National Centre for Risk Analysis & Options Appraisal

Risk Assessment of Road Transport

WS Atkins Environment

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EXECUTIVE SUMMARY

Many authoritative studies have highlighted the severe and widespread environmental impacts of existing and future transport, in particular road transport. In response to these concerns, the Government issued a Green Paper which stresses the need to achieve personal mobility within an economically and environmentally sustainable framework, with a commitment to achieve this objective through detailed proposals to be presented in a White Paper to be delivered in 1998. Within their Risk Profile 1, the Environment Agency (EA) identified a range of environmental risk sources arising from road transport, and undertook a preliminary assessment of the nature, scale, severity and trends of the likely impacts. In order to extend the work undertaken in the production of the Risk Profile and to provide the EA with decision relevant information with which it can contribute to the development of an environmentally sustainable transport policy, a *Project for the Provision of a Risk Assessment on Road Transport* was initiated.

This report provides the results of the first two stages of this project; risk screening and quantitative risk assessment. The risk screening was undertaken by the National Centre for Risk Analysis and Options Appraisal of the EA as a preference illicitation exercise and provided 10 scenarios for quantitative risk assessment. The methodology that was applied within stage 2 of the project involved the construction of event trees, which were designed to enable risks from diverse sources to be compared and ranked, and to allow the effects of management options to be evaluated. Therefore, the event trees addressed environmental pressures but included links with some measure of environmental impact. The data utilised for the construction of each event tree were highly dependent on the available information relating to the considered scenario. Where appropriate, the effects of uncertainties associated with the key input variables on selected event tree risk estimates were assessed, using Monte Carlo simulation modelling.

The quantitative risk assessment of the air quality impacts of road traffic focused on the health effects of PM_{10}. The UK emissions of PM_{10} were disaggregated into a number of categories of sources, both primary and secondary, and the impact of these emissions was assessed by employing estimates of the effects of PM_{10} in the UK. These effects included acute mortality from all causes and respiratory hospital admissions additional and brought forward. Although the environmental pressure section of the event tree proved to be of value, the linking of the emissions to impact required a number of assumptions which significantly increased the uncertainty of the assessment. Key conclusions arising from the assessment included that heavy goods vehicles contribute 41 per cent of the total vehicular PM_{10} emission but only account for 6 per cent of the total kilometerage; that petrol cars are responsible for 22 per cent of the total emissions, which is more than diesel cars; and that PM_{10} is likely to result in approximately 11 thousand deaths and 14 thousand premature hospital admissions in the UK, with the vehicular contribution to these being highly uncertain.

Emphasis was placed on providing a breakdown of the transport sources of carbon dioxide within the quantitative risk assessment of the global climate change impacts of road traffic in the UK. This involved the determination of the proportion of emissions arising from different driving conditions and vehicles, and comparison of these values against total UK emissions. These were subsequently evaluated against global emissions and anticipated impact upon sea level rise. Although the environmental pressure section of the event tree proved to be of value, the linking of the emissions to impact required a number of assumptions which significantly increased the uncertainty of the assessment. Key conclusions arising from the assessment included that vehicular emissions account for 20 per cent of the total UK contribution to global warming, of which 93 per cent arise from carbon dioxide; that about 20 per cent of vehicular carbon dioxide emissions arise through motorway driving, 46 per cent through urban driving and 34 per cent through non-urban driving; and that petrol engined cars are overwhelmingly the most important source of vehicular greenhouse gas emissions.

The quantitative risk assessment of the water quality impacts of leachate arising from landfill of waste vehicle components considered the behaviour of iron, cadmium, mercury and PCBs from shredder residue derived from end of life vehicles in best practice landfill. As the behaviour of substances in landfill is dependent on their concentrations, the approach of employing Monte Carlo simulation to calculate the concentrations throughout the event tree was adopted. The processes considered in the event tree included adsorption of substances onto solid surfaces within the landfill, precipitation of substances, collection and treatment of leachate, leachate loss through the landfill liner and degradation of substances. Key conclusions arising from the assessment were that the concentrations of the substances in leachate are very low and significantly lower than the appropriate Environmental Quality Standards (EQSs) or other guidance.

Two identically structured event trees; one of which addressed metal loads and the other water balance, were utilised in the quantitative risk assessment of the water quality impacts of road run off. These two event trees were linked to allow calculation of metal concentrations. The behaviour of water was based on a general model of the water balance for roads, whilst for copper, zinc and lead the total loads per unit area of road were employed in conjunction with the soluble percentages of metals within the loads. The presence of drainage structures on roads and the behaviour of metals in these structures were also considered. The impact on surface waters was evaluated based on the EQSs for the metals. This was accomplished by considering the mixing of the discharge to surface water with the river discharge. Key conclusions arising from the assessment included that the dominant pathways of metal pollution were direct losses to surface waters with little attenuation and deposition adjacent to the road surface; and that during periods of low flow rivers are vulnerable to large pollution inputs which may elevate the final river concentration to be greater than the value of the appropriate EQS.

Spillages of motor spirits were addressed in the quantitative risk assessment of the water quality impacts of accidental spillages. The event tree considered the likelihood of an accidental spillage occurring, the probability of containment which was derived from the probability of a rain day, plus evaporation, infiltration and run off. In addition, the behaviour of motor spirits in road drainage structures including blockage by safety valves, removal in oil traps and diversion to storage ponds was considered. The impact on surface water was evaluated by considering the mass of motor spirits entering the river. The key conclusions arising from the assessment included that overwhelmingly the most important parameters in determining the mass of motor spirits entering the river were the probability of a rain day and the presence of a safety valve; and that under existing conditions, as described by the event tree, an accidental spillage of motor spirits greater than 15 kg will always lead to a pollution incident, where this is defined by the presence of greater than 0.5 kg of motor spirits in the water course.

For the quantitative risk assessment of the water quality impacts during road construction, a mean rainfall event of 12.9 mm with a 60 minute duration was considered. The pathways by which sediment enters surface waters were addressed including run off, wind erosion, disturbance of stream banks during construction of culverts and bridges, and the drainage system of off site roads. The sediment trapping efficiency of sediment control structures and the behaviour of sediment during the other routes by which it enters surface waters was considered. The impact on surface waters was evaluated based on the EQS for drinking water abstraction. This was accomplished by considering the mixing of the discharge to surface waters with the river discharge. The key conclusions arising from the assessment included that the concentration of sediment in road discharges was found to be most sensitive to the efficiency of temporary control structures, vehicle cleaning practises and rainfall intensity; that the final river concentration was controlled by the river discharge; and that under average conditions, as represented by the event tree, the final river concentration was found to be almost three times the suspended sediment EQS.

Ammonia derived from gully pot cleaning was considered in the quantitative risk assessment of the water quality impacts of road maintenance. The event tree addressed the two stages of gully pot cleaning; removal of water and sediment from gully pots and refilling of the gully pots, and the disposal of black water from the gully cleaning tanker. The presence of various drainage facilities in the pathway from the gully pot outlet was considered as well as the behaviour of ammonia in these facilities. The impact on surface water was evaluated based on the Grade 1 Fisheries Ecosystem EQS. This was accomplished by considering the mixing of the discharge to surface water with the river discharge. Key conclusions arising from the assessment included that in the case of the river flow required to meet the EQS, the over whemingly the most important parameters were the four hour discharge in the river and the background concentration in the river; that the river flows required to meet the EQS were at the lower end of the range of flows; and that the probability of the concentration of ammonia in the river meeting the EQS was just under 0.9, demonstrating that it is unlikely that the EQS will be exceeded.

The quantitative risk assessment of the potential for flooding due to road construction involved the construction of an event tree based on a generic river flow frequency distribution which was compared to thresholds for flooding and erosion. The presence of flood plain storage; the possibility of over bank flow, slow release of water from storage and failure of storage structures; and the possibility of channel erosion were included in the event tree. A general stage-discharge relationship and a flood damage score were used to link the discharge to flood damage. Key conclusions arising from the assessment included that the most likely outcome is river discharge under "normal" conditions; that the most likely source of damage is due to scouring and erosion, and the high costs of urban flooding mean that this category represents the most significant risk; and that all outcomes are controlled by the generic river flow frequency distribution.

Two event trees were constructed for the quantitative assessment of the potential for habitat loss from roadstone quarrying activities. One considered the area of land lost to roadstone quarrying in different regions of England and Wales, and the other considered the different uses of the land surface taken for quarrying prior to its loss. The functional unit of the assessment was road expenditure. The event tree, which took account of the use of secondary aggregate, was derived by consideration of the ratio of landtake to quantity of aggregate extraction, the ratio of road spending to roadstone consumption and the fractions of the road budget spent on construction and maintenance. As the only variable within the assessment with significant uncertainty was the area of landtake per tonne of aggregate extracted and it was not possible to quantify the associated variation, it was considered that a sensitivity analysis would be unlikely to provide useful information and therefore this was not performed. The key conclusions arising from the assessment included that the greatest probability of loss of land surface to quarrying activities was in the East Midlands and for agricultural land; and that the use of secondary aggregate is important in decreasing the landtake.

The assessment of the potential for sensitive habitat loss from new road construction made use of the road schemes currently being considered by the Department of Environment, Transport and the Regions for construction in the next few years and involved the construction of two event trees. The first considered the area of green and brownfield landtake that may arise in the next year in different regions of England and Wales and compared this to the total landtake of this type arising from other development activities, thereby providing an indication of the relative development pressure on habitats in different regions arising from road building and other forms of urbanisation. The second provided a measure of the impact on designated conservation sites by correlating the density of designated sites within each region to the level of road development within that region, thereby providing an indication of the relative pressure to which the designated sites within each region are exposed due to road construction activities. As the only significant source of uncertainty was in the number and size of road schemes being considered, it was regarded that a sensitivity analysis would be unlikely to provide useful information and therefore this was not undertaken. The key conclusions arising from the assessment included that the greatest probability of loss of non-greenbelt land to road construction was in the South East; and that the North West generally had the greatest relative pressure on designated sites.

1. INTRODUCTION

1.1 This draft report presents the results of the first two stages of a *Project for the Provision of a Risk Assessment on Road Transport*. The project is being performed by WS Atkins Environment for the National Centre for Risk Analysis and Options Appraisal (NCRAOA) of the Environment Agency (EA) under Contract Number HOCO 246.

1.2 Many authoritative studies, including the recent report produced by the Royal Commission of Environmental Pollution (RCEP, 1997) have highlighted the severe and widespread environmental impacts of existing and future transport, in particular road transport. In response to these concerns, the Government issued a Green Paper (DETR, 1997a) which stresses the need to achieve personal mobility within an economically and environmentally sustainable framework with the commitment to achieve this objective through detailed proposals to be presented in a White Paper to be delivered in 1998.

1.3 Within their Risk Profile 1 (NCRAOA, 1997) the EA identified a range of environmental risk sources arising from road transport, and undertook a preliminary assessment of the nature, spatial scale, severity and trends of the likely impacts. Although the EA has no formal remit in relation to road transport, it nevertheless has an overall aim to contribute towards the formulation of a sustainable development strategy for the UK. To meet this aim it is essential to balance future transport demand with long term environmental and health protection. In addition, for the cost effective regulation and management of environmentally harmful activities directly within the EA's remit it is necessary for it to possess a clear understanding of the major environmental risks from sources beyond its direct control.

1.4 The aim of the risk assessment is to provide the EA with decision relevant information with which it can contribute in an authoritative and constructive manner to the development of an environmentally sustainable transport policy as part of a Sustainable Development Strategy for the UK. Specifically, the study develops the work undertaken in the production of Risk Profile 1 with the objectives of:

- identifying and quantifying the principle environmental risks of road transport; and

- developing risk management options to ameliorate these priority issues and examine their impact in reducing risk.

1.5 Stage 1 of the project involved risk screening which was undertaken by NCRAOA as a preference illicitation exercise. The results of this exercise provided 10 scenarios for quantitative risk assessment within stage 2 of the project. For all these scenarios event trees have been constructed. These event trees have been designed to enable risks from diverse sources to be compared and ranked, and to allow the effects of management options to be evaluated. Therefore, the event trees have addressed environmental pressures but have included links with some measure of environmental impact. The data utilised for the construction of each event tree were highly dependent on the available information relating to the considered scenario.

1.6 Where appropriate, the effects of uncertainties associated with the values of key input variables on selected event tree risk estimates have been assessed using Monte Carlo simulation modelling. Crystal Ball version 4.0 was utilised for this procedure. The Monte Carlo modelling involved the definition of probability distributions for input variables and the use of Latin hypercube sampling to recalculate event tree risk estimates for a predetermined number of iterations. This method of statistical modelling facilitates calculation of the combined impact of uncertainties inherent in the risk analysis and results in the production of a probability distribution for the selected event tree risk estimates.

1.7 Sensitivity analysis was conducted using rank order correlation, a non parametric technique for quantifying the relationship between two variables. The rank correlation coefficients for input variables represent the degree of correlation, either positive or negative, between the event tree input variables and risk estimates. Sensitivity analysis enables identification of the input variables which have the most significant effect upon the estimates and therefore provides a valuable means by which to prioritise and optimise further resource investment.

1.8 The report is divided into 14 sections as follows:

- Section 1 Introduction;

- Section 2 Risk screening;
- Section 3 Quantitative risk assessment of the air quality impacts of road traffic;
- Section 4 Quantitative risk assessment of the global climate change impacts of road traffic in the UK;
- Section 5 Quantitative risk assessment of the water quality impacts of leachate arising from landfill of waste vehicle components;
- Section 6 Quantitative risk assessment of the water quality impacts of road run off;
- Section 7 Quantitative risk assessment of the water quality impacts of accidental spillages;
- Section 8 Quantitative risk assessment of the water quality impacts during road construction;
- Section 9 Quantitative risk assessment of the water quality impacts of road maintenance;
- Section 10 Quantitative risk assessment of the potential for flooding due to road construction;
- Section 11 Quantitative assessment of the potential for habitat loss from roadstone quarrying activities;
- Section 12 Assessment of the potential for sensitive habitat loss from new road construction;
- Section 13 Conclusions; and
- Section 14 References.

2. RISK SCREENING

2.1 (Section to be added from EA report)

3. QUANTITATIVE RISK ASSESSMENT OF THE AIR QUALITY IMPACTS OF ROAD TRAFFIC

INTRODUCTION

3.1 This section presents the results of a quantitative risk assessment of the air quality impacts of road traffic. Road traffic emits a wide range of pollutants principal amongst these being:

- fine particulate matter (PM_{10});
- nitrogen oxides (the precursor to nitrogen dioxide and nitric acid);
- carbon monoxide;
- lead (from vehicles using leaded fuel);
- sulphur dioxide (from diesel engine vehicles); and
- volatile organic compounds including benzene and 1,3-butadiene.

3.2 These pollutants have a range of impacts acting both singularly and synergenically including impacts upon:

- human health (both through chronic and acute exposure);
- soil and surface or groundwater as a result of acid deposition;
- buildings; and
- vegetation.

3.3 The breadth of the overall project is such that it has not been possible to undertake a quantitative risk assessment for all air pollutants emitted by vehicles and their associated impacts. It has therefore been necessary to focus resources upon specific key issues identified during Stage 1 of the project, risk screening. This exercise identified human health effects of pollution as the priority issue and this is addressed within this assessment. This is not to devalue the importance of other impacts of air pollution but reflects the need to focus limited resources. In the future it is hoped additional resources will be made available to assess quantitatively the risks arising the other impacts of air pollution.

3.4 This risk assessment has focused upon the health effects of *PM_{10}*. This is since:

- there is a growing body of literature to suggest it is this pollutant which is most closely related to greatest health impacts experienced by the public;
- levels of PM_{10} are significantly above UK Standards and Objectives and therefore of particular concern;
- there is no dose-response threshold, which makes assessing health outcomes more straightforward;
- impacts occur both from acute and chronic exposure; and
- levels across the UK are more uniform than for other pollutants.

3.5 The human health effects of air pollution including PM_{10}, are amongst the most extensively researched and well understood environmental issue. There are still, however, significant uncertainties in known dose-responses particularly relating to variation in the response between individuals.

3.6 The event tree methodology to be applied was designed to enable risks from diverse sources of different types to be compared and ranked. It was also intended to enable the effect of management options on these risks to be evaluated. In order to achieve this the event trees have addressed the *environmental pressures* created by the road transport, in this assessment by evaluating *emissions* of PM_{10} from different traffic sources.

3.7 Elevated ambient PM_{10} concentrations and high exposure arise from emissions from a wide variety of activities and sources. These include both primary sources and secondary pollution generated through subsequent atmospheric chemistry of gaseous pollutant releases. Consequently, the health effects of exposure to PM_{10} cannot be simply prescribed to a single source such as road traffic. The proportions of different sources contributing to the ambient concentration of PM_{10} varies greatly both temporally and geographically. To evaluate reliably the contribution of road traffic emissions to exposure and subsequent impacts therefore requires complex exposure modelling involving examining the concentration and time to which individuals are exposed to a pollutant in different micro-environments and the proportion of emissions arising from each source. This is a highly involved and uncertain procedure which goes beyond the scope of the project and does not lend itself to quantitative risk assessment using the event tree approach prescribed for this project.

3.8 To determine the contribution of road traffic sources to health impacts arising from PM_{10} requires some assumption to be applied to simplify the assessment and relate traffic activities and emissions to health outcomes. For the purpose of applying the event tree methodology it has been assumed that exposure to, and therefore the impact of PM_{10} is directly proportional to the *annual average UK emissions*. This assumption has considerable limitations since the proportion of PM_{10} from traffic sources to which individuals are exposed is highly variable depending upon their location. For example, on a national basis traffic accounts for only 25 per cent of PM_{10} emissions, but in London this rises to 77 per cent (LRC, 1998). The extent to which traffic related PM_{10} emissions are responsible for health outcomes is therefore variable. The limitations of the assumption, and effect upon the overall reliability of the assessment are discussed within the conclusions to this section.

METHODOLOGY

3.9 Figure 3.1 presents the outline event tree which illustrates the sources of vehicular and PM_{10} emissions. The total UK emissions have been disaggregated into a number of categories and sub-categories of sources:

- non vehicular;
- primary vehicular:
  - vehicle exhausts;

  - brakes;
  - tyres; and

- secondary vehicular:
  - road surface dust resuspension; and
  - secondary PM_{10} formation.

Figure 3.1 - Event tree for air quality impacts of PM_{10} upon human health

	Non vehicular				
PM10 emissions					
	Vehicular	Primary	Exhaust	Motorways	Petrol cars
					Diesel cars
					Motorcycles
					Buses and coaches
					Petrol LGV
					Diesel LGV
					HGV small
					HGV large
				Built-up	Petrol cars
					Diesel cars
					Motorcycles
					Buses and coaches
					Petrol LGV
					Diesel LGV
					HGV small
					HGV large
				Non Built-up	
					Petrol cars
					Diesel cars
			Tyres		Motorcycles
					Buses and coaches
			Brakes		Petrol LGV
					Diesel LGV
					HGV small
					HGV large
		Secondary	Resuspended dust		
			Secondary Particulate		

Non vehicular emissions

3.10 The first branch of the event tree distinguishes vehicular from non vehicular PM_{10} sources in the UK. The National Atmospheric Emissions Inventory (NAEI) has estimated emissions of PM_{10} from non-vehicular sources. These are reproduced in QUARG (1996) and shown in Table 3.1.

Table 3.1 - Non vehicular PM_{10} emissions: 1993

Source	kt	Per cent UK total
Public power	40	15
Commercial institutional & residential combustion plant	42	16
Industrial combustion plants & processes with combustion	44	17
Non combustion processes	63	24
Non vehicular transport	7	3
Other	1	0
Total	**197**	**75**

Source: QUARG, 1996

3.11 1993 is the most recent year for which estimates of primary PM_{10} emissions have been prepared. Projections to 1995/6 estimate primary emissions from all sources will have declined to about 225 kt of which the non vehicular contribution will remain constant at about 75 per cent. Non vehicular sources are therefore estimated to total 169kt by 1996.

3.12 There is considerable uncertainty in non vehicular PM_{10} emissions since there are few absolute measurements of emissions from processes. QUARG state these can only be considered as reliable within an order of magnitude and this has been employed as the uncertainty statistic for the sensitivity analysis.

Primary vehicular emissions

Activity statistics

3.13 Primary vehicular emissions have been determined using data from the National Transport Statistics (DETR, 1997b). These have been combined with the current DETR approved fleet-weighted emissions factors (LRC, 1998) to estimate emissions. The transport activity statistics provide information on total road kilometerage by type of vehicle and class of road in 1996. These are reproduced in Table 3.2.

Table 3.2 - Road traffic by type of vehicle and class of road, 1996

Billion km	Motorways	Built-up	Non built-up	Total
Cars & taxis	54.6	164.9	136.6	**356.1**
Motorcycles	0.3	2.3	1.6	**4.2**
Buses and coaches	0.5	3.1	1.3	**4.9**
LGV	5.9	17.1	16.4	**39.4**
HGV (Small)	3.8	5.1	6.3	**15.2**
HGV (Large)	5.8	2.6	6.5	**14.9**
Total	**70.9**	**195.1**	**168.7**	**434.7**

Source: DETR, 1997b

3.14 Data on total vehicle kilometres by type are derived from roadside counts which take two forms:

(i) occasional 12 hour counts at a large number of sites to estimate the absolute level of traffic (rotating census); and

(ii) frequent counts at a small number of sites (core census).

3.15 The DETR (1997c) estimate the reliability of these estimates to be ± 2 - 3 per cent at a
95 per cent confidence interval depending upon the category of road. For the purpose of the sensitivity analysis 2.5 per cent has been assumed as the mid-point of this range.

Differentiation by engine type

3.16 Primary PM_{10} emissions originate from:

- exhaust emissions;
- tyre wear; and
- brake wear.

3.17 The level of PM_{10} exhaust emissions from cars and taxis and Light Goods Vehicles (LGVs) are dependent upon, amongst other factors engine type and fuel used. It is therefore necessary to differentiate the number of vehicle kilometres in these categories by engine type in order to quantify the emissions.

3.18 Sixty two per cent of all fuel consumption for vehicle use is petrol gasoline and 38 per cent diesel. Of this, cars account for 93 per cent the total consumption of petrol and 23 per cent that of diesel. Average fuel consumption for petrol engine vehicles is however 31 mpg whilst that for diesel 41 mpg (DETR, 1997b). Based upon these data cars with petrol engines therefore account for 82 per cent of the total kilometerage for cars. All these data are known with a high degree of reliability and the uncertainty is therefore small. For the purpose of the sensitivity analysis an uncertainty of ± 2.5 per cent has been assumed based upon expert judgement.

3.19 It has not been possible to identify similar data for LGVs to determine accurately the proportion of vehicular kilometres driven by diesel and petrol engine vehicles. The approach adopted was therefore to proportion the kilometerage according to the numbers of vehicles with different engine types. This is not ideal since due to the improved fuel efficiency of diesel engine cars these tend to be used by individuals driving a larger numbers of kilometres, it is however, a reasonable approximation. Forty three per cent of registered LGVs are petrol engine and 57 per cent diesel (DETR, 1997b). These fractions have been employed, in Table 3.3, to determine the number of kilometres driven by LGVs with each type of engine. There is greater uncertainty in the LGV estimates due to the less reliable methodology employed, the proportion of petrol engine kilometres is however likely to be in range ± 10 per cent, based upon expert judgement.

Table 3.3 - Vehicle kilometres by engine type

Billion km	Motorways	Built-up	Non built-up	Total
Cars etc. petrol	44.8	135.2	112.0	**292.0**
Cars etc. diesel	9.8	29.7	24.6	**64.1**
Motorcycles	0.3	2.3	1.6	**4.2**
Buses and coaches	0.5	3.1	1.3	**4.9**
LGV petrol	2.5	7.4	7.1	**16.9**
LGV diesel	3.4	9.7	9.3	**22.5**
HGV small	3.8	5.10	6.30	**15.2**
HGV Large	5.8	2.6	6.5	**14.9**
Total	**70.9**	**195.1**	**168.7**	**434.7**

Based upon DETR, 1997b

Emissions factors

3.20 The DETR have approved fleet averaged emissions factors for different vehicle and engine types for 1996 (LRC, 1998). These fleet averaged factors include all primary sources and are therefore the sum of exhaust, tyre and brake emissions. For diesel cars and LGVs these include factors for engines under cold start conditions where emissions are higher. The emissions factors which have been used are shown in Table 3.4.

Total emissions during normal driving conditions

3.21 Employing the emissions factors and numbers of kilometres for each vehicle/engine type/driving condition total primary emissions during normal (hot-engine) driving conditions can be determined, as shown in Table 3.5.

Table 3.4 - Fleet averaged PM_{10} emissions factors, 1996

g km^{-1} (cold starts g per start)	Motorways	Built-up	Non built-up	Cold start
Cars etc. petrol	0.028	0.028	0.028	
Cars etc. diesel	0.157	0.133	0.101	0.133
Motorcycles	0.120	0.120	0.120	
Buses and coaches	0.598	1.347	1.178	
LGV petrol	0.044	0.044	0.044	
LGV diesel	0.227	0.219	0.178	0.228
HGV small	0.677	1.200	0.734	
HGV Large	0.465	0.996	0.583	

Source: LRC, 1998

Table 3.5 - Primary vehicular emissions of PM_{10}, 1996

Emissions (kt)	Motorways	Built-up	Non built-up	Total
Cars etc. petrol	1.3	3.8	3.1	**8.2**
Cars etc. diesel	1.5	3.9	2.5	**8.0**
Motorcycles	0.0	0.3	0.2	**0.5**
Buses and coaches	0.3	4.2	1.5	**6.0**
LGV petrol	0.1	0.3	0.3	**0.7**
LGV diesel	0.8	2.1	1.7	**4.6**
HGV small	2.6	6.1	4.6	**13.3**
HGV large	2.7	2.6	3.8	**9.1**
Total	**9.3**	**23.4**	**17.7**	**50.4**

Cold starts

3.22 Additional emissions occur from diesel cars and LGVs as a result of cold starts. In order to take account of these the number of cold starts is required. It is known that the average urban trip length is 8.4 km (LRC, 1996) and from this the number of urban trips can be estimated. The average journey length in non built-up areas is not known and has therefore been assumed to be the same as in urban areas, this is a conservative estimate. No cold starts are assumed for motorway driving as very few journeys will start so close to the motorway that additional emissions will result from this type of driving.

3.23 Not every trip is made from a cold start (since the engine takes a considerable time to cool). The number of cold starts per vehicle starts is estimated to be 1:1.66 (LRC, 1996) from these data Table 3.6 shows the additional emissions for cold starts.

3.24 In total, cold starts contribute about 0.5 kt to emissions of PM_{10} from diesel cars to which other primary sources total 8.0 kt, about 6 per cent. For diesel LGVs cold starts contribute 0.4 kt, other primary sources contributing 4.6 kt (9 per cent). The contribution of cold starts to PM_{10} emissions from these sources are therefore small, but not insignificant. There is a range of assumptions built into the determination of the additional cold start emissions for cars and LGVs including:

- number of kilometres driven;
- average journey length;
- proportion of journeys made with a cold engine; and
- the cold start emissions factor.

3.25 The uncertainty associated with each of these factors is not known and it is not therefore possible to determine reliably the overall uncertainty in the cold start emissions. However, since the overall contribution of cold start emissions is relatively small it is unlikely to have a significant bearing upon the overall results. For the purpose of undertaking the sensitivity analysis the estimates have been assumed to be correct within an order of magnitude based upon expert judgement.

Table 3.6 - Cold start emissions

	Built-up	Non built-up
Billion km		
Cars etc. diesel	29.7	24.6
LGV diesel	9.7	9.3
Billion starts		
Cars etc. diesel	3.5	2.9
LGV diesel	1.2	1.1
Billion cold starts		
Cars etc. diesel	2.1	1.8
LGV diesel	0.7	0.7
Cold start factor (g start^{-1})		
Cars etc. diesel	0.133	0.133
LGV diesel	0.228	0.228
Additional cold emissions (kt)		
Cars etc. diesel	0.3	0.2
LGV diesel	0.2	0.2

Total primary emissions

3.26 The total primary emissions is the sum of emissions during normal and cold start driving and is shown in Table 3.7. Table 3.8 compares the estimate of total primary vehicular emissions against the estimate of National Atmospheric Emissions Inventory (NAEI) compiled by NETCEN on behalf of the DETR. The most recent inventory has been compiled for 1995, but predictions for 1996 are also available. Table 3.8 demonstrates good overall agreement with the NAEI. For some vehicle types there are disparities between the emissions calculated in this analysis and the NAEI, due to the assumptions employed and the use of updated emissions factors.

Table 3.7 - Total primary vehicular emissions

kt	Motorways	Built-up	Non built-up	Total
Cars etc. petrol	1.3	3.8	3.1	**8.2**
Cars etc. diesel	1.5	4.2	2.7	**8.5**
Motorcycles	0.0	0.3	0.2	**0.5**
Buses and coaches	0.3	4.2	1.5	**6.0**
LGV petrol	0.1	0.3	0.3	**0.7**
LGV diesel	0.8	2.3	1.8	**4.9**
HGV small	2.6	6.1	4.6	**13.3**
HGV large	2.7	2.6	3.8	**9.1**
Total	**9.3**	**23.8**	**18.1**	**51.2**

3.27 It has been necessary to reproduce the NAEI in order to perform the sensitivity analysis and to enable assessment of the likely impact of management options. Good agreement with the NAEI does not therefore demonstrate the confidence of the estimates since the NAEI uses a similar approach to determine national vehicle emissions.

Table 3.8 - Comparison of estimates with national inventory

Emissions (kt)	Total	NAEI 1995	NAEI 1996	Total - NAEI 1996
Cars etc. petrol	**8.2**	10.3	9.4	- 1.2
Cars etc. diesel	**8.5**	4.5	4.1	+ 4.4
Motorcycles	**0.5**	0.4	0.4	+ 0.1
Buses and coaches	**6.0**	6.3	5.7	- 0.3
LGV petrol	**0.7**	0.2	0.2	+ 0.5
LGV diesel	**4.9**	8.3	7.5	- 2.6
HGV small	**13.3**	20.1	18.3	- 5.0
HGV large	**9.1**	7.1	6.5	+ 3.6
Total	**51.2**	**57.2**	**52**	**- 0.8**

Source: NAEI data supplied from QUARG, 1996

Emissions from brakes

3.28 QUARG (1996) estimate wear from brake linings accounts for emissions of 0.00795 g km^{-1} from cars. Based upon this emissions factor it is possible to determine total UK emissions of PM_{10} from brake linings using data from the traffic statistics for kilometerage of different types of vehicles (Table 3.2). Fleet averaged number of wheels for HGVs total in the UK is 10 (DETR, in press) and employing this factor produces estimates of emissions from this source as shown in Table 3.9. Total emissions are in good agreement with those in QUARG.

3.29 The emissions estimate is based upon number of vehicle kilometres, which is known with a reliability of ± 2.5 per cent (as previously discussed), and the emissions factor. The emissions factor is derived from US data and the robustness of the data and appropriateness to UK conditions are not known. QUARG (1996) are unable to quantify the reliability of the estimate, it is therefore assumed be correct within an order of magnitude, this is based upon expert judgement.

Table 3.9 - Emissions of PM_{10} from brakes

kt	Motorways	Built-up	Non built-up	Total	Proportion
Cars etc. petrol	0.36	1.07	0.89	**2.32**	0.61
Cars etc. diesel	0.08	0.24	0.20	**0.51**	0.13
Motorcycles	0.00	0.01	0.01	**0.02**	0.00
Buses and coaches	0.00	0.02	0.01	**0.04**	0.01
LGV petrol	0.02	0.06	0.06	**0.13**	0.04
LGV diesel	0.03	0.08	0.07	**0.18**	0.05
HGV small	0.08	0.10	0.13	**0.30**	0.08
HGV Large	0.12	0.05	0.13	**0.30**	0.08
Total	**0.68**	**1.63**	**1.49**	**3.80**	**1.00**
Proportion	0.18	0.43	0.39	**1.00**	

Emissions from tyres

3.30 QUARG (1996) estimate wear from tyres accounts for emissions of 0.0012 g km^{-1} for cars. Based upon this emissions factor it is possible to determine total UK emissions of PM_{10} from tyres using data from the traffic statistics for kilometerage of different types of vehicles (Table 3.2) and assuming emissions from HGVs in proportion to the number of wheels (i.e., 2.5 times the number of wheels on a car). This value is approximately the same as that estimated in QUARG. Estimates of emissions from tyres are shown in Table 3.10. The emissions factor is derived from US data. The robustness of the data and appropriateness to UK conditions are not known. An uncertainty of an order of magnitude has been assigned to the data, based upon expert judgement.

Table 3.10 - Emissions of PM_{10} from tyres

kt	Motorways	Built-up major	Non built-up	Total	Proportion
Cars etc. petrol	0.05	0.16	0.13	**0.35**	0.61
Cars etc. diesel	0.01	0.04	0.03	**0.08**	0.13
Motorcycles	0.00	0.00	0.00	**0.00**	0.00
Buses and coaches	0.00	0.00	0.00	**0.01**	0.01
LGV petrol	0.00	0.01	0.01	**0.02**	0.04
LGV diesel	0.00	0.01	0.01	**0.03**	0.05
HGV small	0.01	0.02	0.02	**0.05**	0.08
HGV Large	0.02	0.01	0.02	**0.04**	0.08
Total	**0.10**	**0.25**	**0.22**	**0.57**	1.00
Proportion	0.18	0.43	0.39	1.00	

Exhaust emissions

3.31 The exhaust emissions from vehicles can be determined by the difference between the total primary emission (Table 3.7) and the emissions from tyres and brakes (Tables 3.9 and 3.10 respectively). This is shown in Table 3.11.

3.32 The total primary vehicular emissions factor (Table 3.4) was determined by adding the emissions factors for brakes, tyres and exhaust. The confidence in the exhaust emissions is therefore independent of that for tyres and brakes. The lack of knowledge regarding exhaust PM_{10} emissions is such that it is not possible to give reliable quantitative estimates of the accuracy of these factors. Table 3.12 provides an indication of the robustness of the estimates in qualitative terms and an estimate that the emissions factor is within the stated range for the purpose of undertaking sensitivity analysis based upon expert judgement.

Table 3.11 - Exhaust emissions from vehicles

kt	Motorways	Built-up	Non built-up	Total
Cars etc. petrol	0.8	2.5	2.1	**5.5**
Cars etc. diesel	1.5	4.0	2.5	**7.9**
Motorcycles	0.0	0.3	0.2	**0.5**
Buses and coaches	0.3	4.1	1.5	**6.0**
LGV petrol	0.1	0.3	0.2	**0.6**
LGV diesel	0.7	2.2	1.7	**4.7**
HGV small	2.5	6.0	4.5	**13.0**
HGV large	2.6	2.5	3.6	**8.7**
Total	**8.5**	**21.9**	**16.4**	**46.8**

Table 3.12 - Accuracy of PM_{10} vehicular exhaust emissions estimates

Source	Comments	Range
Diesel cars	Based on a number of detailed measurements	± 25 %
Diesel LGV & HGV	Based on a few measurements	± 50 %
Motorcycles	Based on a few measurements	± 50 %
Diesel buses and coaches	Only a few measurements, for some types extrapolated from similar vehicle types	± 50 %
Petrol cars	Only a few measurements, with greater uncertainty for cars without catalysts	± 50 %

Source: QUARG, 1996 and Murrels, 1998

3.33 The proportion of exhaust emissions from each vehicle/engine type is shown in Table 3.13 for each driving environment and location.

Table 3.13 - Proportion of PM_{10} exhaust emissions

	Motorways	Built-up	Non built-up	Total
Proportion by source				
Cars etc. petrol	0.15	0.46	0.38	1.00
Cars etc. diesel	0.18	0.50	0.32	1.00
Motorcycles	0.07	0.55	0.38	1.00
Buses and coaches	0.05	0.70	0.25	1.00
LGV petrol	0.15	0.43	0.42	1.00
LGV diesel	0.16	0.47	0.37	1.00
HGV Small	0.19	0.46	0.35	1.00
HGV Large	0.29	0.29	0.42	1.00
Total	**0.18**	**0.47**	**0.35**	**1.00**
Proportion by driving location				
Cars etc. petrol	0.10	0.12	0.13	**0.12**
Cars etc. diesel	0.17	0.18	0.15	**0.17**
Motorcycles	0.00	0.01	0.01	**0.01**
Buses and coaches	0.03	0.19	0.09	**0.13**
LGV petrol	0.01	0.01	0.01	**0.01**
LGV diesel	0.09	0.10	0.11	**0.10**
HGV Small	0.29	0.27	0.27	**0.28**
HGV Large	0.30	0.12	0.22	**0.19**
Total	1.00	1.00	1.00	**1.00**

SECONDARY PM_{10} VEHICULAR EMISSIONS

Emissions from road dust resuspension

3.34 Information regarding emissions of PM_{10} resuspended from the road surface as a result of vehicle movement is extremely limited. QUARG (1996) state that *annual emissions from road dusts in the UK cannot be estimated with any reliability.* QUARG employ a factor of 0.01 g km^{-1} for cars. Assuming larger vehicles will resuspend more dust in proportion to the number of tyres a similar calculation can be performed as that for emissions from tyres and brake wear but employing the emissions factor and data in Table 3.2 for numbers of kilometres for different driving conditions. The level of confidence is however very low but it has been assumed for the purposes of this project to be correct within two orders of magnitude, based upon expert judgement. Table 3.14 shows the total dust by resuspension emissions.

Table 3.14 - Emissions of dust by resuspension

kt	Motorways	Built-up major	Non built-up	Total	Proportion
Cars etc. petrol	0.45	1.35	1.12	**2.92**	0.61
Cars etc. diesel	0.10	0.30	0.25	**0.64**	0.13
Motorcycles	0.00	0.01	0.01	**0.02**	0.00
Buses and coaches	0.01	0.03	0.01	**0.05**	0.01
LGV petrol	0.03	0.07	0.07	**0.17**	0.04
LGV diesel	0.03	0.10	0.09	**0.22**	0.05
HGV small	0.10	0.13	0.16	**0.38**	0.08
HGV Large	0.15	0.07	0.16	**0.37**	0.08
Total	0.85	2.06	1.87	**4.78**	1.00
Proportion	0.18	0.43	0.39		

Secondary PM_{10} formation

3.35 In addition to direct emissions of PM_{10} from motor vehicle exhausts, gaseous exhaust also contribute to PM_{10} concentrations in ambient air as a consequence of secondary particulate formation. The proportion of secondary particulate matter in the air varies seasonally being greatest in summer when photochemistry is most rapid. The contribution of secondary aerosol to PM_{10} concentrations has been determined using the Hull Acid Rain Model (Metcalfe *et al.*, 1995). Sulphate and nitrate are calculated to be overwhelmingly the most important species produced from sulphur dioxide and nitrogen oxides respectively. Motor vehicles are only an important contributor to nitrogen oxide emissions to which they contribute about 50 per cent. QUARG (1996) estimate that about 2 $\mu g\ m^{-3}$ secondary nitrate PM_{10} arise from motor vehicles or about 8 per cent. During summer episodes this figure is however likely to increase significantly.

3.36 Recent research (Steadman, 1998) suggests secondary PM_{10} accounts for 40 per cent of the daily network mean PM_{10} concentration in the UK. Assuming the nitrate component of this secondary aerosol accounts for about 45 per cent of this (Metcalfe *et al.*, 1995) and motor vehicles account for 50 per cent of the nitrogen oxides precursor emissions of the nitrate then motor vehicles are estimated to account for 9 per cent of secondary aerosol. For the purposes of this study the secondary PM_{10} from motor vehicles accounts for 8.5 per cent of the ambient concentration.

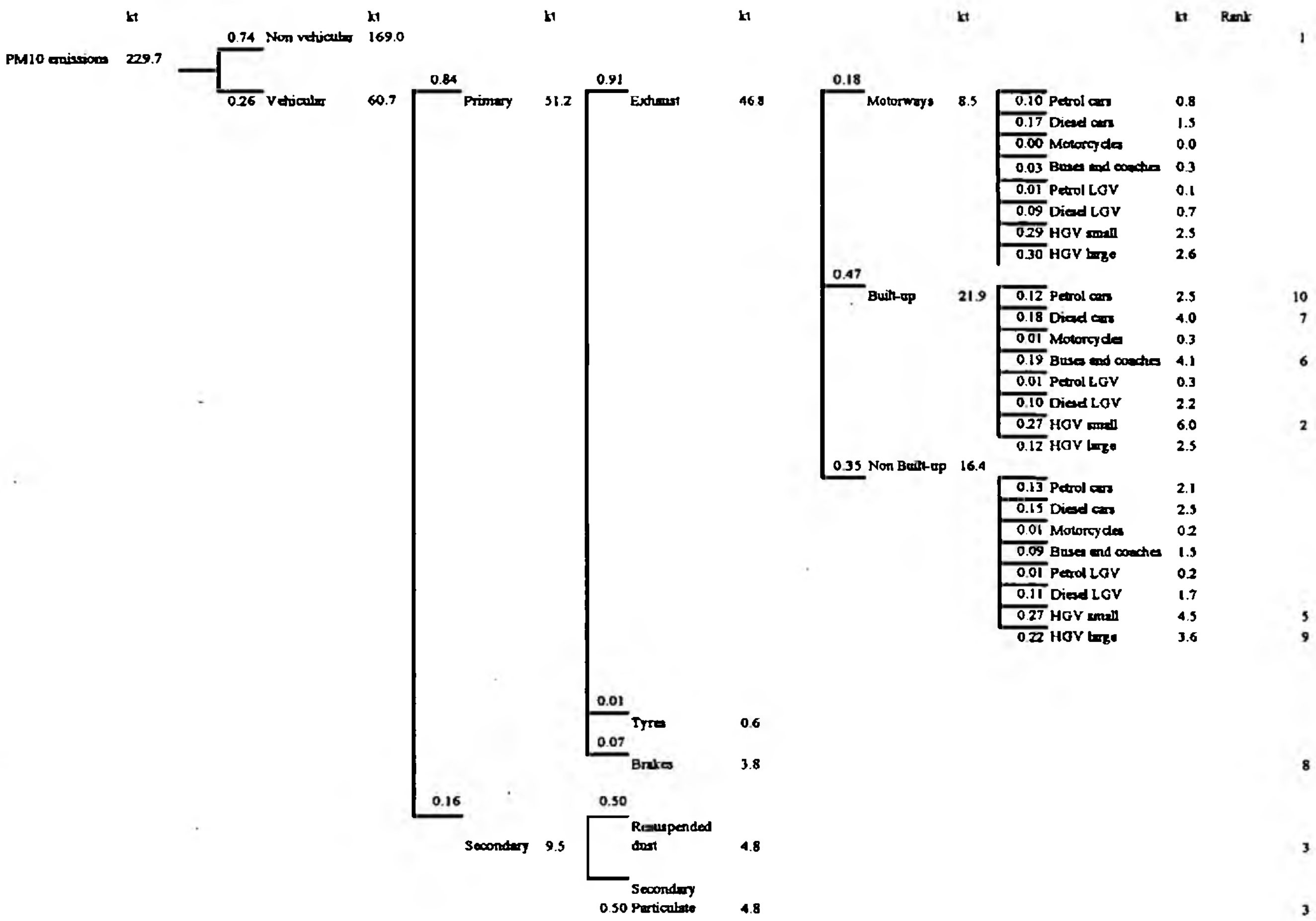
3.37 It is assumed that the ambient concentration arising from vehicles can be equated to the total UK PM_{10} emissions from vehicles. The total secondary particulate emissions is therefore 8.5 per cent of the sum of the total primary emissions (51.2 kt) and resuspended dust (4.8kt). The total "emissions" of PM_{10} through secondary particulate formation is therefore 4.8 kt. Equating the ambient concentration to the UK emission is only a valid assumption if it is assumed there is no transboundary contribution of vehicular PM_{10}. It is known that continental air masses do contain secondary aerosol, but a large proportion of this is sulphate which is not vehicular derived. The assumption is therefore a reasonable first approximation.

3.38 The contribution of secondary PM_{10} to vehicular emissions will vary throughout the year. Furthermore, despite the two estimates producing similar results there is still uncertainty in the estimate. For the purpose of the sensitivity analysis the contribution of secondary aerosol to PM_{10} in the UK as an annual average is assumed to be twice the standard deviation of the two estimates (8 and 9 per cent) the range is therefore 7 to 10 per cent.

VEHICULAR EMISSIONS

3.39 The event tree giving the mass of PM_{10} emissions and proportion for each pathway is shown in Figure 3.2. This demonstrates that overall vehicular emissions account for 25 per cent of UK PM_{10} emissions of which 84 per cent are primary. Direct exhaust emissions are responsible for approximately 77 per cent of total vehicular PM_{10}; brakes about 6 per cent, tyres 2 per cent and resuspended dust and secondary particles 8 per cent each. Of the exhaust emissions nearly half arise through driving in urban areas, a third in non-built up and the rest on motorways.

Figure 3.2 - Event tree for emissions of PM_{10} from vehicles


kt
kt
kt
kt
kt
kt
Rank
PM10 emissions 229.7
0.74 Non vehicular 169.0
1
0.26 Vehicular 60.7
0.84
Primary 51.2
0.91
Exhaust 46.8
0.18
Motorways 8.5
0.10 Petrol cars 0.8
0.17 Diesel cars 1.5
0.00 Motorcycles 0.0
0.03 Buses and coaches 0.3
0.01 Petrol LGV 0.1
0.09 Diesel LGV 0.7
0.29 HGV small 2.5
0.30 HGV large 2.6
0.47
Built-up 21.9
0.12 Petrol cars 2.5 10
0.18 Diesel cars 4.0 7
0.01 Motorcycles 0.3
0.19 Buses and coaches 4.1 6
0.01 Petrol LGV 0.3
0.10 Diesel LGV 2.2
0.27 HGV small 6.0 2
0.12 HGV large 2.5
0.35 Non Built-up 16.4
0.13 Petrol cars 2.1
0.15 Diesel cars 2.5
0.01 Motorcycles 0.2
0.09 Buses and coaches 1.5
0.01 Petrol LGV 0.2
0.11 Diesel LGV 1.7
0.27 HGV small 4.5 5
0.22 HGV large 3.6 9
0.01
Tyres 0.6
0.07
Brakes 3.8 8
0.16
Secondary 9.5
0.50
Resuspended dust 4.8 3
Secondary
0.50 Particulate 4.8 3

3.40 Table 3.15 shows the contributions of different vehicle types to total vehicle emissions. This has been produced by summing the primary and secondary contributions of emissions of each vehicle type. The contribution of the total traffic derived secondary particles from each vehicle type has been determined on the basis of their contribution to vehicular emissions of nitrogen oxides. This is petrol engine cars 62 per cent, HGVs 31 per cent, 6 per cent buses/coaches, others about 1 per cent each (QUARG, 1996).

