Social & Environmental Benefits of Forestry
Phase 2:

BENEFITS AND COSTS OF FORESTS TO WATER SUPPLY AND WATER QUALITY

Report to

Forestry Commission

Edinburgh

from

Kenneth G. Willis

Centre for Research in Environmental Appraisal & Management
University of Newcastle

http://www.newcastle.ac.uk/cream/

August 2002

Social & Environmental Benefits of Forestry
Phase 2:

BENEFITS AND COSTS OF FORESTS TO WATER SUPPLY AND WATER QUALITY

Kenneth G. Willis

August 2002

1. Introduction

Land use change, between agriculture, forestry, and other uses, affects water resources. Different land uses absorb different amounts of rainfall and affect the amount of water reaching underlying aquifers, streams and rivers. Different land uses also have different impacts on water quality in streams and rivers. A considerable amount of research has been directed to quantifying the physical magnitude of these impacts under varying circumstances, although considerable information gaps remain. Much less research has been devoted to assessing the economic value of the impact of forests on water supply and on water quality in Britain.

The objective of this report is to assess, and quantify as far as possible, the impact of forestry on costs and of water supply and water quality. Where quantitative estimates of impact could not be made because of lack of data, qualitative assessments are made with respect to the impact.

The value of water can be estimated in terms of:

- *opportunity cost*: e.g. the cost to society of forestry using the marginal quantity of water rather than some other economic activity;
- *replacement and mitigatory costs*: e.g. the cost of having to develop alternative water sources where forests reduce supply; the reduced cost to society where forests regulate run-off and hence lower flood risks and the need for flood prevention; etc.
- *willingness-to-pay (WTP) by individuals* in terms of use and non-use values for marginal increases in security of supply, enhanced water quality, reductions in interruptions to supply, etc. from changes in water supply and quality due to forests.

There are few benefit or WTP estimates for individuals, for specific water supply and water quality issues created by forests, that can be applied across Britain. Moreover, since water company customers have to pay through their water bills to permit water companies to develop alternative sources of water to meet demand, it seems reasonable to use replacement cost as the relevant measure of value. Hence, replacement and mitigatory costs are mainly employed to measure the impact of forests on water supply and water quality in this report. However, for some issues, e.g. loss of hydro-electricity production, opportunity cost measures might be more appropriate.

This report briefly categorises the main non-market costs and benefits of forestry on water supply and quality. It then documents in more detail the impact of forestry on water supply, and the possible externality cost of woodland if water companies had to replace the water lost through afforestation. The report then investigates the impact of forestry on water availability to other land-uses; reviews the impact of forestry on water quality; before going on to outline the possible costs and benefits of forests in these areas.

Estimates of water supply replacement costs are provided for England and Wales. Lack of data on replacement costs of water precluded the extension of this to Scotland. Similarly lack of data meant that many aspects of the impact of forests on water quality could not be quantified on a comprehensive spatial basis. In addition the lack of data on other externality benefits of woodland e.g. in reducing flooding, soil erosion, etc., mean that many of the positive benefits of forests on water issues are acknowledged but remain unquantified on a spatial basis across Britain.

The report concludes that undertaking a reliable evaluation of the impact of forests on water for Britain as a whole is difficult, both because of a lack of relevant economic data plus the fact that the impacts of forestry on water quantity and quality are strongly influenced by site-specific factors

2. Non-market benefits and costs of forestry on water supply and quality

Forestry can potentially affect the quality and amount of water available to other users. The principal uses of water flowing into and from forested catchment areas are:

- abstraction for potable water (for drinking and commercial uses)
- agriculture and irrigation in down-stream areas
- hydro-electric power generation
- wildlife, including recreational and commercial fisheries
- other recreational uses, such as canoeing and sailing.

The quality of water flowing from forested areas is also important to all of these activities with the exception of hydro-electric power generation. Woodland might improve or denigrate water quality depending on forest management practices and alternative land-use (e.g. agriculture).

Woodland also has positive benefits on water supply and quality. By regulating run-off it may reduce down-stream flooding, prevent soil erosion, etc. There is a lack of comprehensive information on these impacts across Britain. Hence the value of many of the positive benefits of woodland on water issues is difficult to estimate.

The impact of forestry on water that is most easily and comprehensively quantified, and valued spatially, is that of its impact on water availability, e.g. in terms of the lost use value of potable water. However, even for this use, the value of potable water lost through forestry is still subject to considerable uncertainty. As with all the above uses, the extent of the impact of forestry depends upon the proportion of the river catchment area covered by woodland, and type of woodland.

3. Forestry and water supply

The impact of forestry on water availability

Rainfall over land surfaces replenishes groundwater reservoirs and provides runoff in streams and rivers. Some of this rainfall is lost through

- interception of rainfall held on leaves and evaporated by the wind before it reaches the ground;
- transpiration: water drawn up through plant roots and evaporated from leaves through the stomata (small pores in the leaf surface).

The inception of rainfall (hereafter simply termed inception) and transpiration rate for forests is usually greater than that for alternative vegetation, because they have more leaf cover in relation to ground area and a greater aerodynamic roughness of their canopies, and because they have a deeper root system.

Hydrologists and climatologists point out that forestry is important in the interception of rainfall, especially relative to grassland. Forestry increases the inception rate, and hence reduces the amount of rainfall percolating through to the underlying water table, and to streams and rivers (Calder, 1999). Thus forestry can have an important effect on stream flows, but this impact varies according to forest rotation. The Coalburn experiment[1] found that ground preparation through ploughing increased annual total run-off flows (especially by augmenting low flows) and increased peak storm flows (although shortening their duration). In contrast the growth of trees reduced water yields and peak flows, and base flows declined (Robinson *et al* , 1998). Hence semi-mature and mature forests affect the availability of water for abstraction to water companies. Since the demand for potable water is increasing (through population growth and growth in demand for water per capita) forestry may affect the costs that water companies face in abstracting water.

The model developed by Calder and Newson (1979), and subsequently refined (see Calder, 1999), is widely adopted to estimate the annual and seasonal differences in runoff from afforested upland catchments in the UK compared to an alternative vegetation cover, typically grass cover. Assumptions underlying the model are that

(1) evaporation losses from grassland are equal to the annual Penman[2] potential transpiration estimate for grass, E_{Ta} ;
(2) transpiration losses from forest are equal to the annual E_{Ta} value multiplied by the fraction of the year that the canopy is dry;
(3) annual inception loss from forest, with complete canopy coverage, is a simple function of the annual rainfall, P_a ;

---

[1] The Coalburn catchment experiment established in 1966 is Britain's longest running experimental catchment area, situated within Kielder Forest, with over 30 years of observations from open moorland, through tree establishment in 1973, to canopy closure. The tree species planted, the peaty soil types in the catchment, and the need for extensive ground cultivation and drainage to aid tree establishment are typical of many upland forests.

[2] The Penman model is concerned with the determination of potential evapo-transpiration, *PE*. *PE* considers that the soil matrix is at field capacity and that evaporation from the surface is close to maximum. *PE* from a grassland surface is close to E_0 from a large water body, hence the methods used to determine E_0 are also used to calculate *PE*. Thus $PE = f\,E_0$, where f = empirical constant (= 0.6, November, December, January, February; = 0.7, March, April, September, October; and = 0.8, May, June, July, August. So *PE* is typically 70% of lake evaporation and since actual evaporation $\leq PE$, actual evaporation $\leq ET \leq 0.7E_0$ (Tilford, 2000).

