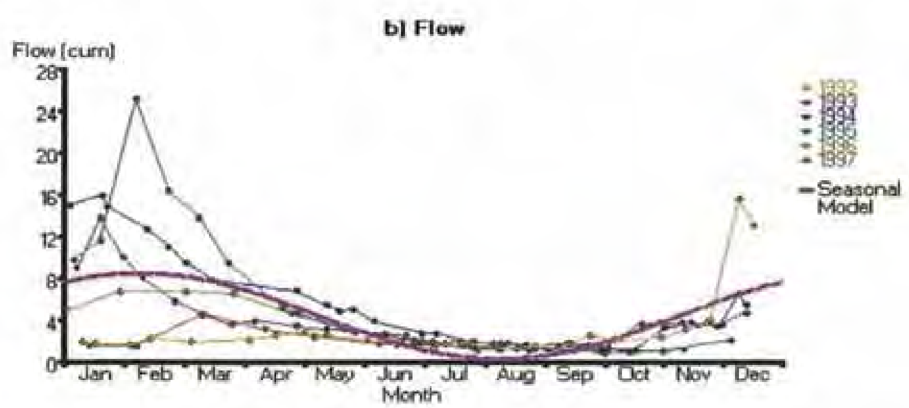
Box 3. Factors obscuring the effects of phosphorus in chalk rivers.

Many factors subject to anthropogenic change are recognised as influencing the composition and health of submerged plant communities in chalk rivers, including substrate coarseness and organic content, water turbidity, external shading (from trees and overhanging vegetation, trace nutrients (including substances such as vitamin B12 and thiamine) and grazing by herbivores of epiphytic and filamentous algae (Mainstone *et al.* 1998). The influence of current velocity on the health of *Ranunculus* beds is of particular relevance to chalk rivers.

In chalk rivers, current velocity is a principal factor influencing the health of *Ranunculus* beds. High current velocities over the winter are vital in washing out filamentous algal growth each year, preventing any cumulative growth from year to year that could otherwise smother the new spring growth of *Ranunculus* and other mid-channel plants. These high flows also help to wash out fine sediments from the gravel beds, priming them for new *Ranunculus* growth. It has been observed that, in years of low flow, epiphytic algal growth on *Ranunculus* tends to be thick and plant growth is poor; in years of high flow there is little epiphytic growth and *Ranunculus* beds are extensive. Whilst the current velocity generated by higher flows does seem to give *Ranunculus* greater resistance to epiphytic build up, it is not clear that current velocity is the only important factor involved in the tendency for algal domination in low flow years. Phosphorus concentrations in the water column also vary greatly with river flow.

Through the growing season in chalk rivers, bioavailable phosphorus concentrations in the water column generally appear to be driven by continuous point sources and the amount of dilution afforded by available river flow. Data from the River Wylye below illustrate the typical seasonality observed in SRP, peaking in summer at the time of minimum dilution despite being the time of highest biological uptake. A lower minimum dilution caused by a low-flow year gives rise to higher phosphorus concentrations, as is evident in 1992 and 1997. The effect is particularly noticeable in spring, the time of maximum *Ranunculus* growth. In cases where concentrations of SRP in the growing season lie below 0.3 mg l^{-1} in a typical year (such as in the Wylye), it is probable that the growth of certain epiphytic and filamentous algae in low flow years is enhanced by greater phosphorus availability. This would exacerbate any direct effects of reduced current velocity and make growth failure of *Ranunculus* more likely in any given year.





Box 4. Sources of phosphorus inputs to chalk river systems.

Sewage treatment works tend to dominate the point source load of phosphorus even in rural areas, although **fish farms** and **water-cress beds** can both be important contributors. A sizeable fish farm (say 40 tonnes annual production) with no effluent treatment can generate the same load of phosphorus as a sewage treatment works serving 1000 people (assuming secondary treatment). Whilst cress beds are amongst the smaller point sources, the usage of phosphorus per unit area is very high and plant uptake can be highly inefficient. This is of particular concern since cress farms often constitute the headwaters of chalk rivers, particularly in Hampshire where 80% of the national production is concentrated. Traditional methods of cress bed fertilisation involve the monthly application of 125 kg of slag, a powdery material containing around 6.5% phosphorus that is applied to the water surface and results in around 10-15% uptake efficiency (the rest being lost downstream). The losses from 1 hectare of cress beds under this system are equivalent to nearly 100 hectares under intensive arable production located on high-risk impermeable soils (Parr *et al.* 1998), much of which enters chalk headwaters during the growing season. More modern methods of fertilisation are now used by the larger growers (see Section 6.5), resulting in lower loss rates. Even so, Casey and Smith (1994) recorded a trebling of mean SRP concentrations in a chalk headwater due to a modern cress farm, from 25 $\mu g\ l^{-1}$ upstream to 72 $\mu g\ l^{-1}$ below the farm.

Discharges from **Ministry of Defence** (MOD) facilities are a concern in that the MOD have large landholdings in a number of chalk river catchments, and until recently their activities lay outside of the normal framework of environmental regulation. As a result, little is known about the phosphorus loads discharged in their effluents. **Industrial effluents** can also be important contributors of phosphorus, although the load varies greatly with the processes involved, such that generalisations are difficult.

Phosphorus binds strongly to the solid phase, with calcium and clay minerals being particularly important binding agents. The majority of phosphorus from **diffuse agricultural sources** is therefore generally delivered in surface run-off associated with the particulate phase (see Mainstone *et al.* 1996). The contribution from agricultural sources to chalk rivers can be greatly reduced compared to other river types through the processes of physical filtration and chemical adsorption within the chalk aquifer. However, particulate run-off from intensively farmed downland can be much higher than expected from such permeable geology, largely due to farm tracks, roads and dry valleys acting as run-off pathways for large areas of land and exacerbated by the presence of impermeable clay cappings over some areas (see Section 5.5). Enriched run-off from intensively grazed and cultivated land in the floodplain can also be important, particularly where arable cropping comes close to the bank edge, where arable fields are subject to inundation, and/or where rapid access to under-drainage systems is available through soil fissures or macropores. The phosphorus enrichment of particulate run-off from agricultural land has been extreme in recent decades, with farmers building up the phosphorus content of their soils as an insurance against any crop growth limitation. This has resulted in most lowland soils having far greater concentrations of extractable phosphorus than required by the crop (Mainstone *et al.* 1996).

Where the chalk is fissured (thus short-circuiting the filtration process) or where soils have been heavily overloaded with organic or artificial fertiliser over the course of many years (thereby contaminating the aquifer), baseflow in the river may begin to be enriched with phosphorus. Agriculture has intensified greatly in many areas of chalk downland over the past sixty years, resulting in the use of very thin and nutrient-poor soils for arable production and intensive grazing. Nutrient application rates to sustain arable crops and higher grass yields on such soils are very high, placing chalk aquifers (particularly shallow ones) in an extremely vulnerable position. *Whilst chalk has a large capacity for phosphorus adsorption and immobilisation, this route of riverine contamination needs to be monitored closely in areas where livestock farming and arable production is most intense, since the problem is long-term in both its making and in its resolution.*

Inputs from **farmyards** may be significant in certain areas, from sources such as yard washings and run-off, leaking or overloaded slurry stores, and leaking silage clamps. **Direct livestock access** to the channel can create an additional diffuse phosphorus load that may be significant, particularly as it creates a highly bioavailable load and tends to occur through the summer months when flows are at a minimum.

The relative contribution from the **unsewered human population** is difficult to estimate, since much of it may be transported periodically to treatment works and the movement of the rest of the load from septic tanks through the soil is very site specific (depending upon factors such as soil characteristics and the age of the system). It is fair to say that in rural parts of chalk river systems, the load from this source may well deserve greater attention in the future.

5.7 Hindrances to migration

5.7.1 Physical barriers

Free access between different sections of the river network is crucial to a wide range of species inhabiting chalk river systems (Section 4). Upstream passage is frequently blocked by artificial structures, particularly hatches and weirs associated with mills, abandoned water meadows or other abstractions.

The problem is most strongly associated with fish, and in chalk rivers the most affected species are salmon, trout, the three lamprey species, eels and rheophilic cyprinids such as dace. However, invertebrates without aerial life stages can be similarly affected in situations where populations have been eliminated in the upper reaches (perhaps due to low flows or a pollution incident). These adverse effects have to be weighed against the importance of weirs as an obstruction to invading non-native species. In some rivers in East Anglia, weirs are currently protecting remaining populations of native crayfish from exotic species that are thriving downstream.

Many structures on chalk rivers are in a state of disrepair, largely due to the abandonment of water meadows and mills, and currently allow free passage for migrating species. Restoring such structures as part of initiatives to reinstate floodplain habitats may have consequences for movements within the river unless mitigation measures are taken.

5.7.2 Fish entrainment at intakes

There are many surface water intakes on chalk rivers, for potable supply, fish farms and water meadows, some of considerable magnitude relative to the river flow. Whilst the abstracted water is typically returned to the river some distance downstream, any fish entrained in the abstracted water are likely to become stranded and die. In some instances, the abstracted volume can represent most of the flow of the river at times of low natural flow.

Unprotected intakes represent a major hazard for migratory species as they follow the flow downstream. Particularly vulnerable are salmon smolts, but the juveniles of brown trout, rheophilic cyprinids and lampreys are also at risk over shorter migration distances. There are well-established downstream migrations among cyprinids in their first few months of life, and among brown trout in their first two years. Studies on the Hampshire Avon have demonstrated that considerable numbers of salmon smolts and juvenile cyprinids may be entrained with the abstracted waters for fish farms.

Although large-scale water-meadow operation was abandoned some decades ago, there is increasing interest in their restoration as a way of restoring wet meadow habitat. There are historical accounts of large losses of juvenile fish down water-meadow carriers, which end in blind ditches with no chance of escape. Great care therefore needs to be taken to avoid reductions in juvenile fish recuitment as a result of the restoration of water-meadow carriers.

5.8 Channel maintenance

5.8.1 Weed cutting

As has been described in Section 4.2, *Ranunculus* beds and other submerged and emergent plant species play host to a wide range of invertebrate species, constituting relatively stable species assemblages in vegetative mesohabitats. They also provide important cover for fish populations and a spawning substrate for a range of coarse fish species in the lower reaches of chalk rivers (see Section 4.4). In addition to this direct function as a habitat, dense *Ranunculus* beds in chalk rivers are known to maintain water levels in the channel, increasing summer depths by up to 80 cm (Lewis 1997) and thereby sustaining channel habitats whilst helping to maintain water table levels in associated riparian areas. The extra water resistance of crowfoot beds in winter additionally increases the likelihood of beneficial flooding of meadowland. Focused and intense scouring of channel gravels is generated by increased current velocities between beds, helping to reduce the extent of siltation. *Weed-cutting has the capacity to interfere with all of these functions if undertaken in an insensitive manner. If undertaken sympathetically, however, cutting can mimic the characteristic habitat mosaic of chalk rivers whilst still allowing the river to perform essential operational functions.*

Channel and marginal vegetation in chalk rivers is managed for flood defence, land drainage and angling purposes, and can be undertaken anywhere from winterbourne sections to the lowest reaches. The *flood defence objective* of weed management is to maintain the flood capacity of the channel, focused on key reaches where property and infrasctructure is at risk. The *land drainage objective* is to keep water levels sufficiently low to maintain land drainage standards in adjacent agricultural land. The *fishery objectives* of weed-cutting are more complicated, but are essentially to:

- maintain adequate open water for angling purposes;
- encourage trout populations to establish normal (small) territories;
- maintain and extend the period of dominance by *Ranunculus* beds;
- permit adequate angler access;
- generate focused scour of gravel substrates for salmonid spawning.

In practical terms, weed-cutting exercises are often performed for more than one purpose, with compromises made between land drainage/flood defence and fishery objectives. Table 5.4 gives a general guide to the timing and nature of weed cuts in relation to purpose. However, weed-cutting regimes are ultimately shaped by channel characteristics, floodplain topography and land use, and historic practices, such that generalisations are difficult.

Table 5.4 The timing and nature of weed-cutting operations in relation to purpose.

Season	Flood defence	Land drainage	Fisheries
Spring	Cuts sometimes undertaken with flood defence objectives in mind, depending on strength of baseflow and weather conditions.	*Main period* – reduces water levels in adjacent agricultural land to maintain drainage standards.	Undertaken in late spring to retain some open water or to stimulate *Ranunculus* growth where this is poor.
Summer		Cuts sometimes undertaken as above if strong baseflows are sustained.	*Main period* - As above, but with more cutting of marginal vegetation. Cuts before flowering designed to extend the period of *Ranunculus* dominance.
Autumn	*Main period* - Heavy cuts typically undertaken on selected river sections.		

In terms of *land drainage*, weed-cutting is typically undertaken in spring and early summer to lower the water table of adjacent fields and maintain it at agreed levels for agricultural purposes. Without any cutting, it is likely that the luxuriant spring *Ranunculus* growth in many chalk river sections would create sufficient obstruction to flow to cause riparian inundation even though baseflows are normally declining at this time of year. Such considerations can also be important in terms of *flood defence*, but the winter period is also critical in terms of flood risk. The typical (though not universal) flood defence practice is therefore a heavy autumn cut to reduce over-wintering biomass of submerged vegetation, which additionally reduces the risks of material being ripped out under high flows and blocking flow-constraining structures (typically culverts, bridges and where the river flows through mills and under properties). It is also thought that the autumn cut has the additional operational benefit of reducing the spring biomass of *Ranunculus*, thereby reducing weed-cutting costs through the growing season.

The manner of *spring and summer cutting for land drainage and flood defence purposes* critically dictates the level of ecological impact. Heavy clearance will result in a rapid and substantial drop in water levels, affecting both instream habitats and the water table of adjacent banksides and riparian meadows. Moist spring soils are essential for wet meadow plant communities (Section 4.2), and year-on-year dessication of the root zone at this time will result in increased competition from species favouring drier conditions. Wet meadow invertebrates and birds also suffer from the loss of moist spring soils, and indirectly from shifts in plant community composition. In the channel, focused scour of gravels through the growing season can be lost, whilst drops in water depth may result in losses of bankside habitat (such as submerged tree root systems) and reduced habitat suitability for characteristic species.

Heavy autumn cuts are likely to be detrimental to both fish and invertebrate communities through the mass removal of overwintering habitat (particularly since non-vegetative refugia can be limited in chalk rivers), whilst reduced risks of winter inundation will disadvantage wet meadow communities. Removal of marginal vegetation can leave the bankside vulnerable to erosion from high winter flows, whilst scouring forces from high winter flows are dissipated across the whole channel. In addition, the natural flushing of accumulated silt and debris created by the ripping out of root masses by high flows is effectively eliminated. On the Test and Itchen there is a belief that the heavy losses of *Ranunculus* root masses incurred if an autumn cut is not undertaken are difficult to replace, since *Ranunculus* proves difficult to re-establish in the denuded gravel (NRA, 1991). If this is the case, it must be that the rooting of shoot fragments and perhaps seed germination and/or seedling development are being hampered by other artificial factors that need to be addressed (perhaps low current velocities). Any changes in the weed-cutting regime would need to be implemented in tandem with other measures (perhaps channel narrowing).

Plates 25 to 27 show a section of the Kennet which is typically subjected to a heavy autumn cut of *Ranunculus*, sometimes resulting in the removal of all plant material completely (note the massive reduction in cover between June and October 1993, Plates 25 and 26). This clearly results in greatly reduced depth, uniform current velocities and massive habitat loss. Channel structure and management is not amenable to the development of marginal emergent vegetation through the summer that would otherwise concentrate flows along a central low-flow channel. Regrowth the following season also seems to be very strong despite the extreme management regime (Plate 27).

Weed cuts undertaken with *fishery objectives* vary greatly from river-to-river and reach-to-reach, from very light management (particularly on smaller rivers) to very intense cutting of both submerged and marginal vegetation (on larger reaches such as the middle and lower Test). The most enlightened management regimes (typically undertaken manually) aim to mimic the characteristic habitat mosaic of submerged vegetation and bare gravel, with significant fringes of marginal vegetation to support young fish and prey items, protect the bank from erosion and provide angler cover. More intensive management practices, largely associated with the most intense fish stocking regimes, can extract too much vegetation, thereby reducing scour, dropping water levels substantially, adversely affecting submerged and marginal habitat opportunities, and leaving the bank vulnerable to erosion. However, since coordinated weed cuts for land drainage, flood defence and/or fishery purposes are undertaken on some rivers (such as the Test and Itchen), it is not always clear how much cutting is undertaken to meet the different objectives of each.

Spring and summer cuts for fishery purposes have the additional objective of encouraging new growth, keeping shoots fresh and extending the dominance of *Ranunculus* as far into the summer as possible. In fact, where the development of *Ranunculus* beds is poor for some reason, cutting is undertaken by fishery managers specifically to stimulate new growth. Whilst the maintenance of *Ranunculus* as a dominant feature of the plant community is not at odds with nature conservation objectives, the scheduling of *Ranunculus* beds under the EU Habitats Directive is intended to protect the *Ranunculus* community as a whole, including associated plant and animal species. The occurrence of submerged beds of plants such as *Callitriche* and *Berula* are an integral feature of the *Ranunculus*-dominated community and therefore need to be catered for in weed-cutting programmes. Consideration of the wider plant community should allow the channel to adjust to a more self-regulating regime in which *Ranunculus* is naturally favoured where current velocities are strongest.

Plate 25 A section of the Kennet in June 1993, choked with brook water crowfoot across its full width.

Plate 26 The same section of the Kennet in October 1993, stripped bare of vegetation following a heavy autumn cut.

Plate 27 The same section of the Kennet in July 1994, showing vigorous growth.

From land drainage and flood defence perspectives, the stimulation of *Ranunculus* growth by cutting has important implications for the costs of weed-cutting regimes. Generally, the more cutting that is undertaken in spring and summer, the more that is required. Research has suggested that, if cutting is curtailed, the maximum biomass attained each year declines, being approximately halved in four years (Dawson 1979). Whilst it is not clear how widely applicable these results are, there is potentially much to be gained in operational terms by keeping the area and frequency of cutting to a minimum, limiting activity to that strictly required to meet land drainage and flood defence objectives. It is also interesting to consider the possible role of nutrient enrichment in very dense growth of *Ranunculus* beds in spring and early summer, and the effect that reductions in sediment and water column phosphorus concentrations may have in terms of naturally maintaining open water for longer periods.

Disposal of cut vegetation can cause ecological damage if dealt with inappropriately, with problems inevitably being multiplied when major cuts along long stretches are undertaken. Cut vegetation is generally caught downstream in a boom or in 'catch areas' from where it can be dragged out. The heaping of vegetation onto bankside areas for anything other than short periods can cause damage to plant and animal communities through smothering and enrichment, whilst the bank can be destabilised and become more vulnerable to erosion. Over time, decomposition of the material can result in leachate entering the river and impairing water quality. Disposal elsewhere on the floodplain can affect meadow vegetation unless care is taken to avoid valuable swards. Long-term storage within the river channel itself (in so-called 'wet pits') constitutes a serious ecological risk, leaving large amounts of highly biodegradable material in direct contact with river water. However, the size of the risk depends on the scale of weed-cutting.

5.8.2 Channel dredging/cleaning

Sediment deposition is the mechanism by which channel size and shape is modified to suit the prevailing flow regime. Given time, any chalk river will develop a natural channel form in the absence of external influences (including intense grazing pressure in riparian areas), reducing its width through the encroachment of marginal vegetation and associated silt accumulation. This enables a central well-scoured channel with variations in current velocity, depth and substrate to be developed. From an operational perspective, dredging is performed to maintain land drainage standards and the flood defence capacity of the channel. From a conservation perspective, dredging maintains the imbalance between channel size/shape and flow regime, thereby perpetuating the problems of resectioning discussed in Section 5.3.

The act of dredging can remove large numbers of epibenthic animals and infauna, including priority species such as the native crayfish, the pea mussel *Pisidium tenuilineatum*, the mayfly *Paraleptophleba wernerii*, and larval populations of all three lamprey species. If performed on a large scale, whole populations are at risk. Although not pertaining to chalk rivers, an example of the impact that dredging can have on threatened benthic species is the case of the pearl mussel (*Margaritifera margaritifera*) in a small tributary in Wales (pers. comm. Ian Killeen, Conchological Services). Soon after the recent discovery of one of the only known thriving populations in the Principality, the population was devastated by wholesale dredging of the channel bed. This highlights very effectively the importance of a detailed knowledge of the distribution of priority benthic species as an aid to directing sensitive dredging practices.

As with cut vegetation, disposal of dredged material is a further source of potential impact. Riparian and floodplain vegetation of high ecological value can be smothered and killed off, along with its associated fauna. If applied close to the river bank, run-off back to the river is likely to occur and the loss of bankside vegetation will exacerbate erosion problems, contributing to channel widening and siltation of riverine substrates.

Fishery interests have traditionally managed the quality of riverine substrates in chalk rivers (the classic chalk stream in particular) to benefit salmonid fish populations. This has involved: 1) *gravel-cleaning*, to remove accumulated silt and prepare the substrate for spawning; 2) *'mudding'*, using hurdles to direct focused flows at siltbeds and thereby eroding them away; and 3) occasional selective dredging to provide deeper pools. The impact of gravel-cleaning and mudding depends on how 'hygienically' they are conducted. If performed across the entire width of the channel, silty habitats essential for supporting a range of key species (such as the three native lamprey species, and plant species such as *Callitriche* spp and *Catabrosa aquatica*) are lost, whilst self-scouring of gravels is impaired. If performed in a targeted way to mitigate against the effects of excessive siltation, with due consideration to the chalk river community as a whole, such practices can enhance the quality of habitats provided. Mudding is a particularly high-risk practice for lamprey populations, since the larvae reside exclusively in siltbeds in slack water.

5.9 Riparian management

The riparian zones of chalk river systems have suffered from increasing pressure from intensive agriculture in recent decades. This has largely taken the form of intensified pasture management and consequent increases in livestock density, with increasing amounts of arable conversion too close to the water's edge. The effects of open access to the river at high levels of livestock density can be seen on many chalk river sections (see Plate 28), creating excessive trampling and poaching and destroying the characteristic riparian plant and faunal assemblages (Section 3). Impacts are particularly acute when livestock are able to roam and graze freely within the river channel. Particulate loads to the river greatly increase, contributing to siltation problems. Erosion is exacerbated if the channel has been deepened and the banks steepened, creating local landslip when trampled. In areas of arable cultivation, bankside vegetation is given little space to develop and links to riparian meadows are lost. In addition, banksides are threatened by the over-spray and drift of herbicides, pesticides and fertilisers, which are generally applied by aerial broadcast with limited control over the accuracy of application.

There has been considerable debate over the conservation benefits and disadvantages of fencing off bankside areas from livestock (see Section 4.3). Fencing can prevent the light grazing and poaching required to maintain the characteristic swards of shallow chalk river banks, and is therefore not beneficial in situations where livestock are grazed at low densities. However, fencing is generally only contemplated where high stock densities in riparian areas are creating bank erosion problems, conditions in which this community type cannot survive. Efforts can and should be made through grant awards to reduce stock densities in riparian meadows, but where negotiations fail there is no real alternative to bank protection. Fencing therefore has to be used in a targeted way to both protect the river channel from bank erosion and to allow a valuable tall herb vegetation to replace an otherwise denuded bank (Plate 29). It is still possible to have limited grazing beyond the fenceline if the fence is designed in such a way as to allow controlled livestock access (see Section 6.4).

The extent of riparian management for *angler access* varies greatly on chalk rivers, from very occasional cutting to frequent mowing. Infrequent management of bank edges is typically accompanied by the cutting of narrow angler paths to facilitate access along the river. Whilst light management regimes allow the characteristic communities of chalk rivers to flourish, the more intensive regimes reduce the ecological value of riparian areas and disrupt the ecological continuity between the river margin and riparian meadows. Frequent mowing creates a short sward, which may have relatively high botanical diversity but which has no opportunity to flower and set seed and provide habitat for characteristic invertebrates and higher animals.