Table 3.15 - Emissions by vehicle type

	Primary driving	Dust resuspension	Secondary particles	Total
Cars etc. petrol	8.2	2.9	2.5	**13.6**
Cars etc. diesel	8.5	0.6	0.1	**9.2**
Motorcycles	0.5	0.0	0.0	**0.5**
Buses and coaches	6.0	0.0	0.3	**6.3**
LGV petrol	0.7	0.2	0.3	**1.2**
LGV diesel	4.9	0.2	0.0	**5.1**
HGV small	13.3	0.4	0.8	**14.5**
HGV large	9.1	0.4	0.8	**10.2**
Total	**51.2**	**4.8**	**4.8**	**60.8**

3.41 Analysis of the data by vehicle type in Table 3.16 demonstrates that petrol engine cars become the second most important source of PM_{10} when secondary sources are taken into contribution increasing from 16 to 22 per cent of the total emissions. To adjust for this increase other vehicle types all emit a slightly lower percentage of the total vehicular emissions. The most important source is small HGVs contributing 24 per cent of emissions, although they account for only 3 per cent of the total vehicle kilometerage. Large HGVs and petrol engine cars account for 17 and 15 per cent of emissions respectively; buses and coaches and LGVs 10 per cent each. Comparison of the proportion of vehicular emissions against that for kilometres driven demonstrates clearly the extent to which emissions of PM_{10} from HGVs are totally disproportionate to the kilometres driven.

Table 3.16 - Contribution of vehicle types to primary and total PM_{10} emissions compared to proportion of kilometres driven

Vehicle type	Primary emissions	Total emissions	Total kms
Cars etc. petrol	16%	22%	67%
Cars etc. diesel	17%	15%	15%
Motorcycles	1%	1%	1%
Buses and coaches	12%	10%	1%
LGV petrol	1%	2%	4%
LGV diesel	10%	8%	5%
HGV small	26%	24%	3%
HGV large	18%	17%	3%

SENSITIVITY ANALYSIS

3.42 As part of this assessment a sensitivity analysis has been undertaken to determine the confidence intervals in the key emissions estimates and to identify the principal uncertainties. The methodology by which the emissions have been estimated involves use of traffic activity statistics combined with emissions factors to derive the mass of emissions released on an annual average basis. In deriving these estimates a large number of parameters and assumptions have been applied each of which has uncertainty associated with it. The derivation of the parameters, assumptions and uncertainties are described in detail within the Methodology sub-section and are summarised in Table 3.17. In most cases the confidence in the parameters used is not known reliably and has been determined based upon expert judgement.

Table 3.17 - Summary of principal parameters, assumptions and uncertainties to derive PM_{10} emissions estimates

Parameter	Value	Confidence[2]	Origin
Non vehicular emissions	see Table 3.1	x 10	QUARG, 1996
Vehicle kilometres by vehicle type	see Table 3.2	2.5%	DETR, 1997b
Proportion of car kilometres by petrol engine	82 %	± 2.5%	DETR, 1997b[1]
Proportion of LGV kilometres by petrol engine	43 %	± 10%	DETR, 1997b[1]
Brake wear emissions factor	0.00795 g km^{-1}	x 10	QUARG, 1996
Tyre wear emissions factor	0.0012 g km^{-1}	x 10	QUARG, 1996
Cold starts contribution	see Table 3.6	x 10	LRC, 1998[1], DETR, 1997b[1],
Fleet averaged exhaust emissions factors	see Table 3.11	see Table 3.12	LRC 1998
Dust resuspension emissions factor	0.01 g km^{-1}	x 100	QUARG, 1996
Fleet averaged number of wheels on HGV	10	Incorporated within dust resuspension factor	DETR, in press
Vehicle contribution to secondary particulate	8.5 %	± 1.5 %	QUARG, 1996[1], Steadman, 1998[1], Metcalfe *et al.*, 1995[1]

[1] derived from

[2] based upon the expert judgement of various individuals. All distributions are assumed to be normal.

Note: Where the uncertainty is described as an order of magnitude this has been taken as being between the upper and lower limits with the best value being the mean between these.

3.43 The sensitivity analysis applied a Monte Carlo simulation approach to derive the range of values and focused upon addressing two key issues, identifying:

(i) key assumptions and parameters in deriving robust emissions estimates; and

(ii) the overall range of the likely emissions for key sources based upon the uncertainties in the parameters and assumptions.

Key assumptions and parameters

3.44 The key assumptions within the analysis were determined using the Monte Carlo simulation and compared on a rank correlation basis. The key five parameters or assumptions with respect to different emissions forecasts are shown in Table 3.18.

Table 3.18 - Key assumptions in deriving vehicular emissions estimates

Rank order	Total vehicle	Proportion vehicular	Primary vehicle	Secondary vehicle
1	Dust resuspension EF[1]	Non vehicular total[2]	Small HGV built up EF	Dust resuspension EF
2	Small HGV built up EF	Dust resuspension EF	Small HGV non built up EF	Proportion secondary particulate
3	Small HGV non built up EF	Small HGV non built up EF	Bus/Coach built up EF	Cars petrol built up
4	Bus/Coach built up EF	HGV large non built up EF	Large HGV non built up	Bus/Coach built up EF
5	Large HGV non built up	Small HGV built up	Cars petrol built up	Large HGV non built up

[1] EF = Emissions Factor

[2] Overwhelmingly the most significant factor.

3.45 Table 3.18 demonstrates that in terms of estimating vehicular PM_{10} emissions the principal uncertainties concern emissions factors for:

- dust resuspension;
- small HGVs;
- large HGVs in non-built-up areas; and
- buses and coaches in built up areas.

3.46 The vehicular contribution to secondary particulate is also important. These are the areas in which further research efforts should be directed to improve knowledge of the sources of UK PM_{10}. The transboundary contribution which was not addressed in detail by this assessment also requires further research. This assessment has also not addressed the non-vehicular PM_{10} contribution in detail. In terms of the total UK emissions of PM_{10} uncertainty in emissions from non traffic sources are however overwhelmingly the most important parameter. The dust resuspension emissions factor is the next most important parameter.

Overall uncertainty

3.47 Using the uncertainty in each of the parameters it is possible to derive uncertainty estimates for the emissions estimates. These are summarised for the principal estimates in Table 3.19. The range of uncertainty has been set at the 5th and 95th percent confidence intervals.

3.48 Table 3.19 demonstrates that confidence in the vehicular emissions estimates are considerably better than those in the non vehicular sources. For most of the parameters uncertainty in the estimates are distributed approximately normally about the median value. The proportion of non vehicular emissions is however significantly skewed (Skewness 1.91). The mean proportion of vehicular emissions is 30 per cent and median 26 per cent compared with the 25 per cent calculated in the NAEI. The range, for the proportion of vehicular emissions to PM_{10}, at the 95 per cent confidence interval, is 16 to 59 per cent. This long tail indicates the potential for vehicular emissions to contribute significantly more to the total UK emissions than is currently estimated.

Table 3.19 - Range of emissions estimates

Estimate	Low	Median	High	Coefficient of variability
Total UK (kt)	106.5	233.0	369.5	0.34
Total vehicular (kt)	53.3	61.2	69.5	0.08
Total non vehicular (kt)	45.6	181.7	308.1	0.46
Proportion vehicular (%)	0.16	0.26	0.57	0.45
Total primary vehicular (kt)	45.3	51.4	57.7	0.07
Total secondary vehicular (kt)	5.5	9.7	14.8	0.29

IMPACT ASSESSMENT

Equating emissions to impacts

3.49 The event tree prepared and evaluated in the previous sub-sections determines the proportion of PM_{10} emissions from different sources in the UK. This will enable subsequent analysis to determine how management strategies will affect the level of emissions. The overall purpose of the event tree was to determine the risk of emissions from different sources to human health. To meet this objective the level of emissions must therefore be related to a health outcome.

3.50 Relating emissions to impacts is a highly uncertain procedure. This is since the effects of air pollution are dependent upon the concentration and duration of exposure, and not directly to the amount of PM_{10} released to air. The local time averaged concentration of pollution is dependent upon a range of factors including both the local level of emissions and subsequent dispersion. Factors which influence the local level of emissions, and proportion of traffic emissions, include the:

- mass of local non-transport emissions and those transported into the local area;
- traffic volume;
- traffic speed;
- local composition of the vehicle fleet; and
- driving conditions (stop-start driving significantly raising emissions).

3.51 Factors which influence the observed concentration include:

- distance from the key sources to the receptor;
- meteorological conditions; and
- the presence of buildings which affect the natural dispersion.

3.52 All these factors vary substantially on both a geographical and temporal basis. To determine local concentrations therefore requires knowledge of *local* emissions and *local* dispersion factors combined using complex dispersion models. These models can determine the instantaneous concentration of pollution within an area or the range of concentrations likely to be experienced throughout a year at a given location. It is therefore possible to determine the likelihood, or severity of, exceedences of air quality criteria *at a given location*.

3.53 It is *not* possible to equate the impact of changes in emissions to pollution concentrations or exceedences of air quality criteria at a *national* level. This is since the range of emissions conditions and dispersion are too complex to model on such a scale. Accordingly, it is not possible to use dispersion models to determine how changes in national emissions will affect the frequency and severity of exceedences of air quality criteria for the UK as a whole. Neither is it possible to use dispersion models to relate national emissions to concentrations experienced in the ambient air on a national level and subsequent exposure.

3.54 A feasibility study undertaken by WS Atkins for the DOT (DETR, in press) into the development of environmental modelling in connection with a national transport model addressed the issue of national pollution modelling. This concluded that to model the relationship between changes in vehicle emissions and that in air quality nationally would require development of generic relationships between vehicle emissions and air quality in different types of environments. To develop robust relationships would require considerable effort but it was ultimately considered feasible to estimate how changes in traffic emissions would affect the number of exceedences of air quality criteria nationally. To date no such model has been produced and, at present, could not be used for the purpose of this assessment.

3.55 In the absence of a scientifically robust approach to relate emissions to concentrations and subsequent impacts the approach adopted in this study has been to *equate annual average emissions of PM_{10} against estimates of the impact*. Directly equating emissions to impacts is a gross assumption with considerable uncertainties since it does not take into account any of the local emissions and dispersion factors which influence local concentrations and exposure. It is however acceptable as a first approximation and working solution to enable the event tree methodology prescribed for this quantitative risk assessment to be related to a risk as distinct from the environmental pressure leading to that risk.

Health criteria

3.56 COMAPE (1998) produced quantitative estimates of the effects of air pollutants in the UK, including PM_{10}. These used premature acute mortality from all causes and respiratory hospital admissions additional and brought forward as the indicators of health effects. Table 3.20 lists the risk factors for PM_{10} and confidence interval employed by COMAPE for these outcomes.

Table 3.20 - Acute mortality from PM_{10} health risk

Health outcome	% change per μg m^{-3}	95 % confidence interval
Mortality (all causes)	0.074	0.062 - 0.086
Respiratory hospital admissions	0.080	0.048 - 0.112

Source: COMAPE, 1998

3.57 COMAPE only quantified health impacts from PM_{10} in urban areas in order to reduce the uncertainties. In urban areas there were a total of about 430,000 deaths in GB and 530,000 hospital admissions for respiratory diseases. For an urban population of 42 million a total of 8,100 deaths and 10,300 early hospital admissions were estimated to be as a result of PM_{10}.

3.58 The event tree which has been prepared is based upon emissions for the UK as a whole, not exclusively urban areas. In urban areas the proportion of locally generated vehicle emissions are much higher than for the UK as a whole. Consequently use of the national estimates would under-estimate the urban vehicle contribution to emissions. One approach to overcome this would be to use local emissions inventory data. However, the pollution levels within urban areas are also affected by emissions from stationary sources upwind of the urban area which are not included in the local inventory. Excluding these transboundary emissions from the local inventories would result in under-estimating the contribution of non traffic sources to PM_{10} levels in the urban area.

3.59 Neither UK nor local inventories are representative of the contribution of PM_{10} from different sources in urban areas. In order to overcome the limitation imposed by the emissions estimates, the COMAPE estimates of health outcomes in urban areas have been scaled on a per capita basis to include the whole UK population. Rural PM_{10} concentrations are lower than those in urban areas and therefore extrapolation of impacts in urban areas to the whole of the UK is a conservative assumption. Data from the continuous monitoring stations for PM_{10} located in rural areas however suggest recorded concentrations are not totally dissimilar to urban background sites (DETR, 1998) and the assumption is therefore a reasonable first approximation. Scaling of health impacts for the UK as a whole is shown in Table 3.21.

Table 3.21 - Health impacts of PM_{10}

Health outcome	UK urban	UK
Mortality (all causes)	8,100	10,800
Respiratory hospital admissions	10,300	13,700

Assumes an urban population of 42 million and UK population of 56 million

3.60 Using the emissions estimates for PM_{10} in the UK with the total impact of PM_{10} exposure in the UK the proportion of premature deaths and early hospital admissions associated with PM_{10} have been calculated in Figures 3.3 and 3.4 respectively. The uncertainty in these estimates arise as a result of:

- relating UK emissions to impacts;
- the epidemiology in determination of the dose-response relationship for PM_{10};
- the exposure assessment undertaken by COMAPE; and
- the emissions estimates.

3.61 Figures 3.3 and 3.4 provide an indication of the premature mortality and hospital admissions brought forward as a result of PM_{10} emissions.

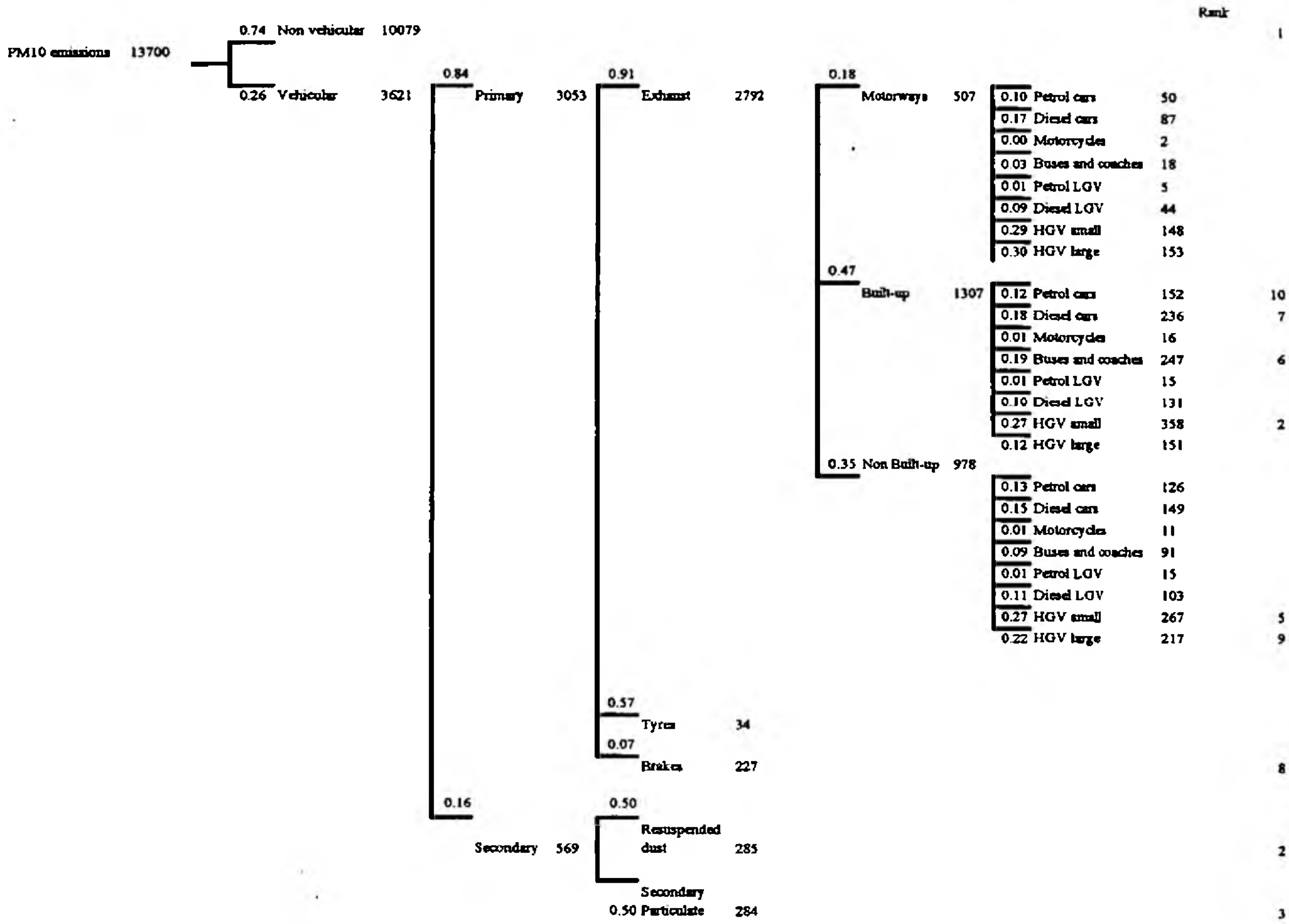
3.62 COMAPE have not assigned confidence intervals to their estimates of mortality and hospital admissions arising from PM_{10}. Furthermore the reliability of the other assumptions are also not known. Since the relationship between emissions and impacts is at best a tenuous one the uncertainty analysis has not been extended to determine the likely range of premature deaths or hospital admissions arising from vehicular PM_{10} emissions. Instead the assessment has been used to determine a rank order of impacts to determine the priority sources as shown in Figures 3.3 and 3.4. This is not ideal but is an unavoidable limitation of applying the event tree methodology.

Figure 3.3 - Event tree for air quality impacts of PM_{10} upon mortality

PM10 emissions 10800

Fraction	Category	Emissions	Rank
0.74	Non vehicular	7945	1
0.26	Vehicular	2855	
0.84	Vehicular – Primary	2407	
0.91	Primary – Exhaust	2201	
0.18	Exhaust – Motorways	399	
0.10	Motorways – Petrol cars	40	
0.17	Motorways – Diesel cars	68	
0.00	Motorways – Motorcycles	2	
0.03	Motorways – Buses and coaches	14	
0.01	Motorways – Petrol LGV	4	
0.09	Motorways – Diesel LGV	34	
0.29	Motorways – HGV small	117	
0.30	Motorways – HGV large	121	
0.47	Exhaust – Built-up	1030	
0.12	Built-up – Petrol cars	120	10
0.18	Built-up – Diesel cars	186	7
0.01	Built-up – Motorcycles	12	
0.19	Built-up – Buses and coaches	195	6
0.01	Built-up – Petrol LGV	12	
0.10	Built-up – Diesel LGV	104	
0.27	Built-up – HGV small	282	2
0.12	Built-up – HGV large	119	
0.35	Exhaust – Non Built-up	771	
0.13	Non Built-up – Petrol cars	99	
0.15	Non Built-up – Diesel cars	117	
0.01	Non Built-up – Motorcycles	9	
0.09	Non Built-up – Buses and coaches	71	
0.01	Non Built-up – Petrol LGV	12	
0.11	Non Built-up – Diesel LGV	81	
0.27	Non Built-up – HGV small	211	5
0.22	Non Built-up – HGV large	171	9
0.57	Primary – Tyres	27	
0.07	Primary – Brakes	179	8
0.16	Vehicular – Secondary	569	
0.50	Secondary – Resuspended dust	225	2
0.50	Secondary – Secondary Particulate	224	3

Figure 3.4 - Event tree for air quality impacts of PM_{10} upon morbidity


Rank
1
0.74 Non vehicular 10079
PM10 emissions 13700
0.26 Vehicular 3621
0.84 Primary 3053
0.91 Exhaust 2792
0.18 Motorways 507
0.10 Petrol cars 50
0.17 Diesel cars 87
0.00 Motorcycles 2
0.03 Buses and coaches 18
0.01 Petrol LGV 5
0.09 Diesel LGV 44
0.29 HGV small 148
0.30 HGV large 153
0.47 Built-up 1307
0.12 Petrol cars 152 10
0.18 Diesel cars 236 7
0.01 Motorcycles 16
0.19 Buses and coaches 247 6
0.01 Petrol LGV 15
0.10 Diesel LGV 131
0.27 HGV small 358 2
0.12 HGV large 151
0.35 Non Built-up 978
0.13 Petrol cars 126
0.15 Diesel cars 149
0.01 Motorcycles 11
0.09 Buses and coaches 91
0.01 Petrol LGV 15
0.11 Diesel LGV 103
0.27 HGV small 267 5
0.22 HGV large 217 9
0.57 Tyres 34
0.07 Brakes 227 8
0.16 Secondary 569
0.50 Resuspended dust 285 2
Secondary
0.50 Particulate 284 3

CONCLUSIONS

3.63 This section has undertaken a quantitative risk assessment of the health impacts of PM_{10} using, as far as was possible, an event tree methodology. Conventionally, risk assessment using an event tree methodology has been applied for site specific assessment. In addition, event trees have not been utilised to assess risks derived from exposure to diverse sources such as road transport before; and this section has highlighted a number of key issues concerned with the use of event trees to quantify risks of this type. In particular, it has demonstrated that although it is possible to proportion the environmental pressure leading to the risk through an event tree approach, linking this pressure to an overall impact requires the use of a number of assumptions which significantly increased the uncertainty and reduced the credibility of the assessment.

3.64 The methodology has been of particular value in the assessment of emissions of PM_{10} and uncertainty in these estimates. Linking these emissions to impacts in a credible manner however presented considerable difficulties. The key conclusions which can be drawn from the assessment therefore relate to the emissions of PM_{10} rather than the impacts. Key amongst these conclusions are that:

- HGVs contribute 41 per cent of total vehicular PM_{10} emissions but only account for 6 per cent of total kilometerage;
- petrol cars are responsible for 22 per cent of total emissions which is more than diesel cars (15 per cent);
- buses and coaches account for 10 per cent of vehicular emissions, but emissions per passenger are considerably lower than for cars;
- knowledge of emissions from stationary sources is very poor;
- improved knowledge of dust resuspension from the road surface will provide the greatest improvement in knowledge of vehicular emissions of PM_{10} followed by HGV emissions factors;
- the vehicular contribution to secondary particulate nitrate may be very significant;

- the proportion of non vehicular PM_{10} emissions is a skewed distribution likely to be in the range 16 to 59 per cent, for which the most likely estimate is 30 per cent;

- overall the UK emissions of PM_{10} are between about 100 and 350 kt of which vehicular emissions are between about 50 to 70 kt; and

- PM_{10} is likely to result in about 11 thousand deaths and 14 thousand premature hospital admissions in the UK, with the vehicle contribution to these being highly uncertain.

3.65 Overall it is reasonable to conclude that the application of an event tree methodology and subsequent sensitivity analysis has been a valuable tool in the evaluation of emissions of PM_{10} but of much more limited application in determination of impacts and risks.

4. QUANTITATIVE RISK ASSESSMENT OF THE GLOBAL CLIMATIC CHANGE IMPACTS OF ROAD TRAFFIC IN THE UK

INTRODUCTION

4.1 This section undertakes a quantitative risk assessment of the global climate change impacts of road use traffic in the UK. The approach adopted is consistent with the other event trees and emphasis has therefore been placed on examination of the environmental pressure exerted by road transport in the UK on climate change. This enables assessment of how management options would effect the calculated level of risk. The event trees therefore focus upon assessment of the *emissions* of greenhouse gases associated with road transport use in the UK. Overwhelmingly the most important emission is that of *carbon dioxide* and the greatest emphasis has therefore been placed upon providing a breakdown of the road transport sources of this greenhouse gas. Other vehicle generated greenhouse gases such as nitrous oxide are also included, but in less detail.

4.2 An event tree approach has been adopted to assess this risk at the request of NCRAOA. The methodology adopted is similar to that used for PM_{10} impacts (Section 3). This involved determination of the proportion of emissions arising from different driving conditions and vehicles and comparison of these values against total UK emissions. These are subsequently evaluated against global emissions and anticipated impacts. This approach has considerable limitations for assessment of the global climate change impacts of road transport use since:

- the environmental pressure, i.e. emissions of greenhouse gases, arise globally;
- impacts result from cumulative emissions of greenhouse gases over many years, emissions in a single year are therefore a poor indicator of the pressure; and

- climate change impacts arise as a consequence of emissions of a number of greenhouse gases and other anthropogenic activities including deforestation. Only some of these emissions are associated with road transport.

4.3 Climate change has widespread impacts, and this project has employed sea-level rise as the indicator. This parameter was chosen since the IPCC are now confident that there is an increase in global mean temperature and sea level whilst for other parameters they are less certain.

4.4 The following sub-section details the approach adopted. Assumptions have been made in a transparent manner, but the limitations of the methodology affect the scientific robustness of the final results. These are discussed further in the conclusions sub-section.

METHODOLOGY

4.5 The event tree approach employed has focused upon determination of the principal emissions of greenhouse gases from road transport sources in the UK, these have been grouped into three main classes:

- carbon dioxide;
- nitrous oxides; and
- others, including non methane volatile organic compounds, carbon monoxide, secondary vehicle generated aerosol, chlorofluorocarbons, etc.

4.6 The emphasis has been placed upon the carbon dioxide emissions since these are overwhelmingly the most important variable. Emissions of methane from the transport sector in the UK are presently negligible compared with other sources.

4.7 The outline event tree shown in Figure 4.1 illustrates how the greenhouse gas emissions from transport sources in the UK have been disaggregated. It utilises data from the National Transport Statistics (DETR, 1997b) combined with fleet weighted emissions factors employed by the DETR (LRC, 1998) to compile emissions inventories. The principal raw data are road traffic by type of vehicle and class of road, 1996, and these data are reproduced in Table 4.1. The same assumptions and uncertainties regarding the split of kilometres between vehicles of different engine types used in the PM_{10} event tree (Section 3) are employed in this analysis.

Table 4.1 - Vehicle kilometres by engine type

Billion km	Motorways	Built-up	Non built-up	Total
Cars etc. petrol	44.8	135.2	112.0	**292.0**
Cars etc. diesel	9.8	29.7	24.6	**64.1**
Motorcycles	0.3	2.3	1.6	**4.2**
Buses and coaches	0.5	3.1	1.3	**4.9**
LGV petrol	2.5	7.4	7.1	**16.9**
LGV diesel	3.4	9.7	9.3	**22.5**
HGV small	3.8	5.10	6.30	**15.2**
HGV Large	5.8	2.6	6.5	**14.9**
Total	**70.9**	**195.1**	**168.7**	**434.7**

Based upon DETR, 1997b

CARBON DIOXIDE

4.8 The carbon dioxide emissions have been determined from DETR approved fleet averaged emissions factors for different vehicle and engine types for 1996 (LRC, 1998). A list of emissions factors which have been used are shown in Table 4.2. The confidence in these estimates has been assumed to be ± 5 per cent, based upon expert judgement. This is significantly better than the PM_{10} estimates since the level of emissions is less dependent upon the driving conditions and can be determined with a reasonably high degree of precision from fuel consumption data which is reliably known. Employing the emissions factors and numbers of kilometres for each vehicle/engine type/driving condition total emissions can be determined, as shown in Table 4.3. These compare favourably with other published sources. The proportion of carbon dioxide vehicular emissions are show in Table 4.4.

Figure 4.1 - Global climate change event tree

Event

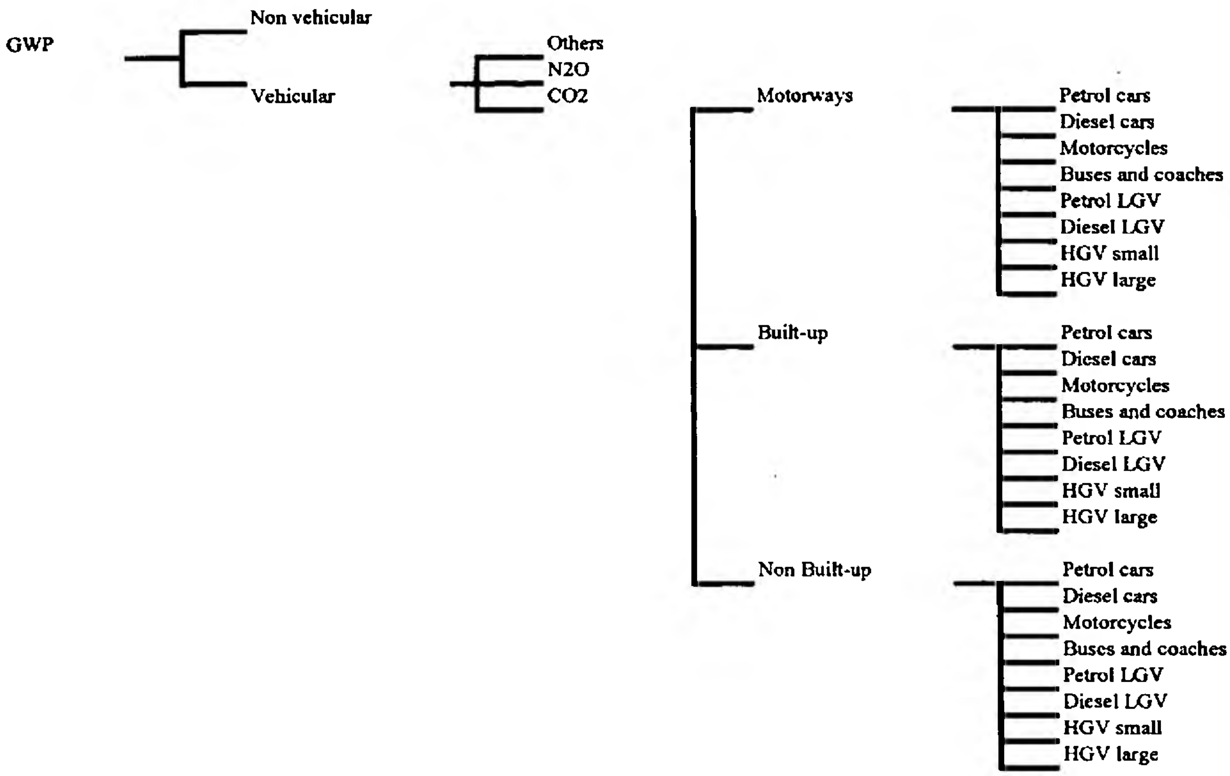

GWP
Non vehicular
Vehicular
Others
N2O
CO2
Motorways
Built-up
Non Built-up
Petrol cars
Diesel cars
Motorcycles
Buses and coaches
Petrol LGV
Diesel LGV
HGV small
HGV large
Petrol cars
Diesel cars
Motorcycles
Buses and coaches
Petrol LGV
Diesel LGV
HGV small
HGV large
Petrol cars
Diesel cars
Motorcycles
Buses and coaches
Petrol LGV
Diesel LGV
HGV small
HGV large

Table 4.2 - Fleet averaged carbon dioxide emissions factors, 1996

$g\ km^{-1}$	Motorways	Built-up	Non built-up
Cars etc. petrol	62.3	63.7	48.8
Cars etc. diesel	59.0	51.8	38.1
Motorcycles	35.6	35.6	35.6
Buses and coaches	199.2	306.5	260.5
LGV petrol	154.4	210.5	93.6
LGV diesel	59.0	51.8	38.1
HGV small	191.5	199.2	191.5
HGV Large	283.5	337.1	344.8

Source: LRC, 1998

Table 4.3 - Carbon dioxide emissions

Emissions (Mt)	Motorways	Built-up	Non built-up	Total
Cars etc. petrol	2.8	8.6	5.5	**16.9**
Cars etc. diesel	0.6	1.5	0.9	**3.1**
Motorcycles	0.0	0.1	0.1	**0.1**
Buses and coaches	0.1	1.0	0.3	**1.4**
LGV petrol	0.4	1.5	0.7	**2.6**
LGV diesel	0.2	0.5	0.4	**1.1**
HGV small	0.7	1.0	1.2	**3.0**
HGV large	1.6	0.9	2.2	**4.8**
Total	**6.4**	**15.1**	**11.3**	**32.8**

Table 4.4 - Proportion of carbon dioxide vehicular emissions

	Motorways	Built-up	Non built-up	Total
Proportion source				
Cars etc. petrol	0.17	0.51	0.32	1.00
Cars etc. diesel	0.19	0.50	0.31	1.00
Motorcycles	0.07	0.55	0.38	1.00
Buses and coaches	0.07	0.68	0.24	1.00
LGV petrol	0.15	0.60	0.25	1.00
LGV diesel	0.19	0.48	0.34	1.00
HGV small	0.25	0.34	0.41	1.00
HGV Large	0.35	0.18	0.47	1.00
Total	0.20	0.46	0.34	1.00
Proportion location				
Cars etc. petrol	0.43	0.57	0.49	0.51
Cars etc. diesel	0.09	0.10	0.08	0.09
Motorcycles	0.00	0.01	0.01	0.00
Buses and coaches	0.02	0.06	0.03	0.04
LGV petrol	0.06	0.10	0.06	0.08
LGV diesel	0.03	0.03	0.03	0.03
HGV small	0.11	0.07	0.11	0.09
HGV Large	0.26	0.06	0.20	0.15
Total	1.00	1.00	1.00	1.00

Nitrous oxide

4.9 Emissions of nitrous oxide account for an equivalent of 7 Mt carbon dioxide per annum in the UK of which about 8 per cent are of vehicular origin (RCEP, 1994). The total vehicular emissions of nitrous oxide are therefore 0.6 Mt carbon dioxide equivalent. This amount is likely to increase both in absolute and proportionate terms with an increasing number of catalyst equipped vehicles and a decline in industrial emissions. These data have been used to determine the contribution of vehicular sources to nitrous oxide emissions. A confidence interval of ± 50 per cent in the vehicle generated nitrous oxide emissions has been used, based upon expert judgement.

Others

4.10 Other greenhouse gases account for about 4 Mt equivalent of carbon dioxide (± 50 per cent), which represents about 2 per cent of the total UK contribution (DETR, 1997d). Vehicles have been estimated to account for between 25 and 75 per cent of these emissions, best estimate 50 per cent ± 25 per cent and therefore the total releases of other gases from transport sources are 2 Mt. This uncertainty is based upon expert judgement.

Non vehicular emissions

4.11 The first branch of the event tree distinguishes vehicular from non vehicular sources of greenhouse gas emissions in the UK. In order to determine the proportion of greenhouse gas emissions from each category it is first necessary to determine the relative contributions of the different greenhouse gases and these are summarised in Table 4.5. The proportion of non vehicular emissions has been determined by calculating the difference between the total emissions and vehicular contribution. This is shown in Table 4.6. The uncertainty in the total emissions has been estimated at ± 5 per cent (DETR, 1997e). Figure 4.2 illustrates the event tree for greenhouse gas emissions based upon the information presented in the previous sections.

Table 4.5 - Relative contribution of UK greenhouse gas emissions to global warming, 1990

Greenhouse gas	Mt carbon dioxide equivalent	Per cent
Carbon dioxide	155	82
Methane	20	12
Nitrous oxide	7	4
Others	4	2
Total	**189**	**100**

Source RCEP, 1994

Table 4.6 - Non vehicular greenhouse gas emissions

Greenhouse gas	Per cent non vehicular	Emissions non vehicular Mt carbon dioxide equivalent
Carbon dioxide	75	113
Methane	100	22
Nitrous Oxide	92	6
Others	50	2
Total	79	**143**

Figure 4.2 - Global warming event tree

- GWP 178 Mt
  - 0.80 Non vehicular — 143 Mt
  - 0.20 Vehicular — 35 Mt
    - 0.06 Others — 2 Mt
    - 0.02 N2O — 1 Mt
    - 0.93 CO2 — 33 Mt
      - 0.20 Motorways — 6 Mt
      - 0.46 Built-up — 15 Mt
      - 0.34 Non Built-up — 11 Mt

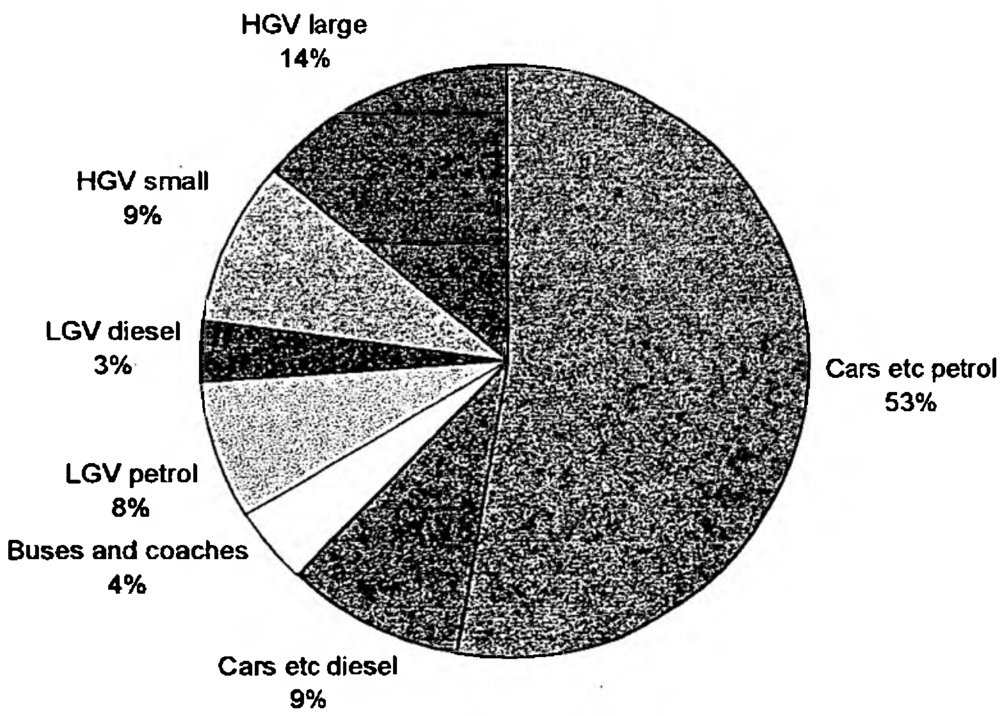
			Mt
Motorways	0.43	Petrol cars	2.79
Motorways	0.09	Diesel cars	0.58
Motorways	0.00	Motorcycles	0.01
Motorways	0.02	Buses and coaches	0.1
Motorways	0.06	Petrol LGV	0.39
Motorways	0.03	Diesel LGV	0.2
Motorways	0.11	HGV small	0.73
Motorways	0.26	HGV large	1.64
Built-up	0.57	Petrol cars	8.61
Built-up	0.10	Diesel cars	1.54
Built-up	0.01	Motorcycles	0.08
Built-up	0.06	Buses and coaches	0.95
Built-up	0.10	Petrol LGV	1.55
Built-up	0.03	Diesel LGV	0.5
Built-up	0.07	HGV small	1.02
Built-up	0.06	HGV large	0.88
Non Built-up	0.49	Petrol cars	5.47
Non Built-up	0.08	Diesel cars	0.94
Non Built-up	0.01	Motorcycles	0.06
Non Built-up	0.03	Buses and coaches	0.34
Non Built-up	0.06	Petrol LGV	0.66
Non Built-up	0.03	Diesel LGV	0.36
Non Built-up	0.11	HGV small	1.21
Non Built-up	0.20	HGV large	2.24

SUMMARY OF EMISSIONS

4.12 Vehicular emissions account for about 20 per cent of the total UK contribution to global warming, of which 93 per cent arise from carbon dioxide. Breaking down the vehicular contribution to global warming it can be seen that about four per cent arises through motorway driving, nine per cent urban driving and seven per cent non urban driving.

4.13 Figure 4.3 presents a summary of the vehicular contribution to emissions of greenhouse gases. The contribution of each vehicle type to nitrous oxide emissions has been proportioned in accordance with the national emissions of nitrogen oxides in a similar manner to which secondary particulate were proportioned in Chapter 3. The "Others" contribution has been proportioned on the basis of kilometerage driven. The figure demonstrates petrol engined cars (including a small contribution from motorcycles) to be overwhelmingly the most important source of vehicular greenhouse gases. It also demonstrates that overall cars account for 64 per cent of vehicular greenhouse gas emissions, goods vehicles 34 per cent and buses and coaches four per cent.

Figure 4.3 - Emissions of greenhouse gases by vehicle type



Note: Others refers to greenhouse gases other than carbon dioxide. These will also be emitted by each of the vehicle types.

SENSITIVITY ANALYSIS

4.14 As part of this assessment a sensitivity analysis has been undertaken to determine the confidence intervals in the key emissions estimates and to identify the principal uncertainties. The methodology by which the emissions have been estimated principally involves use of traffic activity statistics combined with emissions factors to derive the mass of emissions released on an annual average basis. In deriving these estimates a large number of parameters and assumptions have been applied each of which have uncertainty associated with them. The derivation of the parameters, assumptions and uncertainties are described in detail within the methodology sub-section and are summarised in Table 4.7. In some cases the confidence in the parameters used is not known and therefore has been determined based upon expert judgement.

Table 4.7 - Summary of the principal parameters, assumptions and uncertainties used to derive greenhouse gas emissions estimates

Parameter	Value	Confidence[2]	Origin
Non vehicular emissions	see Table 4.6	± 5 per cent	DETR, 1997c
Vehicle kilometres by vehicle type	see Table 4.1	± 2.5%	DETR, 1997b
Proportion of car kilometres by petrol engine	82 %	± 2.5%	DETR, 1997b[1]
Proportion of LGV kilometres by petrol engine	43 %	± 10%	DETR, 1997b[1]
Fleet averaged exhaust emissions factors	see Table 4.2	± 5 per cent	LRC, 1998
Nitrous oxide emissions	0.6 Mt	± 50 per cent	RCEP, 1994[1]
Others emissions	2 Mt	± 50 per cent	DETR, 1997d

[1] derived from

[2] based upon the expert judgement of various individuals. All distributions are assumed to be normal.

4.15 The sensitivity analysis applied a Monte Carlo simulation approach to determine:

(i) key assumptions and parameters in deriving robust emissions estimates; and

(ii) the overall range of the likely emissions for key sources based upon the uncertainties in the parameters and assumptions.

4.16 The effects upon total vehicular emissions of uncertainties associated with key assumptions were assessed using rank order correlation. The key five parameters in determination of the vehicular emissions were:

(i) percentage contribution of vehicular to "Other" greenhouse gases;

(ii) emissions factors for petrol cars for built up driving;

(iii) proportion of light good vehicles with petrol engines;

(iv) emissions factors for petrol cars for non built up driving; and

(v) number of kilometres driven by cars in built up areas.

4.17 In terms of overall greenhouse gas emissions uncertainty in non vehicular contributions were more significant that the vehicular contribution and the most important factor in determination of the proportion of vehicular emissions.

4.18 Using the probability distributions assigned to each of the input parameters it is possible to provide uncertainty estimates for the emissions estimates. These are summarised for the principal estimates in Table 4.8. The range of uncertainty has been set at the 5th and 95th percent confidence intervals. Table 4.8 demonstrates that confidence in the carbon dioxide emissions are much better than for PM_{10}. For example, the entire range for the proportion of vehicular emissions lies between 19 and 20 per cent. This is because the emissions are not heavily dependant upon the driving conditions. The estimate of vehicular emissions is between 34.5 and 36.3 Mt. The result can therefore be considered as being very robust.

Table 4.8 - Range of emissions estimates

Estimate	Low	Median	High
Total UK (Mt)	177.5	178.4	179.2
Total vehicular (Mt)	34.4	35.4	36.4
Total non vehicular (Mt)	142.4	142.9	143.5
Proportion vehicular (%)	19	20	20
Vehicular carbon dioxide (Mt)	32.0	32.8	33.6
Vehicular "Others"	1.5	2.0	2.5
Vehicular nitrous oxide	0.3	0.6	0.9

IMPACT ASSESSMENT

4.19 There is considerable uncertainty regarding the impacts arising from global warming. This is because the changes are global, but small in absolute terms and superimposed upon substantial annual variability. It is now certain that carbon dioxide emissions have caused carbon dioxide concentrations to increase and it is likely that this will result in an increase in average global temperature. Projecting what the change in temperature will be, and its subsequent impacts, however involves considerable uncertainties. The greatest confidence is currently placed in assessment of the impact of global warming upon *sea-level rise* and this impact parameter has therefore been utilised in the impact assessment.

4.20 The event tree examined emissions of greenhouse gases in the UK from transport sources. This addressed the key requirement of NCRAOA that the event tree should focus upon environmental pressures in order that management options could subsequently be considered. Linking UK transport generated emissions to impacts which occur on a global scale and arise from emissions throughout the world requires development of a scientifically justifiable methodology. This process is fraught with difficulties since:

- there is considerable uncertainty in global emissions of greenhouse gases;
- there is uncertainty in the carbon budget such that the known sources, sinks and accumulation of carbon dioxide in the atmosphere do not balance; and
- the long residence time of most greenhouse gases are such that impacts would continue to occur for centuries even if emissions were stabilised at present levels.

4.21 Emissions determined on an annual basis are a poor indicator of subsequent impacts, but the ideal indicator to evaluate the effectiveness of management options. This presents a conundrum in terms of using event trees for the purpose of assessing the risk of UK transport emissions from global warming. In order to overcome this it has been necessary to proportion UK emissions of greenhouse gases on an annual basis against global releases and equate this to the anticipated sea level rise for the next 30 years. This is a significant assumption but does enable a first approximation to be made of the contribution of UK transport emissions to sea level rise from global warming.

4.22 Estimates of total global greenhouse gas emissions are available for a range of scenarios which can be compared against UK projections. Global estimates suggest in 1990 global emissions of about 6,000 ± 2,000 Mt (UNEP, 1993) against total UK emissions of about 143 Mt, of which transport emissions are about 33 Mt. The proportion of UK emissions in total and from transport sources therefore account for 2.4 and 0.6 per cent of global releases respectively. The UK total contribution is likely to decline by 2020 to about 2.2 per cent, but the contribution of transport will remain constant at 0.6 per cent. These data are summarised in Table 4.9.

