Forestry Commission
231 Corstorphine Road
Edinburgh
EH12 7AT
www.forestry.gov.uk

The Opportunities for Woodland on Contaminated Land

INFORMATION NOTE

BY TONY HUTCHINGS OF FOREST RESEARCH

SEPTEMBER 2002

SUMMARY

Woodland is an important component of the urban landscape, improving its appearance and thereby contributing to economic regeneration. It is estimated that over 300 000 ha of land in the UK may be contaminated. Woodland provides a 'soft' end-use that requires less stringent remediation objectives than, for example, the building of residential properties. Remediation of contaminated land can be achieved by: removing or treating the pollutant; breaking or removing the pathway; or protecting or removing the receptor. Woodland establishment has the potential to satisfy all such criteria. Trees are effective at stabilising contaminated land by reducing soil erosion and off-site particulate migration. They can also promote the microbial breakdown of many organic contaminants and help to remove the fraction of metalliferous pollutants that is available to plants, thereby reducing the transfer of contamination and potential exposure to humans and the environment. Trees can, however, acidify soil, which may lead to the mobilisation of some contaminants (particularly the heavy metals). Current evidence suggests that woodland has a strong and positive part to play in the future development of contaminated land, but the use of trees for safe and effective reclamation must be based upon a predictive risk–benefit assessment.

INTRODUCTION

Woodland established on former and existing industrial land provides many social and environmental benefits and contributes strongly to both economic regeneration and sustainable development. Its establishment on derelict and contaminated land has become a strategic priority of the *England Forestry Strategy* (Forestry Commission, 1999).

However, it is recognised that further research is needed to clarify the potential of contaminated land as a medium for tree growth and to determine the role of woodland systems in stabilising (or mobilising) contaminants (Perry and Handley, 2000).

Trees have the potential for phytoremediation and so offer a way to remove or stabilise the contamination. However, there is a risk that the establishment of trees on contaminated land will cause soil acidification, leading to the mobilisation of some contaminants, particularly heavy metals, and an increased risk of their migration into groundwaters and surface waters. The use of trees for the safe and effective reclamation of contaminated land must therefore be assessed using a predictive risk assessment. This should be based on a sound understanding of the factors that influence the success of tree establishment, and the long-term fate of contaminants within forest and woodland ecosystems.

The aim of this Information Note is to make community foresters, planners and developers aware of:

- The extent of contaminated land.
- The viability, implications and benefits of tree establishment on contaminated land.
- Current research that will provide a systematic framework for assessing the feasibility, risks and benefits of tree establishment on contaminated land.

EXTENT OF CONTAMINATED LAND

The Environment Agency has suggested that over 300 000 ha of land (equivalent to approximately one and a half times the area of land enclosed by the M25 motorway) in the UK may be contaminated (ENDS, 1999), covering between 5000 and 20 000 'problem sites'. However, the extent of contaminated land in the UK depends on the definition used, and estimates of the total area and the number of contaminated sites vary widely. The advent of clear definitions and guidance on the identification of contaminated land from the Department for Environment, Food & Rural Affairs (DEFRA) will enable a more realistic and definitive assessment of the extent of contaminated land in the UK (Department of the Environment, Transport and the Regions, 2000).

Under this new guidance, land that contains elevated concentrations of contaminants will *not* be defined as 'contaminated' if *no* 'transport' pathway is identified which leads to a defined 'receptor' likely to suffer from the contaminant(s). Receptors include humans, protected ecological areas, crops, livestock, buildings and controlled waters. Such land is open to conventional reclamation (including the establishment of trees) as long as the reclamation process itself does not pose a threat to a receptor.

Land defined as 'contaminated' under the DEFRA definition can be restored to woodland if it can be shown that the establishment of woodland will aid the remediation of the site. The Government's intention is that remediation should result in land being suitable for beneficial use. Woodland provides a 'soft' end-use that requires less stringent remediation objectives than, for example, the building of residential properties. Remediation can be achieved by: removing or treating the pollutant; breaking or removing the pathway; or protecting or removing the receptor. Woodland establishment has the potential to satisfy all such criteria.

