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Pollution from Roads and Vehicles and Dispersal to the Local Environment:
Final Report and Handbook

Status: Confidential

POLMIT

Pollution of Groundwater and Soil by Road and Traffic Sources: dispersal mechanisms, pathways and mitigation measures

RO-97-SC.1027

Project Co-ordinator: TRL

Partners:

Ministry of Transport, Public Works and Water Management
Directorate-General for Public Works and Water Management
Road and Hydraulic Engineering Division

LCPC

Road Directorate Denmark Ministry of Transport

VTT

Laboratório Nacional de Engenharia Civil

VKI

Swedish National Road and Transport Research Institute

Örebro University

SGI
Swedish Geotechnical Institute

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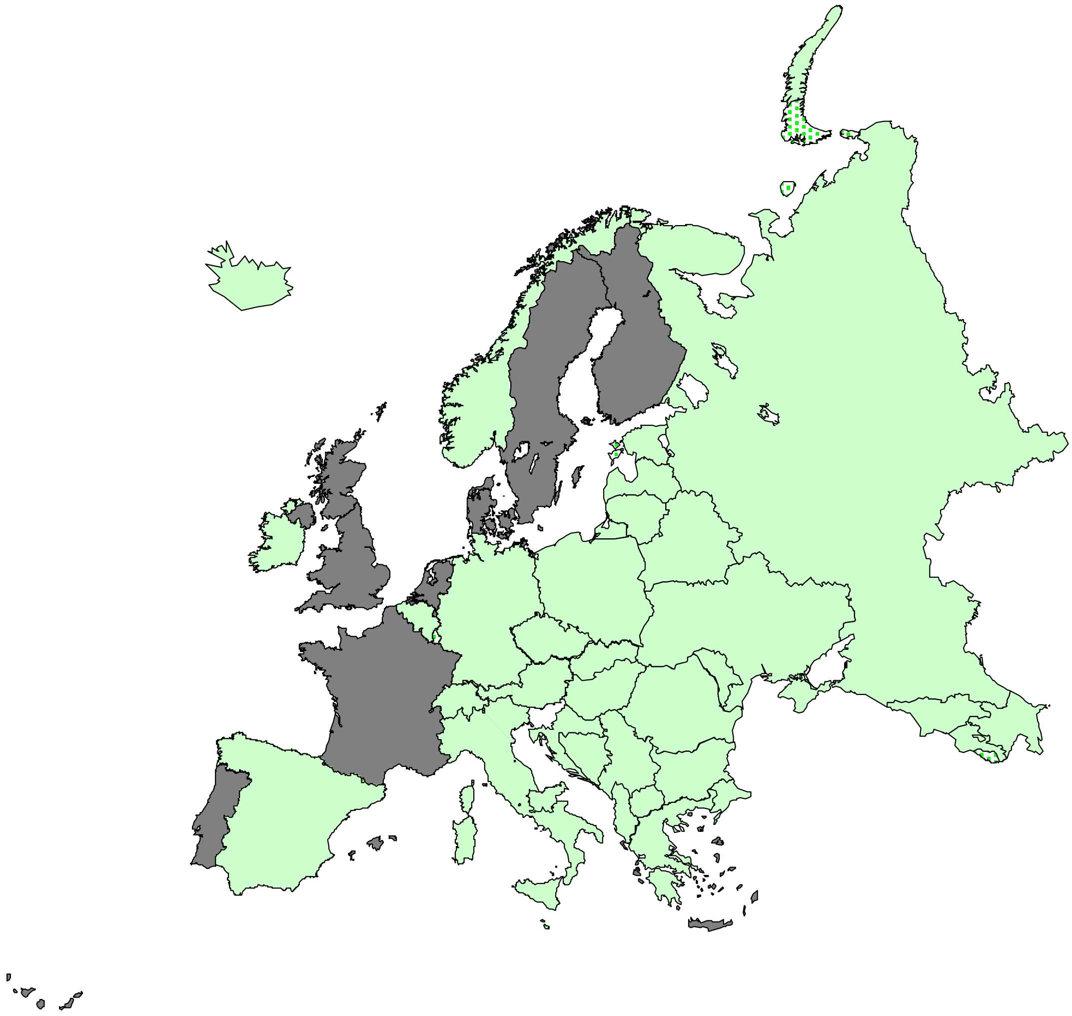
POLMIT:

POLLUTION OF GROUNDWATER AND SOIL BY ROAD AND TRAFFIC SOURCES: DISPERSAL MECHANISMS, PATHWAYS AND MITIGATION MEASURES

PARTICIPATION IN THE ACTION



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POLMIT PARTNERS

The work of POLMIT was undertaken by the following:

Project Co-ordinator:

Transport Research Laboratory (TRL), UK

Main Partners:

Directorate General for Public Works and Water Management (DWW), The Netherlands

Swedish National Road and Transport Institute (VTI), Sweden

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Danish Road Institute (DRI), Denmark

Laboratoire Central des Ponts et Chaussees (LCPC), France

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Associated Partners:

Institute for the Water Environment (VKI), Denmark

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EXECUTIVE SUMMARY

Throughout the working life of a road, both the road and vehicles using the road produce compounds that contaminate the environment. These are derived from the combustion of fuel, wear of vehicle components, wear of road furniture (e.g. crash barriers), degradation of road surfaces, and the application of road maintenance chemicals (mainly de-icing salts).

Much effort has been directed towards understanding how and what concentrations of gaseous and fine particulate material are released into the atmosphere through fuel combustion processes. The consequence of this has been the regulation of compounds derived from fuel combustion processes.

For the large number of remaining compounds released to the terrestrial environment, direct links between transport emissions and impacts on the environment/human health are much more difficult to identify. Past studies have focused on determining concentrations of pollutants in highway runoff, rather than on the concentrations emitted from individual sources, and mitigation measures have been aimed at the treatment of highway runoff, rather than the implementation of source-based measures.

There has been no comprehensive study which has looked at the quantities of unregulated compounds that are released, what proportion of these emissions enter the local roadside environment, the relative importance of each transport mechanism, and where in the environment these compounds are likely to impact.

The POLMIT project was designed, therefore, to address fundamental gaps in current knowledge. Its main objectives were to:

- Obtain up-to-date information on road and vehicle emissions and identify the relative importance of roads and vehicles as a source of terrestrial pollution,
- Monitor the annual loading of pollutants into the local roadside environment at a range of sites across Europe, and identify if and where in the environment pollutants are likely to impact,
- Identify those pathways by which road and vehicle pollutants are transported into the local roadside environment, and any factors that influence the relative importance of each pathway,
- Determine the proportion of each pollutant released that enters the terrestrial environment, and

- Identify where mitigation measures should be targeted to be most effective.

These objectives were achieved by selecting 14 case study sites in seven european countries and carrying out both field monitoring (of the movement and accumulation of compounds derived from roads and vehicles) and desktop studies on these sites over a 30-month period. The sites were chosen to give a range of characteristics in terms of climate, traffic volumes, maintenance activities and road pavement types.

POLLUTANT EMISSIONS

Emission values calculated for the 14 POLMIT monitoring sites are summarised below. Due to the lack of reliable data, these values were regarded only as broad estimates of actual emissions. Metal emission rates were primarily dependant on traffic volume, PAH emission rates primarily on traffic volume and road type, and chloride emission rates primarily on the severity of the winter during the monitoring period, and hence on the application of de-icing salts during the period.

Potential pollutant	**Calculated emission rates (mass/km road/year)***	
Total PAHs	65 - 721	g/km/yr
Cd	1 – 10	g/km/yr
Cr	14 - 162	g/km/yr
Cu	9,248 - 108,893	g/km/yr
Pb	7,391 - 110,984	g/km/yr
Zn	2,479 - 51,369	g/km/yr
Cl	1,225 – 15,249	kg/km/yr

**One carriageway (downwind side) only*

Comparisons with emissions from other sources were difficult to make due to the lack of systematic monitoring/reporting of PAHs and heavy metals undertaken in Europe at the present time. Comparisons of reported atmospheric emissions in the UK indicate that road transport contributes little (if any) Cd or Cr, very small amounts of Cu (2%), but significant amounts of Pb (59%) and Zn (23%). To determine the significance of roads and vehicles to soil and groundwater pollution, concentrations of road/vehicle derived substances reaching surrounding soil and groundwaters were compared with recognised threshold levels (Dutch Intervention and Target levels) to determine their 'polluting potential'.

MECHANISMS OF MOVEMENT

Once released, pollutants are transported into the local roadside environment either by highway runoff or short distance aerial dispersion followed by deposition. Monitoring of the total annual movement of pollutants by each of these mechanisms was undertaken at each of the 14 sites. The total annual transfer rate of each pollutant, by both highway runoff and aerial dispersal, was calculated. The range of transfer rates for each pollutant are summarised below.

Pollutant	**Transfer rates (g/km road/yr)***	
	Highway Runoff	**Aerial dispersal**
Total PAHs	< 1 - 7	< 1
Cd	< 3 - 6	< 1 - 35
Cr	< 1 - 30	< 1 - 156
Cu	< 1 - 1,125	< 26 - 539
Pb	14 - 1,115	< 10 - 541
Zn	111 - 8,091	< 98 - 2,447
Cl* (kg/km/yr)	< 1 - 9,261	< 1 - 2,523

A mass balance approach was used to determine what proportion of the calculated pollutant emissions entered the local terrestrial roadside environment. It was appreciated that, due to difficulties encountered in field monitoring, and recognised weaknesses in the emission calculations, the recovery rates for each pollutant varied greatly from site to site and only general interpretations could be made.

PAHs

Except for a few individual PAHs (indeno-1,2,3-pyrene and benzo-k-fluoranthene) the total transfer rates (mass fluxes) were generally below 10% of the emissions, showing a low recovery of the components in the vicinity of the road. However, problems were encountered during the analysis of these compounds, and it was difficult to determine whether the low concentrations of PAHs recovered were due to natural degradation in the environment (in the presence of sunlight) or degradation during sample storage. Further investigation is needed to decide whether or not PAHs are transported into the local roadside environment in significant concentrations.

Metals

Of the metals, Zn was transported in the greatest quantities followed by Cu and Pb (although the positions of these two elements were sometimes reversed) and finally by Cr and Cd. This generally reflected the magnitude of the emissions of these elements, except in the case of Pb. As Pb is primarily released in fine particulate form from exhaust emissions, it is prone to long distance transport and hence a smaller proportion is found in the local roadside environment.

Strong correlations were found between traffic volume and metal transport, reflecting the vehicle sources of these pollutants. However, road surface type had a marked influence on quantity of metals transported in highway runoff, with porous asphalt appearing to trap sediment in highway runoff, reducing the total quantity of pollutants transported into the local roadside environment.

In most cases the recoveries of Cd were greater than 100%, suggesting that either the emissions were underestimated, or that sources of Cd other than roads and vehicles (e.g. atmospheric deposition) contributed to the measured fluxes. This was supported by the fact that greater quantities of Cd were found in atmospheric deposition compared to highway runoff.

The variation in Cr percentage recovery between the sites was great, but again ranged to over 100%. In a similar manner to Cd, greater quantities of Cr were found in atmospheric deposition compared to highway runoff. A similar explanation to that proposed for Cd could, therefore, be responsible for the observed Cr recovery rates.

Recovery rates for Cu and Pb were relatively low (less than 10% and 5% respectively of the calculated emissions). As Pb is emitted primarily as fine particulates from vehicle exhausts, this material is easily transported large distances, away from the local roadside environment. Cu is derived primarily from the wear of brakes and hence would be expected to be transported in highway runoff following deposition onto the road surface. However, the amount of braking used in motorway driving is much less than that in urban driving. It is possible that the emission rates calculated overestimated the amount of Cu released at the POLMIT sites, leading to a lower apparent recovery rate for Cu.

The recovery of Zn varied greatly, but was generally below 50% of the calculated emission rates. Zn is derived primarily from tyre wear, and released in the form of particulate material deposited on the road surface. However, the particle size range of worn rubber is unknown and significant proportion could be released in the form of fine particulates and transported away from the local roadside environment in a similar manner to Pb.

Chloride

At sites where salt was applied, recovery rates again varied, with recovery rates being 60% or greater where large applications were made, and less than 35% where smaller applications were made. Although the majority of the applied chloride was transported by highway runoff, significant proportions of chloride were also transported by aerial dispersal. However, poor application methods can result in salt being thrown directly into the local roadside environment. Explanations for the low recovery rates at some sites could be that chloride is transported as aerosols over quite long distances, away from the local roadside environment.

Hydrocarbons

Although total hydrocarbon (THC) concentrations were monitored at each of the 14 sites, trends were difficult to distinguish as different methods of analysis were used by some partners, and/or concentrations were below detection limits. Consequently, detailed results were described only for a small number of sites. Wide variations found between sites were thought to be the result of possible accidental spills.

SOIL AND GROUNDWATER POLLUTION

Concentrations of pollutants in soil and groundwater samples were monitored at each of the 14 sites to determine whether they exceeded recognised threshold levels (Dutch intervention levels and target levels) for soil and groundwater quality.

Soil pollution

Soil Intervention levels were only exceeded for Pb, with most of the Pb probably having been deposited when leaded fuel use was at a peak. At some sites Cu and Zn concentrations did approach Intervention levels, but were thought to be derived from the presence of nearby crash barriers, rather than roads/vehicles directly.

Problems were encountered with the determination of both total hydrocarbons (THC) and PAHs in soils. Consequently, although the concentrations of THC and PAHs appeared to be low in many sites, it was not certain whether this was representative of the actual situation.

Groundwater pollution

In general, concentrations of heavy metals found in groundwaters were low even in areas located close to and downstream of the road. Most of the metal concentrations were well below the Dutch Intervention levels for groundwater. Metals are strongly adsorbed to soil surfaces, and are difficult to leach down the soil profile into groundwater. However, elevated concentrations were found when large amounts of de-icing salts were applied, indicating that Cl does facilitate the movement of adsorbed metals.

The Intervention level for chloride was exceeded at most sites at which de-icing salts were applied. At some sites the maximum recorded concentration was almost 5 times the Intervention level. However, concentrations rapidly reduced to below the Intervention level during the summer months when de-icing salts were no longer applied.

In a similar manner to soils, concentrations of total hydrocarbons in groundwater varied greatly from site to site, with the Intervention level being exceeded at five sites. Three of these sites also had elevated concentrations in soil. However, two sites had excessively high concentrations (over 30,000 ug/l) in groundwater alone, possibly indicating a non-road source. The large variation in concentrations reflects the probable accidental nature of the source of this pollutant.

METHODS OF CONTROL

Currently, treatment systems are designed to reduce the concentration of pollutants found in highway runoff. The range of systems available, and their relative efficiencies at removing pollutants, have been reviewed. However, no treatment systems currently exist for those pollutants transported by aerial dispersal. Although not the predominant mechanism of transfer into the local environment, significant quantities of especially zinc and chloride are transported by aerial dispersal. The presence of porous road surfaces was shown to reduce transfer rates by this mechanism, however, at present, the only effective method of treatment currently available for pollutants transported by aerial dispersal is source control.

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INTRODUCTION

INTRODUCTION

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1.1 INTRODUCTION

Throughout the working life of a road, both the road and vehicles using it produce compounds that contaminate the environment. These are derived from the combustion of fuel, wear of vehicle components, wear of road furniture (e.g. crash barriers), degradation of road surfaces, and the application of road maintenance chemicals (mainly de-icing salts).

Gaseous and fine particulate material are released into the atmosphere through vehicle combustion processes, and impact on local, regional and global air quality. This in turn has been linked directly to human health. Consequently, much effort has been directed towards understanding how these compounds are released into the environment, what amounts are currently emitted, their impacts on air quality and subsequently human health, and the development of mitigation measures. As a direct result of these efforts, 6 compounds derived from fuel combustion processes are currently regulated. These are:

- oxides of nitrogen (vehicle exhaust emissions)
- hydrocarbons (vehicle exhausts emissions)
- carbon monoxide (vehicle exhaust emissions)
- particulate material (vehicle exhausts emissions)
- sulphur (fuel content)
- lead (fuel content)

The consequence of this regulation has been a significant reduction in emissions per vehicle over the last 30 years and, in the case of lead, a complete ban on its use in fuel in many countries including most EU members.

For the large number of remaining compounds released to the terrestrial environment, however, direct links between transport emissions and impacts on the environment/human health are much more difficult to identify. A large number of individual road and vehicle sources (brake wear, tyre wear, vehicle exhausts, routine maintenance applications, leaks and spills etc) need to be investigated in detail to determine the concentration of any one pollutant entering the environment. Emission measurements for vehicle component wear are difficult to undertake as they are dependent on a large number of variables that require detailed information which is not readily available. Leaks and spills, by their very nature, also are unpredictable.

Past studies have focused, therefore, on determining concentrations of pollutants in highway runoff, rather than on the emissions from individual sources. This creates another problem in that it is difficult to trace the individual road, vehicle or other source of a pollutant once it has entered the environment. Consequently, if pollutants in highway runoff are found to have an adverse impact on the terrestrial environment, mitigation measures are aimed at the treatment of highway runoff, rather than the implementation of sourced-based measures such as emission regulations.

With traffic volumes forecast to grow (from 488 billion vehicle km in 2000 to 688 billion vehicle km in 2025 in the UK alone), and with ever changing technologies in the road and vehicular industries, it is necessary to determine the importance of road and vehicle pollutants on the terrestrial environment and ensure that current mitigation methods are still effective. Although individual studies within Europe have investigated the movement of one or two pollutants in individual media (runoff, soil, air, water etc), there has been no comprehensive study which has looked at the quantities of unregulated compounds that are released, what proportion of these emissions enter the local roadside environment, the relative importance of each transport mechanism, and where in the environment these compounds are likely to impact.

1.2 AIMS OF POLMIT

The POLMIT project was designed to address the fundamental gaps in current knowledge. Its main objectives were to:

- Obtain up-to-date information on road and vehicle emissions and identify the relative importance of roads and vehicles as a source of terrestrial pollution,
- Monitor the annual loading of pollutants into the local roadside environment at a range of sites across Europe, and identify if and where in the environment pollutants are likely to impact (field monitoring),
- Identify those pathways by which road and vehicle pollutants are transported into the local roadside environment, and any factors that influence the relative importance of each pathway (pollutant mass fluxes),
- Determine the proportion of each pollutant released that enters the terrestrial environment (pollutant mass balances), and
- Identify where mitigation measures should be targeted to be most effective.

The objectives were achieved by selecting 14 case study sites in seven European Countries and carrying out both field monitoring and desk top studies over a 30 month period.

1.3 OUTPUTS FROM POLMIT

The main outputs from POLMIT are a series of reports which present the main findings from each major section of work undertaken:

- Pollution from Roads and Vehicles and Dispersal into the Local Environment: A Literature Review
- Pollution from Roads and Vehicles and Dispersal into the Local Environment: Experimental Case Study Results
- Pollution from Roads and Vehicles and Dispersal into the Local Environment: Pollutant mass fluxes and mass balances

These reports can be found on the POLMIT web site:

trl.co.uk/europeanprojects/polmit/index.htm

To aid the dissemination of the POLMIT work, the main findings will be distilled into a 'Best Practice Guide' for mitigation of road and vehicle pollution, for use by those responsible for implementing policy relating to road and vehicle pollution.

1.4 BENEFITS OF POLMIT

A number of different end users and beneficiaries of the POLMIT work have been identified. These are:

- Scientific end users
- Professional end users
- National Governments, EU and other policy makers
- The general public

1.4.1 Scientific users

The scientific users are expected to be researchers working mainly in the field of environmental pollution (particularly relating to soil, surface water and groundwater) and transport emissions. This extends not just to researchers in the individual member countries of the EU, but also further afield. The principle benefit to them will be the raw data and main findings from the monitoring of 14 case study sites in seven European countries. The main conclusions of this work are outlined in Chapters 4 and 5 of this report. Other benefits will be data relating to vehicle emissions. This work highlighted some serious gaps in knowledge and will serve as a good starting point for further work in this area, including 5th framework projects such as PARTICULATES, which is examining particulate emissions from road vehicles, and ARTEMIS, which is developing a transport emission model for Europe.

1.4.2 Professional users

Professional users are road construction/maintenance engineers and implementers of policy relating to road and vehicle pollution (road authorities, national environment agencies). Understanding of the impacts of road and vehicle pollution on the terrestrial environment, and identification of effective mitigation measures will inform those who are responsible for protecting the environment. The Best Practice Guide will provide a practical tool to enable this understanding to be communicated efficiently and effectively to road construction/maintenance engineers.

1.4.3 National Governments, EU and other policy makers

Information relating to the importance of roads and vehicles as a source of pollution can also be used to inform those policy makers in national governments and the EU to enable informed decisions to be made about the possible need for future source-based mitigation measures.

1.4.4 General public

A better understanding of the sources of environmental pollutants, their transport mechanisms, and their potential impacts, will enable mitigation measures to be targeted more effectively. This not only directly benefits the environment by preserving valuable habitats, but also benefits the population by protecting valuable food and water resources.

1.5 LIMITATIONS OF POLMIT

The development of the work was based mainly on the monitoring of pollution transport from roads and vehicles into the terrestrial roadside environment. Within the terrestrial environment, particular emphasis was placed on soil and groundwaters as these were the most likely final sinks for the pollutants. The impact of pollutants on the environment was assessed only in terms of where particular pollutants accumulated in environment, and by comparing concentrations with recognised target and intervention limits. No attempt was made to measure emissions from the variety of different sources found within the general term of ‘roads and vehicles’ and no attempt was made to monitor the actual impacts of road and vehicle pollutants on the terrestrial environment.

CHAPTER 2

SELECTION OF CASE STUDY SITES

CASE STUDY SITES

SITE CHARACTERISTICS

2.1 CASE STUDY SITES

Although individual studies within Europe have investigated the movement of one or two pollutants in individual media (runoff, soil, air, water etc.), there has been no comprehensive study which has looked at the quantities of unregulated compounds released, what proportion of these emissions enter the local roadside environment, the relative importance of each transport mechanism, and where in the environment these compounds are likely to impact. It has also been difficult to determine the influence of factors such as climate and developments in road pavement design on both the method of transport of any one pollutant and on the quantities of pollutants transported. To address this, it was decided that 2 case study sites would be selected in each of the seven participating countries, giving a range of climate, traffic flows, road pavement types etc. typical of the range encountered across Europe. Pollutant emissions and pollutant movement into the terrestrial environment would then be determined at each of the selected sites using desk top studies and field monitoring respectively. The influence of the site characteristics on pollutant emissions and movement could then be assessed.

2.2 SITE CHARACTERISTICS

Although variations in a small number of specific site characteristics was required, it was important to retain some common features between all sites to ensure the effects of the selected characteristics could be clearly identified. Consequently, the sites chosen were all highway or national road sites, giving consistency in traffic flow patterns, and located away from urban areas as it is difficult to distinguish road and vehicle emissions from other sources of emissions in such complex environments.

Characteristics for which a range of values was required were climate, road pavement type, road age, traffic volume, and maintenance practice. Other variables which were not specifically selected, but which emerged within the selected sites, included hydrology, soil type and geology, topography, and type of road drainage system. Figure 2.1 shows the general location and names of each of the 14 selected sites. A summary of the range of characteristics presented by the 14 selected sites is given in Table 2.1 below, with a detailed list of the characteristics of each site provided in Table 2.2. Examples of the type of “road environment” that was chosen for study are illustrated in Figures 2.2 - 2.4.

Figure 2.1 Map of Europe showing the location of the 14 POLMIT case study sites

Table 2.1 Range of characteristics covered by the 14 selected field study sites

Characteristic	Range
Climate	From Mediterranean via Marine West Coast to Cold West Coast climate.
Geology/soil type	From porous (e.g. chalk, sand, gravel, moraine) to non-porous (e.g. clay) materials.
Groundwater table	From almost ground level to tens of metres below ground.
Land use	From agricultural land to semi-urban areas.
Roadside	Including roads level with, embanked, or cut into the surrounding landscape.
Road age	From 4 to more than 40 years.
Road surface	Including dense asphalt and porous asphalt.
Road-draining system	Ditches, French drains, filter drains, highway sub-drainage or none.
Run-off treatment	Oil traps, detention, retention and infiltration ponds or none.
Traffic volume	From 7,000 to 150,000 vehicles/day.
Speed limit	From 80 to 130 km/h.
Winter-salt usage	Practised or not.
Herbicide usage	Practised or not.