Table 4.9 - Comparison of UK and global carbon dioxide emissions

Year	Global emissions (Mt)	UK emissions transport (Mt)	UK emissions total (Mt)	% UK total of global	% UK transport of global
1990[1]	6000	37	160	2.67%	0.62%
1995	6500	40	165	2.54%	0.62%
2000	7000	43	170	2.43%	0.61%
2005	7500	48	185	2.47%	0.64%
2010	8500	50	197	2.32%	0.59%
2015	9250	55	209	2.26%	0.59%
2020	10000	60	220	2.20%	0.60%
Average				**2.41%**	**0.61%**

[1] employing estimates within the RCEP report for consistency, not those calculated in this document

Source: DETR, 1997d

4.23 By 2020 sea level is anticipated to increase as a global average by 19.2 cm compared with 1990 levels (DETR, 1996), with an associated confidence level of about a factor of two. Emissions of carbon dioxide between 1990 and 2020 are not directly responsible for the increase in sea level rise over the same period due to the long residence time of the gas in the atmosphere. However, if this assumption is made it is possible to use the proportion of UK to global emissions to assess the contribution of UK transport emissions to sea level rise by 2020. Using an average value for the total UK contribution (2.4 per cent) this gives a sea level increase from total UK emissions of 0.46 cm (4600μm). This value can then be applied as the starting point for the event tree. Figure 4.4 illustrates the event tree for the impact of emissions of greenhouse gases from transport sources in the UK to global sea level rise.

Figure 4.4 - Impact of UK transport emissions to global sea level rise by 2010

	um			um			um			um			um	Rank
		0.80	Non vehicular	3687										
GWP	4600				0.02	Others	48							6
					0.06	N2O	13							
		0.20	Vehicular	913	0.93	CO2	847	0.20	Motorways	166	0.43	Petrol cars	72	3
											0.09	Diesel cars	15	
											0.00	Motorcycles	0	
											0.02	Buses and coaches	3	
											0.06	Petrol LGV	10	
											0.03	Diesel LGV	5	
											0.11	HGV small	19	
											0.26	HGV large	42	7
								0.46	Built-up	390	0.57	Petrol cars	222	1
											0.10	Diesel cars	40	8
											0.01	Motorcycles	2	
											0.06	Buses and coaches	25	
											0.10	Petrol LGV	40	8
											0.03	Diesel LGV	13	
											0.07	HGV small	26	
											0.06	HGV large	23	
								0.34	Non Built-up	291	0.49	Petrol cars	141	2
											0.08	Diesel cars	24	
											0.01	Motorcycles	1	
											0.03	Buses and coaches	9	
											0.06	Petrol LGV	17	
											0.03	Diesel LGV	9	
											0.11	HGV small	31	10
											0.20	HGV large	58	4

4.24 Applying the event tree methodology to assess the impact of vehicle emissions upon sea-level rise, as distinct from the environmental pressures they impose, requires the application of a range of significant assumptions. The reliability of such calculations are uncertain and the scientific credibility of assigning a direct relationship between emissions and climate change over the same period is questionable. Accordingly, it is not considered appropriate to extended the sensitivity analysis to determine the range of contributions of vehicular emissions to sea level rise. Instead, the rank of importance of different vehicular sources has been added to the event tree. These are the same as for the emissions discussed in the previous section.

CONCLUSIONS

4.25 This section has undertaken a quantitative risk assessment of the contribution of road traffic to sea level rise as a result of global warming. It has applied, as far as possible, an event tree methodology. Conventionally, risk assessment using an event tree methodology has been applied for site specific impacts and hazards. In addition, event trees have not been utilised before to assess risks derived from exposure to diverse sources such as road transport. Neither have they been used to determine risk associated with a global impact. This section has highlighted a number of key issues regarding the use of event trees to quantify risks of this type. In particular, it has demonstrated that although it is possible to proportion the environmental pressure leading to a risk through an event tree approach, linking this pressure to an overall impact requires the use of a number of assumptions which significantly increased the uncertainties and reduced the credibility of the assessment.

4.26 The methodology has been of value in the assessment of emissions of greenhouse gases and the level of uncertainty in these estimates. Linking these emissions to impacts in a credible manner however presented considerable difficulties. The key conclusions which can be drawn from the assessment are therefore those related to the emission of greenhouses gases from vehicular sources rather than the impacts. The key conclusions are:

- vehicular emissions account for about 20 per cent of the total UK contribution to global warming;

- 93 per cent of the vehicular contribution arise from emissions of carbon dioxide;

- about 20 per cent of vehicular carbon dioxide emissions arises through motorway driving, 46 per cent urban-driving and 34 per cent non-urban driving;

- petrol cars are overwhelmingly the most important source of vehicular greenhouse gas emissions, accounting for over half the vehicular contribution;

- in total, cars account for about 62 per cent of vehicular greenhouse gas emissions, goods vehicles 34 per cent and buses and coaches 4 per cent;

- the key assumptions within the analysis is the percentage contribution of vehicular to "Other" greenhouse gases. Other key assumptions in the analysis relate to emissions factors for petrol cars and kilometerage;

- in terms of overall greenhouse gas emissions uncertainty in non vehicular contributions are more significant than that in the vehicular contribution in determination of the proportion of vehicular emissions; and

- the proportion of vehicular emissions to greenhouse gas releases is estimated to be between 19 and 20 per cent.

4.27 Linking emissions to impacts in a credible manner within the event tree presented considerable difficulties. Furthermore, the added value provided by undertaking this determination was limited whilst stretching the credibility of the overall assessment. For these reasons the uncertainty in sea level rise was not assessed. The overall approach of quantifying emissions and examining the transport sources and associated uncertainties yielded useful information. It would however appear that the application of event trees to quantify *risks* from diverse sources such as traffic with global impacts is of limited value.

5. QUANTITATIVE RISK ASSESSMENT OF THE WATER QUALITY IMPACTS OF LEACHATE ARISING FROM LANDFILL OF WASTE VEHICLE COMPONENTS

INTRODUCTION

5.1 This section provides a quantitative risk assessment of the water quality impacts of leachate arising from landfill of waste vehicle components. Around 8 - 9 million cars are discarded in the European Union each year, producing about 1.9 million tonnes of waste in the form of automotive shredder residue disposed of to landfill (Waste and Environment Today, 1997a). A draft Directive which would make car manufacturers and dismantlers responsible for recovering end of life vehicles (ELVs) was finalised by the European Commission in July 1997 (EC, 1997). The proposal would place a duty on the manufacturers to compensate consumers for any charges that may be made by vehicle dismantlers and sets ambitious targets for recycling and re-use of all car components.

5.2 There is a potential that shredder residue may be added to the EC Hazardous Waste List under new proposals (Waste and Environment Today, 1997b and DETR, 1997f). At present however shredder residues can be landfilled in UK landfills which are licensed to take household waste, although approval depends on the type of landfill, and on the results of chemical analysis of the shredder residue.

STUDY APPROACH

5.3 The majority of end of life vehicles (ELVs) can be recycled to some extent, and only the remnants are shredded and landfilled. The shredders reduce the feedstock material to pieces typically less than 100 mm in size and then air classification and magnetic extraction systems are used to separate the shredded material into three products; ferrous metal, a non-ferrous metal heavy fraction (pre-dominantly non-ferrous metals and rubber), and a light reject fraction which consists predominantly of miscellaneous combustible (foam, wood and plastic) and miscellaneous non-combustible (glass, stones and fine dirt) materials. The ferrous metal product is recycled to steel producers (some is exported), and the non-ferrous metal-rich product is then processed separately for recovery of the non-ferrous metal content. The residue from this process, together with the light reject fraction is currently disposed of to landfill (ACORD, 1995). This is standard procedure if a viable use for the residue cannot be found (DoE, 1995a).

5.4 Due to the age and range of available data on shredder wastes, and the variability in the parameters used to determine the proportion of components in the leachate from a landfill, a large uncertainty in the results of the assessment may be expected. In addition, the behaviour of a waste component in the landfill is dependent on its concentration. Therefore it was considered that employing a Monte Carlo simulation to calculate the results throughout the event tree would be the appropriate approach. This approach allows a range of data for each parameter to be used and the results at each stage to be presented as a probability distribution.

5.5 The data were input to the Monte Carlo simulation as a range and a most likely value. The likely shape of the data distribution was also given, all were assumed to be triangular. The process of randomly sampling the range for each parameter and employing it in the calculation to produce a result was repeated 1,001 times. The 5th, 50th and 95th percentile values were extracted from the resultant frequency distributions of the results.

5.6 The calculated results are provided as g m^{-3} of component in leachate. The volume of leachate used to give this concentration was that produced within the site over 100 years calculated using the HELP model (Schroeder *et al.*, 1994). The event tree includes sorption and precipitation mechanisms in the waste mass, leachate treatment plant and unsaturated zone beneath the landfill.

5.7 Proportioning of components to each branch of the event tree is only applicable to the specific input concentrations for the waste stream, as precipitation needs to be considered and the loss from the leachate is not necessarily directly proportional to the concentration. Any increase in the input concentration above that used for the calculations may result in leachate concentrations above the solubility of the limiting species and precipitation will reduce the concentration to that determined by the solubility product.

5.8 There are a number of assumptions that have been made in order to calculate the concentrations of each component of the shredder residue from vehicles within the event tree. The main ones are listed below whilst the rest are covered in the following sub-section:

- best practice landfilling was assumed, as detailed in Waste Management Paper (WMP) 26B (DoE, 1995b), which relates to capping and liner quality and thus influx and efflux of water and leachate;

- in calculating an initial concentration in the leachate, a worst case scenario has been assumed, this implies that all the component in the waste is solubilised into the leachate;

- the volume of rain infiltration into the site over 100 years was assumed to solubilise all the component, and that volume of leachate was used in calculating the initial concentration of the component in the leachate; and

- information on the mass of vehicles disposed of to landfill is scant and a range on the data has been calculated from the range of total shredder residue to landfill and the likely range of percentage of vehicle residue in that material.

METHODOLOGY

5.9 Recent data on the composition of shredder residue ("fluff") are shown in Table 5.1. The data derive from a life cycle analysis which is currently being undertaken on behalf of the EA and are based on a shredder feed of ELVs only, assuming current dismantling practices and material recovery. Although the data are as yet only provisional, they are probably the most current data for the UK (Dowdell, 1997). However the fractions considered within these data are relatively broad and are not suitable for use in this assessment.

Table 5.1 - Composition of shredder residue from ELVs (1988)

Component	Composition (% by wt)
Ferrous metal	0.5
Aluminium	0.2
Copper	<0.1
Lead	0.2
Plastics	59.8
Rubber	12.4
Glass	4.7
Wood	4.3
Other materials	14.5
Lubricants	3.4

5.10 An earlier study (Table 5.2) provided the range of metal contents determined for shredder residues, based on analyses conducted in Canada in the early 1990s and in the UK in the late 1980s, and compared these with typical values for household waste (ACORD, 1995). This study separated total shredder wastes into more disaggregated fractions and these data are sufficiently specific to be employed in the assessment. However, it should be remembered that considerable changes in car composition have occurred since the 1980s, with increases in plastic composition, decreases in PCB content of ELVs, and decreases in cadmium, chromium and other heavy metal contents. Additionally, there has been an increase in the level of dismantling of ELVs during this time, with increased recovery of material. Table 5.3 provides data for PCBs in shredder residues from various feedstocks (ACORD, 1995). Legislation to restrict PCBs was introduced in the 1990s and the level in shredder residues is declining, although concern over its presence in the residues remains. The total shredder waste includes non vehicle material which makes up 40 - 50 per cent of the waste.

Table 5.2 - Typical metal content of shredder residue and household waste

Metal	Shredder residue (% wt)	Household waste (% wt)
Aluminium	1.3-1.7	1.6-1.7
Copper	0.3-2.4	0.01
Zinc	0.9-3.2	0.03
Iron	10-11	5
Potassium	0.3-0.4	0.3-0.4
Magnesium	0.7-0.8	0.2-0.3
Sodium	1.1-1.4	1.0-1.2
Lead	0.024-0.19	0.014-0.015
Nickel	0.035-0.057	0.006-0.007
Cadmium	0.004-0.025	0.0008-0.001
Chromium	0.033-0.049	0.012-0.013
Mercury	0.0004-0.0005	0.00002

Source: ACORD, 1995

Table 5.3 - PCB content of shredder residues from various feedstocks (1990)

Shredder feedstock	PCB content (mg kg^{-1})
Cars	8
Light iron	10
Cookers	12
Washing machines	44
Refrigerators	36

Source: ACORD, 1995

5.11 The waste components chosen for evaluation include cadmium and mercury (which have EQSs set for surface waters), iron (the metal present at the highest concentrations in the "fluff") and PCBs (present in the "fluff" and of environmental concern). The procedure for calculating the effects on the leachate concentration arising from the components in the "fluff" assumed that the "fluff" was landfilled as part of the total Controlled Waste stream. The total mass of Controlled Waste going to landfill per year ranged between 60 and 120 Mt y^{-1} (Jones, 1997) as shown in Table 5.4, with a most likely value of 90 Mt y^{-1}. Of that Controlled Waste, the mass of "fluff" going to landfill was taken to be 325 kt y^{-1} (ACORD, 1995). The range on this value was calculated from the range on the total mass of shredder residue landfilled each year; 550,000 to 650,000 t y^{-1}, and the likely range of the percentage of vehicle residue in that material; 50 to 60 per cent. This therefore provided a range for the shredder residue of 275,000 to 390,000 t y^{-1}.

Table 5.4 - Data used in Monte Carlo simulation

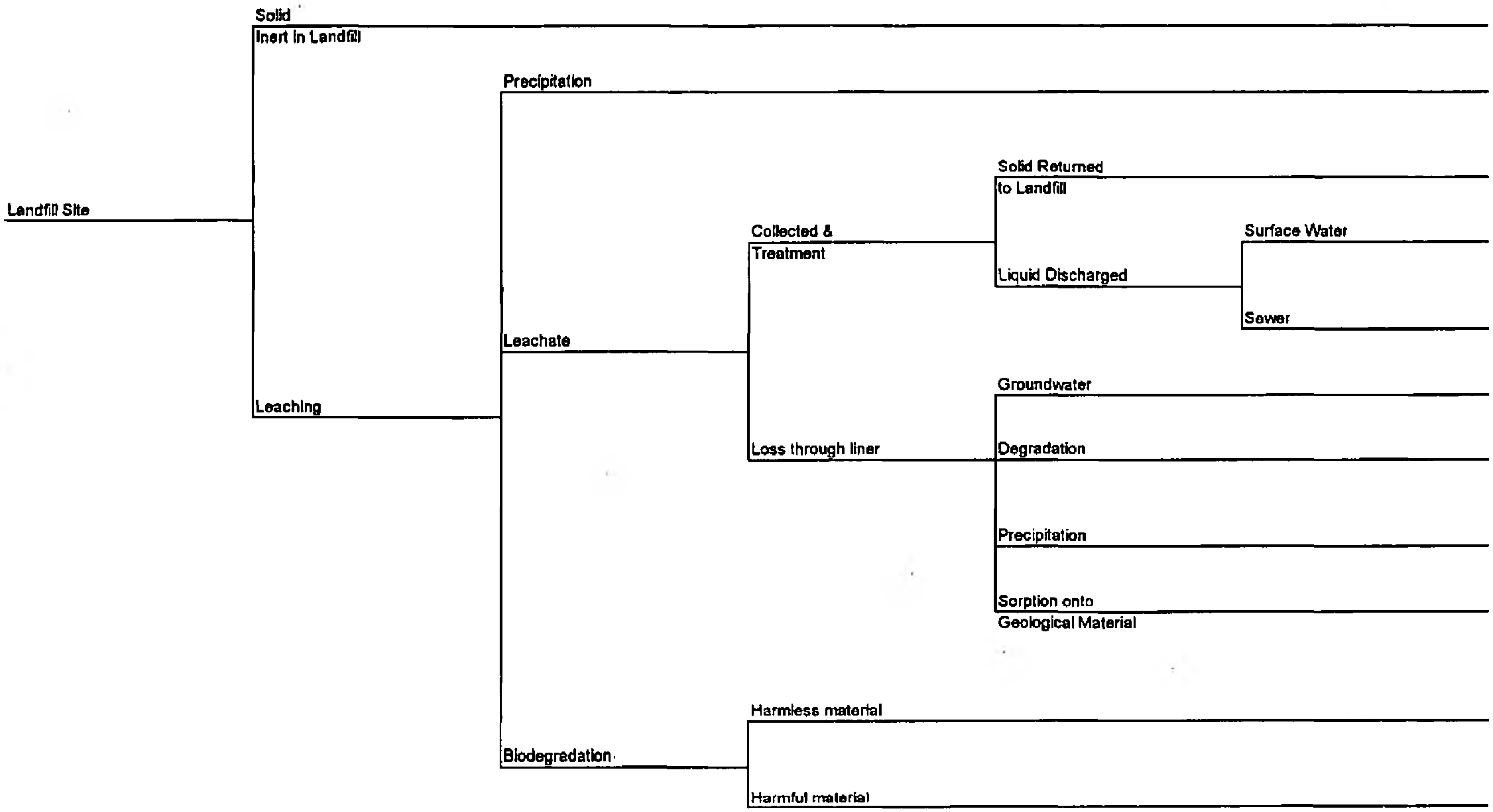
Parameter	Max	Most likely	Min
Shredder residue (t y^{-1})	275,000	325,000	390,000
Controlled waste to landfill (Mt y^{-1})	120	90	60
Leachate (m^3)	11.0	7.30	4.42
	PCBs		
Concentration in shredder residue (% wt)	0.0016	0.0008	0
K_d	17,000	16,661	16,000
	Hg		
Concentration in shredder residue (% wt)	0.00090	0.00045	0
K_d	1,500	1,200	900
	Cd		
Concentration in shredder residue (% wt)	0.05	0.0145	0
K_d	3,100	1,400	100
	Fe		
Concentration in shredder residue (% wt)	22.0	10.5	0
K_d	800	1,000	1,200

5.12 The concentrations of specific, potentially contaminating, components in the total shredder residue are presented in Table 5.2. To obtain a range for each component it was assumed that vehicle residues comprise 50% of total shredder waste, and the maximum concentration of the component was twice the concentration in the total shredder waste. This assumed that the non vehicle "fluff" fraction did not contribute to the component concentration, i.e. all the component was in the vehicle residue. The minimum concentration in each case was zero, this assumed that the "fluff" contributed zero percent to the total shredder waste concentration. The most likely figure was taken as the mean of the range given in Table 5.2. For PCBs, the data in Table 5.3 were employed.

5.13 The event tree for the landfill system shown in Figure 5.1 indicates the various pathways by which the components can be lost from the leachate. The concentrations of the components in leachate throughout the event tree were calculated by reference to the behaviour of the components within the landfill system.

Figure 5.1 - Event tree for the landfill system

Figure 5.1: Event Tree Structure for Lanfill Leachate



5.14 The concentration of the component in the Controlled Waste stream was assumed to dissolve fully in the landfill leachate (Table 5.4). The ratio of waste to leachate was approximately 1 to 0.73. This assumes a depth of waste of 10 metres (an approximate figure used in other work (WS Atkins, 1997a)) and a range for the leachate volume as given in Table 5.4. The leachate concentration was calculated using Monte Carlo simulation, and as for the rest of the results, the 5th, 50th and 95th percentile results were extracted from the range obtained for 1,001 runs.

5.15 The concentrations of each component (for 5th, 50th and 95th percentile results) were subsequently partitioned between the waste surface and the leachate. This partitioning was calculated using the K_d for the component taken from the literature and specific sorption modelling work (Christensen *et al.*, 1994, Environment Agency, 1994 and WS Atkins, 1998). Therefore a leachate concentration in equilibrium with the sorbed concentration was calculated, thus partitioning the component between the solid and liquid phase.

5.16 The leachate component concentration was further modified to account for the solubility of the most likely species in that environment (anaerobic). This was undertaken for cadmium, mercury and iron (PCBs are not considered to precipitate) (DoE, 1993 and WS Atkins, 1998) and the solubility of the likely species formed was used to modify the concentration of the component (Table 5.5). If the component concentration in the leachate was lower than the solubility of this species then the concentration was not affected by precipitation, if it was higher then the leachate concentration was assumed to be the maximum solubility concentration for that species and precipitation was assumed to occur. In addition, the possibility of biodegradation was included, but this was not applicable for any of the considered components.

Table 5.5 - Solubility Products for Metal Species

Species	Environment	Solubility product (K_{sp})
FeS	Anaerobic	6×10^{2}
$Fe(OH)_3$	Aerobic	2.8×10^{-39}
CdS	Anaerobic	8.0×10^{-7}
$CdCO_3$	Anaerobic/ Aerobic	1.0×10^{-12}
HgS	Anaerobic	$2 \times 10^{-32} - 4 \times 10^{-33}$ (1)
Hg_2Cl_2	Anaerobic/ Aerobic	1.43×10^{-18}
Hg^0 (metallic mercury)	Anaerobic	10 - 40 $\mu g\ l^{-1}$ (2)

1. Black and red forms

2. Source: WS Atkins, 1997b

Source: Lide, 1997

5.17 Leachate was then assumed either to be collected or lost through the liner. This division was calculated using a landfill water balance model (HELP3, Hydrological Evaluation of Landfill Performance (Schroeder *et al.*, 1994)). The landfill design used for inputs into the model was consistent with best practice criteria presented in WMP 26B (DoE, 1995b), see Table 5.6 for data used. The split calculated was, 80.3% collected and 19.7% lost through the liner.

Table 5.6 - Data used in HELP model

Parameter	Value
Surface cover	Soil
Surface slope (%)	5
Surface cover thickness (m)	1
Clay cap thickness (m)	1
Cap permeability ($m\ s^{-1}$)	10^{-9}
Drainage layer thickness (m)	0.25
distance between drains (m)	25
Slope (%)	5
Liner material	HDPE
Liner permeability ($m\ s^{-1}$)	10^{-13}
Pinholes (ha^{-1})	8
Other defects (ha^{-1})	8
Rainfall ($mm\ y^{-1}$)	665

5.18 Collected leachate was assumed to be treated using aerobic biological methods (aerated lagoon). The speciation of metals may change at this stage and thus effect the solubility (see Table 5.5). Iron was assumed to be converted from FeS (anearobic) to $Fe(OH)_3$ (aerobic). The iron concentration in the effluent leaving the treatment plant was mediated by $Fe(OH)_3$ solubility ($K_{sp} = 2.8 \times 10^{-39}$). Sorption to, and co-precipitation with, $Fe(OH)_3$ for other components at this stage were not included, because the data to describe these processes are not readily available.

5.19 The majority of effluent from the treatment plant was assumed to go to sewer, with only a small amount discharged to surface water (Gronow, 1998). This was likely to be the case as the discharge limits to sewer are usually higher than to surface waters. Therefore the split was calculated as 95% to sewer and 5% to surface waters.

5.20 Components in the leachate lost through the liner were assumed to undergo further sorption, precipitation and degradation processes in the unsaturated zone beneath the landfill. The sorption process was considered first, the partitioning between geological material and leachate being calculated using the K_d for the component (Table 5.4). The leachate component was then further modified to account for the solubility of the most likely species in that environment (aerobic). This was undertaken for cadmium, mercury and iron (PCBs were not considered to precipitate). The leachate component was then further modified to account for degradation. The degradation processes in this environment differ from those within the landfill, and are mediated by variable oxidation regimes. Therefore, components recalcitrant in anaerobic landfill environments may be degraded. PCBs in the unsaturated zone are fully or partially degraded in this type of environment (DoE, 1990a and DoE, 1991a), a 50% degradation has been assumed in this case.

5.21 Table 5.7 shows the parameters utilised in the event tree.

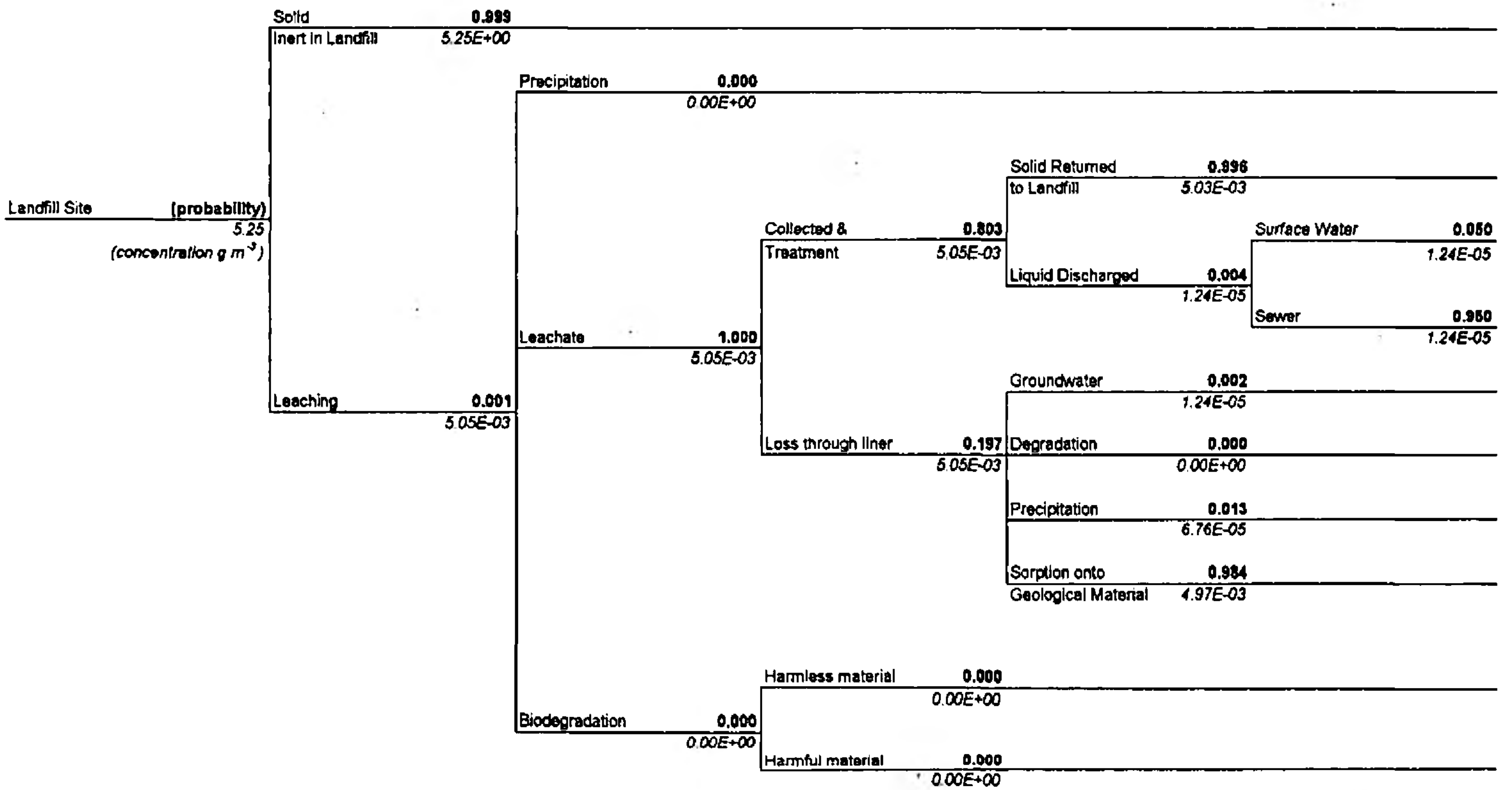
Table 5.7 - Parameters utilised in the event tree

Parameter	Value	Distribution	Comments
Mass of controlled waste to landfill	See Table 5.4	Triangular	Taken from Jones (1997)
Mass of vehicle shredder residue to landfill	See Table 5.4	Triangular	Calculated from data taken from ACORD (1995)
Concentration of component in vehicle shredder residue	See Table 5.4	Triangular	Taken from ACORD (1995), and calculated for concentration in total controlled waste stream
Leachate volume	See Table 5.4	Triangular	Calculated using HELP model (Schroeder *et al.*, 1994) and best practice landfill design, taken from WMP 26B (DoE, 1995b)
Partition coefficients, for leachate to solid phase	See Table 5.4	Triangular	Taken from Christensen *et al.*, (1994), Environment Agency (1994) and WS Atkins (1998b)
Solubility products for components	See Table 5.5	-	Taken from WS Atkins, 1997b and Lide, 1997
Division between collection and loss through liner	80.3:19.7	-	Calculated using HELP model (Schroeder *et al.*, 1994) and best practice landfill design, taken from WMP 26B (DoE, 1995b)
Division between sewer and surface water	95:5	-	Based on Gronow (1998)
Degradation of PCBs in the unsaturated zone beneath the landfill	50%	-	Expert judgement based on DoE (1990a) and DoE (1991a)

5.22 Figures 5.2 to 5.5 show the event trees for iron, cadmium, mercury and PCBs. The branch probabilities were assigned assuming that the concentrations entering the landfill are those stated. The probabilities are not directly relatable to the concentration going into the site, as precipitation and degradation need to be taken into account. Tables 5.8 to 5.11 provide the results obtained for iron, cadmium, mercury and PCBs.

Figure 5.2 - Event tree for iron for the landfill system

Figure 5.2: End of Life Vehicles
Effect on Leachate from Iron



Concentration ($g\ m^{-3}$)	Combined Probability	Probability Rank
5.25E+00	9.99E-01	1
0.00E+00	0.00E+00	8
5.03E-03	7.76E-04	2
1.24E-05	1.54E-07	7
1.24E-05	2.93E-06	4
1.24E-05	4.69E-07	6
0.00E+00	0.00E+00	8
6.76E-05	2.56E-06	5
4.97E-03	1.88E-04	3
0.00E+00	0.00E+00	8
0.00E+00	0.00E+00	8

Figure 5.3 - Event tree for cadmium for the landfill system

Figure 5.3: End of Life Vehicles
Effect on Leachate from Cd

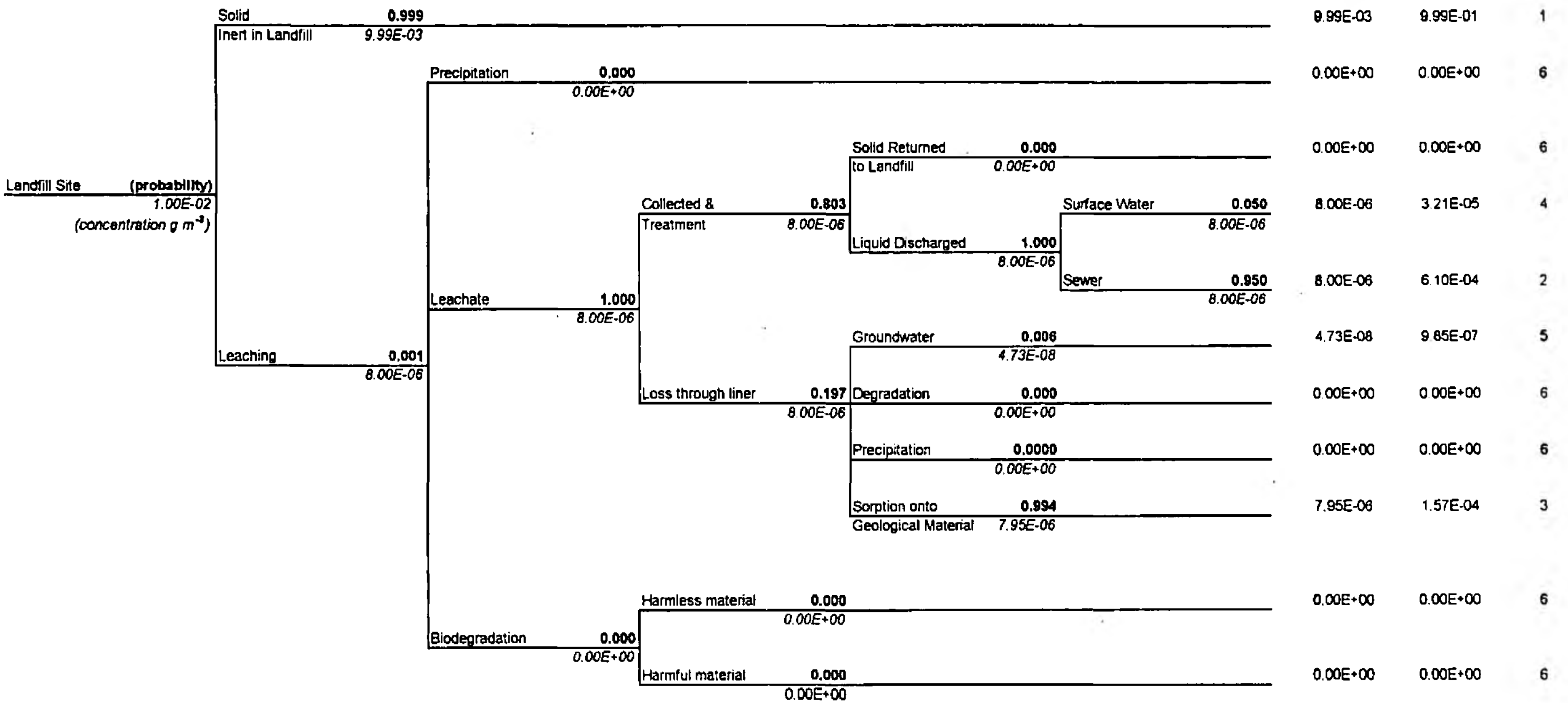


Figure 5.4 - Event tree for mercury for the landfill system

Figure 5.4: End of Life Vehicles
Effect on Leachate from Hg

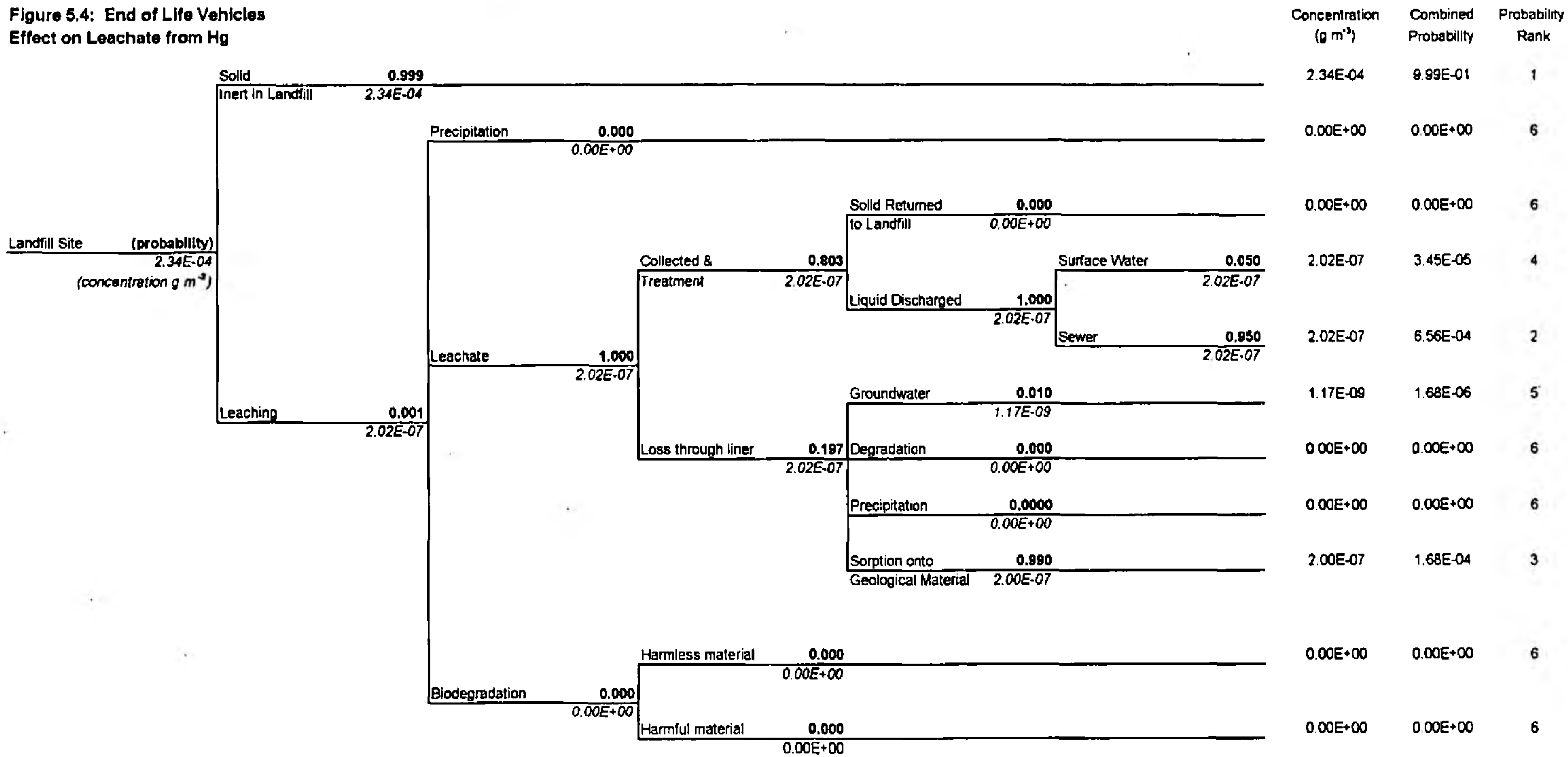


Figure 5.5 - Event tree for PCBs for the landfill system

Figure 5.5: End of Life Vehicles
Effect on Leachate from PCBs

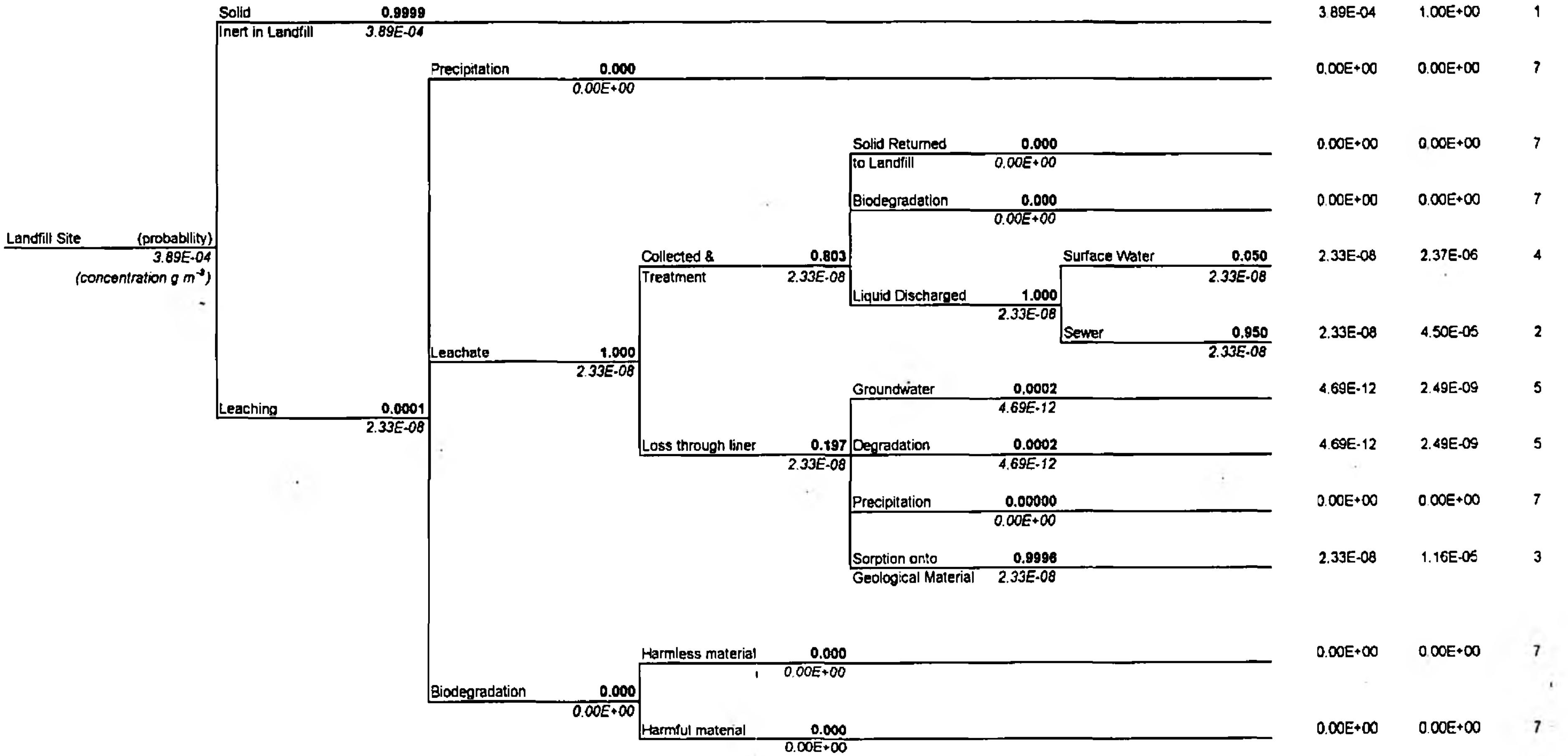


Table 5.8 - Results obtained for iron

	Percentile values (g m^{-3})		
Pathway	**5th**	**50th**	**95th**
To landfill	1.71	5.17	10.60
Solid (inert)	1.708	5.165	10.589
Leaching of substances	1.70 x 10^{-3}	5.20 x 10^{-3}	1.07 x 10^{-2}
Precipitation		0	
Leachate	1.70 x 10^{-3}	5.20 x 10^{-3}	1.07 x 10^{-2}
Controlled & treatment	1.70 x 10^{-3}	5.20 x 10^{-3}	1.07 x 10^{-2}
Solids returned to landfill	1.69 x 10^{-3}	5.19 x 10^{-3}	1.149 x 10^{-2}
Liquid discharged		1.24 x 10^{-5}	
Surface water		1.24 x 10^{-5}	
Sewer		1.24 x 10^{-5}	
Loss through liner	1.70 x 10^{-3}	5.20 x 10^{-3}	1.07 x 10^{-2}
Groundwater	1.24 x 10^{-5}	1.24 x 10^{-5}	1.24 x 10^{-5}
Degradation		0	
Precipitation	3.5 x 10^{-6}	2.40 x 10^{-5}	5.45 x 10^{-5}
Sorption onto geological matter	1.68 x 10^{-3}	5.16 x 10^{-3}	1.06 x 10^{-2}

Table 5.9 - Results obtained for cadmium

	Percentile values ($g\ m^{-3}$)		
Pathway	**5th**	**50th**	**95th**
To landfill	3.03×10^{-3}	9.83×10^{-3}	2.28×10^{-2}
Solid (inert)	0.0030	0.0098	0.0228
Leaching of substances	1.94×10^{-6}	6.71×10^{-6}	2.39×10^{-5}
Precipitation		0	
Leachate	1.94×10^{-6}	6.71×10^{-6}	2.39×10^{-5}
Controlled & treatment	1.94×10^{-6}	6.71×10^{-6}	2.39×10^{-5}
Solids returned to landfill		0	
Liquid discharged	1.94×10^{-6}	6.71×10^{-6}	2.39×10^{-5}
Surface water	1.94×10^{-6}	6.71×10^{-6}	2.39×10^{-5}
Sewer	1.94×10^{-6}	6.71×10^{-6}	2.39×10^{-5}
Loss through liner	1.94×10^{-6}	6.71×10^{-6}	2.39×10^{-5}
Groundwater	1.37×10^{-8}	4.42×10^{-8}	1.42×10^{-7}
Degradation		0	
Precipitation		0	
Sorption onto geological matter	1.93×10^{-6}	6.67×10^{-6}	2.38×10^{-5}

Table 5.10 - Results obtained for mercury

Pathway	Percentile values ($g\ m^{-3}$) 5th	50th	95th
To landfill	7.55×10^{-5}	2.30×10^{-4}	4.75×10^{-4}
Solid (inert)	7.54×10^{-5}	2.30×10^{-4}	4.75×10^{-4}
Leaching of substances	6.36×10^{-7}	1.93×10^{-7}	4.02×10^{-7}
Precipitation		0	
Leachate	6.36×10^{-7}	1.93×10^{-7}	4.02×10^{-7}
Controlled & treatment	6.36×10^{-7}	1.93×10^{-7}	4.02×10^{-7}
Solids returned to landfill		0	
Liquid discharged	6.36×10^{-7}	1.93×10^{-7}	4.02×10^{-7}
Surface water	6.36×10^{-7}	1.93×10^{-7}	4.02×10^{-7}
Sewer	6.36×10^{-7}	1.93×10^{-7}	4.02×10^{-7}
Loss through liner	6.36×10^{-7}	1.93×10^{-7}	4.02×10^{-7}
Groundwater	4.87×10^{-10}	1.13×10^{-9}	2.11×10^{-9}
Degradation		0	
Precipitation		0	
Sorption onto geological matter	6.31×10^{-8}	1.91×10^{-7}	3.99×10^{-7}

Table 5.11 - Results obtained for PCBs

	Percentile values (g m^{-3})		
Pathway	**5th**	**50th**	**95th**
To landfill	2.59×10^{-4}	3.89×10^{-4}	6.10×10^{-4}
Solid (inert)	2.59×10^{-4}	3.89×10^{-4}	6.10×10^{-4}
Leaching of substances	1.56×10^{-8}	2.36×10^{-8}	3.68×10^{-8}
Precipitation		0	
Leachate	1.56×10^{-8}	2.36×10^{-8}	3.68×10^{-8}
Controlled & treatment	1.56×10^{-8}	2.36×10^{-8}	3.68×10^{-8}
Solids returned to landfill		0	
Liquid discharged	1.56×10^{-8}	2.36×10^{-8}	3.68×10^{-8}
Surface water	1.56×10^{-8}	2.36×10^{-8}	3.68×10^{-8}
Sewer	1.56×10^{-8}	2.36×10^{-8}	3.68×10^{-8}
Loss through liner	1.56×10^{-8}	2.36×10^{-8}	3.68×10^{-8}
Groundwater	2.59×10^{-12}	4.84×10^{-12}	7.83×10^{-12}
Degradation	2.59×10^{-12}	4.84×10^{-12}	7.83×10^{-12}
Precipitation		0	
Sorption onto geological matter	1.56×10^{-8}	2.30×10^{-8}	3.68×10^{-8}

5.23 The concentrations of components shown in Figures 5.2 to 5.5 and Tables 5.8 to 5.11 relate to that proportion of the waste which is derived from ELV shredder residue. Therefore, these consider the "most likely" values of shredder residue and total controlled waste (see Table 5.4), the shredder residue comprises around 4×10^{-3} per cent of the total waste to landfill on average. Thus the leachate concentrations provided in the figures only represent the amount of component derived from the shredder residue in a co-disposal site. The other (majority) component of waste in the landfill will add significantly to the concentrations derived in these event trees. Thus if the chemical composition of the other waste in this theoretical landfill is similar to that in the shredder residue, then the total leachate concentrations could be around 4 x 10^3 higher than the values presented here for the shredder residue proportion alone. The actual values of leachate calculated for the whole waste would vary depending on precipitation and other processes within the landfill.

