Draft Final Report **R&D Project 340**

Buffer Zones for Conservation of Rivers and Bankside Habitats

Freshwater Environments Group
International Centre Of Landscape Ecology
Loughborough University of Technology
R&D 340/1/Y

By

Dr Andrew R.G. Large

and

Professor Geoffrey E. Petts

March 1991

CONTENTS | Page

CONTENTS | Page

FIGURES

TABLES

PLATES

FOREWORD

This study was carried out by the Freshwater Environments Group of the International Centre of Landscape Ecology, Loughborough University of Technology for the National Rivers Authority, administered by NRA Yorkshire Region. The authors would like to thank the following for assistance given during the project and production of the report:

Dr Max Wade, Director, **Mr David Evans**, and **Mr Ed Darby** of the *International Centre of Landscape Ecology* (ICOLE) for assistance in the setting up, administration and running of workshop sessions, and for contributions to the compilation of the report; and **Professor John Brock**, Visiting Professor from the School of Agribusiness, Arizona State University, USA, for assistance in both the literature review and workshop phases of the project.

We would also like to acknowledge the support of the NRA's Project Officer, **Dr John Pygott**, for his cooperation and assistance.

Many organizations and individuals contributed to the workshop discussions and freely provided copies of reports and papers, to all we offer our sincere thanks. Our particular thanks go to colleagues from overseas who gave of their time to attend the final workshop: **Dr Bryce Cooper** of the Water Quality Centre, New Zealand; **Mr Georg Humborg** of the University of Karlsruhe, Germany; **Dr Gilles Pinay** of the Centre for Renewable Resource Ecology, Toulouse, France; and **Dr Elizabeth Monosowski** of the World Bank.

SUMMARY

This project was funded by the National Rivers Authority and focused on the role of buffer zones for the conservation of rivers and bankside habitats. The desk-top study involved three phases. Phase 1 involved an international literature review based on computer-based searches and a network of personal contacts. From a synthesis of this data base, opportunities for buffer zones along British rivers were defined. In Phase 2 these opportunities were discussed at two workshops involving NRA staff and representatives from a range of interested organisations including the Countryside Commission, English Nature, Nature Conservancy Council for Scotland, Joint Nature Conservation Committee, World Wide Fund for Nature (UK), ADAS, National Farmers Union and National Trust. Following this meeting, in Phase 3, a first draft report was prepared and discussed at an international workshop involving invited experts on the different issues raised. Thus, this Final Report presents a critical and objective assessment of the potential for implementing a policy using buffer zones to enhance the conservation value of river corridors throughout England and Wales.

The evidence provided by a synthesis of material contained in over 220 publications clearly establishes the importance of riparian buffer zones for nature conservation in the three main areas of a drainage network: the headwater channels within the production zone (1st-3rd order streams); the channel within the transfer zone; and the floodplain river within the storage zone. Buffer zones are shown to provide not only valuable habitats for a diversity of wetland and terrestrial flora and fauna but also important cover and shade for, and particulate organic matter inputs to, the aquatic system.

Along the channel margin primary habitats of gravel bars, sand banks, eroding banks in alluvium, and cutoff channels and backwaters linked to the main channel are of particular value as these habitats have been severely affected by recent and historic river management. Floodplain wetlands and woodlands also have particularly high conservation value. However, narrow riparian strips along river banks having little management and grassland adjacent to rivers are important for many species, and would markedly improve the conservation value along river reaches that are currently cultivated up to the channel banks. Within upland catchments used for conifer plantations, a narrow zone of broadleaved trees can significantly enhance conservation values.

The minimum effective width of the buffer zone for nature conservation ranges from 1-2 m for small ditches, to 10 m for small upland streams, and to 100 m for large floodplain rivers. It is important to emphasise that even a narrow (1-5 m) riparian strip of grasses and herbs can markedly enhance the conservation value of the river corridor within cultivated landscapes. Trees and wetland patches add to the potential value of the corridor for conservation. Along large rivers, a buffer zone comprising woodland or wetland "islands" and ponds connected by ditches, hedgerows, the riparian strip, or grassland creates valuable wildlife habitat. The species composition of the buffer zone varies according to geographical setting.

All buffer zones have benefits for pollution control, especially where problems are caused by overland flow or diffuse sub-surface flow. Where pollution control is the main target, the optimum width is 20-30 m. In many areas of lowland England, however, the buffer zone could be bypassed by flow in drains. New drain designs and the incorporation of reconstructed wetlands and catchwater systems to intercept pipeflow, are being investigated to overcome this problem. To be effective, all streams and ditches within the production zone need to be bounded by buffer zones and this represents a considerable length of channel. In one example from the East Midlands, a 57 km^2 catchment is shown to

contain over 60 km of headwater channel length. Such channels are often outside the NRA's responsibility as they are not classed as main river.

Buffer zones offer considerable opportunities for enhancing conservation values and improving water-quality. They also offer benefits for recreation and amenity. Thus, they should be seen as having a multi-functional role in river management. There are a number of schemes available to encourage the creation of buffer zones: set-aside, environmentally sensitive areas, countryside stewardship and countryside premium. However, to maximize the potential, buffer zones should be integrated within catchment management plans.

It is recommended that a small number of pilot schemes should be implemented to include representative examples of different river types and situations. The design of the buffer zone should be formulated following an assessment of site potential and discussions with landowners and other interested parties. The assessment of site potential should give due regard to existing features, available survey data (such as river corridor surveys), and any historic information. This study indentifies a range of targets for reconstructed buffer zones, and these should be taken into account in project design. The involvement of major landowners, such as the National Trust, Ministry of defence and Crown Estates in the pilot schemes is recommended.

KEY WORDS

riparian buffer zones, literature review, nature conservation, wildlife habitat, water quality control, water storage, production zone, floodplain, management targets

Section 1
PROJECT DESCRIPTION

This project seeks to determine the effectiveness of riparian buffer zones in enhancing the conservation value of river corridor habitats and in achieving other benefits such as reducing pollution benefits to rivers. There are three specific objectives:

(i) to review existing information on the application and effectiveness of buffer zones in river management (Section 3)

(ii) to identify opportunities for and constraints against development of riparian buffer zones in England and Wales (Section 4)

The project aims to provide a comprehensive review of scientific knowledge on buffer zones and a critical evaluation of the effectiveness of different types (size, floristic composition, continuity etc.) of buffer for river management. Attention is given to the role of Governmental and non-governmental organisations in potential implementation of such management. Consultation with a range of riparian planners and managers has been carried out, to ascertain the response of these bodies to such management.

(iii) to produce recommendations for the most appropriate management strategies for riparian buffer zones which take into account:

a) benefits in terms of environmental improvement
b) costs to landowners
c) the framework (existing and potential) necessary to allow implementation.

Recommendations regarding implementation, and suggestions as to how this can best be structured are presented in Section 5).

Section 2
METHODS

2.1 Literature Review

The literature review covered not only the UK and Europe, but also the USA , Australia and New Zealand. As well as using computer searches, workers in the field of fluvial systems research and restoration world-wide were contacted directly (Appendix A). The literature review was used to supply background scientific information to enable preparation of a series of potential scenarios ranging from simple to complex buffer zone structure and function (Tables 4.2 and 4.4). These were presented to a series of workshops (Appendices B and C).

2.2 Workshops

There were two approaches which could have been carried out in relation to discussion of the concept of river protection areas with interested parties - riparian planners, managers and land users. The first would have been to visit such parties and discuss the concept of buffer zones for conservation of rivers and bankside habitats in the light of their own particular interests and experiences. The second option was to bring such parties together to discuss the feasibility of introducing buffer zones in a general forum. The second option was chosen.

2.2.1 *One-day workshops*

Those invited to the workshops included governmental conservation bodies, including English Nature, the Nature Conservancy Council for Scotland, and the Nature Conservancy Council for Wales. Invitations were also sent to the Department of the Environment and to the headquarters of the World Wide Fund for Nature and the National Rivers Authority. A wide range of voluntary conservation bodies were contacted, as were a range of riparian users and planners including the National Farmers Union, and angling, fisheries and organizations (such as the Sports Council) representing recreation interests.

2.2.2 *International workshop*

A two-day workshop was held at Loughborough University on 23-24 January 1992. Details of the workshop are given in Appendix C. A range of expert opinion on buffer zones, their use and their potential for implementation was expressed, and the main conclusions of the meeting are incorporated with the literature review results in Section 4.

Section 3
THE SCIENTIFIC LITERATURE ON RIPARIAN BUFFERS

3.1 Background

The importance of river margin ecosystems to the overall ecological function of the river corridor has only recently been fully appreciated. Early works such as those by Cummins (1974) and Hynes (1975) outlined the importance of considering the fluvial hydrosystem in an holistic framework. More recent works (for example Johnson & McCormick 1979, Welcomme 1979, Hynes 1983, Cummins *et al.* 1984, Décamps 1984, Petts 1984, Winterbourn 1986, Salo *et al.* 1986, Petersen *et al*, 1987, Holland 1988, Pringle *et al.* 1988, Naiman *et al.* 1988,1989, Ward 1989a,1989b, Naiman & Décamps 1990, Décamps *et al.* 1990, Pinay *et al.* 1990) have developed and expanded this viewpoint. To date however, vegetation studies concerning the effects of regulatory measures (for example Bravard *et al.* 1986, Dister *et al.* 1990, Nilsson *et al.* 1989) have been relatively uncommon, with most studies concerning effects on fauna (examples being Ward & Stamford 1983, Petts *et al.* 1989, Petts *et al.* 1992).

Odum (1978) has stated that riparian zones may have their greatest value as buffers and filter between man's urban and agricultural development and his most vital life-support resource - water. Décamps (1984) concluded that the time has come to analyse the problems arising from river ecology and to develop a landscape ecology of river valleys.

Throughout Europe and North America natural buffer zones have been destroyed by deforestation, land drainage, river regulation and cultivation (Petts *et al* 1989, Petts 1990). Swift (1984) has catalogued the nationwide loss of riparian habitat in the USA, estimating that of 75-100 million ha only 25-35 million ha remain, loss being directly attributable to water resource development. It is now apparent that riparian buffer zones have an important role to play in managing and restoring watercourses for both enhanced wildlife value and improved water quality. Consideration of scientific research carried out in Britain, and elsewhere where research on riparian systems is at a more advanced stage, will be necessary in promulgating ecologically sound management strategies for our rivers in the UK.

The objective of this section is to outline the range of work which has, and which is being carried out on, riparian buffer systems and on the potential for ecologically-sensitive management strategies based on their natural characteristics. A further important aspect is to highlight the gaps in the scientific literature covering riparian systems and their function.

3.2 Buffer Zones: a Multi-functional Management Tool?

The effects of regulation on the natural biotic diversity of river corridors is well-documented (for example Boon 1988, Mann 1988, Welcomme 1989). This regulation has also had an effect on the water quality characteristics of Britain's rivers (Petts 1988). Contamination of water is becoming a limiting factor determining the usable amount of water resource in Europe. As the literature shows, riparian vegetation plays an important role in a number of functions in the fluvial hydrosystem (Figure 3.1). Not least among these are the acknowledged roles of provision of habitat for wildlife, water quality control functions via absorption of excess nutrients from catchment land use and the less easily-definable (but no less important) socio-economic consequences of maintenance of a more diverse semi-natural or natural vegetation cover along the aquatic-terrestrial boundary.

This review attempts to address the role that buffer zones of semi-natural or natural vegetation play in river corridor management for both wildlife and water quality control. Among the questions that the literature addresses are those regarding (i) size and structure of buffers necessary to carry out different functions, such as water quality control (ii) the effects of buffer zone management on constituent biotic components of the hydrosystem and (iii) the effect of buffers on sedimentation and flood control.

3.3 The Influence of Heterogeneity

Several North American ecologists (examples being Wallace *et al.* 1977, Cummins 1979, Vannote *et al.* 1980, Brussock *et al.* 1985, Statzner & Higler 1985) have discussed the idea of a continuum from the headwaters of a river to the mouth. Nilsson (1986) described a continuum related to climatic gradients for rivers in Sweden, with deviations caused by variations in substrate type and current velocity. Vannote *et al.* (1980) have pointed to different immigration directions for different species being also possibly responsible for variation in species richness along river corridors. Several authors (for example Vannote

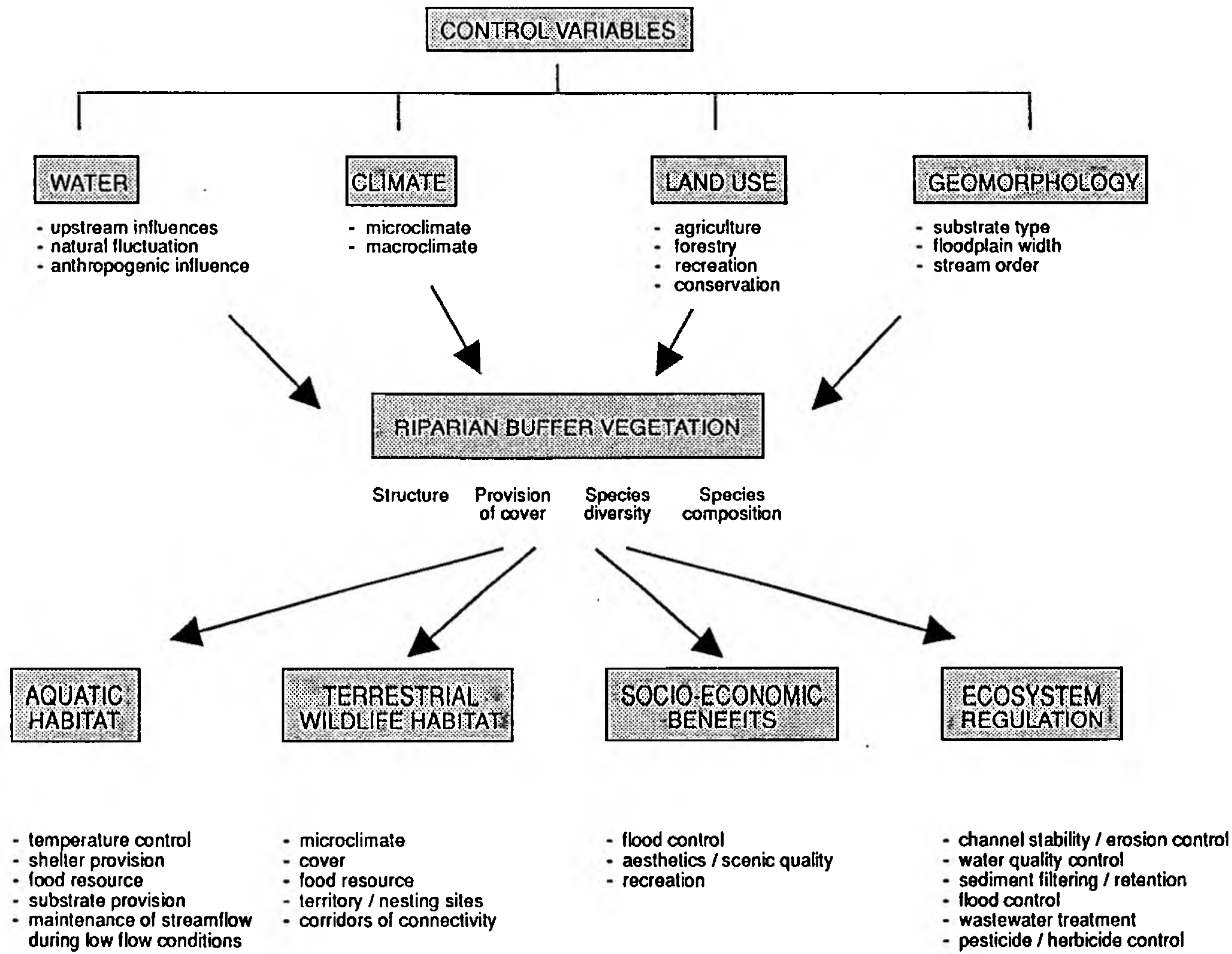

Figure 3.1 Model of buffer zone functions in the landscape (modified from Risser & Harris 1989, Rabeni 1991 and others).

et al. 1980, Ward & Stanford 1983, Minshall *et al.* 1985) have pointed out that both species richness and temporal and spatial environmental heterogeneity should be highest in the mid-reaches of undisturbed rivers and relatively low close to the headwaters and mouth. Thus, river management for conservation has differing application for upstream and downstream situations.

As Décamps (1984) points out, during the 1970's, the effect of riparian vegetation on natural river systems was considered mainly in a management perspective (examples being Horton & Campbell 1974, Karr & Schlosser 1978). More recently, workers have begun to classify rivers on the basis of their conservation potential (examples being Slater *et al.* 1987, Swanson *et al.* 1988, Naiman *et al.* 1991).

Décamps (1984) has identified width, degree of heterogeneity and connectivity as factors characterising river corridors. Heterogeneity is determined mainly by topography, elevation in relation to river level, and sediment permeability. Conchou & Pautou (1987), and Nilsson *et al.* (1989) have discussed the influence of heterogeneity in influencing the development of vegetation stands present along riverbanks, concluding that total species richness increased with substrate heterogeneity. Pinay *et al.* (in press) showed that soils characteristic of depositional situations act as a sink for carbon, nitrogen and phosphorous. On the other hand, soils susceptible to erosion act as potential nutrient sources during high water periods. A naturally vegetated buffer zone can also catch and retain sediment carried by overland flow from agricultural land and other developed landscapes (Brown *et al.* 1990). Thus, Pinay *et al.* (1989) draw attention to the need for consideration of the degree of heterogeneity within the riparian ecotone for better understanding of physiochemical and microbiological processes occurring within these systems.

The frequency and duration of inundation, related to elevation differences, are also important. Work by Nilsson & Grelsson (1989) points to the significance of flooding in undisturbed situations in influencing vegetation distribution as a result of litter displacement. Nilsson *et al.* (1991) have also discussed the effects of river regulation on riparian vegetation in Sweden, showing that species-richness was higher in unregulated reaches when compared to regulated ones.