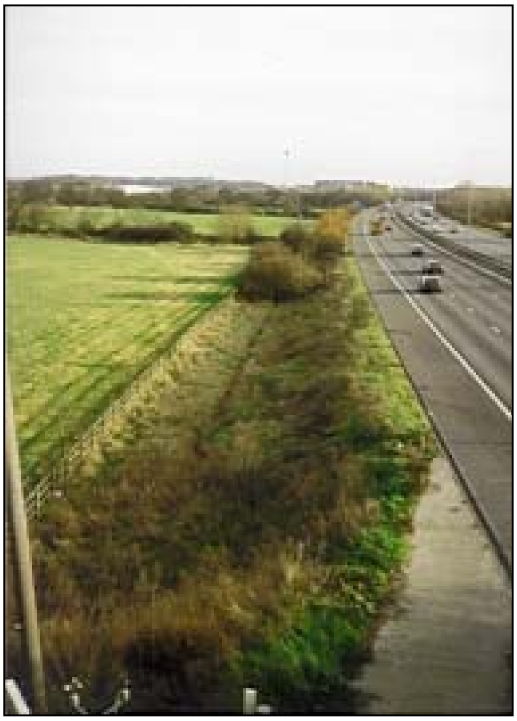

Figure 2.2 Site A Reading

Figure 2.3 Sites D - Spaarnwoude and C- Nieuwegein

Figure 2.4 Site M – Recta do Cabo

Table 2.2 Field-site description

Characteristic	A, Reading, Great Britain	B, Oxford, Great Britain	C, Nieuwegein, Netherlands	D, Spaarnwoude, Netherlands
Highway number	M4	M40	A2	A9
ADT (% heavy)	98 200 (9.8%)	77 700 (9.6%)	150,000	90,000
Speed limit	113 km/h	113 km/h	100 km/h	120 km/h
Road type; lanes	2x3 +2 hardshoulders	2x3 +2 hardshoulders	2x3 +2 hardshoulders	2x2 +2 hardshoulders
Road construction year	1971	1973	Unknown	Unknown
Pavement	Dense asphalt	Dense asphalt over stone mastic asphalt	Porous asphalt	Porous asphalt
Re-paving year	1990 maintenance overlay	1997	~1989	~1989
Winter-salt usage	As required	As required	As required	As required
Verges	Grass verge	Grass verge	Flat, grass + sound wall	Flat, grass
Ditches	Yes	No	Yes at 2 m	Yes at 25 m
Road-draining system	Filter drain / ditch	French Drain	None	None
Run-off treatment	None	Oil trap	None	None
Annual mean precipitation	400-500	400-500	700	700
Mean temp Jan/June	Annually 5-20 ºC	Annually 5-20 ºC	Jan 5 ºC, June 20 ºC	Jan 5 ºC, June 20 ºC
Geology	Sand and gravel	Chalk	River clay	Polder
Soil	Sandy clay loam	Sandy clay	clay loam	silt loam
Groundwater character	Perched water table 1.55 m	Perched water table around 2.5 m	1.7 m below ground surface	2.5 m below ground surface
Topography	Flat	Gentle rolling hills	Flat	Flat
Relative elevation	+2 m	Towards London -4 m; Away is flat	0	0
Road inclining	Flat	2% incline in the London direction	Flat	Flat
Land use; vegetation	Agricultural land / grass / shrubs on verges	Agricultural land / grass / shrubs on verges	Agricultural / urban	Agricultural
Nearest city/population	10 km SW Reading / 71 600	22 km W Oxford / 67 900	Nieuwegein	20 km from Amsterdam/Haarlem
Other R&D use of site	On-going air monitoring	None	Old R&D site	Old R&D site

Table 2.2 (continued)

Characteristic	E, Svaneberg, Sweden	F, Norsholm, Sweden	G, Lohja, Finland	H, Utti, Finland
Highway number	E 20	E 4	VT 25	VT 6
ADT (% heavy)	7 350 (20.7 %)	18 040 (17.0 %)	13 700 (11 %)	8000 (17 %)
Speed limit	90 km/h	110 km/h	80 km/h	100 km/h (80 in winter)
Road type; lanes	1 x 1	2 x 2	1 x 1	1 x 1
Road construction year	Before 1975	1992	1963	1950s
Pavement	Conventional asphalt	Conventional asphalt	Conventional asphalt	Conventional asphalt
Re-paving year	Unknown	Unknown	Unknown	Unknown
Winter-salt usage	As required	As required	7-10t/km during normal winters	6 tonnes/km during normal winters
Verges	Grass, herbs	Grass, herbs	Grass, herbs	Grass, herbs
Ditches	No proper ditches	Shallow ditches	Shallow ditches	Yes
Road-draining system	None?	Yes	None	None
Run-off treatment	None	None	None	None
Annual mean precipitation	500-600	500-600	500-700	500-700
Mean temp Jan/June	Jan 3 ºC; July 15 ºC	Jan 3 ºC; July 16 ºC	Jan 6 ºC; July 17 ºC	Jan 9 ºC; July 17 ºC
Geology			Salpausselkä esker	Marginal deposit of Salpausselkä
Soil	Sand + silt (1 m) on clay	Clay	Sand, gravel	Sand, gravel
Groundwater character	High GW level		Low GW level	Low GW level
Topography	Flat	Flat	Esker	Flat
Relative elevation	1-2 m	+ 2 m	1-2 m	1 m
Road inclining	Flat	Flat	Flat	Flat
Land use; vegetation	Forest (Picea, Pinus)	Agricultural / forest	Forest	Forest
Nearest city/population	23 km E Link/87000; 18 km W Norrk/83000	10 km SW Mariestad/16000	5 km E Lohja/34 000	13 km NE Kouvola/32 000
Other R&D use of site	Monitored since 1978	Site of PhD study 1997-	None	None

Table 2.2 (continued)

Characteristic	I, Vejenbrod, Denmark	J, Rud, Denmark	K, Erdre, France	L, Houdan, France
Highway number	M14	M70	A 11	RN 12
ADT (% heavy)	29 000 (4%)	22 000 (19%)	24 000 (7 %)	21,000
Speed limit	110 km/h	110 km/h	130 km/h	110 km/h
Road type; lanes	2x2 +2 hardshoulders	2x2 +2 hardshoulders	2 x 2	2 x 3
Road construction year	1974	1994	1992	1971
Pavement	Asphalt	Asphalt	Originally conventional asphalt; 1996 porous asphalt	2 lanes conventional asphalt, 3 porous asphalt
Re-paving year	1983	1994	1996	1979; 1991/93
Winter-salt usage	As required	As required	Infrequent	As required
Verges	Grass, bushes	Grass, bushes	Grass; wooded	Grass; wooded
Ditches	None	None	Yes	Yes
Road-draining system	Highway sub-drainage	Highway subdrainage	Ditches	Ditches
Run-off treatment	Detention pond	Detention pond	Retention pond, oil separator	None
Annual mean precipitation	700	700	727	720
Mean temp Jan/June	Jan 0 ºC; July 17 ºC. Annual mean 8 ºC	Jan 0 ºC; July 17 ºC. Annual mean 8 ºC	Annual mean 12 ºC	Annual mean 12 ºC
Geology	Till landscape	Till landscape	Granitic	Sedimentary bassin
Soil	Boulder clay	Boulder clay	Silt-sand	Silt-sand
Groundwater character	2-3 m below ground surface	2-3 m below ground surface	< 4m below ground surface	< 4m below ground surface
Topography	Flat	Flat	Flat	Flat
Relative elevation	+1-2 m	+2-3 m	level	Below surroundings
Road inclining	Flat	Flat	Flat	Flat
Land use; vegetation	Agriculture / golf course	Agriculture	Close to river Erdre	Wood
Nearest city/population	2 km NE Niverod/5 000 & 12 km Hilleröd/30 000	6 km SW Hadsten/7 000 & 16 km Randers/50 000	8 km from Nantes/500 000	50 km from Paris
Other R&D use of site	New R&D site	New R&D site, planned to continue after POLMIT	On-going R&D	On-going R&D

Table 2.2 (continued)

Characteristic	M, Recta, Portugal	N, Vila, Portugal
Highway number	EN 10	IP 4
ADT (% heavy)	21 800 (9.3 % ?)	8500
Speed limit	90 km/h	120 km/h
Road type; lanes	1 x 1	1 x 1
Road construction year	1946	1995
Pavement	Conventional asphalt	Conventional asphalt
Re-paving year	Unknown	None
Winter-salt usage	None	None
Verges	No vegetation	Asphalt
Ditches	Yes	Yes
Road-draining system	Ditches	Highway sub-drainage / Ditch / infiltration pond
Run-off treatment	None	Retention / infiltration pond
Annual mean precipitation	634	800
Mean temp Jan/June	Annual mean 15.2 ºC	Annual mean 17 ºC
Geology	Quatenary and Miocene sands	Granites
Soil	Sand and clay	Material from weathered granites
Groundwater character	Phreatic	Phreatic
Topography	Flat	High mountain, sloping
Relative elevation	+1 m	+5 m
Road inclining	None	To the south
Land use; vegetation	Arable land, perm irrigated; scattered trees	Agriculture / forest
Nearest city/population	30 km NE Lisbon	11 km from Vila Real/51 000
Other R&D use of site	Site of on-going MSc study	Site of on-going PhD study

CHAPTER 3:

TERRESTRIAL POLLUTION FROM ROADS AND VEHICLES

SOURCES OF TERRESTRIAL POLLUTION

POLLUTANT EMISSION CALCULATIONS FOR THE POLMIT SITES

COMPARISON OF ROAD AND VEHICLE EMISSIONS WITH OTHER SOURCES

3.1 SOURCES OF TERRESTRIAL POLLUTION

Pollution from vehicles and roads arises from a variety of individual sources, including:

- Vehicle exhaust emissions
- Vehicle component wear
- Road maintenance operations
- Road degradation
- Litter, leaks and spills
- Atmospheric deposition

3.1.1 Vehicle exhaust emissions

Vehicle exhaust emissions result not only from the products of complete combustion (carbon dioxide (CO_2) and water), but also from partial combustion, losses from lubrication and hydraulic systems, fuel contaminants, fuel additives, and products from engine wear. Consequently a complex mixture of compounds is released. This includes:

- Carbon monoxide (CO)
- Oxides of nitrogen (NO_x)
- Hydrocarbons (HC)
- Sulphur dioxide (SO_2)
- Methane (CH_4)
- Lead (Pb) and other heavy metals

Most are emitted as gaseous or fine particulate material and, consequently, impact on air quality. Vehicle exhaust emissions will contribute to terrestrial pollution when fine particulate material is washed out of the atmosphere by rainfall and returned to the road surface as a component of atmospheric deposition, when larger particulate material is deposited directly onto the road surface, and when secondary pollutants are formed and deposition e.g. nitric and sulphuric acid in 'acid rain'. Geographically, the main direct effects on the terrestrial environment are limited to the area near to the road as the rapid dispersion and dilution of exhaust pollutants in the atmosphere quickly reduces their concentrations to levels at which there are minimal risks to either health or plants outside of the local roadside environment .

The emission rates of vehicle exhausts depend on a large number of factors, which can be divided into two broad categories (Abbott *et al.,* 1995):

- Technical factors relating to the design and engineering of the vehicle;
- Operational factors relating to the way in which the vehicle is used.

These factors are described in more detail below, along with some of the developments that have been used to control vehicle exhaust emissions.

Technical factors

Fundamental differences between vehicles, such as weight, engine size and fuel type, account for significant variations in emission rates, and are summarised in Table 3.1.

Table 3.1 Technical factors affecting vehicle emissions (Cloke *et al*., 1997).

Factor	Examples
Engine type	Spark ignition, compression ignition
Engine size	
Fuel type / composition	Petrol, diesel, alternative fuels
Transmission	Automatic, manual
Engine management	Electronic ignition, mechanical timing
Exhaust after-treatment	Oxidation or three-way catalysts, particulate trap, no controls
Maintenance level	
Other characteristics	Aerodynamics / size / weight / age

As an example, Table 3.2 provides a comparison of the emission rates of some pollutants, from petrol (non-catalyst) and diesel cars measured under typical urban driving conditions.

Table 3.2 A Comparison of emission rates for some pollutants from non-catalyst petrol and diesel cars (Abbott *et al*., 1995).

Pollutant	Emission rate (g/km)	
	Petrol	Diesel
Oxides of nitrogen	2.00	0.80
Hydrocarbons	4.00	0.30
Carbon monoxide	40.00	1.00
Methane	0.10	0.03
Sulphur dioxide	0.10	0.20
Lead	0.02	-
Particulates	0.02	0.50

A number of technical developments have been utilised to control exhaust emissions. For example, treating exhaust emissions can reduce pollutant emission rates. The applicability of this technology is strongly dependent, however, on the type of engine and fuel:

- Three-way catalysts, used on petrol vehicles can remove most of the CO, HC and NO_X;
- Oxidation catalysts, which can be used on both types but are generally fitted to diesel powered vehicles, can remove CO and HC, but not NO_X;
- Particulate traps, used on diesel vehicles, have been shown to remove 90 per cent or more (by mass) of the exhaust particles.

Another means of controlling emissions is through the specification of the fuels which vehicles use. The most important change has been the ban on the use of leaded fuel. Other fuel properties, which have an effect on emissions, are also regulated. These include limits on the amount of benzene in unleaded petrol and on the amount of sulphur in petrol and diesel.

Operational Factors

Emissions are considerably less from freely flowing traffic at moderate speeds than from traffic whose flow is restricted by queues, or from traffic accelerating fast or moving at high speeds (Egeback, 1987; Hernandez *et al*., 1992; DOT, 1994). The highest emissions of CO and HC are associated with low average speeds. Abbott *et al.* (1995) explained that low speed journeys are typified by frequent stops and starts, accelerations, and decelerations in response to traffic congestion or other disruptions to a vehicle’s progress, and these operations are inefficient in fuel usage, fuel combustion and the operation of emission control systems. As the average speed increases, the operation of the vehicle becomes more efficient, so less fuel is used and less pollutant emissions are produced. At high speeds, there is a tendency for emissions to increase again because the operation of an engine to deliver the power needed to travel at high speeds is not the optimum in terms of fuel consumption and pollutant formation.

The emission rates of oxides of nitrogen are however highest at high average vehicle speeds (Boulter & Webster, 1997). This is because their rate of formation is governed largely by the peak temperatures reached during combustion, and these high temperatures occur under high speed and load conditions.

Another operational factor that determines vehicle emission rates is the temperature of the engine. An engine that is cold is inefficient and extra fuel has to supplied for satisfactory operation. During the cold start period, fuel consumption and emissions of the main pollutants (CO, HC, NO_X and CO_2) are generally elevated (Cloke *et al*., 1997). The extent of the increase depends on a number of factors including the engine temperature at the onset of a trip, the trip length and the ambient temperature, and also varies greatly from vehicle to vehicle (Boulter, 1997). The effect is greatly compounded in the cases of vehicles with catalytic emission control systems. Catalysts do not begin to work until their temperature reaches a ‘light-off’ value of around 300°C, they also require an accurately controlled exhaust composition for full effectiveness. So, not only does a cold engine produce more emissions, but they are also not treated by the catalyst system.

Traffic management schemes are now concentrating on decreasing vehicle emissions by, for example:

- reducing the number of vehicle kilometres travelled,
- reducing the number of short trips made (because of the significant contribution from cold start emissions),
- reducing the number of stops that need to be made in a journey,
- encouraging a shift to other modes of transport.

The calculation of pollutants from vehicle exhaust emissions, although complicated, has been well studied and a comprehensive methodology is given in the final report of a European Commission 4th framework Project – MEET (Methodology for Calculating Transport Emissions and Energy Consumption, 1999).

3.1.2 Vehicle components

Corrosion and wear of vehicle components such as brakes, tyres, radiators, body work and engine parts is potentially a major source of a number of different pollutants. It is difficult to quantify the amount of wear of the different components. It is also difficult to identify the precise component from which any one pollutant is released, owing to the large variation in materials used for individual components for individual makes and models of vehicles. Consequently, reported emissions values from vehicle components are scarce, and those that do exist have been based on theoretical estimates, using assumptions about the chemical composition of an individual component (Lindgren, 1998).

Kobriger (1984) reported vehicular deposition (total solids < 250 μm) to be 0.31 g/km/vehicle during summer and 0.98 g/km/vehicle during winter. The higher winter value was explained by increased vehicle exhaust emissions, increased rusting of the car body (due to de-icing salts), and increased 'carry on' deposition.

For particular pollutants, Revitt *et al*. (1990) identified literature values of 28 mg/vehicle/km lead, 3 mg/vehicle/km zinc, 2.5 μg/km cadmium, and 0.011-0.45 μg/vehicle/km chromium, but some values varied by over 3 orders of magnitude. General information on the types of compounds released from specific components is given below. Wear rates and/or emission values are given where available.

Tyres

A tyre consists of approximately 85% rubber mix, 12 % steel and 3 % textiles; the precise composition varies depending on the manufacturer. Within a life time of use, a tyre losses between 10-20% of its total weight (Environment Agency, 1998), giving rise to particles which initially are relatively large but which successively change to smaller fractions. Specific tyre wear rates reported in the literature vary between 0.024 – 0.36 g/vehicle/km (Rogge *et al.*, 1993).

A considerable proportion of the total zinc from roads and vehicles is considered to originate from tyres, zinc oxide being used to maker the rubber compound and zinc being present in brass which is used to coat the steel wires. Table 3.3 summarises the total wear rate and emission rates of varying heavy metals, derived from tyre use on urban roads in Germany (Muschack, 1990). Muschack found a significant increase in tyre abrasion on motorways compared to other roads, which was explained by the larger traffic volume and the higher speeds.

Table 3.3 Tyre abrasion on urban roads (Muschack, 1990).

Type of road	Total abrasion	Lead	Chromium	Copper	Nickel	Zinc
	kg/km/yr	g/km/yr				
Residential way	55	24	4	5	4	14
Residential street	68	84	14	199	13	47
Distributor road	100	157	26	36	25	88
Main distributor road	153	241	40	55	38	135
Main road	242	506	84	115	80	284
Duel carriageway	347	1108	185	225	176	621
Motorway	657	1145	241	329	230	810

In addition to tyre wear, the use of studded tyres in northern European countries during winter also contributes to pollutant loads. This results mainly from the increased wear of the road pavement material (see below) but also wear of the studs themselves. Traditionally these have been made from steel, but more recent developments have led to the introduction of light-weight studs with a steel pin surrounded by a casing of plastic or light metal; commonly an aluminium alloy to make them sufficiently wear resistant. The wear rate of new studs is estimated to be less than 0.01 g of stud material/vehicle/km. With further developments in stud design, and the introduction of studless winter tyres, the significance of this already minor source of pollution is expected to decrease further in the future (Lindgren, 1998).

Brakes

Pollutants associated with brake lining wear include copper, chromium, nickel, lead, iron, asbestos (Muschak, 1990; Kobriger, 1984) and manganese (Sanssalone & Buchberger, 1996). Organic pollutants resulting from hydraulic fluids may also be present. The exact composition of brake linings, disks and drums varies depending on the manufacturer, and is not often specified. General types as reported by Lingren (1999) include asbestos, non-asbestos organic, resin bonded metallic (semi-metallic), sintered metallic, and carbon-carbon. The recent ban on the use of asbestos in brake liners, and the introduction of new types of brake liners containing e.g. antimony, nickel and titanium, will alter the type and quantities of elements/compounds released from this source. Copper used in car brake linings is thought to be responsible for one-third of copper pollution found in Stockholm (Swedish EPA web site (http://www.environ.se)).

Others

Paint which flakes away from car body work can contain a range of both heavy metals and hydrocarbons.

Copper is an essential component of many alloys in used in the manufacture of vehicles, and can be found in radiators, wiring, heating elements, bearings, radiators, starter motors and other engine parts. The emission of copper is set to decline as more radiators are being made of aluminium; though this will mean that levels of aluminium will increase.

The corrosion of galvanised steel parts will release zinc, and the attrition of steel parts releases nickel, chromium, vanadium, tungsten and molybdenum (Amrhein *et al*., 1992).

3.1.3 Road degradation

The constituents of road pavement wear are dependant mainly on the type of pavement. The most common form is asphalt (a mixture of bitumen and mineral aggregates (up to 96%)). Trace quantities of both metals (Lindgren, 1996) and PAHs (20-110 ppm, Houdt & Goeman, 1992) are present in bitumen. Aggregates tend to be natural geological materials and may contain metal oxides, carbonates and trace elements. Table 3.4 compares the abrasion rates from different types of road and the emission rates of metals from these roads.

Table 3.4 Emissions from abrasion of urban roads (Muschack, 1990).

Type of road	Total abrasion	Lead	Chromium	Copper	Nickel	Zinc
	kg/(ha.a)	g/(ha.a)				
Distributor road	3152	322	1125	161	3688	517
Main distributor road	4850	495	1731	247	5674	795
Main road	7665	782	2736	391	8968	1257
Duel carriageway	11000	1124	3927	561	12870	1804
Motorway	10000	1020	3570	510	11700	1640

A worn road surface is considered to give higher pollution concentrations than a less worn surface (Bickmore & Dutton, 1984a; Bjelkas & Lindmark, 1993).

Asphalt wear particles are characterised by large diameters compared with vehicle exhaust emissions, the majority $>100\ \mu$m (Larsen *et al*., 1988).

According to a Swedish study, the use of studded tyres in winter months leads to extensive road wear (450,000 tonnes annually) (Carlsson *et al*., 1992). However, road wear is diminishing due to new improved studs, development of winter tyres without studs, and more wear-resistant road materials. If lightweight studs with the stud body made of light metal or plastics can replace conventional steel studs, abrasion of surfacings can be reduced by about 50 % (VTI, 1996).

Leaching of chemicals can occur through degradation and weathering of the road material, not least in the passage of water through cracks. In those cases where road construction materials contain waste products such as blast furnace slags, steel slags, fly ashes and bottom ashes, leaching of heavy metals may occur (Bjelkas & Lindmark, 1993).

Thermoplastic pastes or paints used in road markings are subject to mechanical wear and are also a source of pollution. Titanium oxide is used in white paint, oils are used as softeners, rubber and plastic improve durability and stability. Consequently, both organic and inorganic compounds can be released.

3.1.4 Litter, leaks and spills

Pollutants such as waste oils, hydraulic fluids, fuels, antifreeze, litter, grit, and organic solids arising from roadside vehicle maintenance, regularly contribute to the total pollution loading from roads and vehicles. It is difficult to predict the range and quantity of pollutants released accurately due the wide range of materials that can be released, and the unpredictable nature of the occurrence of leaks and accidents.

Litter will generally result in elevated levels of solids which may or may not break down in the environment. Leaks from vehicle lubrication and hydraulic systems provide a steady source of fluid hydrocarbons. Lubricating oils also contain organic phosphates, metals and PAHs, the latter two derived from engine parts (Dussart, 1984). Volatile hydrocarbons are emitted by the evaporation of fuel. Barlow (1993) estimated that 45 per cent of vehicle hydrocarbon emissions in the UK were produced by evaporation.

Although minor in terms of total loading, large spills resulting from individual accidents are potentially the most serious source of terrestrial contaminants associated with roads, especially because of the unpredictable nature of the materials involved. Chemicals, paints, food products and waste materials of all types are some of the more serious pollutants concerned.

Urine and excrement deposited on roads and adjacent pavements by animals contributes to the organic content of the sediment. Dead animals will also decompose to release particulate and soluble contaminants and various bacteria, including streptococci and coliforms. European studies seem to indicate that pollution by such materials is made worse by mechanical sweeping or street washing. Road sweeping is intended to remove litter, faeces and leaves for example. In reality the mechanical sweeping usually employed may do little more than break up the target into smaller particles that remain on the road and are more easily transported by water into drainage systems (Luker & Montague, 1994).

3.1.5 Road maintenance operations

Maintenance operations include the clearance of snow or ice in winter and the control of weeds and vegetation on roadside verges and central reservations. At less frequent intervals it also includes the cleaning of drainage systems, resurfacing of roads and refurbishment of street furniture (but these are not covered in this report).

De-icing

Highway Authorities or administrators are required to keep roads safe and clear of snow. Snow is often removed by mechanical means. However, the control of ice is usually tackled using de-icing chemicals. The most commonly used de-icing chemical is rock salt (sodium chloride). Its widespread use is the result of its effective de-icing properties, easy storage, good handling and spreading properties, and relatively low cost. Sodium ferricyanide is often added to rock salt to prevent caking, and compounds containing phosphorus may also be added as rust inhibitors (Luker & Montague, 1994).

The composition of rock salt can vary depending on the source. Hedley and Lockley (1975) gave an average composition of UK rock salt as 91% sodium chloride and 9% insoluble residue (mostly clay marl), with impurities of iron, nickel, lead, zinc, chromium and cyanide. Colwill *et al.* (1984) quoted an insoluble fraction of 6%, the majority of which was grit, and bromide as another impurity. In America, sodium chloride used for de-icing was found to be 98% pure with traces of other elements (Granato *et al*, 1995). In order of magnitude, these were sulphate, calcium, potassium, bromide, vanadium, magnesium, and fluoride. Other elements, including heavy metals, were detected but had a mass ratio to chloride of less than 0.0001.

Current recommended application rates for rock salt are 10 g/m^2 as precaution against frost or light snow, and 20-40 g/m^2 if freezing conditions are expected after rain, or if continuous snowfall is expected (DOT, 1992). Salt will melt ice and snow at temperatures down to -21^oC, but below -10^oC, the amount needed increases to the extent that it becomes both environmentally and economically undesirable. Consequently, when temperatures fall below -10°C, other chemicals, or mixtures may be used (see below).

A large proportion of the salt applied to roads is eventually dissolved on the road surface and discharged via the local drainage system into natural surface waters or, in the case of soakaways, to soils and groundwaters. This can lead to a seasonal elevation of the sodium and chloride concentrations in surface and groundwaters in the vicinity of roads. Rock salt also causes corrosion of vehicles and steel reinforcements in road structures such as bridges, and can directly damage concrete (termed spalling or scaling).

In recent years, with the introduction of advanced meteorological forecasting and ice prediction techniques, and more efficient spreading techniques, there has been an overall reduction of 10-20% in the number of occasions where salt was applied compared with practice in the late eighties (Luker & Montague, 1994), and an overall reduction in the amount of salt applied. However, no mention was made of the severity of the winters in either of these periods. Despite this reduction, increasing concern over the environmental impacts of rock salt (especially in northern European countries) has led to the testing and limited introduction of other de-icing chemicals, particularly on vulnerable sections of roads. These include urea, calcium magnesium acetate and potassium acetate.