In areas where agricultural improvement has not taken place, *agricultural neglect* is another risk that also has important implications for the characteristic flora and fauna of riparian meadows. Without some form of management regime, meadows become dominated by coarse, ruderal plant species (such as creeping thistle, nettle and greater willowherb), competing with smaller herbs for light, space and nutrients and forming a thick detrital layer through which many species cannot germinate and/or grow. Examples are widespread on chalk rivers, such as on the upper Nar in Norfolk, the Wye in Buckinghamshire and the Itchen. Whilst such abandoned meadows are by no means bereft of ecological value (being particularly good for invertebrate species and supporting large numbers of adult invertebrates with aquatic larval stages), the large-scale replacement of lightly grazed meadowland of high botanical diversity with an important invertebrate fauna, with this type of coarse vegetation is not desirable. It is therefore important that further neglect is avoided and consideration is given to the ecological restoration of such land.

5.10 Manipulation of fish populations

Most classic chalk streams and some larger chalk river sections (the Test and Itchen) are managed as trout fisheries and anglers pay premium prices for the prime fishing provided. Fishery interests have played an important role in preventing impacts on the physical and chemical quality of chalk river systems, and the angling revenues generated have enabled many riparian landowners to resist pressures towards agricultural intensification alongside chalk streams. However, fulfilling angler demand on some chalk streams involves intensive stocking with both brown and rainbow trout to provide high densities of takeable fish. The turnover of fish is very high and the result is effectively a 'put-and-take' fishery. On other chalk streams the management approach is geared towards encouraging natural recruitment, such that a wide range of philosophies exists amongst fishery owners. In the downstream sections of some large chalk river sections, fish populations are managed as rheophilic cyprinid fisheries focusing on species such as dace, chub, roach and barbel. The coarse fishing policy of catch-and-release means that far less stocking is undertaken.

In addition to stocking, removal of 'undesirable' fish species is standard fishery practice in many classic chalk streams. The status of grayling in any given river reach is determined by the local preferences of resident anglers. In some situations the species is regularly removed by netting, electric fishing and angling; while in other places it is tolerated or even welcomed as a sport fish (such as on the Dorset Frome). The active discouragement of the species is all the more unfortunate for its inclusion on Annex II (species requiring strict protection) of the Berne Convention on endangered habitats and species. Populations tend to be tenacious as long as environmental conditions are favourable, and the indications are that the species is not permanently excluded; however, densities are greatly reduced along river reaches where intensive control is practised.

Owing to their piscivorous diet, pike are generally ruthlessly persecuted by all legal means and many illegal ones, but their almost ubiquitous distribution in chalk streams indicates their resilience. Mann (1982) reported that small pike were a major component of the diet of larger pike, and that cannibalism was the main cause of natural mortality of fish between 6 months and 2 years of age. This throws doubt on the effectiveness of removal of large pike as a method of control, and it may be that populations are actually enhanced by such activity. It is certainly the case that the species still persists on stretches of chalk stream that have been subjected to intense control efforts.

In intensively managed chalk streams, the overall effect is to artificially increase competitive and predatory pressure on wild fish, whilst further distorting community balance through active elimination of pike and grayling. In some rivers, salmonid dominance is being artificially extended down into reaches that would otherwise be dominated by grayling or rheophilic cyprinids (particularly dace and chub). In such cases, habitat conditions (particularly the quality of gravel substrates) are such that viable trout fisheries cannot be sustained without considerable management effort, often including the stocking of rainbow trout because they are more tolerant of reduced habitat suitability for salmonids.

Whilst the genetic integrity of many wild stocks of chalk stream brown trout will already have been heavily compromised, there are still risks to other populations that have to date remained largely unaffected by stocking. However, such remaining populations are generally recognised and afforded great protection by the fishery owner. The rainbow trout generates no genetic risk to resident brown trout populations, but the stocking of a non-native species is directly at odds with the conservation of the native fish fauna of chalk streams. Even though the species has established few self-sustaining populations in Britain, the species competes with wild fish for limited resources (particularly space and food) all the time it continues to be stocked. Natural spawning has been recorded on some chalk river SSSIs (the Lambourn and the Dorset Frome) and there is always a risk of further populations establishing (although strains of rainbow trout are now used that have a low tendency to spawn in the UK).

Competition for limited space between stocked and wild fish is likely to be more important than competition for food, since brown and rainbow trout are strongly territorial, both within and between species. There is evidence to suggest that many stocked fish are caught rapidly, and they may not feed extensively in the river prior to capture owing to difficulties in switching from farm food to a natural diet. The largest stock fish often show a loss of body condition once removed from a farmed diet and released into the river, indicating difficulties in finding and competing for food. There is no evidence for significant direct predation by stocked trout on the juveniles of the resident fish fauna (Barnard *et al.* 1997), although research on rainbow trout is continuing.

Disease transfer through intensive stocking represents a further risk of intensive management, and not only in relation to fish diseases. There is evidence that crayfish plague can be carried on the slime and scales of fish, making the practice of stocking fish into uninfected waters from fish farms in infected waters a very high risk practice.

Plate 28 Heavy bankside erosion on the Till, probably exacerbated by limited over-deepening.

Plate 29 Fencing of eroding banksides on the Devil's Brook, showing the tall herb vegetation generated.

5.11 Bird species of management concern

The populations of certain bird species have historically been controlled by river keepers on chalk rivers, and in particular the classic chalk stream. This has included the suppression of species thought to prey significantly on different salmonid life stages, as well as species deemed to interfer with optimal chalk stream habitat for salmonids.

Mute swans have long been regarded by river keepers as a species requiring control due to their grazing activity on *Ranunculus* beds. For centuries, populations were kept in check by gamekeepers and the 'ranching' system employed by the nobility, where swans were rounded up each year and a proportion were sent off to be fattened in 'swanneries' for Christmas. The loss of interest in the bird as Christmas fare led to the abandonment of the system, but population control was still undertaken by river keepers through the use of techniques such as egg-pricking.

The past few decades have seen considerable increases in swan numbers. Data collected under the BTO Common Bird Census and Waterways Bird Survey (Crick *et al.* 1998) indicate large increases in breeding populations across the country (100% over the period 1972 to 1996 and 59% over the period 1974 to 1996 respectively). In Hampshire chalk river catchments specifically (Clarke and Eyre 1993), the National Swan Census has recorded a doubling of swan numbers in the period 1978 to 1990 (from 400 to 823), in line with countrywide trends. Casual observations on chalk rivers indicate that juveniles have taken advantage of the excellent winter feeding opportunities afforded by improved grassland and autumn-sown cereals, and have formed large non-breeding adult flocks of perhaps 75 - 100 individuals in some areas (such as the Wylye and other Hampshire Avon tributaries).

The consequence for the river is large numbers of birds alighting on some stretches of chalk stream in May, June and July to feed on *Ranunculus* beds, completely grazing off large areas (up to one or two kilometres of river length). This denudes the river of submerged plant habitat at a crucial time and can be adversely affecting water levels and flow regimes (including scouring strength). Such flocks can overwhelm any adult males holding territory (depending on flock size and the strength of the cob), and at such densities the species does considerable damage to the well-being of the river. Whilst it is possible that this large-scale grazing behaviour is exacerbated by low flows and other anthropogenic influences, measures to control the level of impact are required at least in the short-term to control swan grazing where it is known to be a problem.

The **cormorant** has become of increasing concern to fishery owners nationally due to its burgeoning inland populations. The species has increased greatly in recent years, forming breeding colonies on gravel pits and other still waters, and there is natural concern over the impact on fish populations. In England, inland nesting of cormorants has increased from being sporadic before 1981 to a total population of 1,000 pairs in 1996 (Sellars *et al.* 1997), increasing at an annual rate of 60%. Up to 35% of the population overwinters inland, particularly in Cumbria, the Midlands and south-east England, with maximum numbers typically occurring in December to February. Whilst populations tend to be centred on gravel pits and reservoirs rather than rivers, the survey coverage of rivers tends to be poor (pers. comm. N. Carter, BTO).

The rapid increase in cormorant numbers has coincided with an increase in inland fish farming activity and intensive fish stocking for angling purposes (Marquiss and Carss 1994). Whilst serious predation has been demonstrated in a few small enclosed systems such as fish farms, there is as yet no evidence to substantiate claims of significant impact on riverine fish populations (Marquiss and Carss 1994). On-going collaborative research due to be completed soon should throw further light on the subject. If damage does occur, it is likely to be focused on intensively stocked reaches (as long as fish are stocked at a manageable size for the birds).

5.12 Decline of the native crayfish

The problems of the native crayfish (*Austropotamobius pallipes*) deserve separate consideration, since the key factors implicated in the species' dramatic decline are unique to the species rather than being related specifically to physical or chemical impacts. Whilst physical stress from low flows and pollution episodes can always produce heavy mortalities, the effect is only temporary as long as unaffected populations are available to recolonise from adjacent sites. A lack of physical refuges (such as overhanging vegetation, submerged tree root systems and cobbly substrates) will heavily constrain the species, but this is not a problem on many chalk rivers where catastrophic declines have been recorded. Long-term impacts on populations have been produced by the spread of non-native crayfish species and the occurrence of crayfish plague (for which non-native species are carriers).

Non-native introductions in England began with interest in the culture of the North American signal crayfish (*Pacifastacus leniusculus*) for the table, with many implants occurring from the mid 1970s onwards into fish farm ponds and lakes and some directly into the wild (Holdich and Rogers 1997a). Stock control was poor and populations of signal crayfish became established throughout southern England and further afield. Outbreaks of crayfish plague, a fungal infection to which *A. pallipes* is particularly susceptible, began in the early 1980s and have wiped out many populations of our native crayfish across England and Wales. Non-native crayfish, which are resistant to the disease, are typically the source of infection, but it does not require contact with infected crayfish. The disease can be carried in waters from infected populations (such as downstream of a crayfish farm or an infected population in the wild) and on the slime and scales of fish transported from infected waters to uninfected areas (perhaps even on sampling equipment). On the Hampshire Avon, crayfish plague occurred shortly after the establishment of a crayfish farm in the headwaters (pers. comm Graham Lightfoot, Environment Agency).

Population losses have been greatest in the south of England, with chalk rivers being particularly hard hit as a consequence. Populations have been virtually eliminated on many chalk river systems, and no remaining populations can be regarded as safe. Whilst no plague outbreaks have been reported since 1993, *A. pallipes* has been replaced in many river networks by populations of signal crayfish and a range of other exotic species brought over for culture more recently (Holdich and Rogers 1997a). Even where plague does not seem to have occurred (outbreaks are very difficult to verify), *A. pallipes* has lost out to non-native species through competition and predation, and has little chance of re-establishing where non-native populations are established (Holdich and Domaniewski 1995). Holdich and Rogers (1997b) have classified all catchments in England and Wales according to the status of *A. pallipes* and non-native species, with the majority of chalk river catchments assigned to category C. This indicates a widespread occurrence or local abundance of non-native crayfish and a limited distribution of *A. pallipes*.

The case of the Test and Itchen catchments is worthy of further consideration. The Test supports three crayfish farms along its length, and signal crayfish are relatively widespread in the river whilst *A. pallipes* is very restricted. There are no crayfish farms on the Itchen and no signal crayfish are apparent in the river, but *A. pallipes* has declined to the point where is only occurs in two isolated headwaters. It is thought that fish introductions from farms on the Test to the Itchen have transmitted the plague vector to Itchen populations, which have then transferred the disease upstream until impassable barriers prevent further spread.

5.13 Commercial watercress beds as a habitat

Whilst commercial cress beds have historically been an important habitat for threatened wetland bird species in chalk river valleys, there have been recent population declines that may be associated with changes in management operations. In Hampshire, watercress beds held 30 over-wintering water pipits in 1978/79, whilst only one was found in the winter of 1989/90 (Pain 1990). The large decline in Hampshire redshank populations in recent years may be connected with the intensive management of watercress beds (Clark and Eyre 1993). Cress beds are also a habitat favoured by the water shrew, which appears to be better able to cope with the intensification of management.

The habitat provided by watercress beds has changed dramatically in recent decades, and it is not particularly surprising that they have become less hospitable to wetland bird species. Prior to modern management practices, the cress crop would have been grown in around 6 inches of water and not harvested until it was 12-18 inches in height. Harvesting consisted of cutting the shoot tops, leaving continuous leafy cover through the year. This form of management is still practised by some independent growers (Plate 30), but it is uneconomical compared to the production systems of the large growers (two companies are responsible for around 75% of the total national production). Modern culture methods use a water depth of one inch and harvesting at a maximum shoot height of 6 inches, at which time the cress is cut down to stubble (see Plate 31). With more efficient nutrient delivery and the cutting of young shoots, harvesting is very frequent and creates much more noise and physical disturbance. In addition, bed-cleaning and disinfection occur on a rotational basis, adding to disturbance levels. This latter factor alone could account for the observed declines in breeding and overwintering birds.

Pest and disease control is a further factor, which may constrain wetland bird and water shrew populations, largely through impacts upon invertebrate prey populations. Outbreaks of flea and mustard beetles (colonising from neighbouring arable crops) and midges are controlled with Malathion, whilst aphids are eradicated with Dimethoate. The spray application of these organophosphates to control insect pests is likely to have a large impact upon prey availability within intensively farmed cress beds. Zinc is applied to cress beds over the winter months (October to March) to control crook root, with recommended target concentrations of around 100 $\mu g\ l^{-1}$ (Casey and Smith 1994). The selective elimination of *Gammarus* below cress beds has been tentatively linked to zinc applications, supported by observations of suppressed feeding rates in caged *Gammarus* (Roddie 1992). If populations are affected downstream, *Gammarus* living within the beds themselves are presumably even more acutely affected.

The physical structure of cress bed walls is critical to the suitability of this habitat to the native crayfish. Traditional brick walls that are imperfectly maintained will provide plenty of crevices to act as a place of refuge, whilst the modern concrete walls (Plate 31) have smooth surfaces with no habitat opportunities for the species. The fine gravel substrate of both traditional and modern cress beds offers no refuge opportunities.

5.14 Spread of non-native plant species

There are several non-native plant species of particular concern that are highly competitive in riparian areas, forming dense stands of vegetation that overwhelm the native bankside flora (through competition for light, root space and nutrients). Japanese knotweed (*Fallopia japonica*) spreads vegetatively and colonises new areas largely by root fragments. It has benefited greatly in river corridors from the transport of soil containing root material, and is extremely difficult to eliminate once present, forming very dense, tall stands (up to 3 metres) which are extremely effective at blocking light to other plants. Giant hogweed (*Heracleum mantegazzianum*) is a very tall perennial plant (up to 5 metres) with prodigious seed production, each plant producing up to 50,000 seeds each year. Himalayan balsam (*Impatiens glandulifera*) is a tall annual plant that spreads rapidly along river corridors (such as on the River Wye, a small chalk stream running through High Wycombe), forming large stands with some restricted opportunities for the growth of taller native plants. It produces around 800 seeds per plant each year, which are ejected forcibly from the seedpod and can be dispersed by water.

All three species are widespread in the geographical area covering chalk rivers in the UK and so pose a very real threat to native riparian vegetation.

Plate 30 Traditionally managed cress bed on the River Chess at Chenies.

Plate 31 Intensively managed cress beds on the upper Itchen at Alresford.

6. Management for mitigation and restoration

6.1 Introduction and principles

This section aims to give guidance on measures that will, or are likely to, benefit the characteristic wildlife communities of chalk river systems described in Section 3. These measures have been placed in a simple framework (Figure 6.1) that aims to establish a strategic approach to enhancement and restoration work at a scale of whole catchment or sub-catchment. This is consistent with the requirements of the EU Habitats Directive and UK Biodiversity Action Plan, in that quantitative targets are ultimately set against which progress and 'favourable conservation status' can be monitored in relation to priority habitats and species.

Conservation objectives can be seen as a qualitative vision of the river corridor and associated wetland areas, establishing which habitats require particular attention in terms of spatial extent and quality, and which species require special consideration in terms of protection, enhancement and re-establishment. Examples might include the protection of remaining lightly grazed riparian pasture and its re-establishment in other areas where possible, or the retention of sea lamprey spawning grounds and their restoration at historical sites. The establishment of such qualitative objectives can be seen as the precursor to setting quantitative targets, either in terms of the area or quality of favoured habitats or the size or density of populations of priority species. If too little is known about a habitat or species, in terms of its historical and/or its current quantitative status, target-setting can be deferred until more information becomes available.

Nature conservation objectives have to take account of public expectation and the legitimate requirements of river, water and catchment users. The public perception of what form a chalk river and its associated habitats and communities should take appears to be largely in line with the nature conservation perspective, given that a large-scale reversion to the assumed primeval state (see Section 2.2) is socially and economically impractical. The biggest hurdle is, therefore, to balance nature conservation objectives with existing and proposed river/water uses and catchment land use.

Once targets (or at least objectives) are in place, management actions can be identified and prioritised. Figure 6.1 indicates how different sections of this guidance document may provide useful information for each step in the process. *However, it is important to recognise that the guidance is generic in nature and that objectives ultimately have to be based on a detailed knowledge of the river system in question, in terms of its physical, chemical and biological history and its current conservation value.*

As described in Section 5, the interactions between different human activities and mechanisms of impact mean that the application of measures to alleviate an individual impact may not bring about the desired ecological improvements. Whilst detailed local investigation of critical factors may reveal certain actions that will create the largest beneficial effects, *integrated application of a suite of measures to a range of activities and mechanisms of impact is the most reliable approach to achieving conservation aims.*

Table 6.1 summarises key mitigation, enhancement and restoration measures for tackling major problems in chalk river systems. These are discussed in more detail in the text together with consideration of other possible measures that cannot be recommended on nature conservation grounds. Any of the recommended measures will go some way towards improving ecological status. *However, there is a vital need to develop holistic strategies that consider the catchment as a functional unit, beginning with the fundamental questions of how large a river channel should be, how much water it should carry, and how it should interact with its floodplain.* Once these questions are addressed, considerations of routine management and pollution control can be superimposed.

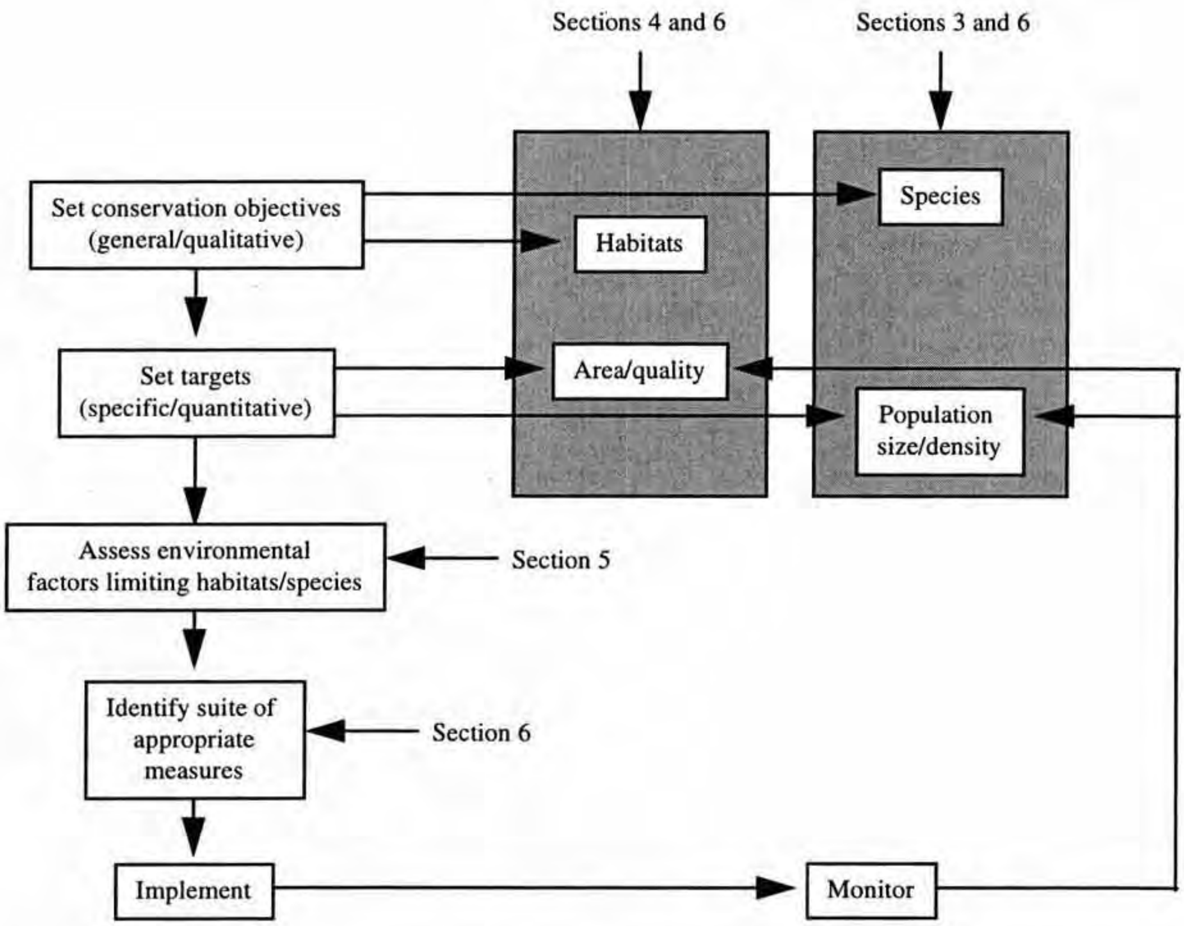


Figure 6.1 Management framework linking tasks to information within this handbook

A range of organisations have an interest in developing and implementating such catchment-level strategies. English Nature is the statutory body responsible for undertaking and promoting nature conservation in England, with particular responsibility for designated wildlife sites. The Environment Agency is responsible for flood protection and river engineering, control of water quality and abstraction and regulation of fishery management, whilst having associated duties to further and promote the conservation of flora and fauna. The Ministry of Agriculture, Fisheries and Food (MAFF) funds flood defence and agricultural production as well as a range of agri-environment schemes. Local management of the river, riparian and floodplain areas is undertaken by landowners and fishery managers and is crucial to the well-being of chalk river communities. *It is clear that, for catchment level to be successful, there needs to be close liaison and cooperation between English Nature, the various functions of the Environment Agency, MAFF, landowners and fishery managers, working towards a common vision of the ecology and landscape of chalk river catchments.*

Table 6.1 Summary of principal mitigation, enhancement and restoration measures recommended for use in chalk river systems, indicating the issues addressed by their application

Activities and mitigation/enhancement measures	Channel restoratn.	Floodpl. restoratn.	Alleviation of low flows	Riparian enhancement	Alleviation of eutrophicn.	Alleviation of siltation	Fish community
River engineering							
Channel reforming							
♥Establishment of one-stage channel narrowing to produce appropriate dimensions to flow.	*	*	*	*	*	*	
♥Longitudinal and cross-sectional reprofiling to create diversity in channel gradient and depth (in line with historical geomorphology).	*		*		*	*	
♥Channel bed-raising/ gravel reintroduction.	*	*		*			
•Removal of impounding weirs.	*					*	
•Introduction of instream deflectors, flow concentrators, groynes or gravel bars within oversized channel, typically set at low-flow water levels.	*		*		*	*	
•Establishment of two-stage channel. (with narrowing of low-flow channel).	*		*	*	*	*	
Bank reprofiling				*			
♥Restoration of water meadow carriers and hatches or creation of new carriers.		*			*	*	
•Land-lowering in riparian areas	*	*		*			
♥Clay bunding where necessary to hydrologically isolate areas of high flood acceptability from areas where flooding is undesirable.	*	*			*	*	
♥Following hydrological engineering, recreation of key lost floodplain habitats, particularly large reedbeds and woodland		*					

Activities and mitigation/enhancement measures	Channel restoratn.	Floodpl. restoratn.	Alleviation of low flows	Riparian enhancement	Alleviation of eutrophicn.	Alleviation of siltation	Fish community
carr.							
Water resource management							
♥Enhance infiltration to aquifer through increased water retention in catchment soils.	*	*	*	*	*	*	
♥Reduce demand on water resources (water conservation and leakage control).	*	*	*	*	*	*	
•Measures to redistribute abstraction pressure within catchment.			*		*	*	
•Temporary flow augmentation as a short-term mitigation measure against extreme drought.			*		*	*	
Channel maintenance							
♥Limited weed-cutting intensity in spring/summer, focusing on central part of the channel.	*	*	*	*		*	
♥Weed-cutting in patches to mimic natural habitat mosaic.	*					*	
•Summer spring/summer cutting of vegetation in bands across the channel.			*	*			
♥Restriction of autumn weed-cutting.	*	*		*	*	*	
•Restriction of dredging activity, focused on central part of the channel.	*		*				
♥Mature tree retention and targeted tree planting.	*			*			
Discharge consenting							
♥Treatment of point discharges, including phosphorus-stripping.					*	*	
Agricultural /riparian management							
♥Rationalisation of nutrient inputs to pastures and arable land, matching nutrient applications to soil/crop requirements.					*		

Activities and mitigation/enhancement measures	Channel restoratn.	Floodpl. restoratn.	Alleviation of low flows	Riparian enhancement	Alleviation of eutrophicn.	Alleviation of siltation	Fish community
♥Encouragement of low-phosphorus diets for livestock and fish.					*		
♥Improved methods of nutrient delivery to grass and arable crops (timing and method of application).					*		
♥Establishment of efficient nutrient management on all cress farms.					*		
♥Elimination of arable cropping in riparian fields and land elsewhere that is vulnerable to erosion (particularly downland), in favour of permanent grassland.		*		*	*	*	
♥Use of soil conservation measures on all arable land.					*	*	
♥Autumn/winter flooding of riparian land with stable permanent vegetation.		*		*	*	*	
•Widening of the strip of permanent vegetation between cropped area and river and ditch systems.				*	*	*	
♥Reduction in livestock densities in riparian areas and land elsewhere that is vulnerable to erosion.		*		*	*	*	
•Bankside fencing where livestock densities cannot be reduced to acceptable levels.				*	*	*	
♥Establishment of buffer areas across key run-off pathways.					*	*	
•Selective cleaning of gravels.					*	*	
♥Reduction in the mowing intensity of riparian vegetation for angler access.				*			
•Retention/maintenance of mature trees and scrub (where beneficial).				*			
•Targeted tree planting and scrub development (where beneficial).	*			*			
MOD activities							
♥Assessment of phosphorus and solids loads in discharges and control if necessary.					*	*	

Activities and mitigation/enhancement measures	Channel restoratn.	Floodpl. restoratn.	Alleviation of low flows	Riparian enhancement	Alleviation of eutrophicn.	Alleviation of siltation	Fish community
♥Interception of run-off from disturbed soil and compacted tracks.						*	
♥Restriction of vehicular access to watercourses.	*			*			
Fish population management							
♥No stocking of rainbow trout.							*
♥Promotion of catch-and-release philosophy in salmonid fisheries.							*
♥Reductions in bag limits and increases in size thresholds for takeable fish imposed on salmonid anglers.							*
♥As fish removals are reduced by the above, reduce levels of stock input.							*
♥Rear fish from native stock, with regular addition of broodstock from the wild to prevent genetic deterioration.							*
♥Encourage the wider adoption of grayling as a sport fish.							*
♥Facilitate passage for **all** migrating species (such as salmonids, lampreys, eels and rheophilic coarse fish) at key artificial obstructions.							*

♥ Best practice, to be applied wherever possible where a need is identified.