(4) soil moisture deficits are insufficient to limit transpiration from grass or trees in the wet upland area of the UK.

The model for annual evaporation is:

$$E_a = E_{Ta} + f(P_a\alpha - w_a E_{Ta})$$

where α = the inception fraction (35-40% for regions in the UK where rainfall exceeds 1000mm); w = the fraction of the year when the canopy is wet (~0.000122P_a); f = the fraction of the catchment area under forest cover.

Climatologists and hydrologists advise that there is little difference in inception rate, especially for conifers, between summer and winter. However, there is a *net* difference between trees and the alternative vegetation. Trees result in an approximately 30% inception loss compared to grass and moorland grasses; but where the alternative is bracken then the inception loss from trees is only of the order of 18%-20% (Newson, 2001).

Transpiration from the canopy occurs when the leaves are dry. Transpiration is variable, but mainly driven by climate. The transpiration rate does not vary much between tree species, even between broadleaves and conifers. There is an approximate 15% loss through transpiration when the canopy is dry, whilst transpiration ceases when the canopy is wet (Newson, 2001).

The balance between inception and transpiration varies depending upon climate, and can vary between summer and winter. Thus, for Thetford forest the transpiration rate is twice the inception rate, because the East Anglian climate is characterised by rain on 5% of days compared with 20% of days with rain in the uplands of Britain.

The difference in water yield between mature forest and grassland in the lowlands is less than that in the uplands. It is argued that the drier and less windy climate of the lowlands reduces the size and importance of inception loss, so that in the lowlands the difference between forestry and grassland is believed to be marginal (Forestry Commission, 2000).

The Calder-Newson model is used to estimate decreases in water availability through forestry for England and Wales (see Tables 1 and 2). Rainfall (rainfall in mm) and annual evaporation (effective transpiration rates E_{Ta}) were obtained from MAFF (1976) information on the agricultural climate of England and Wales. Woodland cover (forest %) was supplied by the Forestry Commission for the year 2000, from the national inventory of trees and woodland that covers all woodland (private and public) in Britain. Inception is taken to vary according to rainfall.[3] From this information the loss in mm per hectare can be estimated. This multiplied by the forested hectares (adjusted to take account of felled, newly planted, and forested area) gives the reduction in the amount of rainfall available under forestry, relative to grassland

[3] Inception rates were taken to be

rainfall (mm)	*inception*	*rainfall (mm)*	*inception*
≥ 1000	0.30	700-799	0.15
900-999	0.25	600-699	0.10
800-899	0.20	≤ 599	0.05

coverage, from the Calder-Newson model can then be converted into a cubic metre loss per hectare. This is expressed at a county level.

There are a number of errors in applying this approach to estimating the m^3 loss of water per hectare by county. The rainfall data produced by MAFF are for agricultural districts that frequently cut across county boundaries. There is often more than one agroclimatic area per county; but where this is the case information for the agroclimatic area in which most woodland in that county is based was used. Although the standard against which water loss due to forestry is calculated as grassland, different counties also have varying amounts of other land-uses (heather, urban areas, etc.). In areas where the alternative land-use is heather, the Calder-Newson model will over-estimate water loss due to forestry [if the model was applied unmodified to Scotland this would have major implications for the estimated impact of forestry on water]. In areas covered by urban development, the direction of relative error is uncertain, and depends upon the inception and transpiration rates under grass compared to urban land-use. The *net* transpiration and inception loss due to forestry also depends upon the forest rotation. Clear felled areas will have the same transpiration and inception rates as grassland. The national woodland survey provides information on tree type [broadleaved, coniferous, mixed (broadleaved and coniferous where each is <80% of all tree area), coppice, coppice with standards, shrub, felled, ground prepared for planting, young trees, and total woodland area]. Tree coverage was taken as total woodland minus felled area minus ground prepared for planting. Identifying 'young trees' is problematic since they are revealed from image representations on 1:25,000 areal photographs. These images reveal trees as having been planted (seen as dots representing rows of visible trees on the photograph) but tree crown development is insufficient to distinguish between broadleaved and conifer. In the case of 'young trees' the number of hectares was divided equally between forested and non-forested areas (i.e. newly planted woodland area was deemed to be equivalent in hydrological terms to grassland). This produced a modified estimate of the area of forest by county in the penultimate columns of Tables 1 and 2.

In addition, whilst the Calder & Newson model is probably the most amenable to this type of assessment, it does not separate out the effects of broadleaves from conifers. Some recent evidence suggests that broadleaves have a lower water use compared to conifers (Roberts *et al*, 2001). Thus the adoption of the Calder-Newson model will overestimate the loss and thus the overall cost of water due woodland in areas of broadleaved woodland. This is especially the case for areas overlying chalk, the principal groundwater aquifer in England, where research has shown broadleaved woodland might actually use less water than grass (so that there would be a net benefit rather than cost).

Nevertheless, it remains difficult to predict accurately the water quantity impacts of lowland forestry because

1. in the lowlands transpiration generally exceeds inception. Tree physiology exerts a strong influence over transpiration rates, depending upon interactions between atmospheric demand and available soil water. Hence this can result in lower or higher transpiration rates compared with different agricultural crops.

2. there is limited information on the evaporation losses for different tree species growing on contrasting soil types in lowland Britain (Calder, 2002).

A hydrological land-use model of Greenwood Community Forest in Nottingham, using parameter values derived from the earlier study for chalk, but amended to take account of the differences in soil water availability for sand and clay-loam soil, found that annual evaporation from broadleaved woodland on sandy soil was 93mm (20.2%) higher than that from grassland. This implies that afforestation would reduce the average recharge (of the aquifer) and runoff by 51%. The predicted reduction in recharge plus runoff on clay-loam soil was 62% (Calder, 2002). The impact of a three-fold increase in woodland cover from 9% to 27%, within Greenwood Community Forest, was estimated to reduce annual recharge and runoff by 11% (over a 24 year period).

A comprehensive assessment of the impact of broadleaves on water supply by soil/geology types remains to be undertaken. Until this is completed predicting the effect of forestry on water supply in lowland Britain remains uncertain.

Other factors likely to overestimate the water use costs of woodland in upland Britain are the failure to account for the higher water inception rate of heather and bracken, the additional water yield resulting from forest drainage, and the fact that in some areas conifer forest will be located downstream or outside of the utilisable water resource. It is also important to note that while the adjusted forest area figure includes 'young trees' (<60 cm height), this will greatly underestimate the area of pre-canopy closure crop that could be expected to have lower inception and transpiration rates than the standard for conifers.

It should be noted that the Forestry UK Standard affects the management practice in second rotations of woodland, resulting in increased levels of broadleaves, open space and a more varied age distribution. All of these changes are likely to reduce interception levels.

Clearly, there are many practical problems in estimating in detail the impact of forestry on water supply. Nevertheless, given the estimates of the physical impact of forestry on water availability, an economic value for this loss of m^3 of water due to woodland now needs to be calculated.

Marginal cost of supplying potable water

The foregoing section illustrates how forestry can potentially reduce the amount of water available to the water industry compared with its alternative land-use (say grassland for broadleaved and moorland for conifer trees). Forestry generally reduces run-off into rivers, thus reducing the amount of water available for abstraction from this source; and forestry also reduces the amount of water percolating down into the water table, thus reducing water available for abstraction from this source. If the amount of water available for abstraction is reduced then this may increase abstraction costs to the water industry, but only if alternative sources of water supply have to be developed.