Roadside weed control

The use of herbicides and pesticides on roads has been banned in many European countries. However, triazine herbicides, including atrazine and simazine, are still used for weed control on roadside verges (of the POLMIT partners, only the UK still applied herbicides for this purpose). This group of herbicides is more mobile but less persistent than their organo-chlorine predecessors. There is concern over the use of these pesticides, however, as they have been detected in groundwater supplies.

3.1.6 Atmospheric deposition

The deposition of air-borne pollutants of local or distant origin also contributes to pollution of the roadside environment. The deposition may occur in precipitation during storms or as dustfall during dry periods. Solids, nutrients, metals, and biodegradable organics may all be contributed by atmospheric fallout (Sartor & Boyd, 1972; Gupta *et al.,* 1981). The relative importance of this source increases when the volume of traffic decreases.

The surrounding land use has an important effect on the amount and type of pollution in dustfall. Driscoll *et al.* (1990) concluded that surrounding land use is the most important factor that influences constituent loads in atmospheric deposition. Roads in or near urban areas have been shown to have significantly higher levels of pollutant loading from dustfall than those in rural areas mainly due to the larger number of sources present in urban areas (Gupta *et al*., 1981b).

Bellinger *et al.* (1982) quote a study in Chicago where an exceptional 70 % of road dust was attributed to atmospheric fallout. Hedley and Lockley (1975) quote figures of 116 tonnes/km^2/annum in Birmingham (UK), but this was only 1.2 % of the total. The extreme difference between these two results may be partly due to atmospheric and weather patterns. However, Luker and Montague (1994) suggest issues such as estimation method, allocation of provenance and possible problems with sampling could have exacerbated the real differences.

3.2 POLLUTANT EMISSION CALCULATIONS FOR THE POLMIT SITES

It can be seen that, apart from vehicle exhaust emissions, there is very little information available on the quantities of pollutants emitted form the various road and vehicle sources. There is even less information which indicates the quantities of pollutants derived from roads and vehicles as a whole. This information is vital if the importance of pollution from roads and vehicles is to be fully understood. To address this, the emissions from various component sources at each of the POLMIT sites were estimated to give a total emission value. Due to the scarcity of data sources, emission values were calculated for a limited number of pollutants.

- Heavy Metals: Cd, Cr, Cu, Pb and Zn
- Hydrocarbons: PAHs and total hydrocarbons
- De-icing salts: Cl

3.2.1 Data requirements

The data required to perform the calculations were grouped as followed:

Traffic data:

- Total volume of traffic at the study sites (number of vehicles per day).
- The traffic distribution at the study sites (percentage of different types of cars, trucks, motorcycles, etc.).

Emission data:

- **Vehicle Exhaust emissions**. Specific emissions of pollutants from each type of vehicle (i.e. diesel car, gasoline cars, heavy/light trucks, old/ new vehicles) as a result of fuel combustion. These specific emissions vary with speed.
- **Non-vehicle exhaust emissions.** Specific emissions of pollutant from each type of vehicle due to tyre wear and brake wear.
- **Road and maintenance-related emissions**. Specific emissions of pollutants due to wear of the road surface, corrosion of crash barriers (if any), and maintenance practice (de-icing chemicals and herbicides, when applied).

Due to the unpredictable nature of accidents, the calculation of emissions due to accidents was not included in the calculations. Other pollutant sources which have not been considered, or for which there no data were available are:

- Road construction material,
- Wear and tear of other vehicle components (engine wear, bumpers, bodywork, paint etc.),
- Road paint,
- Sediment on vehicle undercarriages, and
- Windscreen wash (containing organic compounds which have not being investigated).

The data used for the purpose of emission calculations were based primarily on information obtained from the literature, supported by limited measurements conducted within the POLMIT project. The different data sources are listed in Table 3.5.

Table 3.5 Sources of emission data

Type of data	**Source**
Exhaust emissions	
Fuel consumption	European Environment Agency,1999
PAH	European Environment Agency,1999
Heavy metals	Legret & Pagotto, 1999
Non-exhaust emissions	
Brakes	
Particle deposition rates	Legret & Pagotto, 1999
PAH	Ministerie van VROM ,1997
Heavy metals	Legret & Pagotto, 1999
Tyres	
Wear rates	Legret & Pagotto, 1999
PAH	Ministerie van VROM, 1997
Heavy metals	Legret & Pagotto, 1999
Road and maintenance emissions	
Road wearing	
PAH & heavy metals	Ministerie van VROM, 1997
De-icing	
Heavy metals, except Cr	Legret & Pagotto, 1999
Cr	VKI – analysis of salt sample

3.2.2 Methodology

For the calculations, it was assumed that the traffic distribution at each study site followed the same distribution pattern as the national traffic of the country. Based on the specific emissions, the total emission E(X) of each pollutant X at each study site was calculated according to:

$$E(X) = E_{ex}(X) + E_{n\text{-}ex}(X) + E_{RM}(X) \qquad (1)$$

$E_{ex}(X)$, the total emission of pollutant X due to exhaust was given by:

$$E_{ex}(X) = \Sigma\, E_{ex,i}(X) \cdot n_i \qquad (2)$$

where $E_{ex,i}(X)$ is the specific emission of pollutant X per km due to exhaust from a specific vehicle type i and n_i is the traffic density of the vehicle type i at the study site (number/day). $E_{ex}(X)$ is expressed in g/km·day

$$n_i = TD \cdot d_I \qquad (3)$$

where TD is the traffic density at the study site and d_i is the national proportion of the specific vehicle type i in percent.

$E_{n\text{-}ex}(X)$, the total emission of pollutant X due to tyre or brake wear is given by:

$$E_{n\text{-}ex}(X) = \Sigma\, E_{n\text{-}ex,i,\ tyre}(X) \cdot n_i + \Sigma\, E_{n\text{-}ex,i,\ brake}(X) \cdot n_I \qquad (4)$$

where $E_{n\text{-}ex,i,\ tyre}(X)$ and $E_{n\text{-}ex,i,\ brake}(X)$ are the specific emissions of pollutant X/km due to the wear of tyres and brakes from a specific vehicle type i. $E_{n\text{-}ex}(X)$ is expressed in g/km·day

$E_{RM}(X)$ is the sum of the different emissions of pollutant X due to road wear, corrosion of crash barriers, and maintenance procedures. The emission due to road wear is dependent on the total number of vehicles, whereas corrosion and maintenance can be assessed more directly.

The specific emissions due to exhaust will vary with the type of vehicle considered and the average speed at the study site. Specific emission factors are not known for every type of vehicle. In order to increase the possibility of specific emission factors being available and applicable in each country, the POLMIT Consortium defined groups of vehicles. These are shown in Table 3.6.

Table 3.6 Vehicle categories

Vehicle Types	Categories
Passenger cars:	Petrol, pre-catalyst Petrol catalyst Diesel
Commercial light-duty vehicles:	Petrol (<3.5t), Conv. Petrol (<3.5t), EURO1 Diesel (<3.5t), EURO1,DI Diesel (<3.5t), EURO1,IDI
Commercial heavy-duty vehicles:	Diesel (3.5-7.5t) Diesel (7.5-16t) Diesel (16-32t) Diesel (>32t)
Coaches	
Motorcycles	

The methodology described above was applied to create three templates (see POLMIT report 'Pollution from Roads and Vehicles and Dispersal into the Local Environment: Mass Flux and Mass Balance Calculations' for details) which were used to calculate emissions based on the traffic pattern of the countries and of the POLMIT study sites.

3.1.3 Results of emission calculations at the POLMIT sites

The results of the emission calculations at all 14 study sites are shown in Table 3.7 along with the total traffic density at each site. The emission values and traffic densities in Table 3.7 are representative for pollutants emitted from one side of the road (one carriageway) only.

It can be seen from Table 3.7 that chloride was emitted into the terrestrial environment in the greatest amounts at all sites except in Portugal and Holland, where there had been no de-icing practice during the monitoring period. For all other countries, usually with cold winter climates, the annual release of chloride exceeded 1 tonne per kilometre. This of course varies from year to year depending on the severity of the winter.

Apart from chloride, the species that were emitted in the largest amounts at all sites were Zn, Cu, and Pb. The sources of Zn include tyre wear, brake wear and crash barriers wherever present. Cu is released primarily as result of brake wear. Pb is released primarily in the form of exhaust emissions from pre-catalyst vehicles using leaded fuel. PAH are primarily emitted in the form of exhaust emissions, with fluoranthene and naphthalene being the most abundant compounds.

Table 3.7 Results of estimated emissions

Parameter	Unit	Great Britain		The Netherlands		Sweden		Finland		Denmark		France		Portugal	
		Site A Reading	Site B Oxford	Site C Nieuwegein	Site D Spaarnwoude	Site E Svaneberg	Site F Norsholm	Site G Lohja	Site H Utti	Site I Vejenbrød	Site J Rud	Site K Erdre	Site L Houdan	Site M Recta	Site N Vila
Total PAH	g/km.yr	703	562	3,531	3,043	311	721			94	65	169	157	425	154
Total Hydrocarbons	g/km.yr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.			n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
fluoranthene	g/km.yr	318	252	645	558	51	116			46	32	90	80	71	26
benz-a-pyrene	g/km.yr	34	27	63	55	5	11			5.2	3.7	8	8	6.8	2.4
indeno-1,2,3-pyrene	g/km.yr	20	16	38	32	3	7			3.1	2.0	6	5	4.3	1.6
benzo-g,h,I-perylene	g/km.yr	116	96	222	196	20	41			19	14	25	23	23	8.0
benzo-k-fluoranthene	g/km.yr	32	26	57	49	7	14			3.0	2.1	8	7	7.6	2.3
naphthalene	g/km.yr	183	146	362	310	47	104			18	12	32	34	54	16
Cd	g/km.yr	6	5	10	9,1	1	3			1.6	1.9	2	2	1.5	0.6
Cr	g/km.yr	92	72	162	142	14	34			23	24	27	25	20	7.2
Cu	g/km.yr	59,998	47,206	108,893	93,376	9,773	23,067			9,248	5,998	14,586	13,180	13,508	4,921
Pb	g/km.yr	48,768	39,718	110,219	110,984	9,940	28,177			20,659	13,207	7,391	6,319	15,062	6,040
Zn	g/km.yr	28,165	22,216	51,369	44,231	5,285	12,047			3,771	2,479	7,676	7,356	6,994	2,839
Cl	kg/km.yr	1,492	1,225	0	0	6,648	15,249			8,601	6,710	3,050	3,050	0	0
Traffic density	10^3 veh./yr	17,922	14,180	27,375	16,425	1,341	3,292			4,471	3,212	4,380	3,833	3,887	1,540

Note: n.d.: no data available

3.3 COMPARISON OF ROAD AND VEHICLE EMISSIONS WITH OTHER SOURCES

Although many reports (e.g. EEA Signals 2001 (www.eea.eu.int)) give indications of the relative magnitude of pollutant emissions from different sources, it is often difficult to obtain the raw data on which these indications are made.

For example, the Convention on Long Range Transboundary Air Pollution (LRTAP), signed in 1979, establishes a broad framework for co-operative action on reducing the impact of air pollution and sets up a process for negotiating concrete measures to control emissions of air pollutants through legally binding protocols. In this process, the main objective of the EMEP programme (Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe) is to regularly provide Governments and subsidiary bodies under the LRTAP Convention with qualified scientific information to support the development and further evaluation of the international protocols on emission reductions negotiated within the Convention.

Initially, the EMEP programme focused on assessing the transboundary transport of acidification and eutrophication, the scope of the programme has widened to address the formation of ground level ozone and, more recently, of persistent organic pollutants (POPs), heavy metals and particulate matter.

The chemical components of concern are summarised below:

- sulphur oxides
- nitrogen oxides
- ammonia
- non-methane volatile organic compounds
- methane
- carbon monoxide
- carbon dioxide
- heavy metals (priority metals: cadmium (Cd), mercury (Hg), lead (Pb))
- selected POPs

It was agreed that all member states of the United Nations Economic Council of Europe (UNECE) should report their emissions using the same groups of sources. This enabled comparisons between countries to be performed. The main source groups are presented below:

- Public power (large plant generating electricity)

- Commercial, institutional, and residential combustion plant
- Industrial combustion plant and processes with combustion
- Non-combustion processes for example the production of sulphuric acid
- Extraction and distribution of fossil fuels
- Solvent use
- Road transport
- Other transport
- Waste treatment & disposal
- Agriculture
- Nature

Although this database considers only atmospheric emissions (and not those released to soil or groundwater) from different sources, and currently only covers a limited number of pollutants, it does give an indication of the relative importance of road transport. Unfortunately, only total figures for Pb and Cd could be found for a wide range of countries, as presented in Table 3.8.

However, further information (and sometimes more detail) can be obtained from individual country reports. For example, air pollution monitoring in the UK gives comparisons of emissions from the different industrial sources. Heavy metals of relevance to the POLMIT project are given below in Table 3.9. The percentage contribution of road transport to the total emission (for each pollutant) is given in table 3.10.

It can clearly be seen that road transport contributes relatively minor (if any) amounts of Cd and Cr or Cu, but significant proportions of Pb and Zn, to the atmosphere in the UK. However, it is obvious from the large variations in total Cd and Pb emitted in different countries that the relative distribution of road transport to pollution emissions will vary greatly depending on the size and type of each source present.

More systematic monitoring and reporting is now being undertaken across Europe, not just for atmospheric emissions but also for emissions to soil and groundwater. An overview of the latest activities and data sources available relating to pollutant emissions can be obtained from the Annual Topic Updates, produced by the EEA (www.eea.eu.int).

Table 3.8 Anthropogenic Cd and Pb emissions to the atmosphere in the EMEP region

Country	Emissions (t/yr) in 1999	
	Cd	Pb
Albania	0.60	24
Armenia	1.46	60
Austria	1.50	34
Azerbaijan	3.14	144
Belarus	1.42	38
Belgium	3.31	212
Bosnia & Herzegovina	0.28	5
Bulgaria	13.57	224
Croatia	1.06	183
Cyprus	0.20	75
Czech Republic	2.72	157
Denmark	0.71	7
Estonia	0.78	45
Finland	0.56	14
France	12.08	868
Georgia	2.43	112
Germany	11.00	542
Greece	3.00	470
Hungary	2.99	39
Iceland	0.17	0
Ireland	1.65	88
Italy	29.90	2174
Kazakhstan	0.44	20
Latvia	0.32	12
Lithuania	2.01	19
Luxembourg	0.05	2
Netherlands	1.01	35
Norway	1.10	6
Poland	55.10	694
Portugal	3.36	392
Republic of Moldova	0.15	11
Romania	20.65	517
Russian Federation	50.90	2339
Slovakia	7.54	53
Slovenia	1.62	50
Spain	13.54	944
Sweden	0.80	38
Switzerland	2.18	131
The FYR of Macedonia	5.23	119
Turkey	14.00	774
Ukraine	43.20	2564
United Kingdom	7.01	534
Yugoslavia	6.32	358
Total, kt	**331**	**15.1**

Table 3.9 Emissions of heavy metal from UK sources

Anthropogenic Sources		Pollutant emissions (t/yr)				
Category 1	**Category 2**	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**
Combustion in Energy Production & Transfer	Public Power	0	17	13	16	9
	Public Power (waste Incineration)	0	0	0	1	12
	Petroleum Refining Plants	0	0	1	1	12
	Other Combustion & Transfer	0	0	0	0	0
Combustion in Commercial, Institutional, Residential Combustion Plant	Residential Plant	0	4	4	16	7
	Commercial, Public & Agricultural Combustion	0	0	2	2	2
Combustion in Industry	Iron & Steel Combustion	0	1	5	10	12
	Non-Ferrous Metals	2	0	7	21	38
	Glass Production	1	3	1	52	12
	Other Combustion in Industry	1	5	9	27	70
Production Processes	Iron & Steel	1	15	8	34	206
	Non-Ferrous Metals	0	0	4	4	26
	Processes in Industry	0	20	5	32	19
Road Transport	Road Transport Combustion	0	0	1	327	1
	Road Transport Brake & Tyre Wear	0	0	0	0	10
Other Transport & Machinery	Railways	0	0	0	0	0
	Other Mobile Sources & Machinery	0	0	0	6	0
Waste Treatment & Disposal	Waste Incineration	1	0	0	4	5
TOTAL		**6**	**67**	**59**	**553**	**442**

Source: *http://www.aeat.co.uk/netcen/airqual/statbase/emissions.html*

Table 3.10 Contribution of road transport to atmospheric metal emissions in the UK

Metal	**% contribution from road transport**
Cd	0
Cr	0
Cu	2#
Pb	59#
Zn	23*

all from combustion of fuel *almost all from tyre and brake wear

CHAPTER 4:

POLLUTANT DISPERSAL INTO THE ENVIRONMENT

MECHANISMS OF DISPERSAL

MONITORING OF POLLUTANT DISPERSAL AT THE POLMIT SITES

SAMPLING AND ANALYSIS

RESULTS AND DISCUSSION

4.1 MECHANISMS OF DISPERSAL

Pollutants originating from roads and vehicles are deposited on the surface of the road and transported into the local roadside environment by two main mechanisms:

- highway runoff, and
- aerial dispersion.

The latter involves the transportation of material by wind in dry weather, or by vehicle splash and wind-blown spray in wet weather. Long-distance atmospheric dispersion is another major mechanism of transportation, particularly of gaseous and fine particulate material. However, as this impacts mainly on the atmospheric rather than the terrestrial environment, it is not addressed in any detail here. The reader is referred to the final report of the EC-funded MEET project (Methodology for Calculating Transport Emissions and Energy Consumption, 1999) for more detailed information on this topic.

The actual mechanism by which a particular pollutant is transported depends on the physical form in which the pollutant is emitted, the chemical properties of the pollutant, the climatic conditions and, to some extent, the type of road pavement. For example, the main transportation processes for liquid pollutants deposited on the road surface will be highway runoff or evaporation. They may, however, be subject to some aerial deposition in wet weather due to vehicle splash. In contrast, particulate material is prone to wind blow in dry weather. Consequently, the relative importance of each mechanism is dictated by the climatic conditions in any given period: continual rainfall will promote transport by runoff; dry periods will encourage more transport by aerial dispersion.

4.1.1 Runoff

As highway runoff is the predominant transport mechanism for most pollutants, and as quantification of the source(s) of road and vehicle pollutants is very difficult, many past studies have focused on determining the concentrations of pollutants in highway runoff. Consequently, concentrations of pollutants in highway runoff have often been used as surrogate indicators of the quantities of pollutants emitted from roads and vehicles.

A number of studies have been conducted on the quality of runoff from different road types. Table 4.1 provides examples of the ranges of figures recorded from two motorway sites, three urban road sites and one rural road site(from Colwill *et al*., 1984; Strecker *et al*., 1990).

The intensity of the precipitation influences the runoff volume and pollutant concentrations, giving rise to the large variations identified in Table 4.1. A condition often studied is the heavy pollution load that occurs at the beginning of a storm event (Gupta *et al*., 1981; Bickmore & Dutton, 1984; Morrison *et al*., 1989; Beckwith *et al*., 1990). During a very short period, water flow brings about the removal of considerable quantities of pollutants, which may have accumulated on the road surface, and in its immediate vicinity, during the antecedent dry period. This 'first flush' may often have a pronounced shock effect on the biota in those waters receiving the runoff. Less intense and more prolonged rainfall has less impact due to the greater dilution of pollutants in the runoff and possibly greater volumes of water in the receiving watercourse.

Harrison and Wilson (1985) found that although the 'first flush' can be a significant mechanism for pollutant transport, the importance of its effect varied from storm to storm, being affected not only by rainfall volume and intensity, but also by the length of the antecedent dry period, and the number of vehicles travelling through the storm. They observed that even light rains removed soluble deposits that had accumulated on the road since the last runoff event. Sediment particles, however, may remain on the road surface until the intensity of rainfall is sufficient both to mobilise them and transport them from the road surface. The impact of raindrops may be significant in loosening some particles. The finest fraction (< 63 µm) of sediment in highway runoff is the most important in terms of pollution transport (Laxen & Harrison, 1977; Ellis, 1979) as, although this may typically be only 6 % of the total mass of sediment, it can constitute up to 50 % of the pollution load of associated metals, hydrocarbons, nutrients and herbicides (Collins & Ridgeway, 1980).

The pollutant concentrations in runoff also vary to a certain extent with season. During spring in northern European countries, thawing snow that has accumulated in the vicinity of a road may temporarily give rise to large fluxes of particle-bound heavy metals and PAH (Lygren *et al*., 1984; Johansen *et al*., 1985). Copper, zinc and cadmium are among the substances that may occur in very high concentrations at the start of thawing. A study by Chalmers University of Technology has shown that the concentrations of bio-available heavy metals were higher in melt water than in runoff from the same catchment. The flow of cadmium was also found to decrease when the flow of chloride decreased during ongoing snow melting (Morrison *et al*., 1986).

Table 4.1 Runoff pollutant concentrations from various studies

Pollutant	Rainfall	Motorway I*	Motorway II	Urban I	Urban II	Urban III	Rural
Electrical conductivity (µS/cm)	8–80	25–22 000	25–18 000	6-2000	-	-	-
Total solids (mg/l)	18–24	< 15–12 860	110–5700	145-21640	11-40	-	-
Total dissolved solids (mg/l)	-	12–12 560	-	66-3050	-	-	-
Total volatile solids (mg/l)	-	< 20–940	-	12-1600	-	-	-
Volatile suspended solids (mg/l)	-	-	-	12-1500	-	20-78	6-25
Total suspended solids (mg/l)	2–13	18–3430	-	2-11300	-	68-295	12-135
Oil / hydrocarbons (mg/l)	-	6–40	8–400	0-400	3-31	-	-
COD (mg/l)	2.5–32	36 575	-	5-3100	-	57-227	28-85
Chloride (mg/l)	1–11	1–6714	159–2174	4-17000	4-27	-	-
Bromide (mg/l)	-	0.05–6.0	-	0.02-6.0	-	-	-
Total lead (mg/l)	0.000024–0.01	0.1–8.0	0.34–2.4	0.01-14.5	0.01-0.15	0.1-1.5	0.024-0.27
Total zinc (mg/l)	0.0002–0.05	0.12–4.0	0.17–3.6	1.0-15	0.02-1.9	0.19-0.56	0.035-0.18
Total cadmium (mg/l)	0.000013–0.000056	< 0.003-0.1	-	0.002-0.4	-	-	-
Total copper (mg/l)	0.00006–0.00005	0.007–0.03	0.05–0.69	0.007-2.5	0.010-0.12	0.025-0.12	0.01-0.05
Total chromium (mg/l)	0.000023–0.00008	0.018–0.085	-	0.018-0.27	-	-	-
Total nickel (mg/l)	-	0.036–1.55	-	0.02-1.5	-	-	-
Total organic carbon (mg/l)	1–18	-	-	5.120	-	8-74	3-17
Nitrate & nitrite (mg/l)	0.01–5.0	-	-	0.3-6.9	-	0.4-1.5	0.2-0.9
Total nitrogen (mg/l)	0.5–9.9	-	1.4–3.3	0.2-14	0.2-1.0	1.0-3.2	0.3-2.2
Total phosphorus (mg/l)	0.001–0.35	-	-	0.3-4.4	-	0.2-1.0	0.1-0.5
BOD (mg/l)	1-15	-	12–32	25-700	8-25	-	-

Rainwater and snow fall can add their own adsorbed and dissolved pollutants to the loads carried by highway runoff, particularly scavenged particulate matter (see Chapter 3). Consequently, the pollutants found in highway runoff may be derived from sources other than roads and vehicles. The first rain after a long dry period may be particularly heavily laden with air pollutants, derived from a variety of sources, which can be deposited onto the road surface and form part of the highway runoff pollutant load.

The quality of the rain can also exacerbate the effect of other pollution sources, for example, in coastal areas higher sodium and chloride concentrations in rainfall may increase the susceptibility of vehicles to corrosion. Air pollution in industrial areas can also increase the acidity and therefore erosive power of precipitation giving rise to the commonly named acid rain encountered in areas of northern Europe (essentially a dilute mixture of sulphuric and nitric acid). A road drainage study in Sweden noted rainfall pH of between 3.8 and 4.9 (Morrison *et al.*, 1988).

4.1.2 Aerial dispersion

After release, some particulate material will be dispersed in the atmosphere by turbulent air currents that prevail in the vicinity of moving traffic. Fine particulate material (between 0.1 and 25 μm) will remain suspended in the atmosphere and impact on the atmospheric environment (Elsom, 1992; Wayne, 1993). All particles, however, can be subject to one of three deposition processes:

- **Gravitational settling:** removal of most of the particles greater than 25 μm in diameter;
- **Dry deposition:** is dependent upon the concentration gradient between the surface and the atmosphere and the factors associated with the properties of both the pollutant and the surface;
- **Scavenging by precipitation or wet deposition:** pollutants carried up into the clouds by convection motion may become droplet nuclei or be dissolved in cloud water and transported back to the surface via rain or snow. Below the cloud, precipitation can also intercept particles and deposit them on the surface.

