1994/113

Institute of Hydrology

[redacted]

Natural Environment Research Council

Natural
Environment
Research
Council

EurAqua First Technical Review

Land Use Change and Water Resources

United Kingdom Country Paper

J.R.Blackie and J.P.Moores
Institute of Hydrology, Wallingford, UK

Acknowledgements

This paper has been compiled with assistance from the National Rivers Authority. The authors are also grateful for input from Brian Wilkinson, Tony Debney and other colleagues at the Institute of Hydrology.

Contents

Introduction

The total land area of the UK is 240,000 km^2 approximately 70% of which is farmland, 10% is forest, and a further 10% is wetlands and semi-natural habitats. The remaining 10% is mainly urban land but also includes major transport routes, mineral workings and derelict land (DoE, 1992). About one third of agricultural land is arable, mainly in lowlands of southern and eastern Britain, and two thirds is grassland and rough grazing land, the latter concentrated in the upland and mountain areas in the north and west. These areas have varied considerably during this century as political and economic priorities have changed and will continue to do so in the future particularly as a result of the economic incentives generated by the evolution of the CAP and the increasing pressure from environmental interests.

The UK as a whole is well endowed with water resources with an annual average rainfall of 1000mm, well distributed through the year, and an estimated annual potential evaporative demand of some 450mm. At a national level the UK's water resources are not heavily exploited. Only 25% of groundwater and 10% of surface water resources are utilised (DoE, 1992). However, these figures mask regional disparities resulting from the spatial distribution of rainfall and of areas of maximum resource demand. Annual rainfall decreases rapidly from west to east. Some parts of the mountainous north-west receive in excess of 3000mm whilst the eastern and south-eastern lowlands, where the major part of the population is based and the industrial and agricultural demand is greatest, receives annual totals of 600mm or less. The geology of the country provides some balancing effects. The major groundwater aquifers are predominantly in the drier East and South-East (chalk and limestone areas) and in "normal" rainfall years these receive substantial recharge during the winter months. Despite this the annual water surpluses in southern England can be as low as 3% as compared to over 90% in the north (DoE, 1992). The wet Western and Northern uplands have little storage, however, and exploitation of their abundant rainfall requires considerable capital expenditure in reservoirs and river regulation schemes.

Pressure on water resources is increasing, with a 4% increase in abstraction from all sources between 1980 and 1990 (DoE, 1992). The major demand is for piped mains supply (see figure 1), a sector which increased by 13 % over the same period.

Whilst rainfall, evaporation, geology and soils are the primary factors determining the water resources available in a given area, the type and extent of vegetation cover and the methods used to manage it can significantly influence the quantity, quality and time distribution of streamflow or groundwater recharge. Urbanisation results in a higher proportion of direct runoff; afforestation, particularly in high rainfall areas, can increase the evaporative loss by up to 80%; intensive arable farming results in a reduction in water quality as fertilizers, herbicides and pesticides are leached into the streams and aquifers.

Land use can be regarded as an interface between producers (agriculture, forestry, manufacturing industry), the water supply industry and, in more recent times, a range of environmental interests. It has been an area of much conflict, exacerbated by a dearth of factual knowledge. Research and long term monitoring, particularly over the last 40 years, has improved the knowledge base considerably and this has lead to a more constructive level of dialogue where agreement or compromise can be based on fact rather than preconceptions. In the uplands for example forestry development and water supply still have conflicting priorities but agreed guidelines, based on information derived from dedicated research in this aspect of land use, are now applied to each area under discussion.

Our knowledge of land use effects is far from complete however and, as changing economic and political circumstances and the development of new crops add to the range of uses, greater investment in research in this discipline will be required. Greater effectiveness in the use of this investment can be achieved by identifying aspects of common interest within the EU and coordinating the research activities.

Abstractions from surface water and groundwater; by purpose, 1990 *England and Wales*

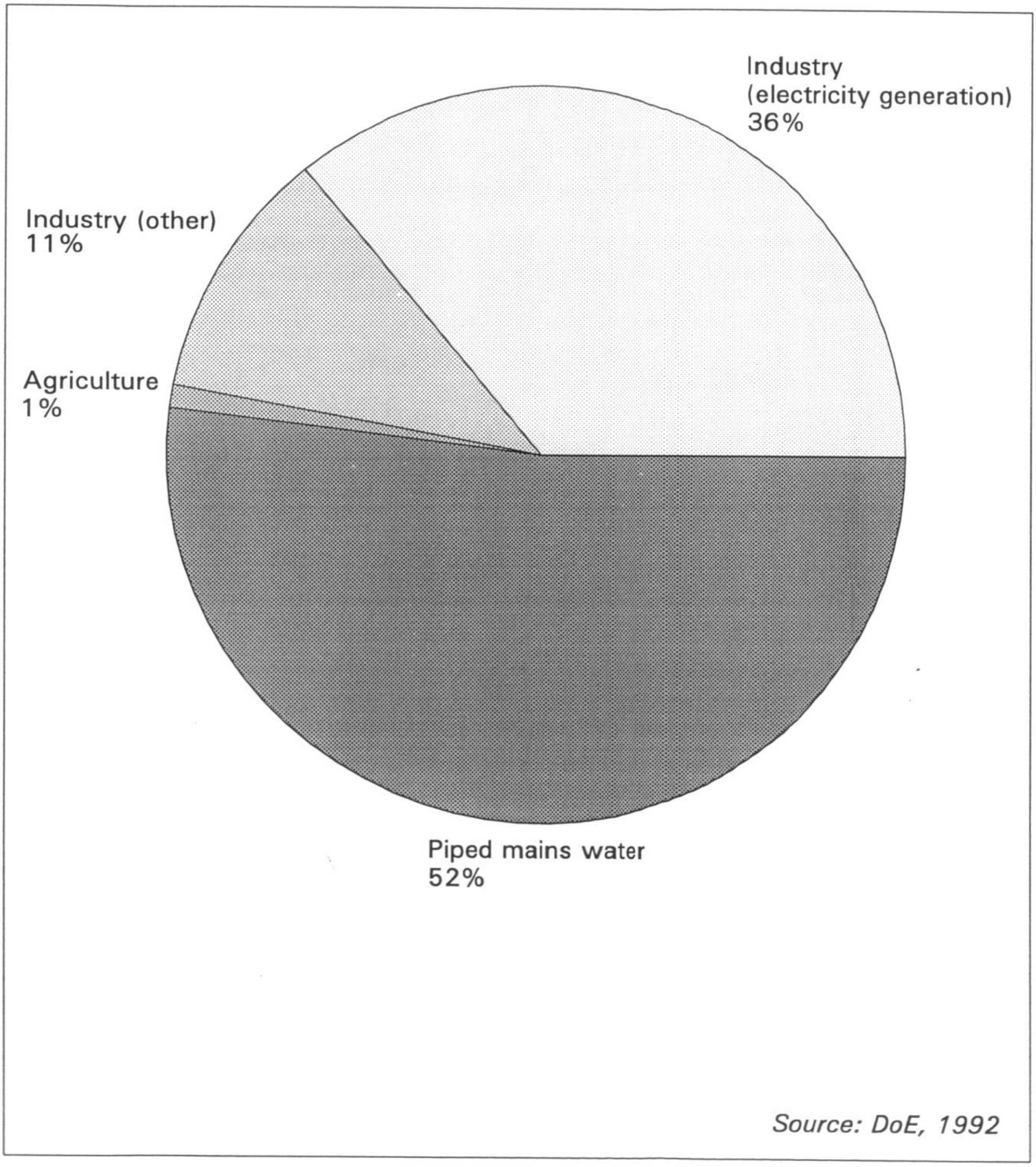


Figure 1

1 Important trends in recent land use change having implications for water resources

Trends in UK land use over the post-war period are presented in table 1.1. Over this period there have been two main themes in land use change; the expansion of urban development into rural areas and the impact of agricultural modernisation on farm land (Parry et al, 1992). These and the other important trends in land use change are discussed below.

Table 1.1 Trends in UK land use 1947-1980 (DoE, 1992)

	land use as proportion total UK area (%)				
	woodland and forests	semi-natural	water and wetlands	agriculture	other*
1947	7.0	12.6	1.3	72.7	6.4
1969	7.9	10.1	1.1	72.1	8.8
1980	7.9	9.2	1.1	71.8	9.9

* mainly urban but also includes transport and mineral workings

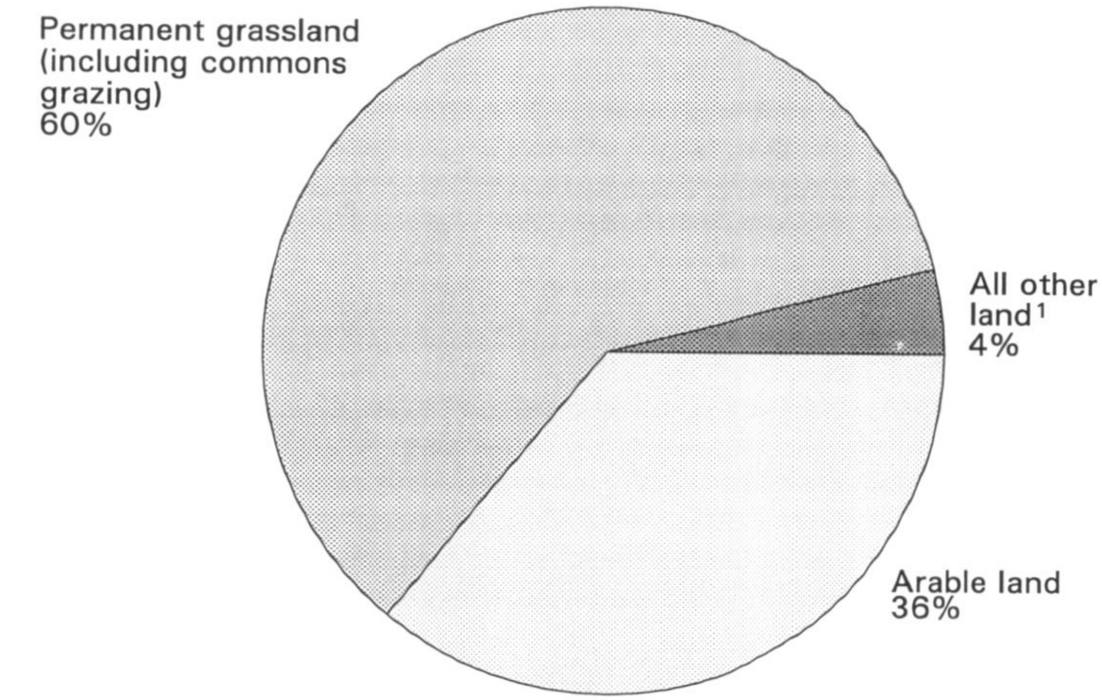
Agriculture

The modernisation of agriculture in the UK over the past 50 years has involved three changes in the nature of production: intensification; specialisation by farm and region; and increasing scale (Parry et al, 1992). The increase in productivity arising from intensification has arisen largely through the increased use of fertilisers, pesticides and herbicides, certainly until the 1980s. In conjunction with this has been the mechanisation of farming practice and a resulting increase in field size.

These advances have enabled farmers to exploit more fully local advantages of climate and soil with the result that agriculture has been subject to increased regional specialisation. Whilst there has been an increase in the area of arable land throughout the UK as a whole to about one third of all agricultural land (DoE, 1992) (see figure 2), this has been concentrated in the south and east of the country. In the north and west the dominant change in land use has been the improvement of rough grazing to temporary pasture, with 15% of rough grazing land lost over the UK as a whole between 1933 and 1980 (Parry et al, 1992).

Since the early 1980s a number of minor, but increasingly important, trends in agriculture affecting land use have become evident. These include changes in both crop types and farming practice. Whilst the total area under cereals, and especially barley, has declined (see figure 3) the area under oil seed rape has quadrupled to 8% of total arable land (DoE, 1992).

