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Trees and Drought Project on Lowland England

(TADPOLE)

Draft Scoping Study Report

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1. Introduction

1.1 BACKGROUND

The combination of recent Government proposals, laid out in the 1995 White Paper on Rural England, to double the area of forests within England by the year 2045, together with scenarios of hotter drier summers and wetter winters being given credibility by Government, has raised questions (see submission to House of Commons Select Committee on the Environment) concerning the possible impacts on water resources of such a large change in land use.

It was recognised at the interdepartmental (DOE, EA, FA, FC, IH) meeting of 10 December 1996 that the potential impacts on water resources resulting from the proposed afforestation could reach parity with the projected impacts resulting from climate change. In broad terms, if an extra 8% of the land area in England were placed under forest and if this land use change resulted in a 4-5% national reduction in runoff or recharge, the resource replacement costs would be in the order of one billion pounds. The environmental and amenity impacts of reduced low flows in rivers, as a result of this afforestation, were also recognised as a cause for concern of similar magnitude.

The research proposed here is to provide information so that holistic decisions can be made with regard to the benefits of forests including amenity, timber, recreation, and, in some situations, ecology and set against some hydrological and environmental disbenefits. Ultimately decisions will be required at the European, National, and local scales with regard to the impacts of land use change as a result of changes to CAP and national policies affecting land use. The TADPOLE project outlined here will be directed towards identifying the hydrological impacts in terms of water quantity, but should be seen as part of a suite of ongoing impact studies identifying the other hydrological (ie. quality), ecological, environmental and socio-economic implications of land use change. It is anticipated that land use change, predicted from the Centre for Agricultural Strategy's LUAM model, taking into account different anticipated CAP reform policies, will provide land use change scenarios which can be used to explore the impacts of these different policy scenarios. The results of the study will be aimed at providing the necessary information to the EA, DOE, FA, Welsh and Scottish Offices to facilitate policy decisions. At a more local scale it is anticipated that the models developed may be used to assist decision making in relation to forest location and tree species to minimise any adverse environmental and hydrological effects.

1.2 PRESENT STATUS OF KNOWLEDGE

It is not possible at present to make an accurate prediction of the hydrological impacts of afforestation because of lack of knowledge of the evaporative characteristics of different tree species/soil type combinations.

Virtually no information is available on the evaporative characteristics of trees growing on soils overlying sandstone geology or for that matter on derelict soils, although in the Midlands, for example, much of the new planting is taking place on these soils.

A further area of uncertainty relates to the evaporation from small forest blocks. Present information on the evaporative characteristics of forest relate to forest of large areal extent, yet much of the new planting is on small size blocks of 2-3 ha. The extent of the enhanced evaporation due to edge effects is not well understood although it would be expected that an area of forest made up of small blocks would evaporate significantly more than the same extent of forest composed of one compact block.

There is also doubt whether some published information on the evaporative characteristics of broadleaf forest on chalk soils is correct, so it may not always be possible, using existing information, to determine the direction of the impact, let alone the magnitude. Results from these earlier studies have also been used to estimate forest impacts on soils overlying sandstone geology, and may also have led to misleading conclusions.

Interactions between water quality and quantity also need to be examined. For example, woodlands can protect water supplies from nitrate pollution associated with agriculture and this benefit needs to be balanced against any reduction in water yield.

Nitrate concentrations within groundwaters have been steadily rising over the last 20 years due to leaching losses from intensive agriculture. This trend is expected to continue for at least the next 10 to 15 years. Many sources, particularly those within the Triassic sandstone aquifer in the UK midlands, are now close to, or exceed the mandatory 50 mg/l standard for potable water. The protection afforded by forests has recently been recognised and new bore holes sunk within existing forest areas to tap the low nitrate water (nitrate concentrations less than 10 mg/l) for blending purposes. The development of such sources could avoid the need for expensive nitrate removal treatment.

At the interdepartmental meeting an outline research proposal was presented which was aimed at obtaining this information:

The objectives of the proposal would be threefold. Firstly, given the FC maps showing the areas of proposed forestry and the application of the HYLUC model, to provide initial information on the likely range of the impacts, geographically distributed, throughout the UK. Secondly studies would be carried out to determine the evaporative characteristics of combinations of tree species/soil types for which data are lacking at present to allow greater accuracy in the prediction of the impacts. Thirdly, longer term monitoring studies involving treatments where one land use was replaced by another, i.e. forests replaced by grassland and afforestation of grassland, would be carried out to allow confirmation of model predictions of the hydrological impacts of changes in land use and confirmation of model parameters.