EXTENT OF WOODLAND ON CONTAMINATED LAND

Until recently it was widely believed that natural colonisation of trees on heavy metal contaminated sites was rare. In 1998, Forest Research conducted a postal questionnaire to determine the frequency of trees or woodland on contaminated land. Survey forms were sent to local authorities, woodland owners, industry and government agencies in the UK. The survey identified 250 sites covering an area of over 3200 ha from 27 former contaminating land-uses (Table 1) and currently supporting a range of 20 tree species (Table 2). Because the survey was neither comprehensive nor systematic, the results probably underestimate woodland occurrence on this type of land. However, the survey demonstrated that many tree species became established on a wide range of materials containing heavy metal and organic contaminants. This suggests that tree species are tolerant of some forms of contamination, and that there are reasonable grounds to suppose that woodland can be re-established on such land. Nevertheless, the survey does not show how tree performance is affected by contamination.

Seven contaminated sites of four former land-uses (marked with an asterisk in Table 1), supporting a wide species range (marked with an asterisk in Table 2) of both planted and naturally regenerated trees, were visited to assess how the health and vigour of trees was affected by contamination. The growth and vigour of the tree species at six of the seven sites was seemingly unaffected by contamination, even though the accepted trigger and threshold concentrations were exceeded for at least one contaminant measured (ICRCL, 1987).

Table 1

Former contaminating land-uses identified in the surveys as currently supporting trees.

Brickworks	Chemical works
Cokeworks	Collieries
Concrete works	Drilling sites
Firing ranges	Gasworks
Iron & steel works	Jute/flax works
Landfill sites	Light industry
Metal recycling plants	Metalliferous mines*
Municipal facilities	Munitions factories & depots
Papermills	Pig bristle drying plants
Planting works*	Power stations
Railways	Scrap yards
Sewage works	Smelting works*
Tanneries	Tipping sites*
Wood processing plants	

*Denotes site types visited in the health survey.

Table 2

Tree species identified in the surveys.

Alder*	Ash*
Beech	Birch
Blackthorn	Cherry*
Elder	Hawthorn
Horse chestnut	Lime
Maple	Monterey pine*
Norway spruce*	Oak*
Poplar*	Rowan*
Scots pine*	Sitka spruce
Sycamore*	Willow*

*Denotes species which were included in the health survey.

Tree survival, growth and physiological function can be affected detrimentally by many contaminants (e.g. Burton *et al.,* 1986). The upper critical concentration at which such effects take place varies for both tree species and contaminant[1]. However, our research together with other published data clearly show that trees can survive contaminant levels far greater than those laid down in current guidelines (ICRCL, 1987).

High concentrations of potentially toxic elements (PTEs) affect root growth, and roots typically accumulate significantly higher amounts of metals than the above-ground biomass. Lead, arsenic, cobalt, chromium, mercury and tin remain mainly in the root system while copper, nickel and selenium have an intermediate mobility. In contrast, cadmium and zinc are readily translocated within the tree and become concentrated in the above-ground biomass.

EFFECTS OF WOODLAND ON CONTAMINATED LAND

The retention of metals by soils and their availability to plants are largely dependent on the partition of metals between the soil solid and solution phases. Important soil properties which affect the partitioning of metals include pH, organic matter, clay minerals, hydrous oxides, carbonate content, redox status and soil moisture status.

Most tree species gradually acidify the soil with time (e.g. Moffat, 1991), and so increase the solubility, and subsequently the mobility, of most heavy metals. There is therefore an argument that trees are unsuitable for re-vegetating sites with heavy metals where there is a risk of water pollution. However, there is no field evidence of this mechanism occurring, and metals mobilised in this way are likely to be immobilised in the tissues of the trees before they present a significant threat to the wider environment.

The input of organic matter by trees will also reduce contaminant mobility. Both organic contaminants and PTEs form insoluble complexes with organic matter. For example, the residence time of lead in soils rich in organic matter has been calculated as hundreds of thousands of years (Manceau *et al.,* 1996). Although no field evidence is available, the input of organic matter by trees could counter the mobilisation effects of acidification. However, soluble organo-metallic complexes may also form in the soil solution and lead to some mobility of contaminants.

High heavy metal concentrations in organic matter slow down its decomposition by reducing the activity of soil invertebrates and micro-organisms. On sites with low to moderate contamination, the concentrations of contaminants are likely to be insufficient to significantly influence organic matter decomposition. As contaminated litter decomposes, heavy metals are released back into the soil. If organic matter and plant cover can be built up to a point where natural decay of vegetation produces further organic matter, normal cycling is established, thus reducing the risk of toxicity (Williamson *et al.,* 1982) and of released heavy metals being leached to controlled or potable waters.

The incorporation of soil amendments such as composted organic matter and crushed limestone can be used to control the mobility and reduce the availability to plants (phytoavailability) of contaminants to levels that can be tolerated by trees. This form of reclamation will also increase nutrient availability and thus aid tree growth and survival. Soil amendments can also be used to optimise soil carbon:nitrogen ratios to promote the microbial degradation of organic contaminants.