Agricultural land use, 1990 *UK*

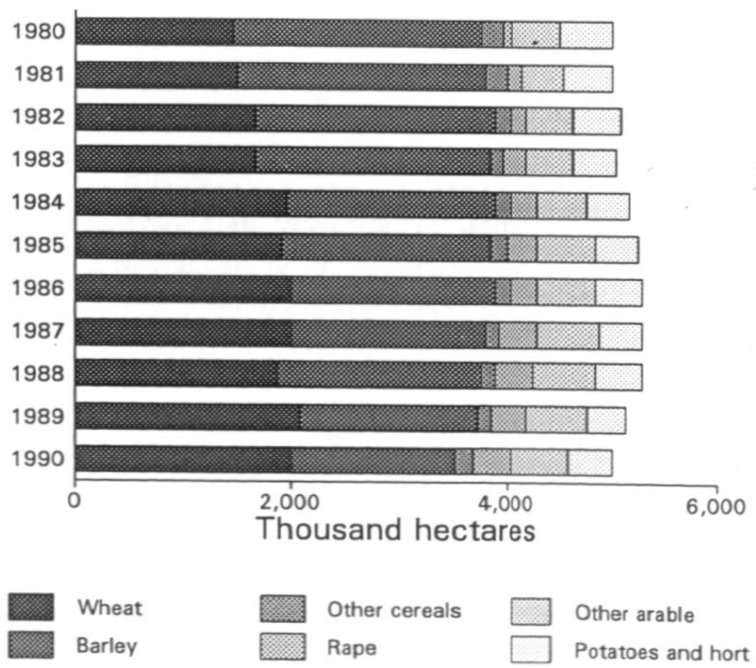


Note 1: Including woodland and land designated under the Set-Aside Scheme

Source: DoE, 1992

Figure 2

Crop area by type of crop, 1980 to 1990 *UK*



Source: DoE, 1992

Figure 3

Over the same period there has been an overall reduction in the application of nitrate fertilisers (although still heavy in the main areas of arable production) and an increase in the area of farmland taken out of production under the Farm Woodland and EU's 'Set Aside' schemes.

Other important trends in agricultural land use include the increase in irrigation, particularly in the South East of England and the expansion of drainage improvements, especially in relation to arable farmland. Between 40 and 50 % of agricultural land in the UK is subject to under drainage, more than any other country in the EU (European Commission, 1987).

Urban/industrial development

The total urban area in the UK is estimated to be increasing by 10% per decade (Parry et al, 1992). In the early pre-war period the majority of this expansion was confined to existing urban areas. In recent years there has been an increasing trend for urbanisation in less urbanised regions. Although much of the increase in urban area has been at the expense of agricultural land there are indications that the trend is slowing down with only 0.5%, or 15000 ha/year, of agricultural land subject to urban development over the past 5 years (Parry et al, 1992).

The changes in land use associated with urban development not only include the development of green field sites for industrial and residential purposes but also the extraction of materials required for building purposes. Some 200 million tonnes of aggregate are required in Britain each year for construction, most of which must be quarried on land. Mineral extraction methods often have very large environmental impacts, as can the landfill, waste disposal and land reclamation which follow (NERC, 1992b).

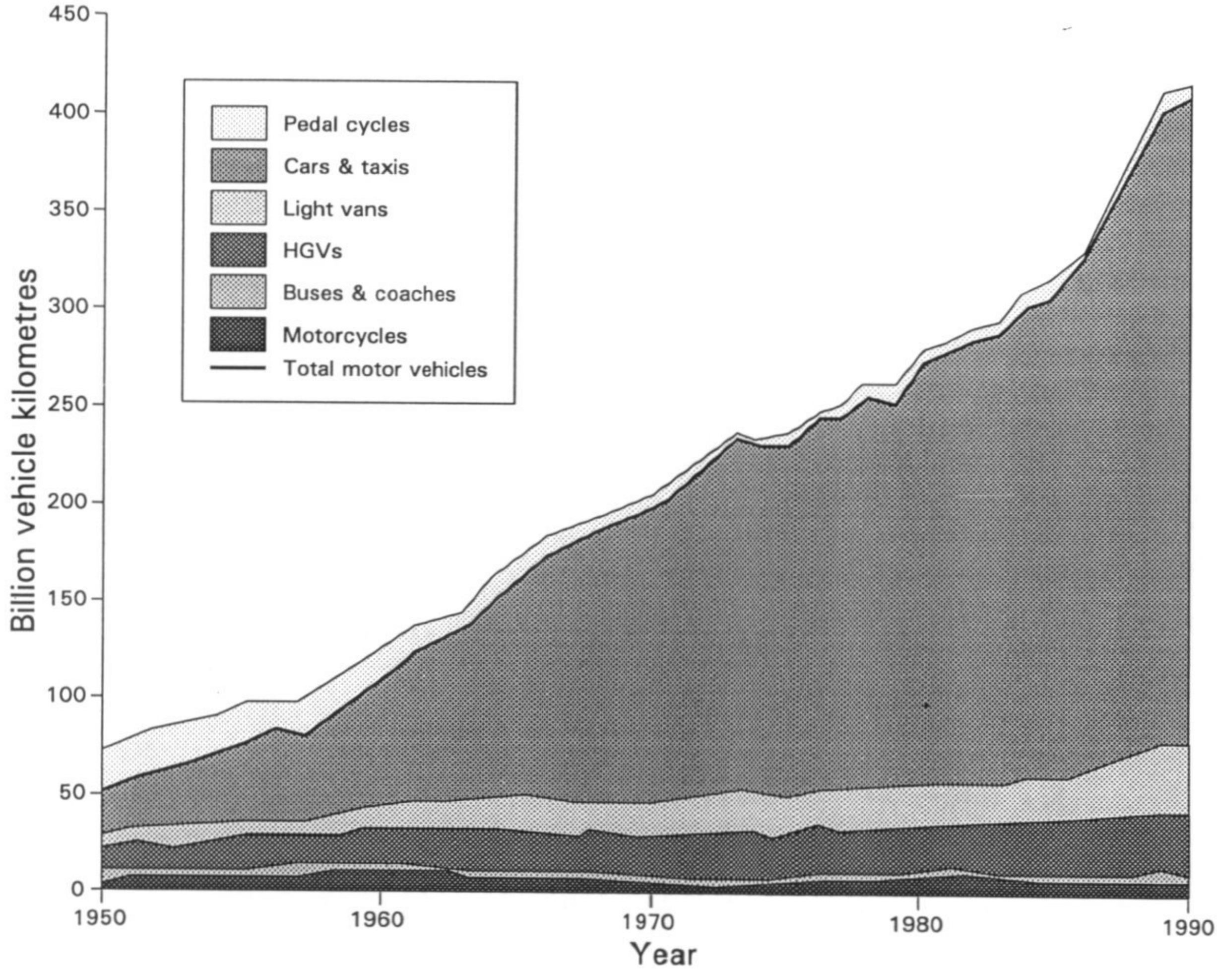
Transport/navigation

The dominant feature of change in the transport system of the UK over the past 50 years has been the expansion of the road network. The growth of road traffic, shown in figure 4, has been dominated by a massive increase in the number of cars on the road, from 2.5 million in 1951 to 20 million in 1990 (DoE, 1992). Over the decade 1980-1990 alone the total length of motorways in the UK increased by 20% whilst all roads increased by 5%.

The increased area occupied by roads has been largely at the expense of farmland and other rural land with a number of notable cases involving conflict between road construction and conservation interests. Between 1985 and 1990 some 14 070 ha was consumed by road construction, 50 % of which was farmland, 16% was uncultivated and 33% was urban or part of the existing road network.

After years in decline the canal system in UK has seen a slow but steady growth in the last three decades driven by the enthusiasm of restoration groups and the rapidly growing leisure sailing industry. Consideration is being given to the extent to which parts of the canal network could be adapted to act as a long distance water transfer system.

Growth of traffic by type of vehicle, 1950 to 1990 *GB*



Note: 1990 - provisional estimate

Source: DoE, 1992

Figure 4

Forest and woodland

Britain has only some 10% of its land area under forest, although this figure has doubled over the past 50 years. In Europe only Holland and Ireland have lower % covers. This figure compares with some 29% in Germany and 27% in France (European Commission, 1987).

The Forestry Commission was formed after the first world war to initiate a programme of reforestation. Its work and, increasingly, that of private sector forestry companies and landowners has now raised the area to the present figure mainly through the planting of conifers on areas of poor upland moorland and mountain soils formerly used for low density sheep grazing. Between 1947 and 1991 the total area of coniferous forest in the UK increased from 0.38 million ha to 1.5 million ha (DoE, 1992) (see figure 5) Despite some slowing down of the planting rates in the late 1980s and early 1990s due to changes in tax laws and political debate, this upland planting programme is scheduled to continue well into the next century. This large scale conversion of upland grazing and moorland to conifer (mainly spruce) plantation is the major land use change in UK this century with one third of all lost farmland going to forestry (Parry et al, 1992).

Lowland and broadleaf forestry has received less encouragement but this situation is changing fast with planning now under way for the development of a number of "community forests" close to major lowland conurbations. In addition farmers are now being encouraged by MAFF to take up the offer of farm forestry grants to allow small scale forest development on good agricultural land. The area under new plantings of broadleaf woodland increased from 600 ha in 1979/80 to 6300 ha in 1991/92 (DoE, 1992) (see figure 6).

Wetlands and natural habitats

The drive to maximise agricultural production resulted in a rapid decline in areas of wetland and other natural (or semi-natural) habitats in the UK from the 1940s until very recently, an acceleration of a general trend that had been going on for centuries. Between 1947 and 1985 an estimated 50% of all ancient broadleaf woodlands, 50% of lowland fens and marshes, 60% of heathlands and 80% of chalk grasslands was lost to farming (Parry et al, 1992). Figure 7 shows the loss of virtually all of the area of semi-natural pasture and meadow to improved grassland in lowland England and Wales.

MAFF and conservation interests are now encouraging a reversal of this trend. In particular there has been an increase in the number and area on nature reserves and areas designated as Sites of Special Scientific Interest (SSSIs). There is also increased awareness amongst river engineers and water resource managers of the value of river floodplains and other wetland areas for flood control and water quality improvements. Some river systems have therefore been subject to attempts to restore 'natural' floodplain conditions, particularly as a flood defence measure.