The focus of the work would be centred in the Midlands where a large proportion of the new forestry is planned. Oak and Corsican pine on soils overlying sandstone aquifers have been identified as priority species/ soil type combinations. (Loughborough University is in the process of identifying hydrological study sites related to water quality in the National Forest and there may be opportunities for linking these with the proposed water quantity studies).

The study would also review and possibly reinterpret results from previous studies on the water use of different vegetation types on chalk soils: Thetford, Bridgets Farm, Fleam Dyke and Black Wood. It is believed that the Black Wood study, if reassessed from a soil physics perspective, may provide an alternative interpretation of the soil moisture deficit measurements, which might indicate that broadleaf forest evaporation was <u>greater</u> than that of grass.

It was agreed at the meeting that a scoping study should be carried out (terms of reference given in Appendix 1) to determine the likely range of the hydrological impacts as precursor to decisions being made on the priorities for research in the main research programme.

2. Chalk Site Study

2.1 INTRODUCTION

The chalk site chosen for the scoping study investigation is Black Wood, a 2.7 km^2 Forestry Commission woodland, situated about 15 km north of Winchester in Hampshire, Grid Reference SU534428. The site has been subject to detailed hydrological studies of the hydrological impacts of broadleaf woodlands by the Institute of Hydrology and the British Geological Survey and the main findings of the research were presented in a report to the NRA, Project Report 115/03/ST (Harding *et al.* 1992).

The interpretation of the data obtained from this study is re-examined in the light of recent developments in our understanding of forest impacts worldwide (Calder, 1996). The modelling structure (LUCKY) used for this re-analysis is based on the daily time step evaporation modelling originally developed for upland UK forests (Calder, 1990), makes use of the soil moisture accounting procedures developed in earlier studies of the soil moisture regime under grassland sites (Calder *et al.*, 1983). It has been further developed to take into account forest interception parameters (Harding *et al.*, 1992) for both the summer (foliated) and winter (unfoliated) conditions and runs in conjunction with the IDRISI GIS.

2.2 THE 1989-91 BLACK WOOD STUDY

Harding and colleagues (Harding *et al.* 1992) were able to demonstrate from independent measurements of transpiration and interception loss from the broadleaf forest at Black Wood that evaporation models could be calibrated which, when used with a drainage model for the chalk, were able to describe the measured soil moisture deficits within the chalk soils beneath the forest. This apparent internal consistency between different, independent measurements provided confidence both in the integrity of the measurements and the interpretations derived from these results. The long term estimates, expressed in units of mm per year, of the water use on chalk were calculated as 399 for ash, 423 for beech and 468 for grass. The importance of these results as far as the UK water industry is concerned is that they implied a hydrological benefit in terms of increased aquifer recharge if grassland were to be replaced by broadleaf forest.

However re-examination of the Black Wood data indicates that they are amenable to an alternative interpretation. In the original study it was assumed that considerable drainage occurs from the soil profile during deficit conditions. The drainage function used had the form:

$$D = Ae^{-B\,SMD}$$

Where the parameters A and B had values 2.33 and 0.0043 for ash and 2.77 and 0.00977 for Beech. With these drainage functions, very considerable drainage during deficit conditions is predicted (Figure 1.), much greater than would normally be expected and has been measured at other chalk sites (Cooper, personal communication) where the total drainage from the soil profile during deficit conditions would be expected to be of the order of 25 mm. If the estimated (unmeasured) drainage (ie. recharge) were too high this would result in evaporation losses being underestimated by an equivalent amount. It should be noted however that this interpretation is not consistent with the independent measurements of transpiration made at Black Wood (Roberts and Rosier, 1994).