5.24 To summarise the results of this assessment, the concentrations of iron, cadmium, mercury and PCBs in the liquid discharged and that leaching to groundwater have been tabulated and compared with the existing EQSs or other guidance, and also with measured concentrations in landfill leachates from surveys of predominantly domestic waste landfills (Table 5.12).

Table 5.12 - Comparison of results with Environmental Standards or guidance and measured concentrations

	Concentration (g m^{-3} leachate)			
Component	**Liquid discharged**	**Liquid to groundwater**	**Environmental Standard or guidance**	**Range in literature**
Iron	1.24×10^{-5}	1.24×10^{-5}	1 (guidance)	1.6 - 1200 (2)
Cadmium	6.71×10^{-6}	4.42×10^{-8}	5×10^{-3} (EQS)	2×10^{-3} - 2×10^{-2} (1)
Mercury	1.93×10^{-7}	1.13×10^{-9}	1×10^{-3} (EQS)	6×10^{-4} - 1×10^{-2} (2)
PCBs	2.36×10^{-8}	4.84×10^{-12}	1×10^{-4} (EC drinking water)	5×10^{-5} - 3×10^{-4} (2)

1: DoE, 1990b

2: DoE, 1995c

5.25 It can clearly be seen from Table 5.12that the concentrations of these components arising from landfill disposal of shredder residue from ELVs are very low and significantly lower than the appropriate existing EQSs or other guidance even before dilution in the environment is taken into account. In addition, it should be remembered that conservative assumptions have been made in setting the ranges used for the calculations in this assessment.

CONCLUSIONS

5.26 This section has undertaken a quantitative risk assessment of the water quality impacts of leachate arising from landfill of waste vehicle components. The approach of employing a Monte Carlo simulation to calculate the results throughout the event tree was successfully adopted. This was considered necessary as the behaviour of a waste component in landfill is dependant on its concentration. The event tree demonstrated that the concentrations of iron, cadmium, mercury and PCBs arising from the landfill disposal of shredder residue of ELVs are very low and significantly lower than the appropriate existing EQSs or other guidance even before dilution in the environment is taken into account.

6. QUANTITATIVE RISK ASSESSMENT OF THE WATER QUALITY IMPACTS OF ROAD RUNOFF

INTRODUCTION

6.1 This section presents the results of a quantitative risk assessment of the water quality impacts of road runoff. Three heavy metals, copper, zinc and lead were chosen for the road runoff event trees. The use of both copper and zinc is widespread in the car industry, for car bodies and parts such as brake linings and tyres. Copper is highly toxic at low concentrations and zinc is the most important heavy metal in terms of its contribution to total load. Although lead presents a lower threat to the environment today than it did in the 1970s and 1980s, the lead event tree is a useful example because there are many data on lead concentrations in road runoff that can be used for event tree validation.

METHODOLOGY

6.2 The road runoff event trees were structured to follow the pathway of runoff of sediment and pollutants until these reach a headwater stream or river, percolate to groundwater or are "lost" to either the atmosphere or soil storage. They consist of two identically structured event trees, one for heavy metal loads and one for water balance. In the first tree the branch probabilities describe the likelihood of the movement of the pollutant load along a certain pathway, whereas in the second tree the branch probabilities describe the movement of water. These trees are linked so that the heavy metal concentrations can be calculated in the impact column of the first tree using the equation:

- Concentration = $k \times (M/V)$

Where the mass (M) is the pollution load in kg $ha^{-1}\ a^{-1}$, volume (V) is the water depth in mm and k is a conversion factor to output the mean path concentration in micrograms per litre.

6.3 The branch probabilities for the first level of water balance tree were calculated based on a general model of the water balance for roads in England and Wales (Fig. 6.1) and data from Colwill *et al.*, (1984) and Baldwin *et al.*, (1997). The mean values of the hydrological balance are summarised in Table 6.1. The runoff coefficient was allowed to vary between 50 and 90 percent in the Monte Carlo simulation, so that the worst case, in terms of concentration of any pollutant, was included in the analysis. The water budget for roads can be summarised as:

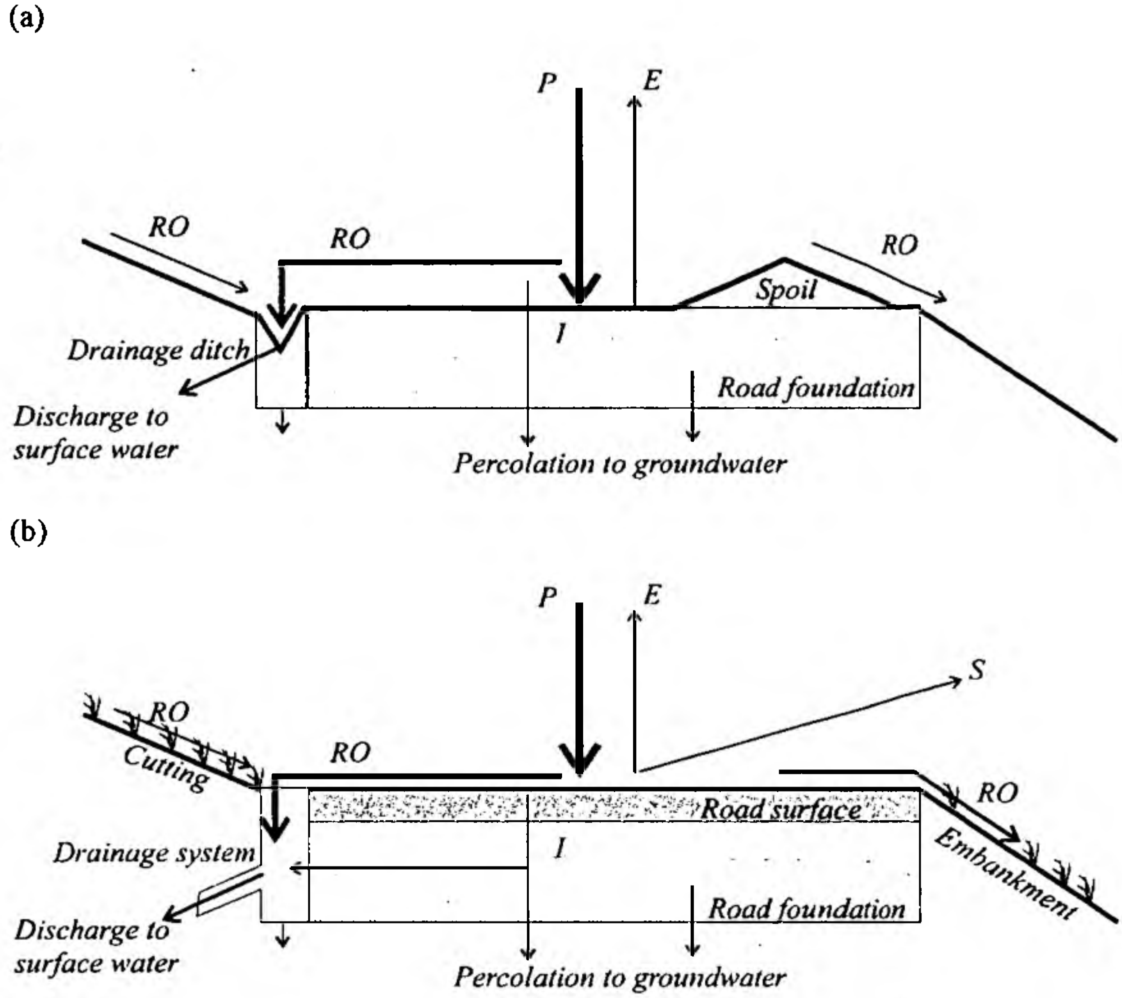
- P = RO + I + E + S + X

where P is the mean annual precipitation (mm), RO is the amount of runoff, I is the amount of infiltration, E is evaporation, S is road spray and X is the change in water storage. For the Monte Carlo simulation P is assumed to be normally distributed with a standard deviation of 88 mm which accounts for the large regional variations of mean annual P in England and Wales. X is assumed to equal zero on an annual time step, RO can be estimated based on a runoff coefficient, and E and S can be combined as turbulence and evaporative losses.

Table 6.1 - Mean water balance data

Variable	Annual P mean	Units	Distribution	s.d.	Source
P (England and Wales)	912	mm	Normal	88	Estimate based on Hydrometric Register
			Event tree level 1		
Runoff coefficient	70	%	Normal	7	Range 50 - 90 per cent
Infiltration	5	%	-	-	Baldwin *et al.*, 1997 and Colwill *et al.*, 1984
Turbulence losses and evaporation	25	%	Normal	8	Range 5 - 50 per cent. Calculated as the balance of other components. Minimum value based on Colwill *et al.*, 1984.
			Final river concentration		
River discharge	45	mm	Log normal	60	Mean monthly river discharge based on a stratified sample of 34 rivers throughout England and Wales.

Figure 6.1 - Schematics of road drainage (a) during construction phase and (b) after completion



6.4 The total pollution load per unit area of road was calculated as follows:

- the mean annual loads of copper, zinc and lead for different road classes were based on Luker and Montague (1994) (Table 6.2); and

- an area-weighted mean loading was calculated based on the area of different road classes (Table 6.3) and their respective mean pollutant loading from above.

6.5 In addition two assumptions were introduced for the Monte Carlo simulation and scenario testing.

- It was assumed that pollutant load had a log normal distribution. The parameters for the distribution were based on the area-weighted mean load and mean motorway load. The 50th percentile was set to equal the area weighted mean load and the 75th percentile was set to equal the mean motorway pollutant load. In a generic model the selection of these parameters is a matter of judgement, and in this case they were chosen to represent a worst case scenario, in which sediment and heavy metals had accumulated on the surface for several days before being washed away.

- It was assumed that pollution loads increased linearly with traffic volume. A regression was established between the mean number of vehicles km^{-1} a^{-1} and the load of each pollutant in kg ha^{-1} a^{-1} based on the data included in Luker and Montague (1994) . The R^2 in each case was above 95 per cent, but the relationship should be applied with caution beyond the upper range of the data (57,000 vehicles km^{-1} a^{-1}). These equations could be used to evaluate the impact of changing traffic densities on water quality.

6.6 The first level probabilities in the heavy metal load event trees are calculated based on two input variables, the soluble percentage of the metal load ($P(HM_{diss})$) which was derived from the literature (Table 6.2) and the amount of turbulence losses which includes wind blown dusts and dissolved metal in road spray ($P(HM_{turb})$). The mean turbulence losses were estimated using data from Colwill *et al.*, (1994). The probability of an aliquot of heavy metal infiltrating into the road surface P(HMI) is calculated as follows:

- $P(HMI) = 0.01 \times HM_{diss} \times P(I)$

where P(I) is the probability of infiltration in the water balance tree. The probability of movement in runoff is calculated as:

- P(HMrunoff) = 1 - P(HMI) - P(HMturb)

Table 6.2 - Heavy metal loads on road surfaces

Annual mean loads (kg ha^{-1} a^{-1})	Copper	Zinc	Lead
Area weighted mean	0.59	0.87	0.84
Mean	1.57	2.63	2.14
Motorways	3.88	6.77	5.20
Trunk Roads	1.16	1.89	1.59
Principal Roads	0.95	1.52	1.32
Other	0.28	0.32	0.44
Sediment-associated fractions			
Sub 63 µm load per cent	70	60	46
Sediment bound per cent	71	67	95
In solution per cent	29	33	5

Average figures calculated from data in Collins and Ridgeway (1980), Colwill *et al.* (1984), Foster and Charlesworth (1994), Hadley and Lockley (1975), Homer and Mar (1983), Luker and Montague (1994), Muschack (1990), Pope *et al.*. (1978) and Xanthopolous and Hahn (1993).

6.7 The second level probabilities are identical in the water balance and heavy metal load trees and simply reflect the likelihood of different drainage structures across England and Wales. These were based on the questionnaire survey findings of Luker and Montague (1994) and the percentage coverage of road types for England and Wales (Tables 6.3 and 6.4). Detailed data on the total numbers of different drainage structures in roads in England and Wales are not available. The third and subsequent branch probabilities describe the removal of heavy metals from any drainage structure and the routing of the remaining load to rivers, groundwater or other drainage structures. The probabilities for pollution removal were calculated based on the following:

- the percentages of dissolved and sediment-associated heavy metal load (Table 6.2);
- the percentages of sediment-associated heavy metal load attached to sub 63 µm and greater than 63 µm sediment fractions (Table 6.5);

- the trapping efficiencies for different structures based on literature sources (Table 6.5); and

- the assumption that routine maintenance of gully pots and drains only removed 90 per cent of sediment and resulted in the other 10 per cent being washed into the drainage system.

6.8 Therefore the branch probabilities for sediment and heavy metal removal are dependent on the characteristics of the heavy metal and the trapping efficiency of the drainage structure. The general equation used is:

- P(Removal) = 0.9 × ((A × TrapA) + (B × TrapB))

Where A is the fraction of heavy metal load attached to sediment below 63 μm, TrapA is the structure's trapping efficiency, B is the remaining sediment-associated fraction and TrapB is the trapping efficiency for this sediment fraction. The factor of 0.9 accounts for the maintenance assumption (described above).

Table 6.3 - Estimate of the distribution of roads by EA region

		Road length (km)				
EA region	**Total land area (km²)**	**Motorway**	**Trunk roads**	**Principal roads**	**Other**	**Total**
Anglian	26,795	198	1,693	3,847	37,637	43,375
Midlands	21,666	740	1,763	4,733	44,091	51,327
North East	22,777	412	1,207	4,073	36,983	42,675
North West	14,445	800	1,002	3,480	30,416	35,698
South West	20,802	280	1,092	3,617	38,192	43,181
Southern	10,604	396	620	2,405	21,638	25,059
Thames	12,917	712	847	3,640	29,094	34,293
WALES	21262	145	1583	2624	29023	33375
Total	151,268	3,683	9,807	28,541	267,737	309,768

Source: British Road Federation, 1990 for County and Metropolitan District data and EA administrative maps to generalise for each EA region.

Table 6.4 - The percentage of total road area covered by different road types by EA region

EA region	Motorways	Trunk Roads	Principal Roads	Other	Total
Anglian	0.02	0.10	0.12	0.76	1.00
Midlands	0.05	0.09	0.12	0.74	1.00
North East	0.03	0.07	0.13	0.76	1.00
North West	0.08	0.07	0.12	0.73	1.00
South West	0.02	0.07	0.11	0.80	1.00
Southern	0.06	0.06	0.13	0.75	1.00
Thames	0.07	0.06	0.14	0.73	1.00
WALES	0.02	0.12	0.10	0.76	1.00
Mean	0.05	0.08	0.12	0.75	1.00

Calculated using data from Table 6.3 by assuming a unit carriageway width of 3.65m and standard numbers of lanes per road type.

Table 6.5 - Estimated drainage structure removal efficiencies

	Copper		Zinc		Lead	
Structure	**0 - 63 mm**	**63 + mm**	**0 - 63 mm**	**63 + mm**	**0 - 63 mm**	**63 + mm**
Gully pot	15	68	15	68	15	68
Filter drain	83	83	81	81	83	83
Surface water channel	0	10	0	10	0	10
Infiltration basin/Soakaway	49	49	44	44	49	49
Storm water storage basin	62	62	38	38	62	62
Oil Filter	12	12	12	12	12	12
Reed Bed	90	90	90	90	90	90

Source: Colwill *et al.*, 1984, Luker and Montague, 1994, Nuttal *et al.*,1997 and Pope *et al.*,1978.

6.9 The heavy metals which are not removed are discharged into another drainage structure, the river or groundwater. The probabilities for particular structures are applied as before but are reduced by a factor equivalent to one minus the mass removed. The remaining heavy metal load is discharged to surface water or groundwater. The mass balance calculations which link the branch probabilities enable scenario testing and Monte Carlo simulation based on the removal efficiencies of different structures as well as the input variables at the front end of the event trees.

6.10 The main pathway for water and pollutants from the road surface to rivers is via gully pots and directly to the nearest surface water without any pollution control treatment. It is estimated that gully pots are used on 70 per cent of roads in England and Wales, therefore a probability of 0.7 was assumed for the event tree. The sediment trapping efficiency of gully pots is dependent on sediment size. Karunaratne (1992) estimated that the trapping efficiency of a 450 mm diameter British Standard (BS) gully pot varied between 15 per cent for fines (sub 63 μm) and between 35 and 95 per cent for sediment sizes between 63 μm and 300 μm.

6.11 It is estimated that filter drains or French drains are used on 20 per cent of roads in England and Wales, therefore a branch probability of 0.2 was assumed for the event tree. They consist of a perforated pipe within a back-filled gravel trench and are used mostly in road cuttings. Most water is piped to the nearest river or soakaway but a small percentage will percolate to groundwater from the base of the trench. Although they can be effective at removing between 80 and 85 per cent of suspended sediment and heavy metals, recent DETR policy has discouraged the use of filter drains in new roads due to:

- costs of construction and maintenance;
- problems of stone scatter onto the highway; and
- risks of groundwater pollution from dissolved or heavy aqueous pollutants.

6.12 Surface water channels are a newer design which may become more widespread in the future. Currently 10 per cent of motorways and 5 per cent of other major roads use surface water channels, which translates to only 2 per cent of the existing road network, therefore a probability of 0.2 was assumed for the event tree. They offer no protection in terms of pollution control except for easy access for road sweeping and removal of any accumulated sediments

6.13 Verge ditches and other informal drainage systems are used on minor rural roads. Water drains directly from the road surface into ditches parallel to the road. In this analysis the verge ditches are considered as part of the stream network so processes within the ditches are not considered. Despite the lack of any formal drainage treatment, grass ditches are quite an effective form of pollution control under normal flow conditions and where traffic loading is low. The main risk to headwater streams occurs when accumulated sediment-associated pollutants are flushed from the ditches during intense rainfall events.

6.14 The construction of other forms of drainage, such as permeable infiltration pavements and grass swales is not widespread in the UK. There is some evidence that these structures can reduce pollutant loading (e.g. Pratt *et al.*, 1989). However they are not considered directly in the event trees, but will behave in a similar manner to soakaways and informal verge ditches respectively.

6.15 The main pathway to groundwater is through gully pots, to soakaways and infiltration ponds, which under average flow conditions can remove approximately 50 per cent of the pollution load. In both cases, there is a low probability of any treatment, e.g. oil filters, sediment traps or reed bed systems, except in the case of new major roads which are likely to have a range of pollution control measures. It is estimated that soakaways are used on 20 per cent of roads in England and Wales.

6.16 Reed beds can filter up to 94 per cent of suspended sediment under regulated flow conditions. In a study of 34 sites CIRIA reported an average efficiency of 66 per cent for water suspended solids (Nuttel *et al.*, 1997). Road runoff treatment systems based on reed beds and wetland lagoons have only been implemented at a small number of sites. There are difficulties in implementing successful reed bed systems for highway road runoff for the following reasons:

- optimum pollution removal requires a slow and constant discharge;
- during intense rainfall events high pollutant loads are likely to by-pass the reed bed system due to rapid discharge of storm water;
- during summer conditions road discharges may be too low to support wetland habitats; and
- pre-treatment of road runoff is essential for the successful establishment of wetland treatment systems, which may include the use of oil traps, sediment tanks, oil booms and bed load traps.

CALCULATION OF FINAL RIVER CONCENTRATIONS

6.17 The road runoff event trees trace the volume of road runoff and the mass of selected pollutants until they are discharged into surface water or groundwater or removed from the hydrological system. At this stage the concentration of road discharges can be calculated, but the impact on river water quality depends upon:

- the flow conditions in the receiving water;
- the background concentrations of heavy metals in the receiving water;
- the road area compared to the total catchment area, the discharge volumes and metal loads in the event trees were calculated per unit area; and
- the EQS for each of the considered heavy metals (Table 6.6).

6.18 A river discharge database was developed based on 30 years of monthly mean discharge data from 35 catchments in England and Wales ranging in size from 87 to 9948 km^2 (EA, pers. comm.). The mean monthly flows were converted to mm of runoff to standardise the data set for different catchment areas. A log normal distribution was fitted to the data with a mean of 45mm per month and a standard deviation of 51mm per month. The background river concentrations of heavy metals were based on data from the Harmonised Monitoring Scheme and EA data (WS Atkins, 1995). Both these variables were input into the sensitivity analysis as frequency distributions.

6.19 Based on the roads database (Table 6.3 & 6.4) the average road area in England and Wales is 1.78 per cent of land area. This calculation assumed a standard number of lanes for different road types, for example 6 lanes for a motorway, and a unit carriageway width of 3.65 m. On a regional basis road area does not increase to above 2 per cent of land area but in urban catchments it may be much higher.

6.20 The EQS is dependent upon a functional classification of rivers based on their use for fisheries or drinking water abstraction (Table 6.6). For copper and lead the drinking water EQSs were used in this assessment and for zinc a Fisheries Ecosystem (FE) standard was used because road discharges are unlikely to impact on the high drinking water EQS.

6.21 The final concentrations can be calculated using a mixing equation based on the following assumptions:

- each pollutant was assumed to be conservative once discharged into the river; and

- the annual pollution load in road runoff was assumed to be distributed equally for each month of the year.

6.22 The final river concentration (CRIVER) was calculated as:

- $$C_{RIVER} = \frac{M1.xAREA1 + M2.xAREA2}{V1xAREA1 + V2xAREA2}$$

where M1 and V1 are the total mass of heavy metals and discharge from all river pathways, AREA1 is the road area, M2 and V2 are the background metal loads and river discharge and AREA2 is the non-road catchment area. M1 and V2 are calculated from the event tree, M2 is calculated based on the background concentration and V2 is based on the mean monthly flow distribution. The impact of AREA cancels out at this stage because the percentage of road area is constant at 1.78 per cent. The equation can be rearranged to estimate the discharge (V2) required to meet the EQS (CRIVER).

Table 6.6 - Environmental Quality Standards for event tree variables

Parameter	Units	Drinking water standards	Grade 1 fisheries ecosystem standard
Copper	$\mu g\ l^{-1}$	**50**	5 - 112
Zinc	$\mu g\ l^{-1}$	3000	**300** (30 - 500)
Lead	$\mu g\ l^{-1}$	**50**	-

Fisheries ecosystem standard is proportional to water hardness determined by $CaCO_3$ concentrations. Fisheries ecosystem standard for copper is for dissolved copper concentrations. Selected EQSs are highlighted in bold type.

RESULTS AND SENSITIVITY ANALYSIS

6.23 The results of the event trees represent a generalised description of heavy metal pollution from roads in England and Wales. They are based on a large number of assumptions and in specific cases road runoff concentrations may be higher or lower than the range of values "predicted" by the event tree.

6.24 The average metal loads and road runoff concentrations are summarised in the event trees. For each heavy metal approximately 43 per cent of the deposited heavy metal load is discharged to surface water, 5 per cent is discharged to groundwater, 27 percent is removed from the drainage system and the remaining 25 per cent is deposited on land adjacent to the road surface. The four most important pathways are summarised in Table 6.8 using data for copper. The dominant pathway for heavy metal pollution is road runoff through gully pots and straight into the surface waters. The metal concentrations discharged by this pathway will normally exceed the EQS for both drinking water and freshwater fisheries.

6.25 The full range of road runoff and river concentrations, are summarised in Table 6.7. In each case the range of road runoff concentrations are of the same magnitude as those reported in the literature (e.g. Collins and Ridgeway, 1980, Colwill *et al.*, 1984, Foster and Charlesworth 1994, Pope *et al.*, 1978 and Xanthopolous and Hahn, 1993). The average final concentrations were less than EQS but the 95th percentile concentrations for Copper and Lead were greater than the drinking water standards.

Table 6.7 - Impacts of road runoff on heavy metal concentrations in rivers and streams

	Zinc	Copper	Lead
Concentrations in road runoff ($\mu g\ l^{-1}$)			
Mean (range)	395 (17 - 3344)	248 (16 - 1700)	291 (20 - 1975)
Final river concentration ($\mu g\ l^{-1}$)			
Mean (range)	65 (1.5 - 1686)	24 (0.4-557)	33 (0.5 - 671)
95th percentile	206	79	108
Flow required to meet EQS (mm d^{-1})			
Mean (range)	0.1 (0 - 0.32)	0.26 (0 - 9.4)	0.35 (0.04 - 12.6)

Note: The average daily flow from the rivers database was 1.45 mm.

Table 6.8 - Important pathways for pollutant loads in road runoff

Data for copper	Mean mass kg ha^{-1} road a^{-1}	Mean concentration $\mu g\ l^{-1}$	Probability	Rank
Discharge into river through gully pots	1.79E-01	55.35	0.304	1
Turbulence losses to soil stores adjacent to road	1.48E-01	64.69	0.250	2
Removal from filter drains	6.48E-02	n/a	0.11	3
Removal from gully pots	5.98E-02	n/a	0.11	4

6.26 For the sensitivity analysis five variables were input as frequency distributions:

- the annual mean precipitation
- the runoff coefficient
- the pollution loading
- the average monthly river discharge
- the background river load.

6.27 The parameters for the distributions are summarised in Table 6.1, for the hydrological variables, and Table 6.2 for the pollutant loads. The results of the sensitivity analysis are summarised for copper in Figures 6.5 and 6.6. The concentration of road runoff is almost entirely controlled by loading. The final river concentration is most sensitive to river discharge, highlighting the vulnerability of rivers during low flow conditions. This period is likely to coincide with the highest loadings in the summer when intense rainfall events transport large pollutant loads which have accumulated during antecedent dry periods.

CONCLUSIONS

6.28 The water quality event trees trace the pathways of water and metal loads from the road surface river and groundwater discharges. The dominant pathways of heavy metal pollution were identified as direct losses to surface waters with little attenuation and deposition adjacent to the road surface. The results highlight the vulnerability of rivers during periods of low flow to large pollution inputs which may elevate river concentration above the EQS. Although high lead loads were predicted these may be too high due to the uptake of lead free petrol and subsequent reduction in lead deposits on road surfaces. High copper loads represent the greatest risk of heavy metal pollution in surface waters.

Figure 6.2 - Lead event tree

Lead load

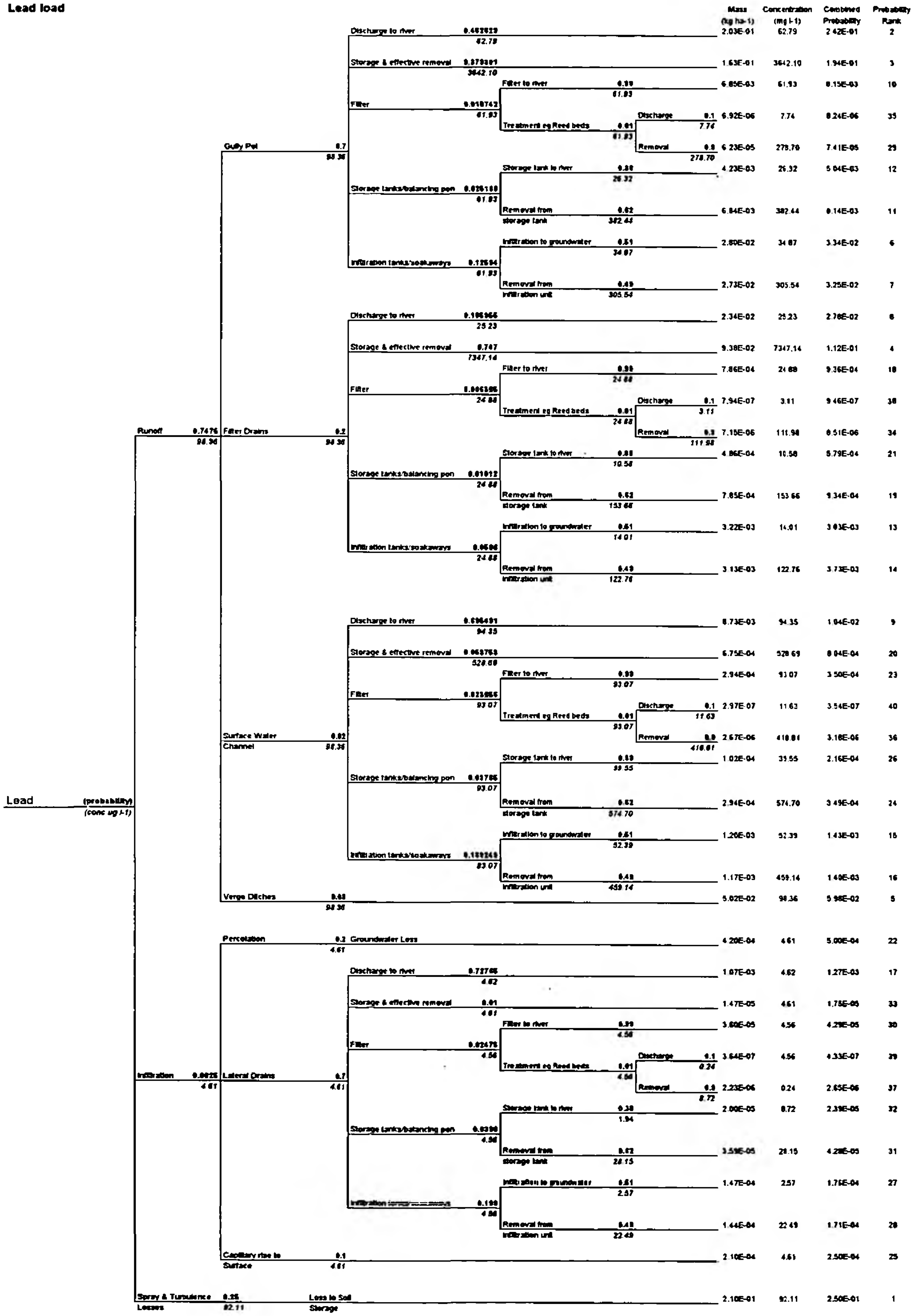

Mass (kg ha-1)
Concentration (mg l-1)
Combined Probability
Probability Rank
Lead
(probability)
(conc ug l-1)
Runoff
Infiltration
Spray & Turbulence Losses
Gully Pot
Filter Drains
Surface Water Channel
Verge Ditches
Percolation
Groundwater Loss
Lateral Drains
Capillary rise to Surface
Loss to Soil Storage
Discharge to river
Storage & effective removal
Filter
Filter to river
Treatment eg Reed beds
Discharge
Removal
Storage tanks/balancing pon
Storage tank to river
Removal from storage tank
Infiltration tanks/soakaways
Infiltration to groundwater
Removal from infiltration unit

Figure 6.3 - Copper event tree

Copper Loads

Copper loads (probability) (conc ug l-1)

Pathway	Sub-pathway	Treatment	Fate	Further fate	Mass (kg ha-1)	Concentration (mg l-1)	Combined Probability	Probability Rank
Runoff 0.7366 (67.97)	Gully Pot 0.7 (67.97)	Discharge to river 0.590348 (55.35)			1.79E-01	55.35	3.04E-01	1
		Storage & effective removal 0.196812 (1337.81)			5.98E-02	1337.81	1.01E-01	4
		Filter 0.02908 (54.60)	Filter to river 0.99 (54.60)		6.04E-03	54.60	1.02E-02	10
			Treatment eg Reed beds 0.01 (54.60)	Discharge 0.1 (6.82)	6.10E-06	6.82	1.03E-05	35
				Removal 0.9 (245.68)	5.49E-05	245.68	9.30E-06	33
		Storage tanks/balancing ponds 0.082128 (54.60)	Storage tank to river 0.38 (23.20)		3.73E-03	23.20	6.33E-03	13
			Removal from storage tank 0.62 (337.13)		6.03E-03	337.13	1.02E-02	11
		Infiltration tanks/soakaways 0.100838 (54.60)	Infiltration to groundwater 0.51 (30.74)		2.47E-02	30.74	4.19E-02	6
			Removal from infiltration unit 0.49 (269.34)		2.41E-02	269.34	4.08E-02	7
	Filter Drains 0.2 (67.97)	Discharge to river 0.185366 (17.43)			1.61E-02	17.43	2.74E-02	8
		Storage & effective removal 0.747 (5077.65)			6.48E-02	5077.65	1.10E-01	3
		Filter 0.008808 (17.20)	Filter to river 0.99 (17.20)		5.43E-04	17.20	9.21E-04	22
			Treatment eg Reed beds 0.01 (17.20)	Discharge 0.1 (2.15)	5.49E-07	2.15	9.30E-07	39
				Removal 0.9 (77.39)	4.94E-06	77.39	8.37E-06	36
		Storage tanks/balancing ponds 0.01012 (17.20)	Storage tank to river 0.38 (7.31)		3.36E-04	7.31	5.69E-04	24
			Removal from storage tank 0.62 (106.19)		5.42E-04	106.19	9.19E-04	23
		Infiltration tanks/soakaways 0.0606 (17.20)	Infiltration to groundwater 0.51 (9.68)		2.23E-03	9.68	3.77E-03	14
			Removal from infiltration unit 0.49 (64.84)		2.17E-03	64.84	3.67E-03	15
	Surface Water Chann 0.02 (67.97)	Discharge to river 0.71296 (66.84)			6.19E-03	66.84	1.05E-02	9
		Storage & effective removal 0.03 (203.92)			2.60E-04	203.92	4.41E-04	25
		Filter 0.02426 (65.93)	Filter to river 0.99 (65.93)		2.08E-04	65.93	3.53E-04	26
			Treatment eg Reed beds 0.01 (65.93)	Discharge 0.1 (8.24)	2.10E-07	8.24	3.57E-07	40
				Removal 0.9 (296.71)	1.89E-06	296.71	3.21E-06	37
		Storage tanks/balancing ponds 0.0331 (65.93)	Storage tank to river 0.38 (28.02)		1.29E-04	28.02	2.18E-04	30
			Removal from storage tank 0.62 (407.15)		2.08E-04	407.15	3.52E-04	27
		Infiltration tanks/soakaways 0.194 (65.93)	Infiltration to groundwater 0.51 (37.12)		8.53E-04	37.12	1.45E-03	18
			Removal from infiltration unit 0.49 (325.28)		8.31E-04	325.28	1.41E-03	19
	Verge Ditches 0.08 (67.97)				3.47E-02	67.97	5.88E-02	5
Infiltration 0.0146 (18.76)	Percolation 0.2 (18.76)	Groundwater Loss			1.71E-03	18.76	2.90E-03	16
	Lateral Drains 0.7 (18.76)	Discharge to river 0.72766 (18.83)			4.36E-03	18.83	7.39E-03	12
		Storage & effective removal 0.01 (18.76)			5.99E-05	18.76	1.02E-04	32
		Filter 0.02476 (18.57)	Filter to river 0.99 (18.57)		1.47E-04	18.57	2.49E-04	28
			Treatment eg Reed beds 0.01 (18.57)	Discharge 0.1 (0.99)	1.48E-06	18.57	2.51E-06	38
				Removal 0.9 (35.52)	9.07E-06	0.99	1.54E-05	34
		Storage tanks/balancing ponds 0.0396 (18.67)	Storage tank to river 0.38 (7.89)		8.16E-05	35.52	1.38E-04	31
			Removal from storage tank 0.62 (114.69)		1.46E-04	114.69	2.48E-04	29
		Infiltration tanks/soakaways 0.198 (18.57)	Infiltration to groundwater 0.51 (10.46)		6.01E-04	10.46	1.02E-03	20
			Removal from infiltration unit 0.49 (91.63)		5.85E-04	91.63	9.91E-04	21
	Capillary rise to surfa 0.1 (18.76)				8.56E-04	18.76	1.45E-03	17
Spray & Turbulence Losses 0.25 (64.69)	Loss to Soil Storage				1.48E-01	64.69	2.50E-01	2

Figure 6.4 - Zinc event tree

Zinc load

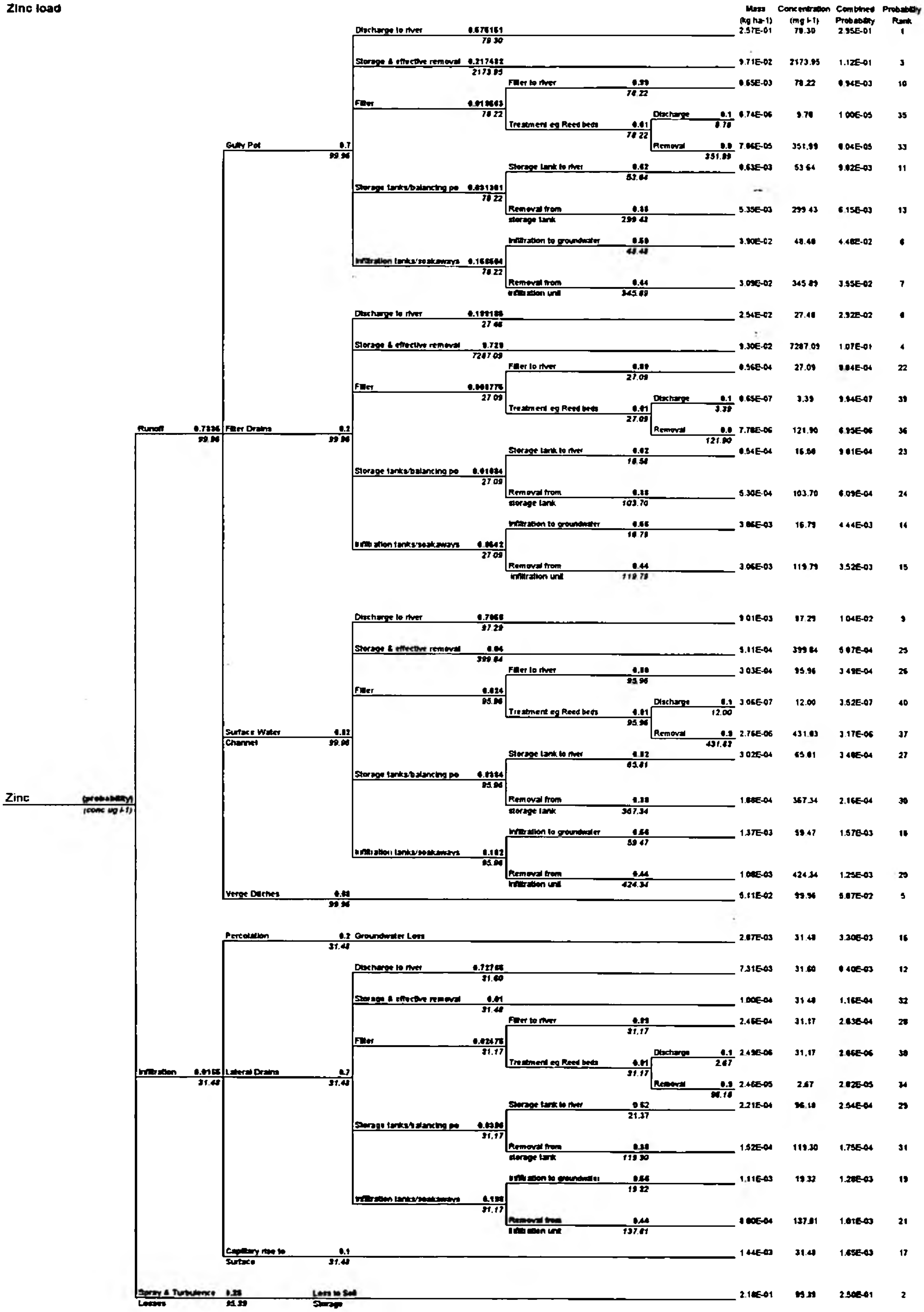

Zinc (probability) (conc ug l-1)
Runoff 0.7836 99.96
Infiltration 0.0155 31.48
Spray & Turbulence Losses 0.25 95.39
Loss to Soil Storage
Gully Pot 0.7 99.96
Filter Drains 0.2 99.96
Surface Water Channel 0.02 99.96
Verge Ditches 0.08 99.96
Percolation 0.2 31.48
Groundwater Loss
Lateral Drains 0.7 31.48
Capillary rise to Surface 0.1 31.48
Discharge to river
Storage & effective removal
Filter
Filter to river
Treatment eg Reed beds
Discharge
Removal
Storage tanks/balancing po
Storage tank to river
Removal from storage tank
Infiltration tanks/soakaways
Infiltration to groundwater
Removal from infiltration unit
Mass (kg ha-1)
Concentration (mg l-1)
Combined Probability
Probability Rank
2.57E-01 78.30 2.95E-01 1
9.71E-02 2173.95 1.12E-01 3
8.65E-03 78.22 8.94E-03 10
8.74E-06 9.78 1.00E-05 35
7.86E-05 351.99 8.04E-05 33
8.63E-03 53.64 9.82E-03 11
5.35E-03 299.43 6.15E-03 13
3.90E-02 48.48 4.48E-02 6
3.09E-02 345.89 3.55E-02 7
2.54E-02 27.48 2.92E-02 8
9.30E-02 7287.09 1.07E-01 4
8.56E-04 27.09 9.84E-04 22
8.65E-07 3.39 9.94E-07 39
7.78E-06 121.90 8.95E-06 36
8.54E-04 16.88 9.81E-04 23
5.30E-04 103.70 6.09E-04 24
3.86E-03 16.79 4.44E-03 14
3.06E-03 119.79 3.52E-03 15
9.01E-03 87.29 1.04E-02 9
5.11E-04 399.84 5.87E-04 25
3.03E-04 95.96 3.49E-04 26
3.06E-07 12.00 3.52E-07 40
2.76E-06 431.83 3.17E-06 37
3.02E-04 65.81 3.48E-04 27
1.88E-04 367.34 2.16E-04 30
1.37E-03 59.47 1.57E-03 18
1.08E-03 424.34 1.25E-03 20
5.11E-02 99.96 5.87E-02 5
2.87E-03 31.48 3.30E-03 16
7.31E-03 31.60 8.40E-03 12
1.00E-04 31.48 1.15E-04 32
2.46E-04 31.17 2.83E-04 28
2.49E-06 31.17 2.86E-06 38
2.46E-05 2.67 2.82E-05 34
2.21E-04 96.18 2.54E-04 29
1.52E-04 119.30 1.75E-04 31
1.11E-03 19.32 1.28E-03 19
8.80E-04 137.81 1.01E-03 21
1.44E-03 31.48 1.65E-03 17
2.18E-01 95.39 2.50E-01 2

Figure 6.5 - Output distributions for (a) Copper concentrations in road runoff, (b) Copper river concentrations, (c) River discharge required to meet EQS of 50 $\mu g\ l^{-1}$

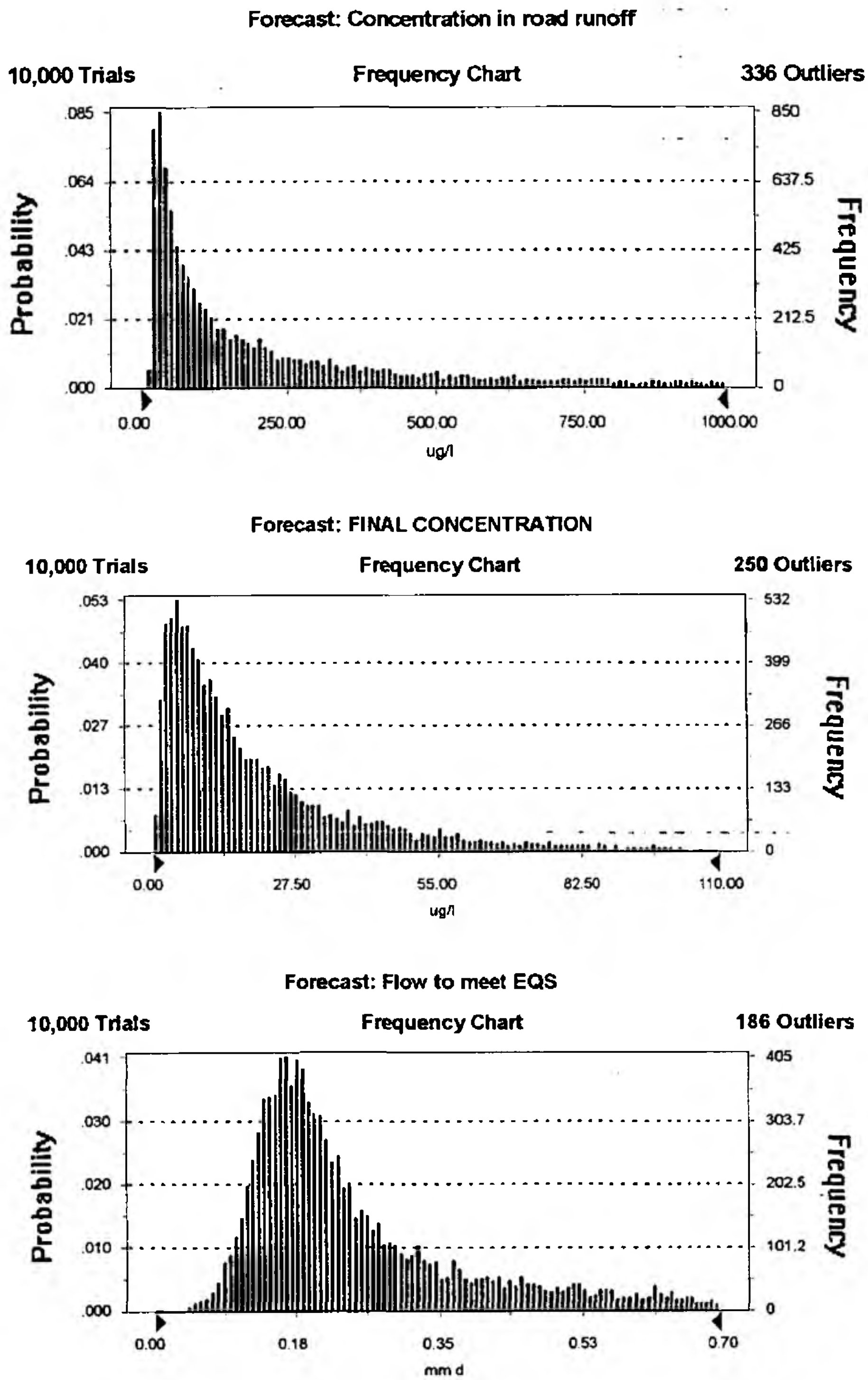
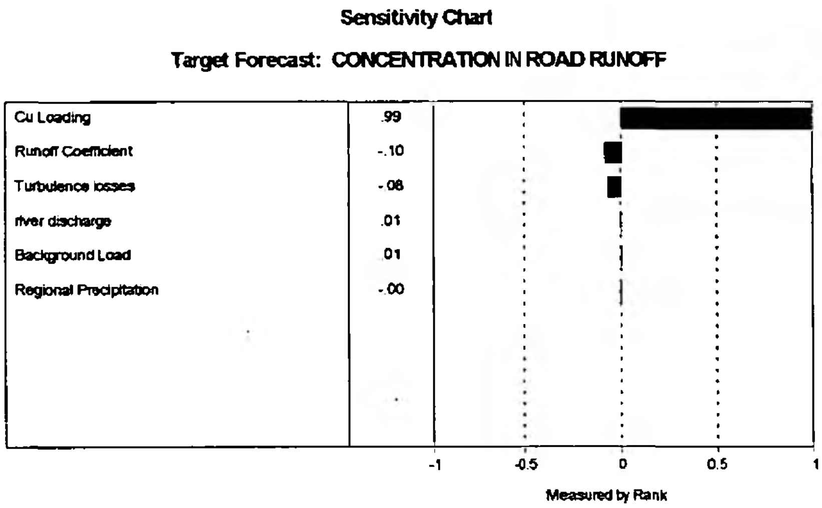
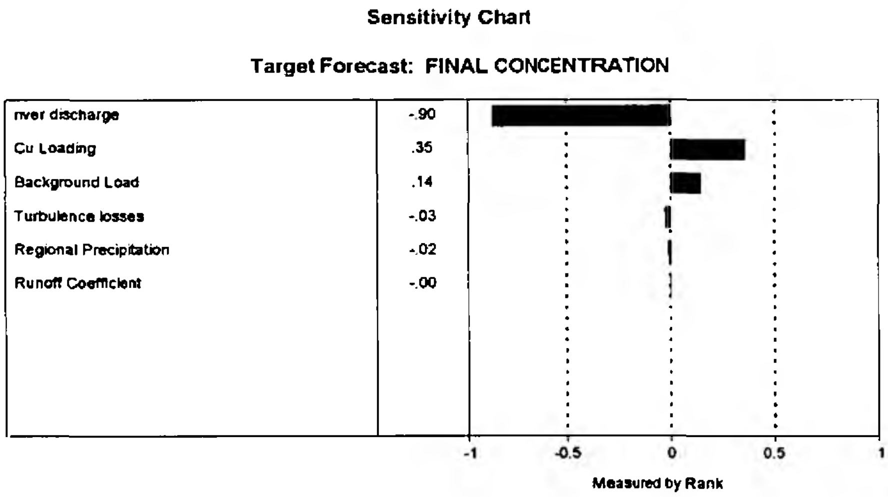


Figure 6.6 - Tornado charts for (a) Copper concentrations in road runoff, (b) Copper river concentrations, (c) River discharge required to meet EQS of 50 µg/l





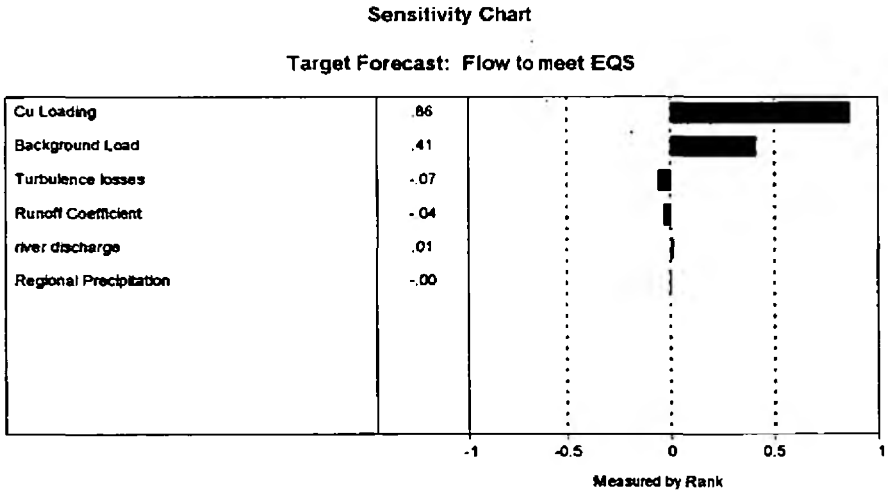


Table 6.9 - Water quality water balance probabilities

	P (X)	Explanation
		Level 1
Runoff	0.70	The amount of runoff as a percentage of total precipitation. Included in Monte Carlo simulation with a range between 0.50 - 0.90
Infiltration	0.05	The amount of rainfall that infiltrates into the road surface. Based on Baldwin *et al.*, 1997; Colwill *et al.*, 1984.
Turbulence losses and evaporation	0.25	Calculated as the balance of other components. Minimum value based on Colwill *et al.*,1984.
		Level 2
Gully pot	0.70	The main form of water collection from the road surface. Used on approximately 70 per cent of all roads in the UK (Luker and Montague, 1994).
Filter drain	0.20	Used on approximately 20 percent of all UK roads (Luker and Montague, 1994).
Surface water channel	0.02	A new form of drainage only used on new major roads (Luker and Montague, 1994). Calculated based on 50 per cent of all major roads (4 per cent) in England and Wales.
Verge ditches	0.08	The balance from the above.
Percolation	0.20	Expert judgement.
Lateral drains	0.70	Expert judgement.
Capillary rise to surface	0.10	Expert judgement.