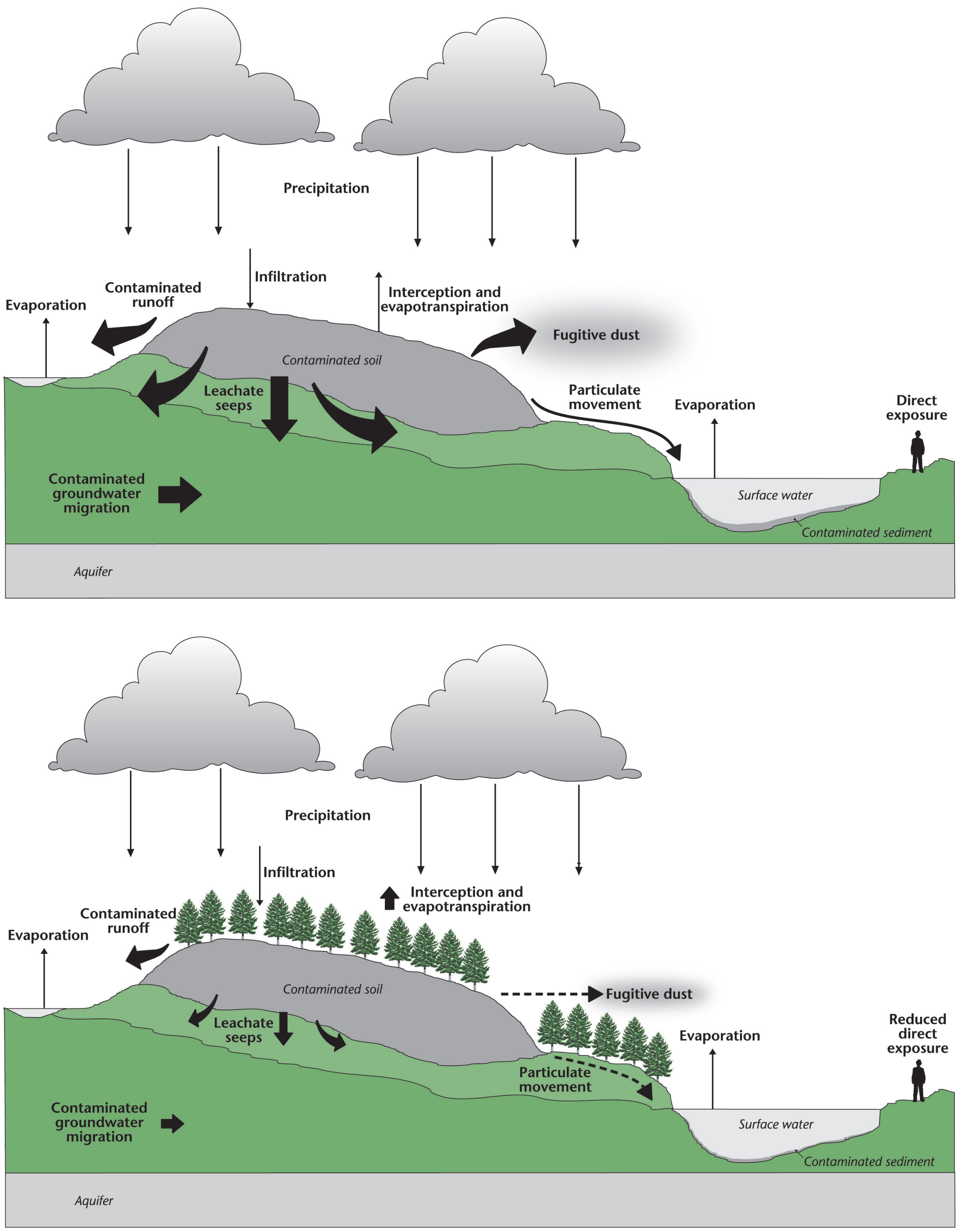
Other materials that could be used in the reclamation of contaminated land include treated sewage sludge and animal slurries, straw, clay quarry waste, charcoal, seaweed, spent mushroom compost and wood residues. However, further research is needed to test their efficacy.