The marginal cost (MC) of reduced surface and ground water available to the water industry will vary with the amount of forest cover in the area, and with the particular schemes each individual water company adopts to equate the marginal demand and supply of water in each of the water resource zones in its area. This might involve additional groundwater pumping from boreholes; the development of additional pipelines to import water from other catchment areas, or other infrastructure (e.g. reservoirs) etc. MC might also vary with rainfall levels and with location (the importance of location might be usefully explored in future research using GIS to document what water catchments are used for water abstraction).

Where no additional infrastructure is required and water deficits can be met by additional abstraction from existing boreholes then the short run marginal costs (SRMC) per million litres (Ml) in 2001 are: power £25; chemicals, <£1 for good groundwater sources; chemicals, ~£2 for groundwater sources with enhanced treatment e.g. nitrates; chemicals, ~£15 for surface water sources (McMahon, 2001).

However, forestry is a long-term investment and hence it is more appropriate to use the long run marginal costs (LRMC) of water supply to estimate the environmental costs of forestry. OFWAT now requires water companies[4] to produce accurate and consistent estimates of their long run marginal costs (LRMC) of water supply. These are estimates for the total cost of abstracting the next cubic metre (m^3) of water, including any capital investment costs. OFWAT regards LRMC not as a theoretical concept but as a central reference point for sound decision-making by both companies and the regulator (OFWAT, 8-5-2001). Hence LRMC can be argued to provide a sound basis upon which to estimate the environmental costs of forestry on water in this study. Of course OFWAT recognises that LRMC are forecasts and rely on engineering judgements, and that such forecasts are subject to errors and uncertainties. LRMC estimates will vary depending upon whether demand is spread evenly across water resource zones within each company area, or whether demand is expected to be evenly spread across zones.

OFWAT recognises two methodological approaches to estimating LRMC: (a) average incremental cost (AIC) approach (b) perturbation (P) approach. Both approaches are based on optimal least cost solutions to addressing demand/supply imbalances. The AIC approach estimates LRMC as:

(*PV of extra capital and operating costs of the optimal strategy)* /
(*PV of discounted volumes of additional water supplied or saved)*

Thus the AIC approach considers the level at which future increments of output must be sold to ensure total incremental cost recovery, given forecast changes in demand and supply. In the P approach LRMC is calculated as the change in the

(*PV of schemes required to maintain the supply/demand balance*) /
(*PV of marginal change in expected demand*)

The P approach considers the change in forecasted future system costs arising from a permanent increment or decrement in forecast pattern of future demand. Whilst both

[4] There are some 26 water companies in England. The Anglian Water Company is counted as two here since it covers separated geographic areas: East Anglia and Hartlepool areas

approaches are based upon present value (*PV*) over a 25 year time horizon, the P approach is more explicitly concerned with decision-making at the 'margin'.

The LRMC curve could be approximated by forecasting unit costs of the 'next representative scheme' (i.e. the AIC approach but only focusing on the first step in the supply/demand balance program). Evidence from companies' submissions to OFWAT suggests that the 'next representative scheme' approach is sensitive to significant unit cost disparities between different schemes in companies' investment schedules. Therefore, the *PV* methodology over a longer time horizon in the 'average incremental cost' and the 'perturbation' approaches is to be preferred.

OFWAT does not view the LRMC estimation as a standardised calculation. However, water companies are required make explicit their assumptions, and present a thorough analysis that is demonstrably consistent with the company's Water Resource Plan. Thus OFWAT seeks to foster consistency in the approach to estimating LRMC and in the level of analysis.

Most, although not all, companies have adopted the AIC approach. The AIC approach relates future costs and volume growth. The AIC approach requires consideration of the relationship between future costs and volume growth. However, it is necessary to separate out changes in future costs that are independent of volume growth. Water company studies of LRMC submitted to OFWAT suggest variation in terms of cost inclusions and exclusions in the AIC approach, in particular on issues dealing with metering[5], leakage[6], security of supply, and demand management.[7] OFWAT (undated) has provided guidance on which costs should be included and which costs should be excluded, to ensure standardisation of LRMC estimates. Thus, the LRMC estimates provided by companies can be considered to be the most sound and robust marginal cost estimates available to assess the environmental costs of forestry with respect to water.

Table 3 shows a wide variation in LRMC depending upon company and area. Variations in the LRMC occur as a result of varying prices per m^3 of water for water abstraction, treatment, and transport and distribution, depending upon local circumstances.

LRMC include costs of provision of additional resources that might involve a variety of different schemes ranging from new boreholes, increased abstractions, or winter storage mechanisms. Distribution costs are included since additional distribution

---

[5] A number of LRMC submissions do not clarify whether metering costs have been included. The OFWAT view is that since metering influences demand, and demand reduction associated with metering may be treated as a substitute for development of new resources and treatment facilities, then the costs associated with metering should be included in a LRMC.

[6] Leakage reduction forms a significant part of many companies' least cost investment schedules, because it makes more treated water available to customers. Since it is therefore a direct substitute for development of new resources and treatment works, OFWAT believes that costs associated with reducing leakages, in present and future periods, should be reflected in companies' LRMCs.

[7] Where water companies choose demand management measures as part of their least cost supply-demand balance program, these costs should be included in the calculation of LRMC.

costs might be involved for new sources of supply [although if such distribution costs are not involved for the marginal loss of water due to forestry, the inclusion of distribution costs will over-estimate the externality costs of forests]. Distribution costs are higher in Wales and north-west England and also in south-east-England; with a relatively low cost band running from the Bristol Channel to the Humber (OFWAT, 2001).

Externality cost of forestry on water supply
The externality cost of forestry in terms of the increased costs of water abstraction can thus be approximated by

$$WS_{ex} = WS_{lrmc} - WS_{srmc}.$$

where WS_{ex} = external costs of water supply attributable to forestry; WS_{lrmc} = long run marginal costs of increasing water supply; WS_{srmc} = short run marginal cost (SRMC) of increasing water supply. Treatment costs are included in LRMC, and comprise a variety of chemicals and power. These marginal costs are subtracted in the equation above from the LRMC since they would probably be incurred in any case to treat water that forestry precluded.

Tables 1 and 2 provide an estimate of the externality cost of forestry on water availability. This varies by county and is a function of the annual evaporation above the annual Penman potential evaporation, climatic conditions, proportion of the year the canopy is wet, the amount of forest coverage, and the LMRC-SRMC of water abstraction.

If there was a direct one-to-one trade-off between forestry and water availability, the external costs of forestry on water supply might be as estimated in the final column of Tables 1 and 2. These indicate an externality cost of £52.491 million for England and £35.357 million for Wales. Since the LRMC is defined by OFWAT (2001) as the present value (PV) of the expected costs of the optimal supply strategy, per unit of water, the costs in Tables 1 and 2 are capitalised costs.

The capitalised cost of the impact of forestry on water supply, estimated at £88 million for England and Wales in this report, should be seen as an upper-bound estimate: the maximum possible cost that the current area forestry entails. This equates to an annual externality cost of £5.3 million (at 6% discount rate). In practice the cost of forestry in terms of water supply will be much lower.

The estimates should also be regarded as 'ball-park' estimates because it is not possible to directly map LRMC estimates from water company areas direct to local authority county areas. More than one water company can cover the same county (e.g. in the case of Kent, Hampshire, Surrey, Sussex, Durham, etc.). Moreover, the LRMC curves relate to companies as a whole, but LRMC are likely to vary significantly between company areas, especially for major companies such as Dwr Cymru that covers the whole of Wales, United Utilities which covers north-west England, and Severn Trent which covers vast areas of the Midlands.