Forest cover, 1905 to 1991 *GB*

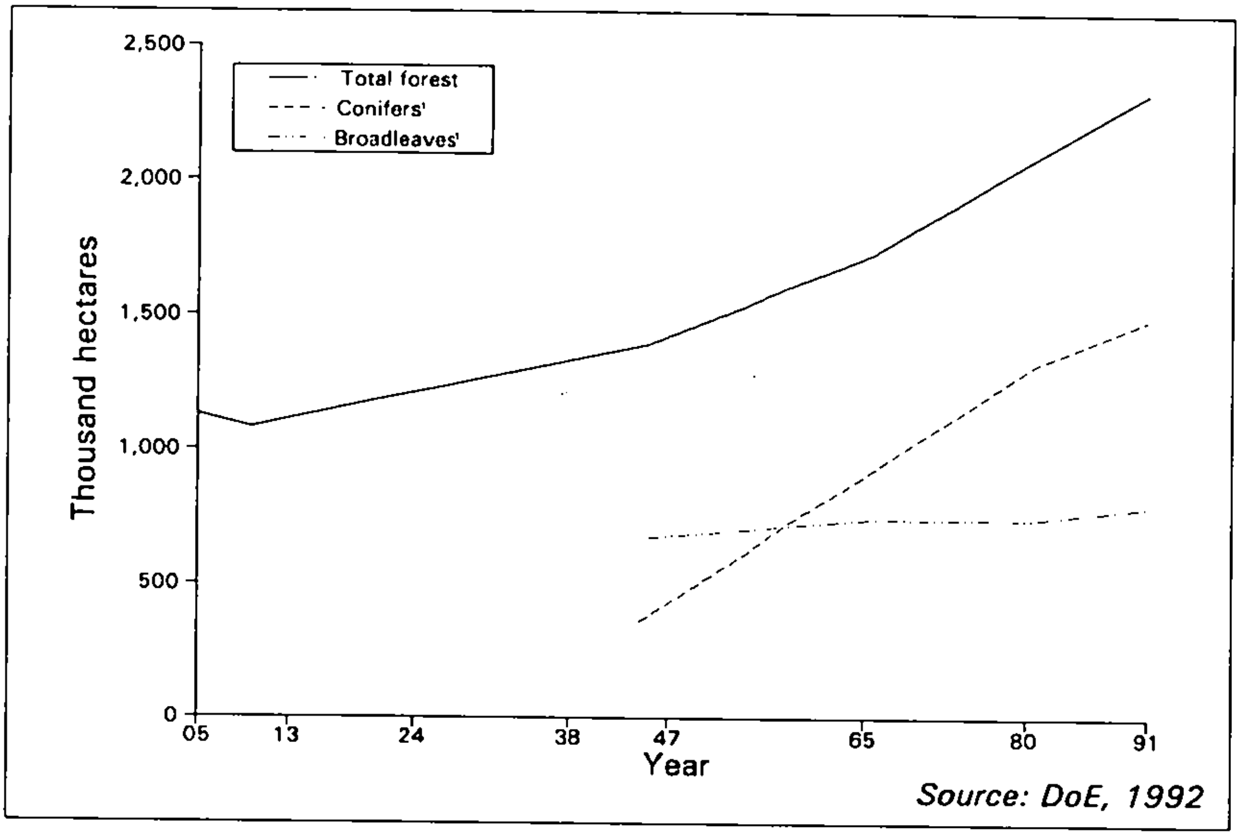


Figure 5

New planting; conifers and broadleaves, 1979-80 to 1991-92 *GB*

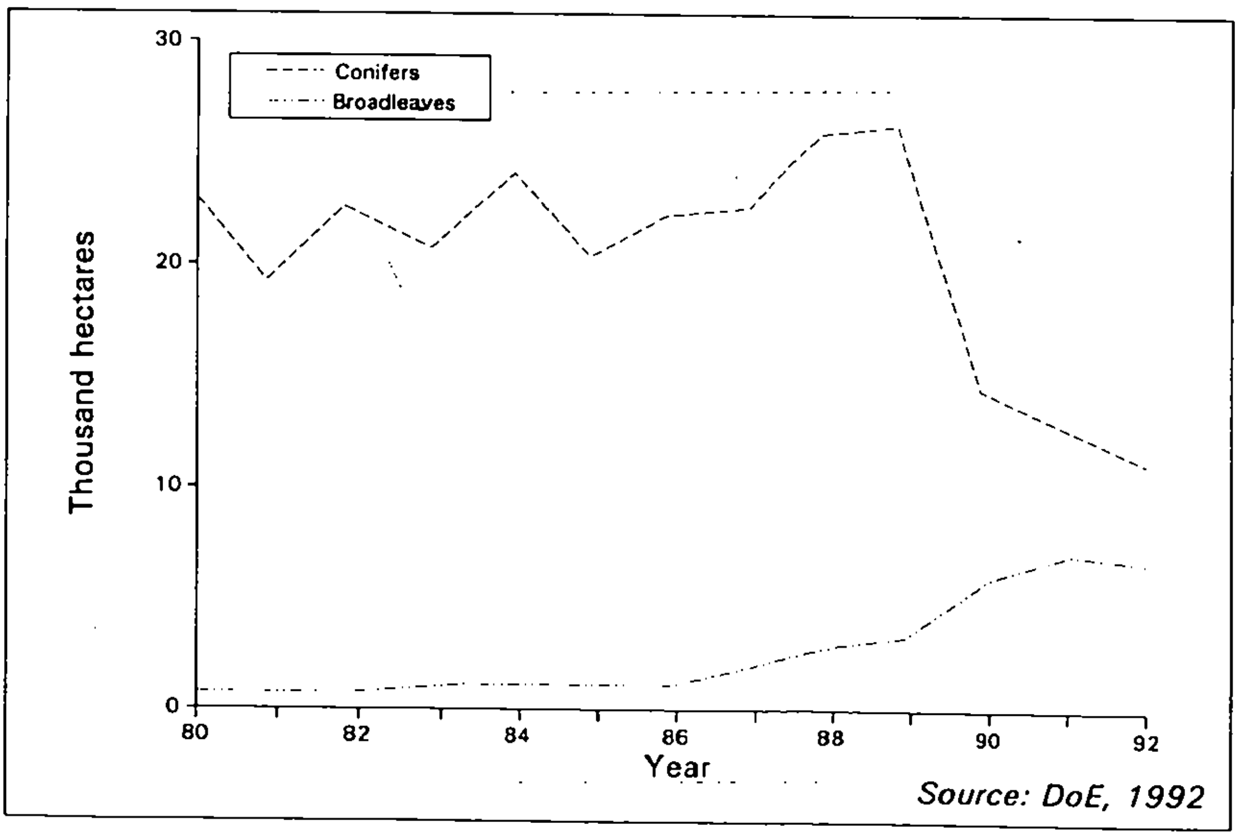
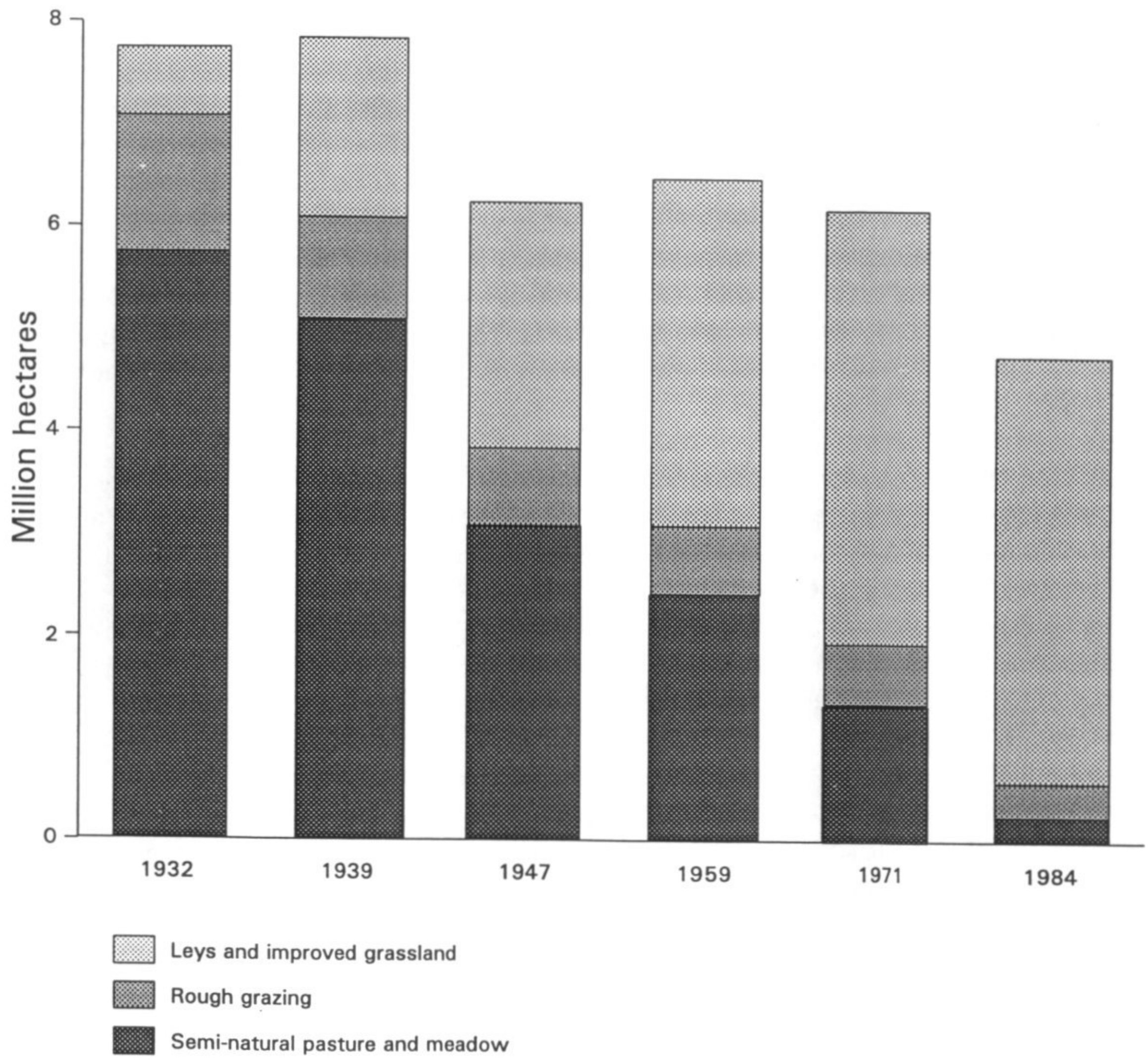


Figure 6

Changes in lowland grassland, 1932 to 1984
England and Wales



Source: DoE, 1992

Figure 7

2 Factors determining identified trends in land use change

Economic, Policy and Legislation

The major changes in farming practice affecting land use change in agricultural areas between the 1940s and the late 1970s were stimulated by the drive to increase production and productivity, based on the assumption that this was beneficial for the nation's economy. Since joining the European Community in the 1970s farming has become increasingly influenced by the availability of grants and subsidies under the Common Agricultural Policy (CAP). The impact of CAP on land use is most readily seen in the conversion of rough grazing to improved farmland for cropping and the yellowing of the landscape with oil-seed rape. In recent years the expansion of arable land has slowed in response to a reduction in the subsidy of cereal production under CAP.

From the 1980s onwards it has become clear that over-production in the EU has been and still is occurring on a massive scale. In what can be seen as something of a philosophical shift the provision of farming grants in recent years has had as one of its aims that of diversification away from the production of crops and livestock. The growth of farmland forestry and 'set aside' land are obvious recent examples of the influence of EU policy on the agricultural landscape.

In addition to changes in CAP and other areas of EU economic policy the recent GATT agreement also has wide reaching implications for agriculture. At the core of the agreement is the reduction of trade barriers and the 'freeing' of markets, a move which will result in increased uncertainty in the price of agricultural produce around the world. Farmers in the EU, no longer protected by external tariffs, will have to operate in an environment of increased competitiveness. This may well result in a decrease in the number of farmers and, consequently, in the total area of agricultural land.

Agriculture is also having to make changes in practice and land use in response to policies reflecting growing concern for the environment. The creation of Environmentally Sensitive Areas, covering a total area of 785, 600 ha in Britain (DoE, 1992), is intended to alter the way in which farmers manage their land to the benefit of wildlife and the appearance of the countryside. This policy has been supplemented by other schemes such as the Countryside Premium Scheme and the Countryside Stewardship Scheme, both of which have been promoted by the Countryside Commission in the UK to encourage environmentally-friendly farm management (Phillips, 1992).

There have also been new policy initiatives relating to specific aspects of agricultural practice. The setting of European Union limits on water quality has had implications for fertiliser use with their application restricted in locations designated as nitrate sensitive areas (NSAs) and nitrate vulnerable zones (NVZs) (see figure 8). EU and MAFF policy on agricultural pollution have also had an impact, with increasing emphasis placed on the 'polluter pays' principle.

Nitrate Sensitive Areas and Nitrate Vunerable Zones

(source: DoE, 1992)

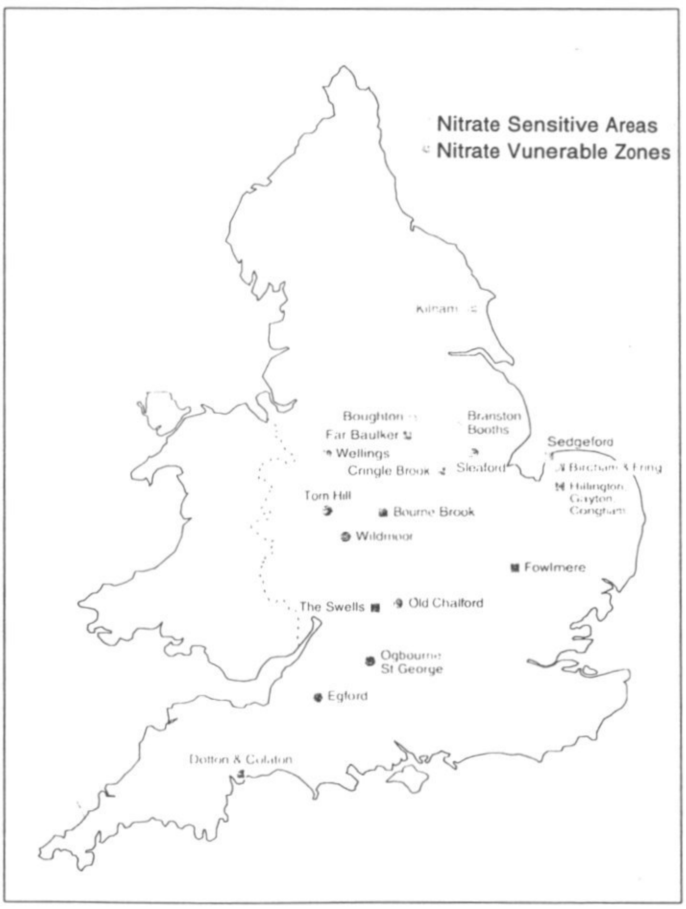


Figure 8

The increase in the forested area of the UK is also largely the result of economic forces. The original rationale for the large scale afforestation of upland Britain in the post-war years was to increase domestic timber production considerably above the 5-10% of total consumption which was then the case. More recently forestry has provided a convenient tax loophole encouraging an increase in the number and area of privately owned plantations. Legislation in the late 1980s to reform the tax laws in the UK prompted a fall in the rate of growth of this sector. However, in the light of a recent revision in the forestry grant system the afforestation of Britain's uplands may again take an upturn (Pearce, 1994).

