Project 003

Impact of Lowland Forestry on Water Quality

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IMPACT OF LOWLAND FORESTRY ON WATER QUALITY

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IMPACT OF LOWLAND FORESTRY ON WATER QUALITY

by M D Newson

SUMMARY

Present public policies to encourage the planting of woodland in the lowlands of England and Wales are contemporary but inconsistent with policies designed to improve water quality in rural areas. Nevertheless, it is widely assumed that afforestation under the Set-Aside scheme may result in an improvement of river water quality.

The literature on the water quality effects of broadleaved forests in the lowlands is very sparse. In the lowlands small-scale, short-duration ecological studies have been carried out on chemical cycling. Results from long running, highly-resourced catchment experiments abroad (eg Hubbards Brook, Coweeta) may be transferred only with great care, in direction of effects but not magnitude. The literature concludes that tree canopies are efficient at trapping aerosols (including pollutants) but that mature forest soils act as huge and modulating storages of elements. The most profound stream effects are recorded after "biotic deregulation" of chemical cycles, eg felling; even so, there is inherent resistance and resilience in the system under forests and good management can promote both. Sediment yields under forestry are potentially high; again management is all-important.

Recent and ongoing research specific to lowland England and Wales is likely to be inadequate as a working base for NRA policy. Recommendations are given for research including identification of policy options open to NRA and on decision-support systems for policy intervention.

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CURRENT TRENDS IN LAND AND WATER MANAGEMENT

Two major trends of public policy development which have potentially major repercussions for river basin management are occurring at the same time as the privatisation of the water industry in England and Wales. They are:

(i) Adjustment of levels of agricultural production in the European Community via policies leading to less intensive land-use practices. Notable amongst these policies is Set-Aside (MAFF 1988a)

(ii) Controls of land-use and land management in support of long term improvements of water quality. These may be voluntary, in the form of "good practice" (MAFF/ Forestry Commission 1988) or statutory; notable amongst statutory controls is the EC's draft Directive (EC Document 4136/89) on "vulnerable zones", currently being translated by the UK Government into policies for Nitrate Sensitive Areas (NSAs) (Dept of the Environment 1988, House of Lords 1989).

It should be noted, too, that the water industry's concerns over short-term improvements in pollution control are also extending to agricultural practice via tighter codes of good practice in relation, particularly, to livestock farming and its episodic discharges of silage liquor and slurry (see Water Authorities Association 1988, Water Act 1989).

Figure 1 attempts to show these two parallel developments; at present they do not produce identical outcomes. For example the Set-Aside policy is not a long-term one; even within the farm unit there can be a rotation of land into and out of Set-Aside - it is the modern equivalent of fallow, but its duration is five years, not one year. Nitrate Sensitive Areas, however, imply a much longer term objective. This policy circumvents most current arguments over water quality standards (notably that between 50 mg l^{-1} and 100 mg l^{-1} nitrate content as the

Maximum Allowable Concentration) in favour of interpreting the long term trends in the nitrate content of groundwater and adopting a long term "precautionary principle".

A change of land use from agriculture to forestry is a major option interpreted from both direct and indirect policy signals. Direct encouragement comes from:

(i) The continuing desire to achieve more self-sufficiency in timber supplies, translated by Government into the Forest Grant Scheme for private plantation initiatives (reformed after the tax benefits from plantation were reduced by the 1988 Budget).

(ii) The search by farmers for a more diverse production profile, encouraged by the Farm Woodlands Scheme (MAFF et al 1988) announced in November 1987. At present farm woodland constitutes under 15% of British forestry (Monks and Brittan 1989 and Figure 2).

Indirect encouragement comes from:

(i) The Set-Aside scheme, which has two woodland options (MAFF 1989).

(ii) The House of Lords Select Committee (1989) concluded that the corollary of setting up NSA's was, after an assessment of the costs to arable agriculture in terms of reduced output, "to put land down to grass or to plant trees" (para 157).

Thus, it is highly likely that **afforestation of farmland will be a staple recipe for managing problems of both land and water in the EC.** This raises major problems for both our knowledge-base and our institutional reactions in river basin management. The National Rivers Authority (NRA) in England and Wales (DoE, MAFF, Welsh Office 1987, MAFF 1988b) has a particularly difficult institutional role since its responsibility for the river network, and for the prevention of pollution thereof, places it between land-use issues and water quality issues. The licensing of water abstractions to the privatised supply industry carries a responsibility for the legal and economic consequences of pollution. The need to adopt both the "precautionary principle" and the "polluter pays principle" will see increasing intervention by the NRA in land use issues. Meanwhile the NRA is directly responsible for the health and vitality of the river network. The major problem of the knowledge-base from which NRA must decide policy on farm forestry is that, whilst most of the uptake of afforestation will be lowland, most of the available UK research on the water quality implications of afforestation has been upland. In similar contradiction are the respective species of tree, their management through the crop cycle and the duration of that cycle: we know very little about short (coppicing) or long (timber) rotations for hardwoods but much more about the intermediate conifer (softwood) rotation. The land use which precedes the two forms of afforestation also differs. Upland conifer plantations generally replace moorland which has been undisturbed for 4000 years and which has severe problems of nutrient and drainage status; in the lowlands, trees are also an attractive crop for "difficult" land, but under present policy direction may well ultimately be planted on fertile, cultivated, drained soils under benign climatic conditions.

It is necessary to consider the effects of woodlands in a spatially- and temporally-distributed way. The precise direction and magnitude of any effect will depend on the location of the parcel of land in question in relation to aquifers or to the channel network and the relation of the nearest channel link to the network as a whole. Because we are discussing trees as a crop the effects will vary through the crop cycle and also with management practices (which may well change through time). We now understand that climatic conditions are unlikely to remain stable during the lifetime of the lowland forests now being contemplated and climatic changes need to be considered in making a response. It is a chilling thought that one of the most attractive oakwoods in England was planted (in Northumberland) by Admiral Collingwood on his return from Trafalgar in order to supply, on maturity, timber for battleships!

SECTION 2 - THE EUROPEAN COMMUNITY COMMON AGRICULTURAL POLICY (CAP) "SET-ASIDE" PROGRAMME

The UK joined the European Community (EC) on 1 January 1973 and entered a five-year transition to the high levels of agricultural price support fixed by the original six members to encourage food production after the devastation of World War II. As a result production increased rapidly: in terms of gross value added there has been a 50% expansion of UK production since 1973 and a rise to 83% self-sufficiency in indigenous food types (Marks and Britton 1989). Nevertheless, the number of people involved in agricultural production is only 2.6% of the working population and UK agriculture's share of the total national GDP is the lowest in Europe (1.8% in 1986). Consequently it has been politically easy to "put the brakes on" UK agriculture in order to balance EC production and achieve other goals, principally environmental improvement. Set-Aside must be seen in these contexts although it is primarily a production policy and has been criticised as myopic by environmentalists (Burnham 1989). Latterly, therefore, in East Anglia, Northants, Bedfordshire and Hertfordshire top-up payments have been added to Set-Aside grants with the specific aim of bringing about environmental improvements.

2.1 OVERALL UPTAKE OF, LOCATION OF, AND APPROACHES TO "SET-ASIDE"

The UK has a commitment under the CAP to reduce agricultural production by 20%. Subject to terms and conditions (MAFF 1988) any UK farmer who takes 20% or more of his/her holding out of production for a minimum of 5 years can qualify for grants of approximately £200 per hectare (depending on alternative land use chosen and land classification). Four land use options are offered:

- fallow
- non-agricultural use, eg leisure, rural industries
- small-scale (space and time scales) afforestation
- large-scale " " " "

Because the UK was one of the first EC countries to announce Set-Aside in detail it is already in place for the 1989-90 crop year. MAFF announced in February 1989 that 1820 farmers had set aside a total of 58 000 hectares of land in the scheme. The average area set aside on participating farms is 32 ha, representing on average 28% of that farm but nearer 60% of the eligible arable area. One third of all applicants chose to set aside all of their arable land eligible for the scheme. One third of the applications came from tenant farmers, an important boost for the scheme in some regions. Whilst the largest, most progressive cereals growers were thought unlikely to join, MAFF regarded with satisfaction the fact that Norfolk returned the fourth highest uptake by county.

Tables 1, 2 and 3, taken from MAFF (1989) present total uptake, geographical breakdowns and options taken up for 1988-89. They show quite clearly the following trends:

(i) Table 1 demonstrates clearly the dominance, in terms of uptake, of land in England and of fallow as an option. The table also indicates that woodland schemes are a relatively small contributor to Set-Aside uptake (1.8% of all land set aside).

(ii) Table 2, whilst showing that 8 counties dominated the list of participants (N Yorks, Norfolk, Suffolk, Essex, W Sussex, Oxfordshire, Bucks and Devon cover nearly 40% of participants) they cover rather less of the total land set aside (33%).

(iii) In relation to rivers policies the figures need to be converted into the proportion of the total land in each county. This is done in Figure 3. The map further confirms the Home Counties as dominant in uptake.

(iv) In relation to the main theme of this report, ie lowland afforestation, it appears that, in the three regions providing the lion's share of participants and land (East Midlands, East Anglia, South East), less than 2% of the land in the scheme has been approved for the afforestation option. By contrast, figures of 6% in Scotland and 4.4% in the North suggest that afforestation is a more likely option in the 10% of the uptake area which lies within Less Favoured Areas. In such areas the afforestation is likely to be in or close to the upland zone and with conifers, although from October 1988 there has been a ban on conifer plantation over 800 ft AOD in England (Royal Forestry Society 1989).