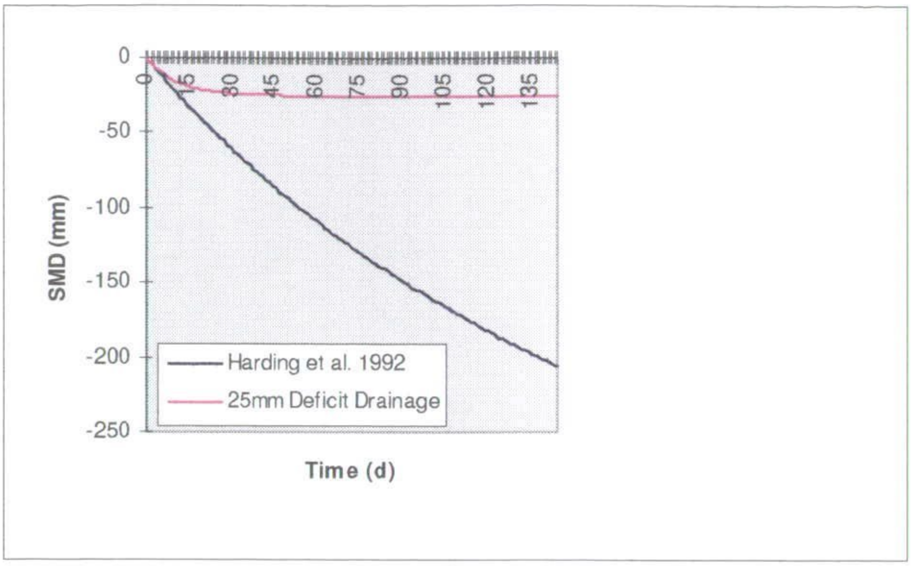


Figure 1*. Drainage function assumed by Harding et al. (1992) for the Black Wood site together with a drainage function thought to be more representative of UK chalk sites*

The question as to whether or not the assumed drainage function for Black Wood is correct leads to three possible scenarios which require investigation:

Blackwood Drainage Function Correct

If the high drainage losses at Black Wood are confirmed, the question is raised as to whether similar drainage losses occurred at the Bridgets Farm Site (some 8 km distant) where parameters for the grassland/chalk evaporation model were derived).

Scenario 1. If the drainage properties of the chalk at the two sites are the same then it would imply that the evaporation from grass on chalk is much less than had been previously assumed and probably less than that of broadleaf forest ie. it would imply that broadleaf forest evaporation is greater than that for grass.

Scenario 2. If the drainage properties of the chalk at Black Wood are different to those at the Bridgets Farm site this would imply that the original interpretation was correct, ie, broadleaf forest evaporation is less than that from grass.

Blackwood Drainage Function Not Correct

Scenario 3. If the Black Wood drainage function is not correct, and the neutron probe measurements of soil water contents are valid, this would imply that broadleaf evaporation is greater than that from grass.

Further research is needed to determine which of the above three scenarios is correct.
For the purposes of this Scoping Study, scenarios 2 and 3 have been chosen as examples, to investigate the possible range of the hydrological (water quantity) impacts arising from broadleaf (beech) afforestation on chalk soils.

2.3 MODEL PREDICTIONS FOR BROADLEAF FOREST/GRASS WATER USE ON CHALK

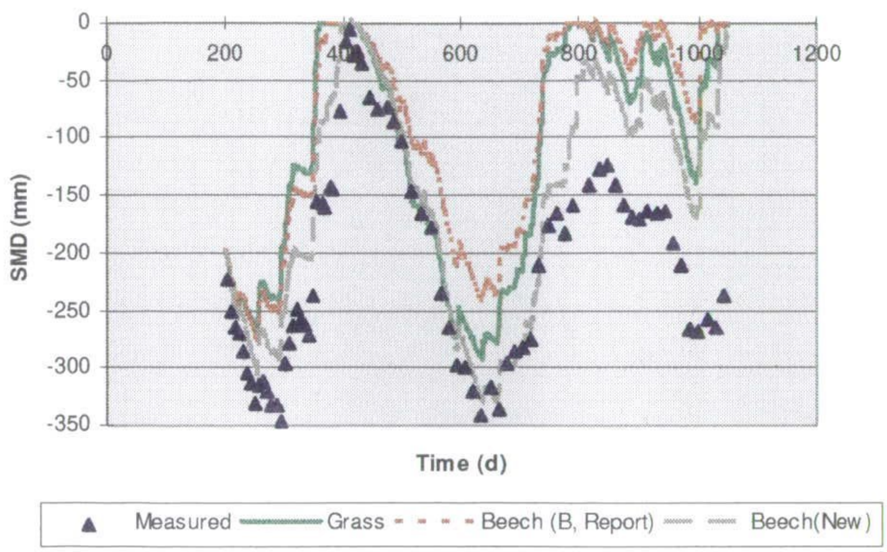


Figure 2. *Model predictions of soil moisture deficits at the Black Wood site for beech, Scenarios 2 (Beech- Black Wood Report, Harding et al. 1992) and 3 (Beech -New), and for grass together with observed SMDs.*