However, there is no evidence that there is, in general, a direct one-to-one relationship between the reduced amount of water available for abstraction due to forestry and additional costs of water abstraction. The water supply problem (excess demand in relation to supply) occurs mainly in the southern and eastern counties of England. Hence, although the effect of forestry on water quantity (because broadleaved-trees rather than conifers are located in these areas) is likely to be lower in the drier and less windy climate of south-east England, its impact on water abstraction costs may be greater because of the shortage of cheap alternative water sources in these areas.

There is a difference in views between academic and government hydrologists on the one hand, and managers and economists in water companies on the other, in their estimate of the impact of forestry on water supply. Hydrologists point to the theoretically large impact of forestry on water availability; whereas British water companies perceive little impact in general of existing forestry on water supply costs (personal communication, 2001).

Structured discussions with ecologists, economists, and managers in three water companies (Northumbrian, Southern, and Yorkshire Water) did not reveal major concerns about the impact of existing forestry on water availability. As one company representative stated "The whole catchment area would have to be afforested to have an appreciable impact on water availability". Clearly, this circumstance does not apply to most English reservoirs (Kielder is perhaps the major exception). Most English reservoirs are mainly located in upland moorland areas where the there is relatively little forestry directly impacting on the catchment. Dwarf shrubs and heather were seen as a significant source of rainfall loss to these upland reservoirs rather than forestry. However, companies did foresee large areas of new woodland as potentially a major problem of water supply.

Precise estimates of the externality costs of forestry in terms of the increased cost of water abstraction would require a forest site by forest site study of the issue. As discussed earlier, the marginal cost of reduced surface and ground water available to the water industry will vary with the particular schemes each individual water company adopts to equate the marginal demand and supply of water in each of the water resource zones in its area. Resources available to this study do not permit an analysis at this level of detail.

The estimates in Tables 1 and 2 are based upon average LRMC. In some cases the costs of specific schemes proposed to augment water supplies might exceed these estimates. For example, Southern Water proposed the Hardham Artificial Recharge Scheme (HARS), near Pulborough, West Sussex, at an estimated capital cost of £11 million, to augment water supply to its Sussex North (and to a lesser extent Sussex Coast) resource zones (covering a population of more than 700,000) due to increasing population and higher demand per person for water. It could be argued that the HARS is required because of the low summer flow in the River Rother, exacerbated through the extensive area of woodland in the Rother catchment area and over the surrounding aquifer beds.

In the HARS, water abstracted from the aquifer in the summer would be replaced (artificially recharged) in the winter months (November-March) with water, up to 20Ml/d, abstracted from the River Rother at Pulborough. The water would, except for chlorination, be fully treated before being pumped into the aquifer. Some injected water would be lost, for instance to springs flowing from the aquifer; but it is thought that 80% of the injected water would be recoverable. The maximum additional abstraction, above the 75 Ml/d from the existing boreholes and Hardham would be limited to 1875 Ml, in any single year.

Additional operating costs would be incurred in the abstraction and treatment of river water prior to recharge depending on the frequency of use. The net present value cost of the additional operating costs was estimated at approximately £6 million assuming use every year.[8] The overall net present value cost of the HARS scheme is therefore approximately £17 million. In practice use of HARS would be used 1 in 10 years. This frequency of use does not affect the capital cost but the additional operating costs would be incurred only 1 in 10 years. The net present value of the additional operating cost is thus £0.6 million. The overall net present cost of HARS is therefore reduced to approximately £11.6 million. Thus, it is clearly not easy to evaluate the costs per m^3 of such water, but if 1875Ml was abstracted only once in 10 years, then the cost of this water would £6.19 per m^3: a cost much higher then the average LRMC reported to OFWAT by Southern Water.

Impact of forestry on water availability to other land uses

The value of the impact of forestry on land uses such as agriculture, hydro-electricity generation, wildlife (including recreational fishing), and other recreation, is site specific and will vary over different areas of Britain. Lack of information prevents a detailed assessment of the impact of forestry on these sectors. For example, forests can affect the amount of water available to hydro-electric production, especially small run-of-river schemes that are developing under the UK non-fossil fuel electricity production obligation and sustainable energy program. However, a detailed appraisal of the impact of forestry on hydro-electricity production would require an assessment of

(1) existing systems: whether larger run-of-river plants could have been installed and the additional net electricity benefits that this would have generated, including carbon values from reductions in fossil fuel electricity production;
(2) potential systems: whether potential hydro-electricity sites had been rendered infeasible because of the existence of forests in the river catchment areas.

There is no information available in the public domain to undertake such an assessment of the impact of forestry on hydro-electric production. Similar data problems arise in assessing the impacts of forestry on water supply to agriculture, wildlife and other recreational uses.

For some activities such as agriculture, reduced water availability due to forestry, is likely to have little or no net cost due to Common Agricultural Policy (CAP) subsidies.[9] The comments below, on the benefits lost to other land-uses (agriculture, hydro-electricity, water based recreation, and wildlife) from forestry, present some general views of the likely impact.

---

[8] Discounted at 6% over 30 years.

[9] CAP subsidies result in excess agricultural production, with the marginal social cost of such production exceeding the value of the marginal production to consumers. Hence constraining forestry to permit more water availability to agriculture will reduce social benefits.

Agricultural benefits

Additional water available by not afforesting land may be available for irrigation in agriculture. Irrigation is financially profitable for some farmers. However, given over-production in cereals and in the dairy industry, together with CAP subsidies, and tariffs at the EU frontier, the use of water for irrigation is unlikely to have a net social benefit.

The lack of benefits in diverting water from natural ecosystem vegetation to agriculture, even in a non-subsidised agricultural case, has been demonstrated in some situations. Kim (1984) simulated the increase in water yield associated with a change in land use management from no grazing to grazing in the Lucky Hills watershed of south-eastern Arizona. Based on a review of the literature Kim (1984) assumes a 30% increase in water yield under grazing over a simulated fifty-year rainfall cycle (based on climatic records). Under the additional assumption that all the extra water would be used for irrigated agriculture and employing a $10/acrefoot value for irrigation water based on studies from the region, Kim calculates the net present value over the fifty years to be $342 at a 7% discount rate. Unfortunately, it is not clear if this is the watershed total or a per acre figure. Assuming the former this comes out to a little over $3/acre for the 108-acre watershed. When Kim adds in the costs of excavating the sediment settling ponds ($1,068) and the benefits of animal weight gain ($740), the net present value of the returns to the land use management change are barely positive at $14 or about ten cents an acre (Aylward, 2000).

Hydro-electricity production

A study of the effects of afforestation on hydroelectricity generation in the Maentwrog catchment in Wales and forty-one catchments in Scotland by Barrow *et al* (1986) indicates that the increased evaporation under afforestation (in comparison with grazing) led financially marginal sites (for forestry) to become financially sub-marginal once hydropower losses were included into the analysis. While there was some variation in results depending on site conditions, the example clearly shows the negative impact on productivity associated with afforestation in a hydroelectric watershed.