Table 1 - Uptake of Set-Aside, 1989-90, by country and option

a) Total UK uptake and distribution by country

	No of farms	Hectares Set-Aside
England	1 314	40 205
Scotland	450	16 183
Wales	35	1 015
NI	17	210
Total UK	1 816	57 613

Note: About 10% of the total area of land entered into the scheme is in the less favoured areas.

b) Split between the land-use options

	No of farms*	Hectares Set-Aside
Permanent fallow	1 430	45 460
Rotational fallow	274	7 104
Woodland (set-aside option)	61	375
Woodland (FWS option)	71	652
Non-agricultural use	298	4 021
Total hectarage set-aside		57 613

* Some farmers are participating in more than one option

Table 2 - Participants and areas of Set-Aside in English counties, 1989-90

County	No of participants	Total area Set-Aside (ha)	Average area participant (ha)
AVON	16	396.67	24.79
BEDFORDSHIRE	23	1234.71	53.68
BERKSHIRE	20	850.65	42.53
BUCKINGHAMSHIRE	63	2496.18	39.62
CAMBRIDGESHIRE	38	1457.34	38.35
CHESHIRE	18	358.49	19.92
CLEVELAND	4	127.93	31.98
CORNWALL	34	800.06	23.53
CUMBRIA	7	384.56	54.94
DERBYSHIRE	19	259.34	13.65
DEVONSHIRE	68	1349.16	19.84
DORSET	23	637.19	28.57
DURHAM	13	281.87	21.68
ESSEX	59	1658.59	28.11
GLOUCESTERSHIRE	39	1391.23	35.67
GREATER LONDON	5	154.69	30.938
GREATER MANCHESTER	6	69.18	11.53
HAMPSHIRE	39	1365.35	35.01
HEREFORD/WORCS	25	423.99	16.96
HERTFORDSHIRE	30	2063.63	68.79
HUMBERSIDE	33	1081.97	32.79
ISLE OF WIGHT	3	57.34	19.11
KENT	46	1281.70	27.86
LANCASHIRE	10	85.21	8.52
LEICESTERSHIRE	21	494.55	23.55
LINCOLNSHIRE	35	1508.12	43.09
MERSEYSIDE	8	174.43	21.80
WEST MIDLANDS	3	31.61	10.54
NORFOLK	65	1763.47	27.13
NORTHAMPTONSHIRE	44	1862.69	42.33
NORTHUMBERLAND	20	1019.09	50.95
NOTTINGHAMSHIRE	15	519.50	34.63
OXFORDSHIRE	51	1284.88	25.19
SHROPSHIRE	12	186.44	15.54
SOMERSET	23	559.69	24.33
STAFFORDSHIRE	20	636.74	31.84
SUFFOLK	83	1911.80	23.03
SURREY	31	1176.52	37.95
EAST SUSSEX	30	767.40	25.58
WEST SUSSEX	50	1448.17	28.96
TYNE AND WEAR	5	151.97	30.39
WARWICKSHIRE	40	1084.86	27.12
WILTSHIRE	30	1236.47	41.22
NORTH YORKSHIRE	70	1645.59	23.51
SOUTH YORKSHIRE	12	377.27	31.44
WEST YORKSHIRE	5	76.48	19.20
	1 314	40 204.77	30.60

Table 3 - Regional allocation of Set-Aside including land-use (options, 1989-90)

Region	Number of applications	in ha	Area to be set-aside of which %					Proportion of the area set-aside as a percentage of		Average area set-aside per applicant (in hectares)
			rotational fallow	permanent fallow	afforest-ation	extensive grazing	Non agri use	arable land (1)	area in cereals (1)	
North	47	1.947	10,5	79,2	4,4	--	6,5	1,0	1,2	41,4
Yorkshire & Humberside	107	3.079	15,6	74,8	1,9	--	7,5	0,5	0,7	28,7
East Midlands	134	4.532	5,1	85,1	1,0	--	7,7	0,5	0,7	38,8
East Anglia	177	5.089	20,4	70,3	1,7	--	7,4	0,6	0,8	28,7
South East	489	16.949	8,6	81,3	0,8	--	9,9	1,6	2,1	34,6
South West	239	6.529	12,7	77,5	1,7	--	6,5	1,2	1,5	27,3
West Midlands	96	2.346	8,3	75,3	0,7	--	12,3	0,5	0,8	24,4
North West	38	.704	13,9	61,2	2,3	--	23,8	0,7	1,1	18,5
Wales	31	.701	25,4	67,3	0,9	--	6,4	0,2	1,0	22,6
Scotland	377	12.726	33	34,8	6	--	12,9	1,1	2,4	33,7
North Ireland	15	.177	8,5	38,1	1,9	--	51,4	0,2	0,3	11,8
Total United Kingdom	1,750	54.779	11,0	79,6	1,4		7,7	0,9	1,3	31,3

Source: Information communicated by the Member State, 16 June 1989

2.2 INCENTIVES TO AGRICULTURE FOR AFFORESTATION

With the remarkably small area entering Set-Aside forestry and with the domination of that area by schemes which are most likely to be upland or marginal we need to investigate the full scope of policies intended to encourage woodland plantation as an alternative to lowland agriculture.

Under Set-Aside the Forestry Commission pays nearly all of the grant for both woodland options and the amount of grant is attractive compared with other Set-Aside options, especially for broadleaved plantations (50% greater than for conifers). The greatest incentive is for small broadleaved plots (0.25-0.9 ha) - at £1575 per ha. However, the Woodland Grant Scheme, under which this Set-Aside option runs (Set-Aside payments are additional) reduces to zero after 10 years, begging the question of wise husbandry. At present, felling requires a licence from the Forestry Commission and their main condition for acceptance is replanting. "In recognition of the need to reassure farmers that the land in question may not be lost to agriculture permanently, there will be a presumption in favour of granting licences for woodlands planted under Set-Aside or Farm Woodlands Scheme without such a replanting concession, providing MAFF agrees and there are no overriding environmental objections" (Duncan, personal communication to WRc, 1989).

Despite this reassurance (to farmers but not, in the author's impression, to the environmental interest) it is likely that a major obstacle to uptake of afforestation under Set-Aside is that Set-Aside is a short-term policy and requires flexibility. The impression of farmers and land-owners is, in contrast to the stability required for afforestation, one of short-term opportunism in policy-making. At the same time as the reassurances about felling in the interests of a return to agriculture the advice is that "Since the farmer will also be making a significant contribution to the costs of establishing the woodlands it will clearly be in his own interests to maintain them for a sufficient length of time to obtain a reasonable economic return" (Duncan, op cit).

By contrast, Set-Aside also offers encouragement to links with another support scheme - the Farm Woodland Scheme (FWS). Planting grants are similar for broadleaves but aid continues for 40 years (for oak and beech). The total area planted must be between 3 ha and 40 ha with no individual plantation <1 ha. There is a national limit to the FWS - 40 000 ha over 3 years from 1988.

Nevertheless, farmers are not happy with the long term projections of reduced income. "Farmers Weekly" (13 January 1989) has reported one estimate of £103 000 losses over 30 years for a 100 ha farm planting 6 ha of trees. Burnham (1989) is also sceptical about uptake in view of an estimate of 2% return on capital and likely community objections to eventual harvesting. Farmers have also complained about the plethora of competing schemes to promote woodland in the UK (Table 4). There is also a considerable problem of timber marketing in the UK, especially for conservationally-acceptable woodland rotations such as coppicing (Everett 1989, Meikle 1989). Meikle concludes, "Private sector marketing is especially fragmented with the result that financial returns on timber are often poor and not representative of the long-term investment in the crop" (p 27).

In view of these comments it is not surprising that uptake of FWS figures is larger in the initial Set-Aside figures (Table 1) than the WGS (652 ha to 375 ha). Nevertheless, the outcomes of both schemes need to be considered by river managers particularly because they may affect different types of farm enterprise, existing land use, soil type, climate etc.

Table 4 - Grants available that encourage plantation of woodlands (source: "Simplify Tree Grants"; Farmers Weekly 8.9.89)

Scheme	payment/ha	min area	operator
Woodland Grant Scheme	615-1575	0.25	FC
Farm Woodland SCheme	190/yr +	3 - 40	MAFF
Farm/Conservation Grant	50%	-	"
Set-Aside Scheme	as FWS	< 40*	"
Amenity Planting Scheme	50%	0.25	CC
Nature Conservation Grants	50%	-	NCC
Licensed Planting Scheme	Trust pays	-	Woodland Trust
Farm Diversification Scheme	25%	amenity	MAFF
Storm Damage Aid	-	Storm	CC/FC
ESA's	-	-	MAFF

\+ = + planting grants 240-1375/ha
* Set-Aside >40 ha

SECTION 3 - LOWLAND AFFORESTATION AND RIVER BASIN MANAGEMENT

At present the indications are that a relatively small amount of land will be afforested in the lowlands; under the two principal schemes to encourage farmers to plant trees, the conifer option in the uplands and on the margins is most likely to dominate. Elsewhere, in response to other fiscal and environmental signals, extensification of existing agricultural activity is most likely because of the assumption that Set-Aside is temporary (Richard 1989). The water interest in the case of upland and marginal afforestation is protected by accepted codes of practice (Forestry Commission 1988) and, for larger plantations (>200 ha), by Environmental Impact Assessment (MAFF 1988c).

The NRA needs, however, to keep a careful watch on the progress of FWS and WGS for two reasons:

(i) To make policy representations if the duration or intensity of support for set-aside and the woodland options were to be changed or if uptake soared (such is the accepted pattern for agricultural innovation - an "S"-shaped curve).

(ii) To anticipate and have prescriptions for the local scale problems which may be encountered under land use changes to woodland now occurring.

3.1 INDICATORS OF THE NATURE AND TYPE OF FUTURE LOWLAND AFFORESTATION

We may differentiate simply between the environmental effects of trees and those of woodlands/forests; in other words **scale** is of great importance. Similarly, another major variable affecting environmental relationships is tree species or species-mix. In the abundant studies of upland forests, inter-specific differences have tended to be submerged by the importance of the canopy architecture of conifers (of whatever species). Roberts (1983) has found that in studies of evapotranspiration from European forests very few differences occur (even with broadleaves) between forest types. When considering effects on water quality, however, tree species are likely to be of importance if only through the relationships between the species or species-mix selected and local conditions of soil and climate; the **management practice** (particularly rotation length) is also likely to vary with species of trees and we know that land management has a particular relevance to water quality variations at the regional level (Newson and Calder 1989). Peterken (1981) provides a comprehensive review of woodland classifications for Britain. It was formerly the botanical tradition to classify by the most abundant species (oakwoods, beechwoods and so on) but in recent decades a general reduction of woodland management has produced greater variety within woods. A more modern statistical approach (Bunce 1982) has produced 32 significantly different plot types from 1648 sample plots in 103 woodlands. Peterken himself has added a further classification, giving 9 main groups of semi-natural woodlands, related to soil type and soil texture - see Table 5. For the purposes of the Farm Woodland Scheme the Nature Conservancy Council (NCC 1988) has produced a classification of "natural species to be encouraged within the numbered zones" (with a map as guidance to these zones), clearly hoping for a re-establishment of certain of the diminished natural woodland habitats; semi-natural woodland in England and Wales declined from 142 000 ha in 1933 to

76 500 ha in 1983 (NCC 1984). However, Evans (1988), taking the Forestry Commission view, stated that the encouragement to lowland planting would produce a domination by oak, with beech, ash and birch close behind in coverage and some sycamore. Oak and beech receive the maximum form of support from the Farm Woodland Scheme.