BENEFITS OF WOODLAND ON CONTAMINATED LAND

'Phytoremediation' and 'phytostabilisation' use plants to immobilise, convert or remove contaminants generated by industrial processes. Conventional 'clean-up' methods involve the removal or isolation of contaminated soil but these are very expensive. Phytoremediation and phytostabilisation using trees are comparatively inexpensive, *in situ* approaches that do not rely on the isolation or transport of contaminated material to other sites. Trees have the potential for restricting or preventing wind erosion, leaching, surface water runoff and erosion and thus weakening pollutant linkage between the site and likely receptors (Figure 1).

[1] Upper critical tissue concentrations are the concentrations in the plant tissues below which growth is unaffected by accumulation of an element and above which toxic effects lead to a reduction in growth.

Figure 1 Potential remedial effects of woodland on contaminated land. Thickness of arrows indicates magnitude of movement.



Vegetation is very effective at reducing erosion by wind and water. Under trees, soil is retained and protected by the presence of roots and foliage while the input of organic matter through leaf senescence increases the binding capacity and therefore the stability of soil. The risk of particulate migration during site cultivation can be minimised by phased planting, establishing a nursery crop such as mixed grasses and/or paying careful consideration to the timing of cultivation operations.

Trees are also effective at trapping and absorbing many airborne pollutant particles with significant heavy metal content (e.g. Beckett *et al.*, 1998), so limiting the spread of contamination. For example, a 150–200 m wide strip of broadleaved woodland was shown to effectively immobilise over 450 kg of airborne dust per ha of woodland (Broadmeadow *et al.*, 1998). Conifers are more effective scavengers of metal particulates than broadleaves (Fergusson *et al.*, 1980). Nevertheless, broadleaves are often used in preference to conifers in areas of high pollution because of the annual replacement of foliage which decreases their accumulated load of toxic particles (Beckett *et al.*, 1998). The effectiveness of deciduous woodland at capturing airborne particulates is reduced after leaf fall, but the efficiency of the filtering system can be increased by using a mixture of evergreen and deciduous species.

Woodland has another important pollutant retention function, as it is effective at retaining sediment material (including sorbed organic, heavy metal and nutrient contaminants). Several studies have demonstrated that woodland is more effective at retaining pollutants bound to sediments than grassland – although the presence of the latter as either an understorey or adjacent strip enhances further removal (e.g. Sheridon *et al.*, 1999).

The potential contamination of controlled waters is a major issue when dealing with contaminated land (DETR, 2000). Compared to most vegetation types, trees have both a high transpiration rate and biomass production. Where the water table is close to the soil surface, the uptake of water causes contaminated groundwater to move into the aerobic rhizosphere where contaminants can be absorbed by the tree or soil particles (Schnoor and Licht, 1990). Once immobilised, the threat of more widespread contamination is reduced.

Metal uptake for some tree species (Table 3) is low when compared to potential amounts of metals present in contaminated soils. The use of trees to restore heavy metal values to within acceptable limits has potential for low contamination scenarios only, and is unlikely if contamination is moderate to high. However, not all of the pollutant has to be removed, as the 'bioavailable' part is the most important for minimising transfer of pollutants to crops or groundwater.

Some tree species are effective at remediating soils contaminated with organic chemical wastes such as solvents, petrochemicals, wood preservatives, explosives and pesticides (Schnoor *et al.*, 1995; Ferro *et al.*, 1997). Organic contaminants can be completely destroyed, by mineralisation to carbon dioxide and water. This is preferable to storing or immobilising them (Ferro *et al.*, 1997). Further research will examine the effectiveness of trees at remediating organically contaminated land.

Table 3

Calculated metal removal by *Salix* spp. and *Betula* spp. assuming a yield of 10 t ha^{-1}

Contaminant	Tree species	Calculated metal uptake (kg ha^{-1})
Cadmium	*Betula* spp. *Salix* spp.	1.5* 0.1 to 1.5**
Copper	*Betula* spp. *Salix* spp.	1.5* 0.05 to 1.5*
Manganese	*Betula* spp.	50*
Nickel	*Salix* spp.	0.01**
Zinc	*Salix* spp.	1.0 to 1.6**

Adapted from: *Goransson and Philippot (1994), **Riddell-Black (1994).

CONTAMINATED LAND RESEARCH

A programme of research was begun in 1998 by Forest Research to develop a systematic approach for determining the potential of contaminated land for supporting woodland (Table 4).