• Measures to be applied where best practice is not feasible or sufficient due to practical constraints, and/or where local circumstances suit.

Note: The table only deals with general habitat-related issues, except for direct effects on the fish community from biological manipulation.

6.2 Making decisions concerning channel dimensions and river flows

6.2.1 Deciding on optimal channel dimensions and ecologically acceptable flows

The channels of many chalk rivers have been widened and deepened for flood defence and land drainage, and this has been exacerbated in many places by bank erosion and over-zealous channel maintenance. The result is that they can no longer perform essential ecological functions efficiently (see Section 5). The problems are compounded by increased pressure on river flows from climate change and abstraction, and so when considering river rehabilitation it is unclear how much blame to assign to each of these factors, and whether to tackle channel dimensions, river flows, river practices or a combination of these. Decisions are made all the more difficult by the tendency of climate change to produce more variable rainfall patterns. Where a periodic drought produces temporary suppressions of river flow, permanent solutions involving channel down-sizing may result in problems when normal flows resume.

The issues of channel size and river flow are inextricably linked, in that an ecologically-suitable river channel can be constructed for a wide range of flow rates by adjusting the overall size and the shape of the channel. This linkage can easily be used in a highly misleading way, such that a natural-looking and self-sustaining river can be created even though it contains only a small proportion of its natural flow due to abstractions. In-river habitats can be optimised for any flow-rate, but the key question is: *'what should be our level of ambition in terms of overall river size?'*

Assuming the channel is optimised in terms of the habitats it can support (and of the access provided for migratory species), the main effect of having a smaller river flow is to reduce habitat areas on a sliding scale, resulting in smaller population sizes but probably little loss of species richness. This makes the process of setting a precise minimum acceptable flow quite arbitrary; *from a nature conservation perspective, the aim must be to set target flows in relation to the river's historical size and power, seeking to reflect its former capacity for providing instream habitats, purifying itself, and sustaining riparian and floodplain habitats dependent on water.* It has to be accepted that it is difficult to identify the exact nature conservation benefits that would accrue from a particular target flow set in this way. This makes the link between the setting of target flows and conservation objectives and targets rather nebulous. However, once the target flow is agreed, more concrete links between it and conservation objectives can be made through the consideration of channel size and morphology.

A schematic of how the decision process for a catchment-based, strategic approach might be structured is given in Figure 6.2. River flows across the catchment are estimated to assess the river's size and power in the absence of abstractions and discharges, paving the way for agreeing target flows that reflect the river's historical strength. In parallel with this, an information base on 'flood acceptability' is generated that ultimately maps areas within the catchment where inundation or high water table levels would be ecologically beneficial and acceptable to the landowner (with appropriate grant awards as necessary). Consideration of floodplain topography and soils would identify situations in which flooding could be limited to areas of high flood acceptability, in conjunction with low-profile clay bunding where required and feasible (care would need to be taken here to blend such control structures into the existing landscape).

This work would allow more radical restoration of the river channel in areas of high flood acceptability, typically giving the river more energy to influence its own geomorphology and allowing a high level of interaction with riparian and floodplain habitats. Where flood acceptability is low, more cautious approaches, working largely within the over-sized channel, are adopted. In both cases, modelling techniques and historical information on engineering works and channel form can be used to screen river reaches for priority attention (Box 5, Figure 6.3) and to design the geomorphology of the new channel, using flow/habitat relationships for key species of conservation concern as necessary (Box 5).

Box 5. Possible approaches to prioritising river reaches and designing channel enhancements.

A range of information sources can be used to identify reaches most in need of channel enhancements and to provide indications of suitable channel modifications. Since the geomorphology of the river in the reference state can only described in vague generic terms (see Section 2.2), there is no substitute for historical information on the river network, including historical large-scale maps, landowner records, old photographs, archives of river engineering works and parish/district records. Such data may include information on planform, river width, depth, cross-sectional profile (including bank form), and substrate type and condition.

Modelling techniques using relationships between channel characteristics and riverine variables that are less artificially influenced by human activity may help in identifying the most physically impacted reaches in a catchment, allowing prioritisation of enhancement and restoration work. Channel width is probably the most accessible channel variable to model in this way. Whilst there are no generic equations available, 'best-fit' relationships between channel width and key variables can be generated for chalk river systems. The difference between the observed channel width and that predicted by the relationship (i.e. the 'residual variation') is a crude measure of how much narrower or wider a site is than might be expected, although it also encompasses natural variations in width that are not accounted for by the explanatory variables used. This deviation from predicted width can be mapped to show where the most 'overwide' sites are located.

By way of illustration, River Habitat Survey data on chalk river SSSIs were used in an analysis of the type described above. Both flow category and distance from source individually accounted for around 50% of the variation in channel width within the RHS dataset, whilst their combination accounted for little more (suggesting that they are both explaining the same portion of the observation variation). Figure 6.3 shows the deviation at each site from the width predicted by the relationship with flow category. This suggests locations in each SSSI catchment where the channel may be considerably overwide, including sites at the lower end of the Hampshire Avon, the middle reaches of the Nar and Test, and the upper reaches of the Frome and Kennet.

It is unclear to what extent these results match the true situation, but the general approach is valid and could be refined to give a reasonable focus to restoration work. It is likely that the use of relationships for single catchments will provide more robust results, particularly if more explanatory variables and non-linear relationships are investigated. The occurrence of multiple channels along many middle and lower reaches of chalk streams is an issue that would need close attention, as well as the tendency for channel width to increase in discrete steps at confluences.

At a detailed ecological level, relationships between flow and habitat can be used to help modify the channel to suit the requirements of characteristic communities, including instream and riparian species. PHABSIM is a useful tool for this purpose (see Section 5.4.3), although work would be required to develop reliable indications of habitat preferences for species of high conservation priority in chalk streams (such as *Ranunculus* species). Application of this detailed model is also time-consuming, and more basic consideration of flow-habitat relationships (perhaps based on extrapolation of PHABSIM results) is likely to be required to apply such thinking to channel enhancement/restoration works on a large scale.

The effect of applying the most ecologically-beneficial restoration procedures permitted by flood acceptability levels is then modelled catchment-wide, in terms of changes in river levels, catchment flood capacity (to include the extra capacity from new dedicated flood areas) and risks to non-target areas. This should allow all interested parties to agree restoration plans, undertaken sequentially and subject to periodic review. Section 6.7 briefly discusses how such an approach might alter the catchment. A large obstacle to the adoption of this type of approach at present is the lack of reliable information and techniques with which to generate widespread data on flow regimes in the absence of human interference in chalk river systems (Box 6), an issue which needs to be addressed as a matter of priority.

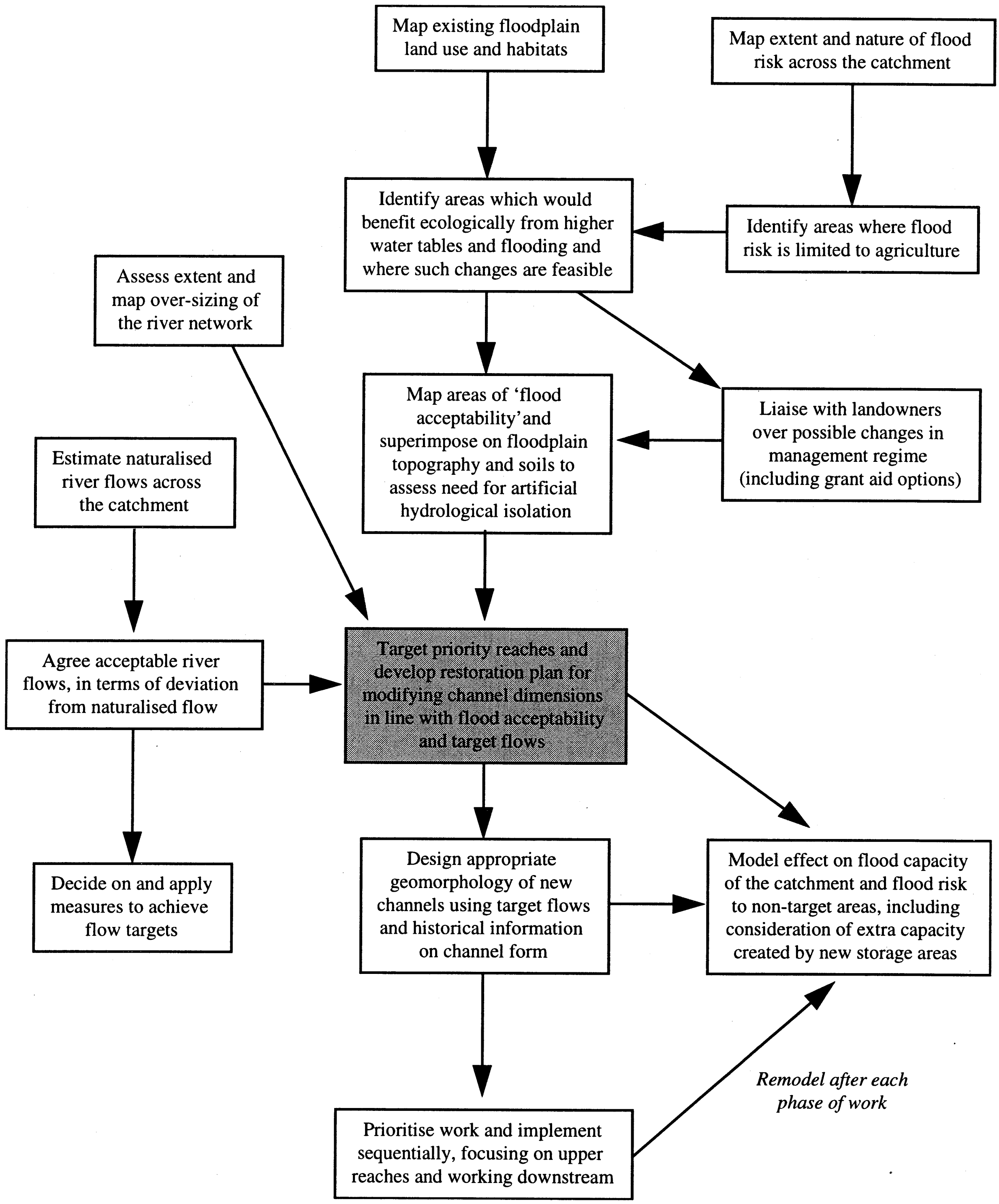


Figure 6.2 **Catchment-based approach to restoring natural river/floodplain interactions.**

Box 6. Flow regimes in the absence of human intervention - filling the information gap.

The naturalised flow of a river is the flow rate in the absence of abstractions and discharges. Although information on naturalised flows is the obvious starting point for holistic river management, reliable data are available for very few sites. At present, basic statistics on natural flows can be estimated anywhere in a river network using the Micro-Low Flows (MLF) modelling package (developed by the Institute of Hydrology), but the procedure is unreliable in groundwater-dominated catchments. Detailed modelling to generate reliable time series data on naturalised flows is only undertaken by the Environment Agency to assess conditions in priority low-flow rivers (under the ALF programme) and river sections that are the subject of strategic licence applications. Once flows have been estimated for main river sections, modelling procedures are available for extrapolating to ungauged locations all over the catchment. The restriction of this approach to a small number of river reaches leaves the majority of rivers (and particularly chalk rivers) with little reliable data on which to base future management decisions.

Detailed modelling is not only hampered by the effort required to model the system, but also by data availability. Accurately estimating a time series of naturalised flows requires detailed information on actual abstraction rates and discharge volumes, as well as the quantification of interactions between groundwaters and the river. Whilst reasonable information is available on abstraction rates as a result of licence conditions, data on discharges and groundwater/river interactions are patchy. Detailed modelling is likely to remain restricted to priority low-flow rivers in the future, so there is a need for a more accessible technique to undertake coarse but reasonably reliable assessments of deviations from the natural flow regime.

Chalk river systems present particular difficulties for the generation of naturalised flows, since groundwater forms such an important part of the water balance. Whilst the existing MLF package may provide usable data for very coarse screening, a better solution would be desirable and is likely to be necessary in most instances. Generic rainfall/run-off relationships may offer the best universal technique for generating time-series data on naturalised flows, using region-based hydrological parameters under development within the Institute of Hydrology. It is likely that such parameters will be incorporated into future versions of the MLF package, and that reasonable time series data will then be available widely across whole catchments up into the headwaters.

More widespread production of naturalised flow data is urgently required if river restoration measures are to be properly planned in a way that is transparent and meaningful. Even relatively coarse screening procedures require significant amounts of effort, but in the long-term such investment will be repaid by the vastly improved knowledge base available for decision-making.

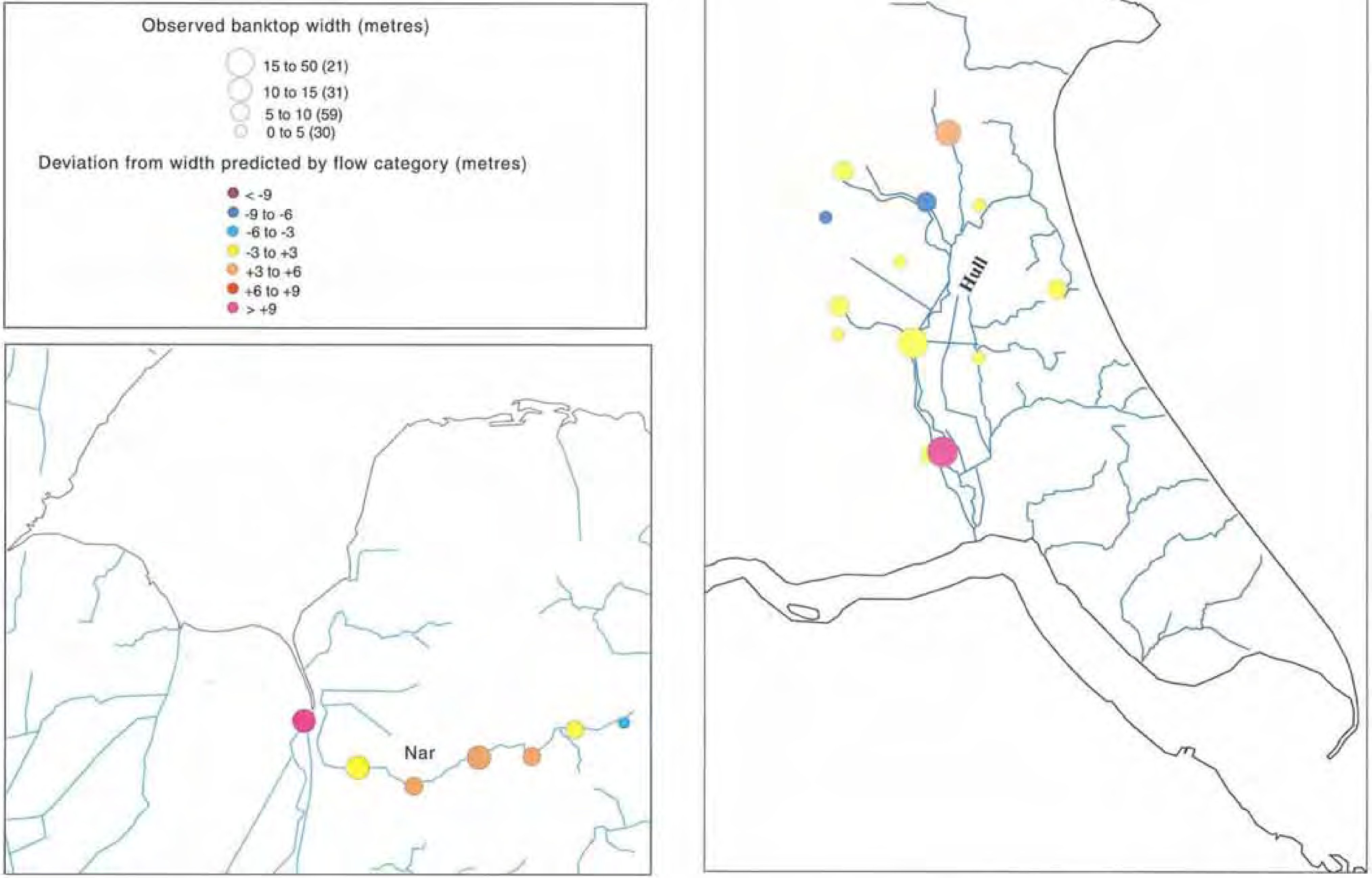
6.2.2 Controlled inundation of floodplain meadows

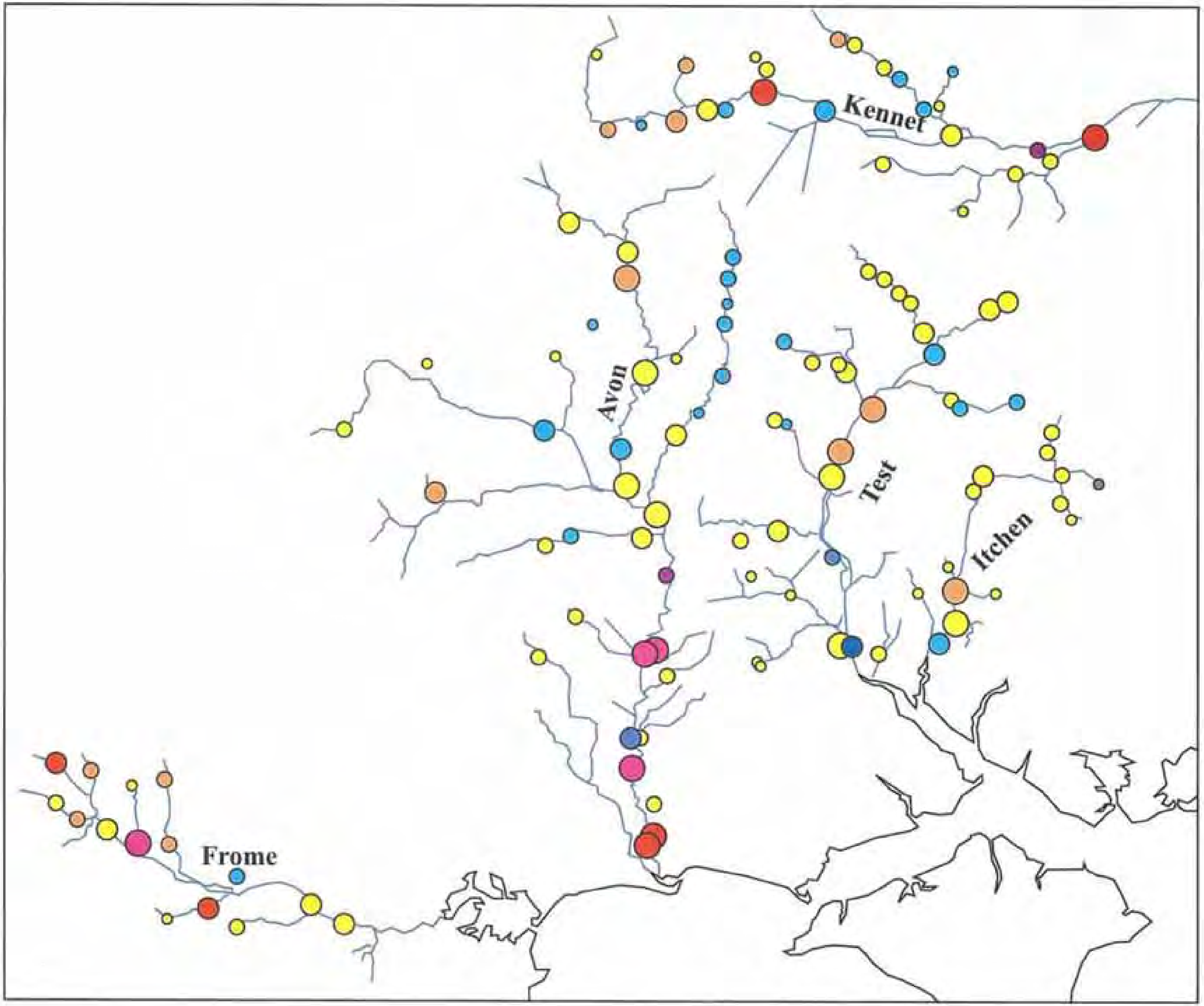
In addition to creating flooding on riparian meadows by restoring the river channel, controlled flooding can also be created by restoring the main carriers of abandoned water meadows. This is an expedient measure in comparison to the more holistic solution of restoring proper river function, but the extra control over the flooding process may reassure many landowners and thereby generate more cooperation. It is envisaged that the two approaches could be implemented hand-in-hand within an overall catchment strategy (see Section 6.7).

Restoration work on carriers and subsidiary channels will have to be decided upon carefully, as many of them may have high nature conservation interest. Later stages of ditch succession are highly important for some priority species (including mollusc species such as *Anisus vorticulus* and *Segmentina nitida,* both likely to occur in chalk river systems), and so it will be important to retain ditch sections in this state on a rotational basis. This said, there will also be benefits of restoration work to ditch systems, by the provision of areas of open water and significant water flow along some ditch sections, creating habitat for juvenile fish and also a range of invertebrates, including the southern damselfly (in southern catchments).