		Level 3
River discharge	0.73	In most cases water is discharged directly to the nearest surface water. Calculated as the balance of other pathways.
Storage and removal	0.01	Estimate. Interstitial water in gully pot sediments.
Filter	0.02	Oil filters are present only on modern major roads (Luker and Montague, 1994). It was assumed that approximately 50 per cent of all motorways have oil filters.
Storage tanks/balancing ponds	0.04	Calculated as the exceedence probability for a 1:25 year storm.
Infiltration/ soakaways	0.20	Used on 20 per cent of UK roads (Luker and Montague, 1994).
		Level 4
Filter to river	0.99	Estimate based on Baldwin *et al.*, 1997.
Treatment	0.01	Estimate. There are very few examples of reed beds and other secondary treatment systems (Baldwin *et al.*,1997).
Storage tank to river	0.90	Estimate. Most stored stormwater is slowly released.
Removal	0.10	Estimate. A small amount of stored water lost to evaporation and percolation.
Infiltration to groundwater	0.90	Estimate.
Removal from infiltration unit/soakaway	0.10	Estimate. Minor losses due to evaporation and seepage to soil water store.
		Level 5
Discharge	0.80	Estimate based on Baldwin *et al.*, 1997.
Removal	0.20	Estimate based on Baldwin *et al.*, 1997. Evaporation and transpiration.

Table 6.10 - Probabilities for pollution loads based on selected values from Copper event tree

	P (X)	Explanation (Values for Copper)
		Level 1
Runoff	0.74	The mass in runoff calculated as the balance of infiltration and turbulence losses
Infiltration	0.01	Calculated based on the dissolved fraction of metal and the amount of infiltration
Turbulence losses and evaporation	0.25	Estimate based on transect study of pollution loads away from roads in Colwill *et al.*, 1994.
		Level 2
Gully pot	0.70	Luker and Montague, 1994. Based on water pathways.
Filter drain	0.20	Luker and Montague, 1994.
Surface water channel	0.02	Luker and Montague, 1994.
Verge ditches	0.08	Luker and Montague, 1994.
Percolation	0.2	Expert opinion
Lateral drains	0.7	Expert opinion
Capillary rise to surface	0.1	Expert opinion
		Level 3
River discharge	0.59	Mass balance. One minus other pathways.
Storage and removal	0.20	Sediment trapping efficiencies e.g. Karunartne, 1992, for gully pots.
Filter	0.02	Used on 50 percent of motorways. Based on data in Luker and Montague, 1994.
Storage tanks/balancing ponds	0.03	Assumed to operate in 1:25 year storms only.
Infiltration/ soakaways	0.16	Luker and Montague, 1994.

	Level 4	
Filter to river	0.99	Mass balance.
Treatment	0.01	Nuttel *et al.*, 1997.
Storage tank to river	0.38	One minus removal probability.
Removal	0.62	Filter efficiency of storage tank, Luker and Montague, 1994.
Infiltration to groundwater	0.90	One minus removal probability.
Removal from infiltration unit/soakaway	0.10	Filter efficiency of soakaway system, Luker and Montague, 1994.
	Level 5	
Discharge	0.10	One minus removal probability.
Removal	0.90	Removal efficiency or reed beds, Nuttel *et al.*, 1997 and Luker and Montague, 1994.

7. QUANTITATIVE RISK ASSESSMENT OF THE WATER QUALITY IMPACTS OF ACCIDENTAL SPILLAGES

INTRODUCTION

7.1 This section provides a quantitative risk assessment of the water quality impacts of accidental spillages of substances. Accidental spillages of industrial products such as motor spirits, chlorine and ammonia, or foodstuffs such as milk or beer, on roads are rare but can have a high environmental cost if not contained. Therefore modern motorways, trunk roads and principal roads are designed with safety valves which can be operated to prevent pollution incidents arising from such accidental spillages.

METHODOLOGY

7.2 The event tree for accidental spillages was based on the:

- likelihood of an accidental spillage occurring;
- probability of a rain day; and
- likelihood of the existence of pollution control structures such as control valves and storage ponds.

7.3 The event tree was constructed for motor spirits. The Health and Safety Commission (1991) have provided 2.1×10^{-8} as the incident frequency per tanker km for motor spirits tankers. This was employed in conjunction with the loaded tanker distance for 1994 of 1.29×10^{8} km (Health and Safety Executive, 1994) to obtain the incident frequency per year of 2.71. These data represent events involving spillages greater then 15 kg and less than 1,500 kg, therefore the lower limit of this range was utilised in the event tree in order to determine the minimum quantity of motor spirits that would enter a water course. The value of the incident frequency per year was used as the input probability for the event tree.

7.4 Once a liquid pollutant has escaped onto the road surface, the likelihood of containment is dependent on the environmental and accident conditions, in particular if the accident occurs during rainfall then the pollutant is likely to enter a water course. Therefore the probability of containment of the pollutant was estimated as one minus the probability of a rain day, that is 0.55. For Monte Carlo analysis a range of 0.4 - 0.5 with a normal distribution was assumed for the probability of a rain day. The likelihood of evaporation or volatilisation is dependent upon the substance spilt, spill dimensions and environmental conditions. For motor spirits atmospheric losses are low and a probability of 0.0002 was assumed in the event tree. In addition, it has been assumed that one per cent of the quantity of substance that is not contained infiltrates and therefore a probability of 0.0045 was assumed for infiltration. The remainder of the substance was assumed to run off.

7.5 The road drainage system was simplified for the event tree because there were no available data on the effectiveness of drainage structures in accident situations. Run off either enters a soakaway or surface water and the probability of entry into a soakaway was assumed to be dependent on the existence of these structures. Luker and Montague (1994) estimated that soakaways are present on 20 per cent of the roads in England and Wales, therefore a probability of 0.2 was employed for soakaways.

7.6 There are two opportunities to reduce pollution, first, with the use of stop valves and secondly, with oil filters. Modern motorways, trunk roads and principal roads include pollution control measures within their drainage systems. The proportion of roads that are major roads in England and Wales is 25 per cent (British Roads Federation, 1990). However only the modern major roads include these measures, therefore the proportion of major roads that include these measures was assumed to be 15 per cent. Based on the assumption that accidents occur with equal frequency on all road types, the probability of a safety valve being present was estimated to be equal to the proportion of roads that include these valves. The probability of the safety valve being operated depends on the accident response time of the emergency services and the existence of an immediate threat at the accident site, however in the event tree the probability of the safety valve being operated was assumed to be equal to the probability of it being present, that is 0.15. For Monte Carlo analysis a range of 0.05 - 0.25 with a normal distribution was assumed for the probability of a safety valve being operated.

7.7 Oil traps are present on 10 per cent of roads in England and Wales (Luker and Montague, 1994). Therefore a probability of 0.1 was assumed for the presence of an oil trap. The traps are designed to separate oil from water and are most effective in dealing with first flush effects rather than continuous oil removal. It was assumed that 50 per cent of oil entering a filter is removed from the road drainage system, therefore a probability of 0.5 was employed for the removal of oil. For Monte Carlo analysis a range of 0.4 - 0.6 with a normal distribution was assumed for the removal of oil. A final measure for pollution control in surface waters is the diversion of pollutant pulses and other clean up operations in rivers and streams. An estimated probability of 0.1 was assumed for diversion to a storage pond.

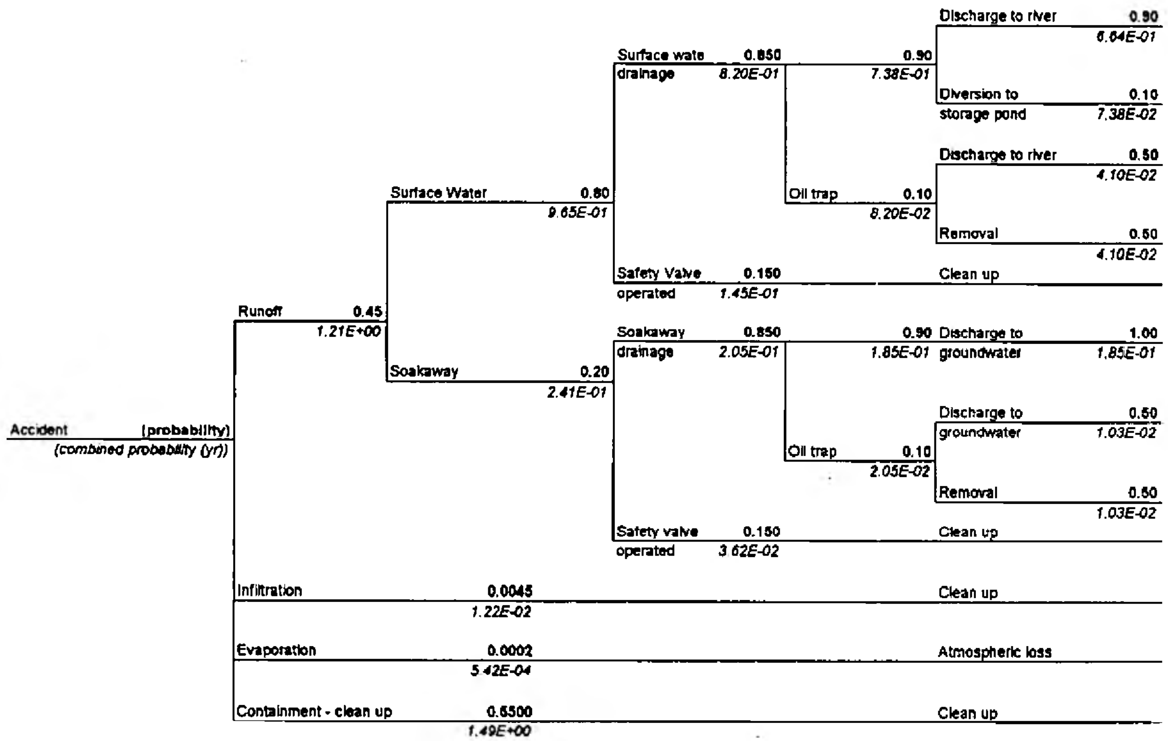
7.8 Figure 7.1 provides the event tree for accidental spillages, whilst Table 7.1 provides the parameters utilised to construct the event tree.

Table 7.1 - Parameters utilised in the event tree

Parameter	Value	Distribution	Comments
Incident frequency for motor spirits tankers	2.1×10^{-8} (tanker km)$^{-1}$	-	Obtained from Health and Safety Commission (1991)
Loaded tanker distance for 1994	1.29×10^{-8} km year^{-1}	-	Obtained from Health and Safety Executive (1994)
Mass of motor spirits spilt'	15 - 1,500 kg	-	Obtained from Health and Safety Commission (1991)

7.9 Table 7.2 provides the values of the branch probabilities utilised in the event tree.

Figure 7.1 - Event tree for accidental spillages



Mass kg	Probability yr	Combined Probability	Annual Mass kg yr-1	Combined Annual Probability	Probability Rank
3.679	6.64E-01	2.45E-01	9.97	1.80	2
0.409	7.38E-02	2.73E-02	1.11	0.20	5
0.227	4.10E-02	1.51E-02	0.62	0.11	6
0.227	4.10E-02	1.51E-02	0.62	0.11	6
0.802	1.45E-01	5.34E-02	2.17	0.39	4
1.022	1.85E-01	6.81E-02	2.77	0.50	3
0.057	1.03E-02	3.79E-03	0.15	0.03	10
0.057	1.03E-02	3.79E-03	0.15	0.03	10
0.200	3.62E-02	1.34E-02	0.54	0.10	8
0.068	1.22E-02	4.50E-03	0.18	0.03	9
0.003	5.42E-04	2.00E-04	0.01	0.00	12
8.250	1.49E+00	5.50E-01	22.36	4.04	1

Table 7.2 - Branch probabilities utilised in the event tree

Branch probability	Value	Comment
	Level 1	
Containment - clean up	0.55	1 - probability of a rain day
Evaporisation / volatilisation	0.0002	Estimate
Infiltration	0.0045	Equal to 1 per cent of the quantity of substance that is not contained
Run off	0.445	1 - all above values
	Level 2	
Soakaway	0.2	Obtained from Luker and Montague (1994)
Surface water	0.8	1 - above value
	Level 3	
Safety valve operated	0.15	Equal to presence of safety valve, which is approximated from proportion of roads that are major roads (Luker and Montague, 1994)
Surface water/soakaway drainage	0.85	1 - above value
	Level 4	
Oil trap in surface water/soakaway drainage	0.1	Luker and Montague (1994)
Continue in surface water/soakaway drainage	0.9	1-above
	Level 5	
Diversion to storage pond	0.1	Estimate
Continue in discharge to river	0.9	1-above
Removal in oil trap	0.5	Estimate
Continue in discharge to river/groundwater	0.5	1- above

7.10 The presence of 0.5 kg of motor spirits in a water course was taken to represent a pollution incident (Chatfield, 1998).

SENSITIVITY ANALYSIS

7.11 The following parameters were input as frequency distributions for the Monte Carlo analysis:

- the probability of a rain day;
- the probability of the presence of a safety valve; and
- the oil trap efficiency.

7.12 Table 7.3 provides an overview of the range of results obtained from the sensitivity analysis.

Table 7.3 - Overview of the range of results obtained from the sensitivity analysis

Parameter	Range of results		
	5th percentile	50th percentile	95th percentile
Mass of motor spirits entering river (kg)	3.54	3.90	4.29
Mass of motor spirits entering river on an annual basis (kg)	9.60	10.6	11.6
Percentage of spillage entering river	23.6	26.0	28.6
Percentage of spillage entering groundwater	6.52	7.18	7.90

7.13 The frequency distribution obtained for the mass of motor spirits entering the river was a normal distribution, and the mass always exceeded 0.5 kg. The annual mass entering the river was obtained by employing the value of 2.71 for the number of incidents in year. The frequency distribution obtained for this mass was also a normal distribution. The percentages of the spillage entering the river and groundwater were always greater than 21 and 5.8 per cent respectively.

7.14 The results of rank correlation indicated that the probabilities of a rain day and of the presence of a safety valve were overwhelmingly the most important parameters in determining the mass of motor spirits entering the river. The efficiency of the oil trap played a minor role.

CONCLUSIONS

7.15 This section has undertaken a risk assessment of the water quality impacts of accidental spillages of motor spirits. The constructed event tree demonstrated that overwhelmingly the most important parameters in determining the mass of motor spirits entering a river were the probability of a rain day and the presence of a safety valve. Under existing conditions an accidental spillage of motor spirits of greater than 15 kg will always lead to a pollution incident in the receiving watercourse.

8. QUANTITATIVE RISK ASSESSMENT OF THE WATER QUALITY IMPACTS DURING ROAD CONSTRUCTION

INTRODUCTION

8.1 This section presents a quantitative risk assessment of the water quality impacts during road construction. Discharges with high suspended sediment concentrations are an important environmental risk during road construction. Suspended sediment concentrations 100 to 300 times background levels have been recorded downstream of building construction sites (Wolman and Schick, 1987). High concentrations of suspended sediments in rivers discourage fish migration and destroy habitats for aquatic macrophytes.

METHODOLOGY

8.2 The event tree considers a mean rainfall event of 12.9 mm with a 60 minute duration, which is equivalent to the average hourly rainfall intensity with a return period of one year (DoE, 1983). This variable is input as a normal distribution with a standard deviation of 3 mm which covers a range of rainfall events with intensities from 3 mm h^{-1} to just over 20 mm h^{-1}. The latter rainfall intensity is equivalent to the average 1:100 year event in England and Wales. The branch probabilities of the event tree describe the pathways of sediment transfer from the construction site, into surface water.

8.3 Sediment enters surface waters due to runoff during high intensity rainfall events, wind erosion mostly during dry periods, disturbance of the stream banks during the construction of culverts and bridges and through the drainage system of off-site roads if construction vehicles and other plant are not cleaned.

8.4 Morgan's (1986) soil erosion model was used to estimate the amount of soil erosion in response to the design rainfall event. The amount of sediment entrained in runoff is a function of:

- the kinetic energy of rainfall;
- the slope angle and slope length of the construction site;
- local topographic conditions; and
- the depth of overland flow.

8.5 The amount of soil eroded (kg m^{-2}) is the minimum of the soil detachment rate (F) and the transport capacity (G).

- $F = K(E\ e^{-aA})^b\ 10^{-3}$

where K is the soil detachability index (J g^{-1}) which is defined as the weight of soil eroded per unit rainfall energy (set to 0.3 which is an average value), E is the kinetic energy of rainfall, A is a soil cover parameter which is 0 for bare soil and the exponents a and b are equal to 0.05 and 1 respectively.

- $G = C\ Q \sin S\ 10^{-3}$

where C is a soil management factor which is equal to 1 for bare soil, Q is the depth of overland flow (mm) and S is the site slope (degrees). The kinetic energy of the design rainfall event can be calculated as:

- $E = I\,(11.9 + 8.7 \log_{10} I)$

where I is the rainfall intensity. The depth of overland flow or runoff can be estimated using the Rational Method:

- $RO = C \times I \times A$

where RO is runoff in mm, C is a runoff coefficient between 0 and 1, and A is the road construction area. The runoff coefficient was set to 0.8 for a compacted soil surface which allows 20 per cent of rainfall to infiltrate or evaporate during the storm event.

8.6 This model was used in the second level of the event tree. The model input parameters and intermediate calculations are summarised in Table 8.1. The probability of erosion is estimated as the soil erosion rate divided by the bulk density or, in other words as the percentage of the top one metre of soil that is entrained in overland flow. The soil erosion probability is highly sensitive to amount of rainfall and will range from 0 to a maximum of around 24 per cent for a rainfall intensity of 20 mm per hour.

Table 8.1 - Input parameters and soil erosion calculations

	Mean	Units	Distribution	Explanation
Bulk density	1.30	kg m^{-3}	Normal	Typical value for Sandy loam soil. Range 1.1 - 1.5
Average slope	2.00	degrees	Normal	Estimated mean site slope including road and embankments. Range 0.01 - 5
Runoff coefficient	0.80	-	Normal	Used to calculate runoff volume using Rational Method. Range 0.7-0.9
Design event precipitation	12.9	mm	Normal	TRRL/FSR (1:1 year 60min) s.d. 3 mm.
Runoff	10.33	mm	-	Rational Method.
Rate of detachment	0.083	kg m^{-2}	-	Calculated in soil erosion model (Morgan, 1986).
Transport capacity	0.004	kg m^{-2}	-	Calculated in soil erosion model (Morgan, 1986).
Erosion	0.004	kg m^{-2}	-	Calculated in soil erosion model (Morgan, 1986).
Percentage eroded	0.28	%	-	Calculated in soil erosion model (Morgan, 1986).
Control structure efficiency	0.90		Normal	Estimate - based on discussion with engineers - range 0.8 - 1.0
Vehicle cleaning efficiency	0.50		Normal	Estimate - based on discussion with engineers - range 0 -1
Sediment trapping efficiency	0.75		Normal	Estimate - based on discussion with engineers - range 0.5 - 1
Redeposition	0.10		Normal	Expert judgement - function of local topography - range 0-0.2

8.7 There is very little information regarding the amount of sediment derived from bank disturbance, wind erosion and from site vehicles but they are included as alternative pathways for sediment transport to surface waters. The probabilities of these pathways were based on discussions with road engineers and the expert opinion of water quality scientists. The former group emphasised the high standards that can be adopted on site to ensure that any discharges meet EA discharge consents and havë lower suspended sediment concentrations than the receiving water body. However, many cases of high suspended sediments downstream of construction sites have been observed and reported in the literature (e.g. Wolman and Schick, 1987) so it was assumed that the best management practices for sediment control were not always adopted.

8.8 The branch probabilities for the event tree are summarised in Table 8.2. The probability of wind erosion and attachment to vehicles were set to 0.01 and 0.05 respectively. The probability of bank disturbance was set to 0.05. Where a road is constructed alongside or across a river the likelihood of a bank disturbance may be higher. However, the event tree considers road locations at various positions in the catchment not just in the flood plain.

Table 8.2 - Summary of branch probabilities

Branch probability	Value	Explanation
	Level 1	
Transport in runoff	0.0028	Calculated using soil erosion model for 1:1 year storm event (NERC, 1975 and Morgan, 1986)
Transport by wind	0.01	Guess
Attachment to vehicles	0.05	Estimate
River bank disturbance	0.01	Estimate based on the area of water features in England and Wales.
Earthworks	0.92	1 - all of above
	Level 2	
Control structures	0.75	Estimate based on discussion with engineers
Redeposition	0.10	Estimate

Discharge to stream	0.15	1 - all of the above
Loss to catchment stores	0.80	Expert judgement
Redeposition in surface waters	0.10	Expert judgement
Redeposition on site	0.10	Expert judgement
Removal by cleaning	0.50	Estimate based on discussion with engineers
Detachment on site	0.25	Expert judgement
Detachment off site	0.25	Expert judgement
	Level 3	
Removal	0.90	Estimate based on discussion with engineers
Discharge	0.10	1 - above

8.9 Level 2 of the event tree considers a range of sediment control structures that may be installed by the road contractor to ensure compliance to discharge consents and minimise environmental impacts. These include temporary drainage structures to divert flow from areas of exposed soil; the use of geotextiles or other temporary soil cover; sediment traps or sediment lagoons along drainage lines and vehicle cleaning equipment with closed water systems. There are very few data concerning the use of these measures for road construction so sediment control measures were combined into a single sediment trapping efficiency. The average sediment control efficiency was set to 75 per cent, with a range between 50 per cent and 100 per cent, based on discussions with engineers.

8.10 The total sediment mass per kilometre of carriageway was calculated using the soil bulk density, a standard unit width of road (3.65 m) and by considering that the top metre of soil was available for movement into earthworks and sensitive to erosion and attachment to vehicles. The impact of increased sediment loads on surface waters was estimated in the same way as for the run off event trees in section 6. For comparison with the EQS for suspended sediment (25 mg l^{-1} for drinking water abstraction), it was assumed that the eroded sediment was diluted by the mean daily flow. Both the mean daily flow and the background suspended sediment concentration were input to the sensitivity analysis as frequency distributions.

RESULTS AND SENSITIVITY ANALYSIS

8.11 The event tree (Figure 8.1) represents a general description of the contribution of road construction to suspended sediment concentrations. It is based on a large number of assumptions and in specific examples of road construction the suspended sediment concentrations may be higher or lower than the range of values "predicted" by the event tree.

8.12 Under average conditions most sediment (88 per cent) on site is incorporated into ground works for road construction. Around 2 per cent of sediment is removed in control structures and less than 0.5 per cent is deposited into surface water. The remainder is deposited elsewhere in the catchment from dirty vehicles or by wind erosion and deposition.

8.13 This small amount of sediment may however have a large impact on water quality. The mean road discharge and final river suspended sediment concentrations were 355 mg l^{-1} and 70 mg l^{-1} respectively. This suggests that road construction discharges are typically 14 times the EQS for suspended sediment concentrations in drinking water and that final river concentrations are almost three times the suspended sediment EQS.

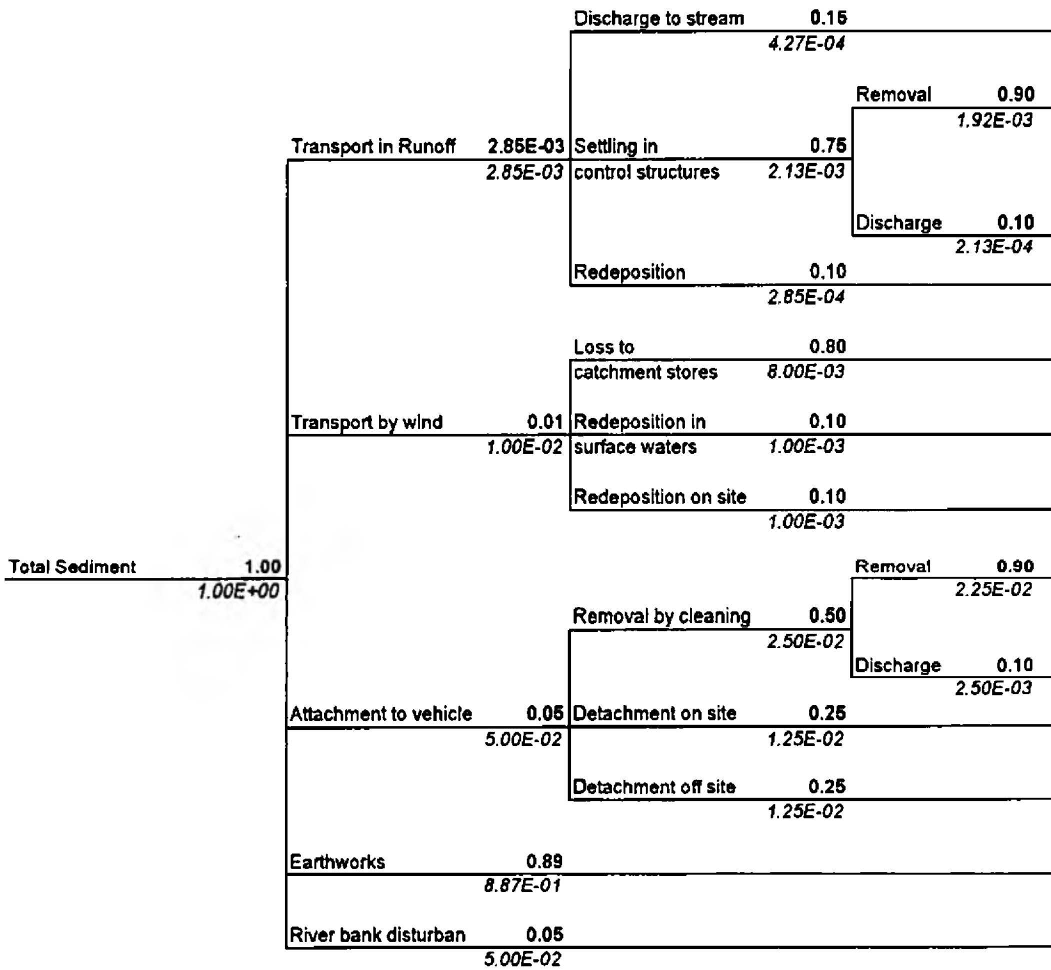
8.14 The concentration of road discharges was most sensitive to the efficiency of temporary control structures, vehicle cleaning practices and rainfall intensity. The final river concentrations were controlled by river discharge. Figures 8.2 and 8.3 provide a summary of the results of the sensitivity analysis.

CONCLUSIONS

8.15 The construction event tree traces the pathways of water and sediment loads from the construction site to surface water. Most sediment is incorporated into the ground works of the road but suspended sediment discharges can impact considerably on surface water quality, in particular when intense storms coincide with periods of lower summer flow.

Figure 8.1 - Sediment event tree

Sediment erosion during construction



Mass kg/km carriageway	Probability	Rank
2.03	4.27E-04	11
9.11	1.92E-03	8
1.01	2.13E-04	13
1.35	2.85E-04	12
37.96	8.00E-03	6
4.75	1.00E-03	9
4.75	1.00E-03	9
106.76	2.25E-02	3
11.86	2.50E-03	7
59.31	1.25E-02	4
59.31	1.25E-02	4
4209.55	8.87E-01	1
237.25	5.00E-02	2

Figure 8.2 - Output frequency distributions for (a) suspended sediment concentrations, (b) final river concentrations, (c) river flow required to meet EQS of 25mg l^{-1}

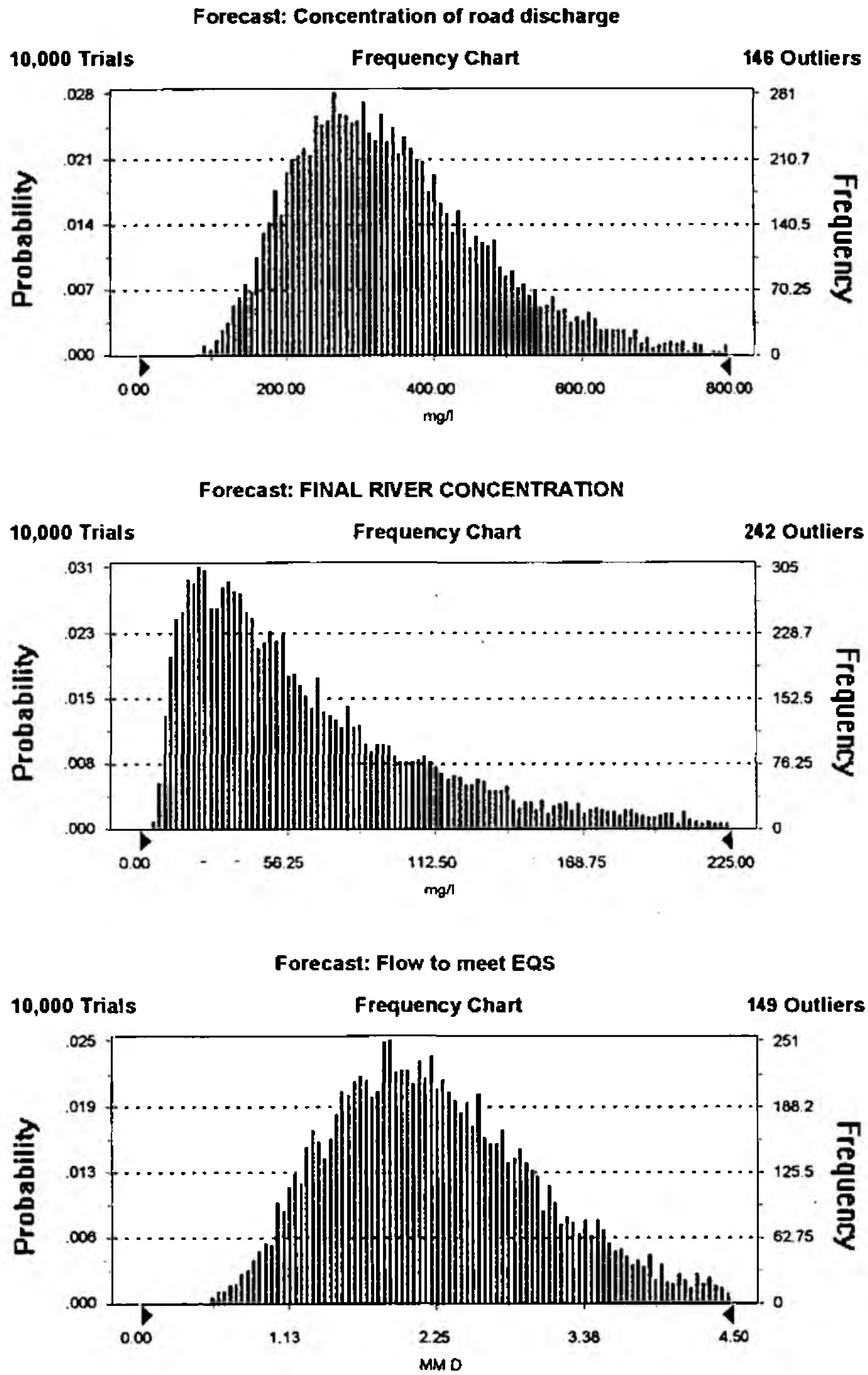
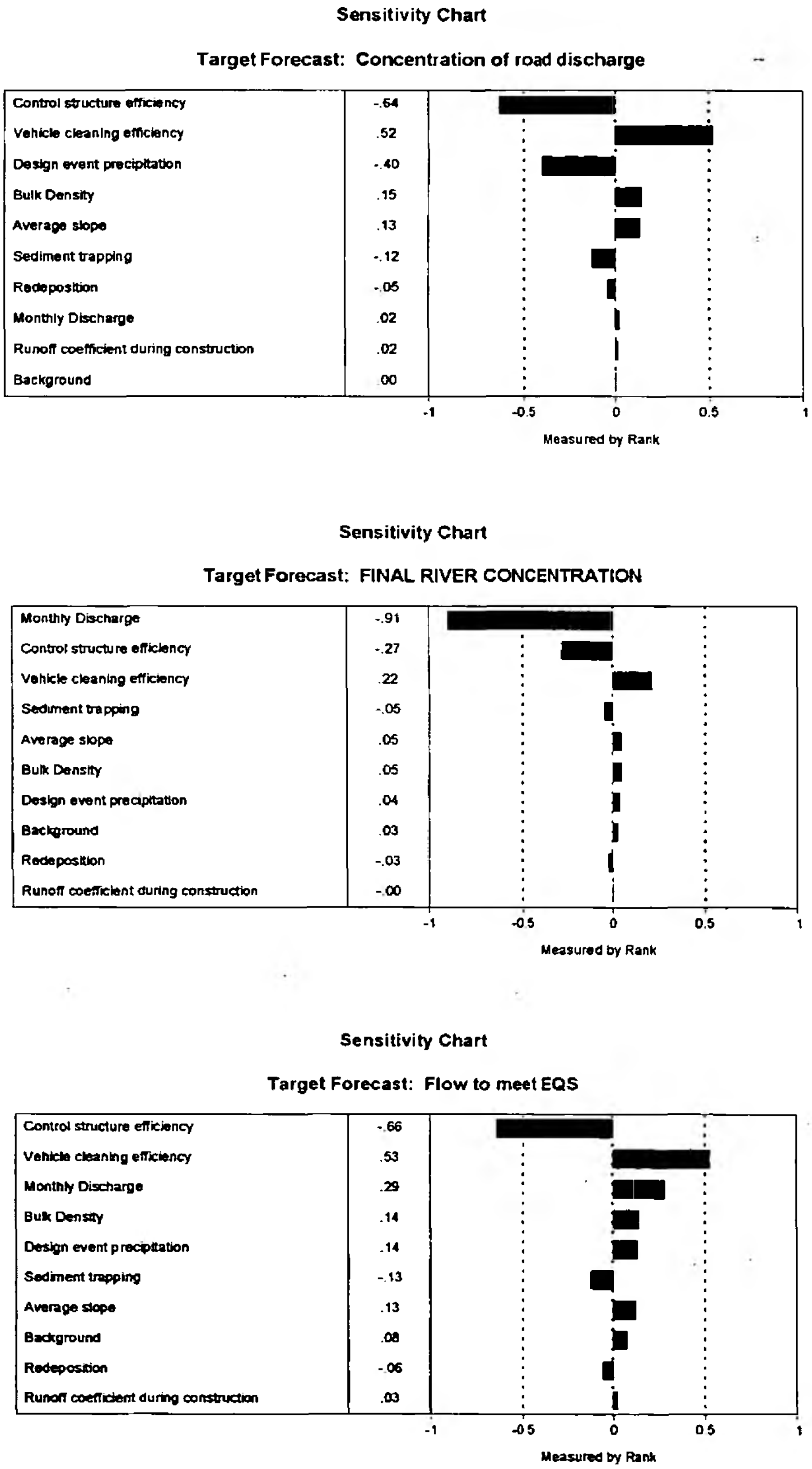


Figure 8.3 - Sensitivity analysis Tornado charts for (a) suspended sediment concentrations, (b) final river concentrations, (c) river flow required to meet EQS of 25mg l^{-1}



9. QUANTITATIVE RISK ASSESSMENT OF THE WATER QUALITY IMPACTS OF ROAD MAINTENANCE

INTRODUCTION

9.1 This section provides a quantitative risk assessment of the water quality impacts of road maintenance. Road maintenance covers a wide variety of procedures from carriageway repairs to winter operations to keep roads free from ice and snow. Based on discussions with the EA (Chatfield, 1998), gully pot cleaning was selected as the procedure to be considered. The importance of gully pot cleaning was confirmed by the fact that this is cited as causing local pollution events (Latimer, 1997) and three EA regions have reported pollution incidents as a result of the procedure (Osborne *et al.*, 1998).

METHODOLOGY

9.2 For the purposes of constructing the event tree emphasis was placed on consideration of:

- the quantities of ammonia discharged through gully pot outlets per hectare during a four hour period;
- the presence of filters/treatment processes or infiltration devices/soakaways in the drainage system; and
- dilution in the receiving river.

9.3 Osborne *et al.* (1998) have studied maintenance procedures for gully pots. The study was based on operations in Oxfordshire, but in the absence of more appropriate data has been taken to be representative of operations throughout England and Wales. A planned cleaning frequency for gullies of once per year is now becoming more common and a team of two operatives will typically empty 80 to 140 gullies per day

(Osborne *et al.*, 1998). A single gully will typically serve 200 m^2 of road (Luker and Montague, 1994) which implies a gully density of 50 per hectare. A batch of 50 gully pots will be emptied over a four hour period. Gully pots are cleaned using vacuum tankers with a capacity of 4,000 to 8,000 litres which normally contain a fixed divide providing an approximate 1:2 split of tanker capacity (Osborne *et al.*, 1998). The smaller section of the tank holds clean water whilst the larger holds collected gully pot liquor and sediment (black water).

Stages of gully pot cleaning

9.4 The first stage of the cleaning process involves removing the water and sediment from the gully pot. After the gully liquor has been sucked out, alternative treatments can be applied (Osborne *et al.*, 1998). The most common method of treatment is to loosen the hardened sediment by physically disturbing it and discharging black water from the tanker into the gully pot (backwashing). Normally some black water is discharged through the gully pot outlet during the sediment flushing process. This discharge is typically 10 litres per gully, but in some cases the discharge can be much greater (Osborne *et al.*, 1998). Therefore, 10 litres was taken to be the best estimate for the discharge per gully and for Monte Carlo analysis a range of 1 to 50 litres with a log normal distribution was assumed. In addition, it has been found that approximately 10 per cent of the sediment originally present in the pot is discharged through the gully pot outlet (Luker and Montague, 1994).

9.5 Osborne *et al.* (1998) provided results of the analysis of water discharged from gully pot outlets during backwashing of the pots with black water. These results are extremely limited as only four samples were analysed, but a value of 16 mg l^{-1} ammonia (as nitrogen) was taken as a best estimate for the concentration. Therefore the load of ammonia discharged per hectare during backwashing was taken to be 8,000 mg as a best estimate with a range of 800 to 24,000 mg with a log normal distribution. It has been assumed that all the ammonia is in solution.

9.6 Alternatives to backwashing with black water involve blocking the outlet to the gully with an airbag before cleaning, and loosening the sediment with high pressure jets of clean water which discharge through a ring of nozzles mounted on the end of a suction pipe. For both of these alternatives the load of ammonia and volume of water discharged from the gully pot outlet will be zero (Osborne *et al.* 1998). Probabilities of 0.001 and 0.05 respectively were assigned to the alternative treatments of employing an airbag and employing a jetter (Butler, 1998). These two treatments were combined to provide a single branch of the event tree with a probability of 0.051. Therefore a probability of 0.949 was assigned to backwashing with black water, which may or may not include discharge of black water. Assuming that the term 'normally' describes an event that occurs with a probability of 0.9, then the probability of black water being discharged during backwashing is 0.854 and the probability that no black water will be discharged during backwashing is 0.0949. In the latter situation discharge from the gully outlet during cleaning is zero.

9.7 The second stage of the cleaning process involves refilling the gully pots. This includes overfilling the gully and allowing the excess water to drain away in order to test that the outlet is not blocked. This leads to a discharge of at least 30 litres per gully (Osborne *et al.*, 1998). Therefore, 45 litres was taken as a best estimate of the discharge per gully and for Monte Carlo analysis a range of 30 to 60 litres (5th and 95th percentiles) with a normal distribution was assumed. Normal practice for most operators is to use black water for this process. Therefore using the previously quoted value of 16 mg l^{-1} ammonia (as nitrogen) as the best estimate of the concentration of ammonia in black water discharged during refilling, the load of ammonia discharged per hectare during refilling with black water was taken to be 36,000 mg as a best estimate with a range of 24,000 to 48,000 mg (5th and 95th percentiles) with a normal distribution. Osborne *at al.* (1998) provided one result for the analysis of water discharged from gully pots during the backwashing of a pot with clean water. This result of 3 mg l^{-1} ammonia (as nitrogen) was employed to represent the best estimate of the concentration of ammonia in water discharged from the gully outlet during refilling with clean water. Therefore the load of ammonia discharged per hectare during refilling with clean water was taken to be 6,750 mg as a best estimate with a range of 4,500 to 9,000 mg (5th and 95th percentiles) with a normal distribution.

9.8 Assuming that the term "normal practice for most operators" describes an event that occurs with a probability of 0.9, then the probability of the black water being employed to refill the gully pot is assumed to be 0.9 and the probability that clean water will be employed to refill the pot is 0.1.