The research programme has six primary objectives:

- to review the place of trees on contaminated land;
- to determine the effects of elevated levels of potentially toxic elements (PTEs) on tree growth and function;
- to establish a PTE tolerance index for a range of tree species and elements;
- to assess the use of soil amendments at reducing PTE mobility and increasing the survival and growth of trees planted in contaminated materials;
- to determine the role of woodlands in stabilising (or mobilising) potentially toxic elements;
- to develop a systematic, rapid and effective method of assessing the risk and cost-benefit of woodland establishment on contaminated land.

Further research is also planned to examine the effectiveness of trees at remediating metal, nutrient and organic contaminants.

Table 4

The development of a systematic approach for assessing the potential of contaminated land for supporting woodland. The approach comprises six linked stages: 1: desktop exercises; 2, 3 and 4: viability of establishment; 5: implications of establishment; 6: risk–benefit analysis based on 1–5.

Stage	Action	Purpose	Research activity
1	Desktop survey, site evaluation and investigation.	Identify contamination type, level and extent.	Utilise historical land-use records, preliminary site visit and soil survey.
2	*In-situ* and *ex-situ* assessment of tree establishment viability.	Assessment of heavy metal phytoavailavility and other predicted effects on tree growth.	Investigate the effects of heavy metals on tree survival and growth. Establish physiological and chemical indicators of health for trees growing on contaminated land. Investigate the use of soil amendments at improving tree survival and growth.
3	Consideration of amendment use to improve tree performance.	Identify optimum soil amendments and test for improved tolerance.	Investigate the potential of trees as biological indicators of heavy metal phytoavailability. Develop methodology for the exotoxicological assessment of contaminated land.
4	Determination of tree establishment type best suited to contaminated land.	Determine optimum species choice and viability of tree establishment.	Determine the compartmentation of heavy metals within trees.
5	Evaluation of the effects of tree establishment on the stabilisation and/or mobilisation of metals.	Predict the effects of tree establishment on contaminant cycling.	Model heavy metal cycling including: particulate capture, metal uptake and partitioning, litter decomposition, and the effects of trees on soil properties.
6	Prediction of woodland establishment viability, implications and rewards.	Utilisation of information from above actions to determine if woodland establishment has a net benefit.	Determine the minimum acceptable standard of woodland establishment for trees on contaminated land. Develop a decision support system for woodland establishment on contaminated land.

CONCLUSIONS

The majority of land that contains elevated concentrations of heavy metals and/or organic contaminants is unlikely to be defined as 'contaminated' under the current DEFRA guidance, as no pollutant linkage will be evident. Such land is open to the establishment of trees, as long as the reclamation process does not produce a pollutant linkage.

Land defined as being 'contaminated' may also be suitable, in whole or in part, for woodland establishment if this will aid the remediation of the site. Trees have the potential to restrict, prevent or enhance contaminant transport pathways. The balance between these benefits and risks depends on the location, contamination status, and soil and groundwater properties of a site. In certain circumstances, trees can be used as part of a remediation package as they are effective at reducing the risk of soil erosion by wind and water and thereby limiting the spread of contamination and potential exposure to humans and the environment. Trees also provide the amenity and landscape benefits of community woodland, especially in urban areas.

Contaminated land provides a harsh environment for tree establishment. Many physiological functions are disturbed when trees are exposed to excess heavy metals. Such disturbance can be irreversible if critical 'plateaux' concentrations of contaminants are exceeded. Soil ameliorants can limit contaminant phytoavailability to levels below critical concentrations.

The use of trees to restore heavy metal values to within acceptable limits may be possible for low to moderate levels of contamination, but unlikely if contamination is moderate to high. Trees, however, remove the bioavailable metal fraction, which is the most important in terms of minimising transfer of pollutants to crops or to groundwater.

Current evidence suggests that woodland has a strong and positive part to play in the future development of contaminated land. Advice on site evaluation and establishment of trees on brownfield and contaminated land is available from the Environmental Research Branch at Alice Holt Lodge (see contact details on page 8).

ACKNOWLEDGEMENTS

The project is a good example of interdisciplinary research involving research organisations, government agencies, local authorities, industry and private woodland owners. The author is grateful to all of those who have made invaluable contributions to this work, especially to Mark Broadmeadow, François Bochereau, Jenny Claridge, Sylvia Cowdry, Eleanor Harland, Andy Moffat, Ian Stubbs, Ernest Ward and John Williams, and to Alan Armstrong, Gareth Price and Helen McKay for critical evaluation of the text.

REFERENCES

BECKETT, K.P., FREER-SMITH, P.H. AND TAYLOR, G. (1998).
Urban woodlands: their role in reducing the effects of particulate pollution.
Environmental Pollution **99**, 347–360.