Social and demographic

The impact of demographic change over the last 50 years upon land use has been twofold. Firstly, the population has been growing (although now relatively static) with a consequent increase in the demand for housing and an expansion of urban area. Much of this increase in urban area has been on green field sites at the outer extremes of existing urban areas. The growth of the country's population has been accompanied by an increase in living standards and greater personal mobility. As highlighted above, the number of motor vehicles has grown rapidly forcing an on-going expansion of the road network.

The second important trend has been in the redistribution of the population from the county's main urban centres to suburban and rural areas. The recent growth of the rural population represents a reverse of a decline over many decades resulting from the rationalisation of the agricultural workforce. It should be noted, however, that in may remote areas the decline continues with the bulk of urban-rural migration concentrated in SE England, SW England and East Anglia.

The typical image representing this trend is of the middle class professional opting to commute to work in the city whilst living in an area of both cheaper housing and a more pleasant environment. Munton et al (1992) note that the growing rural population in southern England is in fact more diverse than this although in general the outward migration from the cities has resulted in the increased social and political sophistication of the rural population. Evidence of this increased level of political awareness can be seen in the growing level of opposition to certain rural developments including road building and recreational developments. The pace of housing development too has slowed in rural areas as a result of such opposition with the result that most new residential developments are now concentrated in urban areas (Munton et al, 1992).

More generally, there has been a trend of growing environmental awareness amongst the population as a whole. Parties with explicitly environmental messages have become increasingly important players on the political scene across Europe. The increase in legislation at both the EU and UK level giving better coverage to environmental matters is undoubtedly partly a response to this trend in popular opinion.

Town and country planning

Town and country planning has perhaps had less of an impact on land use change than might be expected. This is largely due to the fact that there have been a range of contradictory approaches to planning from which a consensus has failed to emerge. Not least of the problems is that various levels of government are involved in planning, from legislative measures at the national level to implementation at the county, borough or district level. In addition there can often exist conflict between strategic planning over the long term and decision making in the short term.

The lack of consensus in planning, for example in relation to rural development, can be seen to derive from two contradictory approaches, each of which has been the driving force behind government policy at different times (Munton et al, 1992). The first approach aims to reduce planning restrictions to encourage rural enterprise. The second places emphasis on the protection and promotion of the amenity value of the countryside and clearly engenders a tightening of planning restrictions. Under this approach England, Wales and Northern Ireland have seen the designation of 10 National Parks and 38 Areas of Outstanding Natural Beauty whilst Scotland has 40 National Scenic Areas. Together, these protected areas account for nearly 20% of the total land area of the UK (DoE, 1992). It is arguable that this latter approach is now dominant in rural planning, with the continued designation of areas of Special Scientific Interest (SSSIs) and, more recently, the creation of community forests in lowland areas.

In recent years the planning process has become subject to new regulations governing the evaluation of the potential impacts of proposed developments through Environmental Impact Assessment (EIA). These regulations were defined by EC Directive 85/337 and implemented in the UK through the Town and Country Planning Act (Assessment of Environmental Effects) Regulations 1988 (SI No. 1199) and a number of subsequent regulations relating to specific types of project (DoE, 1989). The regulations require the preparation of an environmental statement in all cases where developments are classed as 'schedule 1' or where there may be significant environmental effects in 'schedule 2' cases. Where the environmental effects of a development are deemed to be unacceptable planning permission may be withheld and the EIA process can therefore clearly influence the pattern of land use change. Developments subject to EIA (schedules 1 and 2) include a wide range of industries, waste disposal, motorways and other road construction, afforestation, land reclamation and urban development.

3 Impact and quantification of the trends in land use change on water resources

Surface water resources

The main impact of changes in agricultural land use on surface water resources has been through land drainage improvements associated with the conversion of rough grazing to temporary pasture and arable land. However, these changes have little impact on surface water resource yields, more important is the effect on the temporal distribution of flow and in particular on flood peaks. These effects are discussed below.

Similarly, the impact of both urbanisation and the expansion of the road network has largely been in terms of a change in the nature of flow distribution, both on an annual basis and in response to an individual storm. One typical effect of urbanisation is a fall in the water table due to reduced recharge rates with the result that summer low flows suffer a decline. This effect also has important consequences for surface water quality.

In recent years the decline of heavy industry has meant that in some parts of the UK the demand on water resources has fallen. In particular, water resource planning in the 1960s and 1970s to cope with predicted industrial growth has resulted in excess water storage, for example at Kielder Water in Northumberland. Although alternative recreational uses have been found for Kielder Water it remains something of a 'white elephant' and reflects the way in which anticipated, as well as real, changes in the economy and land use can have an influence on water resources.

The most comprehensively investigated and documented effects of land use change on water resources in the UK relate to the growth of forestry over the past 50 years. This major expansion has caused conflict between the forestry and water supply industries as research has quantified the effects of plantation forestry on the quantity and quality of streamflow in the water industry's traditional upland "gathering grounds". Research from as early as the 1950s (Law, 1956) has demonstrated the reduction in runoff and hence yield resulting from upland afforestation.

The results of continued research, such as that at the Institute of Hydrology's Plynlimon research station in Wales, have shown that runoff in upland areas can be as much as 300 mm/year less in forested catchments than in those dominated by open grassland, mainly due to greater evapotranspiration of water from coniferous trees (Blackie, 1994). Figure 9 compares the water balance of two upland catchments in Wales; the Severn, which is largely forested, and the Wye which is not. Annual runoff is clearly less from the forested catchment despite receiving more rainfall in the vast majority of years. The impact of afforestation has been quantified has equivalent to a reduction in yield of 1.5-2.0% for every 10% of a catchment under mature forest (Forestry Commission, 1993).

Water balance components of Rivers Wye and Severn 1969 - 1985 (source: Kirby et al, 1991)

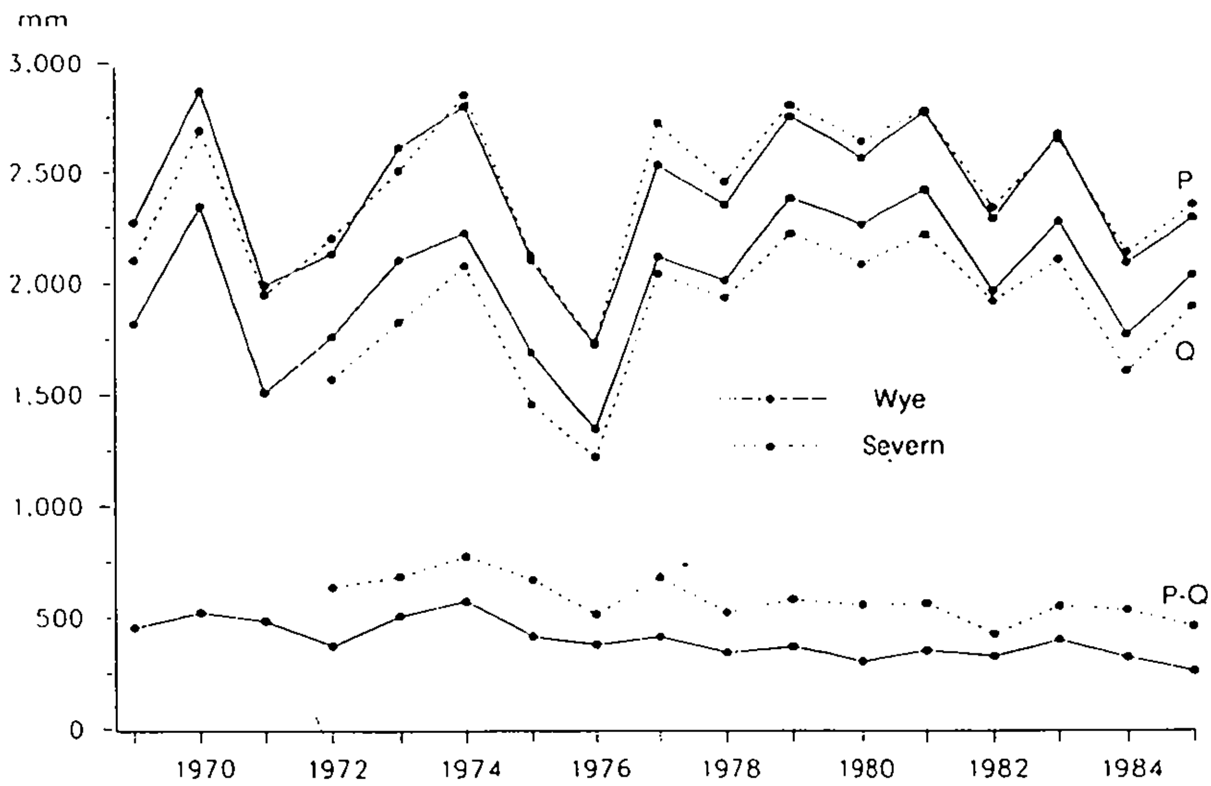


Figure 9

Other research has shown that the impact of upland afforestation can vary considerably from that found at Plynlimon. In certain forested catchments water loss can be less than was the case under previous vegetation. This depends particularly on the evapotranspiration rate of the pre-afforestation vegetation, which can be high in, for example, heather catchments, and the stage of tree growth. At Coalburn in northern England the ploughing and drainage of land prior to afforestation has been found to significantly increase the yield of the catchment (Blackie, 1994). This effect persists through the early stages of tree development for some 18 years before losses return to the previous level due to increased interception and evaporation from the forest canopy. Loss rates also appear to fall after felling although the quantification of this effect is still surrounded by a considerable degree of uncertainty.

Whilst the majority of investigations into the hydrological impact of afforestation in the UK have been concerned with the effect of coniferous forests on the hydrology of upland areas recent proposals for the afforestation of lowland areas with broadleaf species have provided new opportunities for research. In an experimental study conducted in lowland England the water use and water quality of a broadleaf site was compared with that of an area of grassland (Harding et al, 1989; 1992). The findings of the study showed that the planting of broadleaf woodlands has little impact on water use, with a mean annual evapotranspiration rate from ash woodland of 470mm compared to 400mm from open grassland.

There has been little research into the impact of the conservation of wetlands and natural habitats on water resources. Studies to date report both increased and decreased evaporation from wetland areas relative to other land uses (Gilman, 1992). In general it is likely that the restoration and protection of wetland areas will result in a decline in surface water yield for other users, since such areas are usually managed in order to maintain water levels on either an annual or a seasonal basis. More broadly, one impact of growing concern for wetland and habitat management could be an expansion of integrated water resource planning, as an increasing number of water users are having to compete for the available resources.

Groundwater resources

The increase in arable farming and in particular changes in dominant cropping patterns over the past 50 years can be expected to have had some impact on groundwater resources, through the different water use and evapotranspiration rates of different crops. However, it is unlikely that this variation in crop water use is of major significance for groundwater recharge.

Of much greater significance and the subject of much research is the decline in groundwater quality associated with the intensification of agriculture. Of particular concern is the rise in nitrate concentration in groundwater resulting from the conversion of grassland to arable farmland and the increased application of N-based fertilisers, especially in areas of major aquifer recharge in southern and eastern England. A 3 year field study in the chalk downlands of Sussex found that a total of 700 kg N/ha was leached from frequently ploughed fallow land whilst 200 kg N/ha, or 50% of the total quantity of fertiliser applied, was lost from fields of cereal crops subject to fertiliser application (Young, 1986) (see figure 15.5). The decline in groundwater quality associated with leaching of this magnitude is typified by figures from the Triassic sandstone aquifer in the Thames basin which shows an increase in nitrate concentration from 4mg/l in the 1950s to 15mg/l in the 1980s (Wilkinson, 1992).