One important ecological risk with water meadow restoration is that the carriers can be used to feed the meadow at times when the river cannot afford the water, including winters with poor aquifer recharge and also dry summers where landowners might be tempted to irrigate their meadows. Water

Figure 6.3 **Deviations from the channel width predicted by river flow category, using RHS data from chalk river SSSI catchments**




Kennet
Avon
Test
Itchen
Frome

meadows can therefore be an additional water resource burden to the river, in contrast to overbank flooding which only occurs at times of excess water. Carriers can also trap large quantities of migratory fish, so careful thought should be given to their design in any restoration plans.

6.2.3 Designing characteristic chalk river channels and their floodplains

An outline of possible measures for enhancing and restoring the river channel and river-floodplain interactions is given in Table 6.2. The detailed design of channel morphology will vary according to local conditions and historical information, but in all cases it should allow the river to influence its own form over time. In areas of high flood acceptability, the aim of channel restructuring should be to reduce the cross-sectional area of the channel (or family of channels) to a point where saturation or inundation of riparian land can be expected in normal winters. *However, great care should be taken to avoid prolonged inundation of existing flower-rich riparian grasslands (particularly during spring – Gowing and Spoor 1998). Assessment of the likely impact should be undertaken in such cases, considering the nature of the sward and its underlying soil and drainage structure.*

Banks should generally be shallow, with gravel bars positioned within the channel so as to deflect flows and generate a range of current velocities, creating riffles and pools, strongly scoured gravels and slack waters where siltbeds can accumulate in shallow water. In some river sections, it may be necessary to use imported gravels to raise the river bed in order to regain hydrological contact with riparian habitats; however, in many sections it is likely that the desired state can be achieved through channel narrowing and bank reprofiling. The aim of such work is to speed up the natural reduction of channel size to match the prevailing flow regime, which may be prevented by bank erosion from heavy livestock grazing. In some instances, it may be possible to re-create indistinct channels in perennial headwater areas, generating natural braiding in association with carr or meadow vegetation that would mimic the early historical state.

In areas of low flood acceptability, channel restoration will have to be undertaken mainly within the existing channel. In such situations, highly beneficial marginal habitat can be created on berms set at the level of typical summer flows (around the level of 95% exceedence flow). If small berms or bars are positioned in an alternating sequence, variations in depth, current velocity and substrate type can be achieved. Any such work should consider the requirement to restore a natural vegetation sequence through the growing season, allowing the encroachment of marginal vegetation during late summer.

In many instances, it may be possible to allow the river to form a smaller functional channel within the over-sized channel by limiting the dredging and weed-cutting activity that prevents natural erosion and deposition processes and by focusing works on the central part of the channel (see Section 6.3). This will result in a smaller area of bare gravel, but the scouring on this area will result in high gravel quality. Continuing heavy livestock grazing will inhibit the process and should be reduced in intensity or controlled by fencing. Impacts of silt from arable land also need to be controlled, if clean gravels are to be achieved along significant lengths of river.

Land-lowering may be attempted in areas of low flood acceptability, whereby the sub-soil is removed from riparian areas so that an area of grassland is created that is in better hydrological contact with the river. Overall flood defence capacity is maintained, since the river has not altered its relationship with the wider floodplain, and extra flood capacity is also created. This type of operation is ideally suited to amenity parkland, where widespread flooding is not acceptable since it would hamper public use, but where there is sufficient space to broaden the extent of influence of the river. Opportunities can also be taken to narrow the main channel if appropriate.

Table 6.2 Measures for enhancing and restoring characteristic river processes and floodplain interaction

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
1. Addressing channel structure		
Channel reforming		
♥One-stage channel narrowing to produce appropriate dimensions to flow.	♥Re-establishment of strong current velocities and river's capability to influence its own geomorphology. Improved scour of channel gravels. Better hydrological continuity with riparian areas. Improved water depths at low flows. Increased likelihood of floodplain flooding in target areas of high 'flood acceptability' (see Section 6.2), and consequently improved habitat for wetland flora and fauna.	♥Loss of flood defence potential, but can be implemented where flooding is acceptable, flood-risk is low (see Section 6.2) or flood defence benefits accrue downstream from water storage on floodplain. Banks should be kept well vegetated and stable to prevent increased bank erosion. Reductions in agricultural capacity, if currently in arable use. However, pastures may benefit from improved water availability, as many meadows are too dry in the summer.
♥Longitudinal and cross-sectional reprofiling to create diversity in channel gradient and depth (in line with historical geomorphology)	♥Improved variation in water depth, current velocity and substrate under all flow conditions. Provision of slack areas for siltbed development and heavily scoured areas for self-cleaning gravel beds.	
♥Channel bed-raising	♥Better hydrological continuity with channel banks and riparian areas. Increased likelihood of floodplain flooding in target areas of high flood acceptability, and consequently improved habitat for wetland flora and fauna.	♥As above
•Removal of impounding weirs	•Improved current velocities and scour of gravels, allowing more natural influence over geomorphology. Improved access for migratory species and for recolonisation of upstream areas following impact.	•Loss of water depth and possibly reduced hydrological contact with floodplain, both of which may be mitigated by other measures (see above and below). Greater scope for disease transfer and movement of non-native species, particularly in relation to the plight of the native crayfish.
•Introduction of instream deflectors, groynes, flow concentrators or gravel bars within oversized channel, typically set at low-flow water levels.	•Restricts channel width and restores sinuosity at low flows, leading to improved physical diversity in terms of current velocity, water depth and substrate. Flood defence standards can be retained.	•Imposition of artificial constraints on channel form. No improvement in channel/floodplain interaction.
•Establishment of two-stage channel (with narrowing of low-flow channel).	•As above, with creation of wetland berms within the channel that mimic shallow banks.	•As above.
•Restriction of dredging activity, focusing on central part of the channel.	•Reformation of channel diversity through natural erosion/deposition processes and vegetative growth. Focused mid-channel scour during summer flows. Reduction in dredging costs and disposal problems.	•Short-term losses of gravel quality but long-term gains. Loss of flood defence potential so this will usually not be possible in areas of low flood acceptability.

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
♥Bank reprofiling	♥Re-establishment of shallow bank form where this has been lost, creating a gradual transition between channel and riparian flora/fauna. Retention of some steeper bank forms and undercut banks for fish refugia, water voles, kingfishers, sand martins etc.	♥Reduced flood defence potential so this will usually not be possible in areas of low flood acceptability.
Weed-cutting		
♥Limited weed-cutting intensity in spring/summer, focused on central part of the channel.	♥Active marginal growth provides habitat, bank protection and higher water levels in spring/summer. Reduced weed-cutting costs and disposal problems due to reduced stimulation of *Ranunculus* growth.	♥Loss of open water and bankside access for anglers (which can be mitigated for - see Sections 6.3)
♥Weed-cutting in patches to mimic natural habitat mosaic.	♥In conjunction with above, reproduces a characteristic mozaic of bare gravel and submerged plant beds, creating focused scour on gravel substrates.	
•Selective spring/summer cutting of vegetation in strips across the channel	•Improved spring/summer water levels during the low-flow period, allowing better hydrological contact with banks. Increased soil moisture levels in riparian meadows to the advantage of wetland flora/fauna. Reasonable fish visibility for anglers.	•Risk of generating semi-impounded flow with little focused scour and an enhanced risk of silt deposition onto gravels.
♥Restriction of autumn weed-cutting, focusing on central part of the channel.	♥Greater availability of over-wintering habitat, in terms of vegetative cover and areas of slack water. Increased winter flooding of floodplain in target areas of high flood acceptability, and consequently improved habitat for wetland flora and fauna.	♥Possible flood defence consequences, but can be implemented where flooding is acceptable or flood risk is low (see Section 6.2).
♥Mature tree retention and targeted tree planting in riparian areas.	♥Development of tree root systems as instream habitat for fish, native crayfish and other species. Also scope for the control of plant growth where desirable.	♥Risk of loss of characteristic riparian grass swards (see Section 6.4) and adverse changes in species composition in the submerged plant community.
2. Beneficial activities on the floodplain		
♥Sensitive disposal of dredgings and cut weed, retaining any relict floodplain features and wet depressions in the land. Avoid any application to banksides and flower- and/or invertebrate-rich grasslands.	♥Maintenance of existing floodplain value to flora/fauna.	
•Restoration of water meadow carriers and hatches or creation of new carriers.	•Controlled inundation of riparian meadows with consequent benefits to wetland flora/fauna.	•Control of abstraction is needed to maintain acceptable flows within the river channel and suitable flows over the floodplain. Entrapment of migratory species in carriers needs to be avoided.
•Land-lowering in riparian areas	•Establishment of relatively small riparian terraces with good hydrological contact with the river, providing wetland habitat for	•Disposal of large amounts of spoil is required, which must not affect other habitats detrimentally.

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
	characteristic riparian flora and fauna. Possible flood defence benefits from extra storage capacity.	
•Low-profile clay bunding where necessary to hydrologically isolate areas of high flood acceptability from areas where flooding is undesirable.	•Increase in scope for targeted inundation of the floodplain.	•Needs to be undertaken sensitively to avoid impacts on the landscape. Reduced flexibility to cope with changing social/agricultural circumstances.
♥Following hydrological engineering, recreation of key lost floodplain habitats, particularly large reedbeds and woodland carr.	♥Re-establishment of the full diversity of biological communities in chalk river catchments.	♥Requires land purchases or strong landowner cooperation/interest in habitat restoration (with grant aid).
3. Addressing low flows		
3.1 Improvement of flow rates		
♥Enhance infiltration to aquifer through increased water retention in catchment soils.	♥Higher baseflows and reduced pressure on groundwater resource.	
♥Reduce demand on water resources. ♥		
♥Targeted encouragement of water conservation in public and industrial sectors.	♥Reduced abstraction rates and hence higher residual flows.	
♥Targeted control of mains leakage.	♥As above	
•Switching water sources for potable and other uses•		
•Utilisation of sources further down the catchment.	•Reduction in total river length affected by low flows.	
•Import of potable water from catchments not affected by low flows.	•Reduced within-catchment abstraction rates and hence improved flows.	•May generate low flow problems elsewhere in the future.
•Dispersed abstraction.	•Reduction in worst local effects associated with immediate cone of depression.	•More extensive but low-level effects.
•Reduce distance between fish farm intakes and discharges (by pumping if necessary).	•Reduction in spatial extent of low flows.	•Possible reduction in water quality in section downstream of new effluent location.
•Groundwater augmentation by pumping.	•Useful mitigation of the short-term effects of extreme low flows, but should not be seen as a long-term solution.	•Artificial interference in natural recharge process, with particular care needed to protect winterbourne communities. Masking of the root causes of low flow problems together with possible hydrological impacts in adjacent catchments sharing the same aquifer. Should be seen as a temporary mitigation measure.
♣Inter-basin transfers for river flow augmentation.	♣Enhanced flows downstream of transfer point.	♣Possible changes in water chemistry, flow patterns. Potential for the transfer of diseases and non-native species. Possible future flow

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
		problems in donor catchment.
♣Pumped STW effluent transfer.		
♣To upstream reach.	♣Improved flows in low -flow section between abstraction and discharge.	♣Reduction in water quality and increase in nutrient status.
♣For aquifer recharge.	♣As above.	♣Better water quality than above but risk of long-term accumulation of nutrients (particularly phosphorus) in the aquifer.
♣River recirculation.		
♣To upstream reach.	♣Improved flows downstream of point of return.	♣Reduction in water quality and increase in nutrient status.
♣For aquifer recharge.	♣As above.	♣Better water quality than above but risk of long-term accumulation of nutrients (particularly phosphorus) in the aquifer.
♣Bed-lining.	♣As above	♣Permanent loss of continuity with hyporheic zone and instream springs masking fundamental resource problems. Huge losses in naturalness.
3.2 Mitigation against permanently reduced flow rates		
•Modification of channel to match flow rates (see 1).	•Reduction in some effects of low flows (increased water depth, improved substrate quality).	•If low flow problems are associated with abstraction, risk of acceptance of unreasonably high water usage and permanent, artificial reduction in river size.

♥ Best practice, to be applied wherever possible.
• Measures to be applied where best practice is not feasible due to practical constraints, and/or where local circumstances suit.
♣ Measures that are highly likely to be detrimental to nature conservation interests.

Removal of impounding weirs, as on the River Chess in Buckinghamshire, can result in ecological improvements through the re-establishment of a more natural flow regime. Such a move also helps to alleviate siltation problems through increased transport of particulates out of the system, and encourages migratory and colonisation activity. Small impounding weirs are frequently placed in the perennial headwaters of chalk systems to increase water depth and encourage fish populations, but these streams are naturally shallow and their character is greatly altered by impoundment. The flora and fauna may be affected by the reduced current velocities and larger fish species that are encouraged. In addition, recolonisation following extreme drought becomes more difficult for many species dependent on in-river colonisation from downstream areas and those using gravel interstitial areas that can be blocked by increased siltation.

Wherever they occur in the river system, weirs are a potential barrier to the free movement of species, be they strongly migratory in nature (such as salmon and lamprey species) or species that would otherwise be able to colonise more freely (such as following population losses due to pollution incidents). Consideration should, therefore, always be given to their likely effect as an ecological barrier, and an assessment made of the need to provide by-passes. This should include consideration of salmon, trout, lampreys, eels and rheophilic cyprinids with a strong migratory tendency (such as dace). Possible detrimental effects from improving access for introduced species should also be considered, particularly in relation to non-native crayfish species which are currently being restricted in distribution by weirs in some rivers.

6.2.4 Choosing methods for restoring flows

A wide range of options exists for restoring river flows (see Table 6.2), within which there is great variation in terms of benefits to nature conservation. The most benign and therefore most ecologically sympathetic strategy is to improve aquifer recharge by encouraging water retention in catchment soils, whilst abstracting less water by targeting inefficiencies in water supply and consumption (i.e. mains leakage and public/industrial demand). At the other end of the scale are highly interventionist methods that cannot be advocated on nature conservation grounds (effluent transfer, river recirculation and bed-lining), resulting in considerable loss of naturalness and high ecological risk. In between these two extremes, the best ameliorative option is to move abstraction pressure to less damaging locations, either through sinking major boreholes in areas of surplus groundwater (which may be out of the catchment) or through the creation of numerous smaller boreholes that reduce the extreme effects of major draw-down zones. Either may be suitable depending upon local circumstances, which can be tested using hydrological model simulations (see Section 5.4). However, it is important that new abstraction patterns do not merely shift the problem elsewhere rather than resolve the issue comprehensively.

Aquifer recharge in chalk catchments has been reduced considerably in recent decades by urban development (including transport infrastructure) and agricultural intensification, both of which encourage rapid export of water to the river and out of the catchment. The restoration/creation of natural storage areas within the catchment, where more time is allowed for rainfall to percolate down through the soil and into the aquifer, is highly important in terms of relieving pressure on water resources in chalk catchments. The catchment-based approach to restoring river/floodplain interactions advocated in Section 6.2.1 can provide new storage areas close to the river network, but ways of retaining water higher in the catchment are also required, particularly through the interception of key run-off pathways (such as along roads, farm tracks and dry valleys).

The benefits of targeting inefficiencies are difficult to predict, since there are large unknowns relating to public attitudes and leakage detection, but predictions will improve as more proactive and coordinated initiatives are undertaken. It is certainly sensible to defer other more interventionist options on a river system until water conservation initiatives are given a chance to work.

Sewage effluent transfer or river recirculation back up to affected upstream sections have severe implications for the water quality, and particularly the nutrient status, of the river. Either can be used for aquifer recharge rather than direct input to the river system, but it must be recognised that there is no way of losing phosphorus from the catchment other than via river transport. The aquifer will initially strip out phosphorus from nutrient-rich recharge waters, but at some stage in the future the adsorption capacity of the aquifer will become locally exhausted and export to the river is inevitable (hastened by fissure flow). Phosphorus-stripping of effluents is possible, if the phosphorus-laden waste can be used agriculturally or recycled rather than disposed of to sacrificial areas (in which case groundwater contamination is again inevitable - see Section 6.5 and Mainstone *et al.* 1998). Bed lining is a further interventionist option, this time destroying the hydrological link between the river, its deep sediments (the hyporheic zone), any instream springs, and the floodplain. As with effluent transfer and river recirculation, it serves only to mask the underlying problems generating unacceptably low flows and cannot be accepted as a solution in terms of nature conservation.

6.3 Decisions concerning channel maintenance

6.3.1 Weed management

Best practice for nature conservation purposes is to allow plant succession to progress as naturally as possible, starting with a mosaic of submerged plants (*Ranunculus* and other species) and bare gravel in spring and early summer, leading into progressive dominance by encroaching marginal vegetation with a central, strongly scoured channel, and consequent decline in submerged growth in late summer. Good submerged plant cover in spring allows water levels to remain high, with the necessary hydrological contact between the river, its banks and riparian meadows at this critical time of year. Retention of considerable amounts of marginal growth in the late summer and autumn allows focused scouring in the main channel and protects banks against water erosion over the winter period.

In practical terms, the desired effect can be achieved by limiting the frequency and spatial intensity of management to the minimum necessary, and using cutting patterns that mimic the characteristic habitat mosaic and encourages a central low-flow channel. For this to happen, a new understanding needs to be found between interested parties that allows the river to function more naturally, in terms of the diversity and seasonal succession of plant communities and the habitats they provide, but without compromising operational objectives.

In most cases, *land drainage* and *flood defence* requirements can be satisfied by cutting no more than 30% of the channel width at any one time. Where increased water table levels and inundation of riparian meadows are acceptable, even lighter weed cuts can be undertaken. Such light cutting regimes need to be implemented with due consideration of adjacent land use, but land use might be open to change following discussions with riparian landowners (see Section 6.2). An example of good practice on a large winterbourne section is provided in Plates 32 and 33, where management on the Lambourn is focused on limited cutting of *Ranunculus* (in this case *peltatus*) in mid-channel, generating excellent fringing vegetation and strong scour across half the width of the channel. Such light management may not be acceptable on fished river reaches, but in recruitment zones such as this there are important benefits to downstream fish populations derived from the excellent habitat provided.

Cut weed should be collected by booms or in catch areas and allowed to drain on the bank side for a short period prior to final disposal. For small cuts, spreading over land of low ecological interest away from the river is probably the best course of action. For large cuts, unless sufficiently large sacrificial areas of low ecological value can be found away from the river, composting or ensiling are likely to be the best solutions. Normal precautions need to be taken to prevent silage liquor entering the river system, through the establishment and maintenance of reception pits.

Plate 32 A winterbourne section of the Lambourn, April 1995.

Plate 33 The same section of the Lambourn in late June 1995, showing the effects of light weed management focusing on mid-channel.

Best weed-cutting practice for land drainage/flood defence

In spring and early summer

- *Cut up to one third of the channel width as necessary to lower water levels to required land drainage standards.*
- *Match intensity of cut to adjacent land use, using lighter cuts wherever possible.*
- *Cut in patches to mimic the characteristic pattern of bare gravel and submerged plant beds.*
- *Concentrate cutting on the central low-flow channel to maximise scour on mid-channel gravels.*
- *Retain marginal fringe of emergent vegetation.*

In late summer and autumn

- *Cut and remove only that which is of concern in relation to blocking structures downstream.*
- *Concentrate cutting on the central low-flow channel to maximise scour on mid-channel gravels.*
- *Retain strong marginal fringe of emergent vegetation.*
- *Only in very critical 'conveyance' reaches will more than 30% of the channel need to be cleared.*

In terms of *fishery requirements*, many fishery owners already adopt regimes that are broadly in line with nature conservation objectives. Such regimes need to be encouraged along river reaches where a more extreme approach to weed management is currently adopted. A certain amount of reconceptualising of the river would be necessary by anglers of these reaches if an acceptable compromise is to be reached. If best practice is adopted, the river channel will appear somewhat narrower through much of the summer, there is likely to be less open water to spot fish and more vegetation for fish to swim into when hooked, whilst access to the river will be hampered by marginal vegetation.

Best weed-cutting practice for fisheries

- *Cut up to one third of the channel width as necessary to provide open water.*
- *Cut in patches to mimic the characteristic pattern of bare gravel and submerged plant beds and encourage the establishment of small territories by salmonids.*
- *Concentrate cutting on the central low-flow channel to maximise scour on mid-channel gravels.*
- *Leave occasional strips of vegetation across the entire river width in spring to maintain water depth and local water table levels (see Plate 34).*
- *Retain strong marginal fringe of emergent vegetation and some beds of submerged non-Ranunculus species.*
- *Cut gaps in the marginal vegetation as necessary to provide access to the water and for landing fish.*

Adoption of the desired changes by fishery owners and angling clubs may rely on the challenge such a new regime would present to angler skill. There will also be benefits in terms of improved mid-channel gravel scouring and consequently enhanced natural recruitment of salmonids and certain other key fish species. Access to the river can be improved by clearing bays at intervals along the river, providing a firm substrate through the margins to the main channel.

Plate 34	Weed cutting to leave strips of vegetation across the channel so that water levels are maintained.

6.3.2 Channel dredging

Best practice for nature conservation is to retain silt beds where they form part of a natural mosaic of substrate types, typically associated with marginal vegetation in slack water. The occurrence of submerged plants that thrive in silty conditions, such as *Callitriche spp.*, should not be taken as a signal that large-scale dredging is required. Such species are an important component of the diverse plant community characteristic of chalk rivers, and dredging works should seek to maintain this diversity. Limited removal of plants roots and silt (across no more than half the channel width) to help define a low-flow self-scouring channel with wet margins has been undertaken to great effect on a number of chalk streams with over-sized channels, such as the Ver and the Misbourne (Plates 35 to 37). If silt accumulation is a major problem across the whole channel, it is important to identify and control the sources (e.g. cultivation of sloping ground in the catchment). Reduction of channel width may be considered (see Section 6.2) as a short-term solution that is ecologically beneficial and results in reduced maintenance costs. However, this may only serve to move the silt to a stretch of river further downstream. If the source is not dealt with, narrowed channels may not have the capacity to scour eventual loads.

Where dredging has to be undertaken, some marginal siltbeds and emergent plants should always be retained, with works focusing on the middle part of the channel. *Information on the location of priority species reliant on silty/sandy substrates (such as the three lamprey species and the pea mussel Pisidium tenuilineatum) should be gathered and collated and made available to those undertaking dredging works, so that particularly important areas are left untouched.* Side channels and backwaters are important habitats at various stages of in-filling and should not be dredged without clear objectives and consideration of ecological impact.

6.3.3 Gravel cleaning and 'mudding'

As with dredging, the need for gravel cleaning is a sign that more fundamental problems exist. *It should be seen as a mitigation measure whilst longer-term solutions dealing with channel form, inputs of silt and salmonid fish populations are developed.* It is also a necessary measure as a 'kickstart' to normal gravel scouring once the fundamental causes of siltation have been addressed. Mudding can inevitably have serious consequences for species characteristic of siltbeds (such as the lampreys) and should only be undertaken very selectively. Both gravel-cleaning and mudding should focus on the central part of the channel and should ensure the retention of marginal siltbeds and some silted gravels occupied by species such as *Callitriche* spp..

If a programme of gravel cleaning is planned, work should be coordinated along the river and proceed downstream to prevent resilting of cleaned gravels. Cleaning should be conducted at the highest flows for which safe working can be ensured, so as to maximise particulate export from the river system. Where possible, investigations should be made of the fate of resuspended sediments to ensure that problems are not exacerbated downstream. Care should also be taken to avoid enhanced siltation of redds with developing eggs and young.

6.4 Decisions over riparian management

Measures to enhance riparian areas for nature conservation are outlined in Table 6.3. Ideally, the majority of riparian land in the catchment would be managed as open pasture, subject to light grazing and poaching and thereby creating the patchwork of short and medium-length swards and bare soil that supports much of the characteristic flora and fauna of riparian areas along chalk rivers. A significant amount of banklength would also be given over to tall fen vegetation, grazed or cut

Plate 35 A section of the Misbourne choked with vegetation across the full width of the over-sized channel (1 July 1994).

Plate 36 The same section of the Misbourne following limited removal of plants and silt across half the width of the channel (29 September 1994).

Plate 37 The same section of the Misbourne the following summer, exhibiting strong marginal growth with an open, strongly scoured low-flow channel (14 July 1995).

occasionally or not at all. Occasional copses of riparian trees (particularly willow/alder carr) and scrub thickets (both wet and dry) are valuable additional habitats.