Harrison (1990) gives a good review of all these deposition processes. The distance away from the road over which larger particulate material is deposited is controlled by the strength and direction of the wind and the aerodynamic properties of the particles. In strong winds, pollutants can be transported long distances, but the particle concentrations tend to be rapidly diluted. Conversely, light winds can lead to more localised areas of concentrated deposition (Folkeson, 1976; DWW, 1995). There are various estimates of the proportion of particulate lead, from vehicle exhausts, which is transported by aerial means away from the road. For example, a study carried out in the UK showed that 6 % is deposited within 50 m of the road, 86 % is transported further away by air and 8 % enters drain water (Hewitt & Rashed, 1990). Similarly, a budget study by Revitt, Hamilton & Warren (1990) states that only 9 % of the lead from roads is deposited within 100 m, while 100 % of other heavy metals can be deposited within 10 m. Various types of air pollutants generated by traffic may thus have completely different patterns of dispersal. According to Hewitt & Rashed (1990), only 1-5 % of the low-molecular PAH compounds, but about 30 % of the high molecular compounds, are deposited close to the road. In general, however, the amounts of pollutants deposited decrease with distance away from the road. At 30 m from the road the quantities of pollutants deposited are usually at the background deposition level (DWW, 1995).

In wet conditions, vehicle spray can also aid in the aerial dispersion of road and vehicle pollutants. The amount of spray thrown up depends on the vehicle, its tyres, the vehicle speed and the nature of the road surface; spray generated by vehicles becomes more acute as the number of lanes increases, and traffic increases both in intensity and speed. Little information is available on quantities of pollutants that are dispersed in this manner. However, the spray thrown up from vehicle tyres in wet conditions is noticeably reduced with pervious surfacing such as porous asphalt (Nicholls, 1997). Porous asphalt has a high void content and is able to absorb a considerable quantity of water before becoming saturated (a surfacing 40 mm thick having 20 per cent of air voids will (when dry) accept 8 mm of rain). Until the surfacing becomes saturated, little free water remains on the surface to be thrown up as spray. According to Nicholls (1997), 20 mm thick porous asphalt (when new) reduces the amount of spray by about 95 per cent compared to non-porous asphalts. This proportion reduces over time to a long-term value of about 30 per cent. The ability of porous asphalt pavements to reduce dry aerial dispersion has also been noted (DWW, 1995).

4.2 MONITORING OF POLLUTANT DISPERSAL AT THE POLMIT SITES

As shown by the wealth of information available on the concentrations of various pollutants found in highway runoff, previous studies on pollutant dispersal have focused on determining the concentrations of pollutants in highway runoff at various times throughout a rainstorm event. However, as concentrations are influenced by many different factors, it is difficult to interpret this data to give meaningful information on total pollutant loads from roads and vehicles entering the terrestrial roadside environment.

Consequently, it was decided that POLMIT would concentrate on determining the total annual loading (mass flux) of pollutants transported by both highway runoff and aerial dispersion. By concentrating on mass flux calculations, and subsequent movement within the local roadside environment, POLMIT would gain a better insight into:

- the dispersal of traffic-generated compounds to the soil and groundwater in the vicinity of the road;
- the transport mechanisms involved;
- the transport mechanisms that would need to be targeted to ensure effective treatment.

These aims were achieved by equipping the 14 POLMIT case study sites to monitor the movement and accumulation of compounds, derived from roads and vehicles, into and within the local roadside environment.

The design of the sampling and laboratory work was optimised to provide the highest possible information value within the POLMIT framework. This involved identifying four separate programmes of experimental work, comprising:

- an A Programme,
- a B Programme,
- special studies, and
- voluntary studies.

The *A Programme* identified those parameters which were essential to the basic understanding of the movement and accumulation of potential polluting compounds, and comprised measurements and analyses that were performed by all partners at all field sites.

The *B Programme* identified those parameters which were not essential to the basic understanding of the movement and accumulation of potential polluting compounds, but which did add to general understanding, or cover particular areas in more detail. These comprised measurements and analyses that were performed by some partners at selected field sites or on selected occasions.

Special studies, undertaken by one or two partners, were devoted to gaining further understanding of a number of specific issues relating to the movement of pollutants into the local roadside environment. These included topics such as identifying the source of lead found in road-side soils, the degradation of PAHs and identification of a wide range of compounds found in highway runoff.

Voluntary studies, were those investigations undertaken by individual partners at various stages throughout the sampling period to help explain any emerging issues or anomalies in the field sampling results. These included extra measurements, analyses, sampling occasions etc. as decided by individual partners.

The main elements/compounds of interest were:

Heavy Metals: (cadmium, chromium, copper, lead and zinc)
Hydrocarbons: (total hydrocarbons and selected PAHs)
De-icing salts (where applied)
Herbicides (where applied)

Other parameters were also analysed to add to the understanding of the movement and accumulation rates of the above elements/compounds. These depended on the media being sampled:

Soil:	density, texture, moisture content, loss on ignition, pH and base cations;
Water:	electrical conductivity, pH, suspended solids, total organic carbon, alkalinity, sulphate and base cations.

This chapter describes in detail the work performed within the A programme and gives a summary of results obtained from 1 year of field monitoring, carried out at each of the 14 POLMIT field study sites. Reference is made to the B programme, voluntary and special studies where appropriate, but the reader is directed towards the POLMIT report “Pollution from Roads and Vehicles and Dispersal into the Local Roadside Environment: Monitoring of 14 case study sites” and the POLMIT web site for more detailed information and the raw data.

4.3 SAMPLING AND ANALYSIS

Within the A programme of work, sampling devices were installed to collect the following media:

- total deposition,
- road-surface runoff water,
- groundwater,
- soil water,
- open-field precipitation (rainfall).

Sampling devices were installed on the down-wind side of the road (according to prevailing winds) and within 30 m of the road, except for the background total deposition samples (see below). Figure 4.1 shows the location of POLMIT sampling equipment in a typical site. Soil was also collected, but did not require the installation of equipment.

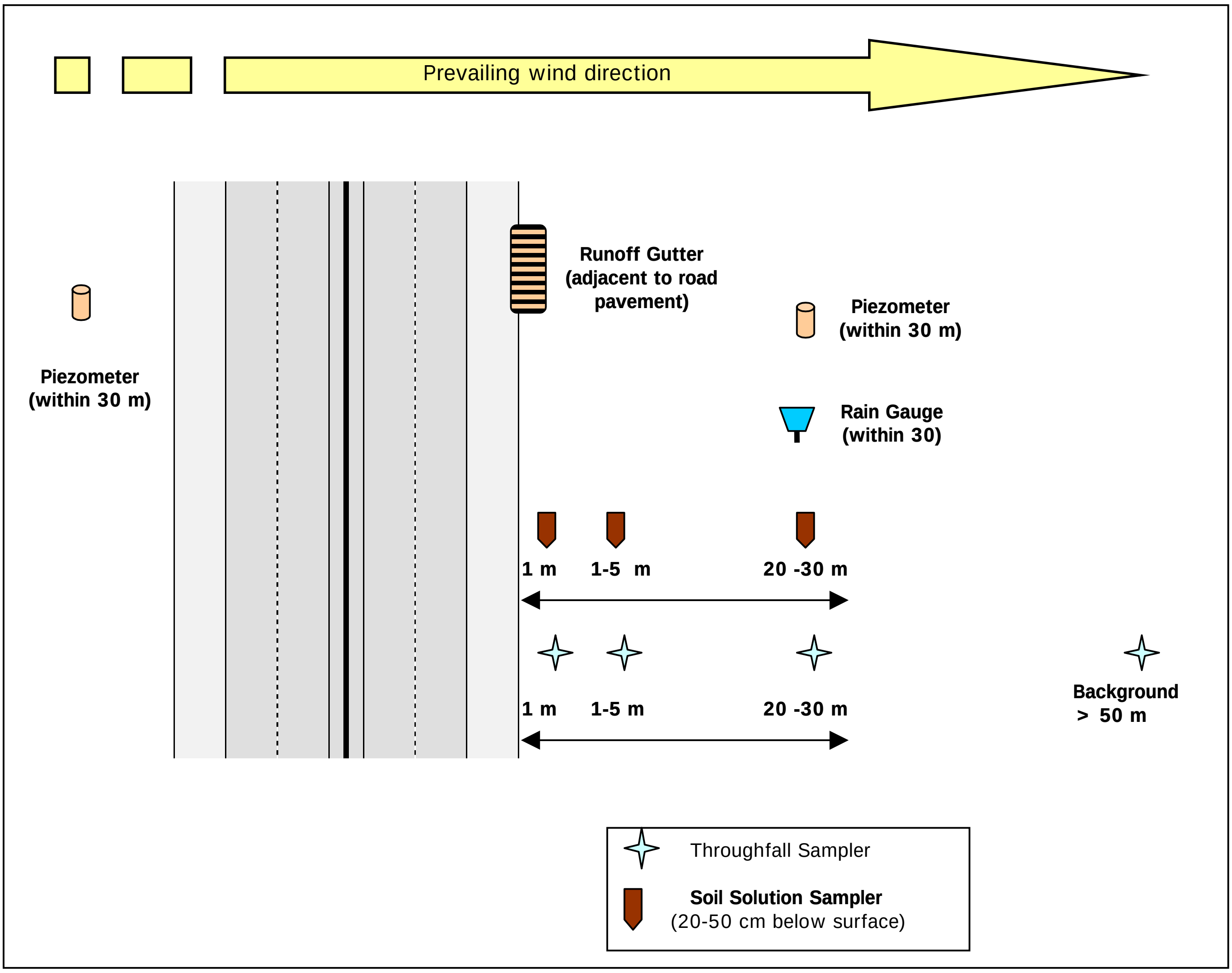

Figure 4.1 Schematic diagram of instrumentation located in POLMIT sites (not to scale)

Each sample collected was uniquely identified with a 12 digit code which identified the sample type (soil, runoff etc.), the sample site, the location within the site (upwind/downwind of road, distance from road, depth etc.), and date of sampling.

As far as practicable, the same types of sampling devices were used by all partners, and special attention was paid to prevent the contamination of samples at all stages of sampling, storage, transport, treatment and analysis. Sampling containers were made of either polyethylene, polycarbonate or teflon (PTFE) as these were known not to leach heavy metals. Containers were acid washed to prevent both the growth of algae and the adsorption of heavy metals onto the walls. Care was also taken in the field to prevent soiling during sample collection, and to protect samples from sunlight. This would reduce the amount of algal growth and prevent photochemical oxidation of organic material.

Standard field and laboratory methods were used for sample collection and analysis, to ensure the results obtained by each partner were directly comparable. It was not possible to dictate the actual methods of analysis used in the POLMIT study as each laboratory used by each partner had its own in-house method (based on recognised standard (ISO) methods). A quality assurance system was devised, however, to ensure that variations in laboratory analysis methodologies did not bias the results. This involved analysing a set of POLMIT quality assurance reference materials alongside each batch of POLMIT samples.

4.3.1 Total deposition

In the POLMIT project, “total deposition” was defined as wet (rainfall, vehicle splash) + dry (windblown particles) deposition. Total deposition was sampled using a “throughfall sampler” which consisted of 4 small gutters (approximately 40 cm long and 1 cm wide) connected to a central collection bottle (Erisman, *et al.* 1998). The gutters were placed on the surface of the soil, underneath any vegetation. This ensured that not only wet deposition, but also dry deposition falling onto the surface of the vegetation was washed off into the gutters during wet periods. Total deposition falling into the gutters flowed by gravity into the collection bottle placed below ground level. Figure 4.2 shows a throughfall sampler (placed above the vegetation so it can be seen easily).

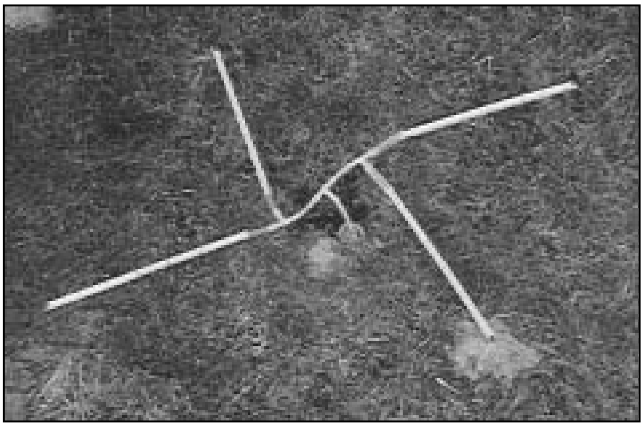

Figure 4.2 Throughfall Sampler

Three throughfall samplers were placed in the road verge to form a transect (see Figure 4.1). One was also placed in a 'background location' over 50 m upwind of the road to determine the concentrations of certain compounds/elements, derived from non-local sources, entering the local roadside environment.

Total deposition was collected continuously on site over the 12 month period, with samples collected for analysis once every three months. During periods of high rainfall, samples were collected more frequently. Samples were stored at between 2-4°C and bulked over the required three month period before being prepared for analysis.

Prior to analysis, each sample of total deposition (collected over a three month period) was split into three sub-samples. The first was not treated in any way and was used for the analysis of pH, electrical conductivity, base cations, chloride, sulphate, alkalinity and suspended solids. To gain an estimate of the concentration of the soluble heavy metals, the second sub-sample was decanted or filtered through 0.45 μm filters before being acidified with HNO_3 and analysed. To gain an estimate of the total metal, TOC, total hydrocarbons and PAHs, the third sub-sample was acidified with HNO_3 to $pH < 2$ and left overnight (16 hours) before being decanted or filtered through a 0.45 μm filter. This effectively 'acid-washed' the particulate fraction present in the sub-sample, ensuring that any elements/compounds adsorbed to the particulate fraction went into solution. A summary of the pre-treatment methods and elements analysed in each pre-treated sample are given in Table 4.2

Table 4.2 Pre-treatment of aqueous samples

Sub-sample	Pre-treatment	Fraction	Elements/Compounds Determined
1	None	-	pH, electrical conductivity, base cations, sulphate, chloride, alkalinity, suspended solids
2	Filtered then acidified	Soluble	Soluble heavy metals
3	Acidified then filtered	Total	TOC, total heavy metals, total hydrocarbons, PAHs

4.3.2 Road-surface runoff

Runoff water was collected using a PVC gutter, 1 m long, 15 cm wide, installed along and immediately adjacent to the asphalt edge (Figure 4.3). The runoff water was collected in ten 25-L polyethylene bottles which were enclosed to keep the bottles sheltered from sunlight and to some extent from soiling.

Figure 4.3 Runoff gutter

Runoff was collected continuously on site over the 12 month period, with the collection bottles being sampled and emptied as required. Volume-proportionate samples were taken from each of the ten runoff containers and combined before being stored at between 2-4°C. Samples collected over a 1 month period were bulked before being prepared for analysis as described above for total deposition.

4.3.3 Groundwater

Groundwater piezometers (3 m long plastic down pipes with holes drilled in the bottom third, similar to that shown in Figure 4.4) were installed on the down-stream side of the road or, at some sites, on both sides of the road. Samples were collected once every three months and stored at 2-4 °C prior to analysis (no pre-treatment was required). Samples were analysed as above, but did not include suspended solids or soluble metals.

4.3.4 Soil solution

Tension lysimeters (porous cups) were installed on the downwind side of the road between 20 and 50 cm below the soil surface to sample soil solution. These consisted of a porous cup into which soil water was drawn with the aid of a vacuum pump. Samples were collected once every three months and stored and analysed in the same manner as for groundwater.

Figure 4.4 Groundwater piezometers

4.3.5 Soil

Soil was sampled on one occasion from four distances at each study site as part of the "A" programme. General soil characteristics (bulk density, texture, moisture and losson ignition) were determined. In addition, sub-samples were air dried and stored at between 2-4°C prior to analysis. Samples were analysed for total and soluble heavy metals, total organic carbon, total hydrocarbons, PAHs, pH, and base cations (see Table 4.3 for details).

Figure 4.5 Rainfall gauge

4.3.6 Open-field precipitation (Rainfall)

The amount of open-field precipitation was quantified using a rain gauge (Figure 4.5). Open-field precipitation was collected continuously, with volumes being regularly monitored and recorded. No chemical analyses were performed on these samples. Other meteorological data (temperature and wind direction) was obtained from local meteorological stations.

Table 4.3 summarises the analyses conducted on each of the media sampled.

Table 4.3 Analyses carried out on each POLMIT sample

Parameter	Total deposition	Runoff	Groundwater	Soil solution	Soil
Volume	✓	✓	–	–	–
Bulk density	–	–	–	–	✓
Texture	–	–	–	–	✓
Moisture	–	–	–	–	✓
Loss on ignition	–	–	–	–	✓
pH	✓	✓	✓	✓	✓
Electrical	✓	✓	✓	✓	✓
Suspended solids	✓	✓	–	–	–
Alkalinity	✓	✓	✓	✓	–
Chloride	✓	✓	✓	✓	✓
Sulphate	✓	✓	✓	✓	✓
Ca	✓	✓	✓	✓	✓
K	✓	✓	✓	✓	✓
Mg	✓	✓	✓	✓	✓
Na	✓	✓	✓	✓	✓
Cd (total)	✓	✓	✓	✓	✓
Cr (total)	✓	✓	✓	✓	✓
Cu (total)	✓	✓	✓	✓	✓
Pb (total)	✓	✓	✓	✓	✓
Zn (total)	✓	✓	✓	✓	✓
Cd (soluble)	✓	✓	-	-	–
Cr (soluble)	✓	✓	-	-	–
Cu (soluble)	✓	✓	-	-	–
Pb (soluble)	✓	✓	-	-	–
Zn (soluble)	✓	✓	-	-	–
TOC	✓	✓	✓	✓	✓
Total hydrocarbons	✓	✓	✓	✓	✓
Seven PAHs	✓	✓	✓	✓	✓

4.4 RESULTS AND DISCUSSION

The following section gives an overview of the results obtained at each of the 14 case study sites. Again, the reader is directed towards the POLMIT report “Pollution from Roads and Vehicles and Dispersal into the Local Roadside Environment: Monitoring of 14 case study sites” for more detailed information and the POLMIT web site for the raw data.

4.4.1 Heavy metals

Runoff

The total annual input (mass flux) of each of the metals investigated is presented in Table 4.4 for each of the sites (see Chapter 2 for a full description of the sites). A full description of how the mass fluxes were calculated is given in the POLMIT report ‘Pollution from Roads and Vehicles and Dispersal into the Local Roadside Environment: Mass Flux and Mass Balance Calculations; Assessment of Pollution of Groundwater and Soils by Road and Traffic Sources’. (Due to climatic difficulties which resulted in infrequent sampling at Sites G and H in Finland, mass flux concentrations could not be calculated).

Table 4.4 Total annual input of metals through road runoff at each site

Site	Traffic density (AADT for one carriageway)	Total annual input (g/km) from one carriageway of the road				
		Cd	Cr	Cu	Pb	Zn
A - Reading	49100	6.0	1	1125	1115	3924
B - Oxford	38850	<7.0	<136	248	208	913
C# - Nieuwegein	75000	1.9	5	116	63	1058
D# - Spaarnwoude	45000	1.1	3	45	43	191
E – Svaneberg	3675	0.3	4	77	27	323
F – Norsholm	9020	1.3	23	314	62	916
I – Vejenbrod	12250	1.0	30	263	90	652
J – Rud	8800	2.0	22	294	89	950
K# - Erdre	12000	< 2.3	<5	<145	130	1,942
L# - Houdan	10500	1.8	8	103	144	<519
M - Recta	10650	0.3	1	12	14	111
N - Vila	4220	<30.0	23	1	40	8,091

< concentrations below the level of detection for one or more sample analysis

porous asphalt road surface

Zn was transported in the greatest quantities at each site, followed by Cu and Pb (although sometimes the positions of these two elements were reversed) and finally by Cr and Cd. This is probably due to the greater number of sources (tyres, crash barriers, brake pads etc.) of Zn and Cu than the other metals. There were no strong correlations (< 0.5) between traffic density and total annual input to confirm this theory. However, it is known that road surface type has a marked influence on the concentration and therefore quantity of metals transported in road runoff. In the case of porous asphalt, sediment present in road runoff is known to settle out and become trapped in the matrix of the road surface structure. Metals adsorbed to, or forming part of, this sediment are therefore retained in the matrix of the road structure. As sediment builds up, the porous nature of the surface is reduced and, in the case of The Netherlands, sediment needs to be removed at regular intervals to maintain the porous properties of the road surface. When separate correlations were carried out between traffic density and total metal input through highway runoff, for both porous and non-porous surfaces, the correlations were much stronger (Cd 0.95, Cu 0.79, Pb 0.84). However, because of the limited number of points in each correlation, a greater range of traffic densities and sites would need to be analysed to confirm their accuracy.

Figures 4.6a-4.6e show the maximum and minimum concentrations of Cd, Cr, Cu, Pb and Zn determined at each of the 14 sites.

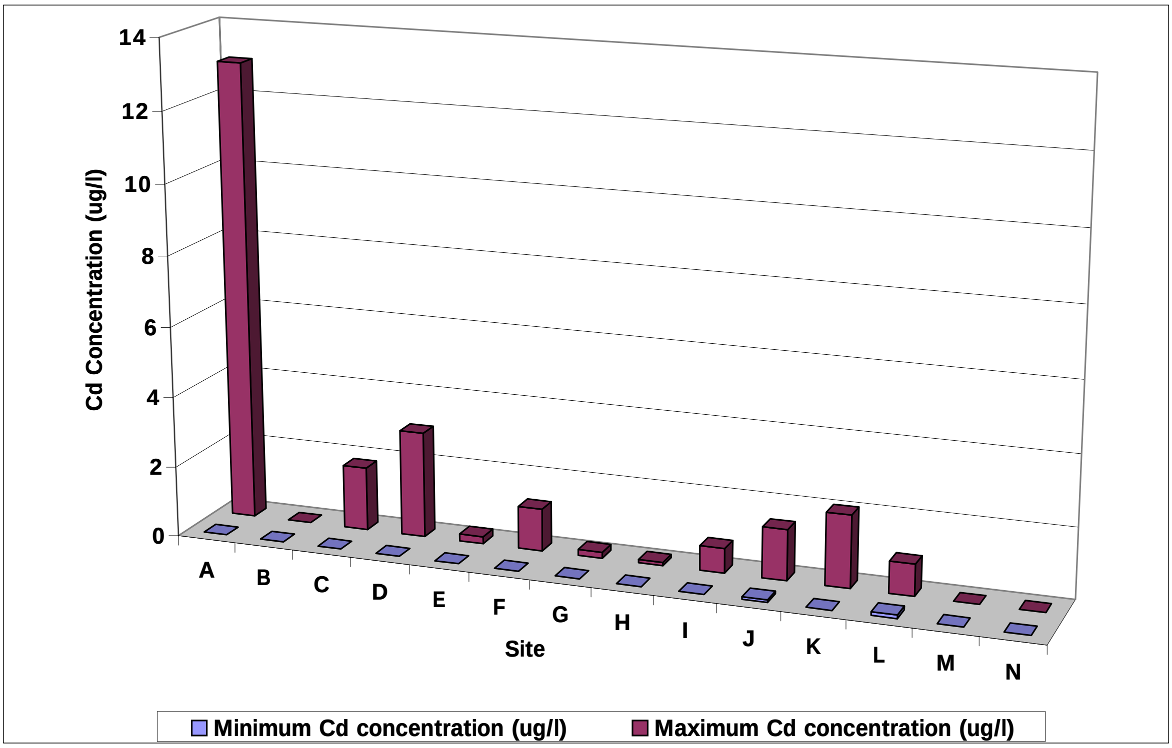

Figure 4.6a Maximum and minimum concentrations of Cd in highway runoff at each of the 14 POLMIT sites

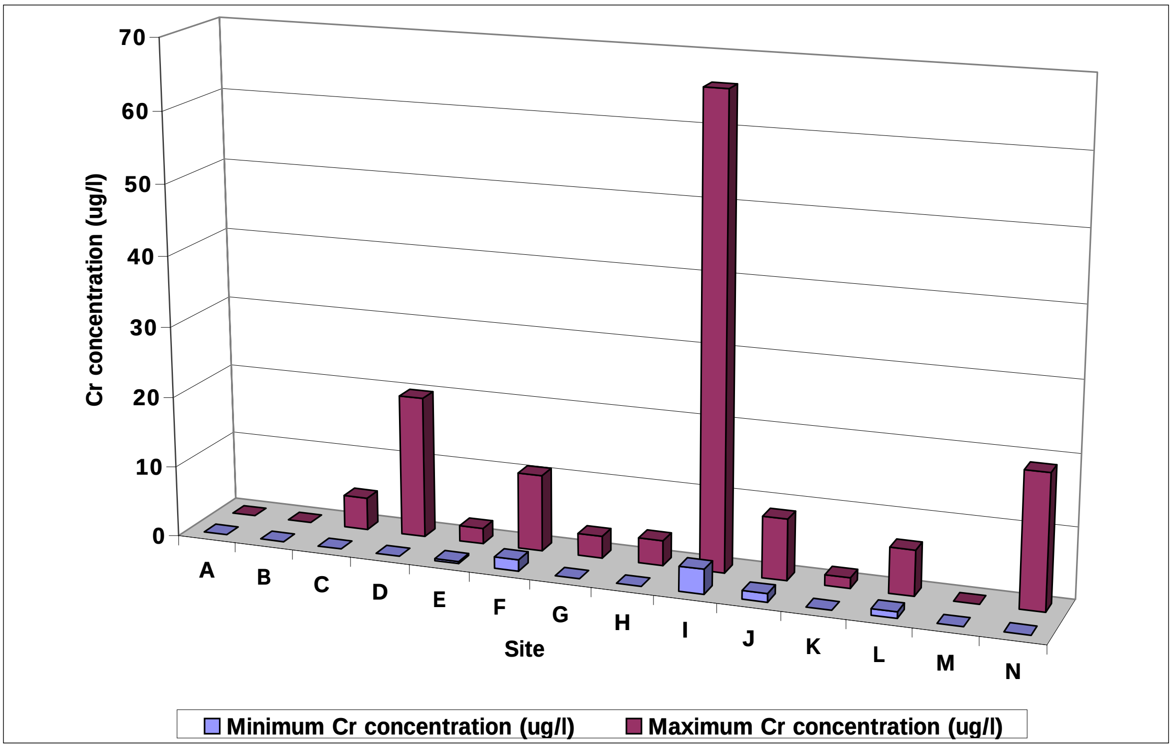

Figure 4.6b Maximum and minimum concentrations of Cr in highway runoff at each of the 14 POLMIT sites