The model predictions of soil moisture deficits due to evaporation obtained with model parameters (Table 1) relating to scenarios 2 and 3 are shown in Figure 2. All the SMD predictions shown in Figure 2 are based on the classical assumption that no drainage takes place during deficit conditions and therefore would be expected to underestimate the actual deficits, by more than 100 mm if Scenario 2 is correct or by ~25 mm under Scenario 3. The model parameters for scenario 2 are those used by Harding *et al.* 1992. The model parameters for scenario 3 were obtained partly from "default" tree values (Calder, 1990) and partly by adjusting the interception model parameters to give a better fit to the observed soil moisture deficits, (SMD). For comparison the measured SMDs are also shown in Figure 2.

Table1. *Evaporation model (LUCKY) parameters representing different vegetation covers on different soils.*

CHALK	Grass, source: Calder *et al.*, 1983, Bridgets Farm	Beech source: Harding *et al.*, 1992, Blackwood	Beech source: New hypothesis, this study.
Step Length	160	1000	1000
Beta	1	0.75	0.9
Gamma	0	2.23	4.46
Delta	-	0.21	0.099
Winter Gamma	0	1.84	3.68
Winter Delta	-	.108	0.099

SAND	Grass, source: Calder et al., 1983, Thetford clearing	Pine, Source: Cooper & Kinniburgh, 1993	Broadleaf Source: Cooper & Kinniburgh, 1993, intercep. parameters new hypothesis.	Mixed Source: Combination of Pine and Broadleaf
Step Length	53	83	83	83
Beta	1	0.9	0.9	0.9
Gamma	0	4.6	4.46	4.6
Delta	-	0.099	0.099	0.099
Winter Gamma	0	4.6	3.68	3.68
Winter Delta	-	0.099	0.099	0.099

CLAY LOAM	Grass, source: Calder *et al.*, 1983, Cam	Pine, Source: Cooper & Kinniburgh, 1993	Broadleaf Source: Cooper & Kinniburgh, 1993, intercep. parameters new hypothesis.	Mixed Source: Combination of Pine and Broadleaf
Step Length	75	200	200	200
Beta	1	0.9	0.9	0.9
Gamma	0	4.6	4.46	4.6
Delta	-	0.099	0.099	0.099
Winter Gamma	0	4.6	3.68	3.68
Winter Delta	-	0.099	0.099	0.099

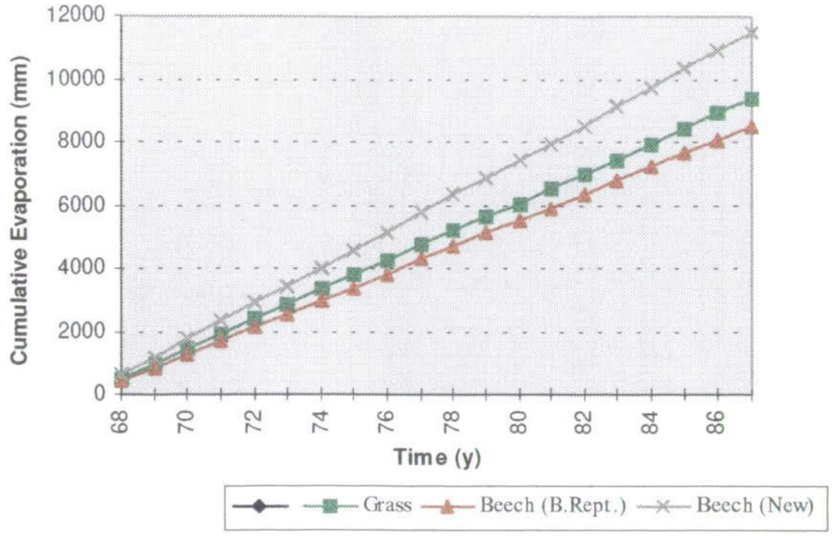


***Figure 3**. Predicted cumulative evaporation for different land uses at the Black Wood chalk site, 1967-1987. Average annual evaporation :Grass, 468; Beech (Black Wood. Rept. Harding et al. 1993), 424; Beech (New), 573; Average annual rain: 741 mm.*

Model predictions of the cumulative evaporation from grass and beech forest, under scenarios 2 and 3 are shown in Figure 3. The scenario 3 assumption (Black Wood drainage function not correct) would indicate that, as a long term average, the annual evaporation from broadleaf forest (beech) is 105 mm higher than that from grassland and that the average recharge (assuming no runoff from the chalk site) would be reduced by 38% as a result of broadleaf afforestation of grassland. This predicted reduction of recharge of 38% should be contrasted with the increase in recharge of 15% predicted by the earlier Blackwood study.