Where livestock grazing has intensified to the point where serious bank erosion is occurring, efforts should be made to reduce stock densities and allow natural recovery (perhaps with temporary fencing of worst affected areas). If, however, there is no possibility of reaching agreement with the landowner over stocking levels, bankside fencing will have to be erected in order to protect the river channel. This will allow valuable tall herb vegetation to develop in place of the heavily damaged short sward. Some light maintenance of the sward in the fenced zone would be beneficial ecologically and also from the perspective of bank stability, generating a tighter sward with greater soil binding capacity. Possibilities for limited grazing should be considered, either by allowing livestock to reach through the fence to graze beyond it, or by occasional release of small numbers of animals into the riparian zone. However, the latter possibility would probably necessitate wider fenced strips to allow livestock mobility, and would be a labour burden to the farmer. Another possibility is occasional scything, but again this would be an additional cost (perhaps offset by grant aid, volunteer effort and/or the use of cut vegetation as stock feed).

Every effort should be made to eliminate arable farming from riparian areas, in favour of permanent grassland or woodland. Where ploughing of riparian fields occurs, buffer strips of at least 5 metres should be negotiated to allow a valuable tall herb sward to develop, which will additionally help to protect the river from agrochemical overspray/drift or soil erosion.

Where riparian vegetation is intensively cut to allow angler access, landowners should be encouraged to adopt a lighter management regime, consisting of a single path scythed mechanically every month or so through the growing season set some way back from the bank, with occasional access points to the river. Bank edges and other areas are best cut once or twice through the summer to provide a relatively tall sward, but staggering the time of cutting to allow continuity of the habitat. Some tall herb vegetation should be allowed to overwinter uncut to provide continuous habitat for invertebrates and small mammals such as water voles.

6.5 Tackling silt and nutrient inputs

6.5.1 Target-setting and holistic management

It is clear that an integrated programme of control is required to combat loads of particulates and nutrients to chalk river systems, involving the effective control of both point and diffuse sources. What is perhaps not so clear is what our objectives should be in terms of target water quality and target loads, against which the success of control efforts can be judged. Whilst some guidance can be given on targets for phosphorus, further consideration is required for solids, and for both elements it is sensible to undertake local investigations to place generic targets in a local context (Box 7). However, the absence of agreed, locally defined target levels is not a reason to delay the implementation of control programmes, which at the current level of anthropogenic inputs can only benefit the chalk river environment. What is essential is adequate monitoring to assess the effectiveness of control programmes in terms of water quality, sediment quality and the biota.

It should be stressed that there is no reason to suppose that reductions in phosphorus levels to the generic target values suggested in Box 7 would result in any adverse ecological consequences. The detailed work of Robach *et al.* (1996) suggests that reducing ambient SRP concentrations in calcareous rivers to an annual mean as low as 40 $\mu g\ l^{-1}$ would not result in the loss of eutrophic plants. Even those species known to thrive in highly enriched conditions immediately below sewage treatment works discharges, such as *Potamogeton pectinatus*, are an important but balanced component of the plant community at these background nutrient levels. The productivity of the macroinvertebrate and fish communities is dependent upon the physical quality of the habitat (including abiotic and vegetative habitats) rather than the artificially elevated nutrient status of the water column. Unless phosphorus levels are driven down to ultra-low levels (probably less than 10 $\mu g\ l^{-1}$), phosphorus concentrations in the water column would still generate adequate populations of benthic, epiphytic and planktonic algae for primary consumers using this food source.

Key measures to combat silt and nutrient inputs are listed in Tables 6.4 and 6.5 respectively, together with other measures discussed above that are associated with re-establishing proper river function that will help to transport loads out of the system. Mass-balance assessments and analysis of water quality and flow data can be used to help determine the contribution from individual point sources to the total phosphorus load in the river, whilst detailed modelling can shed more light on the relative effects of point and diffuse sources on the seasonality and spatial distribution of phosphorus concentrations (see Mainstone *et al.* 1996, 1998). The control of point and diffuse sources is discussed in more detail below.

6.5.2 Point sources

Even in rural areas, sewage effluents are usually important contributors to water column concentrations of bioavailable phosphorus (see Section 5.6). As discrete and highly treatable sources, they should be a prime target for control. Certain industrial and MOD discharges may also provide significant inputs and should be assessed for the need for control. Phosphorus removal techniques should be applied to those effluents carrying significant loads, with an emphasis on upstream works to prevent improvements from being masked by effluents further upstream. Of the available methods, biological removal is the most environmentally benign, involving no extra sludge production and no use of chemical additives. At smaller works, there is no real alternative to chemical dosing to produce a precipitate. Iron is commonly used, but typically results in coloured effluents to the river and also renders much of the phosphorus unavailable to crops (at least in the short-term). The addition of calcium salts to the waste stream is preferable, which allows the retained phosphorus to be recovered for industrial applications. These options are discussed in greater depth in Mainstone *et al* (1998).

The manner of disposal of the phosphorus-rich precipitate from conventional stripping techniques is a matter of concern. It should not be spread to areas of sacrificial land, as this will lead to long-term accumulation and the risk of subsequent export back to the river via the aquifer. There are no additional restrictions on its use as an agricultural fertiliser, and so it should be applied in accordance with crop requirements on nearby farms (see Section 6.5.3). However, the additional land required to spread sludge based on crop and soil phosphorus requirements is considerable. A more desirable option than land spreading is *phosphorus recycling* directly from waste streams, for use in industrial applications (including the fertiliser industry). This is becoming increasingly feasible (see Mainstone *et al.* 1998) and has the potential to replace a non-renewable resource (rock-phosphate used in inorganic fertilisers) with a sustainable reclaimed resource, benefiting the water industry in economic and regulatory contexts, and reducing the mass-transfer of phosphorus into UK catchments (thereby tackling eutrophication problems at their true source). Commercial plants based on different processes are already in existence, and the technology could easily be transfered to the UK.

Primary treatment of effluents is now the norm for fish and cress farms on chalk rivers, typically utilising settlement tanks. Treatment should be established on remaining farms, and regular inspections should be carried out to ensure that settlement ponds are being maintained effectively. The ponds should be fish free so that settlement is not impaired, with screens to prevent access of fish from the farm and the river, and regular electrofishing as a precautionary measure. Desilting should be performed *off-line* periodically, when the build-up begins to impair effective solids retention, and dredgings should be spread to land well away from the drainage network.

Box 7. Setting water quality targets for phosphorus and solids.

a) Phosphorus targets

The risk of adverse effects due to phosphorus declines as phosphorus concentrations approach background levels, such that any incremental reduction should be seen as a positive step towards trophic restoration. Given the sliding scale of ecological risk associated with riverine phosphorus concentrations, and the numerous confounding factors operating, it is unrealistic to expect to identify particular threshold concentrations of phosphorus that will automatically safeguard characteristic chalk river communities. However, it is clear that the level of risk changes most rapidly over the concentration range from natural conditions to around 200-300 $\mu g\ l^{-1}$ (see Section 5.6). A pragmatic approach to setting targets is therefore required, involving the identification of phosphorus levels within this concentration range that are achievable and that approach those expected at low levels of anthropogenic input for chalk rivers (Mainstone *et al.* 1998).

Whilst it is sensible to undertake investigations into the history of phosphorus levels in the river in question using a variety of methods (see Mainstone *et al.* 1998), it is possible to suggest generic target values (as annual means and growing season means) for different chalk river reaches that can be modified based on local knowledge. These values allow for low-level anthropogenic impact but serve to bring phosphorus levels down towards the lower end of the concentration range over which ecological risk changes most rapidly.

Chalk river section	mg l^{-1} SRP
Perennial headwater	0.06
Classic chalk stream	0.06
Large chalk river	0.1

Where clay substrates form a substantial component of the catchment of a river section, these values may need to be revised upwards slightly.

Water column concentrations are inevitably only one facet of riverine enrichment (although they are generally a useful indicator of enrichment in other environmental compartments) and greater attention needs to be focused on the status of the sediment in future. Sediment phosphorus targets for different river types, probably based upon the Equilibrium Phosphate Concentration (see Mainstone *et al.* 1998), ultimately need to be developed to provide a holistic framework for phosphorus control.

b) Solids targets

Whilst it is known that natural concentrations of suspended solids are extremely low in chalk river systems, quantification of target levels that are actually achievable is a more difficult proposition. Ambient suspended solids levels through the summer months are generally acceptable on chalk rivers (of the order of 2 or 3 mg l^{-1}), but target concentrations for the autumn and winter period of high flows (when the majority of the solids load enters the river) is more problematic. The most fruitful avenue of investigation is likely to be observations on chalk river systems that are less intensively managed than UK examples, particularly those in northern and eastern France. Targets need to be set in terms of both suspended solids and bed loads to provide a realistic measure of the success of control programmes. As with phosphorus, local circumstances need to be incorporated into target setting, particularly in relation to the presence of impermeable clay substrates within the catchment.

Low-phosphorus floating food pellets are now available to fish farmers that can greatly increase phosphorus uptake efficiency and thereby reduce phosphorus loads to the river. On cress farms, phosphorus uptake efficiencies can be greatly increased by the use of slow release pellets, augmented by a top-up liquid phosphate that is metered into the top of the beds and monitored at the outflow.

6.5.3 Diffuse sources

Measures to reduce nutrient and solids loads from diffuse agricultural sources can be divided into three categories relating to: the application of materials (essentially inorganic fertilisers and livestock excreta), the retention of particulates and nutrients within the soil, and the transport and off-site retention of the same in designated buffer areas. Key techniques are listed in Figure 6.4, any one of which can bring about reductions in diffuse loads. *However, it is important to recognise that the key to controlling diffuse inputs is combatting the problem at source, making sure that nutrient applications to land are no greater than required by the crop and that the soil/vegetation matrix of individual fields is stable and efficient at binding nutrients and particulates. Off-site retention in buffer areas should be seen as a back-up for when such source controls are unable to cope, and should not be regarded as a comprehensive solution to diffuse pollution problems.* More detailed reading is provided by reviews in Mainstone *et al.* (1994, 1996).

In chalk river systems it is particularly important to consider the high vulnerability of the thin, nutrient-poor soils of downland areas, which are wholly unsuited to intensive grazing and ploughing for arable cropping. Every effort should be made to ensure that such land remains under extensive grazing regimes. Where it cannot be prevented, it is essential that artificial run-off pathways (such as farm tracks, roads and dry valleys) do not allow the poor quality run-off from such land to enter the drainage network, by using features such as cross-drains, vegetated reception areas on shallow-sloping land, and engineered silt traps.

Table 6.3 Measures for enhancing and restoring characteristic riparian vegetation

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
♥Reduction in high livestock densities in riparian meadows.	♥Reduction in excessive trampling/poaching and consequent enhancement of characteristic lightly grazed vegetation.	♥Reduced agricultural income, which may need to be compensated, but improvement in sward quality and reduction in fertiliser costs partially offset reduced profit. Grant aid also available.
•Where reductions to acceptable densities cannot be secured, fencing of banksides.	•Elimination of excessive trampling /poaching and change from a heavily degraded flora/fauna to a valuable tall herb habitat.	•Loss of potential for re-establishing characteristic short sward bankside vegetation and associated fauna, and therefore not suitable over large, continuous lengths.
♥Discouragement of arable cropping in riparian areas and land elsewhere that is vulnerable to erosion (particularly downland), in favour of lightly grazed permanent grassland.	♥Re-establishment of characteristic riparian vegetation and associated fauna.	
•Where arable cropping persists in riparian areas, widening of the strip of permanent vegetation between river and field (to at least 5 metres).	•Establishment of tall herb vegetation of sufficient width to provide a good refugia for mammals, birds and invertebrates. Protection for channel and banks from pesticide overspray and drift.	•Loss of agricultural income which may need to be compensated via grant aid.
♣Measures to restore hydrological continuity between the river channel and riparian areas (see Section 6.2)	♣Enhancement of riparian areas for wetland flora/fauna.	
♥Where riparian vegetation is intensively managed for angler access to river, restrict to narrow angler paths and retain bankside fringe of lightly managed vegetation (preferably 1 metre wide) with limited access points through to the river.	♥Improved vegetation structure and habitat opportunities for riparian fauna.	
•Restriction of tree planting and growth.	•Maintenance of characteristic grass swards through the prevention of shading. Also maintenance of submerged plant community typical of chalk rivers by same mechanism.	
•Targeted tree planting and scrub development.	•Improved habitat for shade-loving plant species, and various bird and mammal species.	•Risk to characteristic riparian swards and associated fauna that needs to be assessed carefully.

♥ Best practice, to be applied wherever possible.

• Measures to be applied where best practice is not feasible due to practical constraints, and/or where local circumstances suit.

♣ Measures that consist of options coming under more than one of the above categories.

Table 6.4 Measures for alleviating siltation problems

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
5.1 Reduction of inputs		
♥Effective solids removal from discharges (cress farms, fish farms and other key point sources).	♥Reduced point source loads.	♥Regulatory monitoring of settlement tank maintenance required for effective solids removal.
♥Elimination of arable cropping in riparian fields and land elsewhere that is vulnerable to erosion (particularly downland), in favour of permanent grassland.	♥Reduced diffuse inputs from soil erosion.	♥Reduced agricultural income, which may need to be compensated via grant aid.
♥Use of soil conservation measures on all arable land, including minimal tillage regimes and improvements in humus content.	♥Reduced generation of particulate run-off.	
•Where arable cropping persists in riparian areas, maintenance of a strip of permanent vegetation between cropped area and river (preferably more than 5 metres) and between cropped area and ditch systems.	•Reduced risk of particulate run-off reaching the river, except during overland flooding when large losses will still occur.	•Reduced agricultural income, which may need to be compensated via grant aid.
♥Reduction in livestock densities in riparian areas and land elsewhere that is vulnerable to erosion.	♥Reduced diffuse inputs from bank erosion and soil erosion.	♥Reduced agricultural income, which may need to be compensated, but improvement in sward quality and reduction in fertiliser costs will partially offset reduced profit.
•Bankside fencing where livestock densities cannot be reduced to acceptable levels and bank erosion is severe.	•Reduced bank erosion and physical trapping of particulates in run-off. Replacement of degraded bankside vegetation with valuable tall herb habitat.	•Loss of potential for re-establishing characteristic short sward bankside vegetation and associated fauna, and therefore not suitable over large, continuous lengths. Also loss of cattle drink habitat unless fencing can be designed to allow low intensity access to the water.
♥Autumn/winter flooding of riparian land with stable, permanent vegetation (see Section 6.2).	♥Deposition of high silt loads and consequent removal from the river system.	
♥Establishment of buffer areas or constructed silt-traps across key run-off pathways connecting primary sources of particulates (mainly arable land and overgrazed pasture) to the river network. This relates to any locations where run-off is focused, such as roads, farm tracks and dry valleys.	♥Reduced inputs from near- and far-field diffuse sources in downland and floodplain areas.	
5.2 Improved export from river system		
•Selective cleaning of gravels.	•Enhanced wash-out of sediment fines.	•Possible loss of key areas of silty habitat for priority species.

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
♥Reduced frequency and extent of channel and marginal weed-cutting.	♥Focused scour on mid-channel gravels and consequent reduction in silt deposition.	
♥Restriction of autumn weed-cutting.	♥Improved wash-out of gravels due to the ripping out of plant root masses under high flows.	♥Possible increased nuisance from vegetation caught in instream structures. Possible problems with reestablishment of *Ranunculus* if other limiting factors are operating.
♥Weed-cutting to mimic natural channels between weedbeds and maintain focused scour.	♥Maintenance of some high bed velocities over gravel in summer.	
♣Channel narrowing (natural or engineered - see Section 6.2).	♣Improved summer and winter transport of solids and increased winter scour of gravels.	♣Possible loss of silty habitats unless slack water areas are retained.
♣Increased summer flow rates (see Section 6.2).	♣Improved transport of solids down river during the low-flow period.	
♣Increased winter flows (see Section 6.2).	♣Improved scour/wash-out of solids from gravels.	

♥ Best practice, to be applied wherever possible.

• Measures to be applied where best practice is not feasible due to practical constraints, and/or where local circumstances suit.

♣ Measures that consist of options coming under more than one of the above categories.

Table 6.5 Measures for alleviating nutrient enrichment (see also Table 6.4)

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
♥Treatment of point discharges.		
♥Phosphorus-stripping at key STW.	♥Reduced load, particularly noticeable during growing season.	♥Disposal of phosphorus-rich waste may create long-term problems (see Section 6.5.2).
♥Improved solids removal from cress farms and fish farms.	♥Reduced phosphorus/organic load, particularly noticeable during growing season.	♥Regulatory monitoring of settlement tank maintenance required for effective solids removal.
♥Identification and treatment of industrial discharges with significant phosphorus loading.	♥Reduced phosphorus/organic load, particularly noticeable during growing season.	
♥Rationalisation of nutrient inputs to pastures and arable land, to maximise the use of livestock excreta and match nutrient applications to soil/crop requirements (establishment of nutrient management plans).	♥Increased crop uptake efficiency and hence reduced load in winter run-off and reduced risk of contaminated groundwater/baseflow. Reduced fertiliser costs to farmer.	
♥Improved methods of nutrient delivery to grass and arable crops (timing and method of application)	♥Reduced application rates and hence loads. Reduced fertiliser costs to farmer.	
♥Measures to reduce diffuse solids loads to river (see Section 6.5.3).	♥Reduced loads of particulate phosphorus	♥Focusing on these measures without nutrient rationalisation on farms may lead to accumulation in soils and long-term problems.
♥Encouragement of the use of low-phosphorus feeds on livestock farms and fish farms, as well as floating pellets on fish farms.	♥Improved conversion efficiencies for phosphorus and hence reduced phosphorus load in livestock and fish excreta.	
♥Establishment of efficient nutrient management on all cress farms.	♥Reduced phosphorus load, particularly noticeable during growing season.	
♣Increased spring/summer flows (see Section 6.2.4).	♣Increased dilution of point source loads through the growing season and consequent reduction in water column concentrations of SRP.	
♥Autumn/winter flooding of riparian land with stable, permanent vegetation (see Section 6.2).	♥Deposition of phosphorus-rich silts and consequent removal from the river system.	
♥Improve transport of solids within river (see Section 6.2).	♥Reduced accumulation of phosphorus within riverine substrates.	

♥ Best practice, to be applied wherever possible.

• Measures to be applied where best practice is not feasible due to practical constraints, and/or where local circumstances suit.

♣ Measures that consist of options coming under more than one of the above categories.

In terms of fertiliser application, the best practice is to burden the soil with only as much nutrients as the growing crop requires, and deliver this as near to the time of crop uptake as possible. Many of the soils in the UK have very high residues of available phosphorus, maintained by the farmer to eliminate any possibility of phosphorus limitation in the crop (Mainstone *et al.* 1996). This has the disadvantage of releasing much more phosphorus into river systems than is necessary. Soil monitoring and maintaining phosphorus at much lower levels, topping up only when the soil cannot support the crop from its reserves, will make a significant contribution to reducing diffuse phosphorus loads. Nutrient management plans are valuable in planning nutrient applications, encouraging regular soil testing and the integration of livestock excreta into fertilisation programmes in a way that maximises its nutritive value prior to consideration of inorganic fertiliser applications.

One problem with the use of livestock excreta is that it contains high concentrations of phosphorus relative to nitrogen. Application of livestock excreta based on crop/soil *phosphorus* requirements therefore means lower volumetric application rates than if based on *nitrogen*. Since nitrogen requirements are typically used to estimate suitable application rates, basing rates on phosphorus can leave the farmer with problems in finding additional land to spread the excreta generated. Whilst entering into agreements with adjacent farmers is a viable proposition (Rutt *et al.* 1992), reducing the phosphorus content of the excreta is probably easier. Typical livestock feeds contain far more phosphorus than required by the animal, such that conversion efficiencies are very low. Low-phosphorus feeds can greatly increase conversion efficiencies and result in much reduced phosphorus concentrations in livestock excreta, thereby bringing applications rates based on phosphorus into line with nitrogen-based rates.

Across the catchment, crops need to be selected according to environmental risk, with the most critical areas being laid down to permanent pasture or hay meadows. A number of land use changes have been associated with increased particulate delivery to chalk river systems in recent years, including the conversion of pasture to potato cultivation and free-range pig husbandry. Both land uses leave bare, unstable soils during periods of high run-off and should be avoided where risks to the river network are high. On all cultivated soils, reduced tillage regimes help to maintain soil stability and structure, whilst tillage across slopes greatly reduces the potential for focused run-off pathways that can transport large particulate and phosphorus loads. The timing of cultivation is also important, with autumn ploughing and sowing producing far greater particulate (and hence phosphorus) loads than delaying tillage and sowing until spring.

In riparian areas, particular efforts should be made to discourage intensive grazing and arable cropping, in favour of the characteristic vegetation types discussed in Section 3 (maintained by light grazing or cutting regimes). Where intensive grazing or arable cropping cannot be prevented on the bankside, riparian buffer zones are an important last resort for preventing bank erosion and near-field run-off of particulates and phosphorus. Their potential in reducing loads from further afield depends upon local hydrology, since the load has to reach the river via overland flow to be retained by the buffer zone. If arriving via sub-surface flows, land drains or ditch systems, the benefits of such buffer zones will be restricted to reducing inputs from the immediate riparian area. Consideration of local hydrological pathways and the relative contributions from near- and far-field sources is therefore essential, if buffer zones are to be established primarily for water quality improvement.

Focusing buffer zones on major run-off pathways is likely to be more effective in relation to financial outlay (in terms of grant aid), including buffer areas or constructed silt-traps situated away from the river network to receive run-off from rural roads and farm tracks, although more extensive riparian buffer zones may be desirable for enhancing the ecology of the riparian zone and the habitat of channel margins. Buffer zones around ditch systems may also need to be considered, as degraded ditches can short-circuit run-off pathways to the river. On land used for military training, a closer inspection is required to determine suitable control measures, but reducing vehicular access to watercourses and establishing cross-drains on tracks are likely to be important.

If overland flow is the main route of nutrient transport to the river at a specific point, particulate retention is generally extremely high in buffer zones as long as the sward is cut frequently, generating a dense sward at ground level. However, many buffer zones are unlikely to be maintained and then efficiency will be reduced. Whatever the management, bank erosion will be greatly reduced by a fenced riparian buffer zone in areas of intensive livestock grazing. In terms of phosphorus control, buffer zones are initially effective since most of the load in run-off is typically associated with the particulate phase; however, there may be a significant build-up of phosphorus-rich particulates within the zone over time, leading to problems in the longer term. This is an important reason why buffer zones should not be established in isolation from more holistic agricultural measures for phosphorus control.