Floodplain inundation is important for both floodplain and river channel processes, especially nutrient dynamics and biological production. Junk *et al.* (1989) and Bayley (in press) have described and discussed the flood pulse concept showing that although floodplains generate their own organic matter compared to instream parts of the river system, their nutrient pool is influenced by lateral exchange with the river channel. Bayley extends this hypothesis to river restoration arguing that restoration of the natural hydrological regime would, as well as providing benefits for fisheries, provide a self-sustaining potential for both recreation and flood control.

The development of riparian systems through time - a feature which has direct implications for long-term riverbank management through buffer zones - is discussed by Amoros *et al.* (1987a, 1987b). This is known as the Reversible Process Concept, (with for instance erosion and deposition being examples of reversible processes). Phillips (1989c) discussed fluvial sediment storage in wetlands in both the USA and the United Kingdom; of sediment reaching streams, 29-93 % is stored in alluvial wetlands. However, progressive sedimentation leads to terrestrialization and a loss of wetland habitat. Bayley (in press) argues that over time optimal areas for particular fauna would shift to different parts of the restored section in response to build-up of sediments. Thus, Phillips (1989b) concluded that wetlands should be managed in the context of the entire drainage basin rather than as discrete units (see section on management below).

3.4 Riparian Buffer Zones to Benefit Wildlife

It is clear that, of the many criteria employed in evaluating the conservation potential of natural areas, diversity and rarity are the most frequently used (examples being Margules & Usher 1981, Spellerberg, 1981, Nilsson 1984, Smith & Theberge 1986, Usher 1986, Greenwood *et al.* in press). The extent of a buffer required to perpetuate populations (i.e. by retaining its carrying capacity) is highly dependent on the long-term quality of the habitat in question. A frequent problem is that habitat management decisions for wildlife are frequently made by considering a limited set of species (Szaro & Rinne 1988).

3.4.1 *Fish*

Many authors (for example Penczak & Zalewski 1974, Burgess & Bider 1980, Mason *et al.* 1984, Moring *et al.* 1985, Wesche *et al.* 1985, Copp & Penaz 1988, Copp 1989, Zalewski *et al.* 1991) describe the value of riparian diversity for fisheries, whilst other works (for example Roseboom & Russell 1985, Backiel & Penczak 1989, Copp 1990, Risser 1990) describe the effect of regulation, with its associated reduction of ecological diversity on fish populations. Ahola (1990) points to the importance of vegetated buffer zones for shading the watercourse, improving the living conditions of fish and other animals and limiting the growth of water plants and algae. Williamson *et al.* (1990) also highlighted the potential benefits to stream fisheries by replanting of retired zones by appropriate tree species, providing shade and habitat. However, for fish populations in upland streams in Wales, aluminium in the labile form (most toxic to fish) increased significantly with increasing percentage of forest cover (Ormerod *et al.* 1989).

Along large rivers the natural floodplain can be seen as a 'stable entity' (Copp 1989) in relation to fish production, but for more disturbed situations Backiel & Penczak (1989) recommend habitat enhancement as a means of improving floodplain fisheries, concluding however that such enhancement must be coupled with water quality improvement for any success to be achieved.

A report by the Salmon Advisory Committee (1991) describes the introduction of riparian buffer zones as an attainable benefit of an integrated approach to catchment management, with benefits being (i) allowing bankside vegetation to develop to provide cover, (ii) provision of food in the form of invertebrates, (iii) reduction of fine solid material, (iv) reduction of the risk of chemical pollution and (v) reduction of the input of fertilisers. The Report highlights the necessity of management of the resultant zone, drawing attention to the Government's 'Environmentally Sensitive Area' scheme and the Countryside Commission's 'Countryside Premium Scheme' as being possible mechanisms at this time for implementation. However, no recommendations for widths of these buffer zones were made in the report.

3.4.2 *Invertebrate fauna*

As buffer strips can greatly influence water temperature and other habitat variables, particularly in low-order streams, they have a considerable impact on invertebrate communities, both instream and in the riparian zone itself. Furthermore, the input of particulate organic matter (twigs and leaves) has been established as important for aquatic invertebrate populations (for example Gregory, 1992). Organic detritus is the most important fuel for running-water food webs. Wetherley *et al.* (in press) and Ormerod *et al.* (in press) showed moorland buffer zones to increase stream macroinvertebrate species diversity in upland catchments with conifer plantations in Wales. The latter study concluded that in upland situations, buffer strips of broadleaf trees and moorland/grassland vegetation

have different effects on taxonomic composition and abundance. They also concluded that these buffer strips are most effective when implemented at the planting stage, although further data are needed to assess the influence of succession. Thus, in discussing the influence of conifer plantations on the distribution of the Golden Ringed Dragonfly in upland Wales, Ormerod *et al.* (1990) called for consideration of the effectiveness of new forest design practices including buffer strips around streams.

For floodplain environments, Petts *et al.* (1992) and Greenwood *et al.* (in press) have displayed the importance of the riparian vegetation, and woodland and wetland patches for maintaining macroinvertebrate assemblage diversity. Cutoff channels have important invertebrate assemblages (see *Regulated Rivers* 1991 issue 6.4) and Stanford & Ward (1988) have pointed to the importance of the hyporheic zone (the interstitial habitat influenced by surface water-groundwater interactions) of floodplains for maintenance of biotic diversity in the main channel. A number of workers (for example Eyre & Foster 1989, Eyre *et al.*, 1986,1990, Petts *et al* 1992, Wright *et al.* 1984) have used macroinvertebrates as indicators of environmental and conservation value.

3.4.3 *Avian fauna*

Riparian habitat supports some of the richest terrestrial vertebrate faunas, and this has been well illustrated by studies in the USA (Risser 1990, Carothers *et al.* 1974, Hubbard 1977). Thompson (1961) and Hehnke & Stone (1978) described how the removal of riparian vegetation along the Sacramento River resulted in 95% fewer birds and 32% fewer species in adjacent agricultural land.

In upland situations, buffering of conifer plantations - often the dominant land use - has been shown to affect biota. Ormerod & Tyler (1990) and Tyler & Ormerod (1990) have discussed the influence of tree type on breeding and feeding ecology of Grey Wagtails, concluding no direct effect with acidification but rather pointing to enhanced prey abundance with broadleaves as explaining why Grey Wagtails prefer broadleaved sites. Ormerod & Tyler (1990) point to the potential for a buffer of broadleaved woodland on the borders of streams through conifer plantations in maintaining Grey Wagtail and other faunal populations.

Particular attention has been paid by workers (for example Pase & Layser 1977, Anderson & Ohmart 1977, Triquet *et al.* 1990) to breeding bird densities in the United States, all concluding that the riparian zone has important influences on the biotic diversity of the total stream ecosystem. Anderson *et al.* (1978) show the importance of re-vegetating riparian floodplain areas for wildlife, with horizontal and vertical foliage density being positively correlated with the number of species in an area. Knopf *et al.* (1988) point out that, while riparian habitat occurs on less than 1% of the western North American landscape, it provides habitats for more species of bird than all other vegetation types combined. 82% of all species breeding in northern Colorado occur in riparian vegetation (Knopf 1985), and 51% of all species in southwestern states in the USA are completely dependant on riparian vegetation (Johnson *et al.* 1977). For the Rhine floodplain in Europe, Dister *et al.* (1990) have described the reduction of avian habitat by transformation of floodplain forests into monoculture plantations and call for "renaturalization" quoting the changing nature of EEC Policy as a spur for implementation.

3.4.4 Other Vertebrates

Riparian buffer zones provide both important habitats and linear corridors for mammals, reptiles and amphibians (Brinson *et al* 1981, Cross 1985, Dickson and Huntley, 1985). Some large species play an important role in sustaining the heterogeneity of the buffer zone. Thus, Johnston & Naiman (1987) have described the habitat requirement of beaver on the north American continent and their role in creating patch diversity in the riparian zone itself - a feature which has importance for other biota.

3.5 Riparian Buffer Zones for Water-quality Control

3.5.1 *Background*

It is now accepted (Cummins 1974, Minshall *et al.* 1985, Pinay *et al.* in press) that riparian buffer zones control the quantity, quality and timing of allochthonous organic matter and nutrients to streams. The primary processes involved are those of retention through (i) interception of sediment-bound nutrients transported by surface run-off - important in the case of phosphorous, (ii) uptake by vegetation or microbes of soluble nutrients - the primary process for nitrate removal, and (iii) absorption by organic and inorganic soil particles. Omernik *et al.* (1981) point to the importance of sediment export from riparian systems in controlling overall nutrient flux, a feature also supported by Karr and Schlosser

(1977). Buffer zones also exert a control on the transport of sediment-bound pesticides and other contaminants.

The key parameter in relation to water quality is the groundwater flow path under the riparian zone. Groundwater flow is rarely a simple flow perpendicular to the channel flow (Hill 1990, Haycock 1991), and the effect of variable permeability of floodplain sediments influencing oblique pathways (Haycock 1991) means that actual retention times of groundwater are often greater than expected. Worldwide, results have shown that in temperate situations riparian soils, in particular riparian organic soils, can significantly reduce the concentration of nutrients in groundwater entering the stream ecosystem itself (for example Yates & Sheridan 1983, Brinson *et al.* 1984, Yarbo *et al.* 1984, Lowrance *et al.* 1984a, Howard-Williams 1985, Jacobs & Gilliam 1985, Lowrance *et al.* 1985b, Howard-Williams *et al.* 1986, Cooke & Cooper 1988, Pinay & Décamps 1988, Cooper 1990, Hill 1990), and more specifically influence the quality of water passing from agricultural systems into the aquatic system. Pesticide movement can also be substantially reduced by diversion through vegetated riparian areas (for example (Asmussen *et al.* 1977, Rohde *et al.* 1980).

3.5.2 *The Role of Forests*

Alluvial forests are known to play an essential role in the operation of lotic systems (Hynes 1975, Douglas Shields & Nunnally 1984, Peterjohn & Correll 1984,1986, Welsch 1991). Peterjohn & Correll (1984) found that cropland appeared to retain less nutrients than forests, incurring the majority of its losses through harvesting. Results obtained by Peterjohn & Correll on the Rhode River, Maryland indicated that coupling natural systems and managed habitats within a river basin may reduce diffuse-source pollutions. Per year, removal of N was in the order of 0.83 kg ammonium-N, 2.7 kg nitrate-N and 11 kg particulate organic-N in surface runoff, and 45.0 kg/ha nitrate-N in sub-surface runoff). Phosphorous removal was in the order of 3.0 kg particulate P per year.

Correll & Weller (1989) found forested wetlands to transpire on average 67% of precipitation and groundwater. Nitrate uptake was highest (97 %) in autumn and lowest (81 %) in winter. The removal varied from 51.2-99.9%, but the inefficiency of 0.06-49 % causes some concern regarding possible downstream impacts. Rhodes *et al.* (1985) found nitrate removal from a headwaters watershed in the Sierra Nevadas to be 99 % through uptake by riparian forests and wetlands.

Osborne & Wiley (1988) found that riparian forests cannot influence either nutrients which are point source (for example municipal treatment plants) or nutrients which have entered the stream upstream. Risser (1990), in discussing Osborne & Wiley's findings, concludes that these forests can have little effect if they are limited to only parts of the watershed and thus cannot influence point sources which avoid the riparian vegetation. Labroue & Pinay (1986) showed alder vegetation to also remove nitrates from groundwater associated with gravel pits in France, and highlighted the importance of available organic carbon, anaerobic conditions and easy NO_3 transport in this removal process.

Dynamics of nutrient cycling at the land-water boundary has received much attention in New Zealand (Rutherford *et al.* 1987, Cooper 1990). In the United Kingdom, Haycock & Burt (1990, 1991) have observed a sharp loss of nitrate by denitrification and assimilation processes as groundwater moved through the riparian zone of floodplain soils. Riparian vegetation is an integral part of this process. The authors advocate setting aside agricultural land to protect groundwater and extension of these schemes to protect surface water. Undrained floodplains can therefore act as barriers to nitrate movement and allow farming and water supply to exist in the same basin.

3.5.3 *Effects of Seasonality*

The effects of seasonality relate to two factors: primary production and the hydrological regime. Kibby (1978), in discussing nutrient dynamics, described riparian wetlands as valves, taking in nutrients in spring and early summer and probably releasing them in late summer and autumn. Field studies on the role of wetlands on nutrient dynamics have principally been (a) input/output studies and (b) studies on uptake of nutrient by specific plant species). Many authors have pointed to significant removal of nitrate (for example Lee *et al.* 1975, Patrick & Reddy 1976, Richardson *et al.* 1978, Rhodes *et al.* 1985). Kibby (1978) presented data pointing to higher concentrations of nitrogen being found in dead plant material, as well as the most active period of uptake being between March and June, when plant growth is at its peak. Vegetation uptake will retain nitrate in the summer period, as denitrification is often lowest at this time of year (Ambus & Lowrance 1991) due to aeration of the soil. Brinson (1977) and Polunin (1982, 1984) have also described in detail the effect of seasonality on decomposition processes and nutrient release in freshwater and wetland systems. Kibby (1978) also emphasized that all wetlands are not automatically have beneficial effects on water quality - the effect of any given wetland on water quality is very dependent on the hydrological characteristics of the area.

Flooding provides an input of organic carbon into the system fuelling denitrification processes within the floodplain soils (Cooper *et al.* 1987, Pinay *et al.* in press). Pautou & Décamps (1989) discuss the influence of soil type and watertable-depth variation on ecological succession, and point to the ability of semi-aquatic communities characterised by high transpiration to absorb large quantities of water, assisting in absorption of nutrients. Pinay *et al.* (1989) pointed to higher accumulation of nitrogen in nitrate form during winter in soils with less waterlogging. In more waterlogged sites an accumulation of ammonia in deep soil levels was observed. Management of water regime and the vegetation structure therefore is essential to maintain the effectiveness of any buffer for water quality.

3.5.4 *Influence of soil type*

Little literature appears to be available on the ability of differing soil types to absorb nutrients. Work by Pautou & Gensac (1973a,1973b) discusses the relationship between hydrological and nitrogen dynamics, showing nitrites to be mainly produced in superficially well-aerated soils, whose underlying layers are well provided with water. Ambus & Lowrance (1991) showed the upper layer of soil to be of particular significance in aiding denitrification, especially in the top 2 cm, but conclude that the extent to which denitrification can remove NO_3 from riparian ecosystems is site-specific and depends on the particular soil in question. Prach *et al* (1988) also point to variation in soil type as being an important factor, showing in a case study floodplain absorption to be effective over a distance of *circa* 20 m. Where dissolved pollutants are of concern, Phillips (1989e) concludes that, along with soil moisture storage capacity, buffer zone width is of most concern - the wider the zone, the greater its effectiveness.

3.6 Composition and Dimensions of Buffer Zone

Among others, Meehan *et al.* (1977), Johnson *et al.* (1977) and Mason *et al.* (1984) have discussed the overall importance of riparian habitats as reservoirs of plant and animal diversity.

3.6.1 *Choice of vegetation*

Attention needs to be paid to the already-existing "natural" and semi-natural communities present along the riverbanks of England and Wales. Works (examples being Mason *et al.*

1984, Curry & Slater 1986, Mason & MacDonald 1990) discuss the distribution of herbaceous and woody riparian vegetation along a series of studied reaches in both upland and lowland situations, with Curry & Slater's study revealing altitude to be most important factor. Newbold & Rush (1989) and the Nature Conservancy Council (1991) advocate setting aside strips of land uncultivated, while from a floodplain planning perspective, Risser & Harris (1989) discuss use of specific riparian species to restrict recreation access to sensitive areas as well as improving degraded wildlife habits and improving bank stability.

Karr & Schlosser (1978) hypothesized that maintenance of more natural near-stream vegetation and channel morphology in agricultural watersheds can lead to significant improvement in water quality and stream biota, and pointed to research carried out in logged areas showing reduction in nitrate inputs to stream systems as a result of introduction of buffer strips. Work by Lowrance *et al.* (1984b,1985a) substantiated this view. However, the alteration in the below ground environment of pH, nutrient status, toxic metal levels and organic matter pathways (Correll, in press) have implications for natural systems such as wetlands downstream from intensively managed situations.

In discussing the benefits of riparian trees both to wildlife conservation and for ecological management of water courses in the United Kingdom, Mason *et al.* (1984) urge the replanting or encouraging natural regeneration of oak, sycamore and ash. The mature root systems of these species provide secure holts for otter but these trees are shunned by the engineer, as their horizontal root systems permit undercutting of the channel bank. A balance has therefore to be struck by planting a strategic mix of both vertical and horizontal rooting species. Densities of these trees are significantly higher in Wales (MacDonald & Mason 1983) where they have significant conservation value.

3.6.2 *Widths to Control Physical Characteristics*

a) ***Bank Erosion.*** Vegetation exerts an important control on bank erosion rates (a practical guide to the use of natural vegetation to protect river banks is given by Hemphill and Bramley, 1989) but in general there is little information available to show how wide buffers need to be for bank protection. Whipple *et al.* (1981) found a correlation between buffer width and bank stability, while for low order north California streams, Erman *et al.* (1977) found 30m buffers to be adequate to maintain bank stability.

b) *Sedimentation.* Vegetated buffer strips have important functional roles by physically intercepting sediment and by reducing surface runoff volume via infiltration (Karr & Schlosser 1977, Rabeni 1991). Peterjohn & Correll (1984) found substantial removal of suspended sediments moving through 19 m of riparian forest in Maryland. Little information is available as to the fate of these sediments. US Department of Agriculture recommendations for minimum widths to minimize sedimentation range from 23 m for coarse sand to 138.5 m for silt. The USDA conclude that control over clay sedimentation cannot be only met by buffers but require wider-scale land management strategies. Rabeni (1991) recommended widths between 23m and 115.5 m whereas Erman *et al.* (1977) found 30 m buffers protected aquatic insect communities from sedimentation. Some will probably be remobilized during high flows and flood events, but most, as shown by Lowrance *et al.* (1986), may be retained for a prolonged period of time. However, buffers have been shown to fail in certain cases due to channelization (Dillaha *et al.* 1986).

c) *Water Temperature.* Riparian vegetation is one of the most important factors controlling water temperature in small streams. Removal of vegetation has been shown to increase water temperature in small, heavily shaded streams (Burton & Likens 1973, Karr & Schlosser 1977, Corbett *et al.* 1978). Shade provided by trees in narrow (10-20 m) buffers is adequate to control the temperature of small streams.