A study in Arenal, Costa Rica confirms the results obtained by Barrow et al. (1986) by showing that water yield gains from reduced afforestation may lead to large efficiency gains in downstream hydroelectric power production (Aylward 1998). Best estimates for both cloud and non-cloud forest areas suggest present values in the range of $250 to $1,100/ha. Sensitivity analysis suggests that while the upper ranges may halve in certain circumstance, they may also rise to almost $5,000/ha if dry periods lengthen or come early in the simulation period. Sensitivity to the distribution of the water yield gain across dry and wet seasons is also simulated. A switching value (where total hydrological externalities go to zero) is only obtained when all of the water yield gain *and* an amount equal to 50 percent of the annual water yield gain is redistributed to arrive during the wet season (when water is less valuable for power generation). When the analysis of livestock productivity is incorporated into a cost-benefit analysis of land use options, it is demonstrated that there are strong synergies between livestock production and hydroelectric power generation in the watershed (Aylward, Echeverría et al. 1998).

In another study undertaken in the Magallanes National Reserve in southern Chile, the effect of a forest thinning on hydrological variables demonstrated positive externalities to accompany the benefits from timber production (Alvarez et al. 1996). The thinning is hypothesized to reduce the rate at which snowmelt occurs as well as reducing the rate of evapotranspiration. The net effect of these two changes is to lower streamflow levels during the snowmelt season and to raise streamflow during the subsequent dry season. The result is a lowered flood frequency and reduction in accompanying dredging costs, as well as an increase in the water supply for water treatment plants in the dry season. The benefits of flood control dominate the other two benefit categories although modest water supply benefits are expected. While the study is relatively unsophisticated it illustrates the potential for land use interventions that are "win-win" in terms of productive and hydrological values.

In the Republic of South Africa, where water is perceived as a critical resource, forestry has been declared a 'stream-flow reduction' activity in terms of the National Water Act 1998. Pricing is seen as a critical part of water conservation and a mechanism to account and correct for broader social and environmental costs. Forestry has to obtain a water-use licence, and this licence is subject to (1) a charge to facilitate catchment management activities and (2) a charge for water: a stream flow reduction charge or water inception levy. The pricing strategy under the National Water Act strategy may differentiate, on an equitable basis, between (i) different types of geographic areas; (ii) different categories of water use; and (iii) different water users. (see http://www.thewaterpage.com/south_africa.htm (01/12/01)

Scott (1998) has argued that stream flow reduction as a result of forestry is well known and understood in South Africa. Stream flow reduction following afforestation is more rapid under eucalypts than under pines, but mature plantations of both species cause mean flow reductions of 5000 cubic metres per annum per planted hectare (500 mm / year in rainfall equivalent) where that much water is available. However, there are uncertainties about the size of effects on drier forest sites where mean annual precipitation is <1000mm. Nevertheless, it is estimated that 1.44 million hectares of plantations use (reduce stream flows) by on average 1.4 billion cu.m/yr, or 3.2% of total surface run-off in South Africa, or roughly 7% of what water is estimated as being utilizable (Scott, 1998).

In Britain no comprehensive data set exists that can be used to estimate the loss of hydro-electricity production due to forestry. Hence, it should be assumed that there is some opportunity cost of forestry in terms of hydro-electricity production. The exact value of this lost production depends upon the price of oil and gas, and the value of carbon reductions in green-house gas emissions by replacing carbon based electricity production with renewable energy production.

Wildlife (including angling) and other recreational uses

A detailed analysis of the reduction in recreational value from lower river and stream flows due to forestry would require a detailed site by site assessment in each catchment area. This is beyond the scope of this study. However, the principal wildlife and recreational loss will probably be to anglers (in terms of lost fishing opportunities), and to the general public (in terms of general amenity value e.g. to walkers along river banks). For general amenity value from recreation walks, a net value would need to be calculated, since woodland both enhances the amenity value of walks along rivers and streams, whilst at the same time marginally reducing the amount of water in the stream.

Data does not exist to estimate the number of sites and the number of fishing days and walking trips affected by lower river and stream flows due to forestry. However, some information from previous studies is available on lost utility and economic value from reductions in river flows that can be used to provide a guide to the economic value of these lost benefits.

A study of the value of flow alleviation in rivers in south-west England by Willis and Garrod (1999) provides estimates for fishing and general recreational losses from reduced flows. A contingent valuation (CV) study revealed anglers were willing to pay £3.80 per day to improve low flow. This aggregated to a *net* value of £5,000 to £32,000 per river per year, depending upon the extent of the low flow, the additional number of fishing days, and substitution effects (proportion of additional days transferred from other non-affected river fishing sites).

Welfare estimates to restore rivers in south-west England to an environmentally acceptable flow regime (EAFR) for informal recreational users were around 4.7 pence per km per household per year, from a choice experiment on 750 households in south-west England. This estimate was confirmed in a separate iterative bidding CV study of general recreational visitors to two of the seven flow rivers in the study.

These values were for restoring a stream or river to an EAFR from one in which sections of the south-west England rivers were *severely* affected by reductions in flows, especially during summer months. A 100% coverage of the catchment area by forests would not reduce river flows to the extent of the rivers investigated by Willis and Garrod (1999). Hence, these values should be regarded as the maximum extent of possible recreational fishing and general amenity losses. More marginal reductions in flow due to forests would result in much more marginal recreational losses. Indeed anglers and general public visitors to rivers in forested areas may not detect any recreational loss from slightly lower stream flows due to forestry. Hence the loss of economic benefits to wildlife and other recreational uses, such as canoeing, from reduced stream flow due to forestry is likely to be minimal.

Water quality impacts of forests

Background
Forests can alter water quality through

- the capture of atmospheric pollution: Conifers enhance the capture of atmospheric acid and other pollutants (termed ‘scavenging’), thus increasing the acidification of water in upland streams and rivers, although there is uncertainty about the scale of the impact.

- forest operations. These can alter drainage water pathways, causing erosion and sedimentation down-stream; whilst pesticides can lead to contamination of soil drainage. Once contaminated it may take decades to restore ground water quality to a level suitable for drinking purposes (Forestry Commission, 2000).

Water quality and forest operations

Forest operations can have differential impacts on water quality over the rotation period, over and above its base quality. Base quality depends upon soil, geology, and alternative vegetation, and land-use. Many upland areas of Britain have acid and acid sensitive soils, reflecting the inability of the bedrock to weather at a sufficient rate to counteract both the acidity generated within the soils, and the impacts of acidic atmospheric pollution.

A study by Neal and Reynolds (1988) assessed the impacts of conifer harvesting and replanting on upland stream water quality. They suggested that harvesting and replanting could lead to increased acidification of stream water from (i) accelerated nitrate leaching from felled sites during year 1 to 3 post felling, caused by disruption to the nutrient cycle, and (ii) soil base cation depletion, although the magnitude of this impact on water quality was hard to gauge. The impact is typically an increase in concentrations of nitrate (typically from less than 1 up to 10 mg-NO_3/l), potassium (typically from less than 1 up to 2 mg/l), phosphate (typically from less than 0.02 up to 0.06 mg-P/l), and ammonium (typically from less than 0.2 up to 0.6 mg-NH_4/l) in certain soils. They found that across all scales of catchment monitoring there was a balance between increased stream acidification due to nitrate generation following felling and decreased stream acidification because of reductions in strong acid anion concentrations. Neal and Reynolds (1998) found that in the vast majority of cases, when set against other temporal variations in water quality, the net acidification effect of felling was hard to discern at the catchment level.

The Coalburn catchment experiment also provides some information on stream water quality (Robinson *et al* , 1998). Recordings here reveal that stream water quality varies greatly over both time and across the catchment, and that there are marked differences in water chemistry that are related to parent soil material.