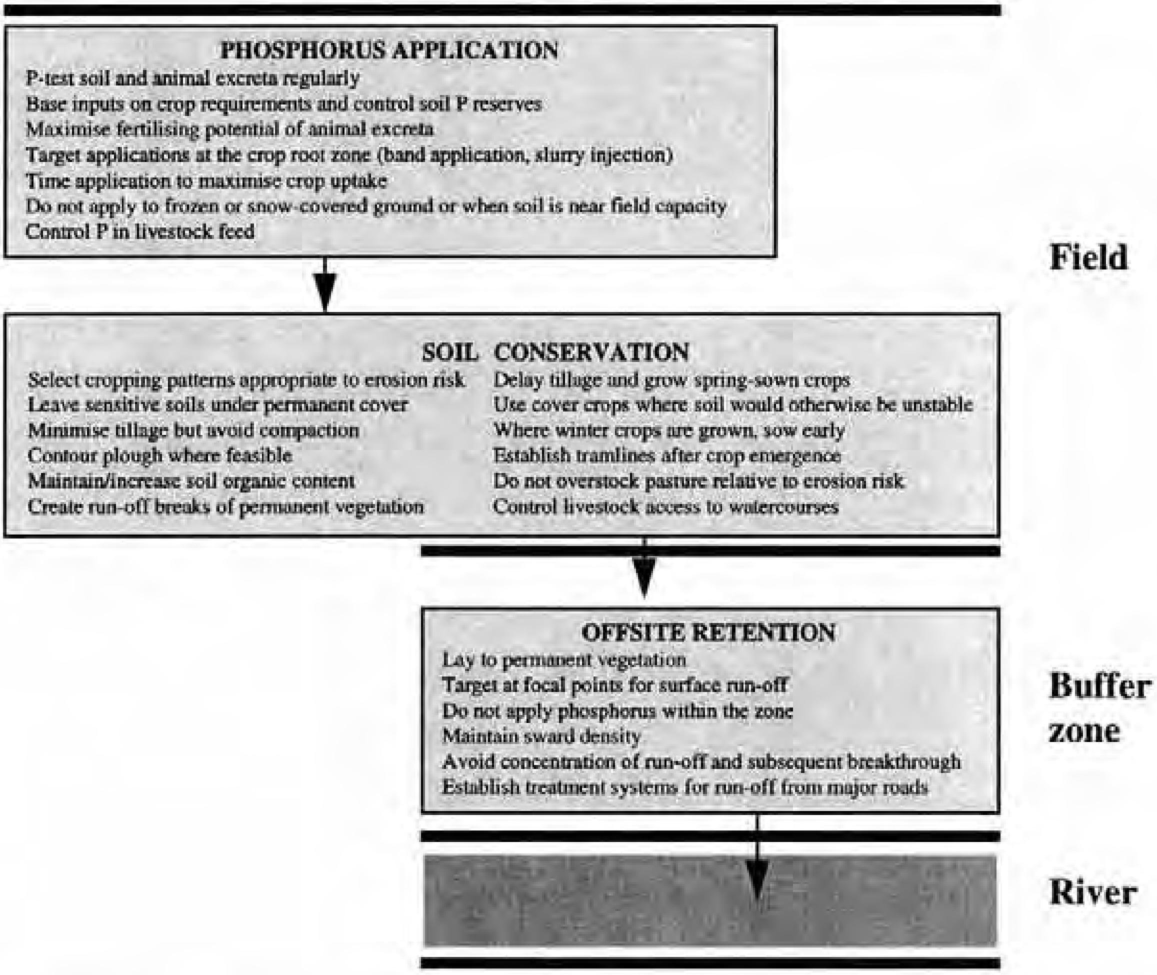


Figure 6.4 **Methods of controlling non-point source loads of particulates and phosphorus to rivers (modified from Mainstone *et al.* 1996).**

In certain instances, such as the interception of highway run-off, specially designed systems for retaining solids (and to a lesser extent phosphorus) will be required, such as wetland treatment systems or grassed channels.

Unmanaged riparian buffer zones can grow into scrub vegetation, which is unlikely to be compatible with conservation objectives if occurring on a large scale (small-scale succession is probably beneficial). It is also not desirable in terms of retention efficiency, since physical filtration is further reduced. Where buffer zones are established, their status therefore needs to be monitored for undesirable changes, at which point some intervention management may be appropriate (occasional mechanical scything, for instance).

6.6 Ecologically sympathetic fisheries management in chalk rivers

Fishery owners have played an important role in the protection of chalk river catchments for centuries, helping chalk rivers to survive in an ecologically valuable state in the face of development pressures. Whilst there are some areas of incompatibility between fishery and nature conservation objectives, mainly associated with the most intensively managed fisheries, the importance of fishery managers in maintaining the ecological quality of chalk rivers in the future is in no doubt. The measures outlined in this section (Table 6.6), focusing on trout fisheries since these are subjected to the most intense management, are already in operation in many sections of chalk stream. *The aim is to move fishery management away from the intensive put-and-take regimes of some fisheries, towards a more ecologically sympathetic philosophy that has long been embraced by many fishery owners, with a focus on natural recruitment within a balanced biological community that is characteristic of the river reach in question.*

Catch-and-release policies are becoming more popular, reducing the pressure to continue stocking trout at high levels, and this should be strongly encouraged along with measures such as reduced bag-limits. Many angling clubs and riparian owners refuse to stock rainbow trout and also tolerate or even encourage populations of grayling as part of the angling experience. Such examples can be used as an illustration of best practice to those who use management regimes that are less sympathetic to the conservation of chalk river communities as a whole. One of the key problems is where salmonid fisheries have been artificially created in river sections (typically downstream reaches) that are naturally unsuited to strong salmonid recruitment, such that any habitat enhancement measures are likely to meet with limited success. Adoption of less intensive management regimes on such reaches may result in the loss of the salmonid fishery and greatly reduced revenues, which is an economic issue that requires consideration.

Pragmatically, changes in the management regime adopted by fishery owners need to occur in parallel with a change in the attitude of their angling customers, since fishery owners with the most intensive management regimes are meeting the demand from some sectors of the angling commumnity for relatively easy catches of large fish that can be taken home for the table. Failure on the part of these fishery owners to satisfy this demand may jeopardise the economic viability of fishery-based river management in these river sections, which could pave the way for more damaging alternative uses of riparian land.

The foundation for ecologically sympathetic fishery management in chalk river systems is, therefore, the encouragement of all chalk-stream anglers to follow the example of those who already embrace the principles of ecological sustainability. This involves angling within the context of a more balanced fish fauna, sustained by diverse habitat opportunities for all stages of the life cycle that reduces the dependency on stocking. Such a regime allows the whole biological community to thrive within a productive ecosystem. *It places emphasis on high angler skill and the broader pleasures of angling on chalk rivers which have long been treasured by many chalk-stream anglers, involving not just the catch but the beauty of the characteristic wildlife and landscape.* Those developing their skills might be encouraged to enjoy grayling fishing on river reaches that are sub-optimal for trout, it being an attractive species of good-eating which is relatively easy to catch.

6.7 Management of winterbournes

Winterbourne reaches merit separate consideration, since the intermittent flows that allow their disinctive flora and fauna to flourish can be misinterpreted as a negative characteristic, with people generally equating a healthy river with all-year-round flows. The establishment of perennial flows in winterbourne sections, such as occurs when a borehole abstraction is discharged into the river upstream of the perennial head, may be as damaging to characteristic winterbourne communities as a reduction in the duration of seasonal flows. The specialised invertebrate species of winterbournes have strategies for surviving the dry phase (see Section 3.4.2) that provide a competitive edge over species of perennial sections, an edge that would disappear if the dry phase was lost. It is important that activities are avoided that reduce the role of ephemeral springs as the driving hydrological force in winterbournes. Effluent returns (such as from water-cress farms and sewage works) and low-flow mitigation measures involving artificial pumping are probably the two main threats.

Artificial reductions in both the seasonal duration of river flow and the local groundwater level inevitably have consequences for the viability of characteristic winterbourne species. Drought stress will reduce the competitive ability of aquatic plant species characteristic of the habitat, in favour of non-aquatic grasses and herbs. The survival strategies of winterbourne invertebrates will be increasingly tested as the dry phase is lengthened. Those species retreating deep into riverine substrates to where water is still present will have longer journeys to make if groundwater levels are drawn down, a particular problem if high silt loads have blocked gravel interstices. There will be large variation in the duration of flow between years, depending on the extent of groundwater recharge, but reductions in the long-term average flow duration should be avoided.

An important point concerning the pattern of flow in winterbournes is that there is no one periodicity of flow that can be said to be ecologically ideal. Those sections with a short dry phase will produce a different community composition to those sections with a long dry phase, and both contribute to the diversity of chalk river habitats. At a catchment level, steps should be taken to maintain a range of flow periodicities within the most natural context possible. The mapping of winterbourne habitats and the characterisation/classification of their existing (and likely historical) flow periodicities is a sensible starting point for this process.

Artificial changes to winterbourne sections that obstruct the strategies employed by some specialist species for withstanding the dry phase are likely to impoverish characteristic winterbourne communities. Siltation of riverine sediments, particularly if accompanied by the creation of a resistant armour-layer, will reduce access to permanently water-filled interstices in deeper layers. Artificial bed-lining, sometimes considered as part of a low-flow mitigation strategy, will completely eliminate this form of refuge. In addition, the establishment of small impounding weirs, sometimes installed to increase water depth and area, can also produce important barriers to species relying on recolonisation from downstream areas following the dry phase. *The effects of human activities on dry-phase survival strategies need to be continuously evaluated if winterbournes are to continue to support their distinctive assemblages of macroinvertebrates.*

6.8 Other management issues

6.8.1 Access and intake safeguards for migrating species

One of the main factors determining the upstream limit of species making significant migratory movements is the presence of impassable control structures. In order to minimise the impact on species distribution, it is important that such structures are tackled in a strategic way that progressively opens up the river network. By-pass structures should be designed to permit access by the full range of species requiring such assistance, including salmon, trout, lampreys, rheophilic cyprinids and eels, depending on local circumstances.

Screening of intakes is feasible (Solomon 1992) but is highly problematic with respect to very small fish with limited swimming ability (such as cyprinid fry). From January 1999, all intakes on rivers supporting migratory salmonids must be fitted with an effective smolt screen (under the Environment Act 1995). However, there is no such protection for fish other than salmon and migratory trout, which continues to be a major omission from the legislation that fails to protect the fish communities of many chalk rivers.

6.8.2 Management of bird populations

The grazing of *Ranunculus* beds by large flocks of unmated mute swans is a growing problem on some chalk rivers. Further work is needed to clarify the magnitude and extent of impact and to identify suitable strategies for minimising adverse effects. Deterrents to keep the birds off certain river reaches may only serve to shift the problem elsewhere. Attracting birds to more favourable feeding opportunities on dedicated adjacent land may exacerbate the problem in the long-term, since survival rates may be enhanced. Egg pricking may be effective but would take time to work through the population (adult swans can live for 40 or 50 years). It will also be hampered if there is significant migration of individuals into the non-breeding flock from other areas (which is highly likely).

Culling of adults is a last resort that may have to be considered under strictly controlled circumstances to reduce the size of non-mating flocks. Along with all wild birds, the mute swan is protected under Part 1 of the Wildlife and Countryside Act 1981. Licences may be granted for control (such as egg pricking or culling) for the purposes of, amongst other things, preventing serious damage to fisheries or to conserve flora and fauna. However, there are legal complications that need to be considered in the case of the mute swan, stemming from the Crown's right over all swans. There are also problems over the public acceptability of culling as a control measure. Until the issue has been given further consideration and less severe control measures have been fully appraised, English Nature is unlikely to endorse applications for control by culling.

The importance of fish predation by cormorants in chalk river systems is less clear. No studies have been reported where significant impacts have been shown to occur on riverine fish populations. A three-year collaborative programme of research into the subject is due to be completed in the near future, which will hopefully shed further light. As with the mute swan, the cormorant is protected under the Wildlife and Countryside Act 1981, and licences may be granted for control (in this case for the purposes of preventing serious damage to fisheries). Until such time as serious damage is proved and available forms of deterrent have tried and failed, English Nature and the Environment Agency would not endorse control by culling.

6.8.3 Management of cress beds as a habitat

Cress beds are a historical part of the headwater structure of many chalk river systems. They provide habitat opportunities for wetland birds and other fauna (including the water shrew) if managed appropriately. Unfortunately, recent intensification of cultivation practices has led to greatly reduced habitat suitability for wildlife. A return to less intensive practices is the only way in which the habitat can be restored, and it is important that possible mechanisms are discussed with cress farmers. Any desirable changes, such as increasing height at harvest, generally reducing the level of physical disturbance and reducing pesticide applications, are likely to result in reduced income and may require some form of grant aid. Where possible, derelict cress beds should be retained as wildlife habitats, whilst traditional cress farmers should be encouraged to maintain their non-intensive management regime.

6.8.4 Management for the native crayfish

Protection and enhancement of native crayfish populations in chalk rivers require special measures because of the specific nature of the threats to their well-being. The keeping of non-native crayfish species is prohibited across much of Britain, but is permitted across an area of England encompassing nearly all chalk rivers (the exceptions being the most northerly examples, in Yorkshire). Farms exist on many of the prime examples of chalk rivers (such as the Test and Hampshire Avon) and constitute a continuing threat to remaining native populations and the re-establishment of the species in areas where it has been eliminated. Existing farms are typically poorly designed to prevent escapes, and crayfish plague can additionally be transmitted in discharge waters. Other sources of disease transmission include fish transfers from infected waters, damp equipment that has been in contact with infected water, and possibly even birds and other animals travelling between infected and plague-free waters.

The main measures that should be considered to conserve and enhance native populations in chalk rivers are outlined below.

- *Improve the design of crayfish farms to prevent further escapes of non-native species, through enforcement of existing legislation (discussed in Holdich and Rogers 1997b).*
- *Avoid the indirect transfer of crayfish plague by preventing the stocking of fish from infected waters (i.e. waters in contact with non-native crayfish) and sterilising field equipment (including boots) where there is a risk of disease transfer to plague-free areas.*
- *Ensure that some well-isolated populations of native crayfish (where contact with non-native species and/or the plague is highly unlikely) exist in each catchment, for use as a local genetic stock in reintroduction exercises.*
- *Control non-native populations in the wild by intensive trapping.*
- *Restock waters with native crayfish (mixed age structure) where the species has been eliminated but: 1) non-native populations have not established; and 2) there is a low risk of further plague occurrences.*

The most suitable populations to protect as a genetic resource are those occupying headwater areas, with impassable weirs preventing the upstream migration of non-native crayfish, or native crayfish carrying the plague vector. It is recognised that trapping is labour-intensive, but the encouragement of volunteer task forces is a feasible approach that might bring about significant suppressions of non-native populations. Limited experiences with restocking of native crayfish have shown that breeding populations can be re-established following plague outbreaks (Holdich and Rogers 1997b), although densities of non-native crayfish would need to be low and other sources of the disease (particularly crayfish farms) would need to have been addressed previously.

6.8.5 Control of non-native plant species

Japanese knotweed, giant hogweed and Himalayan balsam are major threats to the riparian vegetation of chalk rivers and other river types. Great care is required to avoid further accidental assistance to their spread, and action is needed to eliminate existing populations where they occur. It is essential, therefore, that riparian landowners and relevant organisations know what they look like, are aware of the damage they cause to the native flora, and are familiar with the most appropriate methods of control. Early identification and action to eliminate problems will save a great deal of effort. Detailed guidance is provided by the Environment Agency in an informative leaflet.

Table 6.6 Fishery management for the benefit of characteristic chalk stream communities

Issues and mitigation/enhancement measures	Ecological and operational benefits	Key ecological and operational drawbacks to be considered
♥Promotion of habitat enhancement as a means of boosting fish productivity and standing stock.	♥Reduced dependence on stocking and the attendant risks to the native fauna.	
♥Strong discouragement of the stocking of rainbow trout.	♥Restoration of native fish fauna.	
♥Promotion of catch-and-release philosophy in salmonid fisheries.	♥Reduced mortalities and reduced need for high stocking rates.	
♥Reductions in bag limits and increases in size thresholds for takeable fish imposed on salmonid anglers.	♥Reduced mortalities and reduced need for high stocking rates.	
♥As natural recruitment is increased and fish removals are reduced by the above measures, reduce levels of stock input.	♥Reduced pressure on resident fish populations and reduced risks to other fauna (e.g. native crayfish).	♥Increased levels of angler skill required for success.
♥Use sterile (triploid) fish in stocking exercises. Or ♥Rear fish from local native stock, with regular (yearly) addition of broodstock from the wild to prevent genetic deterioration.	♥Protection of genetic integrity of native fish populations.	
♥Encourage the wider adoption of grayling as a sport fish.	♥Reduction in the artificial suppression of grayling populations and restoration of a balanced native fish fauna.	
♥Ensure that fish reared in waters known to contain crayfish plague are not stocked into plague-free areas or waters with known native crayfish populations.	♥Reduced risk to native crayfish populations.	

♥ Best practice, to be applied wherever possible.
• Measures to be applied where best practice is not feasible due to practical constraints, and/or where local circumstances suit.
♣ Measures that consist of options coming under more than one of the above categories.

6.9 Developing a vision of chalk rivers for the future

Working to restore chalk rivers so that they can support their characteristic wildlife is an exciting challenge. In order to succeed, we need a vision for how the river will function, and how it will look within its floodplain, that can be shared by all those with an interest in the river. Piecemeal restoration can be carried out on particular stretches, but this is likely to be affected by catchment-scale influences, such as land-use and development, pollution and flows.

Although management decisions will be taken at site level, they should be made within the context of a broader vision for the catchment supported by maps showing target areas for restoration (Figures 6.5 and 6.6).

A catchment vision may initially appear to be over-ambitious and impractical given the wide range of modern pressures acting to limit ecological quality. However, a step-by-step approach can be adopted as opportunities arise, for instance to deal with sewage effluent, abstractions, and physical constraints. Over a period of years the vision may begin to be realised. Good practice and demonstration sites may influence others who were at first cautious about river restoration or changing land-use practices.

A partnership approach is essential to realising the vision. This should have a pro-active basis and aim to restore lost or degraded ecological functions of the river and its floodplain. The Environment Agency and English Nature will promote this approach and work with local partners on rivers which are candidate Special Areas of Conservation in a programme due to commence in 2000. Initiatives on other chalk rivers will be encouraged in order to deliver the UK Biodiversity Action Plan for chalk rivers, which are one of our most important natural assets viewed on an international scale.

Figure 6.5 Illustration of catchment-based approach to river/floodplain restoration - identification of target areas

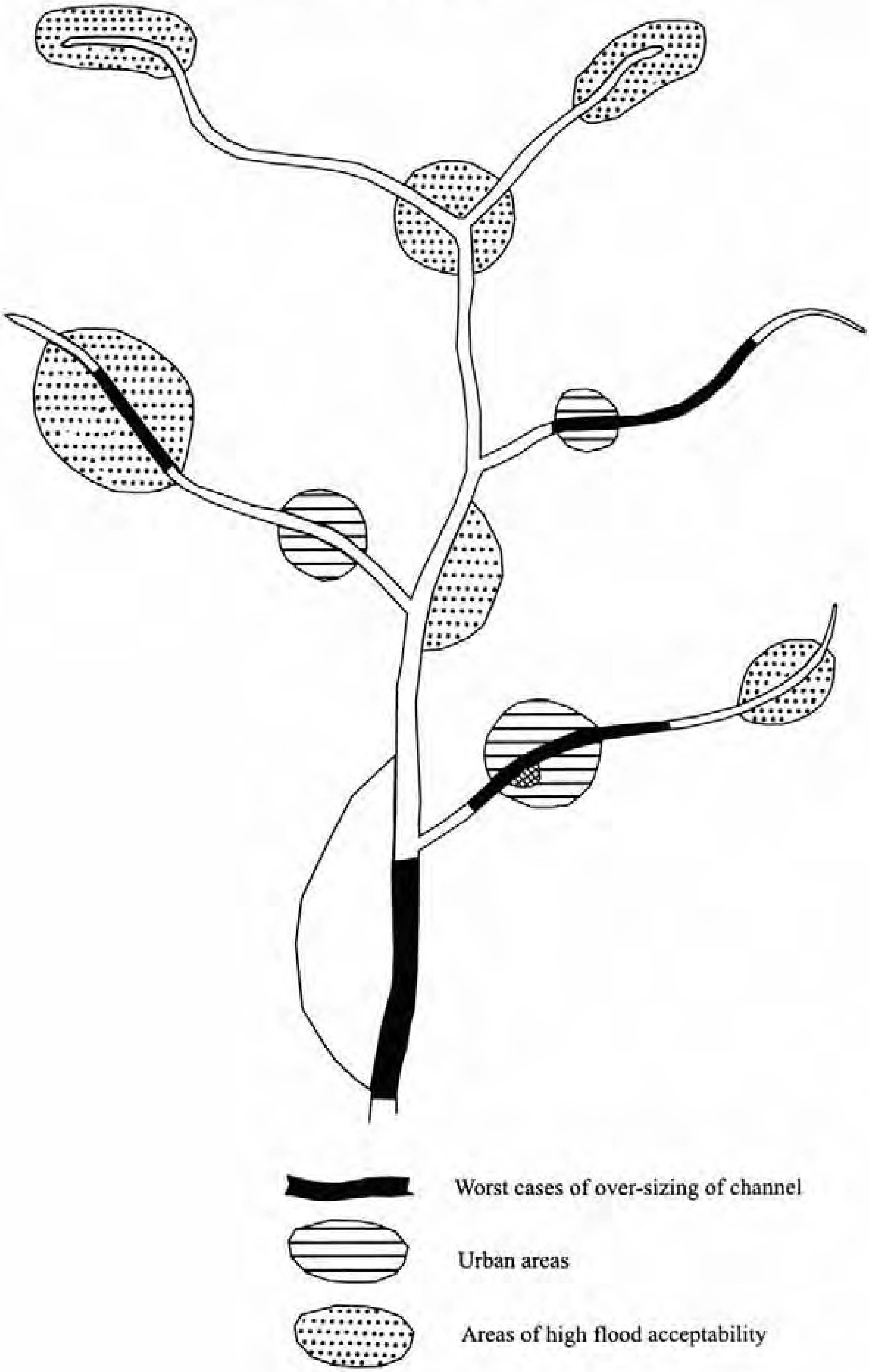
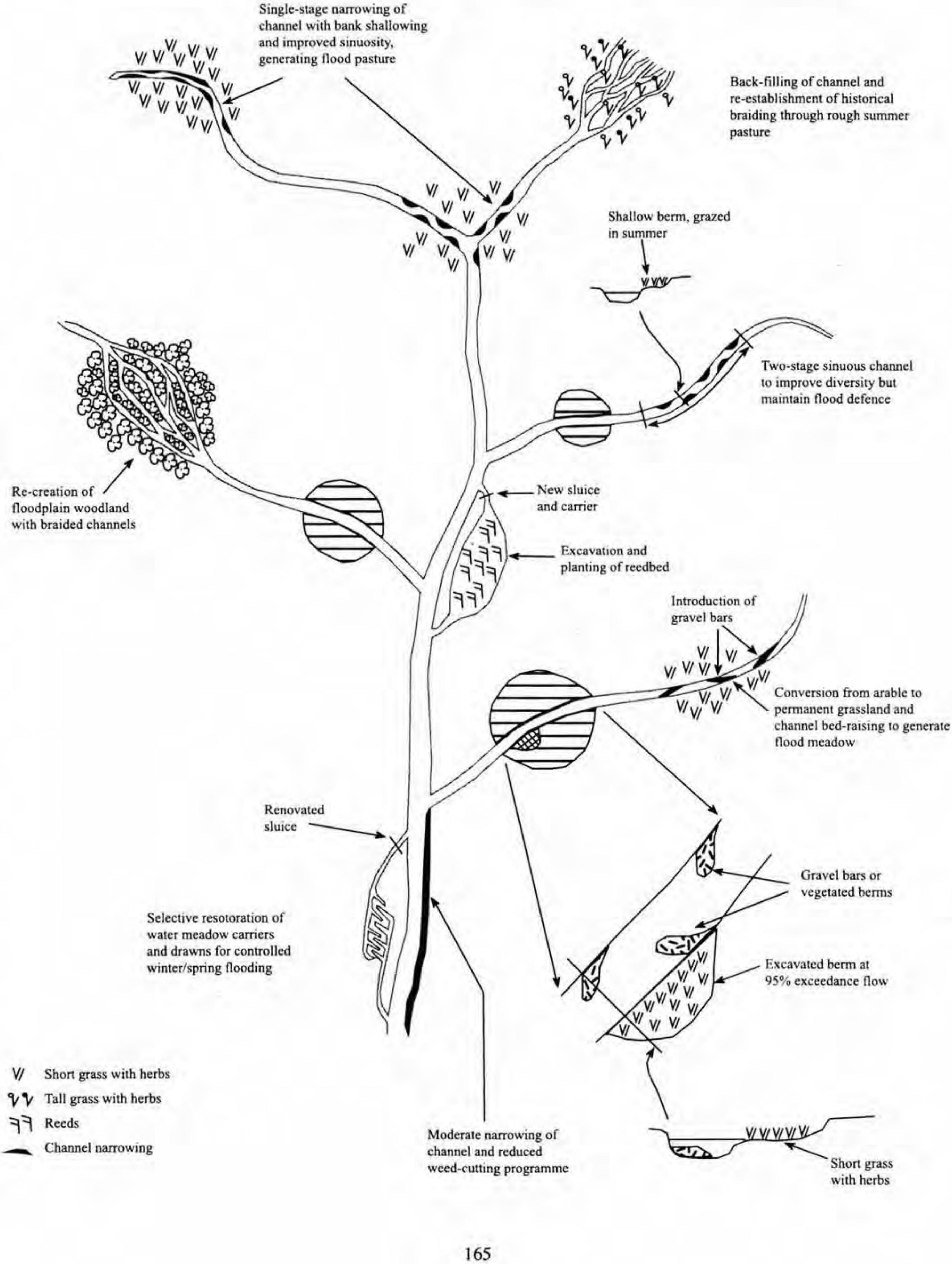


Figure 6.6 Illustration of catchment-based approach to river/floodplain restoration – post-implementation of principal restoration measures



7. Acknowledgements

We are particularly grateful for comments made by members of the Project Steering Group, especially Tim Holzer (Environment Agency) and Doug Kite (English Nature). Thanks are also due to all those who took part in the consultation exercise on the draft document, which generated many useful comments that have greatly enhanced the text. We are particularly grateful to Graham Lightfoot and Paul Briers (Environment Agency, South West Region), who went through the document in great detail and provided helpful responses. Also to Jim Glasspool of the Test and Itchen Association and Colonel Tarver of the Wiltshire Fishery Association, for their detailed comments on fishery management.