3.2 LOCATION OF PROPOSED LOWLAND AFFORESTATION IN RELATION TO RIVERS IN ENGLAND AND WALES

Other than by taking guidance from Figure 3, it is virtually impossible to be specific about the location of future lowland farm afforestation, especially in the detail needed to specify the likely effects on water quality at the scale, and with the requirements, of NRA Management. We may, however, speculate in a variety of ways about the approximate locations at a national scale.

(i) Whilst the FWS proscribes "add-on" woodland or replanting it might be speculated that afforestation schemes will find favour in regions where there is existing expertise and concentrations of contracting firms and processing plants. Figure 4, which shows existing woodland cover in England and Wales must, therefore, be relevant. However, the Forestry Commission's policy for broadleaved woodlands (Forestry Commission 1985) refers instead to expansion in "poorly wooded areas" (including the periphery of towns and cities).

ii) If major land-owners or agencies adopt WGS or FWS it is likely that specific regional concentrations will occur. Cases in point include the Countryside Commission's three 5000 ha Community Forest Schemes (Countryside Commission/Forestry Commission 1989) and local government proposals for forests in the Midlands and the North-West. Six further forests are under active consideration by Countryside Commission and Forestry Commission. These are shown in Figure 5, they amount to a coverage of 25 000 ha, a figure approaching 10% of current farm forestry and over 30 times the current uptake of the afforestation option under Set-Aside

Table 5 - Peterken's classification of semi-natural woodlands (showing preferred soil chemistry and texture)

Class	Type	SA	A	N	Alk	Light	Medium	Heavy
1	Ash/wych elm			*	*			*
2	"/maple/hazel		*	*	*			*
3	"/hazel/ped-unculate oak		*	*		*	*	*
4	"/lime/ped-unculate oak		*	*	*		*	*
5	Lime/pedunc-oak/birches	*					*	
6	Sessile oak/ birches	*	*			*	*	*
7	Alder/birch	*	*	*		*	*	*
8	Sessile oak/	*	*	*	*	*	*	*
9	Hornbeam	*	*		*		*	*
10	Suckering elms			*	*		*	*
11	Pinewoods	*				*		
12	Birchwoods		*			*	*	

SA strongly acid
A acid
N neutral
Alk alkaline

(Figure 6). To put this figure further in perspective at least 16 000 ha of woodland required clearance in SE England following the storm of 16 October, 1987 (DoE, MAFF, FC 1988). Another organisation which might contemplate extensive afforestation is the privatised water industry which owns 131 956 ha of land. The only other possibility for locating the expansion more precisely is to use the guidance provided by MAFF about land suitable to be set aside (even though uptake of afforestation on it may be restricted). The following list is taken directly from MAFF's "Set-Aside - a practical guide" (1988):

LOCATION

North facing and other steep slopes; shading from trees; difficult or distant access; near houses or horticultural crops where spraying is difficult; urban fringe; areas damaged by bird or rabbit grazing or trampling; archaeological sites.

DISEASES AND WEEDS

Soil-borne virus (such as Barley Yellow Mosaic Virus); difficult weed problems (such as brome, black grass); cyst nematode problems.

SOIL

Wind or water erosion; poorly drained areas; acidity; trace element deficiency.

WILDLIFE

There is potential to improve the conservation interest of your farm by setting aside areas such as wet land or subject to flooding; next to ponds, streams or ditches; next to hedgerows or woodlands; next to traditional hay meadows, unimproved grassland, moorland and heath.

PUBLIC ACCESS

Where there are existing rights of way, set-aside could help you fulfil your obligations; providing areas attractive to walkers or riders (eg river banks) could help avoid damage to cropped areas elsewhere; spaces for picknickers might be made near a popular view; access to a revenue-raising non-agricultural use.

STRIPS

> Some land may be suitable for set-aside in the form of strips (which must be at least 15 metres wide) which may be at the edge of the field or through any part of it. Around the edges of fields allowing hedgerows to thicken out to provide cover for game birds; to provide "corridors" linking areas of wildlife interest; to ease agricultural operations by creating turning areas for machinery; to improve access.

Maps of these land types do not exist although many of the factors mentioned are available from topographic mapping and an ambitious geographical information system (GIS) could be set up to aid prediction by successfully overlaying the various classifications. Many of the negative factors (from the standpoint of agricultural production) are also aggregated in the concept of Land Capability Classification.

It is the intention of ADAS to supply statistics on the uptake of various set-aside options by Land Capability Classification but the information is not yet available. Guidance from the Farm Woodland Scheme on the type of land likely to be afforested (MAFF, DAFS, WOAD, FC, 1988) includes:

- Arable land
- Improved grassland
- Unimproved grassland in the Less Favoured Areas

On the topic of watercourses it states (Paragraph 38), "Domestic water supplies must be safeguarded, for example, by planting at some distance from watercourses. The Forestry Commission will advise you of any requirements when considering your application". There is a danger that, if FC Guidelines ("Forests and Water", 1988) are not strictly applied, planting up to channel margins might be permitted by default where there was no local offtake of water to supply.

SECTION 4 - EFFECTS OF LOWLAND FORESTRY ON WATER QUALITY: LITERATURE REVIEW

It has already been stressed that research on the overall hydrological effect of forests in the British Isles has been dominated by the case of upland conifer plantations. Only in exceptional cases have such upland studies considered nutrients (eg Roberts et al 1983) in a comparative study with non-forest land uses. The work has, therefore, proceeded without major reference to the principle routes and chemical exchanges which control nutrient cycling, together with the output behaviour of other related chemicals. The major field studies of conifer forests have concentrated much more on the comparatively simple processes dominated by the canopy, for example interception and acid deposition. The most comprehensive reviews of what has been learned in these upland studies are provided by Good (1987) and the Institute of Hydrology's forthcoming volume describing the Plynlimon experiments (Kirby and Newson 1989, in press).

Only after moving the focus of conifer studies to the **felling** phase of the crop cycle did hydrologists and geochemists begin to encounter the relevance of a detailed approach to chemical (mainly biochemical) cycling. In so doing they found that timber harvesting studies performed in some of the world's famous comparative catchment studies abroad (eg Hubbard's Brook, New Hampshire; Coveeta, N Carolina) provided much needed guidance on the requisite scale, duration and control of field experimentation. Many of the 1500 references quoted by the comprehensive review of harvesting by Blackie et al (1980) derive from relatively few of these prestige experiments.

In the UK, the Institute of Terrestrial Ecology's experiments in Cumbria (Adamson et al 1987) and Wales (Stevens and Hornung 1988) reveal similar effects of the felling of upland conifers to those published abroad, ie, increased runoff and increased nutrient loads but decreased concentrations of those ions with a predominantly atmospheric source. The Welsh study provides more details on leaching of nutrients down the soil profile, which increased for nitrogen after felling to rates equivalent to those under intensive agriculture. It is too early in both studies to detect recovery patterns.

The lessons of thirty years of upland catchment and plot studies of coniferous afforestation for the present consideration of lowland afforestation, largely with broadleaved species, are as follows:

(i) As much control as possible should be achieved; in a field experiment this means very careful attention to the scale, location and duration of the component studies. The greatest utility of, and validation for, results has come from a nested scale approach in which small-scale (plot/lysimeter) studies are located within sub-catchments and so on. This control over and detail of experimentation is progressively sacrificed as the unit of study grows in size towards that which is more relevant to river managers. The trade-off is essential.

(ii) Field experiments should, where possible, be conducted within a strong theoretical framework. The hypothetical system should be structured before instrumentation begins to ensure both comprehensive study and the capacity to recombine the component measurements, eg, in a mathematical model.

(iii) Careful attention should be paid to the management implications of the system studied. Experiments should be carefully located to ensure a forest management regime which is used generally and one which has not been specifically designed or modified for the experimental site/catchment/region. It is also clearly vital in forestry studies to consider the full crop cycle which one may consider to divide into:

- Planting to canopy closure
- Maturing crop
- Felling
- Early stages of next rotation
  (Maitland, Newson and Best 1989, in press).

This literature review will, accordingly, assess each contribution on the basis of its quality judged by the criteria above. It is, therefore, valuable to begin with the total framework provided by biogeochemical cycling concepts and follow through to units of spatial scale relevant to the size of the forests being considered for lowland England and Wales, and to the size of river basins for which management guidance is needed.

4.1 FORESTS AND CHEMICAL CYCLING: GENERAL REVIEW

By initially standing well back from the problem in hand, it is possible to consider all its important components. Figure 7A identifies the controlling processes and pathways in forest chemical cycling; in fact the diagram may be applied to all crops and vegetation covers particularly when reduced to the simple systems diagram of Figure 7B. We may distinguish:

- Atmospheric processes (Canopy)
- Biological processes (Soil) } (Combined here)
- Hydrological processes (Soil/slope/channel) }
- Pedological/geological processes (Soil/rock)

The confounding problem is that the importance of the former and latter groups makes prediction highly regionally biased. It is, therefore, a distinct disadvantage in the present study that we can do little more than speculate about the location of lowland afforestation. The soil is also dominant in respect of its capacity to store and to exchange chemicals; the size of its chemical stores is very large in relation to the fluxes which we are forced to measure in the field.