9.9 After cleaning and refilling of the gully pots the excess liquid contained in the tanker must be disposed of prior to the disposal of the sediment to a licensed landfill site. As each gully should give rise to 50 to 100 litres of dirty water and sediment for disposal (Osborne *et al.*, 1998) this means that 2,500 to 5,000 litres will arise from the emptying of the 50 pots per hectare. This is approximately equal to the available volume of the vacuum tanker for carriage of black water. Assuming that approximately 50 percent of this volume is water, on the basis that the capacity of a gully pot for sediment is approximately half of its total volume (Reid, 1998), the volume of water that will arise from the emptying of 50 pots was assumed to be 1,250 to 2,500 litres (5th and 95th percentiles) as a normal distribution with a best estimate of 1,880 litres. In the situation where clean water has been used to refill the gully pots it would be expected that all of this dirty water will be present in the tanker. Where dirty water is used to refill the gully pots it has been found that little or no excess water is left in the tanker for disposal (Osborne *et al.*, 1998). The majority of the volume of the tanker will be occupied by sediment, which will amount to 2,500 to 5,000 litres of sediment arising from approximately 100 pots. Therefore it was assumed that the best estimate of the volume of water in the tanker in this case was approximately 200 litres.

9.10 Osborne *et al.* (1998) indicated that there are two common methods of disposal of black water; to discharge it through the next gully and to discharge it to a manhole on a foul sewer. Assuming that the term "common" describes an event that that occurs with a probability of 0.7 and that there is equal likelihood of either of the two methods being employed, a probability of 0.35 was assigned to both of these methods. The other methods mentioned by Osborne *et al.* (1998) are acceptance of the water at the sewage treatment works, discharge to infiltration trenches which have been constructed in an approved manner, and disposal at a licensed landfill site. Assuming that these three options are employed on an equal basis, then a probability of 0.1 was assigned to each. All methods of disposal apart from the first will lead to zero discharges from a gully outlet, therefore these methods of disposal were grouped together with an overall probability of 0.65. For the first method of disposal where clean water has been used to refill the gully pots, the dirty water arising from 50 gully pots is assumed to be disposed of per hectare. Whilst for the first method of disposal where black water has been used to refill the gully pots, 100 litres of dirty water is assumed to be disposed of per hectare.

9.11 Osborne *et al.* (1998) provide results of the analysis of black water taken from tankers. The results are extremely limited as only four tankers were sampled, but a value of 16 mg l^{-1} ammonia (as nitrogen) was taken as the best estimate of the concentration. Where clean water has been used to refill the gully pot the load of ammonia discharged through the gully during tanker emptying was taken to be 30,000 mg as a best estimate and for Monte Carlo analysis a range of 20,000 to 40,000 mg (5th and 95th percentiles) with a normal distribution was assumed. Where black water has been used to refill the gully pots the load of ammonia discharged through the gully during tanker emptying was taken to be 1,600 mg as a best estimate. It has been assumed that these loads of ammonia are discharged through the gully outlet.

9.12 For both water and ammonia the total discharges from the gully outlets amount to the sum of the discharges from the two stages of gully pot cleaning plus the discharge arising from the disposal of excess liquid from the gully cleaning tanker.

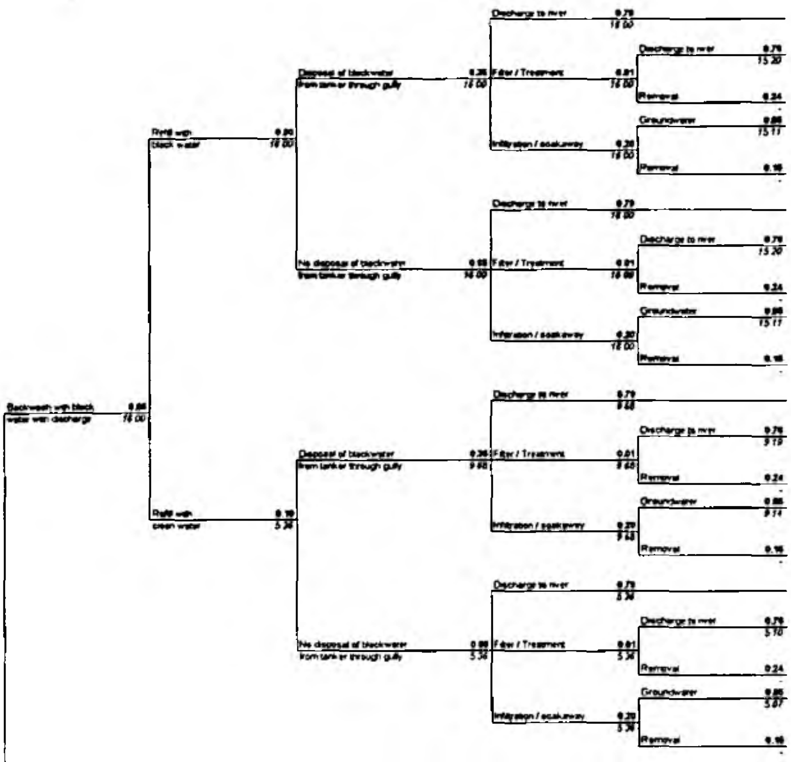
Pathway from gully pot outlet

9.13 After the gully outlet there are three possible pathways that the water and ammonia can follow: discharge to river, passage through a filter or treatment process, or entry into an infiltration system or soakaway. The probabilities for the last two pathways were assigned according to the presence of these facilities on roads in England and Wales. Therefore a probability of 0.2 (Luker and Montague, 1994) was assigned to the infiltration system or soakaway and 0.01 to the filter or treatment process. The latter probability is an estimate based on data from Nuttall *et al.* (1997) and Luker and Montague (1994). Storage tanks or balancing ponds have not been considered as a possible route as it has been assumed that gully cleaning will not be undertaken during a storm.

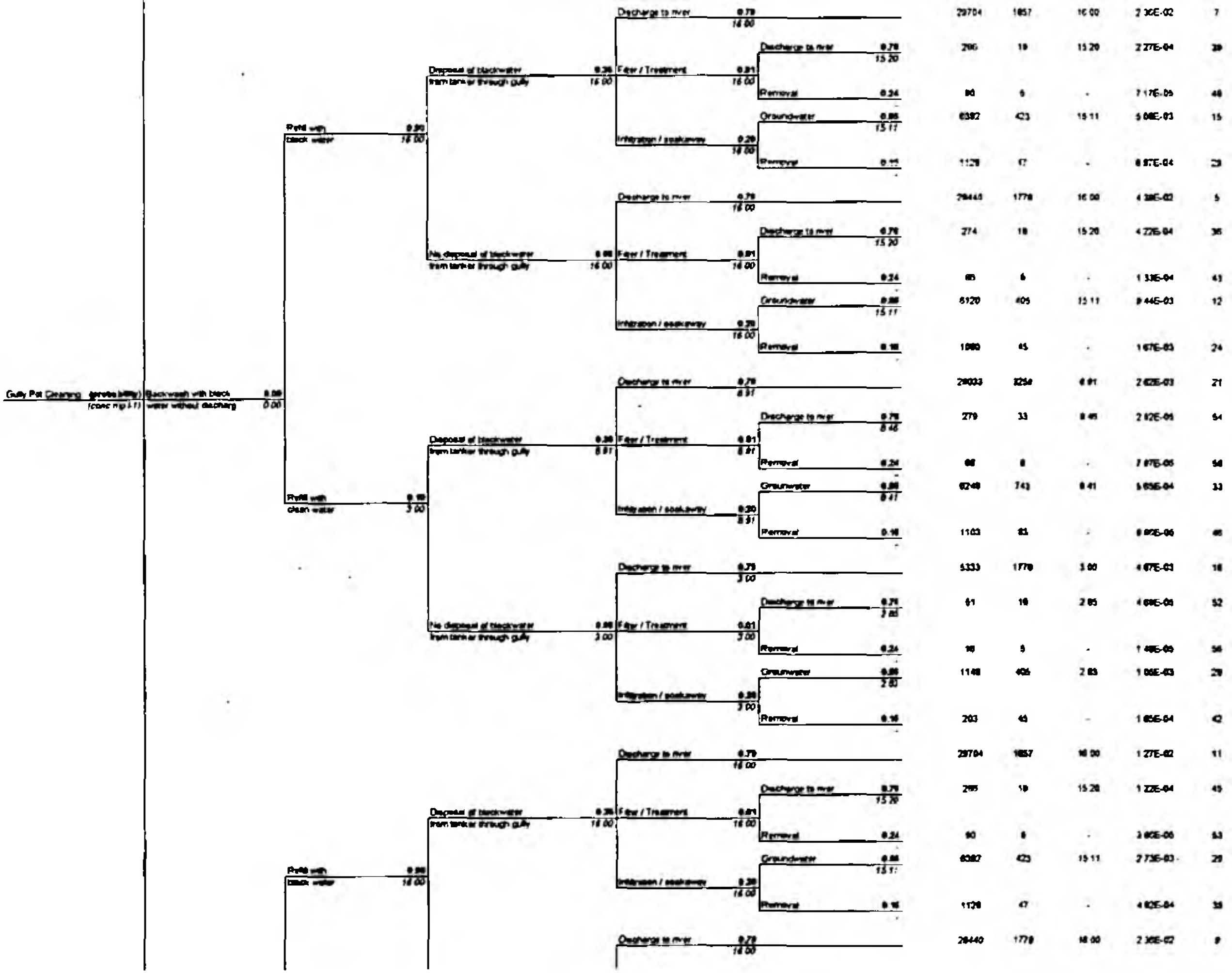
9.14 In the filter or treatment process 24 per cent of the ammonia and 20 per cent of the water were assumed to be removed (Nuttall *et al.*, 1997), with a range of 2 to 46 per cent based on data from Nuttall *et al.* (1997) in the former case. Therefore a probability of 0.24 was assigned to removal of ammonia within the process. In the infiltration or soakaway process 15% of the ammonia and 10% of the water were assumed to be removed. The former percentage is based on expert opinion whilst the latter was obtained from Nuttall *et al.* (1997). Therefore a probability of 0.15 was assigned to removal of ammonia within the process.

9.15 Figure 9.1 provides the event tree for water quality impacts of road maintenance, whilst Tables 9.1 and 9.2 provide the parameters and the branch probabilities utilised in the event tree.

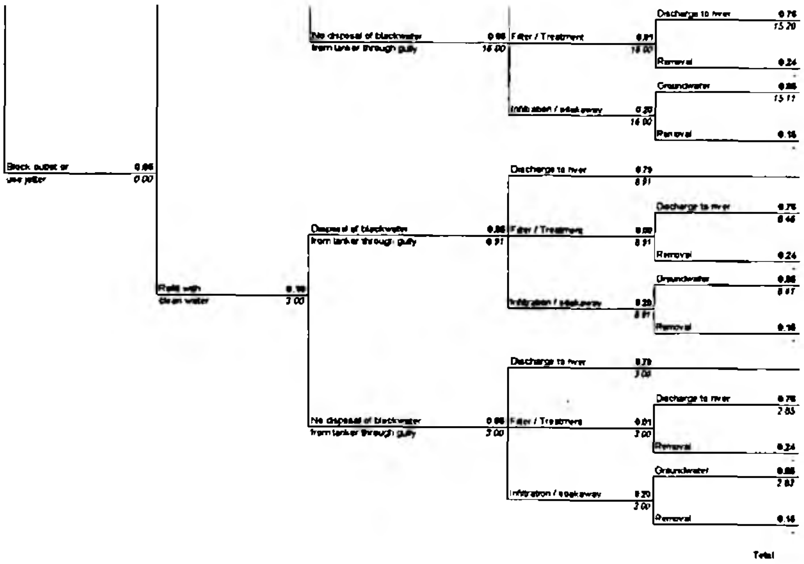
Figure 9.1 - Event tree for water quality impacts of road maintenance



Mass (mg)	ater Volume (l)	Concentration (mg l-1)	Combined Probability	Probability Rank
38024	2252	16.80	2.13E-01	2
347	23	15.20	2.04E-03	23
100	6	-	6.40E-04	32
7712	513	15.11	4.57E-02	4
1358	57	-	8.07E-03	14
34768	2173	16.80	3.95E-01	1
334	22	15.20	3.80E-03	19
105	6	-	1.20E-03	27
7480	495	15.11	8.48E-02	3
1329	56	-	1.50E-02	10
35353	3894	9.08	2.30E-02	7
340	37	9.19	2.27E-04	38
107	9	-	7.17E-05	48
7030	833	9.14	5.09E-03	15
1343	93	-	6.87E-04	29
11653	2173	5.35	4.38E-02	5
112	22	5.10	4.22E-04	35
35	6	-	1.33E-04	43
2508	495	5.07	8.44E-03	12
441	85	-	1.67E-05	24


Gully Pot Cleaning
Backwash with black water without discharg
Refill with black water
Refill with clean water
Disposal of blackwater from tanker through gully
No disposal of blackwater from tanker through gully
Discharge to river
Filter / Treatment
Infiltration / soakaway
Removal
Groundwater

pbreak



274	18	15 20	2 27E-04	41
86	5	-	7 16E-05	50
8120	405	15 11	6 07E-03	17
1080	45	-	8 86E-04	31
29033	3258	8 91	1 41E-03	26
278	33	8 46	1 36E-05	67
88	8	-	4 28E-06	60
8248	743	8 41	3 63E-04	38
1103	83	-	5 30E-05	61
5333	1778	3 00	2 62E-03	22
81	18	2 85	2 52E-05	56
16	5	-	7 80E-06	60
1148	405	2 83	5 64E-04	34
203	45	-	8 06E-05	47
383300	34925		1 00E+00	

Table 9.1 - Parameters utilised in the event tree

Parameter	Value	Distribution	Comments
Number of gullies cleaned per day	80 - 140	-	Obtained from Osborne *et al.* (1998)
Area of road served by a gully	200 m^2	-	Obtained from Luker and Montague (1994)
Capacity of vacuum tanker	4,000 - 8,000 l	-	Obtained from Osborne *et al.* (1998)
Ratio of vacuum tanker capacity between clean water and black water	1:2	-	Obtained from Osborne *et al.* (1998)
Volume of water discharged during backwashing of gully pots with black water when discharge occurs	10 l	Log normal	Obtained from Osborne *et al.* (1998)
Ammonia (as nitrogen) concentration in discharge from gully pot during backwashing with black water	16 mg l^{-1}	-	Obtained from Osborne *et al.* (1998)
Volume of water discharged during backwashing of gully pot when airbag or jetter employed	Zero	-	Obtained from Osborne *et al.* (1998)
Volume of water discharged from gully pot during refilling	45 l	Normal	Obtained from Osborne *et al.* (1998)
Ammonia (as nitrogen) concentration in discharge from gully pot during backwashing with clean water	3 mg l^{-1}	-	Obtained from Osborne *et al.* (1998)
Volume of water and sediment in a gully pot	50 - 100 l	Normal	Obtained from Osborne *et al.* (1998)
Fraction of total capacity of gully pot for sediment	0.5	-	Obtained from Personal Communication (1998c)
Volume of black water in full tanker when clean water used to refill gully pots	1,880 l	Normal	Expert opinion

Volume of black water in full tanker when dirty water used to refill gully pots	200 l	-	Expert opinion
Concentration of ammonia (as nitrogen) in black water from tanker	16 mg l^{-1}	-	Obtained from Osborne *et al.* (1998)
Ammonia removal during filter or treatment process	24%	Normal	Obtained from Nuttall *et al.* (1997)
Water removal during filter or treatment process	20%	-	Obtained from Nuttall *et al.* (1997)
Ammonia removal during infiltration or soakaway process	15%	-	Expert opinion
Water removal during infiltration or soakaway process	10%	-	Obtained from Nuttall *et al.* (1997)

Table 9.2 - Branch probabilities utilised in the event tree

Branch probability	Value	Comment
	Level 1	
Block outlet or use jetter	0.051	Personal Communication (1998b)
Backwash with black water with discharge	0.854	1 - above value combined with assumption for 'normal practice'
Backwash with black water without discharge	0.0949	1 - all above values
	Level 2	
Refill with black water	0.9	Assumption for 'normal practice'
Refill with clean water	0.1	1 - above value
	Level 3	
Disposal of black water from tanker through gully	0.35	Assumption for 'common practice' combined with equal likelihood of two alternatives
No disposal of black water from tanker through gully	0.65	1 - above value
	Level 4	
Filter or treatment	0.01	Estimate based on Nuttall *et al.* (1997) and Luker and Montague (1994)
Infiltration or soakaway	0.2	Luker and Montague (1994)
Discharge to river	0.79	1 - all above values
	Level 5	
Removal during filter or treatment	0.24	Nuttall *et al.* (1994)
Discharge to river	0.76	1 - above value

Removal during infiltration or soakaway	0.15	Expert opinion
Discharge to groundwater	0.850	1 - above value

Dilution in the river

9.16 The event tree (Figure 9.1) traces the volume of water and the mass of ammonia until they are discharged into surface water or groundwater, or removed from the system. The impact on surface water was then evaluated based on the Grade 1 Fisheries Ecosystem EQS of 2.5 mg l^{-1} ammonia (as nitrogen). In order to accomplish this evaluation the discharge into surface water was assumed to be mixed with the river discharge.

9.17 In the mixing process the mass discharge into surface water consisted of the sum for all discharges into surface water of the product of the mass of ammonia and the cumulative probability, and the volume discharge into surface water consisted of the sum for all discharges into surface water of the product of the volume of water and the cumulative probability. A river discharge database was developed based on 30 years of monthly mean discharge data from 35 catchments in England and Wales ranging in size from 87 to 9,948 km^2 (EA, 1998). The mean monthly flows in the river were converted to mm of runoff to standardise the data set for different catchment areas. A log normal distribution was fitted to the data with a mean of 45 mm per month and a standard deviation of 51 mm per month. This was converted to a four hour flow by dividing by 186, and then to a volume flow by employing the appropriate conversion factor.

9.18 The concentration of the gully pot discharge was determined by dividing the mass discharge into surface water by the volume discharge into surface water. A mean background river concentration of ammonia (as nitrogen) of 1 mg l^{-1} with a range of 0 to 2 mg l^{-1} as a normal distribution was assumed, based on data from the Harmonised Monitoring Scheme and the EA (WS Atkins, 1995).

9.19 The following assumptions were made for the mixing of the discharge into surface water and the river discharge:

- ammonia was conservative once discharged into the river;

- the load of ammonia per hectare entered the river over a four hour period; and

- the area of the road surface was equal to 1.78 per cent of the catchment area, which is an average for England and Wales (British Roads Federation, 1990).

9.20 The resulting concentration of ammonia in the river was calculated by employing a simple mixing equation in which the final mass of ammonia was divided by the final volume of water. The final mass of ammonia was obtained from the sum of the mass due to the background concentration in the river and the discharge of ammonia into surface waters, whilst the final volume of water was obtained from the sum of the four hour river flow and the discharge of water into surface waters.

SENSITIVITY ANALYSIS

9.21 The following parameters were input as frequency distributions for the Monte Carlo analysis:

- volume of water discharged during backwashing with black water;

- volume of water discharged during refilling;

- volume of black water in the full tanker when clean water is used to refill the gully pots;

- ammonia removal during filter/treatment process;

- four hourly discharge in receiving water; and

- background river concentration of ammonia.

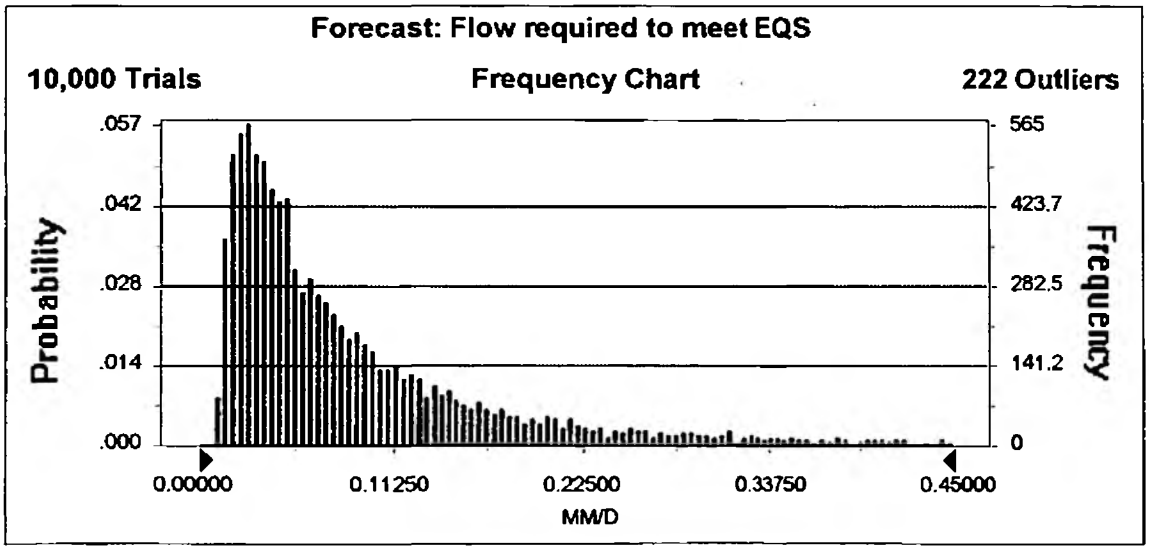
9.22 Table 9.3 provides an overview of the range of results obtained from the sensitivity analysis.

Table 9.3 - Overview of the range of results obtained from the sensitivity analysis

Parameter	Range of results		
	5th percentile	50th percentile	95th percentile
Concentration of ammonia (as nitrogen) in gully pot discharge (mg l^{-1})	10.6	14.6	21.0
River flow required to meet EQS (mm d^{-1})	0.0184	0.0630	0.317
Final concentration of ammonia (as nitrogen) in river (mg l^{-1})	0.669	1.41	3.65

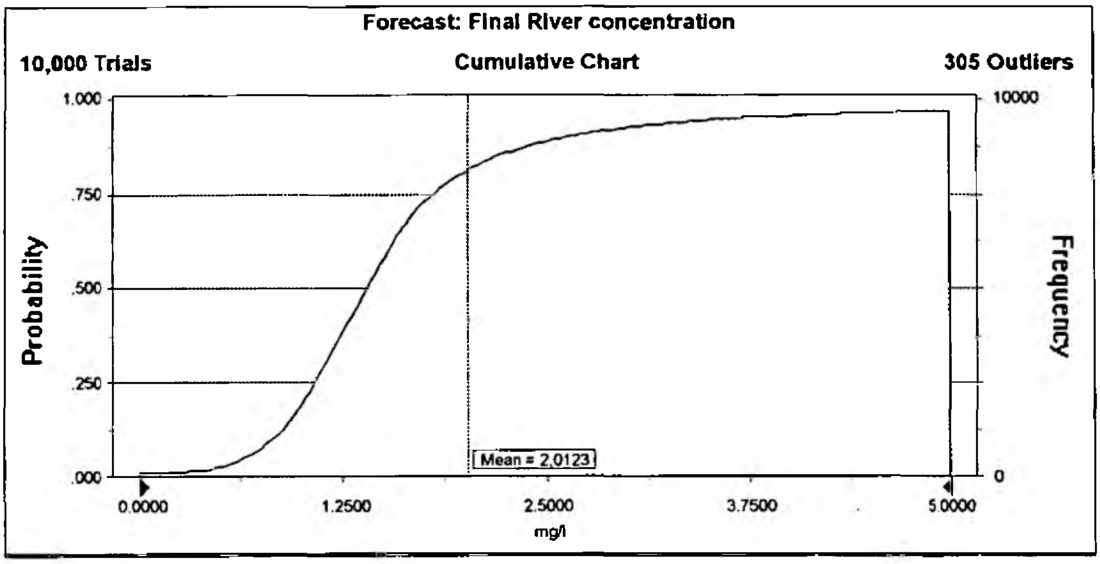
9.23 The frequency distribution obtained for the concentration of ammonia in the gully pot discharge was slightly skewed from normal. However this is to be expected as the distribution is determined from the combination of three distributions (the water discharged during backwashing with black water, during refilling and emptying the tanker) and only the first of these, which is not the most important, is not a normal distribution. Figures 9.2 provides the frequency distribution for the river flow required to meet the EQS, which demonstrates that the required flows are mainly at the lower end of the range.

Figure 9.2 - Frequency distribution for river flow required to meet EQS



9.24 Figure 9.3 provides the cumulative distribution for the final river concentration of ammonia, which demonstrates that the probability of the final river concentration meeting the EQS is just under 0.9.

Figure 9.3 - Cumulative distribution for final river concentration



9.25 The results of rank correlation indicated that the volumes of water discharged during refilling and during backwashing with black water were the most important parameters in determining the concentration of ammonia in the gully pot discharge. For the flow required to meet the EQS, the overwhelmingly most important parameters were the four hourly discharge in the receiving water and the background river concentration.

CONCLUSIONS

9.26 This section has undertaken a risk assessment of the water quality impacts of gully pot cleaning. The constructed event tree and associated representation of mixing in the river have demonstrated that the most important parameters in determining the concentration of ammonia in the gully pot discharge were the volumes of water discharged during refilling of the gully pots and the during the backwashing with black water. In the case of the river flow required to meet the EQS, the overwhelmingly most important parameters were the four hourly discharge in the receiving water and the background river concentration. The river flows required to meet the EQS were mainly at the lower end of the range of flows and the probability of the concentration of ammonia in the river meeting the EQS was just under 0.9, demonstrating that it is unlikely that the EQS will be exceeded.

10. QUANTITATIVE RISK ASSESSMENT OF THE POTENTIAL FOR FLOODING DUE TO ROAD CONSTRUCTION

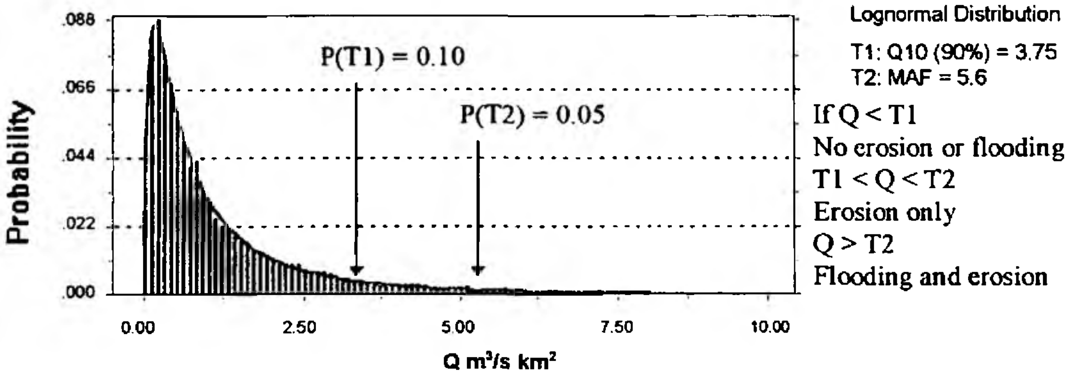
10.1 This section provides a quantitative risk assessment of the potential for flooding due to road construction. Roads can have several impacts on the magnitude and frequency of flooding. The impermeable road surface increases the amount of runoff and the road drainage system transports water rapidly to the nearest surface water or soakaway. At the catchment scale, road construction can increase peak discharge and the time to concentration of the catchment hydrograph. In addition, road construction may impact upon channel morphology with an increase in sediment deposition and loss of channel storage during construction, followed by an increase in stream power and channel capacity due to increased flow velocities (Roberts, 1989).

METHODOLOGY

10.2 The flooding event tree examined the risks of flood damage and the effects of channel erosion as a consequence of road construction. The adopted methodology for constructing the event tree involved 2 stages. Firstly, a generic river flow frequency distribution was derived using the Mean Annual Flood (MAF), percentile (Q10 and Q50) and average discharge data from a long term record of 35 rivers in England and Wales. Secondly, the discharge was linked to flood damage by using a general stage-discharge relationship and a flood damage scoring system.

10.3 The database of river flow data provided MAF and percentile flow data based on continuous monitoring, as well as monthly mean flows, for 35 catchments ranging in size from 87 to 9948 km^2 (EA, 1998). The flow values were divided by catchment area to give standardised flow statistics in $m^3 s^{-1} km^{-1}$. A large number of distributions, including Gumbel Extreme Value, Gamma and Log normal, were fitted to these data based on the mean flow, the Q50 flow and the Q10 flow (90th percentile). However, no distributions fitted the data well for both the Q50 and Q10 flows so, given the emphasis on an accurate representation of peak flows, a log normal distribution was derived with a 90th percentile equal to mean Q10 flow exceedence value and a range of flows which cover the maximum MAF from the database. The derived flow distribution is shown in Figure 10.2. The 50th percentile discharge from the log normal distribution was slightly higher than in the observed data but the Q10 flow was identical.

Figure 10.1 - The log normal discharge frequency distribution based on data from 35 rivers in England and Wales



10.4 In the event tree many of the branch probabilities are dependent on thresholds. For example flooding only occurs when river discharge exceeds bank full capacity and erosion of banks, bed sediments and structures only occurs at high velocities. The starting point for the flooding event tree was the log normal flow distribution which was compared to thresholds for flooding and erosion to determine their branch probabilities. The following assumptions were made:

- the threshold for erosion (T1) was assumed to be equal to the average standardised Q10 discharge which was 3.75 m^3 s^{-1} km^2 ;
- the bank full discharge (T2) was assumed to equal the average standardised MAF from the rivers database which was 5.6 m^3 s^{-1} km^2;
- the thresholds remain the same immediately following a road development (in the longer term changes in channel morphology may take place); and
- road building will increase runoff volumes and river discharge, and reduce time to concentration. The increase in discharge can be predicted using the engineering formulae detailed in paragraph 10.18.

10.5 In the second level of the tree the additional river discharge may be diverted to flood plain storage. Flood plain storage is expensive and its use is not widespread. In addition, it is likely to be used only when flows exceed a certain threshold determined in the engineering design of the structures. Therefore a low probability of 0.05 was selected (Luker and Montague, 1994).

10.6 The third level of the tree considers the possibility of over bank flows, the slow release of water from storage and the likelihood of storage structures failing. The exceedence probability of over bank flows was calculated from the flow frequency distribution (Figure 10.1) and was equal to 0.05. The likelihood of flood plain storage structures failing was considered to be very low, therefore a probability of 0.01 was selected. Most stored water was assumed to discharge back into the river channel at a safe velocity.

10.7 The fourth level of the event tree considers the possibility of channel erosion, scour and bank collapse. The exceedence probability for erosion was calculated in the same way as the probability of over bank flows and was equal to 0.10. In the over bank flow branch the probability that flooding will cause no damage, for example in the case of wetlands, and levels which may benefit from flooding are considered. These areas represent a small proportion of England and Wales, therefore a low probability of no flood damage (0.01) was selected.

10.8 The damage caused by flooding is a function of flood depth, land use and a range of other site specific factors. Most Cost Benefit approaches to flooding base costs on flood water depth (e.g. Penning-Rowsell and Chatterton, 1977). Therefore, river flows in the event tree were converted to flow depths using a generic stage-discharge relationship. The following log-log relationship was chosen:

- $\text{Log } Q = a. \text{Log } H + \text{Log } b$

10.9 A link was then established between flow and flood depth (Figure 10.2). By applying the following formula it was possible to estimate the magnitude of flood damage.

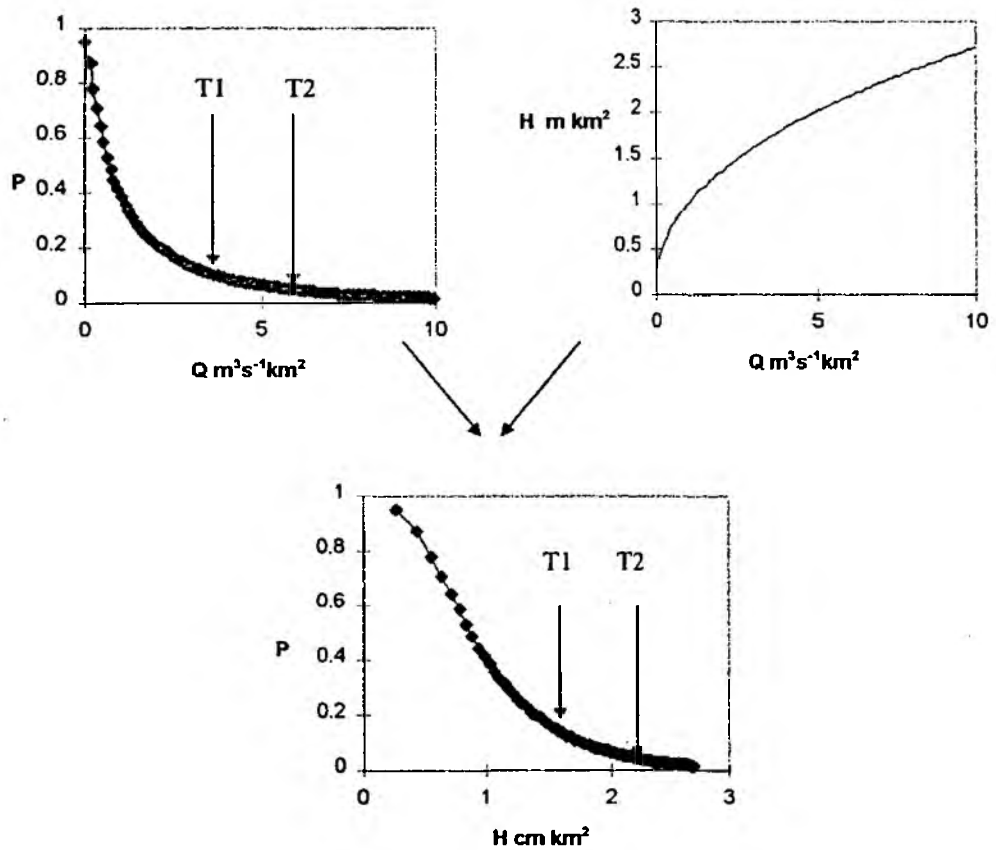
- Damage score = 100 × (H - HT2) / (Hmax-HT2)

where H is the depth, HT2 is the depth at the flood threshold flow (QT2) and Hmax is the maximum flood depth. This produces a range of flood damage scores between 0 and 100 percent.

Figure 10.2 - Estimation of flood costs. (a) Exceedence probability versus standardised discharge, (b) Generic stage-discharge relationship and (c) Exceedence probability versus stage

(a) & (b)

(c)

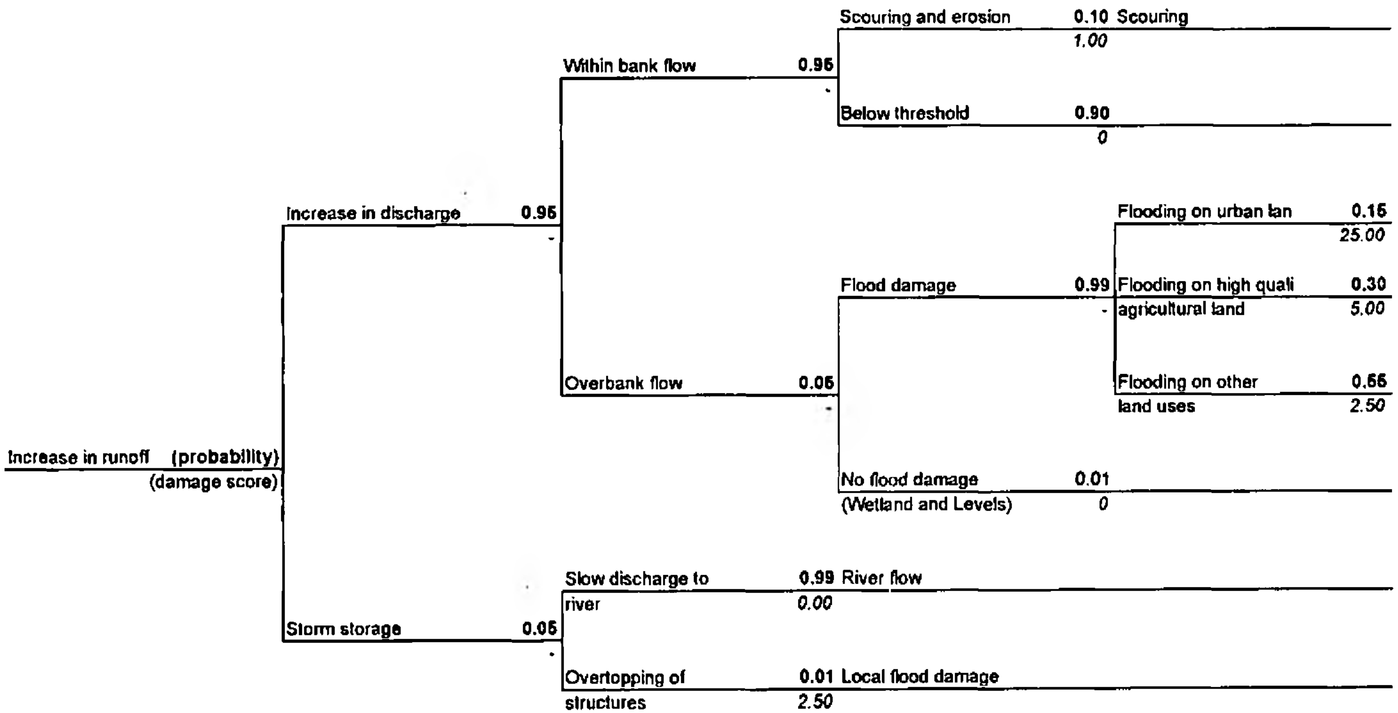


10.10 An identical approach was taken for scour damage and bank erosion when flows remain within the bank. Scour damage is directly proportional to river velocities whereas bank erosion is more complex, being a function of bank moisture conditions, bank soil textures and the speed of the rise and fall of the hydrograph as well as discharge. To calculate a damage score the discharges between the threshold for erosion (Q10) and the maximum discharge were scaled to give damage scores between 0 and 100% per cent.

10.11 The final factor which affects the amount of flood damage is land use type. The costs of flood damage are greatest in urban areas. The costs are highly variable depending upon the type of industrial and domestic properties affected. The damage will also be considerably higher on high quality agricultural land compared to lower quality grasslands and rough grazing land. The final level of the event tree divided the land use in England and Wales into three classes: urban, high grade agricultural and all remaining land uses. The event tree branch probabilities were based on the area of land in England and Wales utilised for each of the three defined land use classes, with 0.15 for urban areas, 0.3 for agricultural and 0.54 for other land uses (DETR, 1997e).

10.12 The relative costs of flooding on different land use types were estimated by applying damage scores and examining the costs of flooding for a range of flows using the flow frequency distribution. The final scores used were the average cost of flooding for different land uses. It was assumed that the cost of urban flooding was 5 times the cost of flooding on agricultural land and 10 times the cost of flooding on other land use types. Figure 10.3 provides the flooding event tree, whilst Table 10.1 provides an overview of the branch probabilities for the event tree.

Figure 10.3 - Flooding event tree



Probability	Probability Rank	Probability * damage	Damage Rank
9.12E-02	2	9.12E-02	2
8.11E-01	1	0	6
7.05E-03	6	1.76E-01	1
1.41E-02	5	7.05E-02	3
2.59E-02	4	6.47E-02	4
4.75E-04	8	0	6
4.95E-02	3	0	6
5.00E-04	7	1.25E-03	5

RESULTS

10.13 The flooding event tree (Figure 10.3) presents a general picture of the risks of flooding due to road building in England and Wales. It is based on a large number of assumptions and there may be a lesser or greater risk of flooding in specific cases depending on engineering design.

10.14 The most likely outcome of the event tree is river discharge under "normal" conditions for which the probability is 0.81. The most likely source of damage is due to scouring and erosion for those periods when flows are greater than the Q10 threshold, as defined in section 10.8. However the high costs of urban flooding mean that this category represents the most significant risk, followed in decreasing order of significance by scouring and erosion, flooding of high quality agricultural land, flooding of other land uses and failure of storm storage structures.

10.15 A sensitivity analysis was conducted on the flooding event tree and this confirmed that all the outcomes were controlled by the log normal flow distribution which was derived from the rivers database. The methodology for this event tree involved linking a frequency distribution of observed flows from a rivers database to branch probabilities for flooding and erosion damage. Damage scores were then calculated by scaling the range of possible outcomes. In order to evaluate the impact of increased road building the flow distribution must be linked to the road area using an appropriate predictive equation. The proposed methodology for linking road building to the flooding event tree is discussed in the following sections.

DISCUSSION

10.16 There are several models which can be used to link catchment hydrological responses to changes in urban area, such as the empirical catchment formulae in the Flood Studies Report (NERC, 1975). However, the impacts of road building are likely to generally be greater than urbanisation because:

- the URBAN land use class in the empirical formulae includes a range of land covers, including urban green space; and
- road drainage must be extremely efficient for safety reasons.

10.17 The "Wallingford Procedure" for the analysis and design of storm water drains provides some appropriate engineering formulae for estimating the likely catchment scale impacts of road building (DoE, 1983).

10.18 The Wallingford Procedure's Modified Rational Method can be used to predict peak discharges (Qp) and time to concentration (TC):

- Qp = 2.78 . Cv . Cr I A

where Qp is the peak discharge in l s^{-1}, Cv is the volumetric runoff coefficient, Cr is the dimensionless routing coefficient, I is rainfall intensity in mm hr^{-1} and A is the catchment area in hectares.

10.19 The equation can be applied to impermeable areas only or catchments areas with a percentage impermeable area (PIMP). For the latter case:

- Cr = PR/100

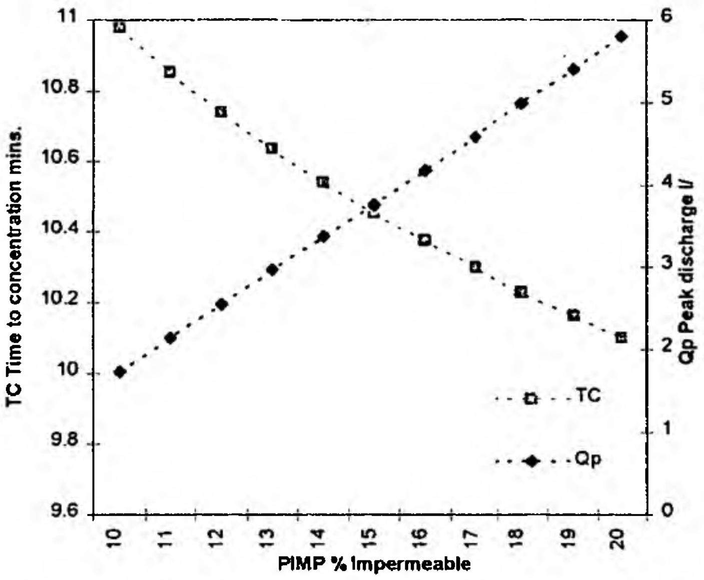
where PR is the percentage runoff. This can be calculated from catchment characteristics:

- PR = 0.829. PIMP + 25.0. SOIL + 0.078.UCWI - 20.7

where SOIL is the soil index from the Flood Studies Report and UCWI is the Urban Catchment Wetness Index which defines the antecedent conditions. The routing coefficient Cr is a function of rainfall "peakiness" and may range between 1 and 2, but a value of 1.3 is routinely used for drainage design. The time to concentration (TC) can be calculated as a function of the time it takes for runoff to enter a drainage pipe (te) and the routing time within a pipe (tf). The time of entry is a function of slope angle and the catchment overland flow length (DoE, 1983).

10.20 Selected results obtained using this methodology for a 100 ha catchment, with average parameters for England and Wales, are presented in Figure 10.4. The variable PIMP was set to equal urban area which, on average, is equal to 15 percent in England and Wales. The selected rainfall intensity was 13.6 mm h^{-1} which is equivalent to the average 60 minute rainfall intensity in England and Wales with a return period of one year (DoE, 1983). Roads contribute very little in terms of urban area. Assuming a unit road width of 3.65 m and a set number of lanes for motorways, major roads and minor roads the average road area based on British Road Federation data is 1.78 percent (British Road Federation, 1990). New road building in any area is unlikely to result in an increase in road area by more than 0.5 - 1 per cent for any catchment, but based on the slope of the PIMP to Qp relationship (Figure. 10.4) this may increase Qp by up to 12 percent.

Figure 10.4 - The sensitivity of peak discharges and time to concentration to impermeable catchment area



Catchment Area: 100 ha Precipitation: 13.6 mm/hr
Soil parameter: 0.325 UCWI Wetness: 100

10.21 The average flow is assumed to increase at the same rate as the predicted peak flow using the Modified Rational Method. Therefore the change in the probability of flooding and erosion due to road building can be predicted because the flow distribution changes but the thresholds remain the same.

CONCLUSIONS

10.22 The flooding event tree describes the risks of scour damage and flooding due to road construction. It was based on a log normal distribution of standardised flows derived from a database of 35 rivers. The greatest risks were associated with flooding in urban areas. The impact of increasing the area of roads can be estimated by linking the Wallingford Procedure for the estimation of peak flows to the log normal distribution of discharge. An increase in road area will increase both the magnitude and frequency of flooding.

Table 10.1 - Branch probabilities for flooding event tree

Parameter	P(X)	Explanation
		Level 1
Increase in river discharge	0.95	Increase in discharge in response to road building. 1 - probability(storm storage)
Diversion to storm storage	0.05	Diversion of additional flow to storage. Luker and Montague, 1994.
		Level 2
Within bank flow	*0.95*	Based on log normal flow distribution. 1 - P(Over-bank flows)
Over-bank flows	*0.05*	Based on log normal flow distribution. The probability of exceeding a threshold for bank full discharge.
Slow discharge to river	0.99	Expert judgement.
Over topping of structures	0.01	Expert judgement.
		Level 3
Scouring and erosion	0.10	Based on log normal flow distribution.
Flow below threshold	0.90	Based on log normal flow distribution. 1 - P(Scouring and erosion)
Flood damage	0.99	1 - P(No flood damage)
No flood damage	0.01	Based on an estimate of Wetland areas which benefit from flooding. Expert judgement.