3.6.3 *Wildlife requirements*

Brown *et al.* (1990) conclude that:

> "to be effective at providing habitat....buffers should be delineated and maintained in such a way so that they protect: the quality of the wetland habitat, the quantity of the habitat that will provide sufficient space for species; and the wildlife in these buffers from adverse impacts of adjacent land uses.'

Johnson *et al.* (1977) point out that the factors which need to be solved include (i) the minimum area and configuration necessary to retain both plant and wildlife values in different riparian habitats, (ii) the maximum distances which can separate islands of given habitat types before adverse effects to, and even loss of wildlife species or populations occur (an example being Knopf *et al.* 1988). In addition (iii) the optimal as well as minimal requirements for enhancing wildlife values for a given habitat type (for example being plant species type and cover) need to be determined. Large *et al.* (in press) have pointed to the potential of quite small semi-natural and natural patches on the floodplain to act as refugia thereby facilitating increases in floristic diversity under more favourable conditions.

Rabeni (1991), in a literature review primarily focussing on water quality protection, but also including habitat values for wildlife, quotes examples of mandatory buffer widths in the USA. Widths were shown to vary from 1.5 m (for forested streams in Idaho) to 92 m (in Wisconsin). Between these bounds there is a wide variation in buffer widths, even in those recommended for similar land uses in different states. In relation to aquatic biota, Budd *et al.* (1987) found a 15 m buffer width to be wide enough to act as a protection barrier to maintain habitat based on fisheries and wildlife needs. Few studies have examined the specific effect of buffer zone width on invertebrate assemblages (Rabeni, 1991). In the USA, Newbold *et al.* (1980) found little significant difference in aquatic invertebrate community structure between buffered and unbuffered low-order streams with a wide (> 30 m) buffer. Where the buffer was narrower, a strong correlation between buffer width and species diversity was found. On the other hand, Noel *et al.* (1986) found 8-9 m buffers strips to be insufficient to prevent logging damage to instream invertebrate communities, reflecting problems of sedimentation.

Rabeni (1991) concluded that relatively wide buffers are required to provide sufficient habitat for riparian wildlife and plants and to function as wildlife corridors linking larger areas of riparian habitat, a feature also seen in discussions of buffer zone for wildlife in east central Florida (Brown *et al.* 1990). Shape and size of the riparian zone does affect some species (cf. Knopf 1985), but a study by Brinson *et al.* (1981) showed most mammal, reptile and amphibian species to concentrate within 60 m of the edge of the stream.

In Germany, Arnold *et al.* (1989) have argued for at least the creation of "pocket-sized" wet biotopes and for the broadening of floodplain to at least five times the width of the main channel for any ecological improvement to be possible through re-creation of meanders, riparian forests and meadows. In the United States, the Washington Department of Ecology (1981) found wildlife habitat to extend beyond the stream bank a minimum of 27.4 m into the upland areas of the river corridor. In Iowa, Stauffer & Best (1980) found bird species diversity to increase with increasing width of wooded riparian habitats, while width of riparian area has also been shown by Dickson & Huntley (1985) to be of importance for small mammals. Cross (1985) found that the leaving of 9 m to 20 m wide wooded strips along stream edges on logged Oregon streams maintained small-mammal populations at levels almost those of nearby undisturbed areas. Other studies (examples being Anderson *et al.* 1977, Geier & Best 1980) have shown the reverse situation also to occur - i.e. loss of riparian diversity and replacement of naturally-occurring riparian woody species with commercial crop alternatives to lead to loss of both species abundance and diversity in riparian areas.

In some studies, the recommended buffer width to protect wildlife habitat has depended on the extent of groundwater draw-down and the slope of the groundwater table. Thus Brown *et al.* (1990) found that the width of the buffer zones along streams in east central Florida for flatwoods and isolated wetlands are between 99 m and 169 m. Where groundwater pollution is a major problem, wider buffer zones are required. Work in the Netherlands (van der Hoek 1987) has discussed the disappearance of vulnerable and rare plant species due to eutrophication of groundwater. This particular study recommended a buffer zone size of 150 m for improving groundwater flow, and for improving floristic diversity in the riparian fringe.

3.6.4 *Nutrient retention / filtering ability*

Regarding water-quality control, Peterjohn & Correll (1984) found significant removal of nutrients from surface runoff and shallow groundwater to occur across a 50 m wide riparian forest in eastern USA. Similarly, for agricultural areas in south Finland, Keskitalo (1990) recommended a buffer strip width of 1-2 m, in places expanded to tens of metres, a view supported by Ahola (1989, 1990), who recommended widths of 1-2 m for small ditches, 5-10 m for brooks and 10-20 m for rivers. Pinay & Décamps (1988) found 30 m of alluvial forest to be sufficient to remove all nitrate. In this study in France, denitrification of up to 50 mg of N_2/ m^2/day was observed in the field; the potential is for more removal.

Rabeni (1991) concludes that a fairly narrow riparian strip (less than 30 m in width) can provide many of the functions of natural riparian systems, with 20 m buffers significantly reducing nitrogen levels in both surface runoff and groundwater. In the eastern USA, Phillips (1989a) has concluded that a 23 m buffer zone width provided for in state legislation is not adequate for non-point pollution removal and recommends an 80 m zone width particularly in estuarine situations. In another study Phillips (1989d) states there is wide variability in the effectiveness of buffer zones, with a range of 15-80 m being appropriate for various land/soil/ vegetation complexes in riparian situations. Kovacic *et al.* (in press) while finding marked reduction of nitrate-N concentrations in both a *Phalaris* buffer and a forested buffer, conclude that modified lateral wetland strips adjacent to rivers are a possible effective alternative to riparian buffers, with forested buffers of potentially greater efficiency.

Smith (1989) found statistically lower concentrations of particulate phosphorous and nitrate-nitrogen concentrations in retired riparian pastures versus grazed pastures. Studies by Smith *et al.* (1989) and Cooper (1990) supported these findings with the Smith *et al.* (1989) results showing that large improvements in water quality can be obtained by managing relatively small stretches along the riverbank. Grassed buffer zones reduced sediment P and N to stream by 80-87% and groundwater N inputs by greater than 90%.

3.6.5 *Constructed wetlands*

Constructed wetlands and reed beds have been advocated as land-treatment systems in sewage systems for removal of BOD and solids with consequent downstream improvement of water quality (DeJong 1976, Gersberg et al. 1984a,1984b, Bayes *et al.* 1989, Butler *et al.* 1990, Burka & Lawrence 1990, Upton & Griffin 1990, Conley *et al.* 1991, Tedaldi & Loehr 1991). Although some studies show their potential for nitrogen removal to remain unclear (Gersberg *et al.* 1983, Bayes *et al.* 1989), others (for example Boyt *et al.* 1977, Mudroch & Capobianco 1979, Tilton & Kadlec 1979, Reddy *et al.* 1982, McIntyre & Riha 1991) demonstrate that constructed vegetated riparian areas have distinct potential for water quality control. Several studies have shown that leakage, especially of phosphorous, may occur (Richardson 1985, Mann 1990, Vanek 1991) following senescence and decomposition of the plant material. However, this can be controlled by maintenance. In addition to provide a useful tool for point source water-quality control, these wetlands play important roles in conservation and provide water storage.

3.6.6 *Integrated Management*

In addition to width, the continuity of the buffer zone is an important variable, not least if optimum management of riparian and instream biota is to be achieved. Mason *et al.* (1984) have discussed the benefits of riparian trees for wildlife conservation in the UK for avian fauna as well as instream biota through shade and organic input. In one example, Dawson (1978) has outlined a plan where trees are planted along the south side of a stream to provide shade, but gaps of approximately 20 m are left at 70 m intervals to permit instream primary production, especially macrophyte growth which provides shelter for invertebrates and fish and an important source of autochthonous detritus. Along floodplain rivers, the buffer zone should be a mosaic of patches rather than a continuous strip - maximizing heterogeneity. Studies reviewed by Brinson *et al.* (1981) suggest that 5-6 ha riparian habitat 'islands' are needed to support near maximum bird diversity, with larger areas required to support raptors.

Water-quality control is also of value for conservation. Howard-Williams (1991), in discussing dynamic processes in natural unforested New Zealand river courses, concluded that in addition to influencing load inputs to the aquatic foodweb and in denitrification and removal of nitrates from both ground and surface waters, the macrophyte cover along river margins was important in increasing habitat for aquatic organisms and others that depend on aquatic vegetation for feeding, cover, nesting etc. In relation to fisheries however, Jansson *et al.* (1990) have shown that although nitrogen can stimulate aquatic production it also accelerates organic matter decomposition which can unbalance the limnic system. Thus in the situations of commercial fisheries, control of nitrate input becomes important.

In unmanaged riparian buffer zones, succession will advance and nutrient release may occur due to senescence and decomposition of the vegetation *in situ* (Vitousek & Reiners 1975). Regarding phosphorous, Kibby (1978) states that wetland systems tend to be quite leaky with a significant release through fragmentation and leaching from the dead plant community throughout the year. Management of the vegetation is needed to minimize nutrient release. For example, removal of macrophytes in the autumn can reduce the possibility of ammonium toxification in the autumn months following senescence, although some studies (for example Debusk & Keddy 1987) show most of the nitrogen loss to occur in gaseous form, therefore indicating little loss of efficiency with time. Furthermore, Omernik *et al.* (1981) state that long-term effects of near-stream vegetation in reducing stream nutrients may be negligible unless other practices are utilised, such as timing nutrient applications to maximise uptake by crops.

3.6.7 *Grazing Management*

Williamson *et al.* (1990) discussed the effects of grazing retirement on bank stability, concluding that grazing itself had little impact on bank morphology, but that benefits of grazing retirement were in the main to remnant areas of native vegetation. In contrast, in a study in the USA, Armour *et al.* (1991) found that grazing did increase erosion as well as reducing the vegetation cover of riparian areas, a question also addressed by Van Haveren

& Jackson (1987). In these studies, better land management strategies were called for in grazed riparian systems, a feature which has been addressed by Clary & Webster (1989). Szaro & Rinne (1988) in discussing ecosystem management for Southwestern US riparian communities, concluded that grazing posed one of the most prevalent forms of disturbance. With regard to the effect of riparian grazing on fisheries, Armour *et al.* (1991) point to reduction of shade, cover and terrestrial food supply, with resultant increases in stream temperature, changes in water quality and stream morphology as being the major apparent effects on fish habitat. Armour *et al.* conclude that, if properly managed, grazing could become an important management tool, benefiting fish and wildlife riparian habitats.

3.7 Implementation of Restoration

Nilsson *et al.* (1991) argue that conservation management of natural riparian communities should take into account the recent recognition that land-water interactions are fundamental for the function of natural water courses. In order to be able to draw up detailed management programmes we must, Nilsson argues, know in more detail the nature of these interactions. Ward (1989a) and Ward & Stanford (1989) have argued for a holistic approach to river restoration within the constraints posed by multiple-use objectives for the catchment, citing the devastating effects of regulation on floodplain-dependent species of fish, whilst stating that buffer strips obviate, "to a remarkable degree", the deterioration of fish habitat condition often associated with disruption of riparian controls. This is in addition to maintaining the integrity of land-water interactions in otherwise altered catchments (see also Karr & Schlosser 1978, Ward 1984). Budd *et al.* (1987), Cohen *et al.* (1987) and Rinne (1990) advocate multi-purpose management functions for riparian ecotone areas in lowland, urban and upland situations respectively, stressing the aesthetic and recreational potential of such areas, as well as their role in water quality and erosion control.

Vitousek & Reiners (1975) point out that, in forests, once storage pools of nutrients reach a steady state, output must equal nutrient input. This will presumably be also true for riparian systems, with attendant implications for long-term management. Pinay *et al.* (1990) also pose pertinent questions as to the management of riparian zones - for example to what extent can the nutrient filtering ability of these riparian zones be extended for groundwater areas heavily loaded in nitrate? Is the size necessary for water quality control sufficient to maintain or enhance avian diversity? In posing these questions however, Pinay *et al.* (1990) make the important point that, although catchment management is the goal, riparian control measures make a useful beginning, due to the fact that most processes governing fluvial landscape dynamics are controlled by riparian areas.

Thus far in the area of resource management, more emphasis has been placed on gathering information, than on effective and efficient use of available information for decision-making and problem-solving (Risser 1990). Nilsson *et al.* (1988) highlight the fact that each river has largely unique vegetation features and that "extensive field surveys" are the only guarantee of success in selecting sites for conservation, whilst Schlosser & Karr (1981) illustrate the problems associated with predicting patterns of water quality where riparian vegetation and channel morphology vary spatially. Lowrance *et al.* (1985a) conclude management must occur on a watershed-by-watershed basis, while Phillips (1989b) recommends management in the context of the drainage basin rather than discrete units. In contrast, Knopf *et al.* (1988) see potential dangers in developing management policy on a site-specific information base, especially when viewed from a national perspective. They point out using examples (for example Wilson & Carothers 1979, Harris 1984, Norse *et al.* 1986) that current conservation thinking in the USA has been preoccupied with the application of area components of island biogeography theory to patterns of population dispersal - rather than using the approach examining faunal redistribution as a function of dispersal capabilities and probabilities (for example Simpson 1965).

Simberloff (1976) suggests that minimal area and shape of wildlife habitat are important determinants of species productivity, while Diamond (1975) supports these conclusions in relation to the narrower, linear habitat of stream corridors. For urban situations, the results of a study by Greer (1982) indicate that management strategies have to protect food resources and include a corridor concept connecting fragmented habitat to larger rural populations. The question of whether a continuous belt of riparian forest is necessary has been discussed by Décamps *et al* (1987) who found that avian species richness increased following fragmentation of the riparian corridor. In terms of cost, Bayley (in press) concludes that restoring a large contiguous river-floodplain area would be more cost-effective than restoring a similar area comprising smaller, disjointed areas along the river.

Rinne (1990) in a review article argues for longer time period of study (>5 years) to develop effective long-term management strategies for wetland forest resources in montane riparian situations. In discussing ecological management, Bravard *et al.* (1986), in a examination of the impact of civil engineering works on community succession, argue for conservation of those communities with a slower succession rate, coupled with a secondary phase of protection of functional units with a high rate of development.

As Risser (1990) points out however, a useful strategy in general may be to separate the "deep-knowledge" theory associated with scientific systems from surface rules for managing those systems. This view, as well as that held by Nilsson (in press) - that action should not be postponed while awaiting more detail - was supported at the recent International workshop on Lowland Stream Restoration held at Lund, Sweden (August 1991). The consensus here was that, on the whole, enough scientific information is available to begin to address some of the problems associated with river systems. Communication of ideas between workers however, becomes a priority. It must be accepted that mistakes will be made, but the direction will be one of progression towards ecologically-sound and sustainable management strategies for our river courses. As Morgan (1978) states

"Good policy analysis recognises that physical truth may be poorly or incompletely known. Its objective is to evaluate, order and structure incomplete knowledge so as to allow decisions to be made with as complete an understanding as possible of the current state of knowledge".

Szaro & Rinne (1988) argue for an ecosystem approach to management of riparian systems, while other researchers in the USA (for example Black *et al.* 1985, Sweep *et al.* 1985, Simcox & Zube 1989, Cook 1991) show positive public attitudes towards preservation of multiple-use river corridor amenities including wildlife habitat, riparian vegetation and open space. Therefore, it appears that communication between scientists, resource managers and the general public is vital in order that ecologically-sound management strategies (including those of riparian buffer zones and other river protection areas) can be put forward for serious consideration.

Section 4

BUFFER ZONES: CONCLUSIONS REGARDING PRACTICAL IMPLICATIONS

4.1 Introduction

This project has demonstrated that there is both a growing body of evidence to suggest that riparian buffer zones could play a major role in landscape management, and a growing desire for environmental enhancement along river corridors. The overwhelming consensus of all three workshops was that buffer zones were potentially a very useful tool for ecologically-sound management of river catchments in England and Wales for nature conservation. In England and Wales, buffer zones could play important roles in advancing the water industry's aim to

"so exercise their functions as to further the conservation and enhancement of natural beauty and the conservation of flora, fauna and geological or physiographical features of special interest..." (Section 48, Wildlife and Countryside Act 1981).

The primary focus of buffer zones would be on the river corridor itself, although it was recognised that more holistic catchment management was desirable. Although potential disadvantages were raised during the course of discussion (Table 4.1), it was felt these were challenges to be overcome, and overall the advantages for nature conservation would outweigh any disadvantages. Three primary roles for riparian buffer zones have been identified (Table 4.2):

1. *Provision of important habitats for biota* with:
    i) high biological diversity;
    ii) high biological productivity; and
    iii) sources for species dispersal.

2. *Regulation of lateral and longitudinal dynamics* by:
    i) influencing movement and migration of birds and mammals;
    ii) provision of nutrient and sediment sinks for agricultural runoff;
    iii) provision of organic matter to the river; and
    iv) provision of water storage.

3. *Enhancement of visual quality and amenity value*

Specifically with regard to floodplain rivers, a fourth role should be added:

4. *Enhancement of nature conservation.* by incorporation of a range of physiographical features, especially cutoff channels and wetlands, of different successional stage.

Objectives of buffer	Disadvantages of buffers	Barriers to implementation	Incentives for implementation
Nature conservation	Potential invasion by undesirable species	Lack of education (public and other professions)	Set aside scheme
Ecosystem function stability	Obstructs access to anglers and other recreation users	Lack of proof of ecological benefits	Countryside stewardship
Recreational area	Interferes with channel maintainence	Implementation costs high to riparian users	Conservation can ride on back of EEC Water Quality Directives
Water quality filtering (nutrients and sediments)	Hampers traditional land uses	Local constraints (e.g. urban development already present)	Potential for alternative crops
Installation on a catchment basis to protect entire fluvial corridor	Interferes with flood defence schemes	Increased tourism	Farm Woodland Grant Scheme
Streambank stabilisation	Reduction of arable land and permanent pasture		
Improving aesthetic and amenity value	Hampers floodplain maintainence		
Mitigating poor water quality	Increased evapotranspiration affecting flows		
Animal habitat - birds, otter			
Restoration of lost vegetation types			

Table 4.1 Summary of objectives for buffers, their disadvantages and barriers and incentives to the implementation as management tools as perceived by riparian planners at the one-day workshops held in November and December 1991.