Urbanisation has had an impact both on the quantity and quality of groundwater resources. The growth of urban areas is typically associated with a fall in the height of the water table due to reduced infiltration and recharge. Associated with such growth is an increase in domestic and industrial water consumption, which, where supply is dominantly groundwater fed, can increase the decline in the water table. However, the reverse is also true and is becoming an increasing problem in several major cities including London. The decline in abstractions from the aquifers underlying the capital has led to rising water tables and associated problems such as drainage difficulties in the London Underground. The large scale extraction of minerals associated with urbanisation can also have a major influence on groundwater levels and patterns of groundwater flow.

Groundwater quality in urban areas is often relatively poor. Pollution can derive from several sources including the discharge of industrial effluents and leakage from city sewerage systems. In addition the decline of heavy industry in many cities has led to large areas of derelict and contaminated land. The risk of groundwater pollution from such sites is often greatest during redevelopment when the ground surface is disturbed, mixing harmful metals, hydrocarbons and other chemicals into the soil profile.

In recent years there has been increasing concern over the potential for pollution of groundwater from landfill sites. This concern relates not only to domestic waste disposal but also to the disposal and storage of industrial, hazardous and radioactive wastes. In total some 8 million tonnes of domestic waste and 60-70 million tonnes of industrial waste is buried in landfills each year in the UK (Parsons, 1986). The main potential pollutants from this waste are a range of organic acids which form as the carbohydrate constituent of the material ferments. Other reactions can occur resulting in the mobilisation of heavy metals. Two alternative strategies exist for waste disposal; containment and 'dilute and disperse'. Whereas the risk of groundwater contamination from a containment site is low, in accordance with some specified level of risk, the dilute and disperse option necessarily involves the flow of leachate into the underlying groundwater. Where properly designed and managed the flow of leachate from such landfills undergoes sufficient dilution so as to minimise the risk of severe groundwater pollution.

The construction of roads can have significant hydrological impact on groundwater regimes. Road construction involves not only the reduction of recharge through the laying of an impervious surface but also can require the excavation of cuttings through geological barriers and the creation of embankments to ease gradients. Operations such as these can disrupt the movement of groundwater and cause changes in the height of the water table. Whilst groundwater levels upslope of a new cutting, for instance, might be expected to fall, those downslope of an earth embankment can rise.

There are also potential water quality impacts of road construction, particularly through the risk of pollution from spills on the road surface. This can not only result in the pollution of surface water but also of groundwater via soakaways in the roadside.

There has been little research into the impact of upland afforestation on groundwater explicitly other than through a consideration of increased evapotranspiration and decreased yields. However, in a recent study focusing on the impact of planting broadleaf forest in lowland England (Cooper and Kinniburgh, 1993) emphasis was placed on the impact on groundwater recharge. Using a model to simulate the uptake of soil moisture under various types of rural land use the study found that the proposed afforestation scheme could, as a result of reduced evaporation, lead to increased groundwater recharge.

In addition, an analysis of water quality changes suggested that the quality of the groundwater would also improve, particularly in terms of nitrate levels. Other research, however, has demonstrated the way in which broadleaf woodlands can increase solute concentrations by atmospheric scavenging (Harding et al, 1992). In particular, this can result in high nitrate concentrations, although remaining lower than under fertilised arable land. This effect was found to vary in degree between different species of tree, with nitrate concentrations lowest under ash woodland.

Wetlands conservation can involve the localised raising of the water table in order to maintain water levels through the year. This can result in changes in groundwater flow patterns and drainage problems for surrounding farmland.

Surface water quality

The increased use of fertilisers and pesticides associated with the intensification of agriculture over the past 50 years has resulted in a deterioration of water quality in many rural areas. Of particular concern has been the increase in concentrations of nitrate and phosphate which has caused severe problems of eutrophication and algal growth throughout Britain. The use of nitrate based fertilisers in the Thames basin increased from 200 000 tonnes in 1949 to 1.5 million tonnes in 1989 (Wilkinson, 1992). There has been a steady increase over recent years in the number of cases in which the nitrate concentration in drinking water supplies has exceeded the EU recommended maximum of 50mg/l. Figure 10 shows trends in nitrate concentrations for four rivers since the late 1920s. Whilst three of these rivers are in dominantly agricultural catchments and have experienced a significant increase in nitrate concentration the fourth, the River Tees, derives largely from an area of upland unimproved moorland and hence, nitrate concentrations have remained relatively stable. The impact of increased nitrate levels in surface water has been demonstrated by a survey performed in 1989 which found algal blooms in 594 out of 914 freshwater bodies, with severe problems recorded in 169 instances (DoE, 1992).

The increased use of pesticides has also had an impact on the quality of surface waters in areas of arable farming. In a study of herbicide pollution in East Anglia Croll (1986) reports concentrations of phenolxyalkanoic acids of up to 5 µg/l and levels of atrazine of up to 1.4 µg/l. These values compare with an EEC Drinking Water Directive of 0.1 µg/l for all herbicide chemicals.

In areas of livestock production problems have been experienced in relation to the contamination of surface waters by diffuse organic pollution. Whilst farm pollution incidents have recieved growing attention less importance has been place in the past on the on-going process by which farm wastes and silage liquor can enter watercourses, both by runoff and leaching.

Trends in nitrate concentrations in four British rivers

(source: Calder, 1993)

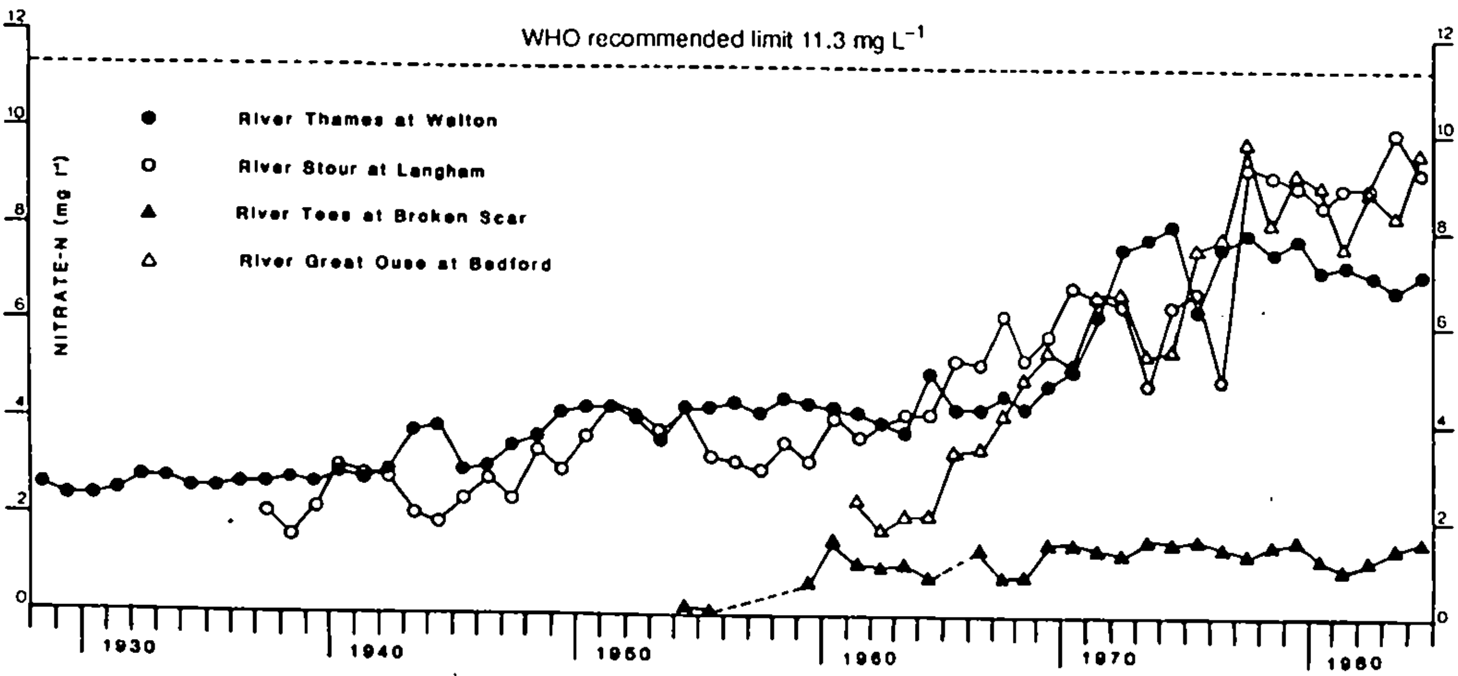


Figure 10

In areas subject to grassland improvement there have also been changes in water quality. In a study based on the monitoring of sites at Plynlimon in Wales a comparison was made of nutrient losses from two drained areas of land, one of which was also subject to cultivation and the application of fertiliser (Roberts et al, 1986). The main findings of the study related to an increase in nitrate concentrations in water draining from the improved land from which, on the basis of modelling studies, it was estimated that a grassland improvement at the catchment scale would result in a fourfold increase nutrient losses.

In addition to the problems associated with the intensification of agriculture, the mechanisation of farming as also had an impact on water quality, if somewhat less directly. The increase in field size resulting from mechanisation has resulted in the loss of a significant proportion of the nation's hedgerows, with an estimated 22% reduction between 1947 and 1985 (Parry et al, 1992). One of the consequences of this has been an increase in soil erosion, both by wind and water. The latter has occurred in response to an increase in the length of furrows associated with larger fields. Water draining along such furrows travels a longer distance before meeting a field border or ditch thereby generating greater erosive power. This has led to increased sediment loads in agricultural waterways, both natural and artificial.

The deterioration of water quality in urban areas is associated with the discharge of effluents from both industry and wastewater/sewage treatment works. The reduction of summer low flows associated with falling water tables has helped to further the decline in water quality standards.

The expansion of the UK's road network has also been associated with a decline in water quality. Sources of pollution include the routine treatment of icy roads with salt, everyday vehicle emissions and major local pollution incidents such as tanker accidents and fuel spillages. Table 2 presents estimated annual loads of selected pollutants based on a study of the water quality of runoff from the M1 motorway north of London (Perry and McIntyre, 1986). Pollutant loads of this magnitude can impose significant additional pressure on waste water treatment facilities and limit the potential reuse of potable water supplies.

***Table** 2 Estimated annual loads of selected pollutants, M1 motorway.*

Pollutant	Load (kg/km/yr)
Total solids (no salting)	2400
Total suspended solids	1500
Total volatile solids	740
Lead	4
Zinc	8
Oil	126
Polynuclear aromatic hydrocarbons	18×10^{-3}

Source: Perry and McIntyre (1986)

The extensive research into the hydrological impact of forestry has found that the expansion of coniferous plantations in the nation's uplands has had important implications not only for water quantity but also for water quality. Sediment yields have been found to be greater in forested catchments as a result of the enhanced soil erosion of forest drains and ditches. Sediment yields in the Coalburn catchment in northern England increased from 4mg/l to 250mg/l after the ploughing of furrows and digging of drainage ditches. The increase in sediment loss from the catchment over the five years after ploughing has been estimated as approximately equal to 50 years of loss at the pre-treatment rate (Robinson, 1994).

Afforestation in hard rock areas with limited chemical buffering capacity has been associated with acidification and increases in concentrations of aluminium and magnesium. In addition the application of pesticides and fertilisers can cause a decline in the water quality of upland streams. The discolouration of water resulting from the disturbance of peaty soils can reduce light penetration with a resulting decline in aquatic plant productivity. Recent research into water quality at Plynlimon has focused not on the impact of afforestation but on the way in which the harvesting of conifers may cause a deterioration in some aspects of stream water quality (Neal et al, 1992). In particular, levels of nitrate and aluminium have been found to increase following logging (see figure 11). Sediment yields also increase, due to the loss of forest cover and the disturbance of soil and other material associated with logging operations (see figure 12). With the loss of the forest canopy, stream water temperatures have also been found to increase, but in contrast with other changes in water quality this may be of potential benefit for stream ecology.

The impact of wetland conservation on water quality is generally assumed to be beneficial, marsh areas representing buffering zones which can help to reduce pollutant concentrations in downstream flows. In areas of peatland, drainage can be detrimental for water quality through the discolouration of streamflow.

Freshwater ecosystems

Freshwater ecosystems have been adversely affected by agricultural intensification over the past 50 years. Increases in nitrate and phosphate concentrations have resulted in widespread eutrophication, a reduction in dissolved oxygen and a resulting decline in the species diversity and density of aquatic ecosystems.