BROADMEADOW, M., BECKETT, P., JACKSON, S., FREER-SMITH, P. AND TAYLOR, G. (1998).
Trees and pollution abatement.
In: *Forest Research: annual report and accounts 1997–1998.*
The Stationery Office, London, pp. 37–43.

BURTON, K.W., MORGAN, E. AND ROIG, A. (1986).
Interactive effects of cadmium, copper and nickel on the growth of Sitka spruce and studies of metal uptake from nutrient solutions.
New Phytologist **103**, 549–557.

DEPARTMENT OF THE ENVIRONMENT, TRANSPORT AND THE REGIONS (2000).
Contaminated land: Implementation of Part IIA of the Environmental Protection Act 1990.
DETR Circular 2/2000. The Stationery Office, London.

ENDS (1999).
April target for new contaminated land regime in England.
ENDS Report **297**, 45–48.
Environmental Data Services, London.

FERGUSSON, J.E., HAYES, R.W., YONG, T.S. AND THIEW, S.H. (1980).
Heavy metal pollution by traffic in Christchurch, New Zealand: lead and cadmium content of dust, soil, and plant samples. *New Zealand Journal of Soil Science* **23**, 293–310.

FERRO, A., KENNEDY, J. AND KNIGHT, D. (1997).
Phyto-remediation of soils contaminated with pentachlorophenol and polyaromatic hydrocarbons.
In situ and on-site bioremediation.
Battelle 4th International Symposium. New Orleans.

FORESTRY COMMISSION (1999).
England forestry strategy: a new focus for England's woodlands. Forestry Commission, Cambridge.

GORANSSON, A. AND PHILIPPOT, S. (1994).
The use of fast growing trees as 'metal-collectors'. In: *Willow vegetation filters for municipal wastewaters and sludges: a biological purification system,* eds P. Aronsson and K. Perttu. Sveriges Lantbruksuniversitet: Report 50. Uppsala, Sweden, 129–132.

ICRCL (1987).
Guidance on the assessment and redevelopment of contaminated land. *Interdepartmental Committee on the Redevelopment of Contaminated Land Guidance Note 59/83 2nd Edition.*
Department of the Environment, London.

MANCEAU, A., BOISSET, M.C., SARRET, G., HAZEMANN, J.L., MENCH, M., CAMBIER, P. AND PROST, R. (1996).
Direct determination of lead speciation in contaminated soil by EXAFS spectroscopy.
Environmental Science and Technology **30**, 1540–1552.

MOFFAT, A.J. (1991).
Forestry and soil protection in the UK.
Soil Use and Management **7**, 145–151.

PERRY, D. AND HANDLEY, J. (2000).
The potential for woodland on urban and industrial wasteland.
Forestry Commission Technical Paper 29.
Forestry Commission, Edinburgh.

RIDDELL-BLACK, D. (1994).
Heavy metal uptake by fast growing willow species. In: *Willow vegetation filters for municipal wastewaters and sludges: a biological purification system,* eds P. Aronsson and K. Perttu. Sveriges Lantbruksuniversitet: Report 50. Uppsala, Sweden, 145–151.

SCHNOOR, J.L. AND LICHT, L.A. (1990).
Deep-rooted poplar trees as an innovative treatment technology for pesticide and toxic organics removal from groundwater. Technical Progress Report. Hazardous Substance Research Center for U.S. Regions 7 and 8, Kansas State University, USA.

SCHNOOR, J.L., LICHT, L.A., McCUTCHEON, S.C., WOLFE, N.L. AND CARREIRA, L.H. (1995).
Phyto-remediation of organic and nutrient contaminants. *Environmental Science and Technology* **29**, 318A–323A.

SHERIDON, J.M., LOWRANCE, R. AND BOSCH, D.D. (1999).
Management effects on runoff and sediment transport in riparian forest buffers. *Transactions of the ASAE* **42**, 55–64. Tifton, Georgia, USA.

WILLIAMSON, N.A., JOHNSON, M.S. AND BRADSHAW, A.D. (1982).
Mine wastes reclamation.
Mining Journal Books Ltd, London.

Enquiries relating to this publication should be addressed to:

Tony Hutchings
Environmental Research Branch
Forest Research
Alice Holt Lodge
Farnham
Surrey
GU10 4LH

Tel: 01420 22255
Fax: 01420 23653

Email: tony.hutchings@forestry.gsi.gov.uk

ISSN 1460-3802
ISBN 0-85538-562-6

FCIN044/PPD(ECD)/21-2K/SEP02