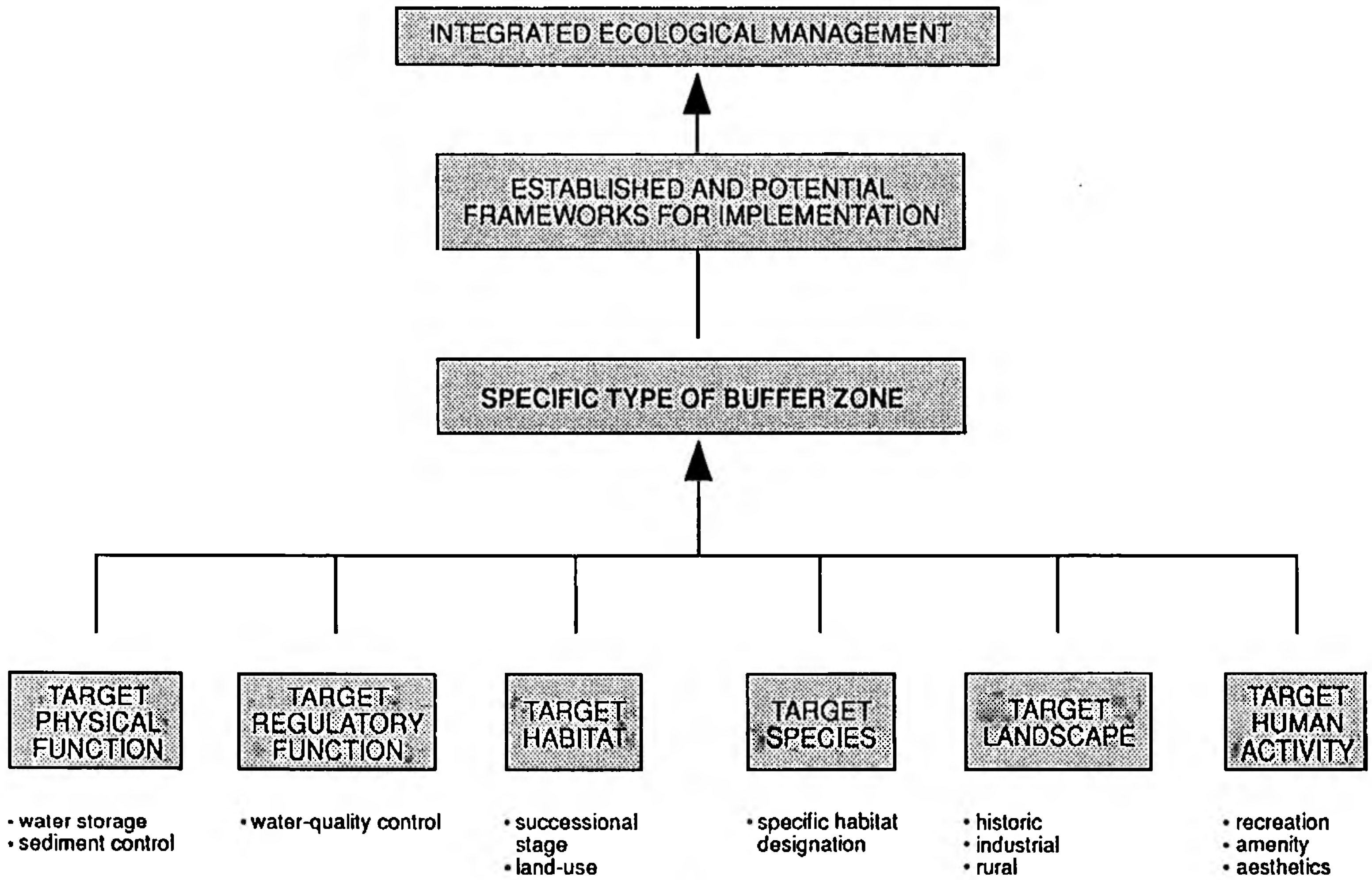

Figure 4.2 Targets for buffer implementation in the UK.

4.1.1 *Geographical setting*

The physiographical and ecological features of rivers vary from ecoregion to ecoregion and from source to mouth. A number of studies have divided England and Wales into two main regions on geological, geomorphological and hydrological criteria. The upland north and west contrast with the lowland south and east. Within these major regions the control of lithology on hydrological (and water-quality) regime (such as shale versus limestone or boulder clay versus chalk) is influential in determining differences between rivers. A comparison of the River Wye and River Derwent in Derbyshire, provides a useful example of this.

In terms of the longitudinal dimension, three main zones can be recognised (Figure 4.1a.). The 'production zone' represents the major source areas for the downstream river (Figure 4.1b). First-, second- and third-order streams may be visualized as tapping water, nutrient and sediment supplies from hillslopes. Rivers of fourth-order and above are usually isolated from adjacent hillslopes by terraces or floodplains which become especially significant in the downstream storage zone. It is this third zone which has particular ecological significance (Figure 4.1c) although it has been most severely affected by regulation, drainage, and agricultural intensification over the past two hundred years (Petts 1988). In summary:

i) Within the production zone, buffer zones have significance for maintaining the quantity and quality of the river flows downstream, and for conserving lotic (running-water habitats), as well as providing conservation areas in their own right.

ii) Within the transfer zone, buffer strips provide important linear habitats, not only within the riparian fringe but also along the channel margin, including shading and cover for fish.

iii) Within the storage zone, again a riparian strip has important ecological value but considerable opportunities exist for environmental enhancement in former floodplain areas, by utilization of patches for nature conservation.

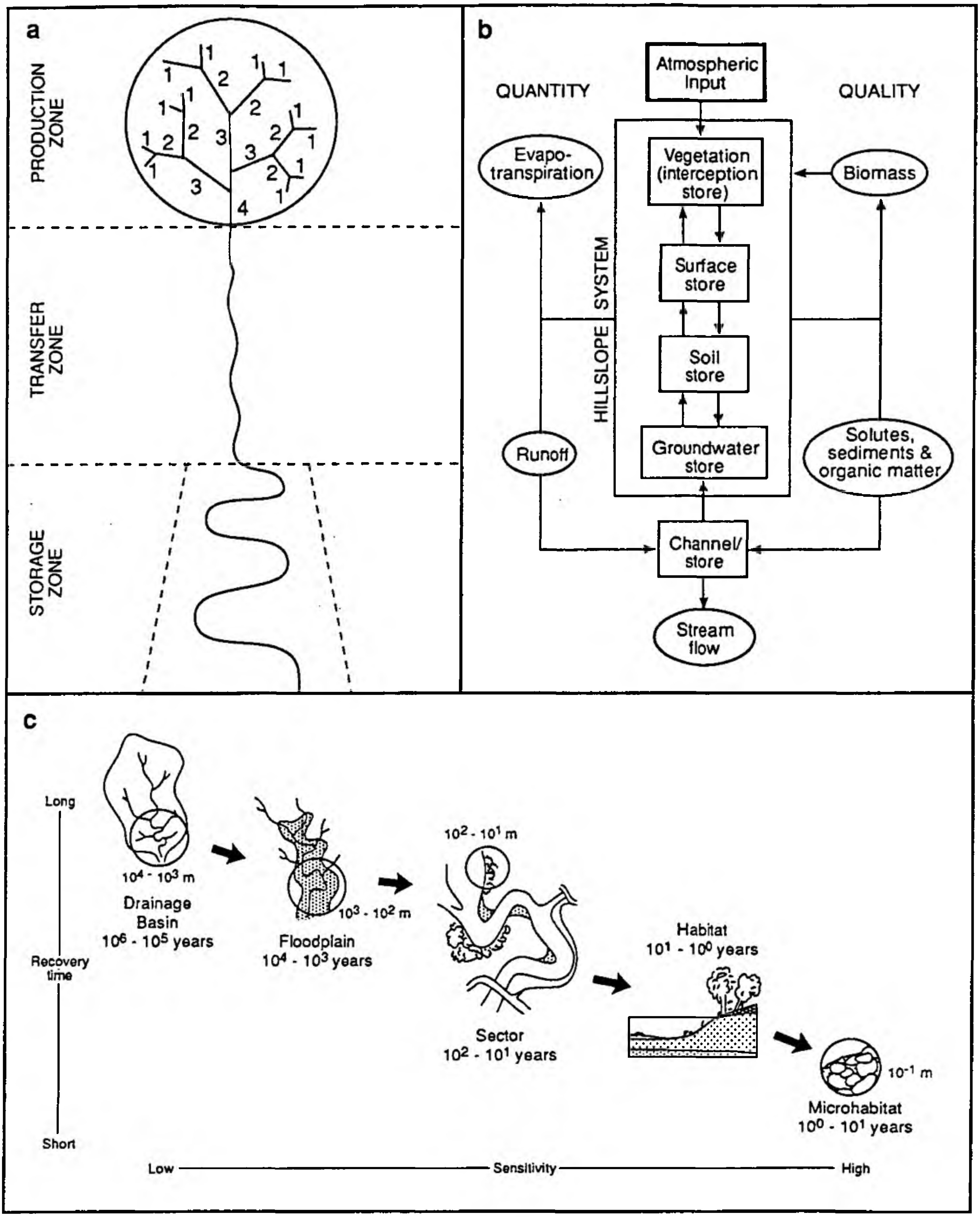

Figure 4.1. (a) Model showing 3 zone-division of the river channel relating to buffer implementation

(b) Process model for Production Zone in 4.1 (a)

(c) Time-sensitivity response model indicating range of potential scales of examination. This study is based on the sector/habitat scale.

4.2 Roles of Buffer Zones

4.2.1 *Buffer zones for conservation*

A riparian zone comprising no more than the river or stream bank *per se* can have considerable ecological importance. In an intensively cultivated landscape, neglected or slightly managed areas along ephemeral or perennial ditches provide important habitats for biota (Petts & Darby 1991). Even along large floodplain rivers, a narrow riparian strip (Plate D1) can have important ecological values, containing a relatively rich flora and fauna (Petts *et al.*, 1992). In such cases, the buffer zone is particularly important for a range of terrestrial vertebrate and invertebrate species.

Larger and physiographically /floristically diverse buffer zones have even greater ecological values. Even 5 m-wide buffer zones with trees and shrubs can introduce important habitat and provide considerable interest, for example, when associated with public footpaths (e.g. Plate A1-A2). At a larger scale, woodland patches, wetlands, backwaters and ponds can create an ecologically rich buffer zone, in many cases supporting rare species (e.g. Plates B1-B2, C1-C2,D2). In such situations the buffer zone may be visualised as a series of patches that should be connected (cf. Section 3.7) but may appear as a 'string of beads' (cf Section 3.6.3) in a landscape sense. Even thin riparian strips (D1-E2) have been shown (Petts *et al.* 1992) to have habitat value.

4.2.2 *Buffer zones for water storage*

Given the current awareness of low-flow problems, the role of buffer zones for water storage was considered in two situations. Firstly, wetland streamhead sites could be useful in contributing to the maintenance of low flows. Secondly, in higher-order situations, floodplains could be used for water retention during high flows with important implications for wetland habitats as well as for flood control.

4.2.3 *Buffer zones for water-quality protection*

Several water-quality problems in rivers, such as pollution by nutrients such as nitrates and phosphates and by pesticides, relate to diffuse sources and require management within the production zone. Land management practices on hillslopes can affect river water-quality in four ways: via overland flow, shallow subsurface flow, pipe flow, and deep subsurface

Plate A1

Plate A2

Plate B1

Plate B2

Plate C1

Plate C2

Plate D1

Plate D2

flow. Lowland streams in agricultural catchments have been markedly affected by ditching and canalization (e.g. Plates E1-E2, F1-F2). The potential for buffers in each of these situations is as follows:

i) Where soil erosion and overland flow constitute a major problem, buffer zones can be very effective in providing sinks for sediments and nutrients - providing they have adequate width. Within narrow buffer zones, water may be ponded until a "channel" route is found through the buffer zone, at which time rapid flow will occur through the buffer zone. It is possible that very narrow strips would be relatively easily overtopped, and studies reported in the literature recommend an optimum width of at least 30 m, but as narrow a zone as 1-2 m has been shown in cases to suffice (cf. Section 3.4.3).

ii) Where diffuse sub-surface flow dominates hillslope-channel fluxes, a buffer zone at the base of the hillslope can be a very effective nutrient sink, especially when it is composed of tree species and has an optimum width of at least 20 m (cf. Section 3.4.3).

iii) In the case of pipe-flow, a buffer zone alone is likely to be ineffective as it will be by-passed. The pipes will need to be broken or intercepted to allow diffuse flow processes to operate. In some cases wetland embayments at the pipe outflow could be created to provide the necessary nutrient sink. In other cases catchwater drains or lagoon systems may be used. Options relating to different types of drain are being developed, such as fin drains to diffuse a point source. Furthermore, the period from October through December is an important period for nutrient release but one when drainage is not so important for the farmer, so less satisfactory drainage may be possible for these months. In these situations, valves could be fitted to plug drains and encourage diffuse seepage at this time (pers. comm. 1992 workshop).

Many floodplains have old channels cutting across them, often at the base of the hillslope. Such channels act as natural interceptors for surface and subsurface runoff from cultivated hillslopes. Such natural components should be exploited, perhaps by dredging to create wetland areas for diffuse-source pollution control and conservation, being important patches in their own right and by providing a connection between patches.

Plate E1

Plate E2

Plate F1

Plate F2

4.3 Management of Buffer Zones

4.3.1 *The need for targets*

In different situations, opportunities for environmental enhancement will relate to different targets. Six general targets can be defined (Figure 4.2).

i) If *water storage* is the target the habitat composition will necessarily be dictated by this functional role.

ii) For *water-quality management* the structure of the buffer zone will again be determined by the desired functional role.

iii) In some situations it may be desirable to define *target habitats* (e.g. woodland', 'wetland' or 'pond') for restoration. The dominant floristic species may be specified, such as willow or alder woodland, but the main aim is to improve the general habitat diversity and perhaps amenity value.

iv) Alternatively, a *target species* may be defined (e.g. otter or kingfisher) in which case very specific habitats would be designed.

v) In other cases, the target may be to *conserve a historic landscape*. This may include industrial as well as rural heritage.

vi) In the final case, the target may be a particular human activity (*recreation or amenity*). This target may constrain the degree to which especially targets in (ii) above can be met.

4.3.2 *Multi-functional roles*

In most cases, buffer zones can be justified on the basis of more than one of the above targets. Trade-offs will be required between the different objectives to determine the optimum management strategy.

4.3.3 *Best practicable environmental option*

The concept of the best practicable environmental option (BPEO) is an approach introduced by the Royal Commission on Environmental Pollution (1976). The significance of the concept for developing buffer zones is highlighted by considering its elements in reverse word order (Table 4.3). The selection of a BPEO requires a systematic approach to decision making in which the practicability of all reasonable options is examined. However, the assessment of practicability recognises that complete evaluations in monetary terms are seldom possible and that, in any case, the BPEO will not necessarily be the cheapest.

Management requires three levels of involvement. First, options should be considered to sustain the hydrological and geomorphological processes that determine the ecology of the river margin, riparian zone, and floodplain. Secondly, management should seek to maintain the diversity of patches *within* the buffer zone. Thirdly, a maintenance programme must be devised to sustain the structural and functional characteristics of the buffer zone. However, a preliminary step is to determine where the buffer zone should be located.

OPTION	The procedure for selecting a BPEO should include a diligent and imaginative search for alternative ways of achieving the desired result.
ENVIRONMENTAL	The evaluation of options for their environmental effects is undertaken early in the decision-making process. Local and remote, short-and long-term effects must be considered, and the possibility of improving the environment should always be explored. Plans should be developed to monitor environmental effects.
PRACTICABLE	'Reasonably practicable' means having regard among other things, for local conditions and circumstances, the financial implications, and the current state of technical knowledge.
BEST	There is never an absolute best. The option chosen as best, based on the interpretation and evaluation of predicted impacts, is unlikely to be best for all time. Flexibility in management is important, and a BPEO must be kept under review.

Table 4.3 Components of the best practicable environmental option. Based on Royal Commission of Environmental Pollution (1988).

4.3.4 *Effective lengths for buffer zones*

The organization of the drainage network can be quantified in a number of ways; Stream Ordering (see Figure 4.1a) being the most commonly used in ecological studies. This enables the lengths of stream segments of different order to be defined using the 'blue-line' network on Ordnance Survey 1:25000 maps. However, first-order 'ditches' (e.g. Plate A1-A2) may not be indicated on the maps as part of the 'blue-line' network so that the length of the important first-order finger-tip tributaries may be significantly underestimated.

Data for the 57 km^2 Kingston Brook in Leicestershire illustrate the problem for buffer zone implementation. The catchment is a flat, agricultural catchment underlain by glacial sands and gravels on Keuper Marl. Examination of the 1:25000 Ordnance Survey maps indicates that the 4th-order channel is 15 km long and there is 9.5 km of 3rd-order stream. The combined length of first- and second-order channel is 54 km. Thus, notwithstanding problems of subsurface pipe flow, the area of buffer zone required <u>for effective water-quality control</u> would be extensive. For the Kingston Brook, the area required would be at least **324 ha**, assuming a buffer zone width of 30 m on each side of the channel. However, <u>a conservation role with some water-quality benefits</u> could be realised with a 5 m-wide buffer zone along each side of the channel, requiring only **54 ha**.

A <u>minimum</u> enhancement of the 4th-order section for <u>conservation</u>, including a narrow (5 m wide) riparian strip, and grassland with 'islands' of wetland (each of 0.2 ha) and woodland (each of 1 ha) would require only about **30 ha** (<u>excluding</u> the grassland which would be used for grazing). The total involved could be as little as **90 ha** (i.e. 6 ha per kilometre of channel).