	Level 4	
Flooding of urban land	0.15	Based on urban land area in England and Wales (DETR, 1997e).
Flooding of high quality agricultural land	0.30	Based on area of high quality agricultural land in England and Wales (DETR, 1997e).
Flooding of other land uses	0.54	All other land uses for England and Wales. 1 - P(above)

11. QUANTITATIVE ASSESSMENT OF THE POTENTIAL FOR HABITAT LOSS FROM ROADSTONE QUARRYING ACTIVITIES

INTRODUCTION

11.1 This section undertakes a quantitative assessment of the potential for habitat loss from roadstone quarrying activities. The construction and maintenance of any road network requires a significant quantity of aggregates in the form of roadstone, sand and gravel. Aggregates used for roadstone comprise around a third of the total amount of material quarried annually (CPRE, 1993). The continued demand for aggregates results in the loss of land surface either to be used as aggregate or to enable the rock underneath to be quarried. In 1988 around 114,000 ha of land were affected by permissions for mineral working or mineral waste disposal indicating that a significant area of the UK is impacted by quarrying activities (DOE, 1991b). This assessment addresses the extent of land loss that can be attributed to quarrying for roadstone.

STUDY APPROACH

11.2 The assessment looks at the area of land surface lost to quarrying for roadstone per £1M spent on road building and maintenance. The results are presented in two event trees, one considering the area of land loss in different regions of England and Wales, and the other considering the different uses of the land surface taken for quarrying prior to its loss. It was decided to keep the regional and land type event trees separate because to join them would suggest that the different land cover types are lost evenly through England and Wales, which is unlikely to be the case. Road expenditure was made the functional unit of the assessment so that the impact of changes in roads policy and funding can be seen.

11.3 To quarry an area of land permission must be granted by the relevant authority. To minimise time and expense spent purchasing land and applying for permissions it is likely that the quarry developer will seek to get permissions for an area of land large enough to supply aggregates for many years, even decades. It is therefore not appropriate to use the area of land for which quarrying permission has been granted as an indicator of annual land loss. Instead the less extensive, but more relevant, data available from land change surveys has been used.

METHODOLOGY AND DATA SOURCES

11.4 To determine the area of land lost to quarries annually from current road spending, information on three key indicators is required:

- the ratio of landtake to quantity of aggregate extraction;
- the ratio of road spending to roadstone consumption; and,
- the fractions of the road budget spent on construction and on maintenance.

11.5 Considerable uncertainty exists in determining the first two of these indicators, most significantly in the ratio of landtake to quantity of aggregate extraction.

11.6 It should be remembered that the majority (60 per cent in 1988 and probably higher now) of quarrying permissions include requirements for post quarry land reclamation, usually for agricultural use (DoE, 1991b). Sand and gravel quarries have relatively short lifespans, and are suitable for reclaiming for agricultural and amenity uses. However, rock quarries (where the vast majority of aggregates for road construction are sourced), are usually much larger operations involving a significantly longer period of active quarrying and a greater depth of extraction. Because of these factors rock quarries generally have a much more significant impact on their surroundings for a longer period, and there is less potential for returning the land to its original use. It is likely that, even with post quarrying habitat recreation, any sensitive habitats existing on land taken for rock quarrying will be irreversibly altered by the quarrying activity.

11.7 For the above reasons land reclamation is not considered in this assessment. It is recognised, though, that many quarries generate new wildlife and amenity areas, which in some cases is an improvement of the ecological value of the pre-quarry land. An assessment of the effectiveness of land reclamation techniques and the extent of new habitat generation would represent a major project in its own right, and is beyond the scope of this study.

Use of secondary aggregate

11.8 The amount of secondary aggregate use in road construction will significantly affect the quantity of primary aggregate required, and when considering potential management options this factor (along with road policy) is likely to be the most influential for reducing the volume of roadstone quarried. It has been estimated that roadbase containing up to 60 per cent of recycled aggregate can still meet the relevant specifications for new road materials (CPRE, 1993), and it has been suggested that 100 per cent of asphalt recycling is possible (CPRE, 1993). Despite these potentially high levels of utilisation, estimates for 1993 were that an average of only 10 per cent of the aggregate used in construction at that time was recycled, partly due to the high additional costs of transportation (CPRE, 1993).

11.9 In this assessment a 10 per cent use of recycled material was used as a benchmark for assessing the impacts of management options designed to increase the use of secondary aggregates in road construction. Because the functional unit for this assessment is hectares of land lost through aggregate extraction, the use of secondary aggregate was represented as a hypothetical area of land saved. The ratio of hypothetical landtake to aggregate quantity is assumed to be the same for secondary aggregate as for primary aggregate.

Ratio of landtake to aggregate extraction

11.10 To estimate the ratio of landtake to aggregate extraction, data were required on the amount of land lost to quarrying during a given period and the amount of aggregate extracted during this period. As discussed previously, it is not appropriate to use annual quarrying permissions to estimate the amount of land lost, because much of the land for which permissions exist will not be impacted for several years, instead data on changes in land use were utilised.

11.11 Statistics on the area of land changing from one use to another are maintained by the DETR and held in their Land Use Change Statistics (LUCS) database (DETR, 1998). This was interrogated to determine the total area of land changing to the mineral extraction use category, and to indicate the previous uses of this land area. Unfortunately data were only available for one year (1992) so it was not possible to determine quantitatively the annual variability, either in terms of total area, or proportion coming from different land uses.

11.12 The use of historical data on the proportion of different land cover types taken for quarrying is justified on the basis that new aggregates will be recovered by the expansion of existing quarries in most cases. Therefore current and near future landtake is likely to be in the same areas as in recent years.

11.13 Data on the area of land taken for a given quantity of aggregate is more uncertain. Where possible a quarry will be developed vertically rather than horizontally, and new land is only taken when absolutely necessary. Land taken in one year may expose a sufficient depth of aggregates for several years quarrying at progressively greater depths. It is hoped that because of the relatively high number of quarries in the UK, (1,300 known in 1995 (BACMI,1996)), the landtake to aggregate quantity ratio will be representative, with some quarries taking new land and others exploiting that taken previously.

11.14 Table 11.1 shows the LUCS dataset obtained for England in 1992. The total area of land changing to mineral extraction use is 957 hectares, the majority of which was previously agricultural.

Table 11.1 - Land changing to mineral use by previous use in England in 1992

Previous use	Area of land (ha)	Percentage
Agricultural land	843	88.1
Agricultural buildings	2	0.2
Forestry and woodland	24	2.5
Rough grassland	30	3.1
Highways and road transport	1	0.1
Natural and semi-natural	3	0.3
Outdoor Recreation	2	0.2
Utilities	3	0.3
Vacant land previously developed	28	2.9
Water	6	0.7
Landfill	12	1.3
Derelict land	3	0.3
Total	**957**	**100**

Source: DETR, 1998

11.15 It was not possible to differentiate the amount of landtake between different regions of England because the DETR stated they had no confidence in their data at this scale, due to the very small areas of land involved. It was considered feasible that the survey could have missed more land changes than it detected when considering a regional scale. This gives an indication of the level of uncertainty that should be associated with the figures in Table 11.1.

11.16 The Quarry Products Association (QPA) keeps statistics on the annual amount of aggregate quarried differentiated by source and end use (BACMI, 1996). In 1992 the GB production of aggregates was 233 Mt, of which production in England made up around 167 Mt (72 per cent of production was estimated to be from England based on the production proportions for 1996).

11.17 The average area of land required per tonne of aggregate can be estimated at:

$$957 \text{ ha} / 167{,}000{,}000 \text{ t} = 0.0057 \text{ ha kt}^{-1} \text{ or } 0.057 \text{ m}^2 \text{ t}^{-1}$$

11.18 As has been discussed previously there are considerable uncertainties associated with this figure due to the lack of data for more than one year, and because the amount of land area required to extract a given quantity of material will vary with the shape of the quarry. Unfortunately data were not available for more than one year and therefore it is impossible to quantify the uncertainty associated with this figure because the amount of variability is unknown.

Ratio of road spending to roadstone consumption

11.19 Statistics were available from the QPA (BACMI, 1996) giving the annual production of roadstone within different regions of England and Wales in 1995, and the annual spending on road construction and maintenance for both motorways and trunk roads, and local roads in England and Wales, also for 1995. Assuming that ten per cent of road construction materials are sourced from secondary aggregate the BACMI data on production can be assumed to represent 90 per cent of the total aggregate used. The assumed volume of secondary aggregate used is therefore 11 per cent of the BACMI production data ((10 / 90) × 100 = 11.11 per cent).

11.20 Information was also available on road spending within different regions of England from 'Transport Statistics Great Britain 1997' (DETR, 1997b). However, the volume of roadstone produced per £1M regional road spending varied very considerably between regions[1]. This indicates that there is little connection between the quantity of roadstone produced and the quantity used in specific regions, and that the roadstone produced in one region is transported to other regions for use. Because regional spending will have little influence on regional production, the whole of England and Wales has been considered in determining the roads budget, and this has been broken down between the different regions according to current production proportions.

11.21 The ratio of spending to primary aggregate demand, determined by the total England and Wales budget for road construction and structural maintenance of local, trunk and

[1] The most extreme examples of this for 1995 are the East Midlands which produced 18378 kt y^{-1} of aggregates and spent £294 M on roads (ratio: 62.5) and East Anglia which produced 452 kt y^{-1} of aggregates and spent £208 M on roads (ratio: 2.2).

motorways, and the volume of road primary aggregates extracted. For 1995 this is (BACMI, 1996):

$$70446 \text{ kt} / £5054 \text{ M} = 13.9 \text{ kt } £\text{M}^{-1}$$

11.22 Data are also available for 1991 and the national ratio is 16 kt £M^{-1}, however if a measure of inflation of three per cent per annum is introduced the ratio in 1995 money is 14.2 kt £M^{-1} a deviation of under two per cent, suggesting the ratio of spending to aggregate use is relatively constant.

11.23 Table 11.2 shows the amount and proportion of primary aggregate produced in different regions of England and Wales. The proportions for 1991 are shown in parentheses.

Table 11.2 - Primary roadstone production in regions of England and Wales per £M spent on road building and structural maintenance

Region	Roadstone production (kt y^{-1}) for 1995 (1991)	Roadstone production (%) for 1995 (1991)	Roadstone production (kt per £M spent nationally on roads) for 1995 (1991)
Northern	6496 (7642)	9 (11)	1.3 (1.6)
North West	3407 (2777)	5 (4)	0.7 (0.6)
Yorkshire and Humberside	8752 (8375)	12 (11)	1.7 (1.7)
East Midlands	18378 (18153)	26 (23)	3.6 (3.3)
West Midlands	5005 (7749)	7 (10)	1.0 (1.4)
East Anglia	452 (391)	<1 (<1)	0.1 (0.1)
South East	1934 (1651)	3 (2)	0.4 (0.3)
South West	15464 (19299)	22 (25)	3.1 (3.6)
Wales	10558 (12709)	15 (16)	2.1 (2.3)
England and Wales	**70446 (78746)**	**100**	**13.9 (14.2)**

Source: BACMI, 1996

11.24 Based on the ratio of road spending to primary aggregate use the quantity of secondary aggregate can be calculated, assuming that 10 per cent of road material used is secondary. If 13.9 kt of primary aggregate is used per £M then the amount of secondary aggregate per £M is equivalent to:

$$13.9 \times (11 / 100) = 1.53 \text{ kt secondary aggregate £M}^{-1}$$

11.25 Because the use of secondary aggregate is being considered as 'saved' land the proportion of landtake avoided in different regions will be the same as that for landtake occurring from primary aggregate use. Table 11.3 shows the amount of secondary aggregate used (and therefore primary aggregate saved) in England and Wales per £M spent on roads, proportioned by the source of the aggregate as if it were primary aggregate.

Table 11.3 - Primary roadstone production saved through the use of 10 per cent secondary aggregate in road construction, per £M spent on roads

Region	Roadstone production saved (kt per £M spent nationally on roads) for 1995 (1991)
Northern	0.14
North West	0.19
Yorkshire and Humberside	0.40
East Midlands	0.01
West Midlands	0.04
East Anglia	0.34
South East	0.11
South West	0.07
Wales	0.23
England and Wales	**1.53**

After: BACMI, 1996

11.26 The total amount of aggregate used per £M spent on roads is therefore equivalent to the sum of 13.9 kt and 1.53 kt at **15.52 kt £M^{-1}**. In the event trees for this assessment the hypothetical landtake for secondary aggregate was assigned in the same proportions (in terms of regional and land type distribution) as the landtake for primary aggregate, because this will indicate the land saved in these areas through the use of secondary aggregate. The impact of increasing the percentage of secondary aggregate used can be modelled by varying the proportion of aggregate consumption using 15.52 kt as 100 per cent.

The ratio of road budget spending on construction and maintenance

11.27 To understand the impact of changes in roads policy on land loss through quarrying it is necessary to differentiate between aggregates used for road construction and aggregates used for road maintenance, and also between the proportion used on local roads and that used on trunk roads and motorways.

11.28 The 1995 roads budget broken down into various categories is shown in Table 11.4, however it is also necessary to consider the different proportion of road spending that goes to aggregate purchase depending on the type of road scheme being undertaken. Road construction schemes require a great deal more clearance and preparation of the ground than is required for road maintenance, this means that a smaller proportion of the budget is spent on aggregate. Therefore maintenance schemes use proportionally more aggregate per £M than construction schemes. Spending breakdowns for a number of road construction schemes are available from the Highways Agency (HA, 1998). These show that an average of 11 per cent of the total budget goes on aggregate purchase. For road maintenance schemes the average expenditure was estimated at 50 per cent (HA, 1998), indicating the much higher relative level of aggregate use by maintenance projects.

11.29 Table 11.4 shows the 1995 roads budget split by road type and activity, the proportion of spending on each activity is adjusted to allow for the different level of aggregate use by maintenance schemes.

Table 11.4 - The 1995 roads budget split by road type and activity

Scheme Type	Expenditure (£M)	Unadjusted total expenditure (%)	Expenditure spent on aggregates (%)	Aggregate expenditure (%)
Construction of m/ways and trunk roads	1242	25	11	9
Maintenance of m/ways and trunk roads	580	11	50	19
Construction of local roads	1337	26	11	9.7
Maintenance of local roads	1895	37	50	62.3
Total	**5054**	**100**	-	**100**

Source: BACMI, 1996 and HA, 1998

Calculation of landtake

11.30 The area of land taken for each £M spent on road building and construction can be determined using the information in Tables 11.1 to 11.4. Each £M of road spending can be considered as 15.52 kt of aggregate of which 13.9 kt is primary aggregate and 1.53 kt is secondary aggregate. This can then be divided between land types or regions, using the proportions shown in Tables 11.1 and 11.2. For each land type or region the aggregate can be further differentiated based on the adjusted proportions of spending on different road types and activities (Table 11.4). For each category the landtake can be calculated based on a ratio of 0.057 m^2 t^{-1}. The area of landtake is divided into landtake for primary aggregate and hypothetical landtake for secondary aggregate. The hypothetical landtake for secondary aggregate represents the area of land that would be required if primary aggregate were used instead of secondary.

RESULTS

11.31 Figures 11.1 and 11.2 show the event trees generated for this study.

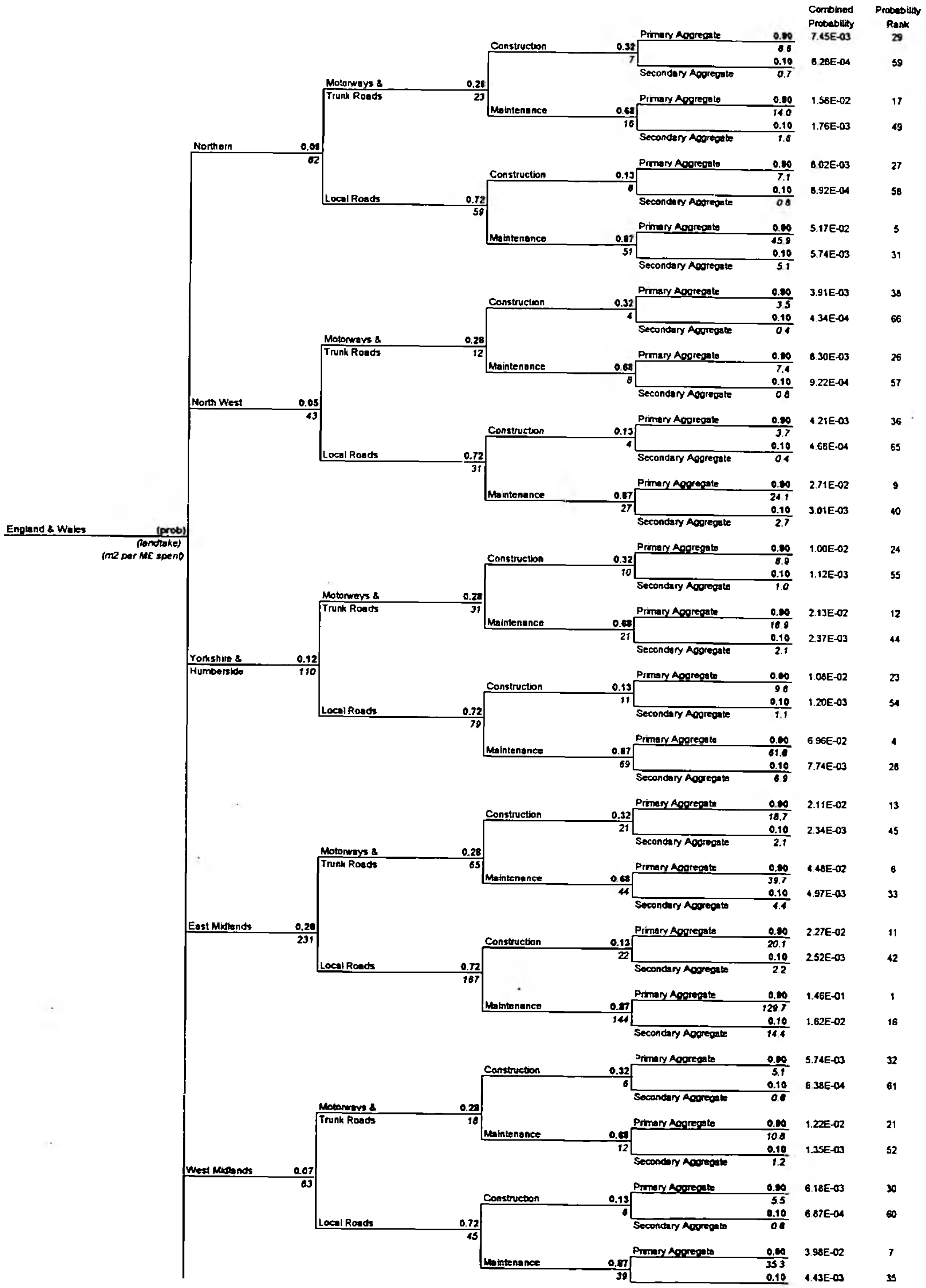
11.32 Figure 11.1 shows the estimates of the area of land lost in different regions of England and Wales, while Figure 11.2 shows the estimates of the area of land lost by land cover type. The functional unit for the event trees is £1M spent on road construction and maintenance. Table 11.5 lists the parameters used in Figures 11.1 and 11.2 and gives details of the level of confidence that can be placed in the figures.

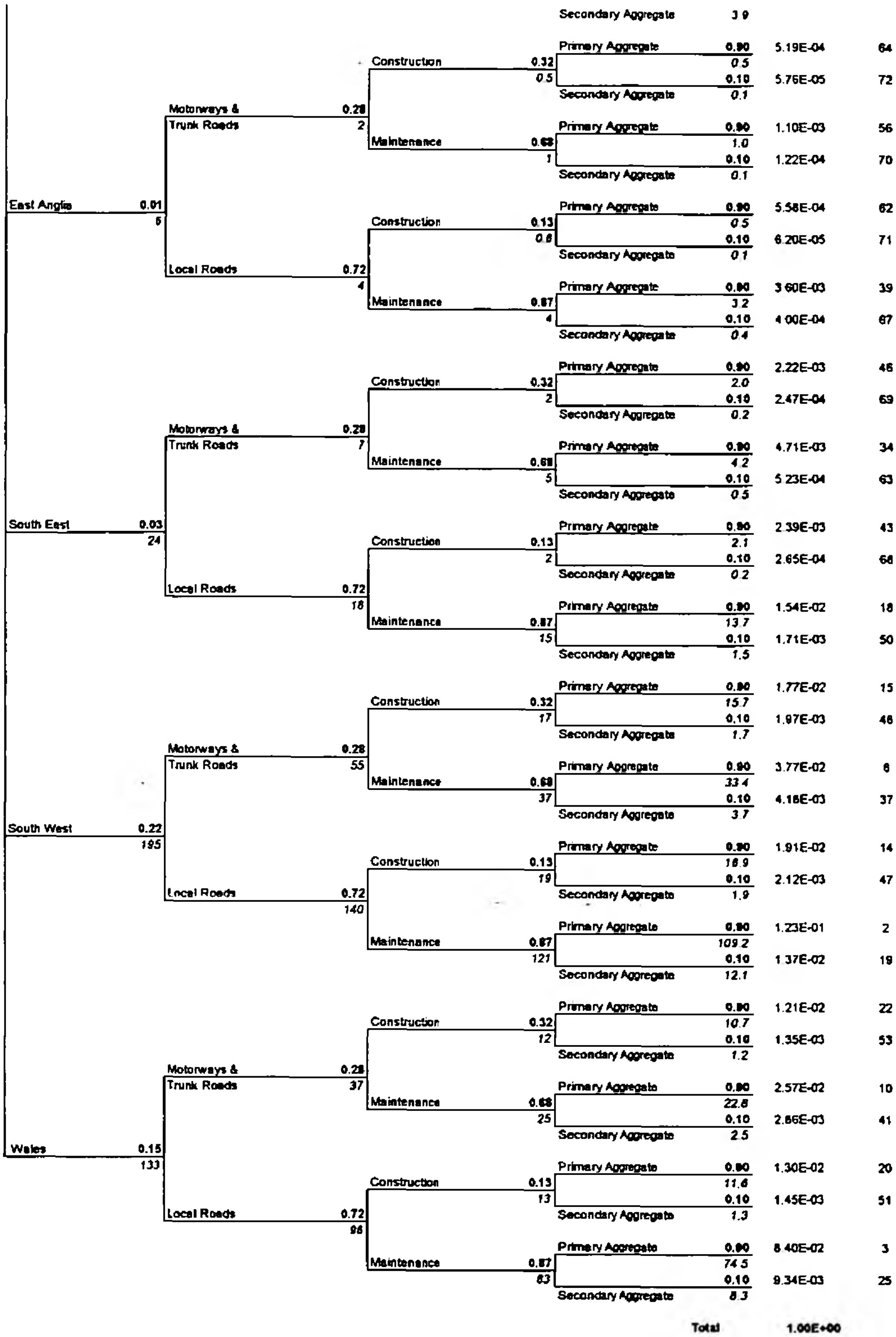
Table 11.5 - Input parameters used for the calculation of landtake from roadstone quarrying activities per £M spent on roads

Parameter	Value	Distribution	Comments
Proportion of secondary aggregate currently used in road construction and maintenance	0.1	-	Estimated from the average proportion of secondary aggregate used in road construction in 1993 (CPRE, 1993)
Aggregate used per £M spending on roads	15.52 kt £M^{-1}	-	Calculated from the ratio of the volume of primary aggregates extracted and the total budget for road construction and maintenance in 1995 (BACMI, 1996) adjusted for the proportion of secondary aggregates currently used
Area of landtake per tonne of aggregate	0.057 m^2 t^{-1}	-	Calculated from the ratio of the land changing to mineral use in England in 1992 (DETR, 1998) and the production of aggregates in England in 1992 (BACMI, 1996)
Area of landtake per £M spending on roads	887 m^2 £M^{-1}	-	Calculated from the above value for aggregate use per £M spending on roads and area of landtake per tonne of aggregate
Landtake per region per £M spending on roads	See Table 11.4 for landtake per region	-	Calculated from above value for area of landtake per £M spending on roads and the proportion per region

Landtake per land type per £M spending on roads	See Table 11.1 for landtake per land type	-	Calculated from above value for area of landtake per £M spending on roads and the proportion per land type
Landtake for motorways and trunk roads, and local roads per £M spending on roads	See Table 11.4 for landtake per road type	-	Calculated from values for landtake per region / land type per £M spending on roads and proportion per road type
Landtake for construction and maintenance per £M spending on roads	See Table 11. for landtake by construction and maintenance	-	Calculated from values for landtake per road types per £M spending on roads and proportion by construction and maintenance

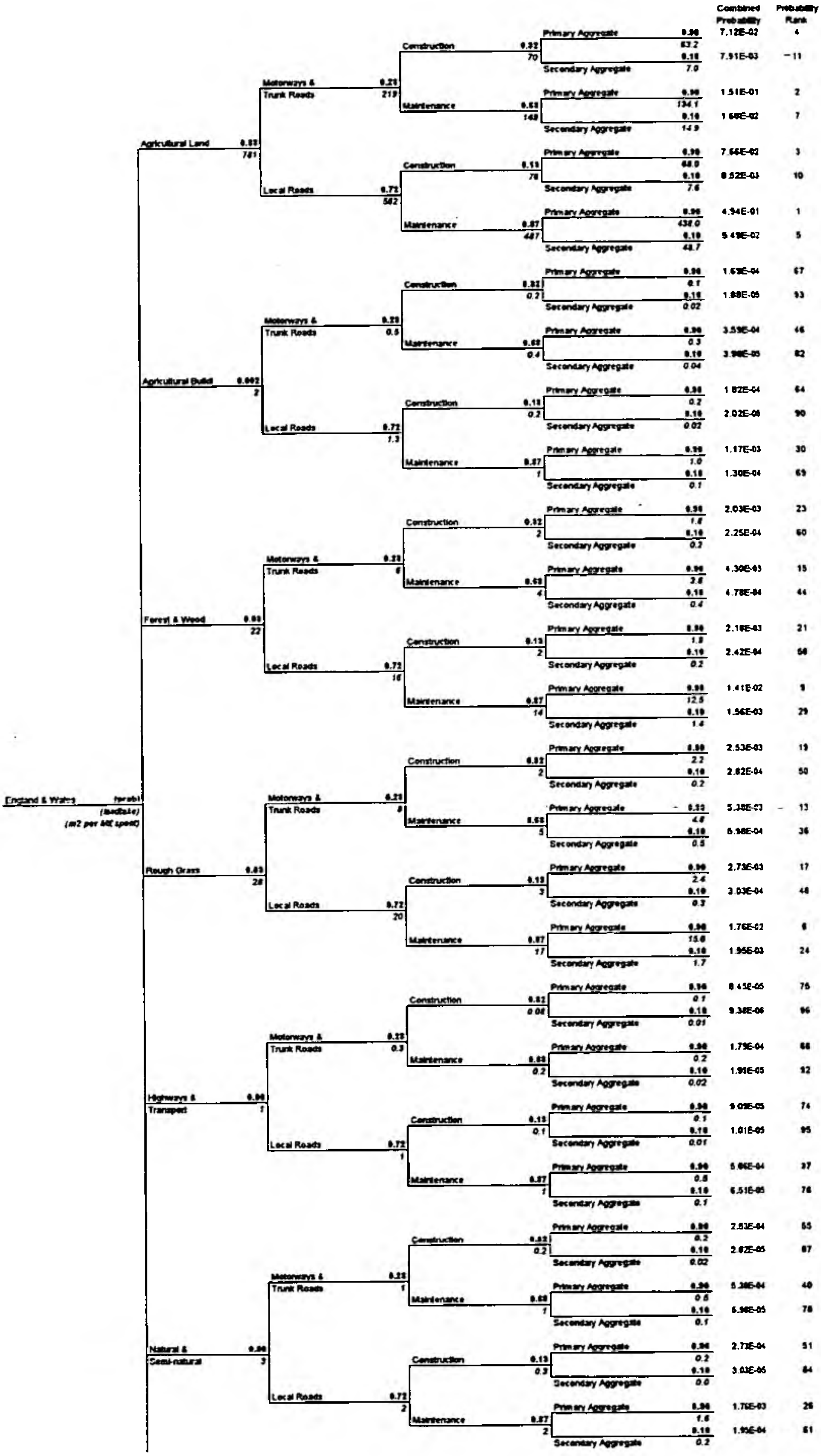
Figure 11.1 - Event tree showing the area of land surface lost to quarrying activities in different regions of England and Wales, per £M spend on road building and maintenance


Combined Probability
Probability Rank
England & Wales
(prob)
(landtake)
(m2 per M£ spent)
Northern 0.09 82
Motorways & Trunk Roads 0.28 23
Construction 0.32 7
Primary Aggregate 0.90 6.6 7.45E-03 29
0.10 Secondary Aggregate 0.7 6.28E-04 59
Maintenance 0.68 16
Primary Aggregate 0.90 14.0 1.56E-02 17
0.10 Secondary Aggregate 1.6 1.76E-03 49
Local Roads 0.72 59
Construction 0.13 8
Primary Aggregate 0.90 7.1 8.02E-03 27
0.10 Secondary Aggregate 0.8 8.92E-04 58
Maintenance 0.87 51
Primary Aggregate 0.90 45.9 5.17E-02 5
0.10 Secondary Aggregate 5.1 5.74E-03 31
North West 0.05 43
Motorways & Trunk Roads 0.28 12
Construction 0.32 4
Primary Aggregate 0.90 3.5 3.91E-03 38
0.10 Secondary Aggregate 0.4 4.34E-04 66
Maintenance 0.68 8
Primary Aggregate 0.90 7.4 8.30E-03 26
0.10 Secondary Aggregate 0.8 9.22E-04 57
Local Roads 0.72 31
Construction 0.13 4
Primary Aggregate 0.90 3.7 4.21E-03 36
0.10 Secondary Aggregate 0.4 4.68E-04 65
Maintenance 0.87 27
Primary Aggregate 0.90 24.1 2.71E-02 9
0.10 Secondary Aggregate 2.7 3.01E-03 40
Yorkshire & Humberside 0.12 110
Motorways & Trunk Roads 0.28 31
Construction 0.32 10
Primary Aggregate 0.90 8.9 1.00E-02 24
0.10 Secondary Aggregate 1.0 1.12E-03 55
Maintenance 0.68 21
Primary Aggregate 0.90 18.9 2.13E-02 12
0.10 Secondary Aggregate 2.1 2.37E-03 44
Local Roads 0.72 79
Construction 0.13 11
Primary Aggregate 0.90 9.6 1.08E-02 23
0.10 Secondary Aggregate 1.1 1.20E-03 54
Maintenance 0.87 69
Primary Aggregate 0.90 61.6 6.96E-02 4
0.10 Secondary Aggregate 6.9 7.74E-03 28
East Midlands 0.28 231
Motorways & Trunk Roads 0.28 65
Construction 0.32 21
Primary Aggregate 0.90 18.7 2.11E-02 13
0.10 Secondary Aggregate 2.1 2.34E-03 45
Maintenance 0.68 44
Primary Aggregate 0.90 39.7 4.48E-02 6
0.10 Secondary Aggregate 4.4 4.97E-03 33
Local Roads 0.72 167
Construction 0.13 22
Primary Aggregate 0.90 20.1 2.27E-02 11
0.10 Secondary Aggregate 2.2 2.52E-03 42
Maintenance 0.87 144
Primary Aggregate 0.90 129.7 1.46E-01 1
0.10 Secondary Aggregate 14.4 1.62E-02 16
West Midlands 0.07 63
Motorways & Trunk Roads 0.28 18
Construction 0.32 6
Primary Aggregate 0.90 5.1 5.74E-03 32
0.10 Secondary Aggregate 0.6 6.38E-04 61
Maintenance 0.68 12
Primary Aggregate 0.90 10.8 1.22E-02 21
0.10 Secondary Aggregate 1.2 1.35E-03 52
Local Roads 0.72 45
Construction 0.13 6
Primary Aggregate 0.90 5.5 6.18E-03 30
0.10 Secondary Aggregate 0.6 6.87E-04 60
Maintenance 0.87 39
Primary Aggregate 0.90 35.3 3.98E-02 7
0.10 4.43E-03 35

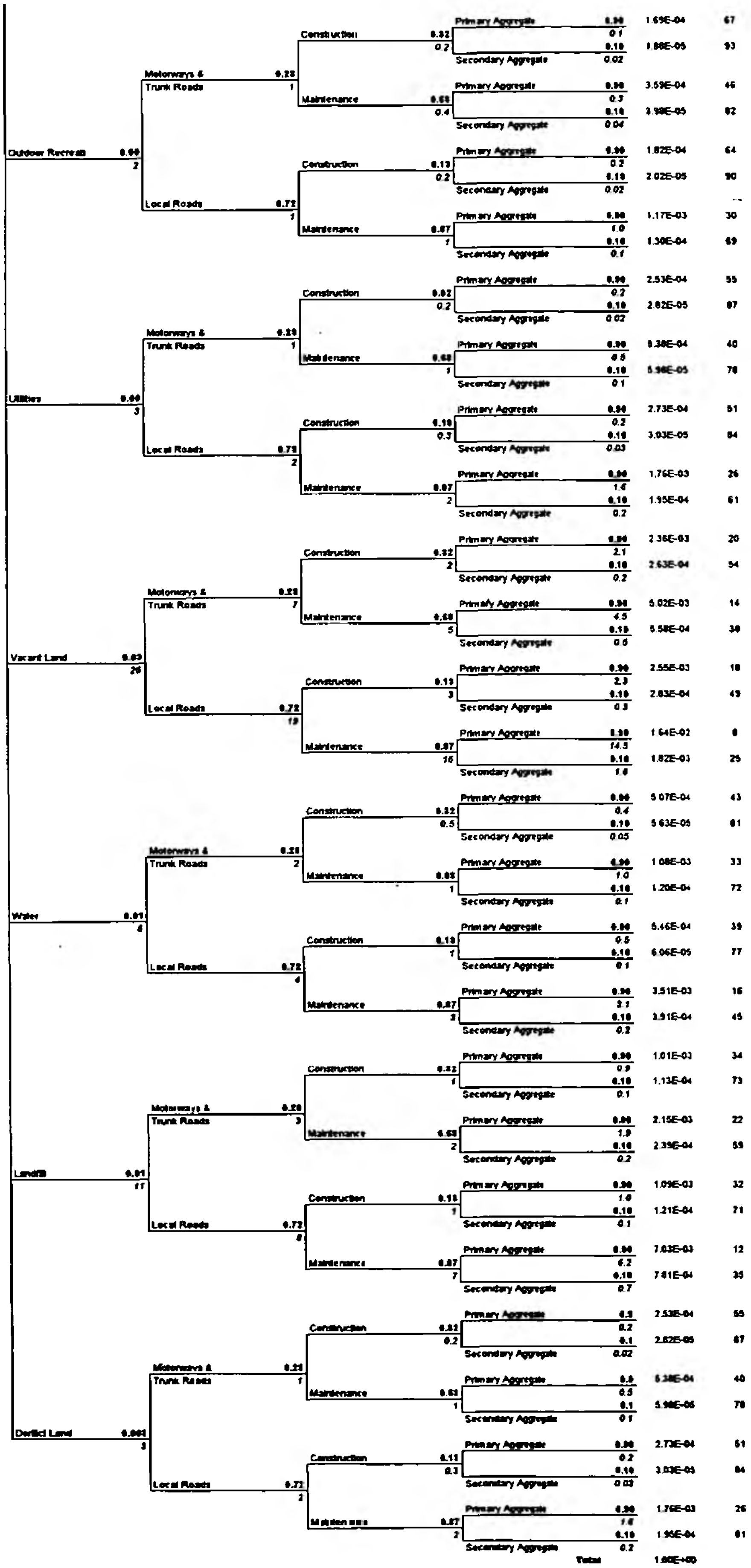


Secondary Aggregate 3 9
Primary Aggregate 0.90 5.19E-04 64
Construction 0.32
0 5
0 5
0.10 5.76E-05 72
Secondary Aggregate 0.1
Motorways & Trunk Roads 0.28
2
Primary Aggregate 0.90 1.10E-03 56
Maintenance 0.68
1.0
1
0.10 1.22E-04 70
Secondary Aggregate 0.1
East Anglia 0.01
5
Primary Aggregate 0.90 5.58E-04 62
Construction 0.13
0 5
0.6
0.10 6.20E-05 71
Secondary Aggregate 0 1
Local Roads 0.72
4
Primary Aggregate 0.90 3 60E-03 39
Maintenance 0.87
3 2
4
0.10 4 00E-04 67
Secondary Aggregate 0 4
Primary Aggregate 0.90 2.22E-03 46
Construction 0.32
2.0
2
0.10 2.47E-04 69
Secondary Aggregate 0.2
Motorways & Trunk Roads 0.28
7
Primary Aggregate 0.90 4.71E-03 34
Maintenance 0.68
4 2
5
0.10 5 23E-04 63
Secondary Aggregate 0 5
South East 0.03
24
Primary Aggregate 0.90 2 39E-03 43
Construction 0.13
2.1
2
0.10 2.65E-04 68
Secondary Aggregate 0 2
Local Roads 0.72
18
Primary Aggregate 0.90 1.54E-02 18
Maintenance 0.87
13 7
15
0.10 1.71E-03 50
Secondary Aggregate 1.5
Primary Aggregate 0.90 1.77E-02 15
Construction 0.32
15.7
17
0.10 1.97E-03 48
Secondary Aggregate 1.7
Motorways & Trunk Roads 0.28
55
Primary Aggregate 0.90 3.77E-02 6
Maintenance 0.68
33 4
37
0.10 4.18E-03 37
Secondary Aggregate 3 7
South West 0.22
195
Primary Aggregate 0.90 1.91E-02 14
Construction 0.13
18 9
19
0.10 2.12E-03 47
Local Roads 0.72
140
Secondary Aggregate 1.9
Primary Aggregate 0.90 1.23E-01 2
Maintenance 0.87
109 2
121
0.10 1 37E-02 19
Secondary Aggregate 12.1
Primary Aggregate 0.90 1.21E-02 22
Construction 0.32
10.7
12
0.10 1.35E-03 53
Secondary Aggregate 1.2
Motorways & Trunk Roads 0.28
37
Primary Aggregate 0.90 2.57E-02 10
Maintenance 0.68
22.8
25
0.10 2.86E-03 41
Secondary Aggregate 2 5
Wales 0.15
133
Primary Aggregate 0.90 1.30E-02 20
Construction 0.13
11.6
13
0.10 1.45E-03 51
Local Roads 0.72
98
Secondary Aggregate 1.3
Primary Aggregate 0.90 8 40E-02 3
Maintenance 0.87
74 5
83
0.10 9.34E-03 25
Secondary Aggregate 8 3
Total 1.00E+00

Figure 11.2 - Event tree showing the area of different land use types lost to quarrying activities, per £M spend on road building and maintenance



Combined Probability
Probability Rank
England & Wales
(m2 per ME spent)
Agricultural Land
Agricultural Build
Forest & Wood
Rough Grass
Highways & Transport
Natural & Semi-natural
Motorways & Trunk Roads
Local Roads
Construction
Maintenance
Primary Aggregate
Secondary Aggregate



Outdoor Recreati
Utilities
Vacant Land
Water
Landfill
Derelict Land
Motorways & Trunk Roads
Local Roads
Construction
Maintenance
Primary Aggregate
Secondary Aggregate
Total

Uncertainties

11.33 The national road budget will vary considerably from year to year. Owing to the current review of roads policy it was not considered useful to base the assessment on mean roads budget data, because this will not be any more accurate than the actual data taken for a specific year. More importantly the ratio of road spending to aggregate extraction is relatively constant year on year (a variation of under 2 per cent is seen in the adjusted 1991 and 1995 figures). This means that road spending can accurately be used as an indicator of aggregate extraction.

11.34 The only variable within the assessment with significant uncertainty was the area of landtake per tonne of aggregate extracted. Because data on land use change was only available for one year it is not possible to quantify the variation in total landtake or in the area of different land types affected. It was estimated that because of the nature of the Land Use Change Survey (aerial photography) and because of the small area of land changing to mineral use in 1992, the area of land missed by the survey could be as large as the area recorded (DETR, 1998). Therefore the landtake data could vary by as much as 100 per cent either way. This factor is therefore by far the most important in determining the area of landtake from road building.

11.35 The methodology provides a framework for assessing the level of landtake likely to arise from a specific road budget. Where the budget is defined (i.e. the proportion spent on different road types and that spent on road construction and maintenance) the volume of aggregate required for different purposes can be determined with accuracy. The only significant uncertainty lies in the area of landtake arising from the extraction of a given quantity of aggregate (and in the proportion of different land use types involved). Variation in the area of landtake in Figure 11.1 (regional distribution of landtake) will not affect the event tree proportions but will alter the total quantity of land taken. However in Figure 11.2 variation in the proportion of landtake from different land use types will affect the proportions within the event tree. Unfortunately because Land Use Change survery data are only available for one year it is impossible to determine whether any particular land use types have a greater fluctuation in annual land use loss to quarrying. If the same variation is used for all land use types there will be no difference in the proportion of landtake between different types.

11.36 Because of the nature of the event trees used in this study (only one significant source of uncertainty, and an unknown variation) it was considered that sensitivity analysis would be unlikely to provide useful information and therefore was not performed.

DISCUSSION

11.37 In addition to estimating the area of land taken per £M spent on roads in general it is also possible to calculate the area of landtake from expenditure on one aspect of the roads budget (i.e. maintenance or construction activities). This indicates the most aggregate intensive activities (i.e. where aggregate reduction measures could be focused).

11.38 To determine the landtake per £M expenditure on a particular activity it is necessary to adjust the landtake estimate in line with the proportion of project expenditure on aggregates as shown in Table 11.4. Tables 11.6 and 11.7 show the estimated area of land taken to provide aggregate per £M spent entirely on construction or maintenance activities. The tables show the significantly greater use of primary aggregate per £M for maintenance activities compared to new construction.

Table 11.6 - Estimated area of regional landtake required to supply primary roadstone per £M spending on construction or maintenance projects

Region	Construction (m^2)	Maintenance (m^2)
Northern	27	122
North West	14	64
Yorkshire and Humberside	36	165
East Midlands	76	346
West Midlands	21	94
East Anglia	2	9
South East	8	36
South West	64	291
Wales	44	199
England and Wales	**292**	**1326**

Table 11.7 - Estimated area of land cover landtake required to supply primary roadstone per £M spending on construction or maintenance projects

Land cover	Construction (m^2)	Maintenance (m^2)
Agricultural land	257	1170
Agricultural buildings	1	3
Forestry and woodland	7	33
Rough grassland	9	42
Highways and road transport	0.3	1
Natural and semi-natural	1	4
Outdoor Recreation	1	3
Utilities	1	4
Vacant land previously developed	9	39
Water	2	8
Landfill	4	17
Derelict land	1	4
Total	**292**	**1328**

11.39 The assessment estimates that 0.0799 ha (799 m^2) of land are lost annually through primary aggregate extraction for each £M spent on road construction and maintenance, the majority of this being from road maintenance schemes (both in total expenditure and in tonnes of aggregate used per £M). However the use of 10 per cent secondary aggregate results in a land saving of 108 m^2 $£M^{-1}$. Increasing the use of secondary aggregate in road construction and maintenance will result in a decreasing amount of landtake by primary aggregate extract per £M spent on roads.

11.40 The majority of the land taken for quarrying is agricultural (88 per cent), and only three per cent is natural or semi natural land. Quarrying activity is focused in the East Midlands and South West.

11.41 The current budget for roads spending is under extensive review, but it is possible to calculate the area of land taken using the 1995 budget (shown in Table 11.4) as an example. Table 11.8 shows the estimated area of land lost in different regions from spending under the 1995 budget, and Table 11.9 shows this by land cover type.

Table 11.8 - Estimated area of land taken by quarrying to supply aggregates for use under the 1995 roads budget, by region

Region	Trunk roads and motorways construction (ha)	Trunk roads and motorways maintenance (ha)	Local road construction (ha)	Local road maintenance (ha)	Total (ha)
Northern	3	7	4	23	37
North West	2	4	2	12	20
Yorkshire and Humberside	5	10	5	31	50
East Midlands	9	20	10	66	105
West Midlands	3	5	3	18	29
East Anglia	0.2	0.5	0.3	2	3
South East	1	2	1	7	11
South West	8	17	9	55	89
Wales	5	12	6	38	61
England and Wales	**36**	**77**	**39**	**252**	**404**

Table 11.9 - Estimated area of land taken by quarrying to supply aggregates for use under the 1995 roads budget, by land cover type

Land cover	Trunk roads and motorways construction (ha)	Trunk roads and motorways maintenance (ha)	Local road construction (ha)	Local road maintenance (ha)	Total (ha)
Agricultural land	32	68	34	222	356
Agricultural buildings	0.1	0.2	0.1	1	1
Forestry and woodland	1	2	1	6	10
Rough grassland	1	2	1	8	13
Highways and road transport	0.04	0.1	0.04	0.3	0.4
Natural and semi-natural	0.1	0.2	0.1	1	1
Outdoor Recreation	0.1	0.2	0.1	1	1
Utilities	0.1	0.2	0.1	1	1
Vacant land previously developed	1	2	1	7	12
Water	0.2	0.5	0.2	2	3
Landfill	0.5	1	0.5	3	5
Derelict land	0.1	0.2	0.1	1	1
Total	**36**	**77**	**39**	**252**	**404**

11.42 It is not possible to assess the impact of the estimated level of land loss without more detailed information on the types of habitats being affected and their vulnerability (influenced by their inherent sensitivity, the size of the habitat patches and the number of similar habitats in the area). This would require more site specific information on types of habitat being lost around individual quarries, and would need to be part of a much larger study. It is clear however that quarrying for roadstone results in the loss of a substantial area of land each year, but that it is the use of roadstone for road maintenance that leads to the major loss.

12. ASSESSMENT OF THE POTENTIAL FOR SENSITIVE HABITAT LOSS FROM NEW ROAD CONSTRUCTION

INTRODUCTION

12.1 This section undertakes an assessment of the potential for sensitive habitat loss from new road construction. Whenever a new road is built, or an existing road widened, land is removed from its previous use and converted to a purely man made habitat which cannot sustain any significant biodiversity and usually has a negative effect on the biodiversity of the habitats either side of it. The area of England and Wales that is currently given over to roads is very considerable, and was estimated at 2,178 km^2 in 1995 (CPRE, 1995). However it is often the linear nature of roads and the resulting degree of habitat fragmentation which causes the most significant effects.