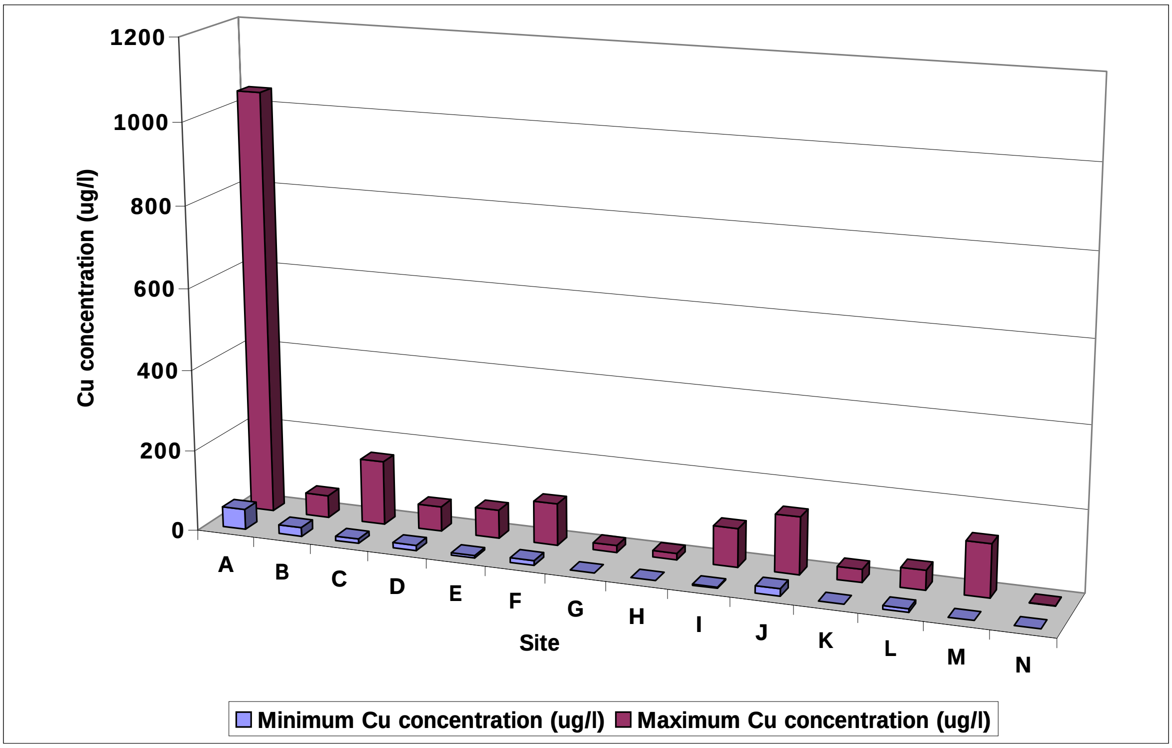

Figure 4.6c Maximum and minimum concentrations of Cu in highway runoff at each of the 14 POLMIT sites

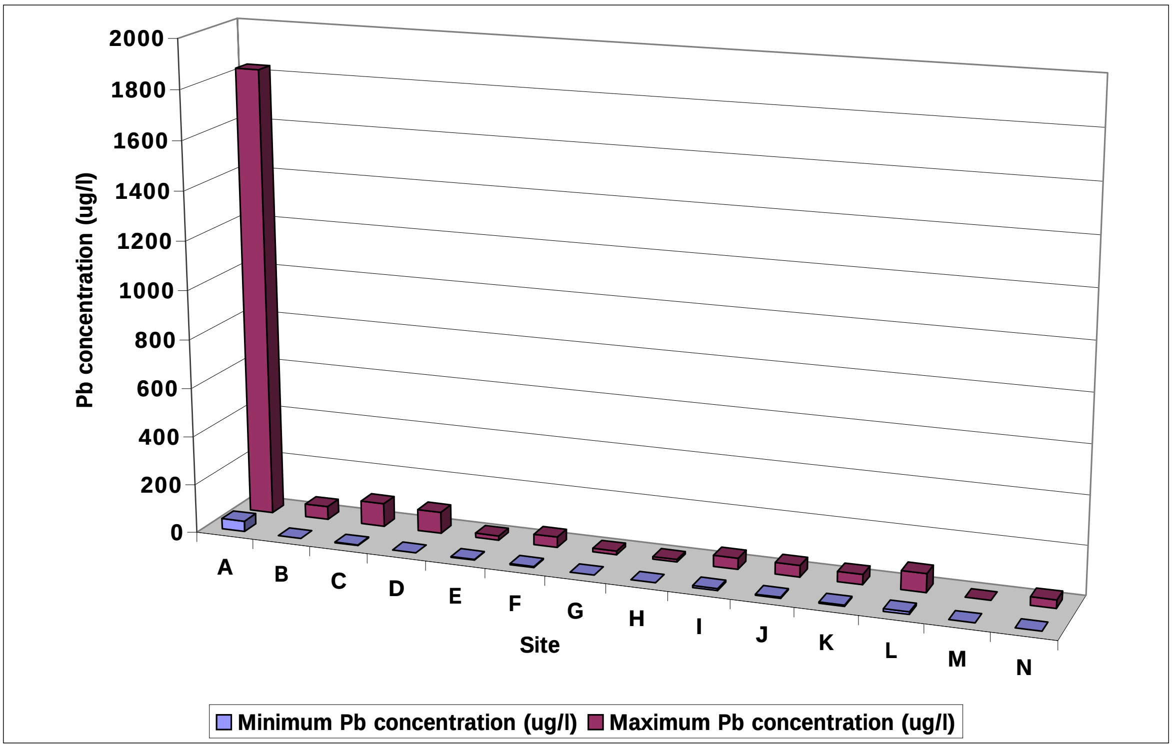

Figure 4.6d Maximum and minimum concentrations of Pb in highway runoff at each of the 14 POLMIT sites

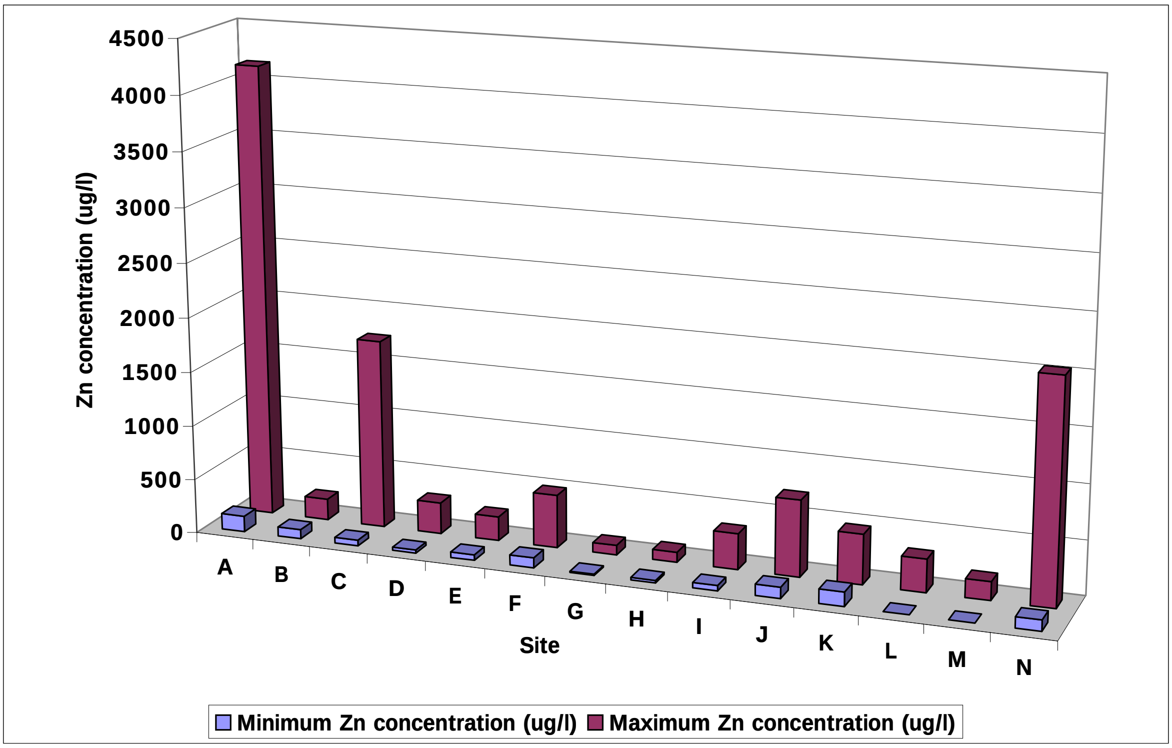

Figure 4.6e Maximum and minimum concentrations of Zn in highway runoff at each of the 14 POLMIT sites

Concentrations of heavy metals in road runoff varied both from site to site and, for any particular site, with time of sampling. The concentrations of metals generally followed the same concentration order as that identified for the total annual input, irrespective of site location:

Zn > Cu ~ Pb > Cr > Cd

The greatest metal concentrations were found in runoff at Site A in the UK. Although this site did not have the greatest traffic density of all 14 sites, it did have the greatest traffic density of those sites with non-porous surfaces. Those sites with greater traffic densities had porous surfaces which reduced the concentration of pollutants.

As well as traffic density and road surface type, climate also influences the concentration of heavy metals found in highway runoff. Seasonal variations in metal concentrations in runoff were often large but not consistent between countries.

For example, Fig 4.7 shows that the concentrations of Cu, Pb and Zn were much greater at site A in the UK during July compared to the rest of the year. This coincided with a very dry period (Figure 4.8). Although the concentrations of these metals were great, the total mass inputs for the month were some of the lowest during the 12 month period. This supports the idea that the high concentration was not due to an increase in source of heavy metals, but simply a lack of dilution.

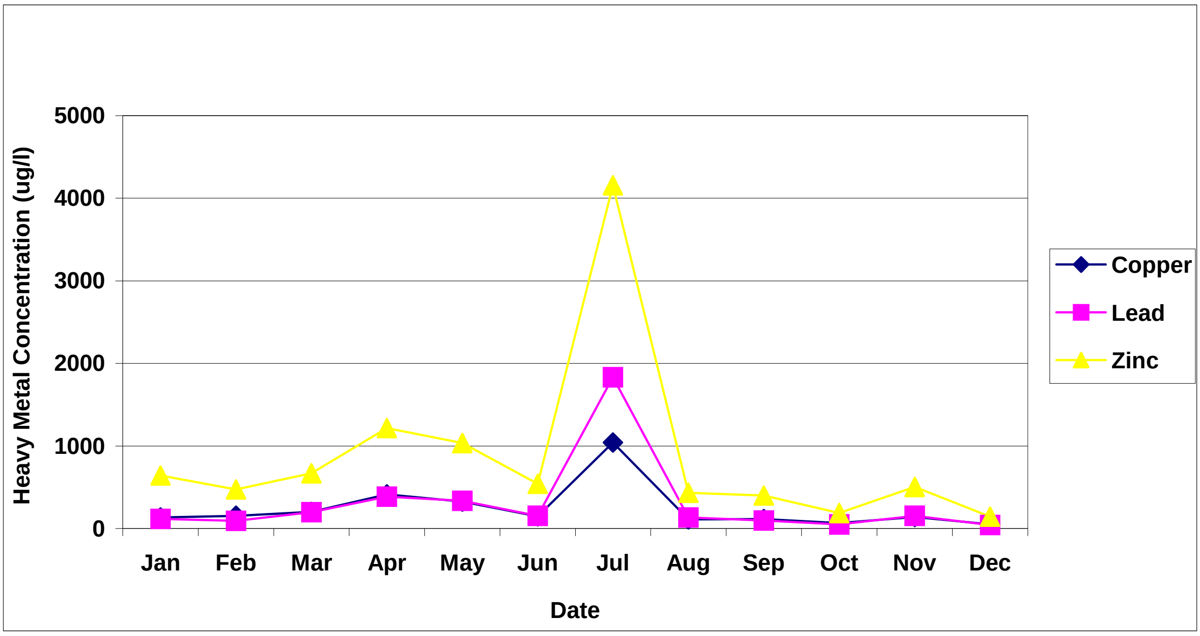

Figure 4.7 Heavy metal concentrations in runoff at Site A in the UK

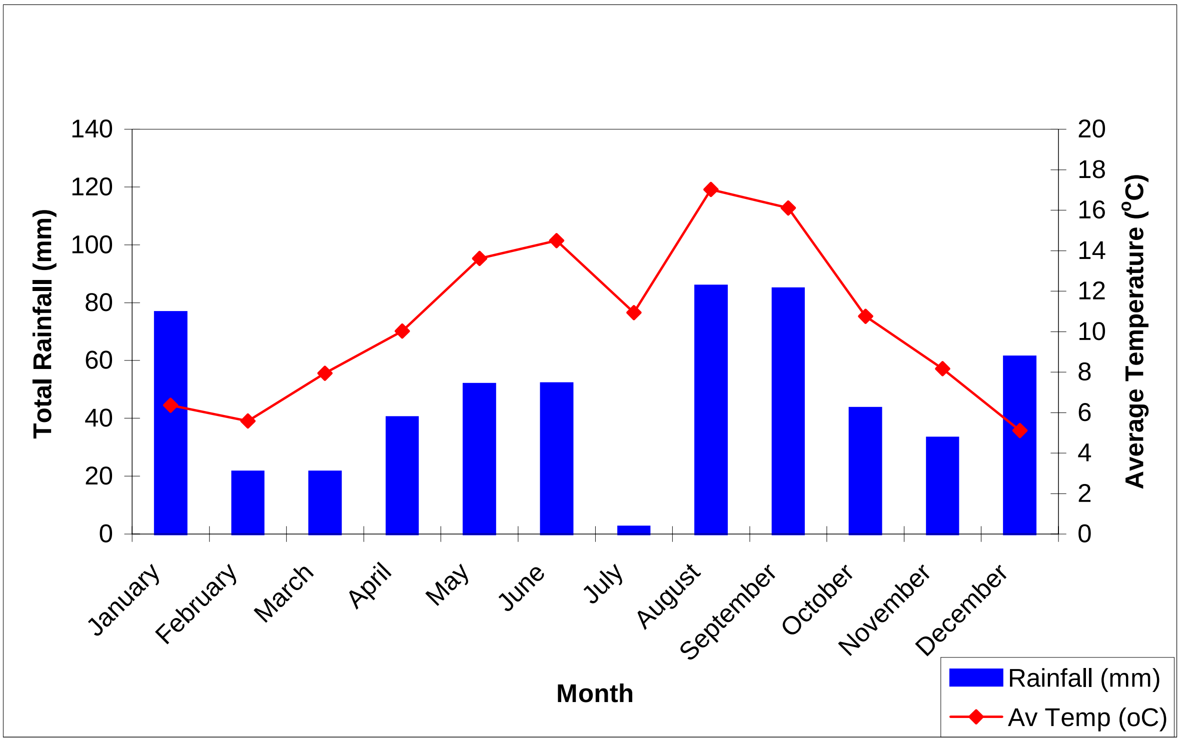

Figure 4.8 Rainfall and temperature at Site A in the UK

Other seasonal variations in metal concentration were related to an increase or decrease in the size of the source of metal. For example, at site J in Denmark, the Zn, Cu and to some extent the Pb concentrations were all elevated during the period November – March (Figure 4.9). This could not be explained by a decrease in rainfall and therefore lack of dilution, but did coincide with an increase in mass input during the same period (Figure 4.10). The same was also found at sites E and F in Sweden. One explanation for this is the increased use of de-icing salts during this period. Rock salt commonly used for de-icing is contaminated with trace amounts of heavy metals. However, the increase may also result from the de-icing salt increasing the rates of corrosion of vehicle components, or reacting with insoluble sources to produce soluble heavy metal salts. This would lead to the release of greater amounts of soluble heavy metals during the winter season.

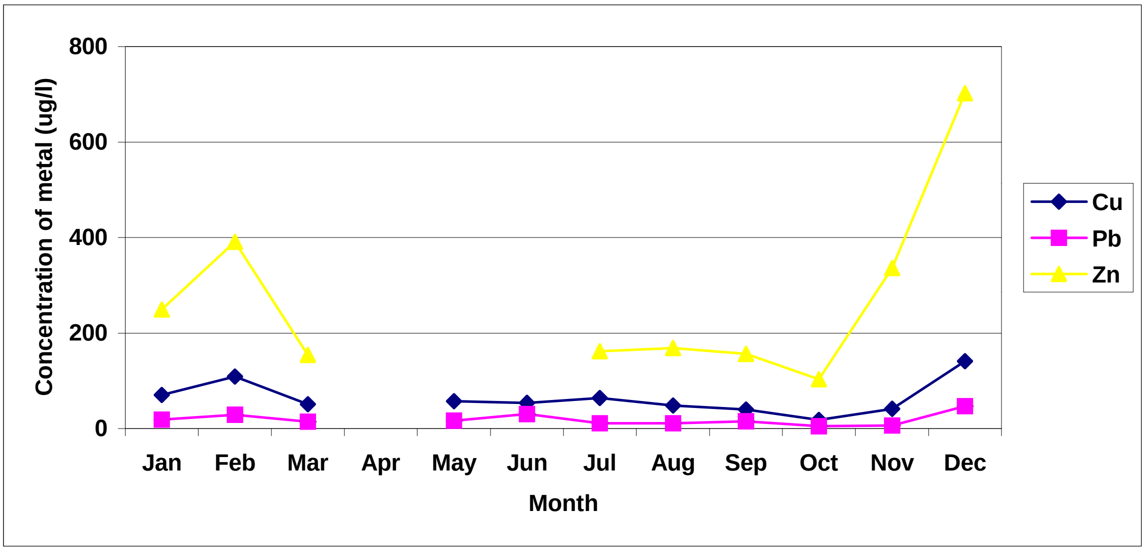

Figure 4.9 Concentration of Cu, Pb and Zn in highway runoff at Site J in Denmark

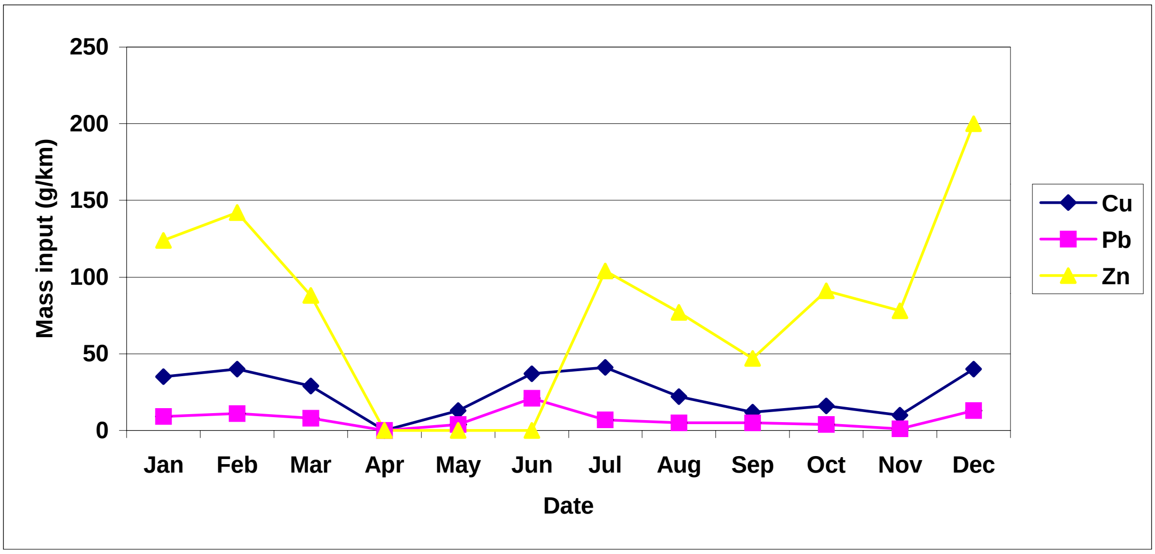

Figure 4.10 Mass input of Cu, Pb and Zn through highway runoff at Site J in Denmark

The elevated mass input of Cu, Pb and Zn found in the summer months is due to some extent to the observed increase in atmospheric deposition of these elements during this period, adding to the metal loading in highway runoff.

Higher Zn concentrations in runoff at some sites (Site K in France and Site N in Portugal) were attributable to the presence of a galvanised crash barrier or metallic guard rails. Studies conducted by LCPC have shown that relatively high concentrations of Zn can be washed from these structures into either highway runoff or directly onto any underlying soil (Legret, 1999; personal communication).

Total deposition

The total annual inputs (mass fluxes) of heavy metals deposited into the road verge via atmospheric deposition (aerial dispersal) are given in Table 4.5. Again, a full description of the method of calculation can be found in the POLMIT report ‘Pollution from Roads and Vehicles and Dispersal into the Local Roadside Environment: Mass Flux and Mass Balance Calculations; Assessment of Pollution of Groundwater and Soils by Road and Traffic Sources’.

Table 4.5 Total annual input of metals through atmospheric deposition at each site

Site	Traffic density (AADT for one carriageway)	Total annual input (g/km) from one carriageway (downwind) of the road				
		Cd	Cr	Cu	Pb	Zn
A - Reading	49100	< 2	< 34	76	< 34	98
B - Oxford	38850	< 5	< 98	115	50	558
C# - Nieuwegein	75000	35	156	536	541	2,447
D# - Spaarnwoude	45000	1.8	4.6	36	141	106
E – Svaneberg	3675	3.7	8.4	197	45	952
F – Norsholm	9020	3.2	27	539	147	1592
I – Vejenbrod	12250	1.6	4.7	332	74	422
J – Rud	8800	0.4	0.5	26	29	322
K# - Erdre	12000	< 1.9	< 1.4	79	57	265
L# - Houdan	10500	< 0.2	< 2	71	< 10	201
M - Recta	10650	< 20	< 198	< 333	< 198	< 534
N - Vila	4220	< 42	< 410	< 410	< 417	< 522

< concentrations below the level of detection for one or more sample analysis

porous asphalt road surface

In a similar manner to runoff, Zn was transported in the greatest quantities, followed by Cu, Pb, Cr and Cd. Again this reflects the relative quantities of each metal emitted from the various road and vehicle sources. The total quantities of heavy metals transported by aerial deposition were generally less than those transported via road runoff. This did not appear to be the case for Site C in The Netherlands. However, the presence of a noise barrier at this site led to an increased deposition of metals at one sampling point, which placed a bias on the total mass input calculations. The results of this site should therefore be viewed with caution. In many cases, the concentrations of Cd and Cr were below detection limits, making accurate mass input values difficult to calculate. Again, these results should be viewed with caution.

The quantities of Zn, Cu and Pb were typically higher in total deposition sampled close to the roads than further away, as clearly shown in Figure 4.11a for Site D in the Netherlands and Figure 4.11b for Site I in Denmark (despite the large differences in mass input at these sites).