4.3.5 *Problems for flood control*

In selecting the BPEO for the management of river margins, the major perceived disadvantage is for flood control. In several instances, the increasing hydraulic roughness of the channel margin and adjacent floodlands has been raised as an argument for *not* enhancing the ecological quality of river corridors. However, the feasibility of using land adjacent to a river for flood storage and the use of the patch concept for environmental enhancement could minimize these problems. For example, in proposing to create floodplain woodland, the ecological benefits of a series of small patches, connected by ditches or grassland, designed to minimize hydraulic problems, would be considerable. On the other hand, any ecological advantages provided by a continuous belt of riparian forest would be outweighed by enhanced flood problems (not to mention recreational conflicts). Seasonal connectivity can also be achieved by flooding, as inundation is important for linking a number of floodplain patch types, for example, some of the hydroseral stages of floodplain backwaters. Regular flooding also assists in the dispersal of both animals and plants, and can be important for floodplain fisheries (cf. Section 3.5.1).

4.3.6 *Design, management and maintenance*

The size, arrangement and connectivity of patches depends on the geographical setting and should give due regard both to the nature of the natural riparian zone and to the existing features of the proposed buffer zone. The relationship between patches is especially important as a particular target species, for example, could be sustainable in a relatively small area if it is found in association with, or connected to, certain other patches. Patches may be linked in some way, such as by hedgerows, by drainage ditches, or by grassland or even certain crops. Bean crops, for example, provide good cover and easy access through the lines of the crop especially for woodland mammals. Indeed, such crops have been shown to be better than hedgerows in providing connectivity between patches. A lot may be achieved with even common grass species and mixed herbage that could be mown. In this situation stock management in the riparian zone becomes a key theme.

In any plan, commitment to habitat maintenance is obviously important. Without maintenance the conservation value may actually become quite depressed through internal competition reducing floristic diversity. In cases management will be necessary to maintain target habitats on the floodplain at specific stages in the terrestrialization progression in order to maximise diversity of habitat (and hence conservation value). Planning is required to ensure that any such maintenance is minimal, but this planning needs to be set in a long-term context. In reality, the maintenance of buffer zones may simply involve the redistribution of costs from current maintenance programmes.

Attention needs to be paid to the potential problem of invasion by undesirable species. Himalayan Balsam, Japanese knotweed and Giant hogweed are examples of species which have proved to be a problem along the waterways of England and Wales. Leaving areas fallow along the margins of waterways will provide potential sites for invasion, and thus a program of continued management to prevent colonization will have to be implemented in areas where spread of such species is a potential threat.

With regard to water quality objectives, there is evidence to suggest that some floodplain wetlands used as a sink for phosphorous in time become ineffective, releasing phosphorous back into circulation in the system. Example of other problems are that (i) some vegetated zones may not be efficient enough through nitrate uptake to reduce significantly the nitrate load during the growing season, (ii) soil waterlogging may not be long enough to provide the anaerobic conditions for denitrification for long enough time to reduce loads, and (iii) organic carbon provided by flood events and through litterfall may not be sufficient to sustain microbial respiration necessary for denitrification.

Although the benefits of buffers for conservation can clearly be stated, constraints affecting implementation will operate (Table 4.4). Catchment management is clearly important and major opportunities for implementation - especially in first to third-order streams, not classed as main river and not often maintained by the NRA - will in all probability depend in the first instance on the cooperation of major land owners, such as the National Trust, the Ministry of Defence, and the Crown Estates. The cooperation of other major representative groups such as the County Landowners Association and the National Farmers Union will also be of importance. Local authorities are involved in the management of such water-courses in the production zone, but it has been suggested that the role of the LA's is not well understood. With regard to urban areas, culverting has eliminated much of the potential available habitat, and here buffers will have little or no impact whatsoever.

4.4.1 *Schemes for promotion of nature conservation*

Although the potential undoubtedly exists for conservation to be added as a rider to EEC water quality objectives and legislation for specific nutrients and farm wastes (Table 4.2), many policies already exist within the EEC and at UK Governmental level that would allow landowners to set land aside for enhancement of specifically the conservation value of the riparian zone and the river corridor in general.

It has been shown that putting arable land over to grass as part of the set-aside programme is of value for nature conservation. Along larger rivers, such a policy might require arable land to be converted to grassland on all floodplain and former floodplain areas up to 100 m from the channel bank. The 'Environmentally Sensitive Area' scheme and the Countryside Commission's 'Countryside Stewardship' and 'Countryside Premium' schemes are also examples of possible mechanisms existing at this time which may facilitate implementation of buffers as management tools. Similar recommendations were made by the Salmon Advisory Committee (1991).

The Countryside Premium Scheme allows additional payments to be made to farmers who allow land to lie fallow for nature conservation and public access. The Countryside Stewardship Scheme run - albeit on a small scale - by the Countryside Commission is specifically targeted at protecting and enhancing the nature conservation interest of semi-natural habitats, including river valleys. Environmentally Sensitive Areas are designed to promote land usage sympathetic to the identified major conservation interest of the area in question. Forestry Commission guidelines (Forestry Commission 1988) provide an example of mechanisns by which conservation can be implemented along upland stream margins.

In general these schemes have potential for encouraging nature conservation along rivers, but are handicapped by the short time-scales allocated for the period that they are valid. Inclusion of suitable riverbank sites in Sites of Special Scientific Interest (SSSI's)would enable English Nature and the Nature Conservancy Council for Wales to prevent changes in land-use likely to cause damage to the nature conservation interest of the site in question in the longer term. This designation is likely to be of most use following re-establishment of the nature conservation interest of the riparian zone by other means. The boundary of the SSSI should extend to include all springs, seepages and water courses (e.g. first-order drains) which supply water to the river reach or sector in question (W. Fojt, personal communication).

Type	Function	Details	Size	Maintenance
Simple	Wildlife	Grazing retirement, strip of land adjacent to aquatic-terrestrial boundary. Land simply fenced off. Width variable and enhancement of habitat value for wildlife dependent on the range of growth forms left or introduced.	1-2 m for small streams to 10-20 m for lowland rivers.	Minimal, some weeding to maintain seral stage. Areas of remnant vegetation.
Simple	Wildlife	Buffers in upland situations bounding coniferous plantations and upland streams	5-20 m	Minimal. Native scrub used, or broadleaves introduced.
Simple	Wildlife, bank stability	Tree planting to provide bankside habitat and bank stability, as well as shade and organic matter for aquatic system	1-2 m for small rivers to 10-20 m for larger areas	Little
Basic	Wildlife, bank stability	Grazing retirement coupled with tree planting to provide a wider variety of habitat. Native species used. Strategic mix of rooting types.	10 m to 5 x stream width	Longer term for tree spp. Shorter term grazing and access restriction.
Intermediate	Wildlife, water quality	Areas away from river bank included in buffer. Patch diversity begins to increase.	10-50 m	Becomes less as natural development encouraged
Complex	Wildlife, water quality, recreation	Large areas of floodplain put over to riparian woodland and ponds. Re-introduction of wetlands on the floodplain. Autogenic input increases	20 m - 200 m and larger patches	Maintenance of pioneer stages including marginal gravels bars, floodplain surfaces and a variety of aquatic habitats. Access permitted after establishment of buffer.
Ideal	Wildlife, water quality, recreation	Large areas of floodplain put over to riparian woodland. Re-introduction of wetlands and ponds on the floodplain. Removal of barrier to channel migration. Re-introduction of meanders. Variety of soil types/substrates included. Restoration of natural hydrological regime providing self-sustaining potential for recreation and flood storage. Self-cycling, mainly autogenic system, with regular input of allogenic material.	50 m-300 m and patches of differing size.	Maintenance of pioneer stages including marginal gravels bars, floodplain surfaces and a variety of aquatic habitats. Access permitted after establishment of buffer. Self-regulation and rejuvenation of succession encouraged.

Table 4.2 Summary of range of options for implementation of buffers in England and Wales.

Type	Purpose	Size & shape	Benefits	Constraints
Simple	Wildlife	Either linear strips or patches. Width will vary from 1-2 m to 20-50 m	Vegetation, smaller fauna	Low. Main problem is in restriction of access (anglers and recreation) by a continuous strip and fencing
Simple	Wildlife, bank stability	Either linear strips or patches. Width will vary from 1-2 m to 20-50 m	Vegetation, smaller to intermediate sized fauna	Low. Main problem is in restriction of access (anglers and recreation) by a continuous strip and fencing
Simple	Wildlife, water quality	Linear strips in upland situations	Vegetation, birds, mammal & fish	Low. More scope for linear belts along streams
Basic	Wildlife, water quality	Linear strips or patches. Scope for linear belts along streams with buffer extended to patches where access required	Vegetation, birds, mammal & fish	Low-medium. Recreation and general access
Complex	Wildlife, water quality, recreation	Linear strips enhanced by introduction of larger patches to maintain territorial requirements of fauna	Vegetation, birds, mammals and floodplain fish. Recreation included	Intermediate. Loss of land, restriction of recreation in places
Ideal	Wildlife , water quality, recreation	Large areas of floodplain put over to riparian forest. Re-introduction of wetlands on the floodplain. Would remove large areas of floodplain, and therefore should be targeted to specific areas where (i) pollution is a problem (ii) areas where it is felt that only by restoring the full structural and functional characteristics of the floodplain can wildlife be enhanced (iii) both surface and sub-surface run-off of pollutants a problem.	Wide range of vegetation, fauna and fisheries. Recreation would develop in parallel with buffer	High. Only possibility is zoning this type in patches. Little chance of linear belts of this type. Loss of land a major consideration

Table 4.4 Some anticipated benefits of buffer zone and possible constraints to their implementation in England and Wales.

Section 5

RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Given the roles of buffer zones established in this report, it is recommended that a policy for protecting, creating and restoring buffer zones along rivers in England and Wales is formulated for early implementation.

5.1.1 Buffer zones should be introduced to protect the conservation value of river reaches having special scientific interest or conservation value.

5.1.2 Buffer zones should be enhanced whenever possible to create and diversify river corridors, particularly by developing the 'habitat island' concept.

5.1.3 Buffer zones should be created where land adjacent to the channel is cultivated to the river edge.

5.1.4 Ecological surveys ('river corridor', invertebrates and fish) of many rivers in England and Wales already exist. It is recommended that site selection for buffer implementation is based on this existing database.

5.2 All buffer zones irrespective of width, heterogeneity, and connectivity have a multi-functional role: especially for nature conservation, water-quality control and recreation. However, there are a number of gaps in our knowledge.

5.2.1 The case for introduction of buffers solely for water-quality control is unclear. The study has highlighted several gaps in the literature. These relate mainly to the ability of different soils and vegetation types to absorb nutrients effectively; the long-term viability of buffers as nutrient sinks in relation to natural ecosystem development; the shorter-term effects of seasonality and the resistance of buffers to perturbations such as flooding. Detailed studies would be necessary to fill these gaps.

5.2.2 The overall consensus of riparian planners and managers who responded to the study was that we need implementation in the near-term future to provide further information as to their function for conservation. More study of the conservation value of different patches is needed to develop on work carried out to date (e.g. Petts *et al.* 1992). More detailed information is needed on the habitat requirements of individual species - this can be obtained from existing patches of nature conservation value, in upland and lowland situations and in low-and high-order streams and rivers.

5.3 Field investigations are required to appraise the success of buffer zones. Ideally before and after comparisons are required, and sites should have an historic database.

5.3.1 It is recommended that field investigations should monitor the development of newly-created strips or patches in relation to the design targets. Here, the influence of natural ecosystem development on habitat availability can be examined. A range of sites should be selected for research. It is recommended that site selection takes account of stream order, altitude and well as the habitat scale (Figure 5.1).

5.3.2 It is recommended that investigation takes place on the sector and habitat scale (cf. Section 4.1.1). On this scale, a variety of different sized and shaped strips and patches with varying structural characteristics and degrees of connectivity can be examined. This scale includes floodplains which become especially significant in the downstream storage zone, as having particular ecological significance (cf. Figures 4.1a & 4.1c) although they have been most severely affected by regulation, drainage, and agricultural intensification in the past.

5.3.3 In addition to attention on the riparian strip, recreation of floodplain patch habitat will be necessary in many lowland situations. It is recommended that this should use as its basis relict hydrogeomorphological features such as abandoned channels, riparian woodlands and wet areas. These areas often function as species refugia and provide a logical starting point for restoration and conservation measures.

5.4 It is recommended that the assistance of major landowners (e.g. National Trust, Ministry of Defence, Crown Estates and local authorities) is sought at an early stage with regard to making land available for experimental sites. Close cooperation with landowners will be a necessary feature of this type of management strategy (see 5.6).

5.5 Further detailed socio-economic investigations may be needed to elucidate implications for the NRA of buffer zone creation, especially given the scale required for effective pollution control from farmland..

5.6 It is recommended that site-specific efforts should be made to involve all interested parties in consultation from the beginning regarding implications of management implementation using buffers.

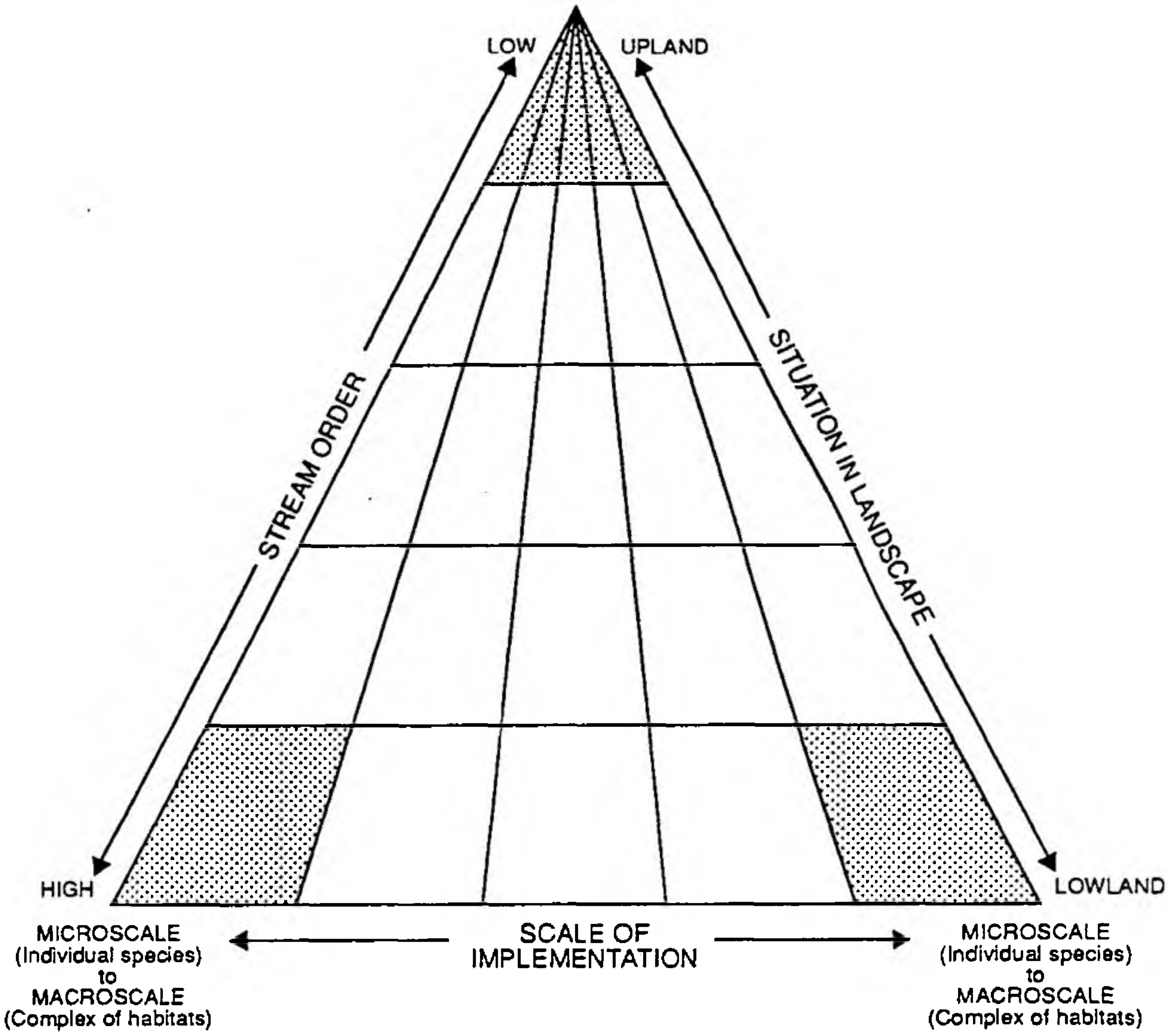

Figure 5.1 Diagram showing recommended target areas for futher investigation of buffer zones for conservation. Situations indicated by shading should be given priority for investigation, with intermediate situations designated for follow-up studies.

APPENDIX A

REFERENCES USED

Ahola, H. 1989. Vegetated buffer zone project of the Vantaa River river basin. *Geografisk Tidsskrift* 89, 22-25.

Ahola, H. 1990. Vegetated buffer zone examinations of the Vantaa river basin. *Aqua Fennica* 20, 65-69.

Ambus P. and Lowrance R. 1991. Comparison of denitrification in two riparian soils. *Soil Science Society of America Journal* 55, 994-997.

Amoros. C. Rostan, J.-C., Pautou, G. & Bravard, J-.P. 1987a. The Reversible Process Concept applied to the environmental management of large river systems. *Environmental Management* 11, 607-617.

Amoros, C., Roux, A.L., Reygrobellet, J.L., Bravard, J-.P. & Pautou, G. 1987b. A method for applied ecological studies of fluvial hydrosystems. *Regulated Rivers: Research and Management* 1, 17-36.

Anderson, B.W. & Ohmart, R.D. 1977. Vegetation structure and bird use in the Lower Colorado River Valley. 23-34. *Importance, preservation and management of riparian habitat: a symposium.* (ed. by R.R. Johnson & D.A. Jones Jr). USDA Forest Service General Technical Report RM-43.