Inevitably, therefore, this review is dominated by work describing the more generalisable biological and hydrological effects of forests, especially of broadleaved species in lowland locations. Even so, it is problematic to transfer results across long distances, particularly where management practices are influential.

Biological and hydrological effects on chemical cycling by forests may be rationalised as follows:

(i) Forests are a tall crop, their canopy modifies the boundary layer considerably producing differences in receipts of precipitation and gaseous/solid deposition from neighbouring land uses. The canopy in broadleaved forests is generally seasonal; leaf-fall both modifies canopy receipts and constitutes a large flux of chemicals to the ground.

(ii) Forests modify the soil beneath them more directly than by seasonal leaf-fall. They clearly reduce soil moisture via the process of interception; argument still rages over their transpiration rates. If not achieving "biological drainage" via this drying activity they tend to produce an improved transfer of soil moisture under gravity via leaf-fall (which provides a litter layer on the soil) and via their extensive coarse root systems. The extent of this drainage "improvement" tends to depend on whether they grow on steep slopes (a favourite location for non-agricultural activities such as afforestation) or on the presence or absence of an artificial drainage network installed during ground preparation for the crop.

4.1.1 Canopy components of chemical cycling

Cryer (1986) suggests that forest canopies produce a ten-fold increase in particulate capture from an airstream compared with a smooth water surface. Canopies are even more efficient in capturing wet deposition under conditions of fog and mist. However, measurement is extremely difficult because simulated canopies are almost impossible to construct and because input-output chemical studies of the canopy include, without separate quantification, the important chemical process of crown leaching. Another very restrictive problem in the present context is that of edge effects: in small plantations the extra efficiency of exchange at the edges will be proportionally more important to the overall chemical cycle of the forest.

Thanks to the "acid rain" controversy recent research has focused not only on canopy efficiency at pollutant capture but upon regional pollution climatologies. Improvements in atmospheric monitoring have led to the production of improved maps of atmospheric deposition; the direct effects of pollutants on tree health are now regularly monitored (Innes 1987). The Forestry Commission's monitoring scheme has been largely restricted to pine and spruce species; although lowland sites are included, the scheme is dominated by work in the North and West of Britain (see Innes 1987, Figure 12). Complicating effects of droughts in 1975, 1976, 1983, 1984, and 1989 invalidate an interpretation of tree damage as directly indicating atmospheric deposition to forest canopies. The most recent overview of the problem of pollutant effects on forests (UK Terrestrial Effects Review Group 1988) concludes that trees are damaged in or near polluted urban areas; controlled experiments suggest that potential damage occurs from SO_2, NO_2 and ozone concentrations reached in lowland Britain but further work is required on multiple stresses and the effect of ozone deserves more attention. The effect of ozone is of particular interest in connection with lowland afforestation since it apparently increases nutrient leaching from forest and forest soils. The Review Group also indicates that pollutant-controlled changes in soil biology could have "knock-on" effects on the chemistry and biology of freshwaters; it labels this area as a high priority for future UK research. Fowler, Cape and Unsworth (1989) suggest that transfers of pollutants in all forms are more efficient for forests than for shorter crops. However, only the reactive gases such as HNO_3, HCL and NH_3 achieve high rates of deposition. Small aerosol particles are also efficiently deposited but under the very particular conditions of low cloud at high elevation sites. Whilst deposition models are as yet relatively simple, their authors predict that afforestation of moorland with conifers in the Kielder Forest area (Northumberland) can increase sulphur and nitrogen inputs by 30% and 90% respectively. Table 6 shows their predictions. They are relevant here in indicating the direction of an effect likely in lowland locations at canopy level.

Table 6 - Atmospheric inputs of sulphur and nitrogen predicted for Kielder Forest (300 m ASL; 1500 mm rain). Units are kg ha^{-1} yr^{-1}.

	Wet deposition		Cloud-water		Dry deposition		Total	
	S	N	S	N	S	N	S	N
Moorland	13.0	8.0	1.3	0.4	3.1	4.0	17.5	12.4
Sitka Spruce	13.0	8.0	6.5	1.9	3.1	13.52	2.7	23.4

4.1.2 Biological (soil) components of chemical cycling

Turning to the gross effects of the forest on nutrient cycling in natural hardwood forests, there is virtually no published UK material. Once again the interest is dominated by the uplands and conifers. Of 61 references quoted by Harrison (1978) only two refer to nutrient cycles in UK hardwood forests and one of those, like Harrison's own study of phosphorous cycling, was conducted on oak-ash woodland in the Lake District. Only Ovington (1962) is widely quoted in all quantitative approaches.

Internationally, the best-known compilations of research results on chemical cycling in hardwood forests are those from Hubbard Brook, New Hampshire, USA (Likens et al 1977, Bormann and Likens 1981). Transfer of results, therefore, appears inevitable. The most recent and most detailed reviews of research at an appropriate scale and under more equivalent climatic conditions for our purposes are those of research at Coweeta Hydrologic Laboratory in North Carolina. Even so, its conditions (altitude 690-1600 m; mean annual precipitation 1600-2500 mm) make transfer acceptable only with considerable care. Consequently only the major principles established by work at Coweeta can be covered here. Swank (1986) describes how Coweeta began operation in 1934; its mixed hardwood (oak, hickory, maple, poplar plus understorey) has been felled in a series of controlled sub-catchment experiments. His paper sets out the basic dimensions of forest nutrient cycling.

> "Much greater quantities of nutrients are stored and recycled within forests than are lost annually in stream water" (p 95)
>
> "Litter fall is the major above ground transfer pathway in the N and Ca cycles of all ecosystems" (p 93)
>
> "It is apparent that resorption, storage and reuse of some nutrients by forest vegetation provides a buffering mechanism of solute loss" (p 95)

Swank clearly sets up the principle of biotic control, via feedbacks and storages of runoff chemistry under mature temperate hardwoods. In his review of other deforestation studies and tabulation of the Coweeta results he adopts, therefore, the term "biotic deregulation" to cover harvesting.

Throughout Swank's treatment of felling effects on stream flow chemistry he emphasises the confusing influence of changed runoff conditions. Clearly these are paramount and are treated in Section 4.1.3 below. Relatively few chemical species have been studied by those researching felling in experimental catchments. At Hubbard Brook (Bormann and Likens 1981) only nitrate, calcium and potassium were sampled, all three increased as stream loads after felling (stream flow itself increased) but recovered after natural regeneration of a herb cover resumed. This pattern is repeated in the Coweeta study; Swank claims it illustrates both resistance (high rates of storage, slow turnover) and resilience, (rapid recovery; high net primary production) to hiatuses such as felling or fires. Biological hiatuses such as invasions by forest predators (eg defoliating worms) produce equally spectacular changes in cycling but, again, are quickly rebalanced.

Because of their conclusions about the importance of litter fall and its biological incorporation to the huge soil chemical store, Swank's review becomes dominated by microbial processes of, for example, sulphur incorporation, which is not balanced by mobilisation at Coweeta, a site receiving sulphur to the level of 68% of all anions. The microbial processes controlling nitrogen cycling explain precisely why nitrogen losses (472 kg ha^{-1} from soil; 337 kg ha^{-1} in stream flow) follow felling:

> (nitrogen losses are)
> "Attributed to accelerated rates of decomposition from more favourable temperature-moisture-nutrient relationship in the clear-cut and enhancement of nitrification rates" (p 116)

A warning against extrapolating the Coweeta results in detail comes later:

> "Based upon the existing literature it is apparent that nitrification rates and the part played by the process in regulating nitrate losses varies tremendously across forest ecosystems" (p 119).

Because the magnitude of regrowth and nitrogen uptake is but one of the regional variables which apply; forest management is also of key importance. Once again, extrapolation is highly problematic. In another paper (Swank 1984) the Coweeta results are again used to stress the site specificity of nutrient cycling: in this case as a result of the importance of atmospheric inputs to the canopy the conclusion is that:

> "Since nutrient inputs and forest management impacts are site-specific, quantification of inputs is needed for a variety of ecosystems concurrent with assessments of nutrient losses. Measurements taken at specific locations should be coupled with mesoscale modelling research to minimise the number of collection stations and improve the accuracy of regional estimates." (Swank 1984, p 319)

4.1.3 Hydrological processes of chemical cycling

North American studies of clear felled hardwood forest catchments have revealed how the resultant changes in stream loads (of nutrients) are conflated with changes in stream flow. Bosch and Hewlett (1982) conclude that deciduous hardwoods experience a 25 mm change in water yield for every 10% change in cover. The many reports of increased losses through interception for UK upland forests are, therefore, confirmed in direction but what is the magnitude of evaporation loss from lowland broadleaves in the UK? The general review by Binns (1980) for foresters reports as follows:

> "It looks as if, in Britain, evergreen forest intercepts one third of the annual rainfall and deciduous forest about one quarter though in any year the actual proportion will depend on the pattern of rainfall."

Elsewhere Binns concludes that water use by lowland forests will differ little from neighbouring "vigorous crops transpiring freely" (cf the profound differences between upland conifers and neighbouring moorland.) The relative importance of interception in producing regional differences in forest hydrology can be revealed by Roberts' (1983) tabulation of transpiration rates by European forests, both conifer and broadleaved (Table 7). Roberts concludes that understorey evaporation balances for canopy differences and that trees efficiently protect against potentially damaging rates of transpiration under dry conditions.

Table 7 - Annual transpiration (mm yr^{-1}) from trees under European conditions (Roberts 1983)

Species	Location	Transpiration
Sitka spruce	Slaidburn, Yorks, UK	340
Norway spruce	FR Germany	362
" "	" "	279
" "	Plynlimon, Wales, UK	290
	" "	340
	" "	330
Scots pine	FR Germany	324
" "	Thetford, Norfolk, UK	353
" "	Crowthorne, Berks, UK	427
Sessile Oak	FR Germany	327
" "	UK	320
Beech	Belgium	344
Mean for NW Europe		333
Coefficient of variation		10%

Hall and Roberts (1988) compare interception rates for conifers and broadleaves at the only environmental range for which data exist (normally their optimum sites, especially measured sites, are geographically exclusive). Taking a mean annual rainfall of 1200 mm they present the following proportions of that rainfall "lost" by interception (see also Figure 10).