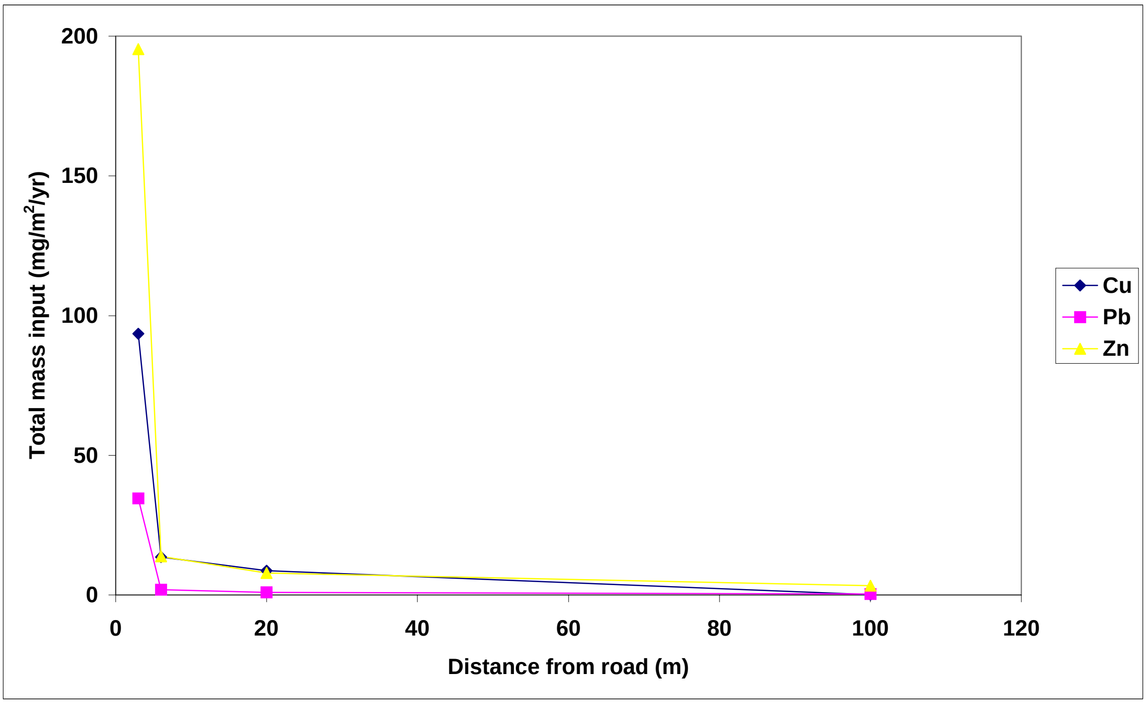

Figure 4.11a Mass input of Zn, Cu and Pb through atmospheric deposition at varying distances from the road at Site D in The Netherlands

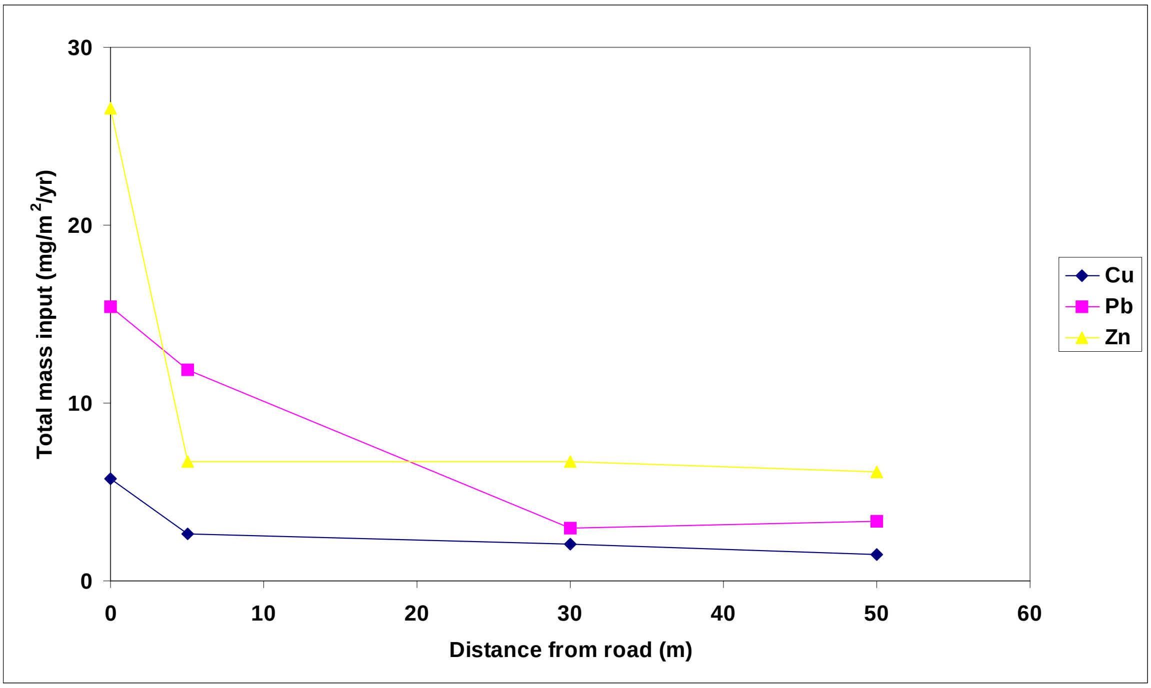

Figure 4.11b Mass input of Zn, Cu and Pb through atmospheric deposition at varying distances from the road at Site I in Denmark

The concentrations levelled off at varying distances from the road e.g. at 8 m (Site L in France) 15 m (Site K in France) or between 5 and 30 m (Site D in the Netherlands). Variations in distance could be due to differences in the strength and prevailing wind direction at each site.

In Sweden and France metal deposition rates were elevated close to the road but some high values were also encountered well away (30 m or greater) from the road. This is thought to result from other non-road sources of these elements. Possible sources were investigated as part of the POLMIT special studies.

The noise barrier located 2 m from the road at Site C in the Netherlands was found to efficiently limit heavy-metal dispersal away from the road, as shown by a rapid decrease in deposition after 2 m. If necessary, such barriers could be used as effective mitigation measures for the control of pollutants transported by aerial dispersion.

Soils

Heavy-metal concentrations were usually highest in topsoil closest to the roads, decreasing down the soil profile and away from the road edge. This trend was most marked at sites where the traffic density was high and/or the road was relatively old. Figure 4.12 shows a typical example.

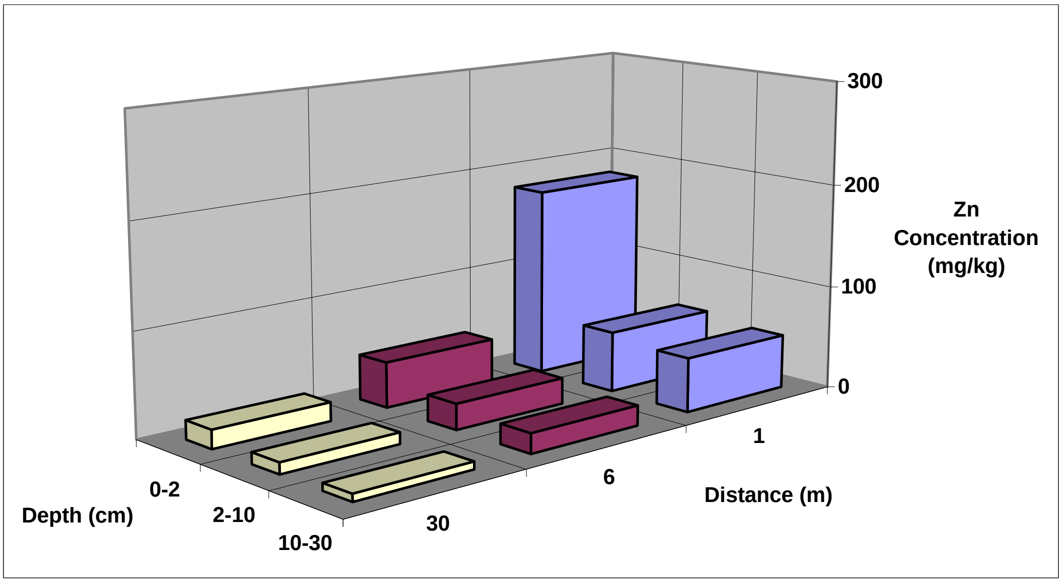

Figure 4.12 Zn concentrations in soil at Site A in the UK

In some instances, the distance gradient was very steep within the first 10 m of the road. At Site D in the Netherlands, where the road carries 90,000 vehicles/day, the Zn and Pb concentrations in the top 10cm decreased by one order of magnitude between 4 and 7 m from the road. Steep gradients in metal concentration with distance were also found at sites where the traffic density was low; for Cu, Pb and Zn at Site I in Denmark and Site F in Sweden; for Pb and Zn at both the French sites (Sites K and L); and for Pb at Site M in Portugal. The gradient down the soil profile was also generally very steep. In the soil closest to the road at Sites C and D in the Netherlands, concentrations of Pb and Zn were both 1 order of magnitude higher in the top 10 cm than at 10-30 cm depth.

In some cases, the distance and depth patterns were unclear, e.g. for some metals in Sweden and Portugal. Figure 4.13 shows the zinc concentrations at site N in Portugal. Here the road is only 5 years old and has a low traffic density (AADT) of 8,500. Consequently there is no marked decrease in concentration with distance or depth.

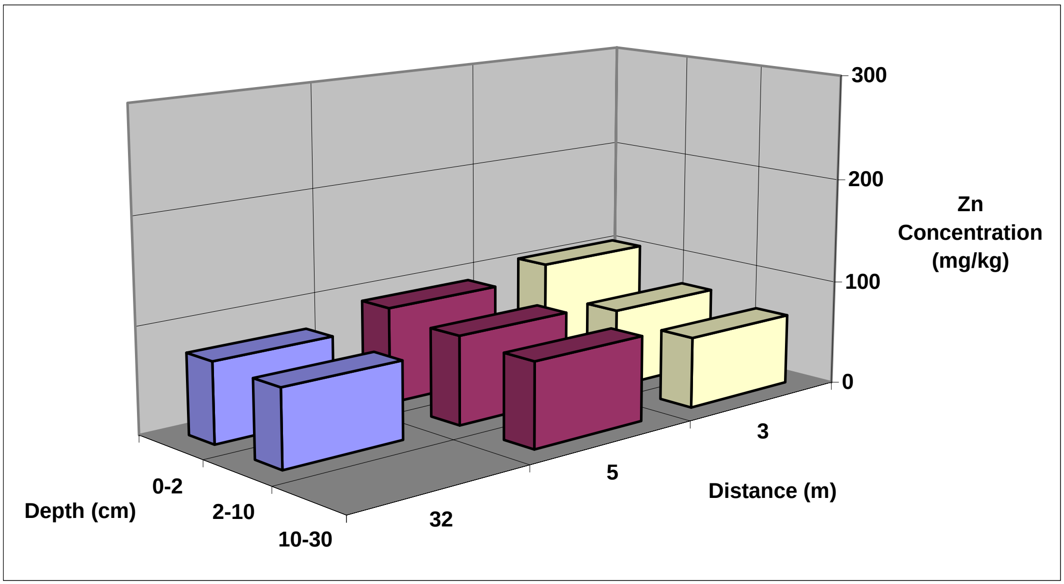

Figure 4.13 Zn concentrations in soil at Site N in Portugal

Soil characteristics (pH and texture), and the chemistry of individual heavy metals, strongly regulate the transport of metals in soils. The rapid transport in coarse-textured or otherwise permeable soils has been demonstrated in the French sites where heavy metals were found to migrate deeper in sandy than in loamy-sandy soil. At Site L in France, where the soil is sandy, Cu, Pb and Zn were found to move down to 30 cm. Figure 4.14 shows relatively high concentrations of Zn even at a depth of 10-30 cm, demonstrating the migration of Zn down through the profile at this site.

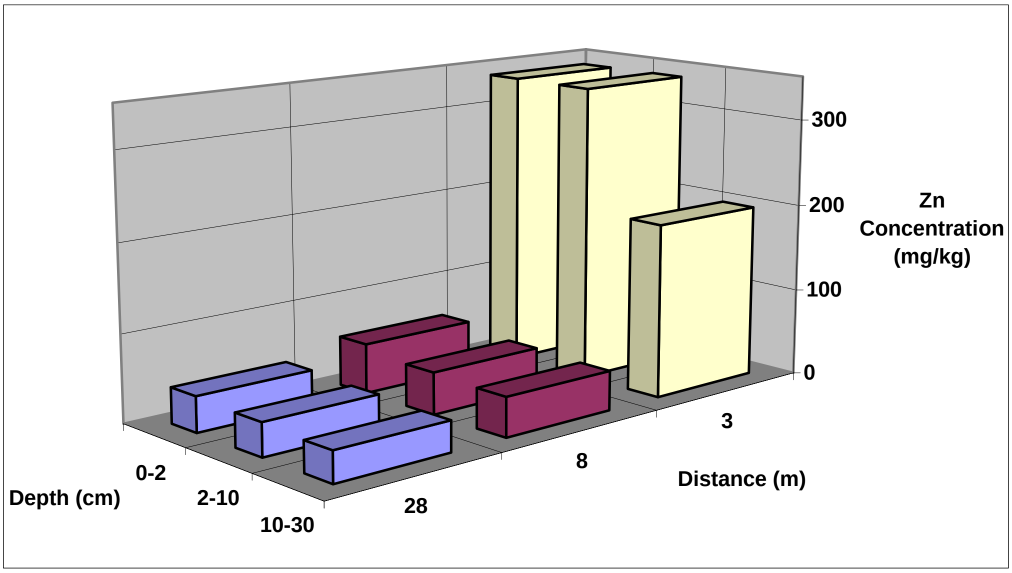

Figure 4.14 Zn concentrations in soil at Site L in France

Figures 4.15a – 4.15e show the maximum and minimum concentrations of Cd, Cr, Cu, Pb and Zn in the soils at each of the 14 POLMIT sites. Dutch Intervention Levels for each heavy metal in soil are denoted by a red line. Soil Intervention levels were only exceeded for Pb, and only then at two sites (Site D in The Netherlands and Site L in France). These sites either have high traffic densities and/or are relatively old, with most of the Pb probably having been deposited when leaded fuel use was at a peak. With the current ban on the use of leaded fuel, Pb concentrations are not expected to increase further.

Cu and Zn concentrations at some sites do approach the Intervention level. In the case of Site K in France elevated concentrations are probably due to the presence of crash barriers. However, in most soils, these metals will be retained in the upper few cms of soil adjacent to the road, and will not migrate further unless disturbed.

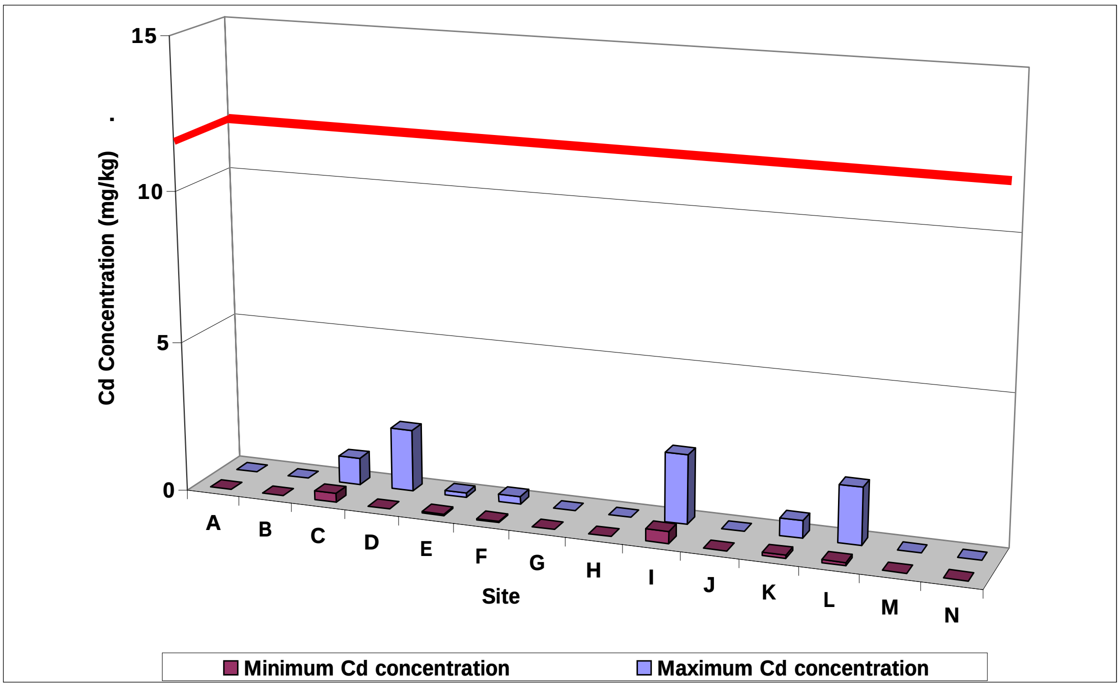

Figure 4.15a Maximum and minimum concentrations of Cd in soil at each of the 14 POLMIT sites

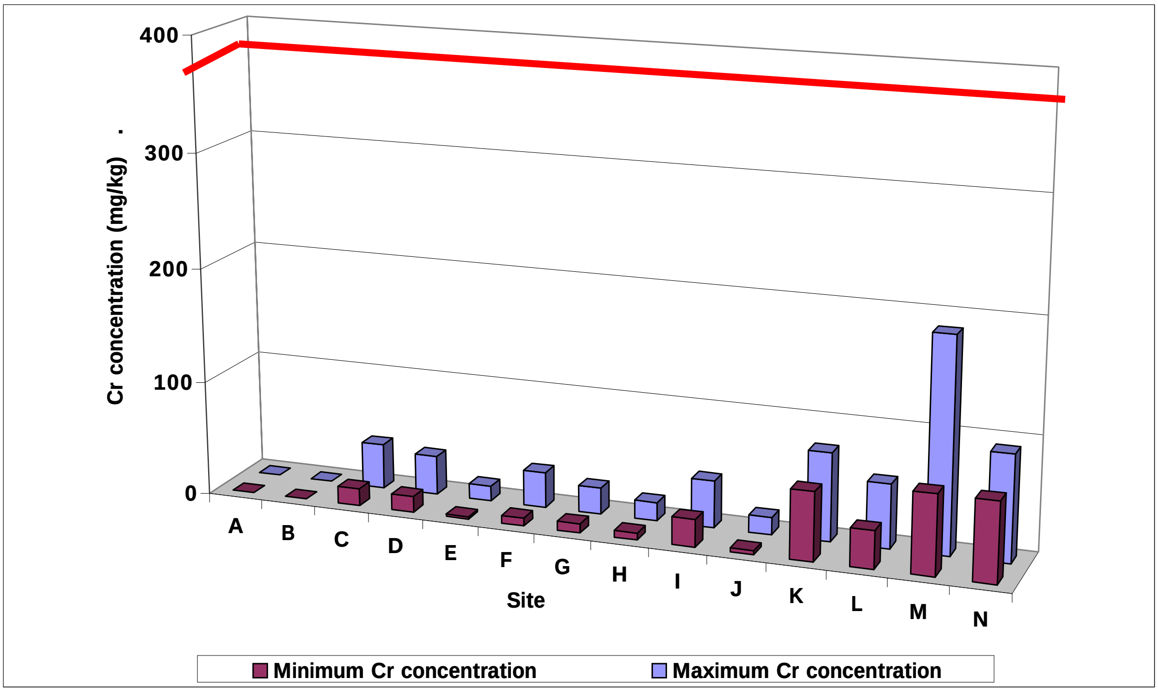

Figure 4.15b Maximum and minimum concentrations of Cr in soil at each of the 14 POLMIT sites

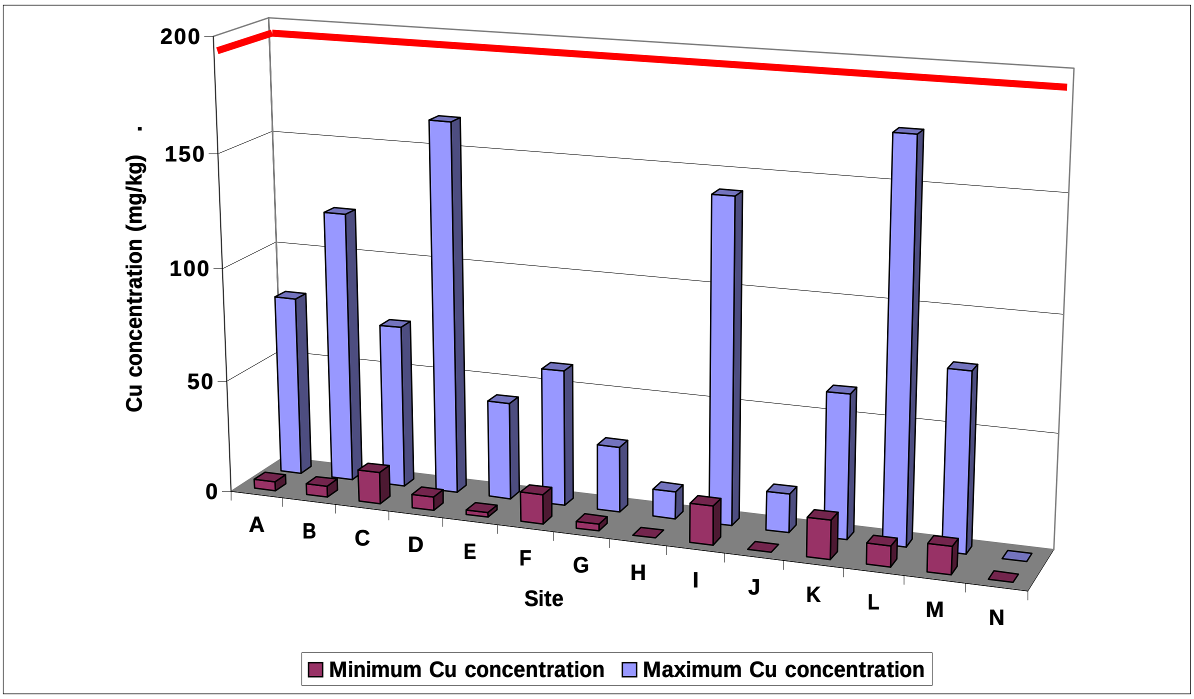

Figure 4.15c Maximum and minimum concentrations of Cu in soil at each of the 14 POLMIT sites

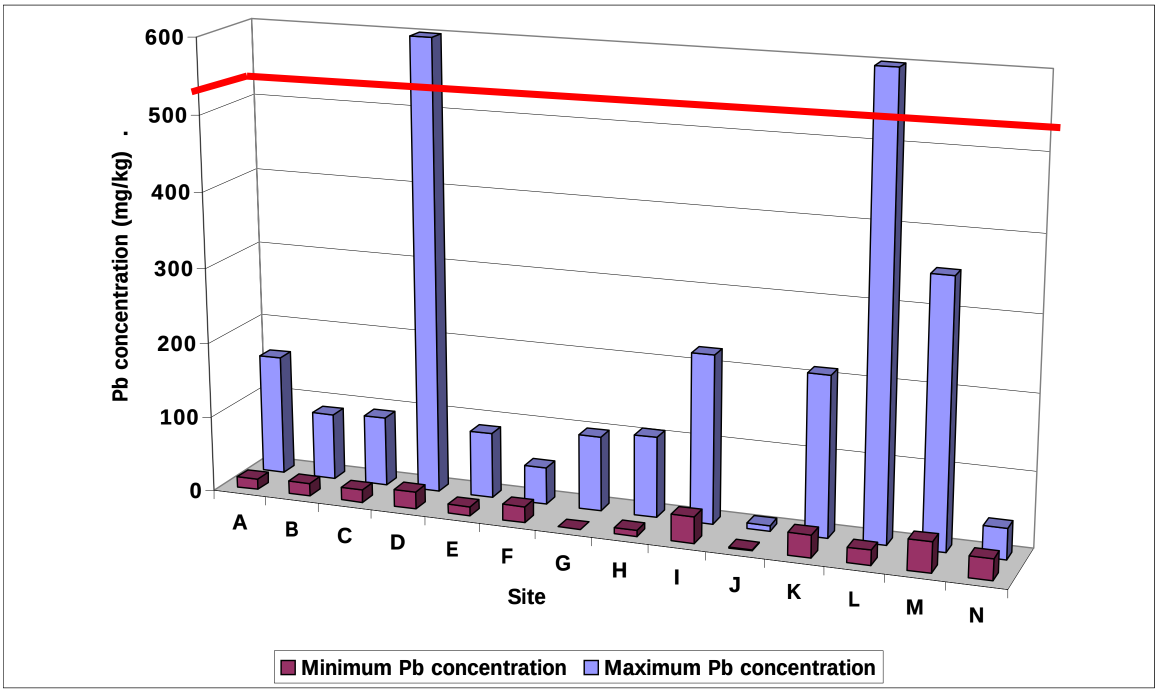

Figure 4.15d Maximum and minimum concentrations of Pb in soil at each of the 14 POLMIT sites

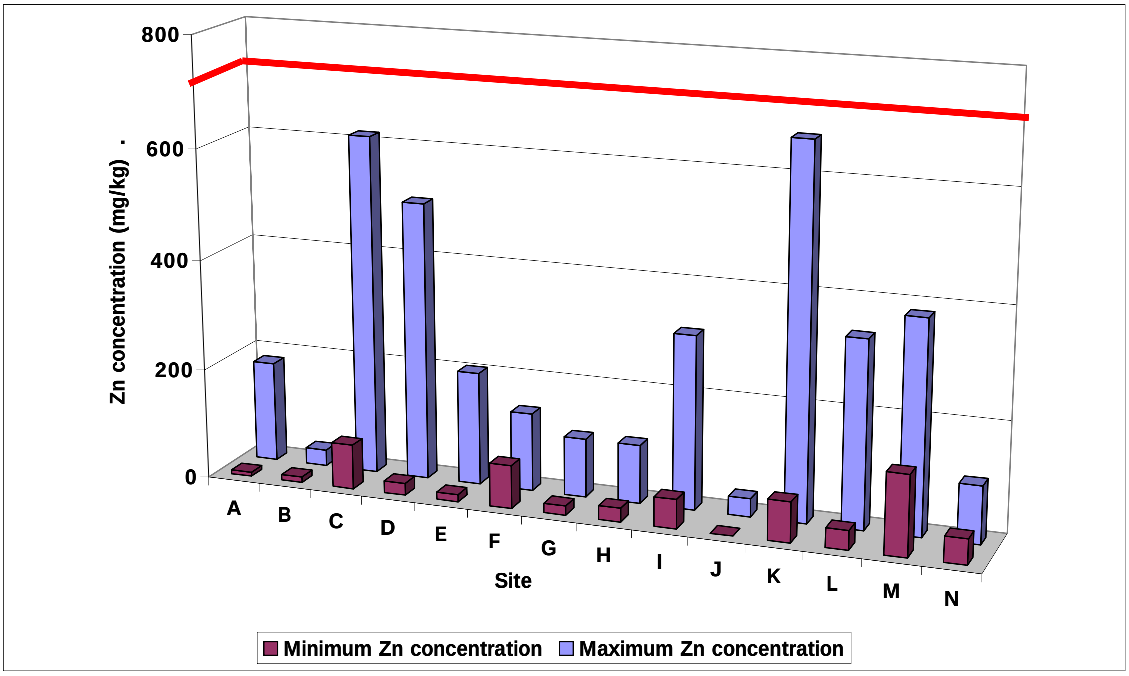

Figure 4.15e Maximum and minimum concentrations of Zn in soil at each of the 14 POLMIT sites

Soil solution

Samples of soil solution could not be extracted from 3 sites (Sites A and B in the UK and site N in Portugal) and could only be extracted at irregular times from the remaining sites. This was due either to the coarse nature of the soil adjacent to the road and/or the lack of rainfall.