Anderson, B.W., Ohmart, R.D. & Disano, J. 1978. Revegetating the riparian floodplain for wildlife. 318-331. *Strategies for protection and management of floodplain wetlands and other riparian ecosystems.* USDA Forest Service, General Technical Report WO-12.

Armour, C.L., Duff, D.A. & Elmore, W. 1991. The effects of livestock grazing on riparian and stream ecosystems. *Fisheries* 16, 7-11.

Arnold, U., Höttges, J. & Rouvé, G. 1989. Removing the strait-jackets from rivers and streams. *German Research* 1, 22-24.

Asmussen, L.E., White, A.W., Hauser, E.W. & Sheridan, J.M. 1977. Reduction of 2-4-D load in surface runoff down a grassed waterway. *Journal of Environmental Quality* 6, 159-162.

Bayes, C.D., Bache, D.H. & Dickson, R.A. 1989. Land-treatment systems: design and performance with special reference to reed-beds. *Journal of the Institution of Water and Environmental Management* 3, 588-597.

Bravard, J-P., Amoros, C. & Pautou, G. 1986. Impact of civil engineering works on the successions of communities in a fluvial system. *Oikos* 47, 92-111.

Backiel, T. & Penczak, T. 1989 The fish and fisheries in the Vistula River and its tributary, the Pilica River. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106, 488-503.

Bayley, P.B. (in press). The flood-pulse advantage and the restoration of river-floodplain systems. *Regulated Rivers: Research and Management.*

Black, S., Broadhurst, P., Hightower, J. & Schauman, S. 1985. The value of riparian habitat and wildlife to the residents of a rapidly urbanizing community. 413-416. *Riparian ecosystems and their management: reconciling conflicting uses.* (ed. by Johnson, R.R. et al.). USDA Forest Service. General Technical Report RM-120.

Boon, P.J. 1988. The impact on river regulation on invertebrate communities in the U>K. *Regulated Rivers: Research and Management* 2, 389-409.

Boyt, F.L., Bayley, S.E & Zoltek, J, 1977. Removal of nutrients from treated municipal wastewater by wetland vegetation. *Journal of the Water Pollution Control Federation* **49**, 789-799.

Brown, M.T., Schaefer, J. & Brandt, K. 1990. *Buffer zones for water, wetlands and wildlife in east central Florida.* Center for Wetlands Publication **89-07** University of Florida.

Brinson, M.M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. *Ecology* **58**, 601-609.

Brinson, M.M., Swift, B.L., Plantico, R.C. & Barclay, J.S. 1981. *Riparian ecosystems: Their ecology and status.* US Fish & Wildlife Service FWS/OBS 82/17.

Brinson, M.M., Bradshaw, H.D. & Kane, E.S. 1984. Nutrient assimilative capacity of an alluvial floodplain swamp. *Journal of Applied Ecology* **21**, 1041-1057.

Brussock, P.P., Brown, A.V. & Dixon, J.C. 1985. Channel form and stream ecosystem models. *Water Resources Bulletin* **21**, 859-866.

Budd, W.W., Cohen, P.L., Saunders, P.R. & Steiner, F.R. 1987. Stream corridor management in the Pacific Northwest, I. Determination of stream corridor widths. *Environmental Management* **11**, 587-597.

Burgess, S.A. & Bider, J.R. 1980. Effects of stream habitat improvements on invertebrates, trout populations and mink activity. *Journal of Wildlife Management* **44**, 871-880.

Burka, U. & Lawrence, P.C. 1990. A new community approach to waste treatment with higher water plants. 359-371. Constructed Wetlands in Water Pollution Control (ed. by P.F. Cooper & C. Findlater. Pergamon Press.

Burton, T.M. & Likens, G.E. 1973. The effect of strip-cutting on stream temperatures in the Hubbard Brook experimental forest, New Hampshire. *BioScience* **23**, 433-435.

Butler, J.E., Loveridge, R.F., Ford, M.G., Bone, D.A. & Ashworth, R.F. 1990. Gravel bed hydrophonic systems used for secondary and tertiary treatment of sewage effluent. *Journal of the Institution of Water and Environmental Management* **4**, 276-283.

Carothers, S.W., Johnson, R.R. & Aitchison, S.W. 1974. Population structure and social organisation of southwestern riparian birds. *American Zoologist* **14**, 97-108.

Clary, W.P. & Webster, B.F. 1989. Managing grazing of riparian areas in the intermountain region. USDA Forest Service General Technical Report INT-263.

Cohen, P.L., Saunders, P.R., Budd, W.W. & Steiner, F.R. 1987. Stream corridor management in the Pacific Northwest, II. Management Strategies. *Environmental Management* **11**, 599-605.

Conchou, O. & Pautou, G. 1987. Modes of colonization of an heterogeneous alluvial area on the edge of the Garonne River by *Phalaris arundinacea* L. *Regulated Rivers: Research and Management* **1**, 37-48.

Conley, L.M., Dick, R.I. & Lion, L.W. 1991. An assessment of the root zone method of wastewater treatment. *Journal of the Water Pollution Control Federation* **63**, 239-247.

Cook, E.A. 1991. Ecosystem modeling as a method for designing synthetic fluvial landscapes: a case study of the Salt River in Arizona. *Landscape and Urban Planning* **20**, 291-308.

Cooke, J.G. & Cooper, A.B. 1988. Sources and sinks of nutrients in a New Zealand hill pasture catchment. III. Nitrogen. *Hydrological Processes* **2**, 135-149.

Cooper, A.B. 1990. Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. *Hydrobiologia* **202**, 13-26.

Cooper, J.R., Gilliam, J.W., Daniels, R.B. & Robarge, W.P. 1987. Riparian areas as filters for agricultural sediment. *Soil Science Society of America Journal* **51**, 416-420.

Copp, G.H. 1989. The habitat diversity and fish reproductive function of floodplain ecosystems. *Environmental Biology of Fishes* 26, 1-27.

Copp, G.H. 1990. Effect of regulation on 0+ fish recruitment in the Great Ouse, a lowland river. *Regulated Rivers: Research and Management* 5, 251-163.

Copp, G.H. & Penaz, M. 1988. Ecology of fish spawning and nursery zones on the flood plain, using a new sampling approach. *Hydrobiologia* **169**, 209-224.

Corbett, E.S., Lynch, J.A & Sopper, W.E. 1978. Timber harvesting practices and water quality in the eastern United States. *Journal of Forestry* **86**, 484-485.

Correll, D.L. & Weller, D.E. 1989. Factors limiting processes in freshwater wetlands: an agricultural primary stream riparian forest. 9-23. *Freshwater Wetlands and Wildlife*. USDOE Symposium Series 61 (ed. by R.R.Sharitz & J.W. Gibbons).

Correll, D.L. (in press). Human impact on the functioning of landscape boundaries. In *The Role of Landscape Boundaries in the Management and Restoration of Changing Environments*. (ed. by P. Risser, R. Naiman & M.M. Holland). Chapman & Hall, New York.

Cross, S.P. 1985. Responses of small mammals to forest riparian perturbations. 269 *Riparian ecosystems and their management: Reconciling conflicting land uses.* (ed. by C.D. Johnson et al.). USDA Forest Service General Technical Report RM-120.

Cummins, K.W. 1974. Structure and function of stream ecosystems. *BioScience* **24**, 631-641.

Cummins, K.W. 1979. The natural stream ecosystem. 7-24. The Ecology of Regulated Streams. (ed. by J.V. Ward and J.A. Stanford). Wiley, New York.

Cummins, K.W., Minshall, G.W., Sedell, J.R., Cushing, C.E. & Petersen, R.C. 1984. Stream ecosystem theory. *Internationale Verinigung für theoretische und angewandte Limnologie, Verhandlungen* **22**, 1818-1827.

Curry, P. & Slater, F.M. 1986. A classification of river corridor vegetation from four catchments in Wales. *Journal of Biogeography* **13**, 119-132.

Dawson, F.H. 1978. Aquatic plant management in semi-natural streams: the role of marginal vegetation. *Journal of Environmental Management* **6**, 213-221.

Debusk, W.F., Reddy, K.R. 1987. Removal of floodwater nitrogen in a cypress swamp receiving primary wastewater effluent. *Hydrobiologia* **153**, 79-86.

DeJong, J. 1976. The purification of wastewater with the aid of rush or reed ponds. 133-139. *Biological Control of Water Pollution.* (ed. by J. Tovrbier & R. Pierson). University of Pennsylvania Press.

Décamps, H. 1984. Towards a landscape ecology of river valleys. 163-178. *Trends in Ecological Research for the 1980's.* (ed. by J.H. Cooley & F.B. Golley). Plenum Press, New York.

Décamps, H., Joachim, J. & Lauga, J. 1987. The importance for birds of the riparian woodlands within the alluvial corridor of the River Garonne, SW France. *Regulated Rivers: Research and Management* **1**, 301-316.

Décamps, H. Fournier, F., Naiman, R.J. & Petersen, R.C. 1990. An international research effort in land/inland water ecotones in landscape management and restoration 1990-1996. *Ambio* **19**, 175-176.

Diamond,J.M. 1975. The island dilemma: lessons of modern biogeographic studies for design of natural reserves. *Biological Conservation* **7**, 129-146.

Dickson, J.G. & Huntley, J.C. 1985. Streamside management zones and wildlife in the South Coastal Plain. 263 *Riparian ecosystems and their management; Reconciling conflicting uses.* USDA Forest Service General Technical Report RM-120.

Dillaha, T.A., Sherrard, J.H. & Lee, D. 1986. *Long-term effectiveness and maintenance of vegetative filter strips.* Virginia Water Resources Research Centre Bulletin No. 153. Blaksburg, Virginia.

Dister, E., Gomer, D., Obrdlik, P., Petermann, P. & Schneider, E. 1990. Water management and ecological perspectives of the Upper Rhine's floodplains. *Regulated Rivers: Research and Management* **5**, 1-15.

Douglas Shields, F. Jr., & Nunnally, N.R. 1984. Environmental aspects of clearing and snagging. *Journal of Environmental Engineering* **110**, 152-165.

Erman, D.C., Newbold, J.C. & Roby, K.B. 1977. *Evaluation of streamside buffer strips for protecting aquatic organisms.* California Water Resources Center, University of California, Davis CA.

Eyre M.D. & Foster, G.N. 1989. A comparison of aquatic Heteroptera and Coleoptera communities as a basis for environmental and conservation assessments in static water sites. *Journal of Applied Entomology* **108**, 217-225.

Eyre, M.D.,Ball, S.G. & Foster, G.N. 1986. An initial classification of the habitats of aquatic Coleoptera in north-east England. *Journal of Applied Ecology* **23**, 841-852.

Eyre, M.D., Foster, G.N. & Foster, A.P. 1990. Factors affecting the distribution of water beetle species assemblages in drains of eastern England. *Journal of Applied Entomology* **109**, 217-225.

Forestry Commission. 1988. *Forest and Water Guidelines.* Forestry Commission, Edinburgh.

Geier, A.R. & Best, L.B. 1980. Habitat selection by small mammals of riparian communities: evaluating effects of habitat alterations. *Journal of Wildlife Management* **44**, 1, 16.

Gersberg, R.M., Elkins, B.V. & Goldman, C.R. 1983. Nitrogen removal in artificial wetlands. *Water Research* **17**, 1009-1014.

Gersberg, R.M., Elkins, B.V. & Goldman, C.R. 1984a. Wastewater treatment by artificial wetlands. *Environmental Science and Technology* **17**, 443-450.

Gersberg, R.M., Elkins, B.V. & Goldman, C.R. 1984b. Use of artificial wetlands to remove nitrogen from wastewater. *Journal of the Water Pollution Control Federation* **56**, 152-156.

Graf, W.L. 1980. Riparian management: a flood control perspective. *Journal of Soil and Water Conservation* **35**, 158-161.

Greenwood, M.T., Bickerton, M.E., Castella, E., Large A.R.G. & Petts, G.E. (in press). The use of Coleoptera (Arthropoda: Insecta) for patch characterisation on the floodplain of the River Trent, UK. *Regulated Rivers: Research and Management* **6.4.**

Greer, D.M. 1982. Urban waterfowl population: ecological evaluation on management and planning. *Environmental Management* **6**, 217-229.

Gregory, K.J. 1982. Vegetation and River Channel Process Interactions. *River Conservation and Management* (ed. by P. Boon, P. Calow & G.E.Petts). John Wiley & Sons, Chichester.

Harris, L.D. 1984. *The Fragmented Forest.* University of Chicago Press, Chicago, Illinois.

Haveren, B.P. Van & Jackson, W.L. Concepts in stream riparian rehabilitation. *Transactions of the 51st North American Wildlife and Natural Resources Conference.*

Haycock, N.E. 1991. *Riparian land as buffer zones in agricultural catchments.* Unpublished D.Phil. Thesis, University of Oxford.

Haycock, N.E. & Burt, T.P. 1990. Handling excess nitrates. *Nature* **348**, 29.

Haycock, N.E. & Burt, T.P. 1991. The sensitivity of rivers to nitrate leaching; the effectiveness of near-stream land as a nutrient retention zone. In *Landscape Sensitivity.* (ed. by R.J. Allison & D.S.G. Thomas). John Wiley & Sons.

Hehnke, M. & Stone, C.P. 1978. Value of riparian vegetation to avian populations along the Sacromento River system. 228-235. *Strategies for protection and management of floodplain wetlands and other riparian ecosystems.* USDA Forest Service, General Technical Report WO-12.

Hemphill, R.W. & M.E.Bramley 1989. *Protection of river and canal banks.* CIRIA and Butterworths, London.

Hill, A.R. 1990. Groundwater cation concentrations in the riparian zone of a forested headwater stream. *Hydrological Processes* **4**, 121-130

Holland , M.M. 1988. SCOPE / MAB technical consultation on landscape boundaries. Report of a SCOPE/MAB Workshop on Ecotones. *Biology International* **17**, 47-107

Horton, J.S., & Campbell, C.J. 1974. *Management of phreatophyte and riparian vegetation for maximum multiple-use values.* USDA Forest Service Research Paper RM-117. Fort Collins, Colorado.

Howard-Williams, C. 1985. Cycling and retention of nitrogen and phosphorous in wetlands. A theoretical and applied perspective. *Freshwater Biology* **15**, 391-431.

Howard-Williams, C. 1991. Dynamic processes in New Zealand land-water ecotones. *New Zealand Journal of Ecology* **15**, 87-98.

Howard-Williams, C., Pickmere, S. & Davies, J. 1986. Nutrient retention and processing in New Zealand streams: the influence of riparian vegetation. *New Zealand Agricultural Science* **20**, 110-114.

Hubbard, J.P. 1977. Importance of riparian ecosystems: biotic considerations. 14-18. *Importance, preservation and management of riparian habitat: a symposium.* (ed. by R.R. Johnson & D.A. Jones Jr). USDA Forest Service General Technical Report RM-43.

Hynes, H.B.N. 1983. Groundwater and stream ecology. *Hydrobiologia* **100**, 93-99.

Hynes, H.B.N. 1975. The stream and its valley. *Internationale Verinigung für theoretische und angewandte Limnologie, Verhandlungen* **19**, 1-15.

Jacobs, T.C. & Gilliam, J.W. 1985. Riparian losses of nitrate from agricultural drainage waters. *Journal of Environmental Quality* **14**, 472-478.

Jansson, M., Andersson, R., Berggen, H., Emanuelsson, U., Espeby, L., Herrmann, L. 1990. *Wetlands and lakes as nitrogen traps.* Swedish Environmental Protection Agency Report 4xxx.

Johnson, R.R., Haight, L.T. & Simpson, J.M. 1977. Endangered species vs. endangered habitats: a concept. 68-79. *Importance, preservation and management of riparian habitat: a symposium.* (ed. by R.R. Johnson & D.A. Jones Jr). USDA Forest Service General Technical Report RM-43.

Johnson, R.R. & McCormick (eds.) 1978. *Strategies for protection and management of floodplain wetlands and other riparian ecosystems.* USDA Forest Service, General Technical Report WO-12.

Johnston, C.A. & Naiman, R.J. 1987. Boundary dynamics at the aquatic-terrestrial interface: the influence of beaver and geomorphology. *Landscape Ecology* **1**, 45-57.

Junk, W.J., Bayley, P.B. & Sparks, R.E. 1989. The flood-pulse concept in river-floodplain systems. *Canadian Journal of Fisheries and Aquatic Sciences* **106**, 110-127.

Karr, J.R. & Schlosser, I.J. 1977. *Impacts of nearstream vegetation and stream morphology on water quality and stream biota.* EPA-600/3-77-097. Environmental Research laboratory, Environmental Protection Agency, Athens, Georgia.

Karr, J.R. & Schlosser, I.J. 1978. Water resources and the land-water interface. *Science* **201**, 229-234.

Keskitalo, J. 1990. Occurrence of vegetated buffer zones along brooks in the catchment area of Lake Tuuslanjärvi, South Finland. *Aqua Fennica* 20, 55-64.

Kibby, H.V. 1978. Effects of wetlands on water quality. 289-298. *Strategies for protection and management of floodplain wetlands and other riparian ecosystems.* USDA Forest Service, General Technical Report WO-12.

Kovacic, D.A., Osborne, L.L. & Dickson, B.C. (in press). Effectiveness of riparian buffers in reducing pollution in the agricultural midwest. *Ecological Applications.*

Knopf, F.L. 1985. Significance of riparian vegetation to breeding birds across an altitudinal cline. 105-111. *Riparian ecosystems and their management: reconciling conflicting uses.* (ed. by Johnson, R.R. et al.). USDA Forest Service. General Technical Report RM-120.

Knopf, F.L., Johnson, R.R., Rich, T., Samson, F.B. & Szaro, R.C. 1988. Conservation of riparian ecosystems in the United States. *The Wilson Bulletin* **100**, 272-284.

Labroue, L. & Pinay, G. 1986. Epuration naturelle des nitrates des eaux souterraines: possibilitiés d'application au réménagement. *Annales Limnologie* **22**, 83-88.

Large, A.R.G., Prach, K., Bickerton, M.A. & Wade, P.M. (in press). The influences of alteration of patch structure and boundary type on management and restoration of the floodplain of the River Trent, England. *Freshwater Biology*

Lee, G.F., Bentley, E. & Amundson, R. 1975. Effects of marshes on water quality. 105-127. *Coupling of Land and Water Systems.* (ed. by A.D. Hasler) Springer-Verlag, New York.