In addition, and against a background of increasing diffuse organic pollution, there has been a growing incidence of farm pollution incidents (see table 3) involving the illegal disposal of animal waste, silage liquor overflows and other chemicals comprising agricultural waste. The resulting increases in BOD and ammonia and growth of sewage fungus have been found to cause reductions in the density and diversity of aquatic macroinvertebrate fauna (Seager, 1992). A number of localised pollution incidents have resulted in severe deterioration in water quality and the creation of 'dead' river reaches.

Changes in different chemical determinands from clearcut and forested catchments, Plynlimon, 1983-90

(source: IH, 1991)

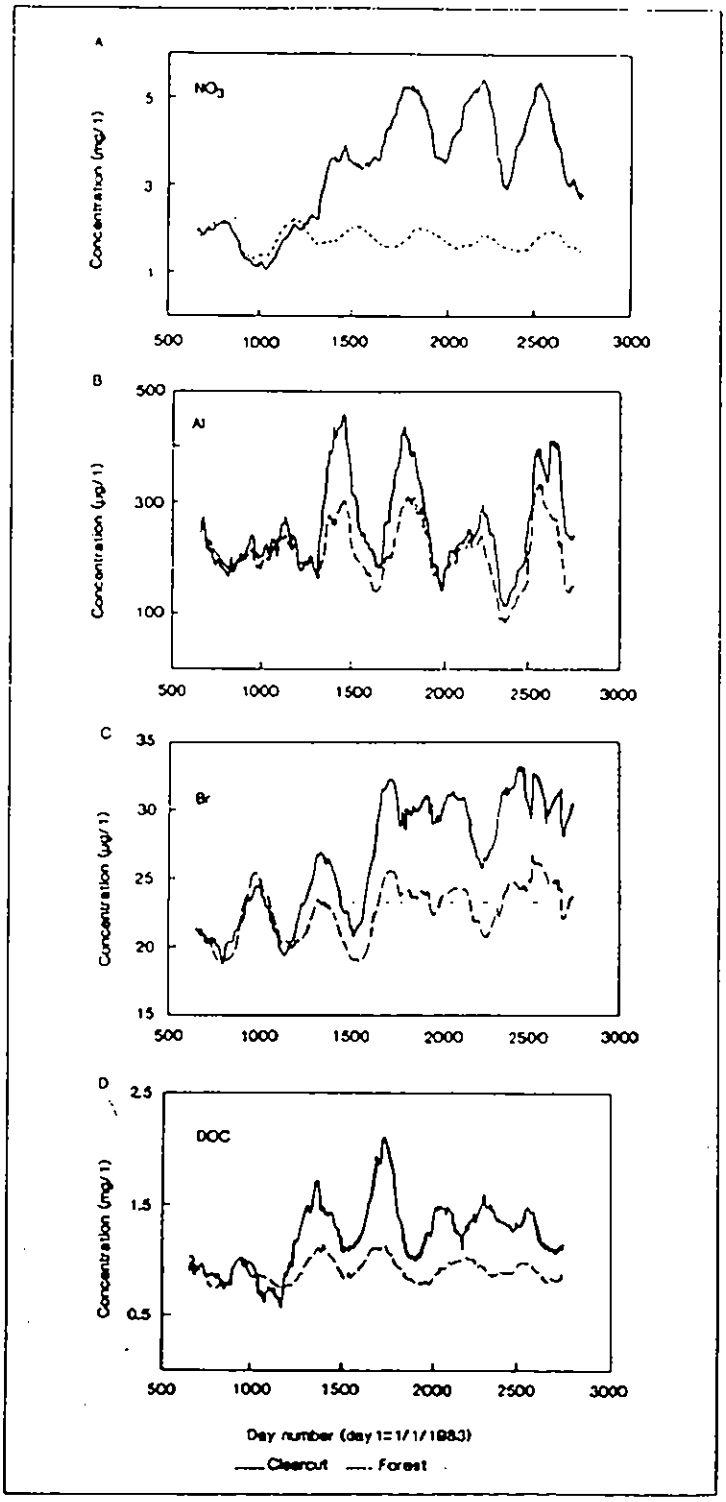


Figure 11

Annual suspended sediment outputs from the Afon Hafren and the Afon Hore subcatchments

(source: Kirby et al, 1991)

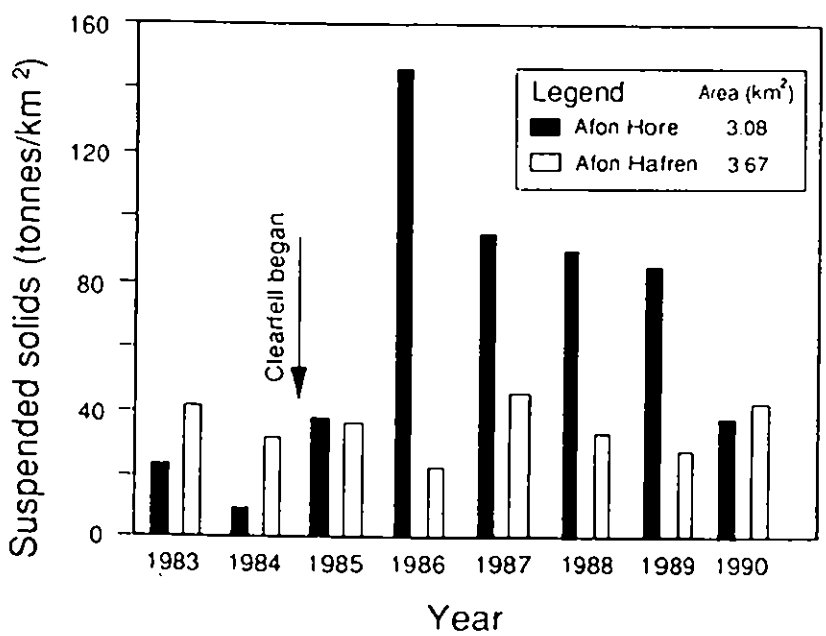


Figure 12

Table 3 Number of serious farm pollution incidents in England and Wales 1974, 1979 and 1984

	1974	1979	1984
Silage	15	189	663
Livestock waste	3	559	1826
Other	43	412	472
Total	61	1160	2961

Source: Hardwick, 1986

The increase in sediment yields associated with forestry ploughing and drainage practices can be extremely harmful for freshwater ecosystems and in particular for fish spawning grounds. In streams with hugh turbidity light penetration is reduced, causing problems for fish feeding and respiration. In spawning grounds the reduced oxygen levels associated with high turbidity can damage the development of fish still in an early life stage. Where sediment settles, siltation can blanket aquatic vegetation and modify substrates leading to a reduction in invertebrate diversity (Forestry Commission, 1993).

A further problem associated with upland afforestation is the loss or reduction in bankside vegetation underneath the forest canopy where conifers have been densely planted alongside stream and river banks. The loss of this vegetation has been found to result in falling trout and salmon populations as the plants both provide shelter for the fish and a habitat for insects on which they feed (Mills, 1986).

In contrast the conservation of wetlands has as one of its aims the restoration and protection of freshwater ecosystems. Successful management of these areas results in greater species diversity and density through the protection or creation of natural and semi-natural habitats to support breeding and feeding requirements.

Flood frequency and low flows

Some of the most important effects of land use change of consequence for water resources relate to changes in the frequency, timing and magnitude of flood flows. The most significant agricultural practice associated with land use change in this respect is the land drainage associated with the improvement of farmland.

In a detailed programme of research involving the field monitoring of plots of artificially drained land and catchments attention was focused on assessing the impact of land drainage on river flows and in particular on flood magnitude (Robinson, 1990). The scope of the study was wide ranging, covering sites of different soil type, drainage systems and land management practices. The main findings of this research indicate that soil type is a very significant factor in determining the hydrological impact of drainage. At the field scale, drainage of clay soils tends to reduce peak flows whilst increasing them in permeable soils.

At the catchment scale many other factors are also of importance and the research indicated that whilst drainage may lower peak flows at the field scale the increased velocity of flow to a main river channel may increase flood magnitudes downstream.

There is a long record of research in the UK in the field of urban hydrology. Of particular relevance is the work undertaken at the Institute of Hydrology on the effects of urbanisation of flood magnitudes and frequency (Packman, 1980). Much of this research has focused on the way in which the increase in impervious area associated with urban development increases the volume and speed of surface runoff when compared to a vegetated catchment. This, combined with the more efficient transport of runoff via artificial drainage and sewerage systems, has been found to cause a reduction in the response time to rainfall and increased peak flows. On the basis of findings such as these the methods for flood frequency analysis developed at IH and presented in the Flood Studies Report (NERC, 1975) have been supplemented with revised procedures specifically designed to cater for urbanised catchments (IH, 1979).

Whilst urbanisation can increase flood risk it has also been associated with falling groundwater levels and reduced river low flows during periods of dry weather. This is caused by a reduction in the proportion of rainfall infiltrating the ground surface.

A specific type of urban development of consequence for river flood regimes is that involving industrial or residential expansion onto river floodplains. This type of development necessarily involves loss in floodplain storage and, when combined with associated river training or localised flood control work, can result in a redistribution of flood risk downstream.

The expansion of the road network has had similar consequences to the increase in urban area. The rapid routing of runoff from the road surface and via subsurface drains combined with the increased volume of runoff, can contribute significantly to increased flood risk and changes in the area most liable to flooding.

The afforestation of Britain's uplands with conifer plantations has as a long term effect that of reducing flood peaks and increasing lag times. Mature forest stands act to 'dampen' the hydrological response of a catchment through increased interception and evapotranspiration. These effects are most significant with low magnitude floods, with the influence of vegetation cover much reduced in the case of extreme events.

Detailed studies such as that at Coalburn near the English/Scottish border (Robinson et al, 1994) have been able to demonstrate the way in which the hydrological impact of upland afforestation during pre-planting drainage and the initial stages of tree growth differ quite markedly from those relating to mature plantations. Of particular significance is the way in which the ploughing and drainage of land before the trees are planted results in higher peak flows (by up to 15-20%), increased low flows and more rapid response times. These characteristics have been found to become less marked as the plantation matures although persisting for 20 years or more before the effects associated with afforestation supersede those resulting from ploughing and drainage.

Wetlands areas can reduce flood risk by acting as a reservoir between upstream and downstream river reaches. Flood peaks are reduced and lag times increased. The restoration of floodplain wetlands is now actively pursued as a flood control measure.

4 Future trends and possible issues in land use change

Climate change

One of the major factors behind the uncertainty surrounding future land use change is uncertainty over the global climate. Climate change and stratospheric ozone depletion, could alter cropping patterns, affect wildlife, and disrupt the living patterns and habits of the world's population. World trading patterns will be forced to respond, with consequent changes in land use (NERC, 1992b).

Parry et al (1992) simulated possible changes in UK land use resulting from climate change. The simulations are based on a scenario which envisages an increase of 1.5°C in summer temperatures and of 1.5-2.5°C in winter temperatures. Rainfall was assumed to increase by 5% in all seasons except summer.

Under this scenario there is a significant northward shift in crop potential across Europe. Areas of southern England could become suitable for crop types such as sunflowers which are not currently grown in the UK. In addition to changes in agricultural land use a shift in climate of this nature could also result in the loss of some of Britain's upland habitats, with every increase of 1.0°C shifting habitat zones upwards by 200 m of altitude.

Other potential causes of land use change

In Europe, the effects of the General Agreement on Tariffs and Trade (GATT) negotiations and the reform of the Common Agricultural Policy are shifting policy away from the post-war emphasis on greater production. Less protected markets will lead to greater fluctuations in commodity prices. Local land use patterns may change sharply in response to economic pressures and opportunities (NERC, 1992b).

Changes in technology will continue to affect land use. Improvements in crop breeding and cultivation practices have allowed agricultural productivity to increase greatly, a trend likely to be continued through development of alternative crops and 'biomass fuels' and advances in bio-technology. If intensive farming is continued, smaller areas will be sufficient to produce the same amount of food. The future disposition of British and European agricultural production, and the use of land surplus to agriculture, are matters of urgent political concern (NERC, 1992b).

Lifestyles and socio-economic arrangements are never static. The increasing demand for rural housing by commuters and retirees, and the dispersal of jobs away from the major conurbations, are changing the structure of rural populations and their demands on the countryside (NERC, 1992b).

Profound changes in environmental attitudes are taking place. There is an expectation that new forms of land use should be environmentally benign, and an increasing desire for land to be used in a sustainable manner. Individual countries and states are responding by encouraging legislative, fiscal and other changes, designed with the requirements of the environment in mind. For example, the creation of Environmentally Sensitive Areas is intended to alter the way in which farmers manage their land to the benefit of wildlife and the appearance of the countryside (NERC, 1992b). The inclusion of EIA in the planning process will also continue to exert an influence on trends in land use change.