We are also indebted to:

- Tim Webb and Graham Scholey (both Environment Agency, Thames Region), Alan Frake and Robert Grew (both Environment Agency, South West Region), who discussed a number of key issues at length;

- Iain Harrison (Institute of Freshwater Ecology), who provided very useful information on the use of riparian vegetation by riverine invertebrates from his current research;

- Nick Carter (British Trust for Ornithology), who supplied information on populations trends in cormorants and mute swans from the Common Birds Census and the Waterways Bird Survey;

- Steven Rothwell (The Watercress Company), who took the time to discuss modern cress bed management;

- David Holdich (Nottingham University), who provided key papers on crayfish issues, and Adrian Hutchings (Sparsholt College), who discussed the plight of the species in southern chalk rivers;

- David Sears (Southampton University), who supplied very useful information on chalk stream geomorphology, including key papers;

- Mike Acreman (Institute of Hydrology), who provided information on PHABSIM and recent IH work on the setting of minimum acceptable flows;

- Marc Naura (Environment Agency, North West Region), who kindly supplied River Habitat Survey data, and Rod Murchie and Tim Holzer (Environment Agency, Southern Region), who provided river flow and water quality data;

- Jackie Smith (English Nature) who proof-read and edited the text and Gordon Leel (English Nature) who re-drew the maps.

Photos/graphs were generously supplied by Nigel Holmes (AEC), Patrick Armitage (IFE), David Solomon, Sara Churchfield (King's College, London), David Holdich, and Phil Smith (Environment Agency, Southern Region).

8. Glossary of terms and acronyms

ALF programme	Alleviation of Low Flows programme, undertaken by the Environment Agency and targeted at worst-affected rivers.
Alevin	Fish fry.
Anastomosed	Physical river form in which a number of stable channels are formed which are linked by smaller lateral channels.
Aufwuchs	Algae and microfauna attached to a variety of substrates.
BAP	Biodiversity Action Plan.
BSG	Biodiversity Steering Group.
BTO	British Trust for Ornithology
Carrier	A ditch leading water from a feeder river to a water-meadow.
Drawn	A ditch transporting water off a water-meadow.
Ensiling	Process of converting vegetation into silage, through anaerobic decomposition in enclosed conditions (clamps or 'big bales').
Freshet	Pulse of water travelling down a river following rainfall.
Habitus	Mode of behaviour generated by morphological adaptations.
Hyporheic zone	Saturated interface between groundwater and surface water below riverbed.
IFE	Institute of Freshwater Ecology.
Infauna	Animals dwelling within the sediment, such as bivalve molluscs.
Lithophilic spawners	Fish species laying eggs on or in stony substrates, including salmon, trout and grayling.
MAFF	Ministry of Agriculture, Fisheries and Food.
Mesohabitat	Descriptor of habitats of intermediate scale (between macro- and micro-habitats), such as gravel substrate or submerged weed.
Mudding	Process of river cleaning whereby river flows are artifically diverted using hurdles, and targeted onto siltbeds so that they are eroded away.
Naturalised flow	River flow in the absence of human influences from abstractions and effluent discharges.
Nutrient spiralling	The process of nutrient transport down a river, involving repeated

	events of plant uptake, sediment deposition and erosion.
NVC	National Vegetation Classification.
Ovarian diapause	Resting phase in the life cycle, at the egg stage.
Perched water table	A water table that is not in contact with the underlying groundwater.
PHABSIM	Physical Habitat Simulation model.
Planform	River form when viewed from above.
RDB	Red Data Book.
Redd	Excavated area in gravel where certain fish species (most notably salmon and trout) lay eggs and then re-cover to allow safe incubation.
RHS	River Habitat Survey.
Ruderal	Coarse plant species typically colonising waste ground.
SAC (cSAC)	Special Area of Conservation (Candidate SAC).
SRP	Soluble Reactive Phosphorus, a measure of bioavailable phosphorus that most closely matches the theoretical parameter 'orthophosphate' (which cannot actually be measured). The Environment Agency monitors Total Reactive Phosphorus (TRP), since it does not filter samples prior to analysis. However, in practical terms there is generally little difference between the two determinands and so the more common term SRP is used throughout this document to avoid unnecessary confusion. See Mainstone *et al.* (1996, 1998) for more detail.
Stream order	A descriptor of spatial position within the river network. The Strahler convention has been adopted in this document (see Beaumont, 1975, for further details).
Tufa	Calcareous deposits forming on streambeds by the chemical precipitation of calcium out of solution in very hard waters.
Total Phosphorus	A measure of all forms of phosphorus, including non-bioavailable forms that may or may not become available at a later date.
Water-meadow	Meadow deliberately inundated over the winter months through controlled flooding via sluices and carriers.
Winterbourne	Headwater stream supplied by a chalk aquifer that is typically dry for a period during the summer.

9. References and further reading

Acornley, R.M. and Sear, D.A. (In press) Sediment transport and siltation of brown trout (*Salmo trutta* L.) spawning gravels in chalk streams. In: Groundwater dominated rivers: proceedings of a seminar held at Southampton University, 1997. Eds. D. Sear and P.D. Armitage. *Hydrological Processes.*

Allan, I.R.H., Herbert., D.W.M. and Alabaster, J.S. (1958) A field and laboratory investigation of fish in a sewage effluent. *Fishery Investigations Series,* **6**, 2. Ministry of Agriculture Food and Fisheries, London.

Auer, MT. and Canale, R.P. (1982a) Ecological studies and mathematical modelling of *Cladophora glomerata* in Lake Huron, North America. 2. Phosphorus uptake kinetics. *Journal of Great Lakes Research,* **8**, 84-92.

Auer, MT. and Canale, R.P. (1982b) Ecological studies and mathematical modelling of *Cladophora glomerata* in Lake Huron, North America. 3. The dependence of growth rates on internal phosphorus pool size. *Journal of Great Lakes Research,* **8**, 93-99.

Auer, MT., Canale, R.P., Grundler, H.C. and Matsuoka, Y. (1982). Ecological studies and mathematical modelling of *Cladophora glomerata* in Lake Huron, North America. 1. Programme description and field monitoring of growth dynamics. *Journal of Great Lakes Research,* **8**, 78-83.

Anon (undated) Ecological Study of the River Lambourn. Report for the period October 1970 to September 1973. 203 pp.

Armitage, P.D., Pardo, I and Brown, A. (1995) Temporal constancy of faunal assemblages in mesohabitats. Application to management. *Archiv fur Hydrobiologie,* **133**, 367-387.

Armitage P. D. and Cannan C.E. (in press) Nested multi-scale surveys in lotic systems - tools for management. In: Advances In River Bottom Ecology. Eds. G. Bretschko and J. Helesic. Backhuys Publishers, Oegstgeest, The Netherlands.

Barnard, S., Wyatt, R.J. and Mainstone, C.P. (1997) The effects of stocked brown trout on the survival of wild fish populations. Environment Agency R&D Technical Report W5. Environment Agency, Bristol.

Beaumont, P. (1975) Hydrology. In: *River Ecology.* Ed. B.A. Whitton. Blackwell Scientific, Oxford.

Beaumont, W.R.C., Welton, J.S., Masters, J.E.G. and Ladle, M. (1995) An investigation of spawning gravels in the Sutton Brook. IFE Report to NRA. NRA, Southern Region.

Berrie, A.D. (1992) The chalk-stream environment. *Hydrobiologia,* **248**, 3-9

Berrie, A.D. and Wright, J.F. (1984) The Winterbourne stream. In: *The Ecology of European Rivers.* Ed. B.A. Whitton. 179-206. Oxford: Blackwell.

Brayshaw, J.D. (1960) Land drainage and fisheries. In: *Salmon and Trout Magazine,* 158, January 1960.

Brookes, A. (1986) Response of aquatic vegetation to sedimentation downstream from channelisation works in England and Wales. *Biological Conservation,* **38**, 351-367.

Buckland, J.D., Wingfield, R.M. and Lazenby, J.B.C. (1998) River Wye - alleviation of low flows study. Draft report to the Environment Agency, Thames Region. Gibb Ltd, Reading.

Butcher, R.W. (1949) Problems of distribution of sessile algae in running water. *Verhandlungen der internationalen Vereinigung fur theoretische und angewandte Limnologie,* **10**, 98-103.

Butcher, R.W. (1946) Studies in the ecology of rivers VI. The algal growth in certain highly calcareous streams. *Journal of Ecology,* **33**, 268-83.

Buxton, J. (Ed) (1981) *The Birds of Wiltshire*. Wiltshire Library and Museum Service. Trowbridge.
Canale, R.P., Auer, M.T. and Graham, J.M. (1982) Ecological studies and mathematical modelling of *Cladophora glomerata* in Lake Huron, North America. 7. Model verification and system response. *Journal of Great Lakes Research*, **8**, 134-143.

Canale, R.P. and Auer, M.T. (1982) Ecological studies and mathematical modelling of *Cladophora glomerata* in Lake Huron, North America. 6. Seasonal and spatial variations in growth kinetics. *Journal of Great Lakes Research*, **8**, 134-143.

Cannan, C.E. and Armitage, P.D. (in press) The influence of catchment geology on the faunal assemblages of the River Frome, Dorset, UK. In: 'The Proceedings of a Workshop on Groundwater Dominated Rivers, Chilworth Manor, University of Southampton, April 17-18 1997'. Eds. D. Sear and P.D. Armitage. *Hydrological Processes*.

Carr, O. and Goulder, R. (1990) Fish farm effluents in rivers - II: effects on inorganic nutrients, algae and the macrophyte *Ranunculus penicillatus*. *Water Research* , **24**, 5, 639-647.

Cartwright, N.G., Painter, H. and Parr, W. (1993) An assessment of the environmental quality standards for inorganic nutrients necessary to prevent eutrophication (nuisance growth of algae). NRA R&D Note 230. NRA, Bristol.

Casey, H. (1981) Discharge and chemical changes in a chalk stream headwater affected by the outflow of a commercial watercress bed. *Environmental Pollution Series B*, **2**, 373-85.

Casey, H. and Clarke, R.T. (1986) The seasonal variation of dissolved reactive phosphate concentrations in the River Frome, Dorset, England. In: *Monitoring to Detect Changes in Water Quality*. Proceedings of the Budapest Symposium, July, 1986. IAHS Publication, No.157, pp. 257-63.

Casey, H. and Ladle, M. (1976) Chemistry and biology of the South Winterbourne, Dorset, England. *Freshwater Biology*, **6**, 1-12.

Casey, H. and Smith, S.M. (1994) The effects of watercress growing on chalk headwater streams in Dorset and Hampshire. *Environmental Pollution*, **85**, 217-228.

Casey, H. and Westlake, D.F. (1974) Growth and nutrient relationships of macrophytes in Sydling Water, a small, unpolluted chalk stream. *Proceedings of the European Weed Research Council 4th International Symposium on Aquatic Weeds*, 1974. pp. 69-76.

Casey, H., Clarke, R.T. and Marker, A.F.H. (1981) The seasonal variation in silicon concentration in chalk streams in relation to diatom growth. *Freshwater Biology*, **11**, 335-44.

Cox, E.J. (1996) *Identification of Freshwater Diatoms from Live Material*. Chapman & Hall, London. 158 pp.

Chanin, P. (1993) *Otters*. British Natural History Series. Whittet Books.

Churchfield, S. (1997) Environment Agency species management guidelines - water shrew (*Noemys fodiens*). In: Species management in aquatic habitats: Compendium of project outputs - Species Action Plans and Management Guidelines. Ed. C.P. Mainstone. R&D Project Record W1/i640/3/M. Environment Agency, Bristol.

Clarke, J.M. and Eyre, J.A. (1992) Birds of Hampshire. Hampshire Ornithological Society.

Clark, J.M and Eyre, J.A. (1993) Birds of Hampshire. Hampshire Ornithological Society.

Cooling, D. (1981) Records of aquatic Coleoptera from rivers in southern England. *Entomologist's Gazette*, **32**, 103-113.

Cramp, S. and Simmons, K.E.L. (1983) *The Birds of the Western Palearctic*. Volume 3. Oxford University Press.

Creed, R.P. (1994) Direct and indirect effects of crayfish grazing in a stream community. *Ecology*, **75**, 7, 2091-2103.

Crick, H.Q.P., Baillie, S.R., Balmer, D.E., Bashford, R.I., Beaven, L.P., Dudley, C., Glue, D.E., Gregory, R.D., Marchant, J.H., Peach, W.J. and Wilson, A.M. (1998) Breeding birds in the wider countryside: their conservation status (1972-1996). BTO Research Report No. 198. British Trust for Ornithology, Thetford.

Dawson, F.H. (1979) *Ranunculus calcareous* and its role in lowland chalk streams. FBA 47th Annual Report. pp60-69.

Drake, M. (1995) The effect of cattle poaching on insects living at the margin of the River Itchen, Hampshire. *British Journal of Entomological Natural History*, **8**, 165-169.

Dunbar, M.J., Elliott, C.R.N., Acreman, M.C. (1996) Guide to conducting a PHABSIM study in the UK. Institute of Hydrology, Wallingford.

Eichenburger, E. and Schlatterr F. (1978) The effect of herbivorous insects on the production of benthic algal vegetation. *Verhandlungen der internationalen Vereinigung fur theoretische und angewandte Limnologie*, **20**, 1806-10.

Evans, G. (1981) A Survey of Wetland Breeding Birds in the Test Valley. Hampshire Bird Report 1980.

Fritsch, F.E. (1949) The lime-encrusted *Phormidium* community of British streams. *Verhandlungen der internationalen Vereinigung fur theoretische und angewandte Limnologie*, **10**, 141-44.

Fritsch, F.E. (1950) *Phormidium incrustatum* (Naeg.) Gom., an important member of the lime encrusted communities of flowing water. *Biologisch Jaarboek*, **70**, 27-39.

Gibbons, D.W., Reid, J.B. and Chapman, R.A. (1993) *The New Atlas of Breeding Birds in Britain and Ireland: 1988-1991*. T. and A.D. Poyser, London.

Giles, N., Phillips, V. and Barnard, S. (1991) *Ecological effects of low flows in chalk streams*. Wiltshire Trust for Nature Conservation, Devizes, Wiltshire.

Gowing, D.J.G. and Spoor, G. (1998) The effect of water table depth on the distribution of plant species on lowland wet grassland. RSPB Symposium of Floodplains, held in London. RSPB.

Green, G.P. and Cade, M. (1997). *Where to watch birds in Dorset, Hampshire and the Isle of Wight*. Helm.

Ham, S. F., Wright, J. F. and Berrie, A. D. (1981) Growth and recession of aquatic macrophytes on an unshaded section of the River Lambourn, England, from 1971-1976. *Freshwater Biology*, **11**, 381-390.

Ham, S. F., Cooling, D. A., Hiley, P. D., Scorgie, H. R. A. and Berrie, A. D. (1982) Growth and recession of aquatic macrophytes on a shaded section of the River Lambourn, England, from 1971-1980. *Freshwater Biology*, **12**, 1-15.

Harrison, S.S.C. and Harris, I.T.B. (in press) Impact of riparian management on aquatic invertebrates.

Haslam, S. M. (1978) *River Plants*. Cambridge University Press.

Haslam, S. M. (1987) *River Plants of Western Europe*. Cambridge University Press.

Hecky, R.E. and Kilham, P. (1988) Nutrient limitation of phytoplankton in freshwater and marine environments: a review of recent evidence on the effects of enrichment, *Limnology and Oceanography*, **33**, 796-822.

Hold, A.J. (1998) Survey of the southern damselfly *Coenagrion mercuriale* in the Itchen Valley Country Park, 1997. Report to the Environment Agency Southern Region, Waterlooville, Hampshire.

Holdich, D.M. and Domaniewski, J.C.J. (1995) Studies on a mixed population of the crayfish *Austropotamobius pallipes* and *Pacifastacus leniusculus* in England. *Freshwater Crayfish*, **10**, 37-45.

Holdich, D.M. and Rogers, W.D. (1997a) Strategy for the management of white-clawed crayfish (*Austropotamobius pallipes*) populations in England and Wales. In: Species management in aquatic habitats: Compendium of project outputs

- research and survey reports on non-mollusc species. Ed. C.P. Mainstone. R&D Project Record W1/i640/2/M. Environment Agency, Bristol

Holdich, D.M. and Rogers, W.D. (1997b) The white-clawed crayfish, *Austropotamobius pallipes*, in Great Britain and Ireland with particular reference to its conservation in Great Britain. *Bulletin Francais de Peche et Pisciculture*, **347**, 597-616.

Holmes, N. T. H. (1996) *Classification of Winterbournes*. A Report to the Environment Agency and other research sponsors, Warboys.

Holmes, N. T. H. (1989) British rivers, a working classification. *British Wildlife*, **1**,1, 20-36.

Holmes, N.T.H. (1985) The River Nar - Its conservation significance. Nar Valley Ornithological Society Annual Report 8, pp 37-42.

Holmes, N.T., Boon, P.J. and Rowell, T.A. (1998) A revised classification system for British rivers based on their aquatic plant communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **8**, 555-578.

Johnson, I.W. & Elliott, C.R.N. (1997) Habitat modelling and instream flow requirements: River Piddle. Report to Environment Agency. Institute of Hydrology, Wallingford.

Johnson, I.W., Elliott, C.R.N. & Gustard, A. (1995) Modelling the effect of groundwater abstraction on salmonid habitat availability in the River Allen, Dorset. *Regulated Rivers: Research and Management*, **10**, 229-238.

Keller, E.A., Kondolf, G.M. and Hagerty, D.J. (1990) Groundwater and fluvial processes; selected observations. In: Groundwater geomorphology: the role of sub-surface water in earth-surface processes and landforms. Eds. C.G. Higgins and D.R. Coates. Geological Society of America Special Paper No. 252, 319-340.

Kelly, M.G. (1998) *Identification of common benthic diatoms in rivers*. AIDGAP Test Version, May 1998. Field Studies Council, Preston Montford. 110 pp.

Kilham, P. and Hecky, R.E. (1988) Comparative ecology of marine and freshwater phytoplankton, *Limnology and Oceanography*, **33**, 779-795.

Ladle, M. and Bass, J. A. B. (1981) The ecology of a small chalk stream and its responses to drying during drought conditions. *Archiv fur Hydrobiologie*, **90**, 448-466.

Ladle, M. and Casey, H. (1971) Growth and nutrient relationships of *Ranunculus penicillatus* var *calcareus* in a small stream. *Proceedings of the European Weed Research Council 3rd international Symposium on Aquatic Weeds*, 53-65.

Ladle, M. and Bass J.A.B. (1981) The ecology of a small chalk stream and its responses to drying during drought conditions. *Archiv fur Hydrobiologie*, **90**, 448-466.

Ladle, M and Welton, J.S. (1984) The ecology of chalk stream invertebrates studied in a recirculating stream. *Annual Report of the Freshwater Biological Association*, **52**, 6379.

Ladle, M. and Westlake, D.F. (1995) River and stream ecosysytems of Great Britain. In *River and Stream Ecosystems*. Eds. C.E. Cushing, K.W. Cummins and G.W. Minshall. *Ecosystems of the World*, **22**, 343-88.

Ladle, M. and Westlake, D.F. (1995) River and Stream Ecosystems of Great Britain. In: *Ecosystems of the World - River and Stream Ecosystems*. Eds. C.E. Cushing, K.W. Cummins and G.W. Minshall. Elsevier, Amsterdam. pp 343-388.

Ladle, M. and Westlake D.F. (1976) Rivieres crayeuses de l'Angleterre et activites humaines. *Bulletin Francais de Pisciculture*, **48**, 261, 198-207.

Lewis, V. (1997) Nature conservation and game fisheries management. English Nature Freshwater Series No. 6. English Nature, Peterborough.

Le Cren, E.D. (1969) Estimates of fish populations and production in small streams in England. In: Symposium on salmon and trout in streams. Ed. T.G. Northcote. pp 269-280. HR MacMillan lectures in fisheries, University of British Columbia, Vancouver.

Mackey, A.P., Ham, S.F., Cooling, D.A. and Berrie, A.D. (1982) An ecological survey of a limestone stream, the river Coln, Gloucestershire, England, in comparison with some chalk streams. *Archiv fur Hydrobiologie* **64**,307-340.

Madsen, B.L. (1997) Danish experiences in river restoration II: the effort beyond restoration. In: River Restoration '96: plenary lectures. Eds. H.O. Hansen and B.L. Madsen. National Environmental Research Institute, Denmark.

Maestrini, S.Y. and Kossut, M.G. (1981) In situ depletion of some marine algae in enclosed dialysis sacks and their use for the determination of nutrient-limiting growth in Ligurian coastal waters (Mediterranean Sea). *Journal of Experimental Marine Biology and Ecology*, **50**, 1-19.

Mainstone, C.P., Parr, W. and Day, M. (1998) Phosphorus in rivers: its ecological importance and the role of effluent stripping in the control of riverine eutrophication. Draft report to English Nature. WRc, Medmenham.

Mainstone, C.P., Davis, R.D., House, A. and Parr, W. (1996) A review of methods for assessing and controlling non-point sources of phosphorus. NRA Project Record 562/5/W. NRA, Bristol.

Mainstone, C.P., Weddepohl, J. and Woodrow, D. (1994) Land management techniques. NRA Project Record 453/7/Y. NRA, Bristol.

Mainstone, C.P., Gulson, J. and Parr, W. (1993) Phosphates in freshwater - standards for nature conservation. English Nature Research Reports No. 73. English Nature, Peterborough.

Maitland, P.S. and Campbell, R.N. (1992) *Freshwater fishes*. Harper Collins, London.

Mann, R.H.K. (1982) The annual food consumption and prey preferences of pike (*Esox lucius*) in the River Frome, Dorset. *Journal of Animal Ecology*, **51**, 81-95.

Mann, R.H.K., Blackburn, J.H. and Beaumont, W.R.C. (1989) The ecology of brown trout (*Salmo trutta*) in English chalk streams. *Freshwater Biology*, **21**, 57-70.

Marchant, J.H. and Hyde, P.A. (1980) Aspects of the distribution of riparian birds on waterways in Britain and Ireland. Bird Study 27, pp 183-202.

Marker, A.F.H. (1976a) The benthic algae of some streams in southern England I. Biomass of the epilithon in some small streams. *Journal of Ecology*, **64**, 343-58.

Marker, A.F.H. (1976b) The benthic algae of some streams in southern England II. The primary production of the epilithon in a small chalk stream. *Journal of Ecology*, **64**, 369-73.

Marker, A.F.H. and Casey, H. (1982) The population and production dynamics of benthic algae in an artificial recirculating hard-water stream. *Philosophical Transactions of the Royal Society*, **(B)298**. 265-308.

Marker, A.F.H., Casey, H. and Rother, J.A. (1984) The seasonal cycle of diatoms in chalk streams. *Verhandlungen der internationalen Vereinigung fur theoretische und angewandte Limnologie*, **22**, 1949-52.