Lowrance, R.R., Todd, R.L. & Asmussen, L.E. 1984a. Nutrient cycling in an agricultural watershed: II. Streamflow and artificial drainage. *Journal of Environmental Quality* **13**, 27-32.

Lowrance, R.R., Todd, R.L., Fair, J., Hendrickson, O., Leonard, R. & Asmussen, L.E. 1984b. Riparian forest as a nutrient filter in agricultural watersheds. *BioScience* **34**, 374-377.

Lowrance, R.R. , Leonard, R. & Sheridan, J. 1985a. Managing riparian ecosystems to control non-point pollution. *Journal of Soil and Water Conservation* **40**, 87-91.

Lowrance, R.R., Leonard, R.A., Asmussen, L.E. & Todd, R.L. 1985b. Nutrient budgets for agricultural watersheds in the southeastern coastal plain. *Ecology* **66**, 287-296.

Lowrance, R.R., Sharpe, J.K. & Sheridan, J.M. 1986. Long-term sediment deposition in the riparian zone of a coastal plain watershed. *Journal of Soil and Water Conservation* **41**, 266-271.

MacDonald, S.M. & Mason, C.F. 1983. Some factors affecting the distribution of otters (*Lutra lutra*). *Mammal Review* **13**, 1-10.

Mann, R.A. 1990. Phosphorous removal by constructed wetlands: substratum adsorption. 97-105. *Constructed Wetlands in Water Pollution Control.* (ed. by P.F. Cooper & C. Findlater. Pergamon Press.

Mann, R.H.K. 1988. Fish and fisheries of regulated rivers in the U.K. *Regulated Rivers: Research and Management* **2**, 411-424.

Margules, C. & Usher, M.B. 1981. Criteria used in assessing wildlife conservation potential: a review. *Biological Conservation* **21**, 79-109.

Mason, C.F. & MacDonald, S.M. 1990. The riparian woody plant community of regulated rivers in eastern England. *Regulated Rivers: Research and Management* **5**, 159-166.

Mason, C.F., MacDonald, S.M. & Hussey, A. 1984. Structure, management and conservation value of the riparian woody plant community. *Biological Conservation* **29**, 201-216.

McIntyre, B.D. & Riha, S.J. 1991. Hydraulic conductivity and nitrogen removal in an artificial wetland system. *Journal of Environmental Quality* **20**, 259-263.

Meehan, W.R., Swanson, F.J. & Sedell, J.R. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. 137-145. *Importance, preservation and management of riparian habitat: a symposium.* (ed. by R.R. Johnson & D.A. Jones Jr). USDA Forest Service General Technical Report RM-43.

Minshall, G.W., Cummins, K.W., Petersen, R.C., Cushing, C.E., Bruns, D.A., Sedell, J.R. & Vannote, R.L. 1985. Development in stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Science* **42**, 1045-1055.

Morgan, M.G. 1978. Bad science and good policy analysis. *Science* **201**, 971.

Moring, J., Garman, G. & Mullen, D. 1985. The value of riparian zones for protecting aquatic systems: general concerns and recent studies in Maine. 315-319. *Riparian ecosystems and their management: reconciling conflicting uses.* (ed. by Johnson, R.R. et al.). USDA Forest Service. General Technical Report RM-120.

Mudroch, A. & Capobianco, J.A. 1979. Effects of treated effluent on a natural marsh. *Journal of the Water Pollution Control Federation* **51**, 2243-2255.

Naiman, R.J. & Décamps, H. (eds.) 1990. *The Ecology and Management of Aquatic-Terrestrial Ecotones.* UNESCO (Paris) & Parthenon Press Publishers.

Naiman, R.J., Décamps, H., Pastor, J. & Johnston, C.A. 1988. The potential importance of boundaries to fluvial systems. *Journal of the North American Benthological Society* **7**, 289-306.

Naiman, R.J., Décamps, H. & Fournier, F. 1989. The role of land/inland water ecotones in landscape management and restoration: a proposal for collaborative research. MAB Digest 4. UNESCO, Paris.

Naiman, R.J., Lonzarich, D.G., Beechie, T.J. & Ralph, S.C. 1991. Stream classification and the assessment of conservation potential. In *Proceedings of conference on the conservation and management of rivers.* (ed. by P. Boon, P. Calow & G.E. Petts). Nature Conservancy Council.

Nature Conservancy Council. 1991. *Nature conservation and pollution from farm wastes.* Nature Conservancy Council, Peterborough.

Newbold, C. & Rush, A. 1989. Set aside and extensification of agricultural production: implications and opportunities for nature conservation and the river engineer. *Proceedings of Institute of Water and Environmental Management annual symposium.* York 1989. IWEM, London.

Newbold, J.D., Erman, D.C. & Roby, K.B. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Canadian Journal of Fisheries and Aquatic Sciences* 37, 1076-1085.

Nilsson, C. 1984. Kriterier för biologisk värdering av natur från skyddssynpunkt. National Swedish Environment Protection Board, PM 1881.

Nilsson, C. 1986. Change in riparian plant community composition along two rivers in northern Sweden. *Canadian Journal of Botany* **64**, 589-592.

Nilsson, C. & Grelsson, G. 1989. The effects of litter displacement on riverbank vegetation. *Canadian Journal of Botany* **68**, 735-741.

Nilsson, C. Grelsson, G., Johansson, M. & Sperens, U. 1988. Can rarity and diversity be predicted in vegetation along riverbanks? *Biological Conservation* **44**, 201-212.

Nilsson, C., Grelsson, G., Johansson, M. & Sperens, U. 1989. Patterns of plant species richness along riverbanks. *Ecology* **70**, 77-84.

Nilsson, C., Ekblad, A., Gardfell, M. and Carlberg, B. 1991. Long-term effects of river regulation on river margin vegetation. *Journal of Applied Ecology* **28**,

Noel, D.S., Martin, C.W. & Federer, C.A. 1986. Effects of forest clearcutting in New England on stream macroinvertebrates and periphyton. *Environmental Management* **10**, 661-670.

Norse, E.A., Rosenbaum, K.L. Wilcove, D.S.,Wilcox, B.A., Romme, W.H., Johnston, D.W. & Stout, M.L. 1986. *Conserving Biological Diversity in our National Forests*. The Wilderness Society. Washington D.C.

Odum, E. 1978. Ecological importance of the riparian zone. 2-4. *Strategies for protection and management of floodplain wetlands and other riparian ecosystems*. (ed. by R.R. Johnson, & J.F. McCormick). USDA Forest Service General Technical Report WO-12.

Omernik, J.M., Abernathy, A.R. & Male, L.M. 1981. Stream nutrient levels and proximity of agricultural and forest land to streams: some relationships. *Journal of Soil and Water Conservation* **36**, 227-231.

Ormerod, S.J. & Tyler, S.J. 1990. The influence of stream acidification and riparian land use on the feeding ecology of Grey Wagtails *Motacilla cinerea* in Wales. *Ibis* **133**, 53-61

Ormerod, S.J., Donald, A.P. & Brown, S.J. 1989. The influence of plantation forestry on the pH and aluminium concentration of upland Welsh streams: a re-examination. *Environmental Pollution* **62**, 47-62.

Ormerod, S.J., Weatherley, N.S. & Merrett, W.J. 1990. The influence of conifer plantations on the distribution of the Golden Ringed Dragonfly *Cordulegaster boltoni* (Odonta) in upland Wales. *Biological Conservation* **53**, 241-251.

Ormerod, S.J., Rundle, S.D., Lloyd, C.E. & Douglas, A.A. (in press). The influence of riparian management on the habitat structure and macroinvertebrate communities of upland streams draining plantation forests. *Journal of Applied Ecology*

Osborne, L.L. & Wiley, M.J. 1988. Empirical relationship between land use/cover and stream water quality in an agricultural watershed. *Journal of Environmental Management* **26**, 9-27.

Pase, C.P. & Layser, E.F. 1977. Classification of riparian habitat in the southwest. 5-9 *Importance, preservation and management of riparian habitat: a symposium*. (ed. by R.R. Johnson & D.A. Jones Jr). USDA Forest Service General Technical Report RM-43.

Patrick, W.H. & Reddy, K.R. 1976. Nitrification-denitrification reactions in flooded soils and water bottoms: dependence on oxygen supply and ammonium diffusion. *Journal of Environmental Quality* **5**, 469-472.

Pautou, G. & Gensac, P. 1973a. La fôret d'Evieu (Ain). Chênaie à charme sur sol hydromorphe. *Ann. Centre Univ. Savoie* **1**, *Sci. Nat.*, 47-55.
Pautou, G. & Gensac, P. 1973b. Recherches écologiques sur quelques types de praires du marais de Lavoirs (Ain). *Ann. Centre Univ. Savoie* **1**, *Sci. Nat.*, 57-63.

Pautou, G. & Décamps, H. 1989. Ecological interactions between the alluvial forests and hydrology of the Upper Rhone. *Archiv für Hydrobiologie* **104**, 13-37.

Penczak, T. & Zalewski, M. 1974. Distribution of fish numbers and biomass in Barbel region of the river and the adjoining old river beds. *Ekologia Polska* **22**, 107-119.

Peterjohn, W.T. & Correll, D.L. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. *Ecology* **65**, 1466-1475.

Peterjohn, W.T. & Correll, D.L. 1986. The effect of riparian forest on the volume and chemical composition of baseflow in an agricultural watershed. 244-262. *Watershed Research Perspectives.* (ed. by D.L. Correll). Smithsonian Press, Washington DC.

Petersen, R.C., Madsen, B.L., Wilzbach, M.A., Magadza, C.H.D., Paarlberg, A., Kullberg, A. & Cummins, K.W. 1987. Stream management: emerging global similarities. *Ambio* **16**, 166-179.

Petts, G.E. 1984. *Impounded Rivers: Perspectives for ecological management.* John Wiley & Sons, Chichester.

Petts, G.E. 1988. Regulated rivers in the United Kingdom. *Regulated Rivers: Research and Management* **2**, 201-220.

Petts, G.E. 1990. Forested river corridors - a lost resource? *Water Engineering and Landscape* (ed. by D.Cosgrove and G.E.Petts). Belhaven, London.

Petts, G.E. & Darby, E. 1991 *Ecological Assessment of Wild Bores in the Fens near Bourne, Lincolnshire* Report to National Rivers Authority, Anglian Region.

Petts, G.E., H.Moller and A.L. Roux 1989 *Historical Changes of Large Alluvial Rivers: Western Europe* Chichester, Wiley

Petts, G.E., Armitage, P. & Gustard, A. 1989. Proceedings form the fourth international symposium on regulated streams. *Regulated Rivers: Research and Management* **3**, 1-394.

Petts, G.E., Large, A.R.G., Greenwood, M.T. & Bickerton, M.E. 1992. Floodplain assessment for restoration and conservation: linking hydrogeomorphology and ecology. 217-234. *Lowland Floodplain Rivers: Geomorphological Perspectives.* (ed. by P.A. Carling and G.E. Petts). John Wiley & Sons, Chichester.

Phillips, J. 1989a. Nonpoint source pollution risk assessment in a watershed context. *Environmental Management* **13**, 493-502.

Phillips, J 1989b. Fluvial sediment storage in a wetland. *Water Resources Bulletin* **25**, 867-873.

Phillips, J. 1989c. Evaluation of North Carolina's estuarine shoreline area of environmental concern from a water quality perspective. *Coastal Management* **17**, 103-117.

Phillips, J. 1989d. Non-point source pollution control effectiveness of riparian forest along a coastal plain river. *Journal of Hydrology* **110**, 221-237.

Phillips, J. 1989e. An evaluation of the factors determining the effectiveness of water quality buffer zones. *Journal of Hydrology* **110**, 133-145.

Pinay, G. & Décamps, H. 1988. The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: a conceptual model. *Regulated Rivers: Research and Management* **2**, 507-516.

Pinay, G., Décamps, H., Arles, C. & Lacassin-Seres, M. 1989. Topographic influence on carbon and nitrogen dynamics in riverine woods. *Archiv für Hydrobiologie* **114**, 401-414.

Pinay , G., Décamps, H., Chauvet, H. & Fustec, E. 1990. Functions of ecotones in fluvial systems. 141-169. *The Ecology and Management of Aquatic-Terrestrial Ecotones*. (ed. by R.J. Naiman & H. Décamps). UNESCO (Paris) & Parthenon Press Publishers.

Pinay, G., Fabre, A., Vervier, P. & Gazelle, F. (in press). Control of C, N, P distribution in soils of riparian forests. *Landscape Ecology*.

Polunin, N. (1982). Processes contributing to the decay of reed (*Phragmites australis*) litter in fresh water. *Archiv für Hydrobiologie* **94**, 182-209.

Polunin, N. 1984. The decomposition of emergent macrophytes in fresh water. *Advances in Ecological Research* **14**, 115-166.

Prach, K. & Rouch, O. (in press). On filter effects of ecotones. *Ekologia (CFSR)*.

Pringle, C.M., Naiman, R.J., Bretschko, G., Karr, J.R., Oswood, M.W., Webster, J.R., Welcomme, R.L. & Winterbourn, M.J. 1988. Patch dynamics in lotic systems: the stream as a mosaic. *Journal of the North American Benthological Society* **7**, 503-524.

Rabeni, C.F. 1991. *Buffer zones for riparian zone management: a literature review.* Department of the Army, New England Division, Corps of Engineers, Waltham MA.

Reddy, K.R., Campbell, K.L., Graetz, D.A. & Portier, K.M. 1982. Use of biological filters for treating agricultural drainage effluents. *Journal of Environmental Quality* **11**, 591-595.

Rhodes, J., Skau, C.M., Greenlee, D. & Brown, D. 1985. Quantification of nitrate uptake by riparian forests and wetlands in an undisturbed headwaters watershed. 175-179. *Riparian ecosystems and their management: reconciling conflicting uses.* (ed. by Johnson, R.R. *et al.*). USDA Forest Service. General Technical Report RM-120.

Richardson, C.J. 1985. Mechanisms controlling phosphorous retention capacity in freshwater wetlands. *Science* **228**, 1424-1427.

Richardson, C.J., Tilton, D.L., Kuclee, J.A., Chamie, J.D.M. & Wentz, A.W. 1978. Nutrient dynamics of northern wetland ecosystems. In *Freshwater Wetlands: Ecological Processes and Management Potential.* (ed. by R.E. Good, D.F. Whigham & R.L. Simpson) Academic Press, New York.

Rinne, J.N. 1990. The utility of stream habitat and biota for identifying potential conflicting forest land uses: Montane riparian areas. *Forest Ecology and Management* **33/34**, 363-383.

Risser, P.G. 1990. The importance of land/land-water ecotones. 7-22 *The Ecology and Management of Aquatic-Terrestrial Ecotones.* (ed. by R.J. Naiman & H. Décamps) UNESCO (Paris) & Parthenon Press Publishers.

Risser, R.J. & Harris, R.R. 1989. Mitigation for impacts to riparian vegetation on western montane streams. 235-265. *Alternatives in Regulated River Management.* (ed. by J. Gore & G.E. Petts). Boca Raton Press.

Rohde, W.A., Asmussen, L.E., Hauser, E.W., Wauchope, R.D. & Allison, H.D. 1980. Trifluralin movement in runoff from a small agricultural watershed. *Journal of Environmental Quality* **9**, 37-42.

Roseboom, D. & Russell, K. 1985. Riparian vegetation reduces streambank and row crop flood damages. 241-244. *Riparian ecosystems and their management: reconciling conflicting uses.* (ed. by Johnson, R.R. *et al.*). USDA Forest Service. General Technical Report RM-120.

Royal Commission. 1976. *Air Pollution Control: an integrated approach.* Royal Commission on Environmental Pollution. 5th Report. HMSO, London.

Royal Commission. 1988. *Best practicable environmental option.* Royal Commission on Environmental Pollution. 12th Report. HMSO, London.

Rutherford, J.C., Williamson, R.B. & Cooper, A.B. 1987. Nitrogen, phosphorous and oxygen dynamics in rivers. 139-165. *Inland Waters of New Zealand.* (ed. by A.B. Viner). DSIR Publishing, Wellington, New Zealand.

Salmon Advisory Committee. 1991. *Factors affecting natural smolt production.* Ministry of Agriculture, Fisheries & Food, Lowestoft.

Salo, J., Kalliola, R., Häkkinen, I., Mäkinen, Y., Niemelä, P., Puhakka, M. & Coley, P.D. 1986. River dynamics and the diversity of Amazon lowland forest. *Nature* **322**, 254-258.

Schlosser, I.C. & Karr, J.R. 1981. Riparian vegetation and channel morphology impact on spatial patterns of water quality in agricultural watersheds. *Environmental Management* **5**, 233-243.

Simberloff, D.S. 1976. Island biogeography theory and conservation practice. *Science* **191**, 285-286.

Simcox, D.E. & Zube, E.H. 1989. Public value orientations toward urban riparian landscapes. *Society and Natural Resources* **2**, 229-239.

Simpson, G.G. 1965. *The Geography of Evolution.* Chilton Books, Philadelphia, Penn.

Slater, F.M., Curry, P. & Chadwell, C, 1987. A practical approach to the examination of the conservation status of vegetation in river corridors in Wales. *Biological Conservation* **40**, 53-68.

Smith, C.M. 1989. Riparian pasture retirement effects on sediment, phosphorous and nitrogen in channelised surface run-off from pastures. *New Zealand Journal of Marine and Freshwater Research* **23**, 139-146.

Smith, C.M., Williamson, R.B. & Cooper, A.B. 1989. Riparian retirement: the effects on streambank stability and water quality. 27-35. *Changing Times.* Proceedings of the New Zealand Soil and Water Conservation Annual Conference. Nelson, New Zealand.

Smith, P.G.R. & Theberge, J.B. 1986. A review of criteria for evaluating natural areas. *Environmental Management* **10**, 715-734.

Spellerberg, I.F. 1981. *Ecological Evaluation for Conservation.* Edward Arnold, London.