3. Midlands Site Study

3.1 INTRODUCTION

The models developed at the Black Wood chalk site were developed and extended for use on sites where soils overlie sandstone (Cooper and Kinniburgh, 1993) and, as the same model parameters were used to describe the evaporative response of broadleaf forest, similar conclusions were drawn for these sandstone sites: that broadleaf afforestation on previously grassland areas would increase recharge. If the reservations concerning the use of these parameters to describe the evaporative response of forest on chalk are well founded, the same reservations must apply to the conclusions drawn of higher evaporative losses from broadleaf forest on sandstone. For these reasons a similar modelling study was conducted at the Midlands site using similar scenarios relating to the original Black Wood assumptions, Scenario 2 and Scenario 3, applicable if the Black Wood drainage function is incorrect.

3.2 CHOICE OF SITE

Following discussions with the Environment Agency (Mr S. Fletcher), Forestry Commission and Nottinghamshire County Council, the Greenwood Community Forest area, as it relates to the Nottinghamshire Triassic sandstone aquifer, was chosen as the Midlands example site.

3.3 MIDLANDS SITE DATABASE

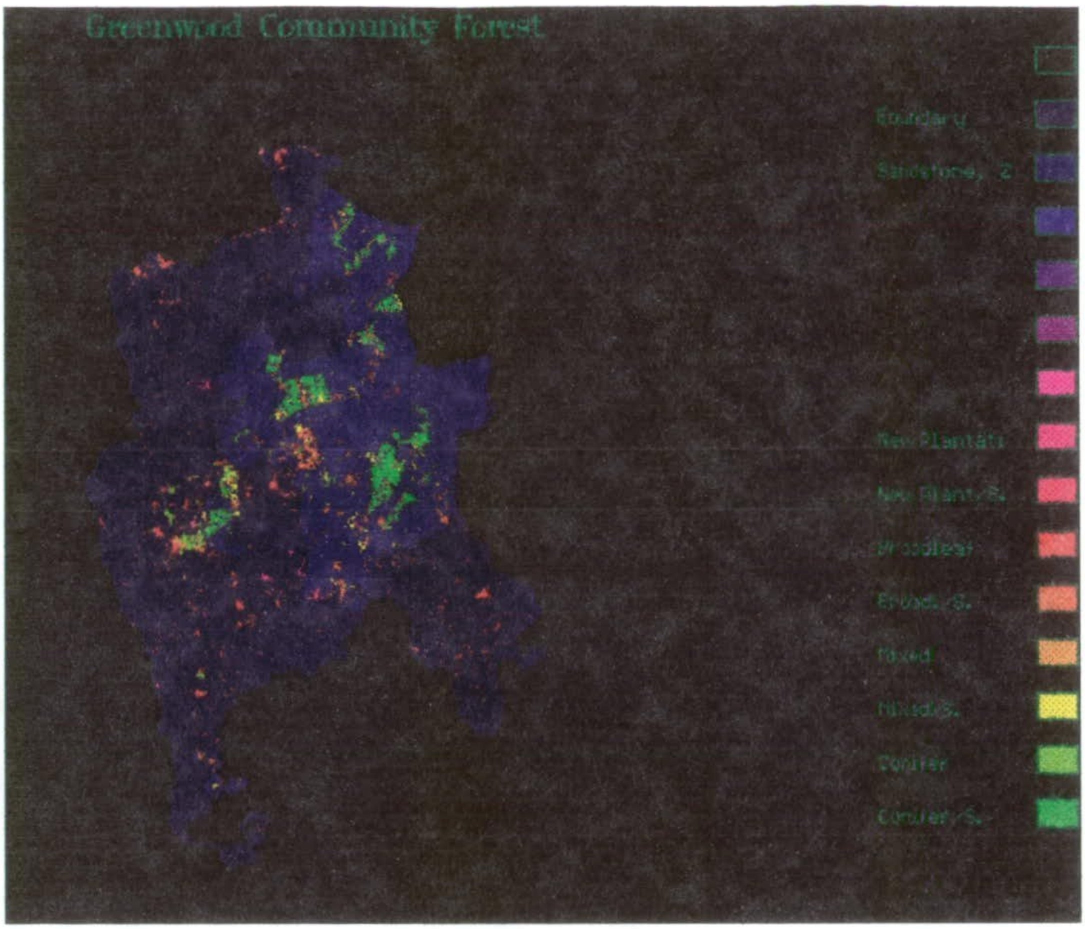
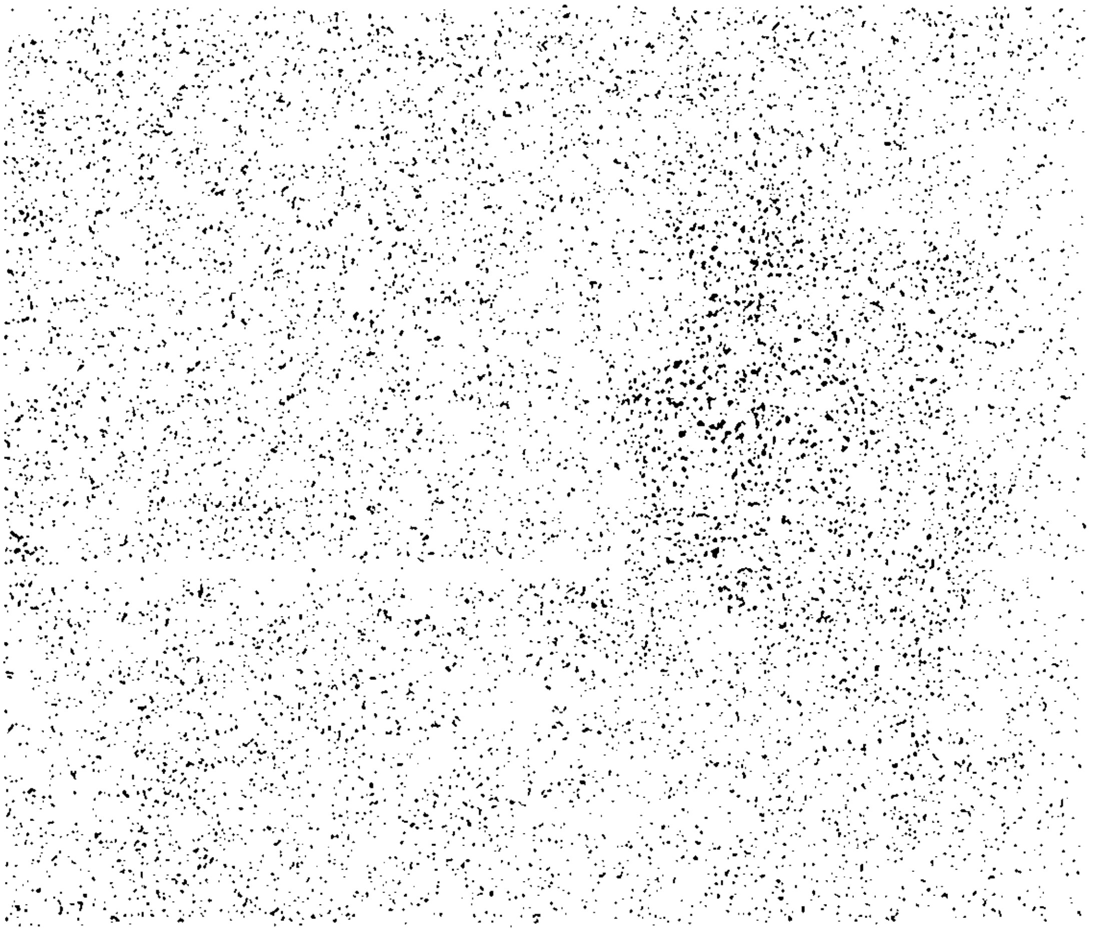


***Figure 4**. Forest cover within the Greenwood Community Forest. The light blue area represents the sandstone outcrop.*

Land use information, relating to forest cover, and the distribution of agriculture and grassland was kindly supplied as GIS files by Nottinghamshire County Council (Mr C. Giles) together with information on landscape zones. Landscape zones are related to the underlying geology and Zone 1 has been taken to represent the outcrop of the Triassic sandstone aquifer within the Greenwood Community Forest. Rainfall and potential evaporation data, together with GIS files of the boundaries of the aquifer were supplied by the EA and Southern Water (Mr T. Bishop). The landcover information was assembled and converted to Idrisi GIS format to provide information on the percentage cover of the different land uses on the different soil types (Table 2). The soils on the sandstone outcrop are regarded as Sand and those outside are assumed to be represented by a Clay-Loam classification in terms of soil water availability.