Water quality issues

A number of other water quality issues are also of current concern in the UK, for which forestry potentially provides benefits.

Cryptosporidium is a parasitic protozoan that causes cryptosporidiosis, an enteric infection in humans and animals. In people it causes abdominal pain, profuse diarrhoea, weight loss, loss of appetite and anorexia, but the infection is usually self-limiting and resolves within a few weeks. In immunocompromised patients the infection is more serious; it can become chronic and is sometimes fatal. Thus because of the increasing prevalence of AIDS, health impacts are likely to grow over time. These protozoa complete their life cycles in one host and their oocysts (spores) are highly infectious. The oocysts are usually transmitted by contaminated water, infected animals, person-to-person spread or contaminated food. *Cryptosporidium* requires a host to multiply in, and cannot grow in foods or water. Water treatment plants cannot usually guarantee to remove all *Cryptosporidium* from water because the oocysts are very small and resistant to chlorine. At present, control of water supplies depends on limiting contamination of input water by animals, manure or sewage, and by careful maintenance of water treatment systems. Many animal species can be infected and is readily passed from animals to humans. Mature oocysts are excreted in faeces. Farmyard manure may contain high numbers of cryptosporidial oocysts and consequently water may be contaminated by manure or slurry washed off fields into rivers; vegetable crops may be contaminated by direct manuring of the fields in which they are grown, although well managed and stored manure and slurry is effective in reducing infectivity through raised temperature and ammonia levels (http://www.fwr.org/crytosp.htm)

Out of 1483 water treatment works in England and Wales, 332 are considered to be at risk. Of sites at risk, 158 are sites with surface water sources, 174 are groundwater sources influenced by surface water, and 188 sites are no under regulatory sampling. Extensive treatment is being installed at some large sites, whilst some sites will be abandoned. Of 65,449 samples taken by end of August 2001, oocysts were detected in 57% of sites and found in 7.8% of samples. However, there were no reported increases in illnesses in areas being monitored under the regulations.

However, at the beginning of August 2002, more than 140,000 residents of Glasgow were advised to boil all drinking water (and water used for preparing food, brushing teeth and bathing babies) until further notice, after cryptosporidium bacterial parasite was found in water supplies in Glasgow. The parasite was discovered in water from the Mugdock Reservoir in Milngavie, East Dunbartonshire, one of the city's main sources of supply. An emergency meeting of health experts and water officials concluded that torrential downpours had probably washed animal faeces, incorporating the bacteria, off surrounding hills into the reservoir. Moreover, because the bacterium does not respond to the usual chemical treatments used to filter water supplies, it was unclear how long the emergency will last. News of the contamination led to a run on bottled water in local supermarkets as residents began panic buying, with one large store selling out in less than two hours (Kelbie, 2002).

In a separate incident in Perth eight children became ill after ingesting the cryptosporidium parasite in a leisure swimming pool, probably through accidental faecal contamination of the water by a swimmer (Cramb, 2002).

Clearly the money and time cost to households of buying bottled water, and boiling water, can be large when substantial numbers of people are affected. Additional utility is lost (inconvenience caused) from the inability of the population in an infected area to use potable water as normal, e.g. for brushing teeth, and other activities that might involve ingesting the water. The closure of a leisure swimming pool can also affect the utility of a substantial number of people.

E.coli O157 can occur in catchment areas where cattle and sheep have direct assess to water and where diffuse pollution inputs exist. In a separate health scare at the beginning of August 2002, 14 people, three of them children were infected with potentially deadly *E.coli O157* after it got into a private water supply to the Rothiemurchus Camp and Caravan Park at Coylumbridge, near Inverness (Kelbie, 2002).

Eutrophication of waters arises mainly from agriculture. All land leaks nutrients, although highest concentrations arising from diffuse pollution coincides with areas having significant hydrological connectivity with receiving waters.

Forested areas reduce the risk of *Cryptosporidium, E.coli O15,* and *Eutrophication* occurring, by precluding alternative agricultural land-uses that produce greater *Cryptosporidium* risks. Thus, benefits, in terms of water quality, might occur by the replacement of agriculture by forestry in water catchment areas where higher levels of *cryptosporidium* have been found in samples of water taken from water treatment works.

However, for all water quality issues, there is no comprehensive set of data available to estimate the effect of trees on different aspects of water quality across Great Britain. Nor is there any information on the value of these water quality improvements in different spatial areas.

Forestry Commission (2000) *Forests and Water Guidelines* aim to remove the harmful external effects of forestry operation on water quality. Thus guidance is provided on all aspects of forest operations to minimise impacts on water quality. This includes buffer areas, between the water-course and riparian zone, and the forest.[10] Obviously for the "scavenging" effect of forests on surface water acidification, the only way to reduce this is to reduce the emission of acid pollutants derived from the combustion of fossil fuels. Depositions of sulphur and nitrogen are expected to continue to decline in the future in response to UK and EU directives. However, areas where critical loads for acidity in freshwaters are exceeded have been identified in the FC guidelines. Where the deposition total (existing plus estimated additional pollutant as a result of scavenging from new planting) exceeds the freshwater critical load, the FC are unlikely to approve woodland grants, until there are further reductions in pollutant emissions or unless ameliorative treatments are applied without detriment to the ecosystem.

By adhering to these *Guidelines* it can be argued that forestry has essentially largely internalised the negative externality impact of forest operations on water quality. This was confirmed in discussions with managers of water companies which had significant amounts of forestry in their water catchment areas. Where Forestry Commission Guidelines had been adhered to, water company managers did not perceive any negative impacts of forestry on water quality.

The afforestation of further agricultural land might produce positive benefits in terms of the reduction of incidents of cryptosporidium and E.coli O157, and also reductions in eutrophication.

Conclusions

The estimation of the social and environmental non-market benefits and costs of forestry with respect to water supply and water quality is subject to a number of

[10] This comes at a 'cost' in terms of loss of shade, addition of large woody debris, and improved habitat along streams. However, it is difficult to quantify the benefits of riparian woodland to the freshwater environment.

problems. First, there are no available comprehensive data-base that can readily be used to estimate the physical impact of forestry on water supply and water quality on a spatial unit basis across Britain. Second, the opportunity cost of water supply and water quality improvements is also not documented on a spatial unit basis. Hence the costs and benefits of forestry on water supply and water quality cannot be mapped in any accurate, robust and reliable manner.

More accurate and reliable data will become available over time. For example, more accurate estimation of run-off in rivers might be derived by the development and application of the surface water yield assessment model developed by Water Resource Associates (2001) across all river catchment areas in Britain.[11] However, until this occurs, it is difficult to provide even “ball-park” estimates of the impact of forestry on water supply and water quality across Britain.

There will be some un-quantified opportunity cost in terms of hydro-electricity production. In addition, there may be a loss of wildlife and recreational benefits from reduced stream flow due to forestry; however, these lost benefits are likely to be miminal.

Whilst a considerable amount of research has been undertaken on the impact of forestry on water quality, the main issues remain a comprehensive assessment of the negative impacts on water quality on a spatial basis; what positive benefits forestry might produce in reducing the negative impacts of agriculture on water quality by the replacement of agriculture as a land-use in some areas; and translating these into economic costs and benefits of changes to water quality.