Stanford, J.A. & Ward, J.V. 1988. The hyporheic habitat of river ecosystems. *Nature* **335**, 64-66

Statzner, B. & Higler, B. 1985. Questions and comments on the River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* **42**, 1038-1044.

Stauffer, D.F. & Best, L.B. 1980. Habitat selection by birds of riparian communities: evaluating effects of habitat alterations. *Journal of Wildlife Management* **44**, 1.

Swanson, S., Miles, R., Leonard, S. & Genz, K. 1988. Classifying rangeland riparian areas: the Nevada Task Force approach. *Journal of Soil and Water Conservation* **43**, 259-263.

Sweep, D., Zilincar, J.M., Smith, B. & Hardy, R. 1985. Integration of riparian management strategies within the context of multiple land management programs in southwestern Wyoming. 371-373. *Riparian ecosystems and their management: reconciling conflicting uses.* (ed. by Johnson, R.R. *et al.*). USDA Forest Service. General Technical Report RM-120.

Swift, B.L. 1984. Status of riparian ecosystems in the United States. *Water Resources Bulletin* **20**, 223-228.

Szaro, R.C. & Rinne, J.N. 1988. Ecosystem approach to management of Southwestern riparian communities. *Transactions of the 53rd North American Wildlife and Natural Resources Conference*. 502-511.

Tedaldi, D.J. & Loehr, R.C. 1991. Performance of an overland flow system treating food-processing wastewater. *Journal of the Water Pollution Control Federation* **63**, 266-275.

Thompson, K. 1961. Riparian forests of the Sacromento Valley, California. *AAAG* **51**, 295-315.

Tilton, D.L. & Kadlec, R.H. 1979. The utilization of a freshwater wetland for nutrient removal from secondarily treated wastewater effluent. *Journal of Environmental Quality* **8**, 328-334.

Triquet, A.M., McPeek, G.A. & McComb, W.C. 1990. Songbird diversity in clearcuts with and without a riparian buffer strip. *Journal of Soil and Water Conservation* **45**, 500-503.

Tyler, S.J. & Ormerod, S.J. 1990. The influence of stream acidification and riparian land use on the breeding ecology of Grey Wagtails *Motacilla cinerea* in Wales. *Ibis* **133**, 286-292.

Upton, J. and Griffin, P. 1990. Reed bed treatment for sewer dykes. 391-398 *Constructed Wetlands in Water Pollution Control*. (ed. by P.F. Cooper & C. Findlater. Pergamon Press.

Usher, M.B. (ed.) 1986. *Wildlife Conservation Evaluation*. Chapman & Hall, London.

van der Hoek, D. 1987. The input of nutrients from arable lands on nutrient poor grassland and their impact on the hydrological aspects of nature management. *Ekologia* **6**, 313-323.

Vanek, V. 1991. Riparian zone as a source of phosphorous for a groundwater-dominated lake. *Water Research* **25**, 409-418.

Vannote, R.L., Minshall, G.W., Cummins, G.W., Sedell, J.R. & Cushing, C.E. 1980. The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Science* **37**, 130-137.

Vitousek, P.M. & Reiners, W.A. 1975. Ecosystem succession and nutrient retention: a hypothesis. *BioScience* **25**, 376-381.

Wallace, J.B., Webster, J.R. & Woodall, W.R. 1977. The role of filter feeders in flowing waters. *Archiv fur Hydrobiologie* **79**, 506-532.

Ward, J.V. 1984. Ecological perspectives in the management of aquatic insect habitat. 558-577. *The Ecology of Aquatic Insects*. (ed. by V.H. Resh & D.M. Rosenberg). Plenum Press, New York.

Ward, J.V. 1989a. The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society* **8**, 2-8.

Ward, J.V. 1989b. Riverine-wetland interactions. 385-400. *Freshwater wetlands and wildlife*. (ed. by R.R. Sharitz & J.W. Gibbons). USDOE Symposium Series **61**. USDOE Office of Scientific and Technical Information, Oak Ridge, Tennessee.

Ward, J.V. & Stanford, J.A. 1983. The serial discontinuity concept of lotic ecosystems. 29-42. *Dynamics of Lotic Ecosystems*. (ed. by T.D. Fontaine III & S.M. Bartell) Ann Arbor Science, MI.

Ward, J.V. & Stanford, J.A. 1989. Riverine ecosystems: the influence of man on catchment dynamics and fish ecology. *Canadian Special Publication of Fisheries and Aquatic Sciences* **106**, 55-64.

Washington Department of Ecology. 1981. *Western Washington urban stream assessment*. Washington Department of Ecology, Office of Water Programs. Water Quality Planning. Olympia, WA.

Welcomme, R.L. 1979. *Fisheries Ecology of Floodplain Rivers*. Longman, London.

Welcomme, R.L. 1989. Floodplain fisheries management. 209-234. *Alternatives in Regulated River Management*. (ed. by. J.A. Gore & G.E. Petts). CRC Press, Boca Raton, Florida.

Welsch, D.J. 1991. *Riparian forest buffers: function and design for protection and enhancement of water resources*. USDA Forest Service. Northeast Area. Report NA-PR-07-91

Wesche, T., Goertler, C. & Frye, C. 1985. Importance and evaluation of instream and riparian cover in smaller trout streams. 325-328. *Riparian ecosystems and their management: reconciling conflicting uses*. (ed. by Johnson, R.R. *et al.*). USDA Forest Service. General Technical Report RM-120.

Wetherley, N.S., Lloyd, C.E., Rundle, S.D. & Ormerod, S.J. (in press). The effects of riparian management on the abundance of macroinvertebrates in streams draining conifer plantations. *Biological Conservation*

Whipple,W., DiLouie, J.M. & Pytalr, T. 1981. Erosion potential of streams in urbanizing areas. *Water Resources Bulletin* **17**, 36-45.

Williamson, R.B., Smith, R.K. & Quinn, J.M. 1990. *The effects of riparian protection on channel form and stability of 6 grazed streams, Southland, New Zealand*. Water Quality Centre Publication **19**, DSIR, Hamilton, New Zealand.

Wilson, M.F. & Carothers, S.W. 1979. Avifauna of island habitats in the Grand Canyon. *Southwestern Naturalist* **24**, 563-576.

Winterbourn, M.J. 1986. Recent advances in our understanding of stream ecosystems. 240-266 *Ecosystem Theory and Application*. (ed. by N. Polunin). Environmental Monographs & Symposia. John Wiley & Sons, Chichester.

Wright, .F., Moss, D., Armitage, P.D. & 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.

Yarbo, L.A., Kuenzler, E.J., Mulholland, P.J. & Sniffen, R.P. 1984. Effects of stream channelization on exports of nitrogen and phosphorous from North Carolina coastal plain watersheds. *Environmental Management* 8, 151-160.

Yates, P. & Sheridan, J.M. 1983. Estimating the effectiveness of vegetated floodplains/wetlands as nitrate-nitrite and orthophosphorous filters. *Agriculture-Ecosystems and Environment* 9, 303-314.

Zalewski, M., Thorpe, J.E. & Gaudin, P. 1991. Fish and land/inland water ecotones. 42-44. *Role of land/inland water ecotones in landscape management and restoration.* Proceedings symposium 5-8 March 1990. UNESCO/MAB, Paris.

APPENDIX A

LIST OF CONTACTS USED IN THE LITERATURE REVIEW PHASE

Asst Prof. Dr A. Abaffy-Bothar & Prof Dr A Berczik	Institute of Ecology and Botany, Hungarian Academy of Sciences
Dr P.B. Bayley	Centre for Aquatic Ecology, Illinois Natural History Survey, USA
Dr G.H. Copp	Division of Environmental Sciences, Hatfield Polytechnic, UK
Dr A.B. Cooper	DSIR Water Quality Center, Hamilton, New Zealand
Dr D.L. Correll	Smithsonian Environmental Research Centre, USA
Dr L. Debano	Arizona State University, USA
Dr Henri Décamps	Directeur, Centre d'Ecologie des Ressources Renouvelables, CNRS, Toulouse Cedex, France
Dr M. Falkenmark	Swedish Natural Science Research Council, Stockholm
Dr F. Fournier	Division SC/ECO UNESCO Paris
Dr C. Frank	Laboratorium fur Angewandte Biologie und Okologie, Ulm-Jungingen, Germany
Dr. J. Gibert	U.R.A.-CNRS, France
Dr A.P. Grootjans	Laboratory for Plant Ecology, University of Groningen, The Netherlands
Dr T.A. Hanley	US Forest Service, Juneau, Alaska
Dr Nick Haycock	Silsoe College, UK
Dr B. Higler	RIN Leersum, The Netherlands
Dr A. Hildrew	Queen Mary and Westfield College, London
Prof. Dr A. Hillbricht-Ilkowska	Institute of Ecology, Polish Academy of Sciences
Prof. Dr K. Hofius	Sekretariat fuer das Internationale Hydrologische Programm, Koblenz, Germany
Univ. Prof Dr G.A. Janauer	Institut fuer Pflanzenphysiologie, Universitaet Wien, Austria
Dr A. Jensen	Dept. of Lands, Adelaide, Australia
Dr E. Jutila	Finnish Game and Fisheries Research Institute, Helsinki, Finland
Dr Z. Kajak	Institute of Ecology, Polish Academy of Sciences
Dr J. Karr	Inst. of Env. Studies, University of Washington USA
Dr T.A. Kharchenko	Hydrobiological Institute, Academy of Sciences of Ukrainia.
Dr B. Kugel	Bayersiches Landesamt Wasserwirtsch, Munchen, Germany
Dr F. Kouwe	GTD Oostbrabant, The Netherlands
Dr W.H. McDowell	Natural Resources, University of New Hampshire, USA
Dr T. Moth Iversen	National Env. Research Institute. Silkeborg, Denmark
Dr E. Muller	Centre d'Ecologie des Ressources Renouvelables, CNRS, Toulouse Cedex, France
Dr R.J. Naiman	Director, Centre for Streamside Studies, University of Washington, USA
Dr L.L. Osborne	Centre for Aquatic Ecology, Illinois Natural History Survey, USA
Dr R.C. Petersen	Dept. of Ecology, Limnology Institute, University of Lund, Sweden.
Prof. Dr E. Pieczynska	Inst. of Zoology, Warsaw University, Poland
Dr W. Pisarek	Dept. of Geobotany, Lodz University, Poland
Dr C.F. Rabeni	University of Missouri, USA
Dr J. Salo	Dept. of Biology, University of Turku, Finland
Dr B. Statzner	CNRS, University Lyons 1, France
J. van Rijen	Ministerie van Laandbouw en Visserij, The Netherlands
Dr W. Platts	Agric. Research Station USDA, Boise Idaho, USA
Dr F. Steiner	Dept. of Planning, Arizona State University
Dr D. Green	School of Agribusiness and Environmental Resources, Arizona State University, USA
Dr D. Patten	Arizona State University, USA
Dr P. Whitehead	Institute of hydrology, UK.
Prof M. Zalewski	Director, Laboratory of Applied Biology, Lodz University, Poland

APPENDIX B

PARTICIPANTS IN ONE-DAY WORKSHOPS

Workshop 1 (25 November 1991) held at NRA Yorkshire Region.

S.Alston	Countryside Commission (Leeds)
L.Chalk	National Rivers Authority (York)
M.Gibson	English Nature (Peterborough)
K.Hills	NRA (Reading)
R.Jarman	National Trust
J.Lloyd	National Farmers Union (Forestry Adviser)
B.McEvoy	NRA (Waltham Cross)
J.Pygott, A.Sansom	NRA (Leeds)
A.Large, J.Brock, E.Darby, D.Evans	ICOLE, Loughborough

Workshop 2 (2 December 1991) held at Loughborough University of Technology.

M.Benton	Derek Lovejoy Partnership (Leicester)
P.Boon	Nature Conservancy Council for Scotland
S.Crute	Chris Blandford Associates
K.Easton	NRA (Severn-Trent)
N.Haycock, E.Hughes	Silsoe Agriculture College
L.Jenkins	NRA (Wessex Region)
A.Large, J.Brock, E.Darby, D.Evans, M.Wade	ICOLE, Loughborough
D.Lepper	Countryside Commission (Birmingham)
A.Muscutt	ADAS, Min. of Agric. Fisheries & Food
C.Newbold	Joint Nature Conservation Committee
K.Poole	NRA (Reading)
A.Powell, G.Witter	World Wide Fund for Nature (UK)
D.Prigmore	NRA (Anglian Region)
C.Redmond	NRA (Reading)

APPENDIX C

INTERNATIONAL WORKSHOP 23-24 JANUARY 1992

Dr Jon Bass	Eastern Rivers Group, Institute of Terrestrial Ecology, Monks Wood Experimental Station, Abbots Ripton, Huntingdon. PE17 2LS
Dr Roger Bettess	Hydraulics Research, Howbery Park, Wallingford, Oxford. OX10 8BA
Dr Jeremy Biggs	Pond Action, School of Biology & Molecular Sciences, Oxford Polytechnic, Gipfy Lane, Headington, Oxford. OX3 0BP
Dr John Brock	Arizona State University/ICOLE, Loughborough University of Technology.
Dr Bryce Cooper	Water Quality Center, Division of Water Sciences, PO Box 11-115, Hamilton, New Zealand.
Mr Ed Darby	ICOLE, Department of Geography, Loughborough University of Technology.
Dr Isobel Drury	Conservation Officer, RSNC-The Wildlife Trusts Partnership, The Green, Witham Park, Waterside Down, Lincoln.
Dr Tony Edwards	Environment Manager, National Rivers Authority (Yorkshire Region), Rivers House, 21 Park Square South, Leeds. LS1 2QG ICOLE, Department of Geography, Loughborough University of Technology.
Dr Alastair Ferguson	Senior Biologist, National Rivers Authority (Anglian Region), Kingfisher House, Orton Goldhay, Peterborough. PE2 0ZR
Dr John Gardiner	National Rivers Authority (Thames Region), King's Meadow House, King's Meadow Lane, Reading, Berkshire.
Dr David Gilvear	Department of Environmental Science, University of Stirling, Stirling FK9 4LA
Dr Ian Grieve	Department of Environmental Science, University of Stirling, Stirling FK9 4LA.
Mr Graham Harris	Ministry of Agriculture, Fisheries& Food, Agricultural Development and Advisory Service, Anstey Hall, Maris Lane, Trumpington, Cambridge. CB2 2LF
Dr Nick Haycock	Department of Agriculture & Water Sciences, Silsoe College, Silsoe, Beds.
Ms Val Holt	Regional Conservation Officer, National Rivers Authority (Severn-Trent Region), Orston Road East, West Bridgford, Notts. NG2 5LA
Mr Georg Humborg	Institut für Wasserbau und Kulturtechnik, Universitat Karlsruhe, Germany.
Dr Rob Jarman	Nature Conservation Advisor, National Trust, Spitalgate Lane, Cirencester, Glos. GL7 2DE
Dr Andy Large	Department of Geography, Loughborough University of Technology.
Dr Elizabeth Monosowski	Consultant, The World Bank, Washington DC 20433 USA.
Dr Adrian Muscutt	Ministry of Agriculture, Fisheries & Food, Agricultural Development and Advisory Service, Anstey Hall, Maris Lane, Trumpington, Cambridge. CB2 2LF
Dr Chris Newbold	Head, Aquatic Pollution & Wetlands Branch, Joint Nature Conservation Committee, Monkstone House, Peterborough. PE1 1JY
Professor Geoff Petts	Department of Geography, Loughborough University of Technology
Dr Giles Pinay	Centre d'Ecologie des Ressources Renouvelables-CNRS, 31055 Toulouse Cédex, France.
Dr John Pygott	Conservation Officer, National Rivers Authority (Yorkshire Region), Olympia House, Gelderd Lane, Leeds. LS12 6DD
Dr Colin Smith	Ecology Research Unit, University of Leicester.
Dr Max Wade	Director ICOLE, Department of Geography, Loughborough University of Technology.
Ms Diana Ward	Royal Society for the Protection of Birds, The Lodge, Sandy, Bedfordshire. SG19 2DL

Workshop Agenda

Thursday 23 January 1992

Session I Buffer zones: background and directions

13.45	Introduction:	Professor Geoff Petts, Head of Geography Department
14.00	Background to buffer zones in the UK	Dr Andy Large, Loughborough University
14.45	Discussion	
15.15	Close	

Session II Buffer zones for water quality protection (Chair: Geoff Petts)

15.45	Upland streams and acidification	Dr Ian Grieve, Stirling University
16.00	Nutrient dynamics in floodplain rivers	Dr Giles Pinay, CERR/CNRS, Toulouse, France
16.15	Application of buffer zones for water quality control	Dr Adrian Muscutt/Mr Graham Harris, ADAS, Cambridge.
16.30	Discussion	
17.15	Close	

Session III Buffer zones: International Perspectives (Chair: Andy Large)

19.15	New Zealand's experience	Dr Bryce Cooper, DSIR, Hamilton, New Zealand
19.30	Germany	Mr Georg Humborg, Universität Karlsruhe, Germany
19.45	EEC Policy and Possibilities	Professor Geoff Petts, Loughborough University
20.00	Discussion	
20.30	Close	

Friday 24th January 1992

Session IV Buffer zones for Nature Conservation and Recreation (Chair: Ed Darby)

09.00	Buffer zone restoration: US Experience	Professor John Brock, Arizona State University
09.15	Lessons from the River Trent, UK	Dr Max Wade, Director, ICOLE
09.30	Restoration of floodplain ponds	Dr Jeremy Biggs, Dept. of Biology & Molecular Sciences, Oxford Polytechnic (PONDLIFE)
09.45	Discussion	
10.15	Close	

Session V Buffer zones: Constraints to implementation (Chair: Max Wade)

10.45	Hydraulic implications for flood control	Dr Roger Bettis, Hydraulics Research, Wallingford
11.00	General constraints	Dr John Gardiner, NRA Thames Region
11.15	Major landowners: a viewpoint	Dr Rob Jarman, National Trust, Cirencester
11.30	Discussion	
12.00	Lunch	

Session VI The future of buffer zones in the UK - conclusions

13.30 Concluding session - the way forward?
Close of workshop