Larch	34%
Lime	32%
Sycamore	25%
Ash	11%

Thus it appears that differences of canopy architecture within broadleaved forest types may produce hydrological differences through net precipitation. However, it must be remembered that the database is extremely restricted and data may be site-specific. At the same symposium, Cape (1988) produced more detail by dividing the interception and stemflow components (stemflow is particularly active in solute transfers):

	Alder	Oak	Spruce	Pine
% interception	14	13	14	33
% stemflow	10	9	12	6

We may, therefore, argue that under hardwood plantations in lowland Britain a measurable reduction of runoff is likely due to interception effects; however, much more research is needed, particularly on the feedback route from reduced soil moisture beneath the canopy to reduced transpiration. This research should also consider interspecific differences of canopy chemical cycling and the role of the understorey vegetation, especially through the seasons.

Turning to the pedological processes influencing chemical cycling beneath broadleaved forests, differences between runoff routes under grassland/short crops and forests are profound in respect of:

(i) The depth of litter/"O" horizon (deep in forests)

(ii) The presence of macropores, including root channels (dense/thick in forests)

(iii) The presence of forest drainage/cultivation lines.

We may largely discount (iii) in the present review since the "new" hardwood plantations in the lowland may generally be created on relatively dry soils and, indeed, soils which have received cultivation and drainage treatments for centuries. The deep litter layer phenomenon may take half the life of the tree crop to build up; consequently, changes in soil structure may be of prime importance. Mosley (1982a) reports that macropores route up to 40% of the net precipitation inputs to slopes underbeech in South Island, New Zealand. However, both rainfall (1500-2600 mm yr^{-1}) and slope angles (30-35 degrees) are high and this may be an extreme result; it is said to be unaffected by disturbances resulting from logging, burning and replanting.

It is interesting to speculate that a very efficient drainage route exists in hardwood forests between the base of the tree, where stemflow concentrates (Crabtree and Trudgill 1985) and the macropore network. Crabtree and Trudgill's site, near Sheffield, revealed very rapid transmission of the 12.5% of precipitation routed down beech trunks, direct to bedrock via structural cracks and root channels.

Nevertheless, it should be remembered that it was from studies of forest soil hydrology that the importance of subsurface runoff was first realised (eg, Whipkey 1965, 1969; Hewlett and Hibbert 1967). It was also realised that "quickflow" to channels could be by subsurface routes in forests. Harr (1977) reports that quickflow averages 38% of gross precipitation under Douglas Fir in Western Oregon. The proportion in the Eastern USA, he claims, is 25%.

Runoff routing will obviously have a profound effect on the water quality emanating from lowland British forests and the initial changes following afforestation will depend almost entirely upon the preceding land-use and its management in respect to soils. For example, in their catchment studies of nutrient cycling in the Welsh uplands, Roberts, Hudson and Blackie (1983) suggest that the reason for a higher nitrate loading under forests was that forest drainage had removed the potential (in saturated soils) for denitrification.

> "From these extreme cases it would appear that soil and soil manipulation is at least as important in determining nitrate concentrations as is vegetation type" (p 40)

This point is further confirmed in the studies carried out in France on riparian woodlands. They can apparently "strip" nitrates from agriculture runoff upslope because of the seasonally anaerobic conditions of the floodplain (Pinay and Decamps 1988). The authors do not, however, make it clear whether forests are a corollary of the undrained soils (which therefore achieve denitrification) or whether the trees make a unique contribution (eg via large organic carbon contributions or uptake of available nitrates). Peterjohn and Cornell (1984) also record the clear benefits of riparian and floodplain forest in the control of diffuse-source pollutants, especially nitrates.

4.2 FORESTS AND STREAM SEDIMENTS: GENERAL REVIEW

The yield of weathered sediments and soils from land to streams is controlled by many environmental and land management variables. Under humid temperate climatic conditions intense rainfalls and steep slopes increase erosion potential but in many upland regions, eg in North and West Britain, climatic feedback to a dense vegetation cover gives protection. Actual rates of erosion, particularly sheetwash of soils, are very low compared with the climatic and gravitational potential. the implications are, however, that removal of the vegetation cover or a change in cropping practice can produce spectacular local increases in soil loss; where hydrological pathways from land to channels are efficient, stream sediment loads increase measurably. England and Wales have no official stream sediment monitoring network; turbidity is measured as part of water quality assessment but this approach is insufficiently detailed in space and time to calibrate the effects of land use change. Nevertheless, university researchers and the Institute of Hydrology have conducted studies which quantify the problem (Newson 1986) particularly in uplands and in relation to coniferous afforestation.

A more important form of erosion in connection with forest management practice is caused by channelised flows. Naturally unprotected soils on steep soils will become gullied; streams receive an input of coarse sediment (cf fine sediment from sheetwash) and this increases bedload transport. Both supply and transport tend to be restricted to flood events. Upland afforestation uses deep cultivation and drainage on steep slopes to achieve suitable growing conditions for conifer growth; poorly designed ditch networks can increase bedload yields considerably (Newson 1980).

Once again in this review one discovers an almost total domination of the UK literature by upland studies whose results are not transferable. This is particularly the case for those effects related to cultivation and drainage which, it is assumed, would not be required on an intensive level in the lowlands. Other aspects of forest management which have a bearing on stream sediment yields are undergoing considerable review and improvement following the "Forests and Water Guidelines" (Forestry Commission 1988). Perhaps caution is needed in the assumption that only upland forests require drainage and consequently become liable to erosion on steep slopes. Tuckfield (1980) reveals a considerable erosion problem in drainage channels dug in the New Forest, Hampshire. Gradients as gentle as 1.5 degrees produced gravel erosion (cf Newson's 2 degrees in his 1980 paper). Stott (1987) working in Macclesfield Forest points to gullying partly caused by disrepair and rupture of agricultural drain systems when an agricultural area is afforested.

Where broadleaf forests have a litter-free floor (or where an understorey is prevented by close planting) other causes of soil erosion may be active; for example in Luxemburg, Hazelhoff et al (1981) estimate increased splash erosion (potentially 15 ton/ha) resulting from earthworm casts. Working in the same oak/beech forests Duijsings (1985) puts this splash erosion beneath the forest into quantitative perspective in a small catchment study. Of the total sediment output of 76.2 tonnes km^{-2} $year^{-1}$, 53% came from streambank erosion (the streams are naturally incising) and 47% from splash, overland flow and a limited amount of throughflow contribution. Murgatroyd and Ternan (1983) conclude that on Dartmoor (under conifers) it is channel width which becomes increased due to suppression of understorey vegetation which would otherwise protect stream banks. Clearly there are warnings in the literature for the managers of lowland forests:

- drainage requires as much care in the lowlands because critical gradients are 1-2 degrees.

- canopy/understorey management requires care to avoid bare soils on the forest floor and bare channel banks.

Morgan (1980) has produced a soil erosivity map of Britain in which some of the highest values are those shown for the lowlands (p 36). Given the increased kinetic energy of some of the bimodally-distributed drop-sizes of throughfall (Vis 1986) it is clear that, even after correction for interception losses, erosion potential may be 30% to 50% greater under hardwoods (Mosley 1982b). I cannot, therefore, share Moffat's optimism:

> "Although there are no reports of soil erosion under existing lowland forests erosion is almost certainly not serious there. Cultivation and drainage are much less than in the uplands, slopes are gentle and rainfall is less. Lowland forest soils are usually fertile and promote a vigorous weed cover. Agricultural land erodes mainly when there is little or no plant cover. Under forestry this will rarely happen and so the risk of erosion will be minimised. Trees will also increase the organic matter content of the soil and thereby increase its stability." (p 43)

Although the magnitudes of sediment yield changes brought about by forestry operations cannot be extrapolated from uplands to lowlands and the detail of management operations may be profoundly different, one lesson is vital. Ground preparation, roading, felling etc, all create a disturbance to the sediment cycle of a forested stream; one must, therefore, show distinctions between natural and cropped forests. It is interesting to note that the recent extension of upland sediment studies into the earliest phases of ground preparation for conifers (eg Burt et al 1983, Leeks and Roberts 1987, Ferguson and Stott 1987; Francis and Taylor 1989) and into the clear felling phase (Ferguson and Stott 1987, Francis and Taylor 1989, Leeks and Roberts 1987, Johnson 1989) indicate that increases in yield may be relatively short term. The forest cycle may, therefore, create conditions of disturbed equilibrium was discussed for the Coalburn catchment by Robinson and Blyth 1982) and developed by Leeks (personal communication, see Figure 8). In conclusion it must be admitted that the results of upland investigations of sediment yields resulting from forestry operations have recently become controversial. Moffat (1988) concluded that:

> "There is no evidence that erosion is extensive under British forests. Even where it occurs the rates are usually comparable with "natural" ones in Britain."

A reply by Soutar (1989) re-tabulates the results obtained by studies in Wales, Yorkshire and Scotland (Table 8) drawing attention to the relative magnitude of yields compared with undisturbed stream environments in the same region (Soutar representing The Nature Conservancy Council has this prime concern). He also points out that Moffat (representing The Forestry Commission) is not comparing "like with like" when using sediment yield figures for the more spectacular cases of lowland (arable) soil erosion. His conclusions are important for the present review:

> "Afforestation in the uplands appears consistently to result in increased soil erosion and sedimentation. In the lowlands, however, afforestation of arable and improved grassland is unlikely to increase erosion. Erosion on arable land is already widespread and increasing in England and Wales (Evans and Cook 1987) and should actually diminish under forestry since land will be tilled and bare very infrequently." (p 85).

4.3 LOWLAND FORESTS AND WATER QUALITY IN ENGLAND AND WALES: SPECIFIC REVIEW

As already demonstrated, there is very little published material of direct relevance to the strategic problem in hand. Whilst lowland afforestation rates are at present very minor, current agricultural/ environmental problems and the direct encouragement of tree planting may well combine in future to make decision-making by the NRA essential on grounds of water quality protection. Such decisions are best made as part of the land allocation process: once into the forest crop cycle on any parcel of land, only accommodation between rival interests is possible (Newson 1989, in press).