Marquiss, M. and Carss, D.N. (1994) Avian piscivores: basis for policy. NRA R&D Note 267. NRA, Bristol.

Mason, C.F. and MacDonald, S.M. (1982) The input of terrestrial invertebrates from tree canopies to a stream. *Freshwater Biology*, **12**, 305-311.

Mather, J. (1986) *The Birds of Yorkshire*. Croom Helm.

Moon, H.P. and Green, F.H.W. (1940) Water meadows in southern England. In: *The land of Britain*. Ed. L.D. Stamp. Geographical Publications, London. Part 89, 373-390.

Moore, J.W. (1978) Seasonal succession of algae in rivers III. Examples from the Wylye, a eutrophic farmland river. *Archiv fur Hydrobiologie*, **83**, 367-76.

Moore, J.W. (1977) Seasonal succession of algae in a eutrophic stream in southern England. *Hydrobiologia*, **53**, 181~192.

Morris, P.A. (1993) *A red data book for British Mammals*. The Mammal Society, London.

NRA (1991) River Test catchment management plan, phase 1. NRA Southern Region, Worthing.

Pain, J. (1990) Water Pipits *(Anthus spinoletta)* on Hampshire watercress beds. Hampshire Bird Report 1989, pp84-86.
Painter, D.S. and Jackson, M.B. (1989) *Cladophora* internal phosphorus verification, *Journal of Great Lakes Research*, **15**, 700-708.

Palmer, S. (Ed) (1991). *Wiltshire Birds*. Wiltshire County Council, Library and Museum Service.

Pardo, I. and Armitage, P.D. (in press) Species assemblages as descriptors of mesohabitats. *Hydrobiologia*.

Parr, W., Mainstone, C.P. and Morgan, N. (1998) Nutrient budget for the upper reaches of the Hampshire Avon. WRc Report to English Nature and the Environment Agency. WRc, Medmenham.

Petts, G.E. (1996) Linking hydrology and ecology: River Wissey Investigations. Report to National Rivers Authority.

Petts, G., Crawford, C. & Clarke, R. (1996) Determination of minimum flows. National Rivers Authority R&D Note 449. NRA, Bristol.

Preston, C.D and Croft, J.M. (1997) *Aquatic plants in Britain and Ireland*. Harley Books, Essex.

Rabeni, C.F. and Smale, M.A. (1995) Effects of siltation on stream fishes and the potential mitigating role of the buffering riparian zone. *Hydrobiologia*, **303**, 211-219.

Racey, P.A. (1995) The use of river corridors by bats. Draft report produced for the Environment Agency under R&D Project i640. Environment Agency, Midlands Region.

Reynolds, C.S. (1984) *The ecology of freshwater phytoplankton*. Cambridge University Press.

Robach, F., Merlin, S., Rolland, T. and Tremolieres, M. (1996) Ecophysiological approach of water quality bioindication using aquatic plant materials. *Ecologie*, **27**, 4, 203-214.

Roddie, B., Kedwards, T. and Crane, M. (1992) Potential impact of water-cress farm discharges on the freshwater amphipod *Gammarus pulex*. *Bulletin of Environmental Contamination and Toxicology*, **48**, 63-90.

Round, F.E. (1989) *Diatoms as water quality indicators in British rivers*. DoE Report, Contract No. 120021-00-37. Department of the Environment, London.

RSPB, NRA and RSNC (1994) *The new rivers and wildlife handbook*. RSPB, Sandy.

Rutt, G.P., Pickering, T., Woodrow, D., Turner, C. and Mainstone, C.P. (1992) Sources of farm pollution and impact on river quality. NRA Project Record 001/13/W. National Rivers Authority, Bristol.

Sear, D., Armitage, P.D. and Dawson, F.H. (In press) Groundwater dominated rivers. In: Groundwater dominated rivers: proceedings of a seminar held at Southampton University, 1997. Eds. D. Sear and P.D. Armitage. *Hydrological Processes*.

Sellars, R.M., Ekins, G.R., Hughes, B. and Kirby, J.S. (1997) Population development of inland breeding cormorants in Great Britain. In: Proceedings of the 4th European cormorant conference, Bologna, Italy, November 1995.

Shamsudin, L. and Sleigh, M.A. (1995) Seasonal changes in composition and biomass of epiphytic algae on the macrophyte *Ranunculus penicillatus* in a chalk stream, with estimates of production and observations on the epiphytes of *Cladophora glomerata*. *Hydrobiologia*, **306**, 2, 85-95.

Simpson, P.B. and Eaton, J.W. (1986) Comparative studies of the photosynthesis of the submerged macrophyte *Elodea canadensis* and the filamentous algae *Cladophora glomerata* and *Spirogyra sp.*. *Aquatic Botany*, **26**, 1-12.

Solbe, J. F. (1982) Fish farm effluents - cause for concern? *Water*, **43**, 22-25.

Solomon, D.J. (1997) Fisheries of the middle and lower Wylye and factors affecting their performance. Report to the Environment Agency, South West Region. Fisheries Department, Blandford.

Solomon, D.J. (1992) Diversion and entrapment of fish at water intakes and outfalls. NRA R&D Report 1. National Rivers Authority, Bristol.

Solomon, D.J. and Paterson, D. (1980) Influence of natural and regulated streamflow on survival of brown trout (*Salmo trutta* L.) in a chalk stream. Environmental Biology of Fishes, **5**, 4, 379-382.

Spink, A.J., Murphy, K.J., Smith, A.M. and Westlake, D.F. (1993) Effects of eutrophication on *Ranunculus penicillatzis* subsp. *pseudofluitans* (Syme) S. Webster and *Potamogeton pectinatis L.* In: Proceedings of the 31st International Symposium on the Biology and Control of Aquatic Plants, Daytona Beach, 1992. pp. 113-7.

Stone, B.H., Sears, J., Cranswick, P.A., Gregory, R.D., Gibbons, D.W., Rehfisch, M.M., Aebischer, N.J., Reid, J.B. (1997). Population estimates of birds in Britain and in the United Kingdom. *British Birds*, **90**,1-22.

Strachan, R. (1997) *Water voles*. British Natural History Series. Whittet Books.

Strachan, R. and Jefferies, D.J. (1996) Otter survey of England 1991-94. The Vincent Wildlife Trust, London.

Strachan, R. and Jefferies, D.J. (1993) The water vole *Arvicola terrestris* in Britain 1989-90: its distribution and changing status. The Vincent Wildlife Trust, London.

Symes, K.L., Armitage, P.D. and Cannan, C.E. (1997) Application of the relational data base approach to a nested study of biological and physical data from a lowland river. *Regulated Rivers: Research and Management*, **13**, 185-198.

Symons, P.E.K, and Heland, M. (1978) Stream habitats and behavioural interactions of underyearling and yearling Atlantic salmon (*Salmo salar*). *Journal of the Fisheries Research Board of Canada*, **35**, 175-183.
UK Biodiversity Steering Group (1995) Biodiversity: the UK Steering Group Report. HMSO, London.

Tippett, R. (1970) Artificial surfaces as a method of studying populations of benthic micro-algae in freshwater. *British Phycological Journal*, **5**, 187-99.

UK Biodiversity Steering Group (1995) Biodiversity: the UK Steering Group Report. HMSO, London.

Warren, R.D., Waters, D.A., Altringham, J.D. and Bullock, D.J. (1997) The ecology and conservation of Daubenton's bat, *Myotis daubentonii*. A report produced for the Environment Agency under R&D Project i640. Environment Agency, Midlands Region.

Welton, J.S., Ladle, M., Bass, J.A.B. and Clarke, R.T. (1991) Grazing of epilithic chironomid larvae at two different velocities in recirculating streams. *Archiv fur Hydrobiologie*, **121**, 405-18.

Westlake, D.F. (1975a) Macrophytes. In: *River Ecology*. Ed. B.A. Whitton. pp. 106-128.

Westlake, D.F. (1975b) The construction and long-term field use of inexpensive aerial and aquatic photometers. In: *Light as an Ecological Factor II*. Eds. G.C. Evans, R. Bainbridge and 0. Rackham. Symposium of the British Ecological Society, **16**, 27–42. Blackwell Scientific Publications, Oxford.

Westlake, D. F. (1968) The ecology of aquatic weeds in relationship to their management. *Proceedings of the 9th British Weed Control Conference*, 372-379.

Westlake, D.F. (1966) The light climate for plants in rivers. In: *Light as an Ecological Factor* Eds R. Bainbridge, G.C. Evans and 0. Rackham. Symposium of the British Ecological Society, **6**, 99-119.

Westlake, D.F. (1956) Pollution Research Unit. *Annual Report of the Freshwater Biological Association*, **24**, 37-38.

Westlake, D.F. (1955) Pollution Research Unit. *Annual Report of the Freshwater Biological Association*, **23**, 36-37.

Westlake, D.F., Casey, H., Dawson, F.H., Ladle, M., Mann, R.K. and Marker, F.N. (1972) The chalk stream ecosystem. In: *Productivity Problems of Freshwaters*. Eds. Z. Kajak and A. Hillbricht-Ilkovska. Proceedings of IBP-UNESCO Symposium on Productivity Problems of Freshwaters, Kazimierz Dolny, May, 1970. pp. 615-35. Polish Scientific Publications, Warsaw.

Whiting, P.J. and Stamm, J. (1995) The hydrology and form of spring-dominated channels. *Geomorphology*, 12, 233-240.

Williams, D.D. and Hynes, H.B.N. (1977) The ecology of temporary streams, II. General remarks on temporary streams. *Int. Revue ges. Hydrobiol.* **62**, 53-61.

Wood P.J. and Armitage P.D. (1997) Silt and siltation in the lotic environment. *Environmental Management*, **21**: 203-217.

Wong, S.L. and Clark, B. (1976) Field determination of the critical nutrient concentrations for *Cladophora* in streams. *Journal of the Fisheries Research Board of Canada*, **33**, 85-92.

Woodrow, D., Parr, W. and Norton, R. (1994) River Eutrophication Risk Modelling: a GIS approach. WRc report to SNIFFER No NR 3698.

Wright, J. F., Blackburn, J.H., Gunn, R.J.M., Furse, M.T., Armitage, P.D., Winder, J.M.., and Symes, K.L. (1996) Macroinvertebrate frequency data for the RIVPACS III sites in Great Britain and their use in conservation evaluation. *Aquatic Conservation, Marine and Freshwater Ecosystems*, **6**, 141-167.

Wright, J.F., Furse, M.T. and Armitage, P.D. (1993) RIVPACS - a technique for evaluating the biological quality of rivers in the UK. *European Water Pollution Control*, **3**, 4, 15-25.

Wright J.F., Furse M.T., Clarke R.T., Moss D., Gunn R.J.M., Blackburn J.H., Symes K.L., Winder J.M., Grieve N.J. and Bass J.A.B. (1995) Testing and further development of RIVPACS. NRA R&D Note 453. NRA, Bristol.

Wright, J.F. (1978) Seasonal variation in the chironomid larvae of a chalk stream. *Verh. Internat. Verein. Limnol.* **20**, 2647-2651.

Wright, J.F. (1992) Spatial and temporal occurrence of invertebrates in a chalk stream, Berkshire, England. *Hydrobiologia*, **248**, 11-30.

Wright, J.F. and Berrie, A D. (1987) Ecological effects of groundwater pumping and a natural drought on the upper reaches of a chalk stream. *Regulated. Rivers: Research and Management*, **1**, 145-160.

Wright, J.F., Blackburn, J.H., Clarke, R.T. and Furse, M.T. (1994) Macroinvertebrate-habitat associations in lowland rivers and their relevance to conservation. *Verh. Internat. Verein. Limnol.* **25**, 1515-1518.

Wright, J.F., Hiley, P.D. and Berrie, A.D. (1981) A nine-year study of the life cycle of *Ephemera danica* Mull. (Ephemeridae:Ephemeroptera) in the River Lambourn. *Ecological Entomology*, **6**, 321-331.

Wright, J.F., Hiley, P.D., Cameron, A.C., Wigham M.E. and Berrie, A.D. (1983) A quantitative study of the macroinvertebrate fauna of five biotopes in the River Lambourn, Berkshire, England. *Archiv fur Hydrobiology*, **96**, 3, 271-292.

Wright, J.F., Moss, D., Armitage, P.D. and Furse, M.T. (1984) A preliminary classification of running-water sites in Great Britain based on macro-invertebrate species and the prediction of community type using environmental data. *Freshwater Biology*, **14**, 221-256.

APPENDIX A Detailed accounts of key plant species inhabiting chalk rivers

Berula erecta (Lesser water-parsnip)

This species is, above all others, characteristic of perennial chalk streams, never being present in non-calcareous streams or those that dry periodically (other than in exceptional droughts). It is rarely found where substrates are silty, preferring to be rooted into firm gravels, often found either in mid-channel where it may never be emergent, or at the margins where it is emergent and flowers each year. As a submerged plant it is mostly associated with shallow chalk streams, but may occur as an emergent species on the margins of deeper and wider systems.

Lesser Water-parsnip has a confined geographical distribution in the UK but it is present in all the SSSI chalk rivers, often being especially common in small, gravel/pebble-bedded reaches. Examples where it is very common include many tributaries of the Avon (e.g. Nine Mile River, Ebble), Itchen, Piddle, Bere Stream, Lambourn, Kennet, Winterbourne, Nar and Hull.

Ranunculus penicillatus subsp. pseudofluitans (Brook water-crowfoot)

This is the perennial species that roots at the nodes and has no entire (laminar) leaves. When not flowering, it is impossible to distinguish it from pond water-crowfoot (*Ranunculus peltata*) in fast-flowing river sites.

As this crowfoot normally persists as a perennial plant, it is not spread rapidly by seedlings. By rooting at the nodes it can spread very rapidly by shoots taking root, and individual plants often 'migrate' on the river bed as the older rooted parts senesce and the younger parts thrive. The habit of rooting at the nodes also leads to plants accreting gravels etc..

Like lesser water-parsnip, brook water-crowfoot is present in all the SSSI chalk rivers, often being common from perennial head to mouth (e.g. Itchen, Piddle, Bere Stream and Lambourn) but absent or rare in downstream reaches of rivers which become deep and sluggish (e.g. Nar, Hull, Kennet). In the Avon it is dominant in the shallowest stretches where there is a combination of gravel beds and fast current velocities. In deeper stretches a large form is present, resembling river water-crowfoot (*Ranunculus fluitans*), but it is a morphological variant of brook water-crowfoot adapted in response to the constant depth and velocity. In contrast, a very short-leaved variant (often recognised as a subsp./variety *vertumnus*) is present in some of the smallest perennial chalk streams (e.g. North Winterbourne, Piddle, Itchen and parts of the Avon catchment).

Other crowfoot species

The identification of water-crowfoot taxa is rarely easy unless material is in full flower or with abundant fruits; many hybrids also make certain identification very difficult.
Ranunculus communities in rivers are a conservation priority in Europe, being a listed habitat under the EU Habitats Directive. In addition to brook water-crowfoot, which characterises perennial, pure, chalk streams, several other species are found in chalk rivers and streams. Pond water-crowfoot is the classic crowfoot of headwaters which dry late in summer (e.g. Lambourn, Kennet, Till), but river water-crowfoot and fan-leaved water-crowfoot (*R. circinatus*) are typical of deeper, more sluggish lowland reaches of chalk rivers when they traverse superficial deposits (e.g. Nar, Wensum, Lark, Wissey, Dorset Stour, Dorset Frome).

Callitriche obtusangula (Blunt-fruited water-starwort)

Unlike many starworts, which are often associated with silty conditions in chalk streams, blunt-fruited water-starwort thrives best where flow is swifter and the bed coarser. It is also extremely rarely found within reaches, which are subject to even very brief drying during droughts. It is found in all chalk river SSSIs, and is particularly common in the Lambourn and Moors river, and non-SSSI rivers such as the Ebble, Till, Nine Mile River and parts of the Mimram. Like other starworts of chalk streams, this species is more tolerant of shade than crowfoot. It is therefore possible that crowfoot replaced starwort in many reaches when pioneering tree clearance and channelization took place.

Increases in starworts other than blunt-fruited water-starwort usually indicate perturbation, especially if it is associated with declines in crowfoot. Most typically this occurs when perennial reaches suffer severe low flows leading to silt deposition, or increases in sediment loads derived from cultivation in the catchment.

Catabrosa aquatica (Whorl-grass)

Whorl-grass is strongly associated with base-rich rivers with a perennial flow, but only in sites where slack water and silt characterise the margins. It is a species which is very typical of silty reaches of chalk streams, especially those with wide accretions of soft mud on the margin. It contracts to having small cover in the winter when flows and velocities are high, spreading into the channel through the summer and autumn as velocity decreases and silt is deposited. It thus does not thrive in chalk streams with steep gradients, or where velocities are fast throughout the year (e.g. much of the Nine Mile River, Lambourn, Winterbourne and Itchen, i.e. where brook water-crowfoot and/or lesser water-parsnip thrive).

Hippurus vulgaris (Mare's-tail)

This is a species which has a wide distribution in the UK, but in English rivers is rarely associated with anything other than chalk streams (or extremely rarely on Oolite). Typically it is present where flow velocity is neither rapid nor sluggish, and where substrates are firm clays or gravels containing consolidated fines. Some stretches of the Test, Itchen and upper Avon have extensive beds which result in control by fishing interests.

Oenanthe fluviatilis (River water-dropwort)

Base-rich rivers are the only systems in which this species will occur. It rarely occurs in pure chalk streams, preferring mixed chalk/clay, or other base-rich, catchments of mixed geology. It is naturally present in many of the chalk river SSSIs, but is reported to have been transplanted into the Dorset Frome. This species has an extremely local world distribution, with the main populations present within the British Isles. Chalk streams and rivers which flow over clay are particularly important, with the Dorset Stour and the Kent Stour both being exceptionally good rivers for supporting this internationally rare plant.

Groenlandia densa (Opposite-leaved pondweed)

This species is more likely to be found in chalk streams and rivers than any other type of river. However it is not confined to such systems and is widely distributed in Europe and Asia. Chalk rivers thus represent a key habitat within the UK, and have become more important in recent decades as the species has been lost from other habitats.

Veronica anagallis-aquatica (Blue water-speedwell and hybrid)

Blue water-speedwell is more closely associated with chalk rivers than any other habitat. Unlike the species cited previously, it is also common in winterbournes. It will grow as a submerged, emergent or marginal wetland plant, always as an annual. It often hybridises with the pink water-speedwell (*V. catenata*), the hybrid frequently colonising the same habitats. The pink water-speedwell has a much wider UK distribution, but is rarely found in chalk streams.

Nasturtium aquaticum agg. (Water-cress)

Water-cress is especially associated with chalk streams, being the classic colonizer late in the year as flow velocities recede and crowfoot declines. However it also occurs more widely in other river types than any of the species cited previously. It is included as a key species of perennial chalk streams because it is the key species likely to be present in little managed chalk streams in late summer and autumn. In such situations crowfoot declines naturally through the summer, but not before water velocity has declined significantly and siltation increased. This habitat is ideal for water-cress to exploit, which it does by growing rapidly from seed, or growing as a raft over the top of crowfoot beds. In heavily managed reaches this is often prevented by cutting the *Ranunculus*, which in turn is stimulated to grow whilst velocity is increased.

APPENDIX B Data from routine survey reaches of the waterways bird survey that are located on chalk rivers

Table B1 Waterways Bird Survey plots on chalk rivers

WBS Plot	River	County	Upstream Grid-reference	Downstream Grid-reference	Upstream altitude (m)	Downstream altitude (m)	Length (km)	Gradient (m/km)	Years covered
043	Frome	Dorset	SY700908	SY723906	53	47	4.5	1.3	1976-79
044	Frome	Dorset	SY826873	SY844871	17	14	5.4	0.6	1976-79
063	Wylye	Wiltshire	ST902433	ST936417	100	91	5.5	1.6	1974-75
200	Candover Stream	Hampshire	SU564354	SU569323	70	55	4.4	3.4	1981-86
208	Nadder	Wiltshire	SU057313	SU087312	60	55	5.4	0.9	1981
250	Wallington	Hampshire	SU672078	SU638083	37	24	4.3	3.0	1981
286	Meon	Hampshire	SU641239	SU618217	79	61	4.8	3.8	1983-88
349	Itchen	Hampshire	SU494315	SU486297	38	37	4.8	0.2	1987-96
381	Frome	Dorset	SY700908	SY721905	53	49	2.2	1.8	1991
388	Test	Hampshire	SU382390	SU360368	39	36	8.0	0.4	1993-96
420	Itchen	Hampshire	SU467214	SU466192	17	11	3.4	1.8	1992

Table B2 **Mean number of bird territories per kilometre along Waterways Bird Survey plots on perennial headwaters**

Species	WBS Plot 200 Candover Stream	WBS Plot 250 Wallington	WBS Plot 286 Meon
Little Grebe	0.6		0.5
Mute Swan			0.5
Canada Goose	0.5		0.7
Mallard	6.4	1.9	4.7
Pochard			0.3
Tufted Duck	0.5		2.6
Water Rail			0.3
Moorhen	3.1	1.2	4.5
Coot	1.8		2.8
Lapwing	1.0		0.7
Snipe	0.2		0.2
Curlew	0.5		
Redshank			0.3
Kingfisher		0.2	0.2
Grey Wagtail	0.5		0.9
Pied Wagtail	0.5	0.5	0.6
Cetti's Warbler			0.07
Sedge Warbler	0.1		0.1
Reed Warbler	0.03		
Whitethroat			0.1
Reed Bunting		0.2	0.3

Table B3 **Mean number of bird territories per kilometre along Waterways Bird Survey plots on middle reaches**

Species	WBS Plot 043 Frome	WBS Plot 044 Frome	WBS Plot 063 Wylye	WBS Plot 208 Nadder	WBS Plot 381 Frome
Little Grebe			0.2	0.4	
Mute Swan	0.6	0.6	0.1	0.6	0.5
Teal			0.2		
Mallard	1.5	1.4	0.6	2.0	1.4
Tufted Duck		0.05	0.1		
Moorhen	3.2	3.2	2.6	3.3	4.1
Coot	0.2		0.1		
Snipe			0.2	0.2	
Redshank		0.1			
Kingfisher	0.1	0.2	0.1	0.2	
Grey Wagtail	0.6	0.3	1.3	0.4	0.5
Pied Wagtail	0.7	0.8	0.3	1.1	
Sedge Warbler	2.3	2.0	0.2	2.4	
Reed Warbler	0.5	2.3	0.2	0.2	1.4
Reed Bunting	0.9	1.6	0.1	0.2	

Table B4 Mean number of bird territories per kilometre along Waterways Bird Survey plots on lower reaches

Species	WBS Plot 349 Itchen	WBS Plot 388 Test	WBS Plot 420 Itchen
Little Grebe	1.7	0.7	0.9
Mute Swan	0.3	0.5	0.9
Canada Goose	1.7	0.3	0.3
Mandarin		0.1	
Gadwall	0.06	0.08	
Mallard	11.0	1.9	1.5
Pochard		0.3	
Tufted Duck	1.1	1.0	0.3
Water Rail		0.1	
Moorhen	2.3	0.9	3.5
Coot	5.4	1.4	5.3
Lapwing	1.5		0.3
Snipe	0.5		
Redshank	0.4	0.02	
Grey Wagtail	0.02	0.4	0.9
Pied Wagtail		0.06	0.3
Cetti's Warbler	0.1	0.3	
Sedge Warbler	7.5	2.4	
Reed Warbler	3.4	0.9	
Whitethroat		0.08	
Reed Bunting	1.6	0.5	0.3

ENGLISH NATURE

English Nature is the government agency that champions wildlife and natural features throughout England.

ENVIRONMENT AGENCY

The Environment Agency is responsible for controlling pollution of air, land and water throughout England and Wales - it also has responsibility for managing water resources, flood defences and freshwater fisheries. It is the statutory contact point for chalk rivers under the UK Biodiversity Action Plan.

Published by Publicity & Marketing,
English Nature, Northminster House, Peterborough PE1 1UA

Web site: http://www.english-nature.org.uk

ISBN 1 85716 463 6

Printed by Lakes (Birmingham) Ltd. Printed on Evolve silk - 75% recycled post-consumer waste, 25% virgin fibre, chlorine-free bleached. 1.5M.