Where samples were collected and analysed, the same order of concentration was found at most of the sites Zn > Cu > Pb ~ Cr > Cd. This reflects not just the quantity of the source of each metal, but also the chemistry of each metal in that Pb is much less soluble than Cu or Zn (Alloway, 1990). According to a B-programme analysis of runoff from the French sites, Cd, Cr, Cu and Zn were found to be mainly in the soluble phase (55% - 76%), while lead was mainly in the particulate phase, (<46% and <15% soluble at sites L and K, respectively).

The chemistry, and the form of release of these metals also accounts for the low concentrations found in the soil solution, compared to concentrations found in highway runoff. Metals are strongly adsorbed to soil (and other) particles. Consequently, metals either adsorb directly to soil particles in the surface of the soil, or, if released in particulate form, will be filtered from the soil solution as the solution percolates down through the soil. This is supported by the elevated concentrations of metals found in the top 2 cm of soil at many sites (see above).

No obvious seasonal trends of metal concentration found in soil solution were identified. However, elevated concentrations of Zn (up to 2000 µg/l) were found at both the French sites (Sites K and L). The presence of crash barriers at site K (increasing the amount of Zn entering the soil at this site) and the presence of freely draining soil at Site L (allowing the rapid downward movement of Zn already in solution) may account for these elevated concentrations.

Groundwater

In general, concentrations of heavy metals found in groundwaters were low even in areas located close to and downstream of the road. No obvious seasonal trends in the metal concentrations were identified either. Figures 4.16a - 4.16e show the maximum and minimum concentrations obtained at each site throughout the 12 month sampling period. As can be seen, most of the metal concentrations were well below the Dutch Intervention Levels for groundwater (as shown by the red line).

The apparent lack of movement down through the soil profile and into groundwater fits well with the elevated concentrations found in roadside soils and the known chemistry of these metals. Metals are strongly adsorbed to soil surfaces, and are difficult to leach down the soil profile into groundwater.

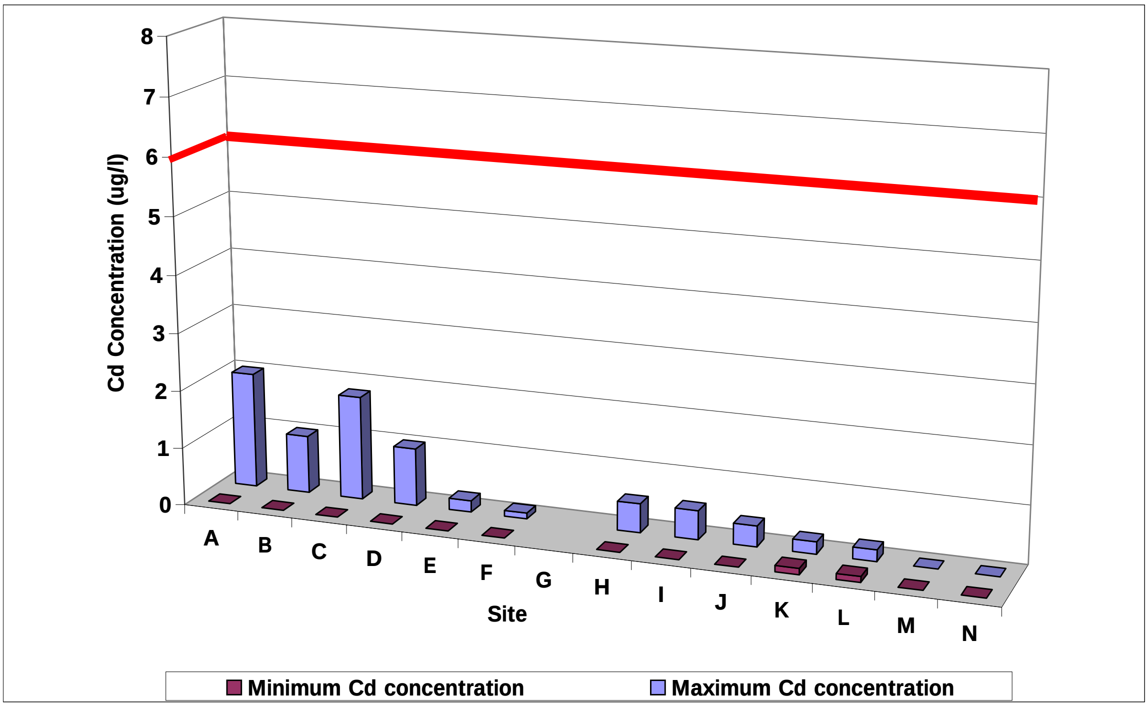

Figure 4.16a Maximum and minimum concentrations of Cd in groundwater at each of the 14 POLMIT sites

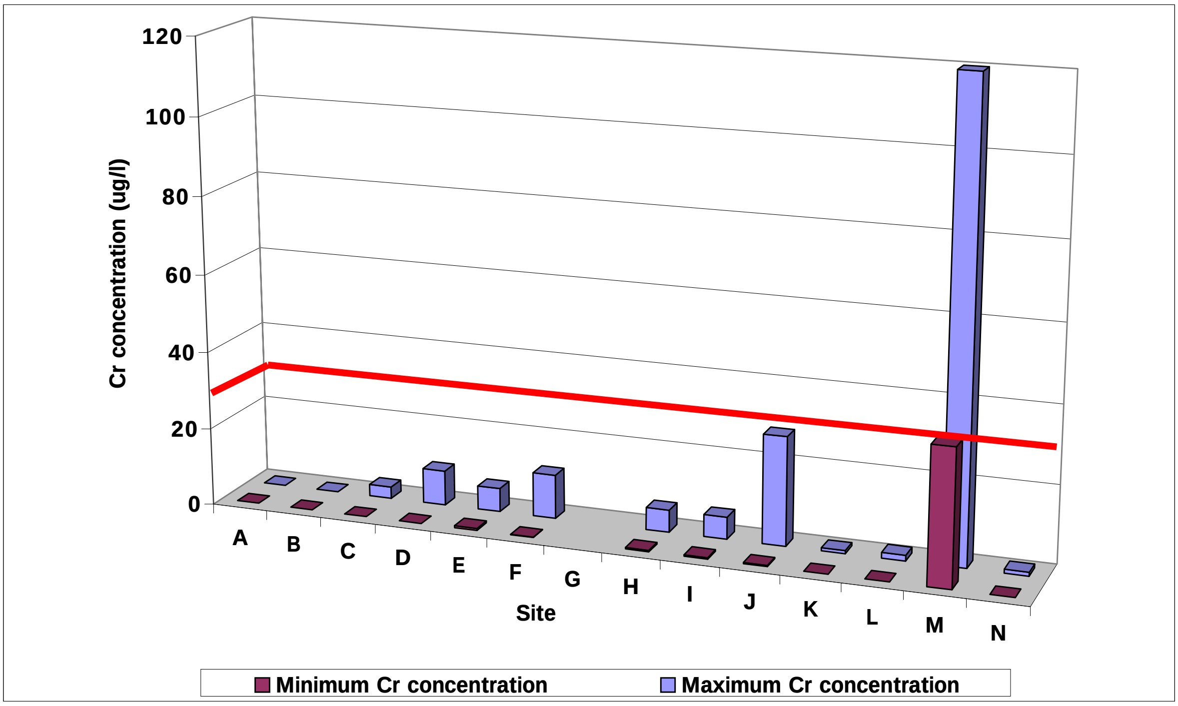

Figure 4.16b Maximum and minimum concentrations of Cr in groundwater at each of the 14 POLMIT sites

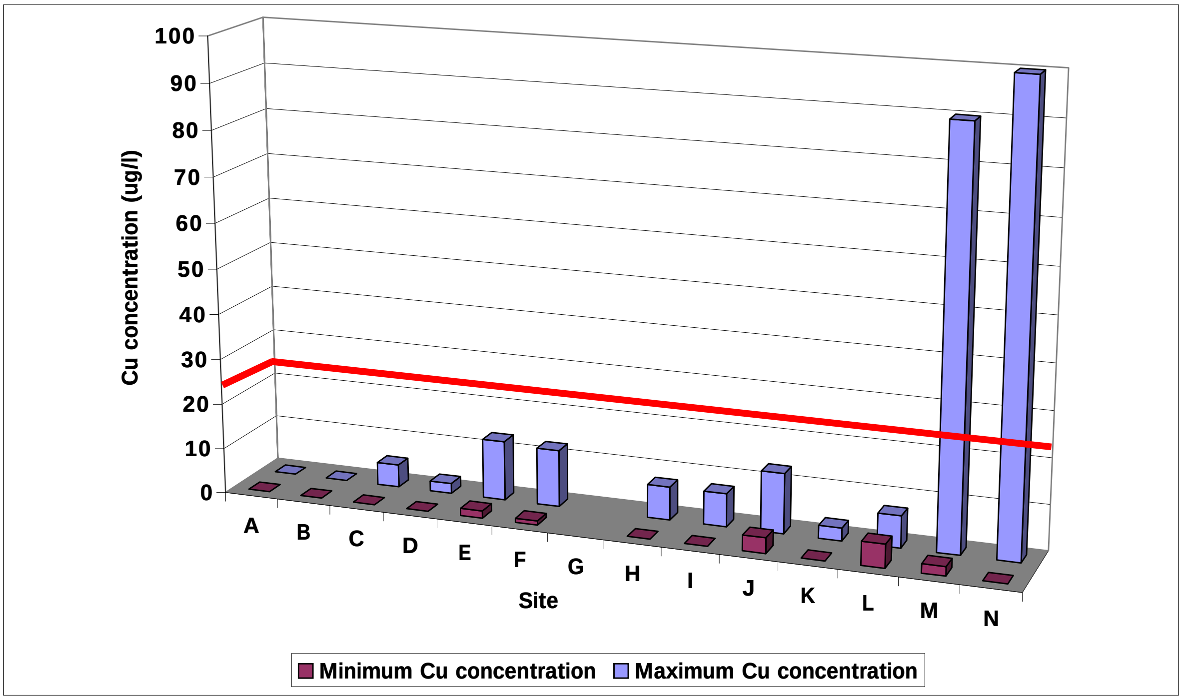

Figure 4.16c Maximum and minimum concentrations of Cu in groundwater at each of the 14 POLMIT sites

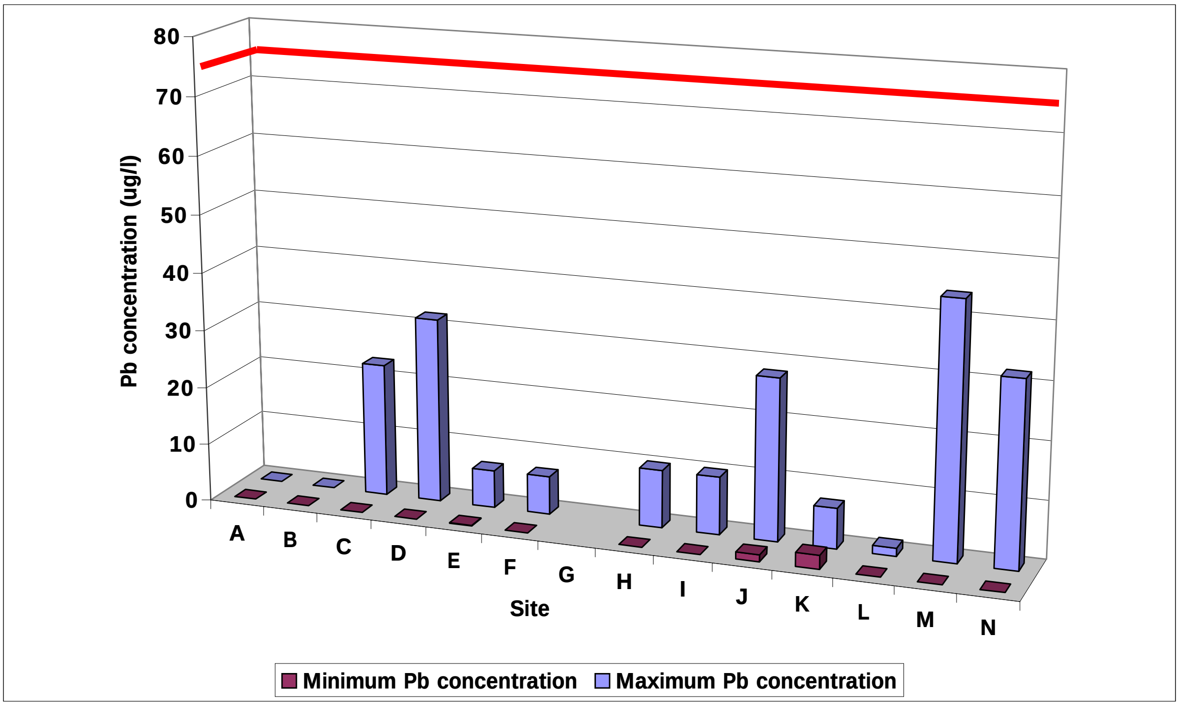

Figure 4.16d Maximum and minimum concentrations of Pb in groundwater at each of the 14 POLMIT sites

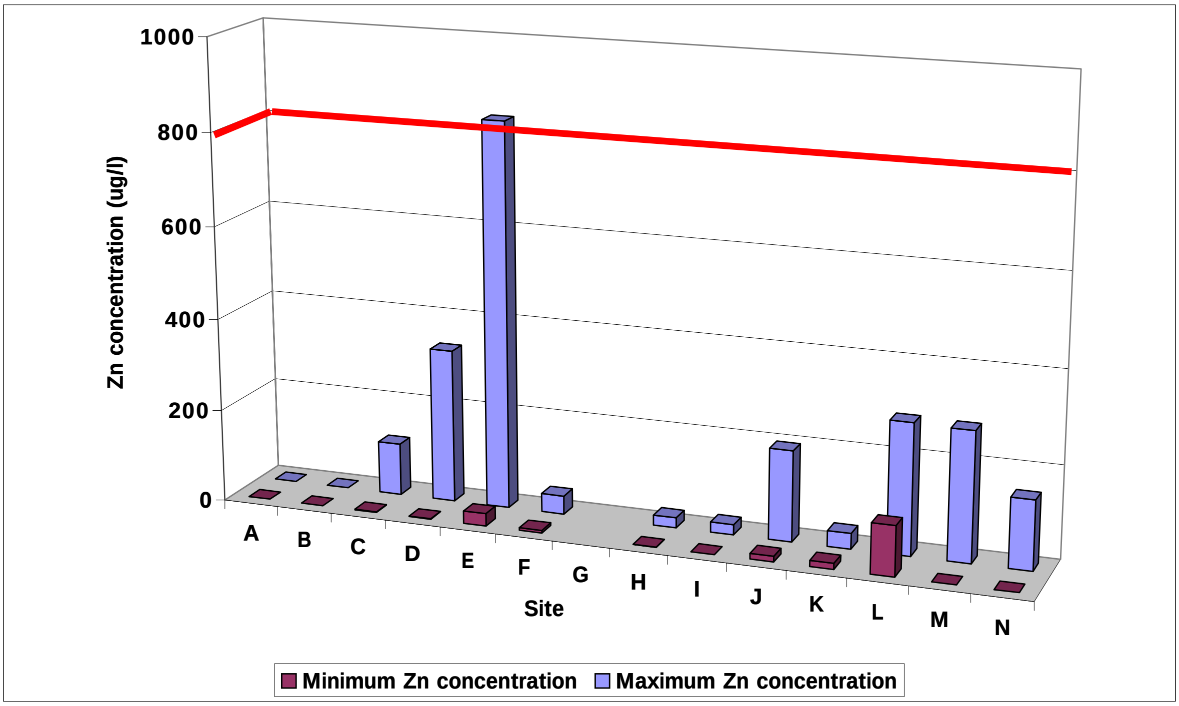

Figure 4.16e Maximum and minimum concentrations of Zn in groundwater at each of the 14 POLMIT sites

For both Cd and Pb, the Dutch intervention levels were not exceeded at any of the 14 sites throughout the sampling period. The Cr intervention level was exceeded only at Site M in Portugal. Here the minimum concentration of Cr determined was also close to the intervention level. It is unlikely that the Cr in groundwater at this site is derived from a roads/vehicle source as both the soil and soil solution concentrations were relatively low compared to the remaining POLMIT sites.

The Cu intervention level was exceeded at both the Portuguese sites (Site M and N). However, the level of detection used for the first batch of samples was high (greater than the intervention level), and for those small number of samples for which a reading was obtained, values were still very close to the detection limit. Consequently, it is not certain how significant these elevated concentrations might be. The Zn intervention level was exceeded on only one occasion at Site E in Sweden.

4.4.2 De-icing salts (denoted by sodium and chloride)

Runoff

The total annual input (mass flux) of chloride at each site is presented in Table 4.6. In many cases where salt was applied, the quantities of chloride entering the local roadside environment through highway runoff were over three orders of magnitude greater than any of the heavy metals investigated. This reflects the direct application of relatively large quantities of de-icing salts to roads in countries where winter ice and snow is encountered. The correlation between amount of salt applied and the mass flux through highway runoff was very strong (0.94).

The large mass fluxes are mirrored by the concentrations of chloride found in highway runoff. Figure 4.17 shows the maximum and minimum concentrations of chloride in highway runoff at each of the 14 POLMIT sites. The greatest concentrations were found at the site where the greatest quantities of de-icing salt were applied (Site F in Sweden). However, large concentrations were also found in Sites C and D in the Netherlands, where no salt was applied. It is possible that the relatively high concentrations could be derived from de-icing salts, applied on nearby roads, being carried on the undercarriage of vehicles and deposited within the monitoring site. The atmospheric deposition values support this theory (see below).

Table 4.6 Total annual input of chloride through road runoff at each site

Site	Quantity of de-icing salt applied to one carriageway during sampling year (kg/km/yr)	Total annual input of Cl from one carriageway of the road (kg/km)
A - Reading	2,446	1,901
B - Oxford	2,008	763
C - Nieuwegein	0	1 .4
D - Spaarnwoude	0	2 .6
E – Svaneberg	10,898	2,522
F – Norsholm	24,998	9,261
I – Vejenbrod	14,100	3,532
J – Rud	11,000	2,269
K - Erdre	7,180	810
L - Houdan	5,000	< 213
M - Recta	0	0 .06
N - Vila	0	0 .02

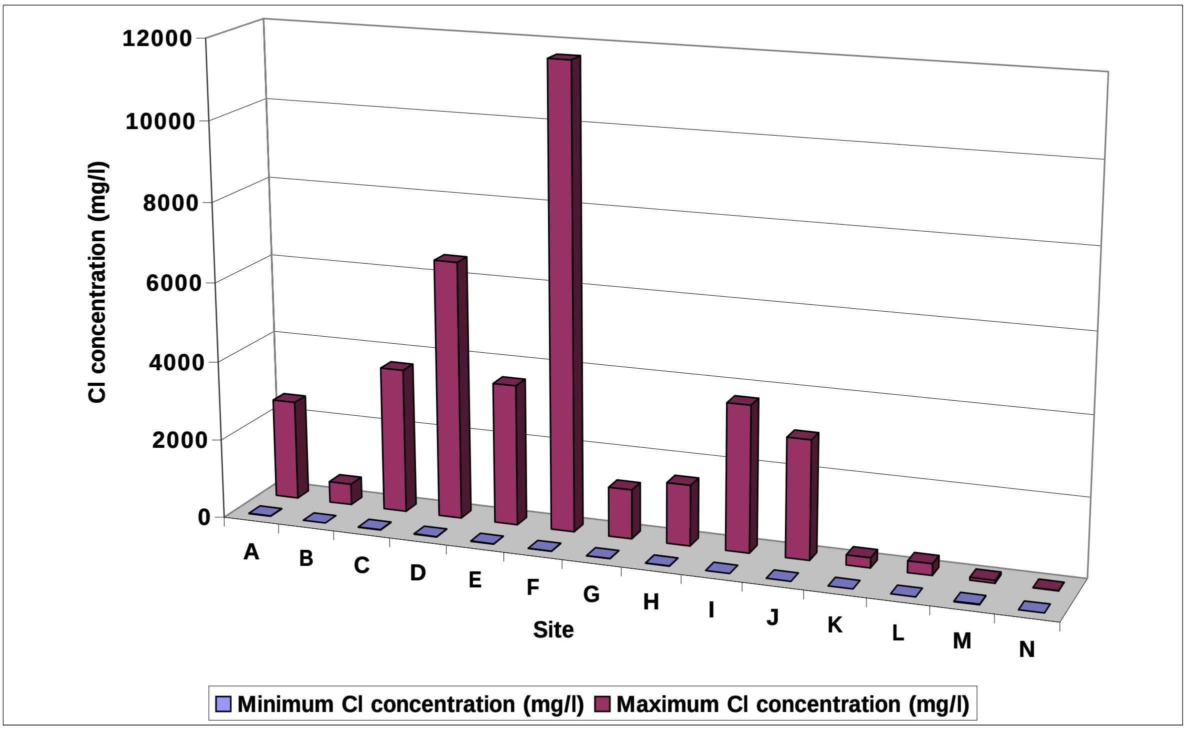

Figure 4.17 Maximum and minimum concentrations of chloride in highway runoff at each of the 14 POLMIT sites

Although climate (specifically rainfall) might result in slight variations in concentration of chloride, the overriding factor that controls the concentration of chloride in highway runoff is the amount applied to the surface of the road (or falling on to the road from the undercarriages/tyres of vehicles). This is clearly demonstrated by Figures 4.18 and 4.19 which show the seasonal variations in chloride concentration and the seasonal mass inputs of chloride at Site E in Sweden and Site J in Denmark.

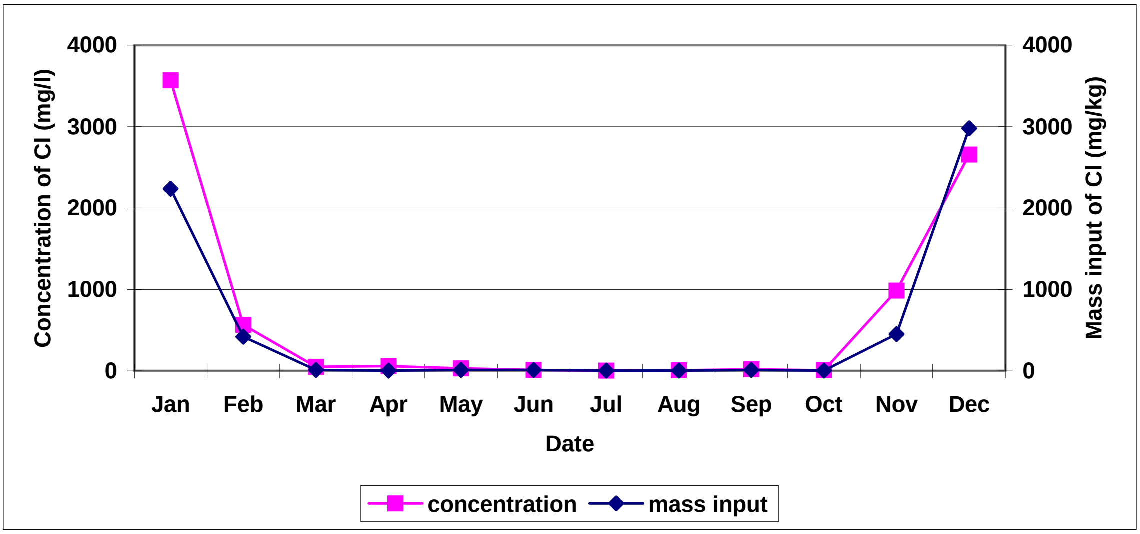

Figure 4.18 Concentration of chloride in highway runoff and mass input of chloride through highway runoff at Site E in Sweden

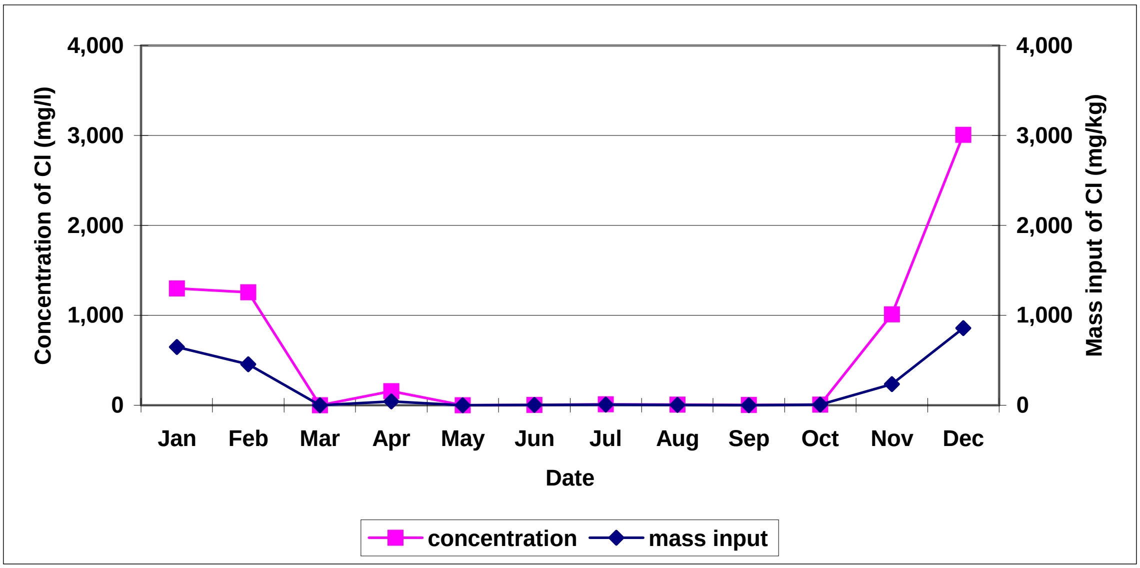

Figure 4.19 Concentration of chloride in highway runoff and mass input of chloride through highway runoff at Site J in Denmark

Table 4.7 shows the total annual input (mass flux) of chloride through atmospheric deposition at each of the 14 sites. In a similar manner to the mass input through highway runoff, the mass inputs through atmospheric deposition are correlated with the amount of salt applied, but the relationship is not as strong (0.78). Greater inputs of Cl through atmospheric deposition might have been expected at site J in Denmark, especially as large amounts of salt were applied to this site, and Cl was found in groundwater. The discrepancy is thought to be due to experimental error, possibly the result of vegetation growing around and deposition samplers, reducing the apparent deposition rates.