The general review, presented above, reveals major problems:

(i) The literature on hardwood/broadleaved forests is dominated by work done abroad. Whilst much of it has been done at the catchment scale and, therefore, includes stream processes as well as forest/soil processes, transfer to UK conditions is very difficult because:

a) It has largely been conducted in mountain, high-rainfall, steep-slope conditions.

b) It has largely been conducted by felling an area and comparing with a forest control.

c) Water quality parameters monitored have largely been those of interest to ecologists and foresters, ie, principally nutrients and principally the easier ones to measure throughout the system.

(ii) The UK literature is dominated by research relating to upland coniferous forests. At first only mature crops were considered but now attention is moving to establishment and felling phases of the crop cycle. Once again, however, transfer of data is very dangerous, not only because the uplands and lowlands are profoundly different natural environments, but because those environments evoke different forest management strategies (currently being modified in the uplands to accommodate the water interest).

Table 8 - Comparative sediment yields (kg ha^{-1} yr^{-1}) from small catchments under forests and moorland (Soutar 1989)

Catchment	Land use	Suspended sediment	Bedload
Llanbrynmair	ploughed	90 prior to ploughing 37	n/a
Llanbrynmair	"	31 prior to ploughing 7	n/a
Hore	felled	571 prior to felling 244	118
Hafren	forest	353	n/a
Tanllwyth	"	121	384
Cyff	moorland	61	64
Coalburn	ploughed	240 prior to ploughing 30	n/a
Monachyle	moorland	380	1
Kirkton	forest	1310	21
Holmestyes	ploughed	513 prior to ploughing 32	n/a

Note that "ploughed" refers to ground preparation for conifer plantation

Perhaps the most difficult aspect of any transfer of data (even of direction, not magnitude) is in deciding the impact of the sequence of land use change to forestry. The soil condition and management practice which precede lowland afforestation may have a profound influence on the early impact of afforestation on water quality.

If we are content for the moment with transferring from the overseas and upland UK literature the direction of forest effects we can tentatively conclude that:

(i) Natural forest systems represent huge chemical storages to which inputs and from which outputs are modulated by feedbacks. Natural forests in most conditions stabilise soils against mechanical erosion.

(ii) Forest crops require management. Some elements of management are misguided to the point where the "normal" resilience and recovery patterns of the forest system are temporarily disturbed. These are the danger points, in time and space, for river basin managers.

Because of the scarcity of specific literature this section is presented in two ways: as Table 9 below, and as an Annotated Bibliography (Appendix A). Two further restrictions apply:

(i) Many studies include only the forest or soil system, omitting the importance of runoff to channels and in-channel processes. Misunderstandings about impacts are very easy if this is not considered: stream processes are very important. Much of the controversy between Moffat (1988) and Soutar (1989) over erosion can be put down to scale discrepancies in the material they quote.

(ii) Impacts must be judged against standards; contamination must not be confused with pollution. Very few scientists take the trouble to position their results on this scale. Once again, an example comes from the uplands. Kay and Stoner (1988) have statistically compared land use problems in West Wales with the frequency of

Table 9 - Water quality effects of lowland forestry in England and Wales: literature review (see also Appendix A)

Author/date	Hydrology*	Nutrients	pH	Turbidity	Pesticides	Metals
Young 1981	(Groundwater)	Reduced NO_3 beneath woodland *cf* grass (Figure 9)				
Kinniburgh 1989	(Groundwater)	Large edge effect ash = beech				
IH 1989	Interception of rain 5-33% @ 1200 mm yr^{-1} larch>lime>sycamore> oak>ash>beech (Figure 10)					
Skeffington 1985			Acid throughfall balanced by metals. Groundwater buffers pH <1 km down-stream compares soil acid from rain and from trees.			
Skeffington 1987			Soil pH little red, under oak; moderate under birch much under pine (Figure 11)			Al in soil under Pine < birch, < oak
Allcock/Morton 1985	Interception 55% for Pine, 33% for birch (NB 1976-77)	Red. N & P beneath trees. Much red. Ca				Inc K & Mg beneath trees
Foster 1987			Oak canopy reduced pH by one unit but g water buffers in floodplain			Heavy metals from soils
Foster *et al*		P red. in forest lake *cf* arable			Forest sed yield <.5x arable (Figure 12)	Mn, Fe, Al higher concs in forest (13)

failure to meet EEC standards by stream samples from a sample group of catchments. Significant positive correlations occur between the proportion of a catchment afforested and failures to meet aluminium, manganese and hydrogen ion limits (Table 10).

Table 10 - Correlation coefficients between forest cover of 13 catchments in mid-Wales and the frequency with which water samples from them fail to meet EC standards (Kay and Stoner 1988)

Surface water directive	r
Aluminium - Guide	0.536
" - Imperative	0.655
Manganese - Guide	0.467
" - Imperative	0.546
Drinking Water Directive	
pH	0.236
Iron - Guide	-0.204
NH_4 Nitrogen - Guide	-0.013
Salmonid Waters Directive	
NH_4 Nitrogen	-0.013
Aluminium	0.657
pH	0.504
Calcium	-0.191
Zinc	0.207

We clearly need the ecologists' systems approach in this field of research but with considerably more emphasis on those variables of importance to aquifer and stream network management. This review has found little or no work on pesticides, metals or turbidity where they were not a by-product of ecological concerns (eg, Picloram herbicide residues were studied at Coweeta by Neary et al 1985).

One final regional hydrological point should be stressed. The lowlands of Britain are underlain by soft sedimentary rocks and these often constitute important aquifers. One third of our water supply comes from such rocks. If there is a dearth of appropriate information relating to surface waters and the river network there is an even greater shortage of information relating to the impact of afforestation on groundwater quality.

SECTION 5 - IMPACT OF LOWLAND FORESTS ON SURFACE AND SUBSURFACE WATER QUALITY: IMPORTANCE OF FOREST SIZE, TYPE, LOCATION AND MANAGEMENT

Whilst foresters in the UK have now begun to appreciate the importance of careful management practice in relation to stream channels and riparian zones (eg, Mills 1980) there is still very little material available for forest managers which stresses the function of the remainder of a watershed including aquifers (cf farmers and Nitrate Sensitive Areas) and the need for comprehensive management of river basins. The USDA Forest Service, for example, offers much more comprehensive hydrological and hydraulic guidance (see Heede 1980). In connection with the expansion of lowland forestry in the UK there is, therefore, a considerable task of technical education to be performed, one which had begun to be implemented by certain water authorities with farmers (in connection with pollution) prior to privatisation.

Obviously a drainage-basin-wide approach offers a scale of sensitivities for forest developments and management techniques; in this section an attempt is made to predict the spatial variability of woodland uptake in a hypothetical transect across a lowland valley (Figure 14). Among the locations suggested by MAFF (1988a) for Set-Aside, the following are relevant:

- Steep slopes; difficult access; urban fringe weed or pest problems; poorly drained, wet, flooded or riparian land; recreation; wildlife corridors.

Woodland plantation is but one Set-Aside option but the emphasis is worthy of note: land which is problematic to high-production farming. Figure 14 therefore attempts to put a more generalised picture on the clues provided by the Set-Aside literature. Location is clearly only one aspect of influence on the change of land use from an NRA perspective. At all three major process levels identified in Section IV as control systems there are interrelationships with forest size, type and management as well as location. The land use and management regime which culminated in a conversion to trees is also extremely relevant. If water managers consider that woodland will be a welcome relief from the water quality problems resulting from intensive arable or livestock production they may well be disappointed. Because of the risk involved in the long-term change of land use, landowners are likely to choose less productive, problem sites for afforestation. There is thus a considerable risk that fertiliser application will be necessary; there is contemporary interest in the use of sewage sludge in forests on poor soils (Berry 1987) and trials are already in progress in Scotland (see "Water Services", March 1989, p 85). In some cases a tree cover will ameliorate the problem (eg, wetness) but in others it may well exacerbate the problem if insufficient care is exercised (eg, erosion). Water/river managers may well eventually discover that changed European food production circumstances may force yet more intensification of existing productive land or a rapid felling of the trees planted in times of surplus - neither would be good for water quality.

Assuming, however, the status quo it should be remembered that an increase in broadleaved woodland has other than purely timber production aims. Water/river management is only one interest prevailing upon landowners proposing plantations. Landscape considerations for broadleaved woodland tabulated by the Forestry Commission (1985) and of relevance here are:

> "Create irregular forest shapes...; Be of a scale in proportion to the size of the landscape; enhance... features such as watercourses, gullies or crags; become increasingly irregular near to water."

These are clearly relevant mainly to planting but arguably felling is the more rapid and intrusive visual effect. Forestry Commission's advice on felling broadleaved woodland refers often to the need to phase and scale the rate of felling to avoid severe visual impact. This accords well with what we can gather about water quality impacts.

If forests are developed for recreation there are clearly "view from" as well as "view of" principles to be followed. Together with the other factors mentioned above and in regions where river valleys are not steep-sided (giving agricultural problems of gradient) we might therefore expect many plantations to be riparian or interfluve in location. There seems at the very least to be a suggestion of a direct relationship between forest size and distance from major rivers. This can have unfortunate consequences for the water interest since small streams with the least potential for natural purification process, are dominated by forest; similarly, the large plantations will tend to cover groundwater recharge zones.

In certain lowland landscapes, however, where the rivers are incised or where there are steep-sided dry valleys there are important "hanging" woodlands covering the slopes, important both visually and for nature conservation.

Guidance on felling also includes reference to the desirability of natural regeneration as a means of restocking cleared areas. This is desirable in landscape terms and also has silvicultural advantages - local provenance of stock has clear advantages of natural selection. However, there are some potential dangers in the advice offered, eg

> "There is no urgency to fell and restock in one year"
> (Forestry Commission 1985, p13).

Guidance from studies of nutrient runoff after felling suggest the advantages of rapid regeneration of some form of plant cover.

> "The conifer component should not exceed 25% of planted stock"

Considerable care is needed over the planting of any conifers in sensitive zones, even as a "nurse species". Coppicing regimes appear much more attractive to the water interest: with an 8 to 15-year rotation and small plots treated with minimal disturbance (1.2 ha is a maximum according to BTCV 1980).