Envisaged trends in land use change and potential impact on water resources

During the 1980s, the area of conventional agricultural production fell, and that of forestry increased. These changes are expected to accelerate during the 1990s. However, in contrast to many other parts of the world, this is likely come about in the UK as a result of EUand national policies to reduce production by setting-aside arable land and encouraging the planting of farm woodland (NERC, 1992b). Studies suggest that as much as three million hectares of agricultural land could be surplus to requirement by the end of the century (Blunden and Curry, 1988), an area equivalent to that of northern England between the River Humber and the Scottish border (see figure 13). With much of this land in Britain's agricultural heartlands there could be a significant increase in the area of lowland woodland and forests. Where the planting of conifer plantations continues in upland areas this is likely to be more sensitively managed than in the past with respect to aesthetic, ecological and, more importantly in the context of this discussion, water resource concerns.

There may well be changes in what are considered as conventional uses of land, and where this happens the impacts of widespread new activities are likely to be particularly uncertain. In practice, very few wholly new land uses are likely to be viable, although certain new forms of cropping, such as agroforestry or agro-pastoralism are being explored. Most 'new uses' are essentially concerned with the establishment of existing land uses in situations where they are unfamiliar, or with the adoption of new functions for familiar usages. Leisure uses, such as community forests with significant recreational value, farm forestry for game or conservation, and golf courses seem to be the main possibilities. Short of a major revolution in planning regulations, the simplest long-term non-controversial 'new' land use is some form of woodland.

The extent to which a large-scale afforestation of Britain's lowlands will actually occur, however, remains surrounded by a good deal of uncertainty. The planting of the 'National Forest' in the English Midlands has already come up against several problems so that, to date, only one million out of a proposed thirty million trees have been planted (Pearce, 1994). At the root of the Forest's problems is the question of land ownership. Much of the area to be forested is currently agricultural land and the majority of farmers have as yet shown little inclination to plant trees, being concerned about both the economic viability of afforestation and plans to allow public access. In contrast, developers with interests in mineral extraction and commercial recreation enterprises have been more willing to plant, since this allows them to pursue activities which might otherwise not receive planning permission. These developments, along with recent changes in legislation seeming to promote coniferous and double-density broadleaf afforestation, have led to increased concern amongst environmentalists that the National Forest, and community forests elsewhere, are driven more by economics than by ecology. There is some doubt as to whether these lowland forests will

Potential agricultural land surplus by the year 2000

(source: Blunden and Curry, 1988)

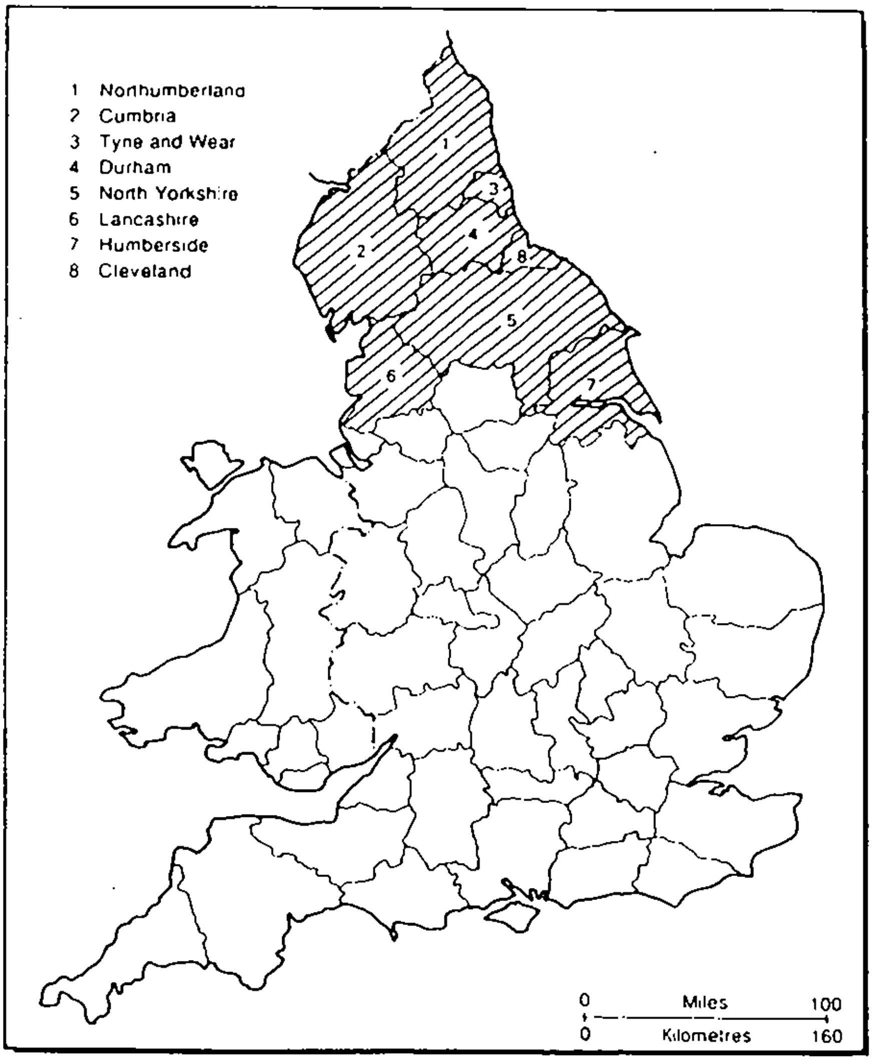


Figure 13

materialise as planned, in which case their impact on land use change may be considerably reduced.

There remains the question of the adoption of more land for housing and roads with an estimated 1.3% of rural land becoming urbanised between 1981 and 2001 (DoE, 1992). As long as demand for new housing and an improved road network continues there will be further loss of land to the extraction of aggregates for construction.

In addition there are likely to be continued moves to re-establish wetlands and to revert to more intelligent management of floodplains. This will coincide with an expansion in the number and area of SSSIs and nature reserves. The total area of intensive arable farming is likely to reduce although the intensity of farming in the remaining areas is likely to remain at today's levels unless positive financial inducements are offered for a decline in the use of intensive practices. Alternatively, there may be a continued increase in the number of farmers opting to concentrate on less intensive forms of agriculture such as organic and free-range farming although this is largely dependent on a continued 'greening' of the markets for agricultural produce.

5 Overview of research addressing land use change effects on water resources

Content and quality of current knowledge base

Information on the land has been gathered and used since the Domesday Book, but many information repositories, such as Land Registers, contain gaps and ambiguities, or do not hold relevant environmental information. Fortunately, the advent of earth observation from satellites and the availability of data in digital formats suitable for rapid computer analysis allow more information to be collected, more rapidly and more comprehensively than ever before. In addition the development and growing sophistication of Geographical Information Systems (GIS) is allowing ever more detailed manipulation of land use and other data for an increasing range of applications.

The National Countryside Surveys (1978, 1984 and 1990), designed and carried out by NERC with support from the Department of the Environment (DOE), the former Nature Conservancy Council (NCC), the British National Space Centre (BNSC) and the Department of Trade and Industry (DTI), have generated an unrivalled database containing hundreds of characteristics of land for the whole UK, based upon a combination of sophisticated sampling on the ground and extensive mapping by satellite (NERC, 1992b).

These surveys have adopted the unique approach to land classification developed by the NERC Institute of Terrestrial Ecology (ITE). All land is allocated to one of 32 distinct classes on the basis of known and stable characteristics, such as geology and climate. This system is now also used as a basis for large scale environmental surveys by many government departments and agencies, universities, planning authorities and others. It is complemented by ITE's land cover map for the whole of Great Britain which distinguishes between 25 identifiable types of vegetation and land cover. This map has been produced using satellite-sensed data validated against field surveys.

An excellent example of how different types of data are being combined to provide new information comes from the Hydrology of Soil Type Programme (HOST) of the NERC Institute of Hydrology (IH). In this, soils data from the Soil Survey and Land Research Centre at the Cranfield Institute of Technology, and the Macaulay Land Use Research Institute in Scotland, are combined with IH data on water storage and movement characteristics to create a database of soil/hydrological classes for the UK. The 29 HOST classes help to identify areas susceptible to flooding, low water flows and groundwater pollution.

Existing land use and monitoring of change

Current land use in the UK is most comprehensively described by the ITE land cover classification outlined above. Data for this and other maps of land use are compiled from a number of sources including field survey, aerial photography, satellite imagery and a range of local, regional or specialist surveys such as those carried out by MAFF and the Ordnance Survey (Bunce et al, 1992).

Changes in UK land use have been monitored through the Countryside Surveys of 1978, 1984 and 1990. The Survey has benefited from the combined expertise of a collaboration of organisations: ITE, DOE, BNSC and the former NCC. Data on land use is compiled by detailed sampling across the UK. There have been a wide range of applications involving the Countryside Survey including EIA and water quality monitoring.

Identification of water resource sensitive areas

There has been a major, and ongoing, initiative in recent years relating to the identification of groundwater resource sensitive areas through the NRA's Groundwater Protection Policy. This policy aims to achieve the UK government's Statutory Water Quality Objectives laid down in the Water Resources Act of 1991 through a range of practices designed to reduce pollution from both point and diffuse sources (NRA, 1992). The policy also covers aspects of water quantity, especially the problem of reduced low flows associated with the over abstraction of groundwater.

There are three main components within the framework of the NRA's policy. The first of these involves the classification and mapping of groundwater vulnerability across England and Wales based on the properties of soil cover, drift, geological strata and depth to water table. The second aspect of the policy is the definition of Source Protection Zones based on pollutant travel times and source catchment areas. The NRA aims to produce maps of around 750 Source Protection Zones in relation to groundwater sources used for major public water supply. Finally, the NRA has produced a series of policy statements relating to all aspects of protection including control of abstractions, waste disposal, contaminated land, disposal of slurries and diffuse pollution. By combining information on groundwater vulnerability, source protection and control of potentially harmful practices the Groundwater Protection Policy will become an important part of the NRA's involvement in the planning process affecting development and changes in land use at the local and regional level.

A more specific development in recent years has been the designation of Nitrate Sensitive Areas (NSAs) and Nitrate Vulnerable Zones (NVZs) in line with EU policy. In the NSAs farmers receive a subsidy linked to the reduction in fertiliser use or the conversion of arable farmland to low intensity grassland. In the NVZs free advice is given to farmers on ways to reduce the risk of nitrate leaching (DoE, 1992).

Principal ongoing research

There is a wealth of research in the UK in the separate fields of land use change and water resources. Where perhaps less effort has been concentrated is at the interface between the two fields. However, with growing pressure on water resources and an increased awareness of the significance of land use change, more emphasis is being placed on research concerned specifically with this issue.

At the forefront of this research is the National Environmental Research Council, through long term studies performed at the Institute of Hydrology (IH) and Institute of Terrestrial Ecology (ITE) and a more recent initiative, the NERC/ESRC Land Use Change Programme (NELUP), which also involves the Economic and Social Research Council (ESRC). A large proportion of the research in this area performed by NERC Institutes has been funded or part-funded by government departments and in particular the Department of the Environment (DoE), the Scottish Office Environment Department (SOED) and the Welsh Office (WO).

Much of the IH's extensive research into the hydrological effects of land use change has been concerned with forestry, and in particular the impact of coniferous afforestation in areas of upland Britain on water resources. In 1967 the Institute established a pair of experimental catchments at Plynlimon, mid-Wales (Kirby et al, 1991). A programme of research was designed which would compare the hydrology of the mainly grassland catchment in the Upper Wye valley with that of the headwater catchment of the River Severn, 70% of which was forested. Although the initial objective of research at Plynlimon was to assess the impact of afforestation on yields, the scope of the study has expanded greatly over the past 25 years. Whilst the assessment of catchment water balances continues, this work has been supplemented with detailed studies of hydrological processes and of water quality. The effects of progressive felling of the forest area are now being studied at both the process and catchment scale.