STUDY APPROACH

12.2 The assessment made use of road schemes currently being considered by the DETR for construction in the next few years. It is not known which, or how many, schemes will go forward to development, therefore the assessment was carried out assuming that 10, 25, 50 or 100 per cent of the schemes would proceed. The resulting probability of construction within a region was then determined by taking the mean of 1,001 random samples of 10, 25, 50 and 100 per cent of the schemes, using the Crystal Ball uncertainty analysis software.

12.3 In estimating the potential habitat loss from future road building several obstacles have to be overcome:

- roads are linear features, therefore the actual area of land lost to a new road or road improvement is likely to be less significant than the arising impact on the habitat either side of the road. Therefore, the route of a road is crucial in making a useful estimate of its impacts in terms of habitat loss;

- the loss of a given area of habitat in one part of the country will have a different impact from the same loss in another area, due to differences in abundance of habitats and in their roles in forming the character of an area;

- it is not possible to determine the routes of all future road schemes in England and Wales because these are not yet known or finalised;

- it is not possible to determine the extent of future road building in England and Wales because this is based on national transport policy which is not yet determined and is liable to periodic change; and,

- historical road building cannot be used as an indicator of future construction because:

  - transport policy has changed;

  - new roads are based on regional demand and this does not link them to a specific habitat type, therefore it cannot be said that the types of habitats previously affected will be those affected in the future; and,

- the impact of road building on designated sites cannot be determined on a generic level because of the variation in site type and in the way certain types of road would affect the nature of the site.

12.4 The above difficulties make predictions of the future extent of habitat loss uncertain. The approach taken in this assessment was to estimate the area of green and brownfield landtake that may arise in the next year in different regions of England and Wales, and to compare this to the total area of landtake of this type arising from other development activities. This gives an indication of the *relative* development pressure on habitats in different regions arising from road building and other forms of urbanisation, but does not estimate the impacts arising from this pressure.

12.5 In addition, a measure of the level of impact on designated conservation sites (Ramsar sites, SSSIs, National Parks, NNRs, AONBs, etc.) was obtained by correlating the density of the designated sites within each region to the level of road development within the region. Both of these factors were derived by normalisation. The density of designated sites was determined by the total area (or number for point features) of sites within the region divided by the area of the region. The level of road development was determined by the predicted area of landtake in the region divided by the area of the region.

12.6 This approach does not provide the probability that a certain-designated site will be impacted, but it does provide a good indication of the *relative* pressure to which the designated sites in each region are exposed due to road construction activities. This makes it possible to identify the regions in which certain types of designated sites are most threatened so that the sites in these areas can be prioritised for protection. It was decided that it was not possible to attempt to quantify the probability of a designated site being impacted because it could not be assumed that the distribution of sites, and road schemes within the region would be random and that landtake was uncorrelated (i.e. road development will often result in a number of adjacent areas being impacted). A significant additional problem was that the level of impact arising from road schemes at different distances from sites cannot be determined generically.

12.7 Because of the different measurement units used in these two assessments it is not possible to include them on the same event tree, therefore two event trees were used. The first is the relative landtake event tree whilst the second is the impact on designated sites event tree. It is recognised that neither of these assessments quantitatively indicates the level or impact of habitat loss from future road building. However, because of the difficulties outlined above it is considered most useful at this stage to consider simple indicators of relative pressure in which greater confidence can be placed.

12.8 A more detailed study is considered inappropriate at this stage for the following reasons:

- it would have resulted in estimates that took no account of the sensitivity of a habitat to fragmentation and so could not adequately estimate the impact of the habitat loss;

- there is currently insufficient information on the different types of landcover in England and Wales to allow the habitat types in an area to be determined. The Countryside Information System only provides information on landcover types such as coniferous and deciduous woodland, agricultural land and grassland. It is difficult to determine the relative significance of these very broad habitat groups; and

- estimates for more than one year are liable to be made invalid by changes in transport policy (especially as the current roads budget is under extensive review).

METHODOLOGY

Relative landtake event tree

12.9 The relative landtake event tree has three levels; one differentiating land by DETR region and two differentiating by landtake and impact categories. The tree compartmentalises England and Wales into DETR regions and indicates the likely level of change resulting from road construction in the next year based on current DETR schemes. None of the schemes currently being reviewed are in Wales so information has not been gathered for this area.

12.10 Data were available on 55 of the 70 road schemes currently being considered by DETR, this information contains details of the amounts of:

- greenfield landtake;
- greenbelt landtake; and,
- brownfield landtake.

12.11 Because it is not known which of the 70 road schemes will go ahead it was decided to determine the possible level of new road building in each region based on the mean of 1,001 random samples of 10, 25, 50 and 100 per cent of the schemes for which information was available. The data on each scheme used in the assessment are shown in Appendix A; for confidentiality reasons the scheme names have been omitted.

12.12 Table 12.1 shows the area of landtake in each region from 1,001 random samples of 10, 25 and 50 per cent of the schemes being considered. A 100 per cent scenario is also included to complete the range of development scales. When the area of landtake from 10, 25 and 50 per cent of the schemes is scaled to a hypothetical 100 per cent a comparison between the area of landtake for each per cent development can be made over different scales of road building policy (10 to 100 per cent). Table 12.2 shows the scaled landtake and standard deviation for each region. The standard deviation is very low indicating that the amount of landtake increases virtually linearly as the percentage of schemes included increases (over 1,001 samples).

Table 12.1 - Area of landtake from 1,001 random samples of 10, 25, 50 and 100 per cent of the road schemes currently being considered by the DETR

Region	10 per cent (ha)	25 per cent (ha)	50 per cent (ha)	100 per cent (ha)
Northern	10	21	48	91
North West	51	120	244	480
Yorkshire and Humberside	63	141	278	559
East Midlands	21	50	10	200
West Midlands	-	-	-	-
East Anglia	17	40	80	163
South East	97	205	418	801
South West	15	39	74	152
England	**277**	**620**	**1,245**	**2,448**

Table 12.2 - Area of landtake from 1,001 random samples of 10, 25 and 50 per cent of the road schemes currently being considered by the DETR - scaled to 100 per cent

Region	10 per cent (x 10)	25 per cent (x 4)	50 per cent (x 2)	100 per cent (x 1)	Mean of scaled landtake	Standard Deviation
Northern	100	85	96	91	93	6
North West	518	483	488	480	492	17
Yorkshire and Humberside	630	566	556	559	578	34
East Midlands	217	203	201	200	205	8
West Midlands	-	-	-	-	-	-
East Anglia	173	160	161	163	164	6
South East	977	823	836	801	859	79
South West	155	156	149	152	153	3
England	**2,773**	**2,480**	**2,491**	**2,448**	**2,548**	**150**

12.13 This near linear increase in landtake with increasing numbers of schemes being included after only 1,001 samples indicates that the probable landtake for a given percentage of schemes can be approximated by the percentage of the total landtake for the region.

12.14 In the event tree the area of landtake in each region, differentiated by land type, for 100 percent of the schemes is compared against the level of other types of urbanising development. To compare the landtake for lower levels of development (10, 25, 50 or any other percentage) it is possible to scale the landtake from 100 per cent.

Impact on designated sites event tree

12.15 The potential impact on designated sites is determined by considering the density of designated sites in each region. Where the sites are area features (i.e. SSSIs, NNRs AONBs, etc.) the density is represented as a proportion of the total land area of the region. Where the sites are point features (i.e. listed buildings, World Heritage Sites, sites of archaeological significance, etc.) the density is represented by the number of sites per km^2 of the region. The density of a site in a region multiplied by the level of road development in the region provides an indication of the level of development pressure to which the sites are exposed. In this assessment it is assumed that 100 per cent of the schemes will proceed, however because of the linear nature of the landtake from different scales of development the relative development pressure will not change even if the scale of road building differs. The level of road development in each region should 100 per cent of the schemes proceed is shown in Table 12.3.

Table 12.3 - Level of road development in each DETR region should 100 per cent of the schemes being considered by the DETR proceed

Region	Area of region (ha)	Landtake should 100 per cent of schemes proceed (ha)	Level of road development
Northern	1,581,500	91	0.000058
North West	750,500	480	0.000640
Yorkshire and Humberside	1,562,000	559	0.000358
East Midlands	1,572,300	200	0.000127
West Midlands	1,301,400	-	0
East Anglia	1,280,000	163	0.000128
South East	2,788,300	801	0.000288
South West	2,463,500	152	0.000062
England	**13,299,500**	**1116**	**0.000184**

DATA SOURCES

12.16 A number of data sources were utilised in determining the regional density of different land types, and the number of designated sites in each region, these are summarised in Table 12.4.

Table 12.4 - Data sources used in determining the current stock of certain land types and habitat resources in different regions of England

Data	Data source	Comments
Area of land in each region	Countryside Information System Database (maintained by the Institute of Terrestrial Ecology)	Provides information on UK land with a resolution of $25m^2$
Area of urban land	Regional Trends 28 (CSO, 1993) and Biodiversity: UK Steering Group Report (Biodiversity Steering Group, 1995a)	Estimates based on an average of 10 per cent of the land in each region, derived from estimated range of 5-15 per cent, and subtracting the area of brownfield land
Area of greenbelt land	Digest of Environmental Statistics (DETR, 1997e)	Gives area of greenbelt land in each region
Area of brownfield land	Digest of Environmental Statistics (DETR, 1997e)	Gives area of derelict land in each region
Area of greenfield land	Regional Trends 28 (CSO, 1993) and Biodiversity: UK Steering Group Report (Biodiversity Steering Group, 1995a)	Estimates based on an average of 90 per cent of the land in each region, derived from estimated range of 85-95 per cent, and subtracting the area of brownfield land
Area and number of SSSIs in each region	Countryside Information System Database (maintained by the Institute of Terrestrial Ecology)	Gives area of SSSIs in England by DETR region
Area and number of NNRs, SACs and Ramsar sites in each region	English Nature database and 6th Annual Report (EN, 1997)	Lists area and location of NNRs, SACs and Ramsar sites in England
National Parks, and AONB	Digest of Environmental Statistics (DETR, 1997e)	Gives area of designated sites in each region
Number of sites of cultural heritage	English Heritage databases	Provides numbers of scheduled ancient monuments, listed buildings and undesignated archaeological sites

12.17 Virtually all of the data obtained were split by standard governmental regions, unfortunately the boundaries of these do not all correspond very well with EA Regions. Governmental regions were used in this assessment because the data were provided in this form and converting the collated data from governmental to EA regions would have introduced additional and unnecessary uncertainties into the assessment. Table 12.5 provides the areas of greenbelt land and brownfield land for each region. The non greenbelt land was determined as the difference between the areas of greenfield and greenbelt land in the region.

Table 12.5 - Areas of greenbelt and brownfield land in each region

Region	Area of greenbelt land (ha)	Area of brownfield land (ha)
Northern	46,500	5,100
North West	241,700	8,700
Yorkshire and Humberside	249,600	5,500
East Midlands	61,500	4,400
West Midlands	209,300	4,900
East Anglia	26,100	1,000
South East	605,800	4,500
South West	78,700	5,500

Source: DETR, 1997e

Regional land types

12.18 Information was obtained on the level of development of greenfield and brownfield land from summaries in the Digest of Environmental Statistics (DETR, 1997e). Information on greenfield sites is based on the DETR landuse change survey (DETR, 1997e). The annual level of urbanisation (land changing from rural to urban use) of greenfield sites, in each county, was estimated by dividing the predicted urbanisation between 1991 and 2016 by 25. This information was then collated to give regional estimates, as can be seen in Table 12.6. This estimate contains uncertainties because development is unlikely to be spread evenly over 25 years.

Table 12.6 - Estimated annual rate of urbanisation of greenfield sites

Region	Projected urban growth between 1991-2016 (ha)	Estimated rate of annual urban growth (ha)
Northern	9,400	376
North West	13,000	520
Yorkshire and Humberside	15,700	628
East Midlands	17,500	700
West Midlands	16,000	640
East Anglia	15,000	600
South East	50,100	2,004
South West	31,100	1,244
Total	**167,800**	**6,712**

Source: DETR, 1997e

12.19 Unfortunately no information was available on the development of greenbelt sites. Therefore it was assumed that a similar proportion of the available land would be developed as is the case for greenfield sites. It is recognised that this may represent a slight overestimate because of the restrictions on the development of greenbelt sites.

12.20 The development of brownfield sites is monitored by the DETR Derelict Land Survey. The total stock of derelict (brownfield) land in each region is shown in Table 12.7. Table 12.7 also indicates the amount of this land developed annually which is based on the average amount developed between 1988 and 1993. This may be an underestimate because it fails to consider the increased rate of brownfield development in the mid to late 1990s. However it represents the best data source currently available.

Table 12.7 - Estimated annual development of brownfield land

Region	Stock of brownfield land in 1993 (ha)	Amount reclaimed between 1988 and 1991 (ha)	Average amount reclaimed annually (ha)
Northern	5,100	1,600	533
North West	8,700	1,700	566
Yorkshire and Humberside	5,500	1,500	500
East Midlands	4,400	1,800	600
West Midlands	4,900	1,500	500
East Anglia	1,000	100	33
South East	4,500	800	266
South West	5,500	600	200
Total	**39,600**	**9,600**	**3,200**

Source: DETR, 1997e

Designated sites within each region

12.21 Using the sources listed in Table 12.4 the numbers and areas of designated landscape, ecological, and heritage sites in each region were calculated. In two cases where the numbers of sites are very high (e.g. there are around 400,000 listed buildings in England and around 250,000 archaeological sites), and no regional or county breakdown was available, the sites were assumed to be relatively evenly distributed throughout the country and therefore the density of the sites in each region was assumed to be the same. For some lower site designations (regional or county designations) information is not held centrally on the number of sites in England and Wales, and there was insufficient time available in this study to contact each county for the information. Therefore no information is presented for these designations.

12.22 Table 12.8 shows the estimated area and number of designated conservation sites within each region of England. Where the sites are point features these are expressed as numbers.

12.23 Table 12.9 shows the density of the designated sites within each region, with area features expressed as a proportion of the regional area, while point features are expressed as a number of sites per ha.

Table 12.8 - Area (and number) of designated conservation sites in different regions of England

	Sites of ecological value (ha)				Sites of landscape value (ha)		Sites of cultural value			
Region	**Ramsar**	**SAC**	**NNR**	**SSSI**	**National Parks**	**AONB**	**World Heritage Sites**	**SAM**	**Grade II Listed buildings***	**Sites of Arch sig.***
Northern	42,226 (9)	163,575 (20)	14,353 (35)	155,400 (481)	361,600	225,500	2	1,825	47,566	29,729
North West	51,582 (7)	32,669 (4)	5,278 (6)	48,860 (179)	10,300	78,000	0	391	22,572	14,108
Yorkshire and Humberside	16,607 (4)	8,358 (4)	3,451 (8)	79,730 (372)	314,600	31,800	1	2,189	46,979	29,362
East Midlands	33,253 (3)	56,334 (4)	11,306 (7)	54,190 (378)	91,700	51,900	0	1,298	47,289	29,556
West Midlands	2,180 (3)	2,403 (8)	2,624 (15)	23,260 (457)	20,200	126,900	1	1,248	39,141	24,463
East Anglia	56,309 (21)	72,832 (13)	10,884 (32)	47,210 (342)	0	91,200	0	874	38,498	24,061

South East	78,276 (20)	85,848 (24)	11,443 (40)	153,200 (863)	0	661,600	3	3,239	83,862	52,414
South West	27,774 (6)	104,253 (32)	11,545 (40)	148,700 (937)	164,700	692,600	2	6,392	74,093	46,308
Total	308,207	526,272	70,886	710,550	963,100	1959,500	9	17,456	400,000	250,000

Source: see Table 12.4

Note: * Numbers of sites based on area of region assuming an even distribution of sites throughout England

Where a site straddles a regional boundary it is considered to be present in both regions with its area evenly distributed between the two.

Table 12.9 - Density of designated conservation sites in different regions of England

	Sites of ecological value				Sites of landscape value		Sites of cultural value (sites ha^{-1})			
Region	**Ramsar**	**SAC**	**NNR**	**SSSI**	**National Parks**	**AONB**	**World Heritage Sites**	**SAM**	**Grade II Listed buildings***	**Sites of Arch sig.***
Northern	0.027	0.103	0.009	0.098	0.229	0.143	0.0000013	0.0012	0.03	0.019
North West	0.069	0.044	0.007	0.065	0.014	0.104	0	0.0005	0.03	0.019
Yorkshire and Humberside	0.011	0.005	0.002	0.051	0.201	0.02	0.0000006	0.0014	0.03	0.019
East Midlands	0.021	0.036	0.007	0.034	0.058	0.033	0	0.0008	0.03	0.019
West Midlands	0.002	0.002	0.002	0.018	0.016	0.098	0.0000008	0.001	0.03	0.019
East Anglia	0.044	0.057	0.009	0.037	0	0.071	0	0.0007	0.03	0.019
South East	0.028	0.031	0.004	0.055	0	0.237	0.0000011	0.0012	0.03	0.019
South West	0.011	0.031	0.005	0.060	0.067	0.281	0.0000008	0.0026	0.03	0.019

Source: see Table 12.4

Note: * Numbers of sites based on area of region assuming an even distribution of sites throughout England

Where a site straddles a regional boundary it is considered to be present in both regions with its area evenly distributed between the two.

RESULTS

12.24 Figures 12.1 and 12.2 show the event trees generated for this study.

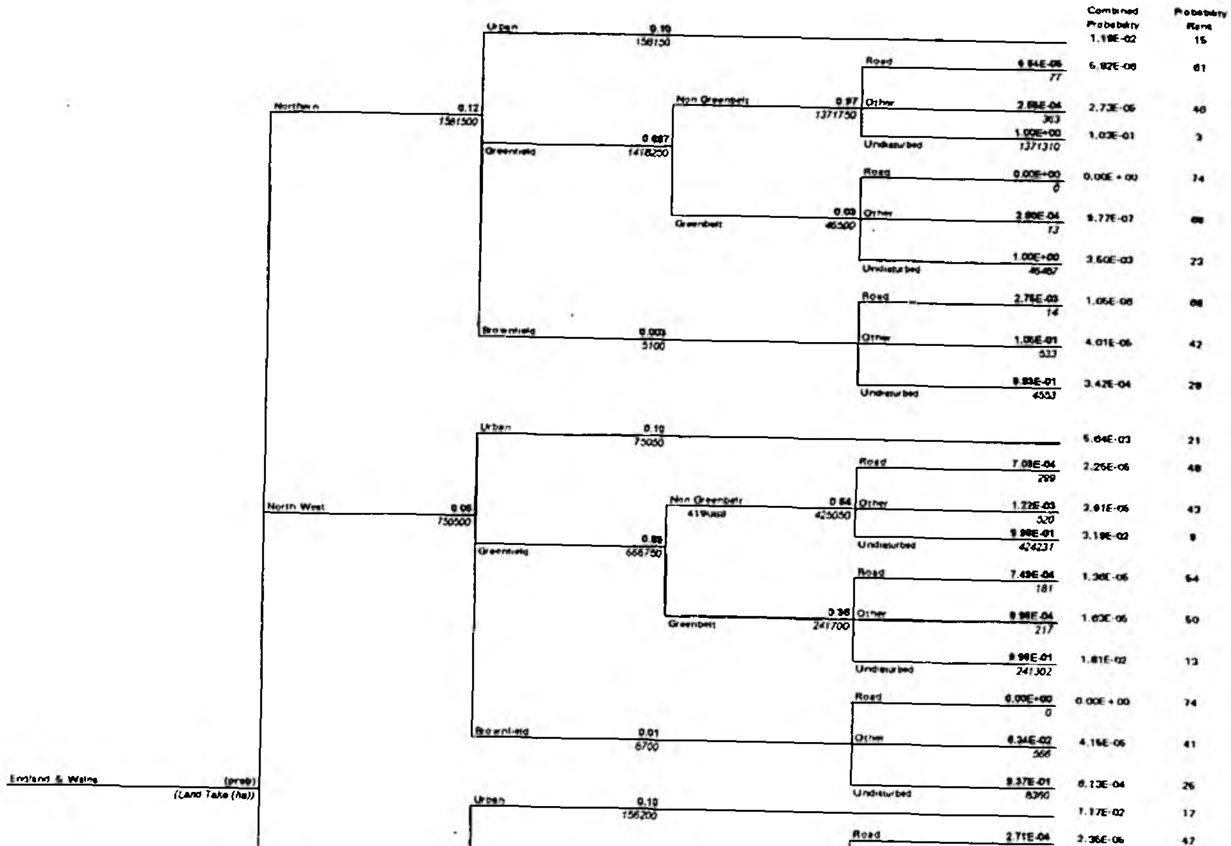
12.25 Figure 12.1 shows the amount and proportion of landtake from all the schemes currently being considered by the DETR in comparison to other forms of urbanisation. Table 12.10 lists the parameters used in Figure 12.1, and gives details of the level of confidence that can be placed in the figures.

Table 12.10 - Parameters utilised in the relative landtake event tree

Parameter	Value	Distribution	Comments
Regional area	See Table 12.3	-	Obtained from the Countryside Information System Database (maintained by the Institute of Terrestrial Ecology)
Urban land area	See Table 12.3 for regional areas	Normal	Estimated as 10 per cent of regional areas as suggested in Biodiversity: The UK Steering Group Report (Biodiversity Steering Group, 1995b)
Greenfield land area	See Table 12.3 for regional areas and Table 12.5 for brownfield areas.	Normal	Estimated as 90 per cent of regional area, as suggested in Biodiversity: The UK Steering Group Report (Biodiversity Steering Group, 1995b), minus the area of brownfield land
Brownfield land area	See Table 12.5	-	Taken from Digest of Environmental Statistics (DETR, 1997e)
Greenbelt land area	See Table 12.5	-	Taken from Digest of Environmental Statistics (DETR, 1997e)
Non greenbelt land area	See Table 12.3 for regional areas and Table 12.5 for brownfield and greenbelt areas	-	Estimated as the greenfield land area minus the greenbelt land area
Area of land taken for road building	See Table 12.3 and Appendix A	-	Based on the landtake calculations for the schemes being considered by the DETR for which information was available
Area of greenfield landtake by other forms of development	See Table 12.6	-	Obtained from Digest of Environmental Statistics (DETR, 1997e)
Area of brownfield landtake by other forms of development	See Table 12.7	-	Obtained from Digest of Environmental Statistics (DETR, 1997e)

Area of greenbelt landtake by other forms of development	See Table 12.6 for greenfield landtake and above for greenbelt and greenfield land area	-	Calculated from greenfield development assuming a similar proportion of land is developed
Area of non green belt landtake by other forms of development	See Table 12.6 for greenfield landtake and above for non greenbelt and greenfield landtake	-	Calculated from greenfield development assuming a similar proportion of land is developed
Area of undisturbed land	See above for areas of landtake for road building and other forms of development	-	Calculated as the remainder of the land in each region after developed land has been removed

Figure 12.1 - Event trees showing relative landtake arising from the development of a hundred per cent of the road schemes currently being considered by the DETR



England & Wales
(prob)
(Land Take (ha))
Northern
0.12
1581500
Urban
0.10
158150
Greenfield
0.897
1418250
Non Greenbelt
0.97
1371750
Greenbelt
0.03
46500
Brownfield
0.003
5100
Road
Other
Undisturbed
North West
0.06
750500
Urban
0.10
75050
Greenfield
0.89
666750
Non Greenbelt
0.64
425050
Greenbelt
0.36
241700
Brownfield
0.01
8700
Urban
0.10
156200
Combined Probability
Probability Rank
1.19E-02
15
6.92E-08
61
2.73E-06
46
1.03E-01
3
0.00E+00
74
9.77E-07
3.60E-03
23
1.05E-06
4.01E-06
42
3.42E-04
28
5.64E-03
21
2.25E-06
48
3.01E-06
43
3.19E-02
9
1.36E-06
54
1.63E-06
50
1.81E-02
13
0.00E+00
74
4.15E-06
41
6.73E-04
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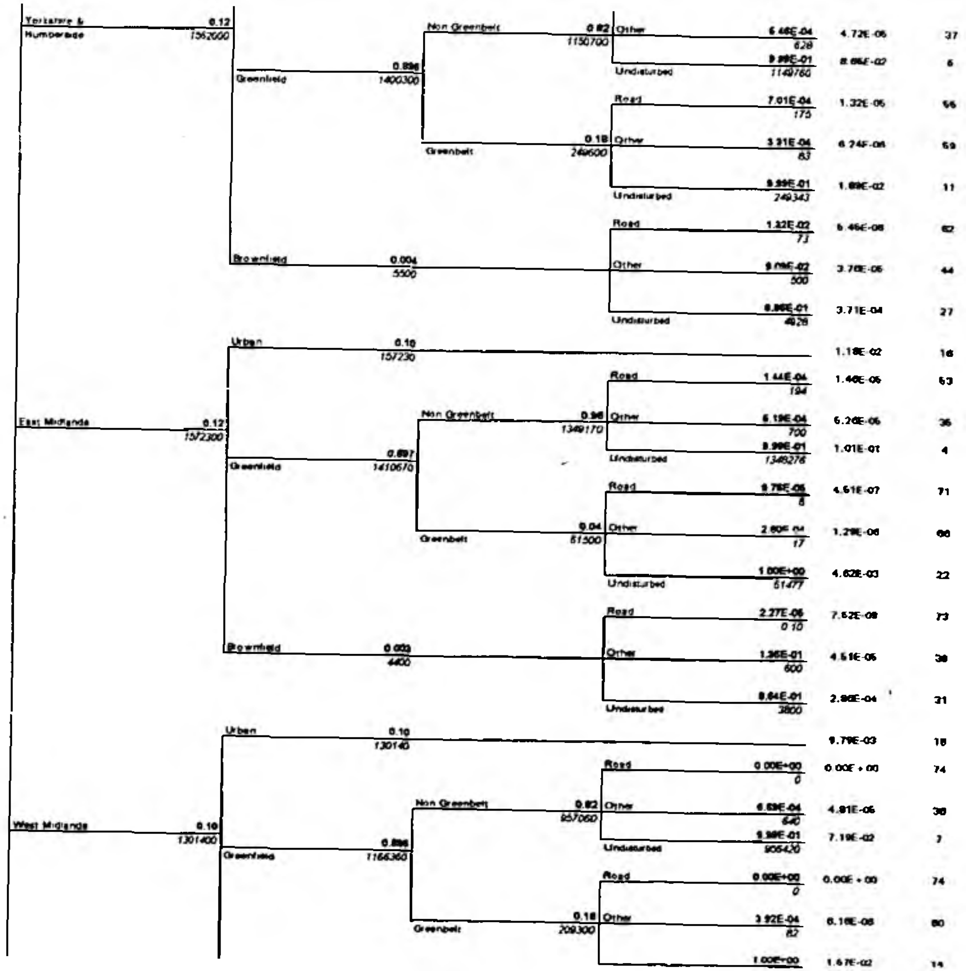
1.17E-02
17
2.36E-06
47
2.71E-04
312



Yorkshire & Humberside
0.12
1562600
Greenfield
0.896
1400300
Non Greenbelt
0.82
1150700
Other
6.48E-04
628
4.72E-05
37
Undisturbed
9.99E-01
1149760
8.66E-02
6
Road
7.01E-04
175
1.32E-05
56
Greenbelt
0.18
249600
Other
3.31E-04
83
6.24E-06
59
Undisturbed
9.99E-01
249343
1.89E-02
11
Brownfield
0.004
5500
Road
1.32E-02
73
6.46E-08
82
Other
9.09E-02
500
3.70E-06
44
Undisturbed
8.86E-01
4928
3.71E-04
27
East Midlands
0.12
1572300
Urban
0.10
157230
1.18E-02
16
Greenfield
0.897
1410670
Non Greenbelt
0.96
1349170
Road
1.44E-04
194
1.40E-06
63
Other
5.19E-04
700
6.20E-06
36
Undisturbed
9.99E-01
1348276
1.01E-01
4
Greenbelt
0.04
61500
Road
9.76E-05
6
4.61E-07
71
Other
2.80E-04
17
1.29E-06
60
Undisturbed
1.00E+00
61477
4.62E-03
22
Brownfield
0.003
4400
Road
2.27E-05
0.10
7.52E-08
73
Other
1.36E-01
600
4.51E-06
38
Undisturbed
8.64E-01
3800
2.86E-04
31
West Midlands
0.10
1301400
Urban
0.10
130140
9.79E-03
18
Greenfield
0.896
1166360
Non Greenbelt
0.82
957060
Road
0.00E+00
0
0.00E+00
74
Other
6.69E-04
640
4.81E-05
30
Undisturbed
9.99E-01
956420
7.19E-02
7
Greenbelt
0.18
209300
Road
0.00E+00
0
0.00E+00
74
Other
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82
6.16E-06
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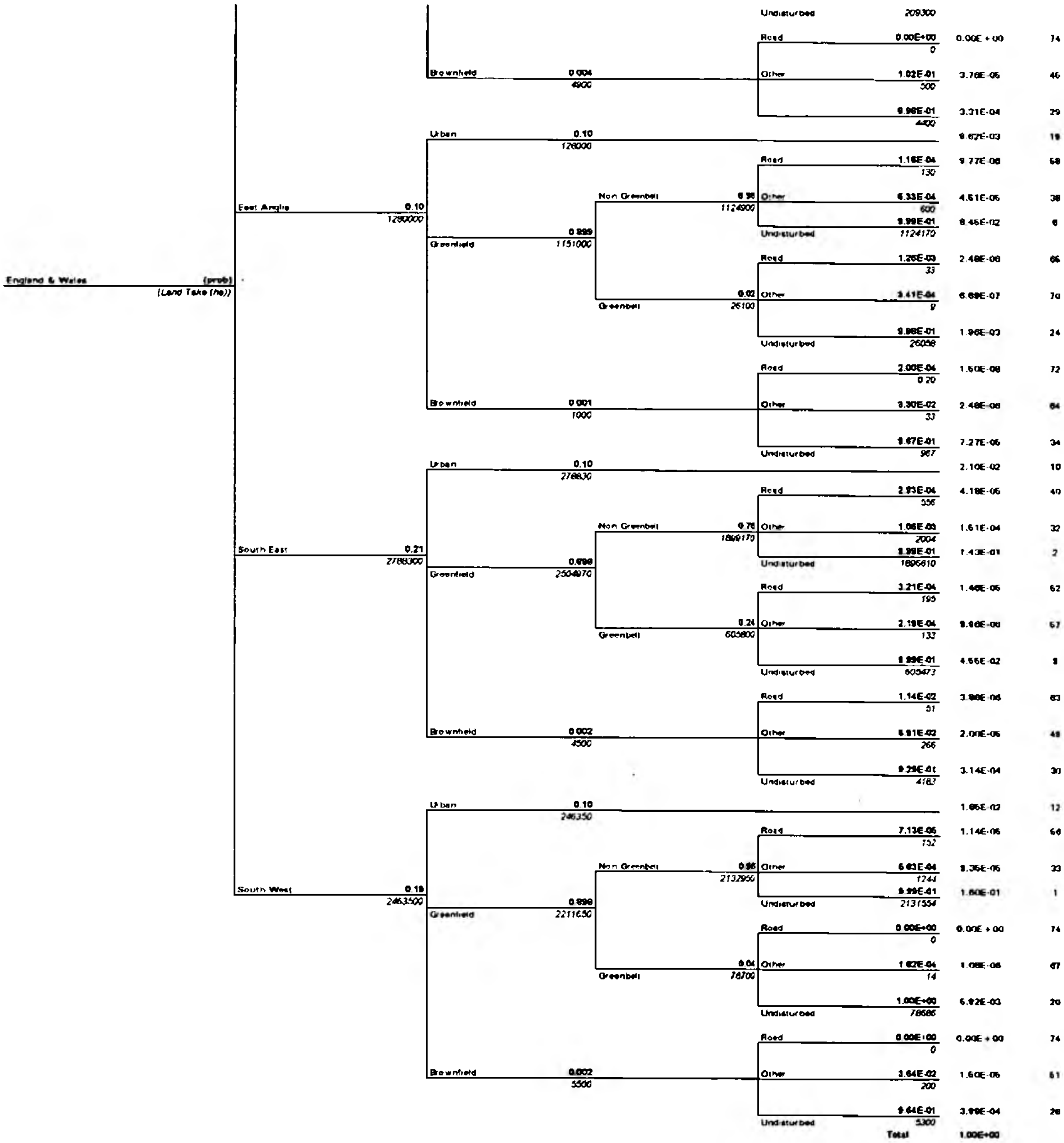
1.00E+00
1.67E-02
14


England & Wales (prob)
[Land Take (ha)]
East Anglia 0.10
1280000
South East 0.21
2788300
South West 0.19
2463500
Brownfield 0.004
4900
Urban 0.10
128000
Greenfield 0.899
1151000
Brownfield 0.001
1000
Urban 0.10
278830
Greenfield 0.898
2504970
Brownfield 0.002
4500
Urban 0.10
246350
Greenfield 0.898
2211650
Brownfield 0.002
5500
Non Greenbelt 0.98
1124900
Greenbelt 0.02
26100
Non Greenbelt 0.76
1899170
Greenbelt 0.24
605800
Non Greenbelt 0.96
2132950
Greenbelt 0.04
78700
Undisturbed 209300
Road 0.00E+00 0 0.00E+00 74
Other 1.02E-01 500 3.76E-06 46
9.98E-01 4400 3.31E-04 29
9.62E-03 19
Road 1.16E-04 130 9.77E-08 58
Other 6.33E-04 600 4.61E-06 38
Undisturbed 9.99E-01 1124170 8.46E-02 6
Road 1.26E-03 33 2.48E-08 66
Other 3.41E-04 9 6.69E-07 70
Undisturbed 9.98E-01 26058 1.96E-03 24
Road 2.00E-04 0.20 1.50E-08 72
Other 3.30E-02 33 2.48E-06 64
Undisturbed 9.67E-01 967 7.27E-05 34
2.10E-02 10
Road 2.93E-04 556 4.18E-05 40
Other 1.06E-03 2004 1.61E-04 32
Undisturbed 9.99E-01 1896610 1.43E-01 2
Road 3.21E-04 195 1.46E-06 62
Other 2.19E-04 133 9.96E-06 57
Undisturbed 9.99E-01 605473 4.56E-02 8
Road 1.14E-02 51 3.86E-06 63
Other 5.91E-02 266 2.00E-05 48
Undisturbed 9.29E-01 4183 3.14E-04 30
1.86E-02 12
Road 7.13E-05 152 1.14E-05 56
Other 5.83E-04 1244 9.36E-05 33
Undisturbed 9.99E-01 2131554 1.60E-01 1
Road 0.00E+00 0 0.00E+00 74
Other 1.82E-04 14 1.08E-06 67
Undisturbed 1.00E+00 78686 5.92E-03 20
Road 0.00E+00 0 0.00E+00 74
Other 3.64E-02 200 1.50E-05 51
Undisturbed 9.64E-01 5300 3.99E-04 28
Total 1.00E+00

12.26 The development pressure is obtained by multiplying the site density in each region (Table 12.9) by the level of road development (Table 12.3). The resulting absolute development pressure is shown in Table 12.11. The relative development pressure in each region is the absolute development pressures normalised to the total development pressure for all regions. Figure 12.2 shows the relative development pressures to which a range of designated sites are exposed in different regions of England.

12.27 Because there is little variation in the proportion of corrected landtake in different regions under the four scales of development modelled (10, 25, 50 and 100 per cent), the *relative* pressures will vary very little, although the absolute pressure will obviously increase with the scale of development.

12.28 Table 12.12 lists the parameters used in Figure 12.2, and gives details of the level of confidence that can be placed in the figures.

Table 12.11 - Development pressures on designated sites in different regions of England resulting from road building (based on 100 per cent of proposed DETR schemes proceeding)

	Sites of ecological value				Sites of landscape value		Sites of cultural value (sites ha^{-1})			
Region	**Ramsar**	**SAC**	**NNR**	**SSSI**	**National Parks**	**AONB**	**World Heritage Sites**	**SAM**	**Grade II Listed buildings***	**Sites of Arch sig.***
Northern	1.54E-06	6.12E-06	5.25E-07	5.68E-06	1.32E-05	8.43E-06	7.31E-11	6.83E-08	1.74E-06	1.09E-06
North West	4.40E-05	2.86E-05	4.50E-06	4.16E-05	8.78E-06	6.83E-05	0.00E+00	3.42E-07	1.92E-05	1.20E-05
Yorkshire and Humberside	3.81E-06	1.98E-06	7.92E-07	1.83E-05	7.22E-05	7.54E-06	2.29E-10	5.19E-07	1.08E-05	6.74E-06
East Midlands	2.69E-06	4.69E-06	9.15E-07	4.39E-06	7.42E-06	4.32E-06	0.00E+00	1.08E-07	3.83E-06	2.39E-06
West Midlands	0	0	0	0	0	0	0	0	0	0
East Anglia	5.61E-06	7.31E-06	1.08E-06	4.70E-06	0.00E+00	9.16E-06	0.00E+00	8.77E-08	3.83E-06	2.40E-06
South East	8.07E-06	9.49E-06	1.18E-06	1.58E-05	0.00E+00	7.32E-05	3.09E-10	3.58E-07	8.65E-06	5.41E-06
South West	6.96E-07	1.96E-06	2.89E-07	3.72E-06	4.13E-06	1.75E-05	5.01E-11	1.62E-07	1.86E-06	1.16E-06
Total	**6.64E-05**	**6.01E-05**	**9.28E-06**	**9.42E-05**	**1.06E-04**	**1.88E-04**	**6.62E-10**	**1.64E-06**	**4.99E-05**	**3.12E-05**

Source: Tables 12.3 and 12.9

Table 12.12 - Parameters utilised in the relative development pressure event tree

Parameter	Data	Distribution	Comment
Area and number of development sites	Table 12.8	-	Obtained from sources listed in Table 12.4
Density of designated sites	Table 12.9	-	Obtained from the area or number of designated sites divided by the regional area
Area of land taken for road building	Table12.3	-	Based on landtake calculations for the schemes being considered by the DETR for which information was available
Level of road development	Table 12.3	-	Obtained by normalising landtake for road building to regional area
Development pressure	Table 12.10	-	Obtained from multiplying the density of designated sites by the level of road development
Relative development pressure	See Table 12.11 for development pressure and total development pressure	-	Obtained by normalising development pressure to total development pressure for all regions.

Uncertainties

12.29 There are obviously uncertainties in the level of road development occurring in different regions of England, but it is not meaningful to quantify these uncertainties because they will vary according to the prevailing transport policy. The level of uncertainty in the landtake required by a specific scheme was low because the scheme design will entail a detailed calculation of the land requirements. Other data used in the assessment were mostly measured land areas which are considered to be well defined data. Therefore, this methodology provides a framework for assessing the cumulative impact for any specific combination of road schemes so that where the combination of schemes is well defined their impact in terms of landtake and development pressure can be determined. Due to the nature of these event trees where the only significant source of uncertainty is in the number and size of road schemes to be considered it is unlikely that quantitative sensitivity analysis with provide useful information, therefore such an analysis has not been undertaken.

Figure 12.2 - Event tree showing the development pressure to which different types of designated sites are exposed by the road schemes currently being considered by the DETR

Ramsar Sites		
	Northern	0.02
	North West	0.66
	Yorkshire and Humberside	0.06
	East Midlands	0.04
	West Midlands	0.00
	East Anglia	0.08
	South East	0.12
	South West	0.01
	Total	**1.00**

Special Areas of Conservation		
	Northern	0.10
	North West	0.48
	Yorkshire and Humberside	0.03
	East Midlands	0.08
	West Midlands	0.00
	East Anglia	0.12
	South East	0.16
	South West	0.03
	Total	**1.00**

National Nature Reserves	
Northern	0.06
North West	0.48
Yorkshire and Humberside	0.09
East Midlands	0.10
West Midlands	0.00
East Anglia	0.12
South East	0.13
South West	0.03
Total	**1.00**

Sites of Special Scientific Interest	
Northern	0.06
North West	0.44
Yorkshire and Humberside	0.19
East Midlands	0.05
West Midlands	0.00
East Anglia	0.05
South East	0.17
South West	0.04
Total	**1.00**

National Park	
Northern	0.12
North West	0.08
Yorkshire and Humberside	0.68
East Midlands	0.07
West Midlands	0.00
East Anglia	0.00
South East	0.00
South West	0.04
Total	**1.00**

Areas of Outstanding Natural Beauty	
Northern	0.04
North West	0.36
Yorkshire and Humberside	0.04
East Midlands	0.02
West Midlands	0.00
East Anglia	0.05
South East	0.39
South West	0.09
Total	**1.00**

World Heritage Sites	
Northern	0.11
North West	0.00
Yorkshire and Humberside	0.35
East Midlands	0.00
West Midlands	0.00
East Anglia	0.00
South East	0.47
South West	0.08
Total	**1.00**

Scheduled Ancient Monuments	
Northern	0.04
North West	0.21
Yorkshire and Humberside	0.32
East Midlands	0.07
West Midlands	0.00
East Anglia	0.05
South East	0.22
South West	0.10
Total	**1.00**

Grade II Listed Buildings		
	Northern	0.03
	North West	0.39
	Yorkshire and Humberside	0.22
	East Midlands	0.08
	West Midlands	0.00
	East Anglia	0.08
	South East	0.17
	South West	0.04
	Total	**1.00**

Archeological sites		
	Northern	0.03
	North West	0.39
	Yorkshire and Humberside	0.22
	East Midlands	0.08
	West Midlands	0.00
	East Anglia	0.08
	South East	0.17
	South West	0.04
	Total	**1.00**

13. CONCLUSIONS

13.1 This report presents the results of the first two stages of a project for the provision of a risk assessment of road transport. Stage 1 of the project, which involved risk screening, was undertaken by the NCRAOA as a preference illicitation exercise. The results of this exercise provided 10 scenarios for quantitative risk assessment within stage 2 of the project. The methodology employed to undertake the quantitative risk assessment involved the construction of event trees. The event trees were designed to enable the risks from diverse sources to be compared and ranked, and to allow the effects of management options to be evaluated. Therefore the event trees addressed environmental pressures but include links with measures of environmental impact. Where appropriate, the effects of uncertainties associated with the values of key input variables on selected event tree risk estimates were assessed, using Monte Carlo simulation modelling. Sensitivity analysis was conducted using rank order correlation.

13.2 For most of the considered scenarios the event tree methodology proved to be of value. However, for the assessment of air quality impacts and of climate change impacts of road traffic, the environmental pressure section of the event tree was valuable but the link to environmental impact required a number of assumptions which significantly increased the uncertainty and reduced the credibility of the assessment. For the assessment of the potential for habitat loss from road construction, the methodology only allowed an assessment of the relative development pressure on habitats in different regions arising from road building and other forms of urbanisation, and the relative pressure to which designated sites within each region are exposed due to road construction activities.

13.3 The quantitative risk assessment of the air quality impacts of road traffic demonstrated that HGVs contribute 41 per cent of the total vehicular PM_{10} emission, but only account for 6 per cent of the total kilometerage and that PM_{10} is likely to results in approximately 11 thousand deaths and 14 thousand premature hospital admissions in the UK, with the vehicular contribution to these being highly uncertain. For the scenario considering the global climate change impacts of road traffic in the

UK, vehicular emissions were found to account for 20 per cent of the total UK contribution to global warming with 93 per cent of this arising from carbon dioxide.

13.4 The quantitative risk assessment of the water quality impacts of leachate arising from landfill of waste vehicle components demonstrated that leachate concentrations are very low and significantly lower than the existing EQSs. The scenario considering the water quality impacts of road run off highlighted the vulnerability of rivers during periods of low flow to large pollution inputs which may elevate river concentrations of certain heavy metals to above the values of the appropriate EQSs. In the case of accidental spillages of motor spirits the quantitative risk assessment indicated that a pollution incident in watercourses will always results from a spillage involving more than 15 kg of motor spirits. The quantitative risk assessment of the water quality impacts during road construction demonstrated that under average conditions, the final concentration of suspended sediment in the river was found to be three times the EQS. The scenario considering the water quality impacts of road maintenance showed that gull pot cleaning is unlikely to lead to an exceedance of the EQS for ammonia in the rivers. In the case of the potential for flooding due to road construction, it was found that the greatest risk of flooding relates to urban flooding.

13.5 The quantitative risk assessment of the potential for habitat loss from roadstone quarrying activities indicated that the greatest probability of habitat loss is in the East Midlands and in relation to agricultural land. In the case of the scenario involving the assessment of the potential for sensitive habitat loss from new road construction the greatest probability for loss of non-greenbelt greenfield land is in the South East, and the North West generally has the greatest relative pressure on designated sites.

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APPENDIX A:

Landtake from Road Schemes currently being considered by the DETR in the 1998 Roads Review

	Land Take (ha)		
Region	Greenfield	Greenbelt	Brownfield
East Anglia		33	
East Anglia	48		0.2
East Anglia	6		
East Anglia	16		
East Anglia	60		
Total East Anglia	130	33	0.2
East Midlands	39		
East Midlands	31		
East Midlands	37		
East Midlands	32		
East Midlands	28	6	
East Midlands	27		0.1
Total East Midlands	194	6	0.1
North West			
North west	150	50	
North West	18	0.12	
North West	131	131	
Total North West	299	181.12	0
Northern	4.2		
Northern	53.4		14
Northern	19.8		
Total Northern	77.4	0	14
South East			
South East	43	43	28
South East	82	70	0.2
South East	0.5		17.8
South East	0.2		1
South East	7.6		
South East	0.1		0.1
South East	4.3	3.4	3.6
South East	21	21	
South East			
South East	0.1	0.1	0.1
South East	18		
South East	20		
South East	37	37	
South East	115		
South East	56.3		0.5
South East	10.3		
South East	4.1		0.1
South East			
South East	40	20	
South East	46		
South East	41		
South East	41.4		
TOtal South East	587.9	194.5	51.4
South West	87		
South West	25		
South West	40		
Total South West	152	0	0

Y & H	22.5		
Y & H	47		
Y & H			
Y & H	19		
Y & H	45	4	
Y & H	22	16	8
Y & H	145	145	51
Y & H	0.22		
Y & H	1.6		12.5
Y & H	0	0	0
Y & H	10	10	1
Total Y & H	312.32	175	72.5
Total E & W	1753	590	138