Direct reference to streams, ponds and wetlands occurs in the guidelines. Ponds, if properly constructed and managed are of advantage to game management. They could also be used positively in forest water management. For example, where cultivation and drainage networks are required for forest establishment they should all be routed via ponds to the natural stream network, offering, thereby, the opportunity for balancing extremes of both water quantity and quality emerging from the forest. Forest wetlands should be treated as having similar protection potential.

Streams and ponds are also of use for fishing and the guidelines suggest (p 15):

> "The fishing potential of woodland streams is enhanced by broadleaved shrubs and trees along a stream edge interspersed with open gaps to give half-shade conditions and access."

It should be stressed in any further revisions that the entire stream network constitutes important habitat not merely those reaches with commercial fishing potential; such guidance is applicable throughout the riparian zone. The work of Mills (1980) requires revision for the specific conditions of lowland woodland. There are, of course, gains and losses in terms of flood protection from riparian woodlands. Poorly managed riparian trees constitute a flood hazard, a fact recognised over 35 years of bank clearance schemes since the Lynmouth flood disaster highlighted the problem. However, woodland is not so demanding of flood protection investment as agriculture and there are benefits of increased bank erosion protection.

Finally, the available guidance on the use of herbicides and fertilisers is important. Whilst competition from ground cover plants is undesirable at establishment or replanting and herbicide is a cheap form of control, the importance of a ground cover at such periods is of direct benefit to erosion protection and nutrient runoff. Whilst where woodland follows intensive arable or grain crops there is unlikely to be the need for heavy fertiliser use it should be remembered that the choice of land units for farm forestry by landowners may well feature "difficult", and hence nutritionally-poor land. The Forestry Commission (1985) specifically refer to:

> "Restored man-made sites, impoverished heath, moorland and chalk downland soils or when nutrient depletion has taken place after prolonged coppice working" (p 17).

It seems from the ecological literature that a forest cover may well be able to correct a certain level of soil impoverishment via foliar and litter processes and caution is clearly desirable before fertiliser application rates are calculated purely from foliar analysis of the preceding cover. Similarly, careful investigation is required of the cycling effect of woodland on restored sites where the site is a deposit of potentially toxic material such as mineral/metal waste.

SECTION 6 - RECOMMENDATIONS FOR RESEARCH IN SUPPORT OF WATER QUALITY PROTECTION AND LAND MANAGEMENT

The findings of this review of published existing and proposed research are as follows:

(i) If, after some initial reluctance and confusion about afforestation, landowners in the lowlands come to regard farm forestry as a sensible strategy (no present indications), it is likely that some form of regional concentration of this land use change will occur. Forests, like agriculture, are part of an industrial cycle which requires infrastructure, investment etc. Possibly the moves by Countryside Commission and some local authorities will substantiate this regional agglomeration. Whilst the NRA is the appropriate institution to operate water quality protection in the face of land use change it must clearly have the appropriate voluntary or statutory links with the appropriate authorities who are, in this case, considerably more diverse than those dealing with agriculture alone.

An initial area of research required for the NRA's institutional role should then address the policy structure and the options available for implementation. Should the NRA seek to manipulate the financial provisions for afforestation in order to bring about, where necessary, the appropriate allocation of land? This would clearly be a national option. However, the lesson of the water industry's response to coniferous afforestation (ie domination by a few authorities - Welsh Water, Strathclyde, Regional Council) taken with the specificity of this knowledge, may suggest a regional scale of intervention via some form of planning process. It is unlikely that the Environmental Assessment procedure will apply to the small areas of afforestation being considered as units, the EA threshold being 200 ha.

Instead of intervening in land allocation, a highly controversial matter as revealed by Nitrate Sensitive Areas, the NRA may consider that a set of "good practice" guidelines similar to those produced mainly for coniferous afforestation should be produced. These are, however, very difficult to implement, especially where action on the ground is taken by numerous small private operators. Clearly too, the NRA would need to identify sensitive sites on soils upon which "good practice" would be more demanding or would be monitored to ensure compliance.

The existing guidelines to good practice for foresters in relation to the water industry refer mainly to conifers in the uplands.

> "There is particular emphasis on the uplands of Britain, where most afforestation is currently taking place and where rivers, lakes and water supply reservoirs are most likely to be affected by land use changes." (Forestry Commission 1988 p 5)

An alternative but overlapping set of guidelines from a conservation viewpoint (Maitland et al 1989, in press) also refers to the uplands.

Both sets fail to respond to the new responsibilities and possibilities opened by reorganisation of the water industry which include much greater powers of control over land use (Newson 1989, in press).

It is perhaps, therefore, now time that the NRA took the initiative. The Forestry Commission guidelines correctly anticipate that forest/water interactions "could become important in the lowlands". As a parallel to Nitrate Sensitive Areas and in anticipation of, rather than response to, water quality problems, it seems reasonable for the NRA to set the lowland guidelines as part of the "precautionary principle". The NRA should aspire to guiding forest production programmes in a comprehensive manner defining hydrologically and ecologically acceptable forest structures and production patterns along the lines of the Auermuehle Production Programme in Western Germany (Bruenig 1986). Already in the UK the ornithological interest is able to specify its preferences for farm woodland types (Bayes 1989).

(ii) The knowledge-base for decision making is, of course, the sine qua non of establishing an institutional infrastructure to make and carry through decisions. The review has uncovered very little material which is directly relevant to the problem of water quality management under plantation hardwoods in lowland Britain. Much of the available work has been done in mountainous watersheds abroad or on conifers in Britain. Most of it is partial, studying only nutrients or only the soil etc. The disciplines carrying out the research have been primarily those of Ecology, Pedology and Forestry. The hydrologists involved have been mainly those elucidating relatively small scale process relationships (hence the mountainous locations which make fluxes more rapid and identifiable and which offer flood protection as another justification for investment).

Before recommending research at an appropriate spatial scale (river basin) and scope of analysis (hydrological and comprehensive water quality) it is valuable to check the scientist's proclivity to the prestige experiment. To suggest a Coweeta, Hubbard's Brook (or even a

Plynlimon) for the Home Counties of England ignores not only the very considerable problem of the expenditure involved but also the ability of such a prestigious experiment to produce practical prescriptions for NRA use.

Because of the problems of extrapolation of results gathered abroad, a group of Dutch studies would repay further detailed investigation (eg Duysings et al 1983, Breemen et al 1988).

A hardwood forest catchment in the lowlands would be difficult to set up in terms of "experimental" and "control" land uses, considering the predominantly small scale of the units being afforested. To achieve good control would almost certainly involve land purchase. Control is a temporal as well as a spatial concept. To be relevant to the forest crop cycle and its variants such as coppicing, experimental treatments would be necessary, requiring an existing forest of some age and long records of calibration for the experimental basins (Likens 1985).

Even if all this could be achieved it is unlikely that research results could be easily extrapolated to other rock types, land use histories and forest management plans unless some form of allocation policy was in place to ensure a more confident prediction/prescription away from the experiment. It would be useful for the NRA to investigate the use of simple Geographic Information Systems (GIS) to aid extrapolation. The Dartington Trust used the ITE, Merlewood, Land Classification's 32 land classes to predict the regional effects of wood energy production on runoff (Downing, personal communication, 1982).

Unfortunately the current "wave" of research proposed on hydrological aspects of lowland forestry (Table 11) is mainly to be carried out at the plot scale; it sensibly pays attention to the significance of groundwater in the lowlands but surface water is not addressed at the river basin scale except at Leeds (where the emphasis is on marginal land close to the uplands) and Newcastle (where the emphasis is much more strategic and policy-orientated than experimental). The land use issues are, in fact, attracting more coherent and consistent research interest than the hydrological/water quality issues, possibly for reasons of cost and of the apparent volatility of water quality issues (standards, enforcement).

Table 11 - Ongoing research into lowland forestry

Research institution	Funding body	Investigation
a) Hydrological issues		
Leeds University	NERC/DoE/FC	Water quality effects of marginal forestry
IH	DoE	Hydrological impacts of hard-wood plantation on lowland Britain
Newcastle University	NERC/SERC	Land use strategy and water quality at the catchment scale
BGS	DoE	Impact of broadleaf plantations on groundwater
b) Land use issues		
Edinburgh University	NERC/DoE/FC	Motives behind farmers' decisions to plant trees
Wye College	MAFF	Farm Woodland Scheme
Reading University	MAFF	Set-Aside uptake

The inescapable conclusion is that the NRA divisions (in the appropriate regions) may also be in possession of the appropriate data. Whilst it is unlikely that the data were gathered within an experimental context, such a context can often be applied a posteriori. For example, during the "Great Storm" of October 1987, 16 000 ha of mainly broadleaved forest cover blew down on (and has been slowly removed from) lowland Britain. Some catchments in the South East must have experienced a profound land use change at a stroke. Streamflow gauges on small catchments have suffered at the hands of cost-cutting but a small sample might well be located within the area of Southern, Wessex, Thames and Anglian regions from which the flow record would be comparable pre- and post-1987. In addition, both surveillance and monitoring data on water quality (Rodda 1980) are likely to be available, the former at gauging stations but the latter over a much wider area (though rural monitoring of compliance/standards is not extensive). Groundwater level and quality records are also likely to be available.

Whilst the "Great Storm" provided an unusual form of felling the impact on the hydrological and biochemical cycles will be a revealing analogue and it is to the hiatuses in the forest cycle that research attention must be given. Some sort of active controlled experimentation seems inevitable. We know nothing about the effects of coppicing or of ground preparation for forests on existing arable/pasture. During a period when the NRA regional programmes of hydrometry and quality surveillance monitoring are being reviewed, urgent consideration should be given to modifications in the light of all rural land use problems. For the specific problem in hand, NRA staff could redeploy efforts into gathering data from sites where broadleaved forest cover is being established or removed. Cooperation with landowners would be essential but since the "plcs" are extensive landowners an understanding pattern and timing of operations might be forthcoming.

The forests from which data have already been gathered acquire a particular significance given the need for data in advance of what might be rapid land use change.