In addition to the programme of research performed at Plynlimon the Institute has undertaken catchment studies in other areas of the UK subject to afforestation. In the early 1980s a similar dual catchment experiment was set up at Balquhidder in the Scottish Highlands in response to a perceived need for research in an area which differed from Plynlimon in terms of both climate and vegetation (Whitehead and Calder, 1993). Whereas the pre-afforestation vegetation at Plynlimon is dominantly grassland, that found at the Balquhidder catchments consists of a much rougher mix of heather and other moorland species. The Balquhidder catchments are also located in more rugged terrain and are subject to a harsher climate, with a greater proportion of precipitation falling as snow. Research at Balquhidder has been broadly along the same lines as that at Plynlimon, with particular emphasis on process studies involving the estimation of evapotranspiration from the varying types of vegetation.

Both the Plynlimon and Balquhidder catchment studies have involved a comparison between a catchment of mainly open moorland vegetation and a one in which mature coniferous forest is the dominant land use. In another study at Coalburn in northern England a single catchment has been monitored continuously from the original moorland vegetation through land preparation, planting and tree growth to the canopy closure stage (Robinson, 1980; Robinson et al, 1994). Studies at Plynlimon, Balquhidder and Coalburn are scheduled to continue for the foreseeable future.

In a separate study the impact of broadleaf afforestation on the water resources of Britain's lowlands has been investigated. The project involved field studies at two sites in southern England, one above a chalk aquifer and the other on clay. The study involved investigation of the impact of broadleaf woodland on the water balance and surface water and groundwater quality (Harding et al, 1992). A follow up study of the effects of intensive coppicing, as an energy source, is now under way.

Whilst IH has led research into the impact of land use change on water resources ITE is at the cutting edge of research into land use classification, the monitoring of land use change and the ecological impact of land use change. The system of land use classification developed by ITE is fundamental to many other lines of research, including NELUP.

The NERC/ESRC Land Use Programme (NELUP) at Newcastle University is developing a series of linked models, starting with economic changes in the agricultural sphere, leading through to models of changes in cropping area in a given catchment, with consequent changes in the use of agrochemicals. The models explore the impacts upon both water resources and ecology. With this type of approach, the environmental consequences for a whole catchment can be deduced from specified changes in pricing or quota policy within agriculture (NERC, 1992b).

The aims of NELUP are threefold: the collation of detailed data from disparate sources and disciplines; the modelling of the impact of land use change resulting from economic stimuli on hydrology and ecology; and the use of the simulation models as a decision support system for long term strategic planning (O'Callaghan, 1992). The user will be the heart of the NELUP system and will communicate with the Decision Support System, which can synthesise the results of the component economic, hydrological and ecological models via a Geographical Information System (GIS) to examine the impact of policy change on the system as a whole. Such programmes are at the cutting edge of land use research, and will evolve rapidly to take advantage of new developments in information technology, land use theory and data acquisition.

Information on land use is provided for a 1km grid from the ITE land cover classification, supplemented by data from MAFF censuses and the farm business survey. In a pilot study, the NELUP system has been applied to the River Rede catchment, a tributary of the River Tyne in north-east England (Dunn et al, 1992; Lunn et al; 1992; and Rushton; 1992). The hydrological impact of land use change in the catchment has been modelled using the physically-based, spatially distributed model, SHE.

Much relevant research into the impact of land use change on water resources is funded by the National Rivers Authority (NRA). On-going projects in the area of rural land use include research into alternative land management techniques for soil and nutrient conservation and the impact of conifer harvesting on water quality and sediment loads (NRA, 1994). Relevant research into groundwater pollution is concentrating on the development of remedial treatment methods for contaminated land, risk assessment methodology for landfills and the long term monitoring of non-containment landfills. The NRA also sponsors a large research effort in the field of conservation. Studies include research into the rehabilitation of degraded habitats (relating to land use and river management practices), wetland creation and conservation and river corridor enhancement.

In addition to the many on-going research programmes funded by the National Rivers Authority, the NRA has also published proposals for several new projects relating to the impact of land use change (NRA, 1994). The most significant of these is 'land use and management change' which aims to "provide strategic information on the distribution, impact and degree of land use change on NRA's statutory duties." In addition a number of more specific proposals have been made. Of particular relevance for rural land use change are proposals for research into alternative farming methods, both in order to reduce phosphate pollution from milk production and to reduce pesticide use in arable farming (NRA, 1994). There are also several proposals for the development of new methods for catchment appraisal and control, especially in relation to the assessment of the impact of floodplain development on flood risk.

Other authorities with responsibility for research into the impact of land use change include government departments with, in addition to the DoE, SOED and WO as mentioned above, the Ministry of Agriculture, Fisheries and Food (MAFF) having a major involvement. Within the Ministry the Land Use, Conservation and Countryside Group (LUCC) has responsibility for policies relating to land use, including planning, land tenure and alternative uses of agricultural land, and conservation. This involves integration of environmental and agricultural policies in the reformed CAP. Under its programme of research LUCC is currently focusing on ESAs, farm diversification and the Farm Woodland Scheme. One scientific objective under research in this latter field is "to investigate the effects of farm woodland on water quality and quantity" (MAFF, 1994).

A second group within MAFF with responsibility for relevant research is the Environmental Protection Division. A principal research theme of this division is concerned with the control of nitrate pollution from agriculture. This research aims to "provide information on how nitrate leaching from agriculture might be reduced so as to enable compliance both with the 1980 EC Drinking Water Quality Directive and with the 1991 EC Nitrate Directive at least cost to the farmer and taxpayer, taking account of wider environmental considerations" (MAFF, 1994). This involves studies into farming systems which reduce nitrate loss via all the major pathways including surface water and groundwater transport. The division is also involved in research into the control of farm wastes and the impact of climate change on agriculture.

Perceived gaps in knowledge base and future research priorities

It is evident that research into the impact of land use change on the quantity and quality of water resources is a major component of hydrological research in the UK. It is also clear, however, that the current level of knowledge is far from complete especially in relation to some of the more recent developments in land use change and water resource management. Areas in which the level of knowledge is relatively poor include:

- Impact of set-aside and lowland broadleaf afforestation on groundwater yields and quality;

- Impact of climate change, including rise in sea level, on land use and water resources;

- Ability of wetlands to act as buffer zones and reduce concentrations of pollutants in surface waters; and

- Impact of second generation plantations and changes in management practices in areas of upland coniferous forest (eg phased felling, mixed planting, river management).

Future research priorities should include projects to improve the level of understanding of these relatively new, and increasingly important, influences on water resources. In some cases such research can be included as part of the evolution of existing programmes, for example hydrological studies in areas of upland coniferous forests will continue to monitor change through the planting and growth of a second generation of trees. In other areas, however, new initiatives are required if we are to predict the implications of Britain's changing landscape for the nation's water resources.

References

Blunden, J. and Curry, N. 1988. A future for our countryside. Oxford: Blackwells,224p.

Bunce, R.G.H., Barr, C.J. and Fuller, R.M. 1992. Integration of methods for detecting land use change, with special reference to Countryside Survey 1990. In Whitby, M.C. (ed), 69-78.

Calder, I.R. 1993. Hydrologic effects of land-use change. In Maidment, D.R.M. (ed) Handbook of Hydrology. McGraw-Hill, 13.1-13.50.

Cooper, J.D. and Kinniburgh, D.G. 1993. Water resource implications of the proposed Greenwood Community Forest.

Croll, B.T. The effects of the agricultural use of herbicides on fresh waters. In Sorbe (ed), 201-209.

Department of the Environment. 1989. Environmental Assessment - a guide to the procedures. London: HMSO.

Department of the Environment. 1992. The UK Environment. London: HMSO, 258p.

Dunn, S., Savage, D. and Mackay, R. Hydrological simulation of the Rede catchment using the système hydrologique Européen (SHE). In Whitby, M.C. (ed), 137-146.

European Commission. 1987. The state of the environment in the European Community 1986. Luxembourg: Office for Official Publications of the European Communities, 369p.

Forestry Commission. 1993. Forests and Water Guidelines, Third Edition. London: HMSO, 32p.

Gilman, K. 1992 Hydrology and wetland conservation. Institute of Hydrology Report.

Harding, R.J., Hall, R.L., Roberts, J.M., Rosier, P.T.W. and Wright, I.R. 1989. Hydrological impacts of hardwood plantation in lowland Britain.

Harding, R.J., Hall, R.L., Neal, C., Roberts, J.M., Rosier, P.T.W. and Kinniburgh, D.G. 1992. Hydrological impacts of broadleaf woodlands: Implications for water use and water quality.

Hardwick, D.C. 1986. The uses of water in UK agriculture and horticulture. In Sorbe (ed), 180-193.

IH. 1979. Design flood estimation in catchments subject to urbanisation. Flood Studies supplementary report 5.

Kirby, C., Newson, M.D. and Gilman, K. 1991. Plynlimon research: the first two decades. IH

Report 109.

Law, F. 1956. The effect of afforestation upon the yield of catchment areas. J. Brit. Waterworks, 38, 484-494.

Lunn, R., Younger, P.L., and Mackay, R. 1992. Development of a methodology for hydrological simulation at the basin scale using SHE. In Whitby, M.C. (ed), 147-158.

Mills, D.H. 1986. The effects of afforestation on salmon and trout rivers and suggestions for their control. In Sorbe (ed), 422-431.

Ministry of Agriculture, Fisheries and Food. 1994. MAFF Environment Research Strategy and Requirements Document 1994-96. London: MAFF Publications, 43p.

Munton, R.J.C., Lowe, P. and Marsden, T. 1992. The social, economic and political context. In Whitby, M.C. (ed), 15-27.

National Environment Research Council. 1975. Flood Studies Report. The Natural Environment Research Council, London.

National Environment Research Council. 1992a. Environmental Aspects of Land Use Change. NERC Conference, The BAFTA Centre, 6 May 1992.

National Environment Research Council. 1992b. The Land of Britain, Land Use Research For the Future. Swindon: NERC, 15p.

National Rivers Authority. 1994. Policy and Practice for the Protection of Groundwater. Bristol: NRA, 52p.

National Rivers Authority. 1994. NRA Research and Development Programme - 1994/95. Bristol: NRA, 27p.

Neal, C., Smith, C.,J. and Hill, S. 1992. Forestry Impact on Upland Water Quality. IH Report No. 119. Wallingford: Institute of Hydrology, 50p.

Newson, M.D. Impact of lowland forestry on water quality. University of Newcastle upon Tyne Department of Geography Seminar Paper No. 60, 47p.

O'Callaghan, J.R. 1992. Decision-making in land use. In Whitby, M.C. (ed), 79-87.

Packman, J.C. 1980. The effects of urbanisation on flood magnitudes and frequency, IH Report 63.

Parry, M.L., Hossell, J.E. and Wright, L.J. 1992. Land Use in the United Kingdom. In Whitby, M.C. (ed), 7-14.

Parsons, R.J. 1986. Waste disposal from urbanisation and its influence on fresh waters. In Sorbe (ed), 85-94.

Perry, R. and McIntyre, A.E. 1986. Impact of motorway runoff upon surface water quality. In Sorbe (ed), 53-67.

Pearce, F. 1994. Greening the Heart of England. New Scientist, 1944: 30-35.

Phillips, A.A.C., 1992. A policy perspective on land use change. In Whitby, M.C. (ed), 173-175.

Roberts, G., Hudson, J.A. and Blackie, J.R. 1986. Effects of grassland improvements on the quality of upland streamflow. IH Report 96.

Robinson, M. 1990. Impact of improved land drainage on river flows. IH Report No. 113. Wallingford: Institute of Hydrology, 226p.

Robinson, M., Jones, T.K. and Blackie, J.R. 1994 The Coalburn catchment experiment - 25 year review. NRA R&D Note 270.

Rushton, S.P., Byrne, J.P. and Young, A.G. 1992. Redesdale: a preliminary test catchment for the NERC/ESRC Land Use Programme. In Whitby, M.C. (ed), 169-173.

Seager, J., Jones, F. and Rutt, G. 1992. Assessment and Control of Farm Pollution. J.IWEM, 6: 48-53.

Solbe, J.F. de L.G. (ed) 1986. Effects of land use on fresh waters. Chichester: Ellis Horwood, 568p.

Whitby, M.C. (ed) 1992. Land use change: the causes and consequences. ITE symposium no. 27. London: HMSO, 201p.

Whitehead, P.G. and Calder, I.R. (eds) 1993. The Balquhidder catchment and process studies. J. Hydrol. Special Issue, 145 (3-4).

Wilkinson, W.B. 1992 Hydrological Aspects: Impacts on Water Yield and Quality. At NERC, 1992a.

Young, C.P. Nitrate in groundwater and the effects of ploughing on release of nitrate. In Sorbe (ed), 221-237.