It can be argued that, to a large extent, many negative externalities from forestry have already been internalised through adherence to the Forestry Commission’s *Forests and Water Guidelines*. However, a more accurate valuation still needs to be undertaken on a range of water supply and water quality externalities. This would permit a more definitive assessment of whether, on balance, the total economic cost of all forestry impacts on water supply and water quality is positive or negative, or simply zero.

References

Alvarez, M., B. Aylward, et al. (1996). *Management of Natural Forest for Off-Site Hydrological Benefits in the Magallenes National Reserve.* the Overseas Development Administration. Santiago, Chile, Corporación Nacional Forestal, Environmental Resources Management, Ltd., British Council.

Aylward, B. (1998). *Economic Valuation of the Downstream Hydrological Effects of Land Use Change: Large Hydroelectric Reservoirs*. Medford, MA, Fletcher School of Law and Diplomacy.

[11] The simulation software provides a consistent methodology for the estimation of run-off in rivers, taking account of a regions hydrological characteristics such as the relative frequency of snow at altitude, extent of peat, etc. The model was tested at four sites in Scotland (River Dee, Loch Lomond, Loch Bradan, and the Meggett-Talla-Fruid scheme.

Aylward, B., J. Echeverría, et al. (1998). *Market and Policy Incentives for Livestock Production and Watershed Protection in Arenal, Costa Rica.* CREED Working Paper Series. London, International Institute for Environment and Development and Institute for Environmental Studies, Free University Amsterdam. **25**.

Barrow, P., A. Hinsley, et al. (1986). The Effect of Afforestation on Hydroelectricity Generation. A Quantitative Assessment. Land Use Policy 4, 141-151.

Calder, Ian R. and Malclom D. Newson (1979). Land-use and upland water resources in Britain: a strategic look. *Water Resources Bulletin* 15, 1628-1639.

Calder, Ian R. (1999). *The Blue Revolution: land-use and integrated water resources management*. Earthscan Publications, London.

Calder, Ian R. (2002). Forests and hydrological services: reconciling public and science perceptions. *Land Use and Water Resources Research* 2, 2.1-2.12.

Cramb, Auslan (2002). Children hit by swimming pool parasite. *The Daily Telegraph 9th August 2002.*

Forestry Commission (2000). *Forests and Water Guidelines. Third Edition*. Forestry Commission, Edinburgh.

Kelbie, Paul (2002). Glasgow water contaminated in torrential rains. *The Independent 5th August 2002.*

Kim, I.-H. (1984). *An Economic Analysis of Watershed Practices: Impact of Grazing on Watershed (Erosion, Sedimentation, Valuation.* Utah State University**:** 104.

McMahon, P. (2001). Personal communication. Southern Water, Brighton.

Ministry of Agriculture, Fisheries and Food (MAFF) (1976). *The Agricultural Climate of England and Wales. Technical Bulletin No. 35*. HMSO., London.

Neal, C. and B. Reynolds (1998). *The Impact of Conifer Harvesting and Replanting on Upland Water Quality. R&D Technical Report P211*. Report by the Institute of Hydrology, Wallingford, and the Institute of Terrestrial Ecology, University of Wales, Bangor, to the Environment Agency, Bristol.

Newson, M. (2001). Personal communication. (Department of Geography, University of Newcastle).

OFWAT (8-5-2001). *The role of long-run marginal costs in the provision and regulation of water services*. Letter *MD170* to Managing Directors of Water Companies. Office of Water Services, Birmingham.

OFWAT (6-2001). *Tariff structure and charges: 2001-2002 report*. June 2001. Office of Water Services, Birmingham.

OFWAT (undated). *Report C: Guidance on LRMC Estimation*. Office of Water Services, Birmingham.

Personal communication (2001) with managers in three water companies: Yorkshire, Southern, and Northumbrian Water.

Roberts, J.M., P.T.W. Rosier, and D.M. Smith (2001). *Effects of Afforestation on Chalk Groundwater Resources*. Final Report to Department of the Environment, Transport and the Regions (DETR). Centre for Ecology and Hydrology, Wallingford, Oxfordshire.

Robinson, M., R.E. Moore, T.R. Nisbet and J.R. Blackie (1998). *From Moorland to Forest: the Coalburn catchment experiment. IH Report No. 133*. Institute of Hydrology, Wallingford.

Scott, David F. (1998). Water pricing in South Africa: a view from the research community. *Commonwealth Forestry news* Sept. 1998 (No. 2). Page 7.

Smith, L.P. (1976). *The Agricultural Climate of England and Wales: Areal Averages. Ministry of Agriculture, Fisheries and Food, Technical Bulletin No. 35*. HMSO, London.

Tilford, K.A. (2000). *Hydrological Science and Water Pollution: surface water hydrology.* Department of Civil and Environmental Engineering, University of Salford.

Water Resource Associates (2001). *Surface Water Yield Assessment: Final Report*. Report to Scotland and Northern Ireland Forum for Environmental Research (SNIFFFER). Foundation for Water Research (FWR), Marlow.

Water Resource Associates (2001). *Surface Water Yield Assessment: Trial Sites Report*. Report to Scotland and Northern Ireland Forum for Environmental Research (SNIFFFER). Foundation for Water Research (FWR), Marlow.

Willis K.G. and G.D. Garrod (1999). Angling and recreation values of -flow alleviation in rivers. *Journal of Environmental Management* 57, 71-83.

Table 1: Externality costs of forestry on water supply in England

COUNTY	LAND AREA OF COUNTY	DECREASE IN WATER DUE TO FORESTRY										
	Hectares	Ea	Eta	forest %	rainfall	inception	canopy wet	loss per ha	forest ha	LRMC p/m3	adj. forest area	cost
Avon	133244	525	518	5.84	865	0.2	0.10553	69.11	7905	0.44	7778	220384
Bedfordshire	123557	575	573	5.16	574	0.15	0.07003	23.72	6645	0.48	6373	68033
Berkshire	125879	532	524	13.26	713	0.15	0.08699	81.38	17625	0.49	16698	625054
Buckingham	187673	510	511	8.58	511	0.05	0.06234	-5.41	16900	0.48	16110	-39229
Cambridgeshire	339963	523	523	1.98	523	0.05	0.06381	-1.43	6900	0.53	6725	-4807
Cheshire	233107	505	502	3.93	786	0.15	0.09589	27.42	9515	0.53	9165	125636
Cleveland	59652	457	455	6.03	669	0.1	0.08162	17.95	3745	0.13	3595	6452
Cornwall & Isles of Scilly	356466	536	514	7.32	1241	0.3	0.15140	215.56	26940	0.49	26080	2586017
Cumbria	682333	410	375	8.29	1663	0.3	0.20289	350.52	62035	0.48	56585	8925274
Derbyshire	262858	432	415	5.87	1151	0.3	0.14042	168.48	15900	0.41	15435	988207
Devon	670961	499	467	9.07	1449	0.3	0.17678	319.40	64465	0.49	60840	8938722
Dorset	265274	554	543	10.12	807	0.2	0.09845	109.23	28150	1.24	26858	3549931
Durham	242907	457	455	5.83	669	0.1	0.08162	17.35	15160	0.57	14165	132729
Essex	367344	540	540	4.02	577	0.05	0.07039	-3.68	15450	0.43	14780	-21776
Gloucestershire	265327	521	514	10.71	775	0.15	0.09455	72.45	29260	0.56	28410	1090970
Greater London	157916	526	524	3.72	713	0.15	0.08699	22.83	5945	0.49	5875	61696
Hampshire	377872	561	543	16.47	807	0.2	0.09845	177.78	65735	0.21	62228	1991280
Hereford & Worcester	392346	509	504	7.62	746	0.15	0.09101	50.31	31050	0.56	29903	797419
Hertfordshire	163928	523	521	7.65	664	0.1	0.08101	18.51	12835	0.35	12540	74273
Humberside	350806	485	484	2.42	655	0.1	0.07991	6.49	8870	0.27	8493	13231