***Table 2**. Calculated areas of different land uses for different vegetation types on the Greenwood Community Forest. Data supplied by Nottinghamshire County Council.*



GREENWOOD COMMUNITY FOREST				
Vegetation	**Idrisi code**	**No. of 50x50m pixels**	**Area (ha)**	**Area (%)**
"Grass"	1	103926	25981.5	62.42
"Grass/Sand	2	47402	11850.5	28.47
New Plantation	7	472	118	0.28
New Plantation/Sand	8	274	68.5	0.16
Broadleaf	9	3389	847.25	2.04
Broadleaf/Sand	10	3198	799.5	1.92
Mixed	11	264	66	0.16
Mixed/Sand	12	1382	345.5	0.83
Conifer	13	517	129.25	0.31
Conifer/Sand	14	5645	1411.25	3.39
Boundary		**166483**	**41620.75**	**100**

3.4 MODEL PREDICTIONS FOR BROADLEAF FOREST/GRASS WATER USE AT THE MIDLANDS SITE

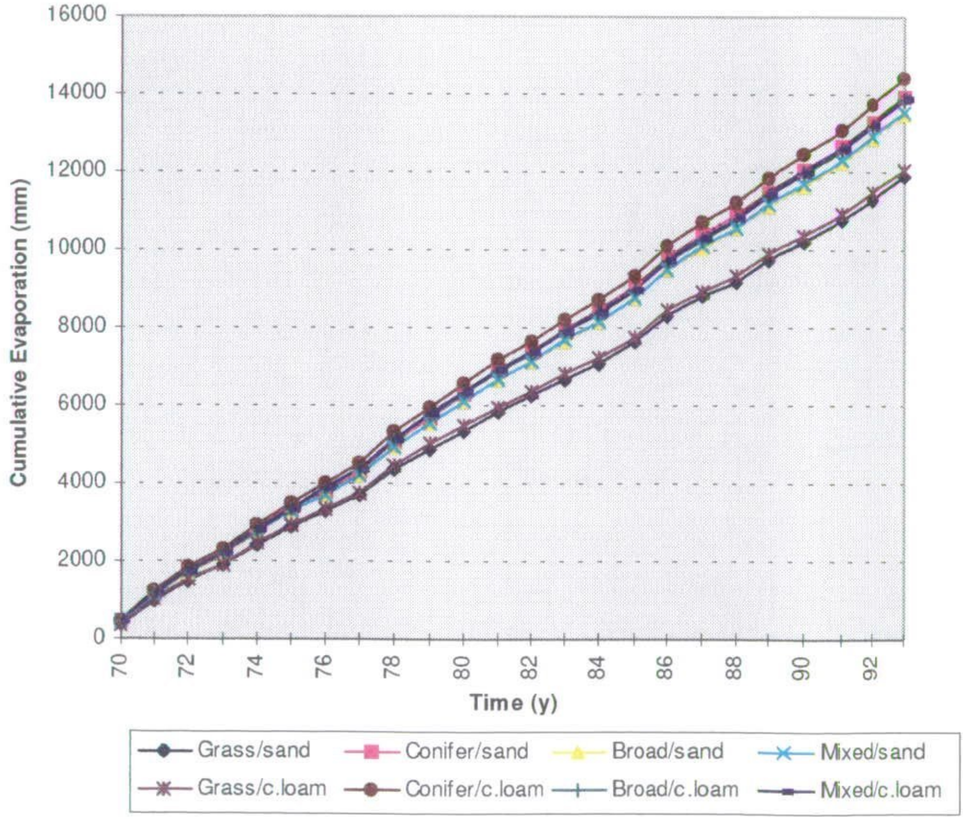


***Figure 5**. Predicted cumulative evaporation for different land uses at the Greenwood Community Forest. Average annual evaporation : Grass/sand, 494; Conifer/sand, 581; Broadleaf/sand, 563; Mixed/sand, 564; Grass/loam, 503;Conifer/loam, 600; Broadleaf/loam, 577; Mixed Woodland/loam, 579 mm. Average annual rain: 628 mm.*

The model predictions of seasonal evaporation, assuming model parameters relating to essentially the same scenarios 2 and 3 used for the chalk site but with different parameter values relating to soil water availability (Table 1.) are shown in Figure 5.