The guiding principles for renewed studies at these sites should remain ecological in scope but targeting is also required to suit the NRA's requirements. The ecological processes of input, biological processing and hydrological outputs have been established for all plant successions by Gorham et al (1979) but there should be particular attention at "rejuvenated sites" in England and Wales to:

- seasonal effects
- interspecific differences (quantity and quality)
- management regime
- effects on aquifers

The patterns of solute and sediment production in a wooded area should be studied along the lines used by Duysings et al (1983). Opportunities for such studies would, for example, be plentiful in the Slapton catchment (Burt et al 1988). Furthermore, the importance of travel in the stream network, including chemical interactions with stream flora and fauna (eg Swank 1986) should be stressed at sites where previous work "ended" at the forest floor.

(iii) If policy research is missing from the "front end" of the NRA's response to lowland afforestation, strategic guidance is also needed "at the rear". Two issues are identified here - that of ecological timescales and equilibria and that of decision support systems.

Broadly speaking the effects of lowland afforestation on river management are likely to be beneficial when compared with those which would have occurred under current agricultural practices or after a further intensification of agriculture. However, productive forestry's crop cycle and mechanised site management techniques will focus the water industry's attention on the hiatuses in land cover and management under forestry. Research is needed under lowland British conditions into the principles of resistance and resilience (Swank 1988) or reaction time and recovery time (Trudgill 1977). The cheapest and most reliable form of data gathering in this area would be biological surveying - stream invertebrates, fish etc which should be used in parallel with water quality monitoring. Long time sequences would be used to elucidate the need for the "precautionary" principles of pollution control or flexibility of resource allocation between say temporarily stressed stream systems and their recovered neighbours.

Finally, in the light of:

(i) The complexity of the decisions to be made.
(ii) The geographical specificity of much of the predictive material and of the processes themselves.

It seems likely that decision-making will be local and specific (or will include a second specific tier within national policies) and that decision making will need formal support.

In Arizona the "MCDM" (Multi-Criterion Decision-Making) technique has been applied to the holistic management of forested watersheds, allowing formal evaluation of this multiple objective set by law (maximising public benefits in an environmentally sound manner). Tecle et al (1987) describe how two decision-support systems prioritise the options and allow sensitivity testings. For such models to be effective, however, requires not only an adequate information base but that it is collated, co-ordinated and made available to the responsible agency (in this case, presumably the NRA). A geographical information system (GIS) would be at the heart of such a model to allow a two-way traffic of data and decisions.

SUMMARY OF RECOMMENDED RESEARCH

i) Policy-oriented research is required to place NRA's role in the institutional, financial and legal context which will make research results an effective tool for decision-making.

ii) Prestige catchment experiments are not recommended because of expense, urgency and problems of extrapolation. The NRA should use the opportunities provided by existing data (eg, in relation to the hiatus of the 1987 storm damage) or by the current appraisals of regional hydrometry, surveillance and monitoring schemes.

iii) Sites from which intensive data have already been gathered should be re-equipped prior to management treatments; the land holding of the privatised water industry offers opportunities for collaborative research.

iv) Research programmes currently under way to provide hydrological data on lowland forests are under-resourced and partial.

v) Basic scientific enquiries, such as those into stability of ecosystems under forest management and formal models of decision support should also be encouraged.

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APPENDIX A - ANNOTATED BIBLIOGRAPHY

YOUNG C P (1981) The distribution and movement of solutes derived from agricultural land in the principal aquifers of the UK, particular reference to nitrate. Water Science Technology 13, 1137-1152.

Reports study of >100 borehole survey of water quality in the Chalk and Triassic Sandstone aquifers. Most of the work focuses upon agricultural nitrate losses to groundwater. However, beneath grassland and woodland the Chalk aquifer was found to be less polluted (Figure 9).

SKEFFINGTON R A (1987) Soil and its responses to acid deposition. CEGB Research 20, 16-29.

An article mainly concerned with the scientific debate over soil acidification. Lysimeter study used both natural rainfall and sulphuric acid. Survey included of pH profiles beneath oak, pine and birch on an acid soil in the Tillingbourne catchment. Differences (oak > beech > pine in soil pH) put down to differences in chemical (nutrient) cycling (Figure 10).

KINNIBURGH D G (1989) Impact of broadleaf plantations on groundwater. Report to Steering Group from BGS.

Ten 10 m-deep boreholes into Chalk in Black Wood (between Basingstoke and Winchester), beneath beech and ash. Two controls on unfertilised grassland. Interstitial water analysed for wide range of major and minor elements.

Large edge effect noted (variables not specified); also not a large difference in the (steady state) profiles between oak and ash.

"There are unlikely to be strong objections to the planting of deciduous woodland on the grounds of either the quality or quantity of groundwater recharge."

INSTITUTE OF HYDROLOGY (1989) Hydrological impacts of hardwood plantation on lowland Britain. IH Report to DoE. Report No 1.

Describes work proposed on canopy and soil processes (mainly hydrological but including chemistry) at Potton Wood near Bedford, (ash and occasional oak with hazel understorey) and Black Wood (see Kinniburgh 1989). Includes review of broadleaf canopy processes and interception rates (Figure 10). Transpiration rates 325 mm ± 18 mm yr^{-1} all over Europe.

"On an annual basis broadleaves (birch, oak, elder) remove nitrate and ammonium ions from rain as it passes through the canopy; increase deposition of sulphate and free hydrogen ions relative to rainfall and tend to show anion deficits below the canopy.

ALCOCK M R and MORTON A J (1985) Nutrient content of throughfall and stemflow in woodland recently established on heathland. J Ecol 73, 625-632.

Reports a study of rainfall quality over heathland and throughfall of stemflow quality below adjacent canopy covers of *Pinus sylvestris* and *Betula pendula*, near Ascot. Potassium and magnesium were enhanced beneath trees (wash-off or canopy leaching - especially Autumn). Phosphorus and nitrogen slightly reduced beneath trees, calcium much reduced, showing tree or epiphyte responds to low soil nutrients status.

FOSTER I D L, DEARING J A, CHARLESWORTH S M and KELLY L A (1987) Applied Geography 7, 115-133.

Compares two catchments draining to small lakes in the Midlands, one predominantly covered by broadleaved forest, the other cultivated. Lake cores reveal differences in flux of sediments, nutrients and metals since 1765 AD. More soil erosion from the arable; higher metal (iron, manganese, aluminium) from the forest but heavy metals brought in by soil erosion on arable. Marked changes represent industrial sources of pollution. Difficulty in separating catchment-lake exchanges.

FOSTER I D L (1987) Acid Buffering in lowland forested ecosystems: a case study in the Trent basin, UK. Proc Vancouver Symposium, IAHS Publ 167, 49-63.

Oak throughfall on average 1.1 pH unit < rainfall in this 95 ha catchment near Coventry UK. Sulphate and chloride are the dominant acid forming anions (not nitrate). Wet pollution increases weathering rates by 5% (becomes 10% if dry deposition is another source of throughfall acidity). Buffering minimal in soils, so metals mobilised - Al, Fe and Mn. However, floodplain groundwater produced buffering and metal contents diminished.

	Al	Mn
Soil	2.52	2.81 mg l^{-1}
Floodplain	0.18	0.42 mg l^{-1}
Stream	0.03	0.03 mg l^{-1}

CARLISLE A, BROWN A H F and WHITE E J (1966) The organic matter and nutrient elements in the precipitation beneath a sessile oak (Quercus petraea) canopy. J Ecol 54 87-98.

Study site: Grizedale Forest. Throughfall measured with 20 polythene raingauges and gauze filters; monthly analyses. June 1963-May 1964 rainfall 1616.9 mm; throughfall 1405.1 mm (stemflow not measured). Reduced nitrogen in throughfall but P, K, Ca, Mg and Na contents increased. Litter contribution also considered: 82.3% of nitrogen to forest floor in litter but less than 3% of sodium.

CARLISLE A, BROWN A H F and WHITE E J (1967) The nutrient content of tree stemflow and ground flora litter and leachates in a sessile oak (Quercus petraea) woodland. J Ecol 55 615-627.

Quantities of water in stemflow small on an area basis but concentrations of Ca, Mg and K relatively high. A 13.9% interception loss on the oak canopy but a further 12.7% loss on the bracken ground flora during July-October. Annually 14.3% total interception (3.7% on bracken). Stemflow only 2.1% of total throughfall reaching ground. Important that high volumes of stemflow saturated soil and reached roots quickly. Loss of nitrogen also from stemflow - leaves first? epiphytes? Stemflow considerably more acid (pH 3.5-3.9). Bark leaching leads to gains in some nutrients in stemflow.

SKEFFINGTON R A (1981) Tillingbourne catchment - Interim report. CEGB RD/L/2083N81

The catchment has a tree cover with a very acid throughfall but soil and streamflow acidification is reduced by metal cations deposited on the canopy as dust. This keeps upstreamflow pH by one unit; it is further enhanced by groundwater contributions in the first kilometre downstream. Even during acid episodes, no lower pH than 5.8 has been recorded in the trout ponds at this point (despite throughfall of pH 2.8).

SKEFFINGTON R A (1985) Effect of acid deposition and natural soil acidification processes on soil; some studies in the Tillingbourne catchment, Leith Hill, Surrey. SEESOIL 2, 18-34.

Study lasted from 1977 to 1982; included bulk precipitation, throughfall, streamflow (volumes, chemistry) and calculation of budgets. Catchment is fed by groundwater from the Lower Greensand (Hythe Beds) - leading to valley mires. Vegetation is oak-birch, heath with subspontaneous pinewoods. Deposition rates for 1981 recorded as follows:

Deposition Rates at Tillingbourne 1981

Under	Water mm	H^+	SO_4^{2-}	NO_3^- keq ha^{-1}	Cl^-	NH_4^+	Organic kg ha^{-1}
Rain	1082	0.64	0.90	0.38	0.92	0.45	31
Bracken	954	0.47	1.00	0.36	0.94	0.58	47
Oak	827	1.31	2.31	0.29	1.57	0.40	236
Birch	796	1.64	2.24	0.27	1.79	0.43	218
Pine	410	6.17	6.01	0.23	3.98	0.37	229

Further details of precipitation chemistry are given by Skeffington (1983).