Isle Of Wight	38014	587	580	11.35	794	0.15	0.09687	71.41	4490	0.21	4315	55464
Kent	373499	534	532	9.27	696	0.1	0.08491	22.64	37855	1.19	34610	909089
Lancashire	306978	495	484	4.01	1133	0.3	0.13823	109.47	13405	0.46	12317	579800
Leicestershire	255087	495	494	3.10	661	0.1	0.08064	8.14	8280	0.56	7908	34123
Lincolnshire	592091	518	517	2.87	605	0.1	0.07381	6.41	17555	0.56	16995	57752
Manchester	128584	493	484	3.17	1133	0.3	0.13823	86.54	4330	0.48	4078	158811
Merseyside	65516	542	538	3.54	837	0.2	0.10211	39.81	2400	0.48	2320	41564
Norfolk	537234	532	530	7.87	623	0.1	0.07601	17.33	44450	0.44	42265	300258
Northamptonshire	236697	512	511	4.91	627	0.1	0.07649	11.59	12380	0.48	11615	60595
Northumberland	502594	427	400	14.28	939	0.25	0.11456	269.79	80070	0.57	71770	10455829
Nottinghamshire	215980	512	510	7.10	622	0.1	0.07588	16.68	16160	0.56	15343	135674
Oxfordshire	260595	507	503	6.15	726	0.15	0.08857	39.57	16875	0.49	16030	291812
Shropshire	348767	502	497	7.26	763	0.15	0.09309	49.50	26220	0.56	25335	664707
Somerset	345207	531	523	6.44	865	0.2	0.10553	75.87	23310	0.49	22218	775395
Staffordshire	271545	482	474	6.50	840	0.2	0.10248	77.63	18300	0.41	17643	520431
Suffolk	379839	534	535	6.18	598	0.05	0.07296	-5.64	27465	0.76	23488	-96760
Surrey	167713	537	524	20.97	713	0.15	0.08699	128.69	37395	0.63	35168	2715494
Sussex - East	179541	541	531	14.58	791	0.15	0.09650	98.28	29095	0.27	26183	617584
Sussex - West	198808	542	531	17.14	778	0.15	0.09492	113.64	37640	0.27	34078	929409
Tyne & Wear	54033	406	404	4.67	670	0.1	0.08174	15.87	2695	0.57	2525	21635
Warwickshire	197854	495	494	3.95	695	0.1	0.08479	10.91	8050	0.56	7810	45149
West Midlands	89874	495	494	2.56	695	0.1	0.08479	7.07	2335	0.56	2303	8628
Wiltshire	347605	516	511	7.35	799	0.15	0.09748	51.48	26625	1.24	25533	1590424
Yorkshire - North	830949	445	437	6.89	808	0.2	0.09858	81.66	59660	0.27	57215	1121348
Yorkshire - South	155941	482	474	7.15	807	0.2	0.09845	82.03	11465	0.27	11148	219483
Yorkshire - West	203417	480	474	5.14	807	0.2	0.09845	58.97	10645	0.27	10455	147974
TOTAL - ENGLAND	13043375								1030180		969295	52491167

Table 2: Externality costs of forestry on water supply in Wales

COUNTY	LAND AREA OF COUNTY	DECEASE IN WATER DUE TO FORESTRY										
	Hectares	Ea	Eta	forest %	rainfall	inception	canopy wet	loss per ha	forest ha	LRMC pm3	adj. forest area	cost
Clwyd	243,015	508	502	8.91	786	0.15	0.09589	62.16	23840	0.46	21660	578928.4
Dyfed	576,575	489	436	11.72	1829	0.30	0.22314	529.05	73870	0.46	67583	15374693.7
Glamorgan -Mid	101,749	523	456	15.80	1728	0.30	0.21082	667.18	17335	0.46	16080	4613172.1
Glamorgan -South	41,622	528	510	6.29	1172	0.30	0.14298	175.29	2750	0.46	2618	197329.3
Glamorgan - West	81,960	578	513	21.60	1258	0.30	0.15348	645.12	19780	0.46	17700	4910010.7
Gwent	137,652	531	508	12.60	953	0.25	0.11627	225.78	18120	0.46	17345	1683912.4
Gwynedd	386,331	482	450	10.96	1184	0.30	0.14445	318.06	46870	0.46	42348	5791711.6
Powys	507,716	505	497	12.18	763	0.15	0.09309	83.05	68895	0.46	61820	2207707.9
TOTALS - WALES	2,076,620			11.90					271,460		247,153	35357466.1

Table 3: Long-Run Marginal Cost Estimates – steady demand.

September 2000 prices

Water company	resources	treatment	bulk transport	local distribution	Total LRMC
	p/m^3	p/m^3	p/m^3	p/m^3	p/m^3
Anglian					
Anglian	16	12	15	1	44
Hartlepool	n/a	n/a	n/a	n/a	13-27
Dwr Cymru	n/a	n/a	n/a	n/a	46
United Utilities	20	5	11	12	48
Northumbrian					
Northumbrian	11	5	28	13	57
Essex	n/a	n/a	n/a	n/a	43
Suffolk	65	0	0	11	76
Severn Trent	14	13	15	14	56
South West	21	21	n/a	7	49
Southern					
Kent Medway	n/a	n/a	n/a	n/a	83
Kent Thanet	n/a	n/a	n/a	n/a	75
Sussex Hastings	n/a	n/a	n/a	n/a	39
Sussex Coast	n/a	n/a	n/a	n/a	27
Sussex North	n/a	n/a	n/a	n/a	22
Hampshire South	n/a	n/a	n/a	n/a	21
Thames	42	3	2	1	49
Wessex	12	12	25	74	124
Yorkshire					
Yorkshire	25	0	0	2	27
York	0	10	13	4	27
Bournemouth & West Hants	17	9	0	26	52
Bristol	14	2	0	0	16
Cambridge	40	4	0	9	53
Dee Valley	10	18	0	25	53
Folkstone & Dover	36	3	18	0	57
Mid Kent	0	94	0	25	119
Portsmouth	3	0	1	5	9
South East					
Northern	16	9	11	23	59
Southern	24	45	30	23	121
S. Staffordshire	8	6	15	11	41
Sutton & E. Surrey	38	0	n/a	25	63
Tendering Hundred	32	6	0	9	48
Three Valleys					
Three Valleys	8	14	13	0	35
North Surrey	34	28	24	4	n/a

All figures rounded to nearest p/m^3.
LRMC for steady demand = cost of incremental load for which peak demand equals average weekly demand.
Some companies have not made separate estimates of four components of total LRMC.
Northumbrian area estimates are based on average costs and not LRMC.
Suffolk area estimate excludes LMRC estimate for distribution.
York area treatment and bulk transport costs are included in resource costs.
Southern Water areas (except for Sussex North area) are 'proxy' average LMRC estimate.
Thames figures apply to London zone only.
In Portsmouth and Sutton & Surrey estimates resource and treatment costs are added together.
South East Water (Northern and Southern areas) excludes customer service & business activities costs of 15p/m^3
Source: OFWAT (8-5-2001)