The scenario 3 assumption would indicate that as a long term average the annual evaporation from broadleaf forest on sand soils is 69 mm higher than that from grassland, and that the average recharge plus runoff would be reduced by 51% as a result of broadleaf afforestation of grassland. For broadleaf afforestation on clay-loam soils the predicted reduction in recharge plus runoff would be 62%.

The calculated cumulative recharge plus runoff for the Greenwood Community Forest is shown in Figure 6 assuming a forest cover scenario relating to the present, and a future scenario representing a three times increase in forestry, where the increases occur in proportion to the present distribution of forestry on the different soil types.

For the purposes of this study the whole of the non-forested area of the Greenwood, including both cereals and grassland, is assumed to have the same evaporative characteristics as grass. Few studies have been made on the annual evaporative loss from cereals but what experimental data that is available indicates (contrary to some modelling studies) that evaporative differences between winter wheat and grassland are not large (Cooper *et al.*, 1990; Wellings, 1984) .

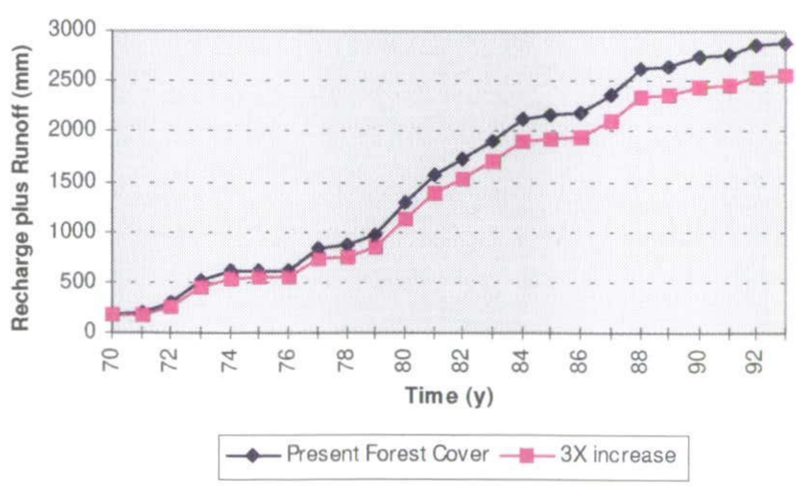


Figure 6. *Calculated Recharge plus Runoff for the whole Greenwood Community Forest for the period 1969-1993 assuming the present forest cover throughout the period and with a 3X increase in forest cover.*

Over the 24 year period from 1969 to 1993 the calculated average reduction in annual recharge plus runoff from the Greenwood Community Forest, as a result of a three times increase in forest cover from the existing 9% to 27%, is 14 mm (11%).

4. Indicative range of Impacts

The model predictions obtained with the different scenarios indicate hugely different projections with regard to the hydrological impact of increased lowland afforestation with broadleaf species. Earlier studies had indicated that broadleaf afforestation of grassland overlying chalk or sandstone bedrock would have beneficial impacts on water resources by increasing recharge. The alternative scenario presented here indicates the opposite. This opposite scenario indicates that both on a national and local perspective the implications could be very significant. Of primary concern, if this scenario were correct, are the local implications of increased forestry in areas where water resources are already being utilised to the limit or where low flows in rivers are causing environmental concerns.

5. Conclusions and Recommendations

The uncertainty with regard to the hydrological (water quantity) impact of broadleaf afforestation is the direct result of a shortage of information and can only be resolved through further research. In general terms the conclusion of this scoping study is that the programme of research outlined in the introduction is still recommended. Clearly the impacts of these forests on hydrology encompass more than quantity issues. The balance between probable water quality benefits and water quantity disbenefits needs to be taken into account, particularly as it relates to water blending to reduce nitrate levels. At a more holistic level the balance between the hydrological impacts and the environmental, ecological and socio-economic benefits of the forests needs to be considered, and, although outside the remit of the proposed research programme, this is a research topic which might be considered to run in parallel and to draw data from the proposed TADPOLE project.

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