Table 4.7 Total annual input of chloride through atmospheric deposition at each site

Site	Quantity of de-icing salt applied to one carriageway during sampling year (kg/km/yr)	Total annual input of Cl from one carriageway of the road (kg/km)
A	2,446	340
B	2,008	229
C#	0	8.6
D#	0	0.17
E	10,898	2,523
F	24,998	2,494
I	14,100	1,583
J	11,000	3.2
K#	7,180	21
L#	5,000	<109
M	0	<0.04
N	0	<0.07

It can be seen from Figures 4.20a – 4.20c that the atmospheric deposition of chloride fell sharply with increasing distance from the road. At most sites deposition rates were close to background within 10 m of the road. It was interesting to note that despite no de-icing salts being applied to either the Dutch or French sites, an increase in chloride deposition was encountered close to the road at Site D in the Netherlands and Site L in France. The total amount deposited close to the road at these sites was small in comparison to those sites to which de-icing salts were applied. It is possible that the de-icing salts, applied to local roads, were being carried on the undercarriage and tyres of vehicles and deposited within the monitoring site. Once deposited, a proportion would be prone to atmospheric dispersal and deposition.

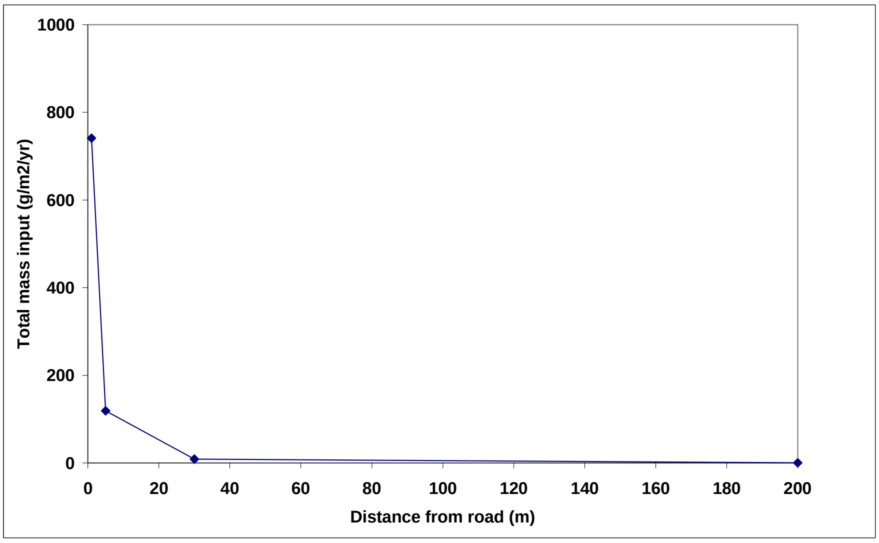

Figure 4.20a Total mass input of chloride with distance from the road at Site E in Sweden

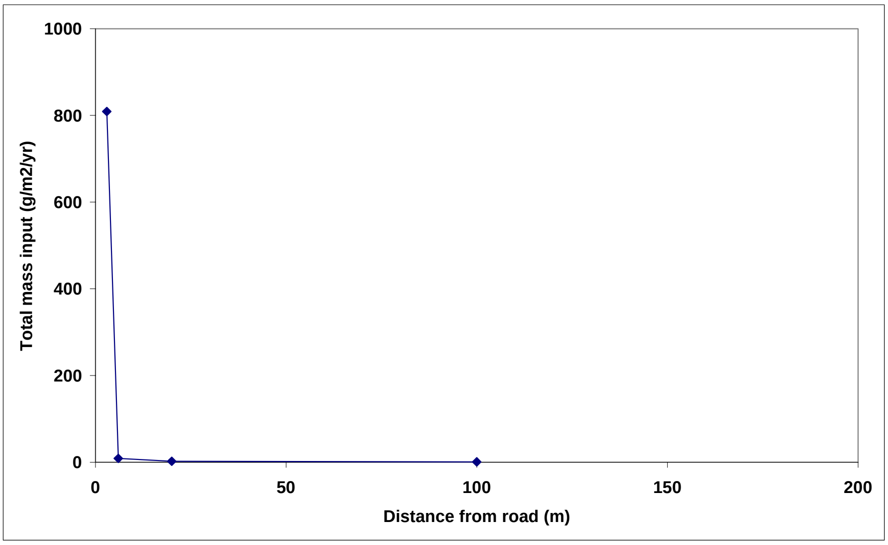

Figure 4.20b Total mass input of chloride with distance from the road at Site I in Denmark

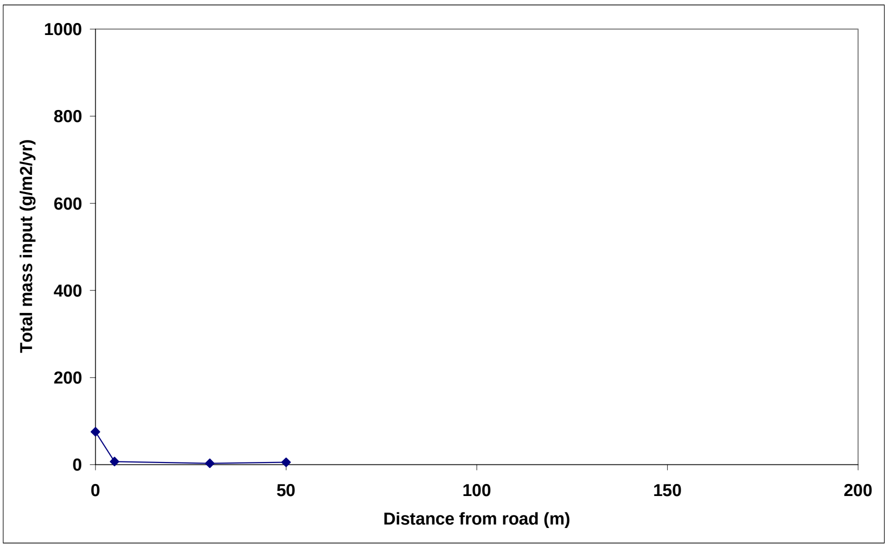

Figure 4.20c Total mass input of chloride with distance from the road at Site D in The Netherlands

Deviations from this trend were found at some sites. For example, at the second site in France (Site K), the reverse trend was found; greater quantities of chloride were deposited with distance from the road. This indicated a non-road source of chloride at this site.

A higher deposition of chloride (1131 g/m^2/yr) was determined in total deposition falling from the noise barrier located 2m from the road, compared to that deposited adjacent to the road (23 g/m^2/yr) at Site C in the Netherlands. It is not certain whether this resulted from the noise barrier preventing further movement of de-icing salts into the road verge by aerial means, or whether the noise barrier was contributing to the total loading of chloride at this distance.

Soil

Although chloride does not adsorb to soil particles, some chloride may be retained in the soil solution surrounding soil particles (see below), and consequently, concentrations of chloride can be determined in soil. Chloride concentrations in soil were analysed at 8 of the 14 sites but no distinct trends in concentration with depth or distance from the road were found, reflecting the mobility of this ion. Chloride has relatively little impact on soils and vegetation and consequently no Intervention Level has been established for chloride in soil.

Soil solution

Soil solution concentrations reflected the mobility of chloride and its inability to remain strongly adsorbed to soil particles. Although concentration measurements were sporadic, elevated concentrations were found at those sites to which de-icing salts had been applied, with concentrations decreasing with distance from the road. Elevated concentrations were also found at Sites C and D in the Netherlands. Again, this is thought to result from the transportation of salt, applied to roads elsewhere, being carried into the monitoring area and deposited onto local road side soils. The noise barrier at Site C may also have contributed to the loading of chloride.

Groundwater

Figure 4. 21 shows the maximum and minimum concentrations of chloride found in groundwater during the 12 month sampling period at each of the 14 sites. The Dutch Intervention Level for chloride in groundwater is denoted by the red line.

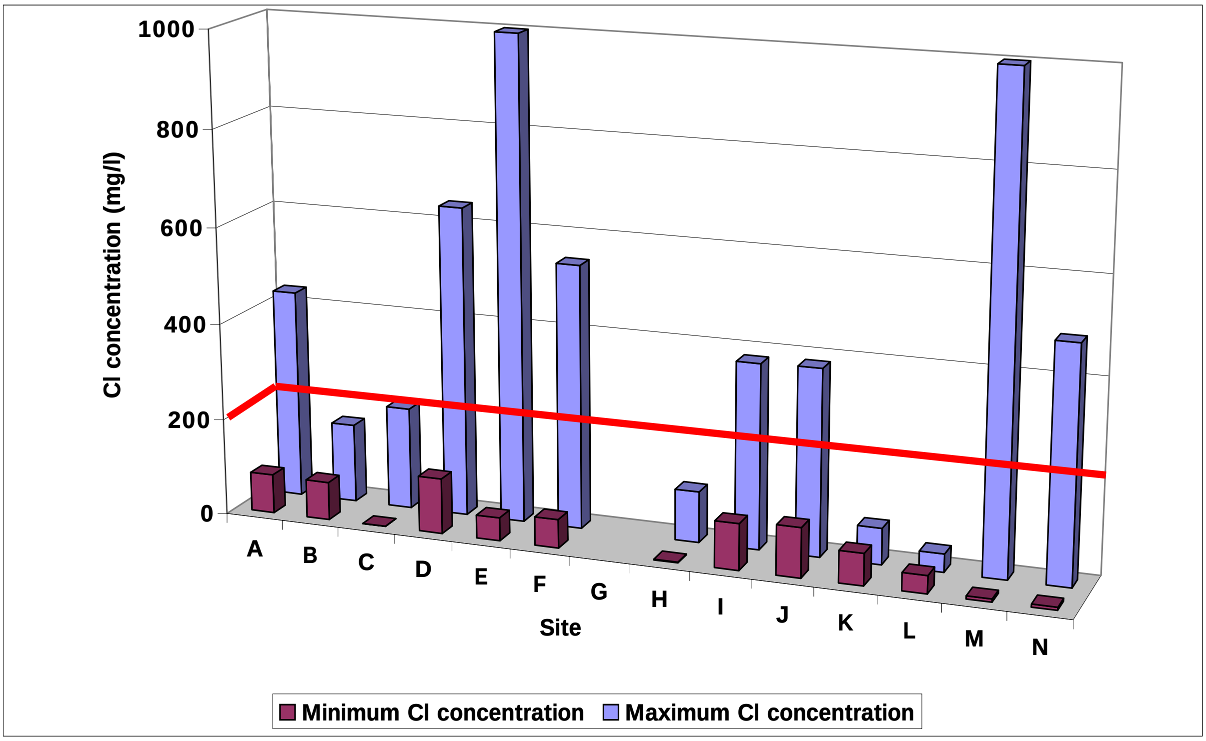

Figure 4.21 Maximum and minimum concentrations of Cl in groundwater at each of the 14 POLMIT sites

The Intervention Level for chloride was exceeded at most sites at which de-icing salts were applied. However, concentrations rapidly reduced to below the Intervention Level during the summer months when de-icing salts were no longer applied. Elevated concentrations of chloride were also found at Sites M and N where no de-icing salts were applied. Further investigation sourced the elevated chloride concentrations as being an adjacent canal.

It was also interesting to note that significant differences in chloride concentrations were found immediately upstream and downstream of the road at many sites. Figure 4.22 gives an example of this at Sites I and J in Denmark. It would appear that concentrations are rapidly diluted by less contaminated groundwater upstream of the road. This rapid dilution effect is also supported by the fact that elevated concentrations of chloride derived from de-icing salts are not found at drinking water abstraction points (Environment Agency, 1999; personal communication). Consequently, the application of de-icing salt poses no current significant risk to groundwater quality. However, some doubt remains as to whether or not groundwater aquifers will be able to continue to dilute the seasonal peak in chloride concentrations.

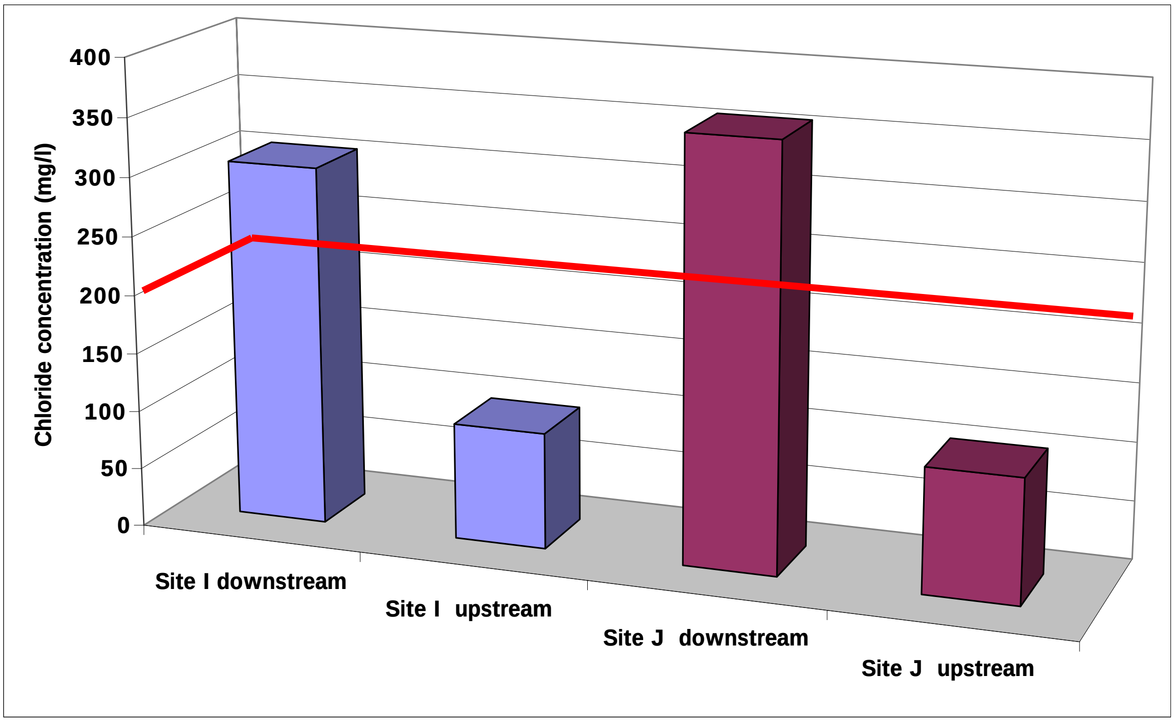

Figure 4.22 Concentrations of chloride found downstream and upstream of the road during the period Jan-Mar (Sites I and J in Denmark)

As de-icing salts are also a source of sodium, concentrations of sodium reaching groundwater were also investigated. Figure 4.23 shows that the concentration of sodium was elevated above the Intervention Level at only 3 of the 14 sites. The greatest concentration was found at Site M in Portugal, but again, the source of sodium at this site was not the application of de-icing salts. In a similar manner to that of chloride, the concentrations of sodium in groundwater at the remaining sites were closely related to the application of de-icing salts, with concentrations decreasing quickly in the summer months.

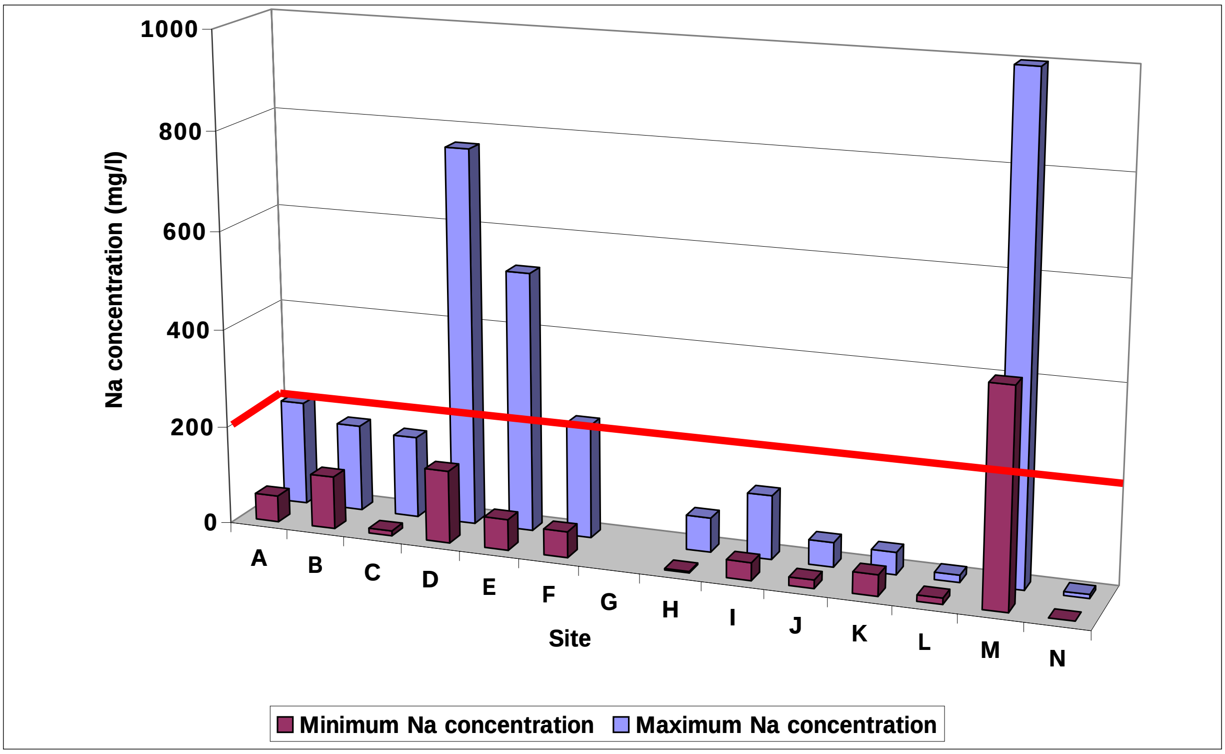

Figure 4.23 Maximum and minimum concentrations of Na in groundwater at each of the 14 POLMIT sites

4.4.3 Hydrocarbons (including PAHs)

Trends in total hydrocarbon (THC) concentrations were difficult to distinguish as different methods of analysis were used by some partners (Sites E and F in Sweden), concentrations were always below detection limit (Sites A and B in the UK) or levels of detection were sometimes greater than recognised threshold levels. Consequently, detailed results have been described only for those sites (I and J in Denmark and K and L in France) which show a consistent trend in movement through all the media (runoff, total deposition, soil and groundwaters).

Runoff

Figure 4.24 Shows the concentrations of THC in runoff throughout the 12 month monitoring period. There appears to be a winter high at all three sites, however occasional high concentrations in summer were also found (in June at Site J and in August at site K). The concentrations were much higher at Site I in Denmark indicating a large source of THC. The traffic density at this site (AADT of 29,000) is not much greater than that at Site J (22,000) and site K (25,000). It is not known whether the large concentrations of THC at Site I resulted from an accidental spillage or a non-traffic source.

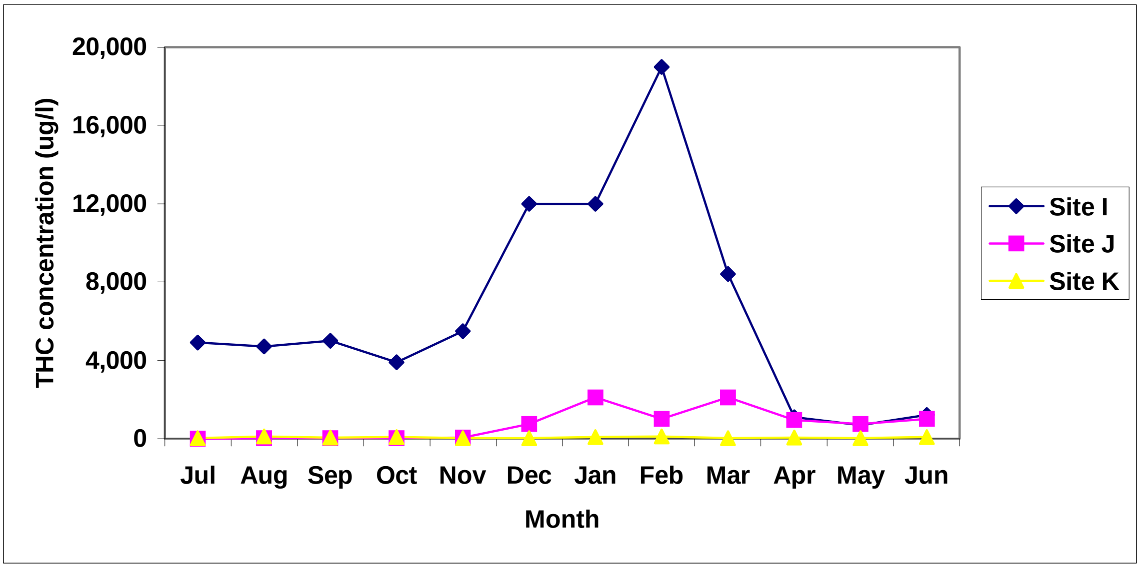

Figure 4.24 Concentrations of THC in runoff at Sites I and J in Denmark and site K in France

Total deposition

The concentrations of THC found in total deposition showed no trends with distance from the road or time. However in the case of Site I in Denmark, the total amounts deposited showed a marked decrease with distance from the road, as shown in Figure 4.25. It clearly demonstrates a large influx of THC in January – March at 3 m from the road, but increased deposition was not found further away from the road during this time period. Much lower and more sporadic deposition rates were found in Sites J and K.

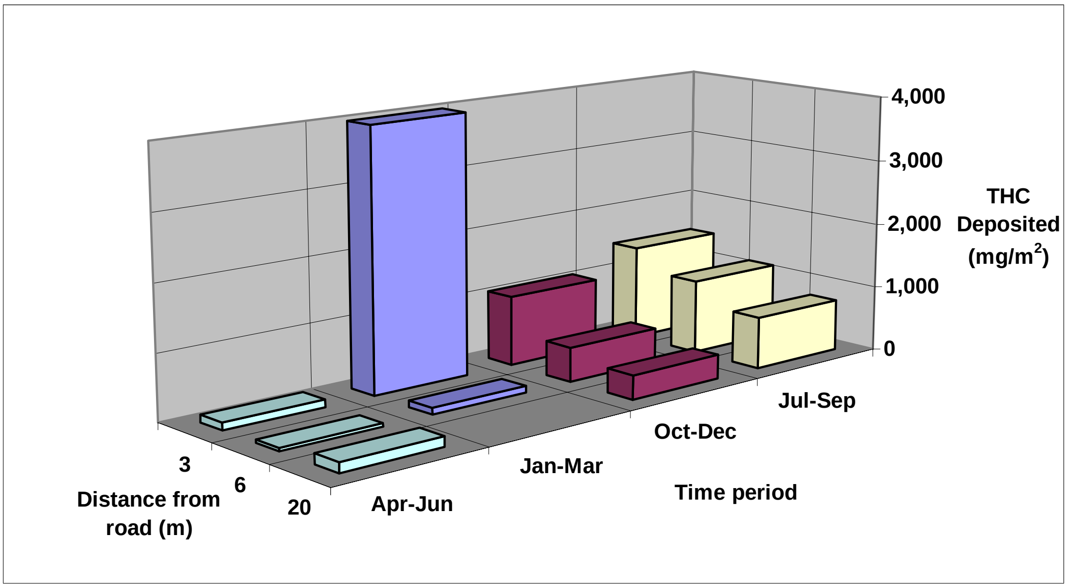

Figure 4.25 Total mass of THC deposited with time and distance from the road at Site I in Denmark

Soil

Figure 4.26 shows the maximum and minimum concentrations of THC found at all 14 sites, with the EU threshold level for THC indicated by a red line. It clearly demonstrates the large differences in concentration found between sites. At the Danish Sites (I and J), the greater concentrations of THC found in runoff and total deposition are reflected in the high soil concentration. Figure 4.27 shows the location of the greatest concentration of THC at this site (3 m from the road and in the top 10 cm). The same trends were also found for Site L in France.

Despite the very low concentrations of THC found in runoff and total deposition at the Finnish sites (Sites G and H), these sites had the highest THC concentrations in soil. The concentrations of THC did not decrease with distance from the road, with significant concentrations still being found 20-30 m from the road, indicating a non-road source for this contaminant.

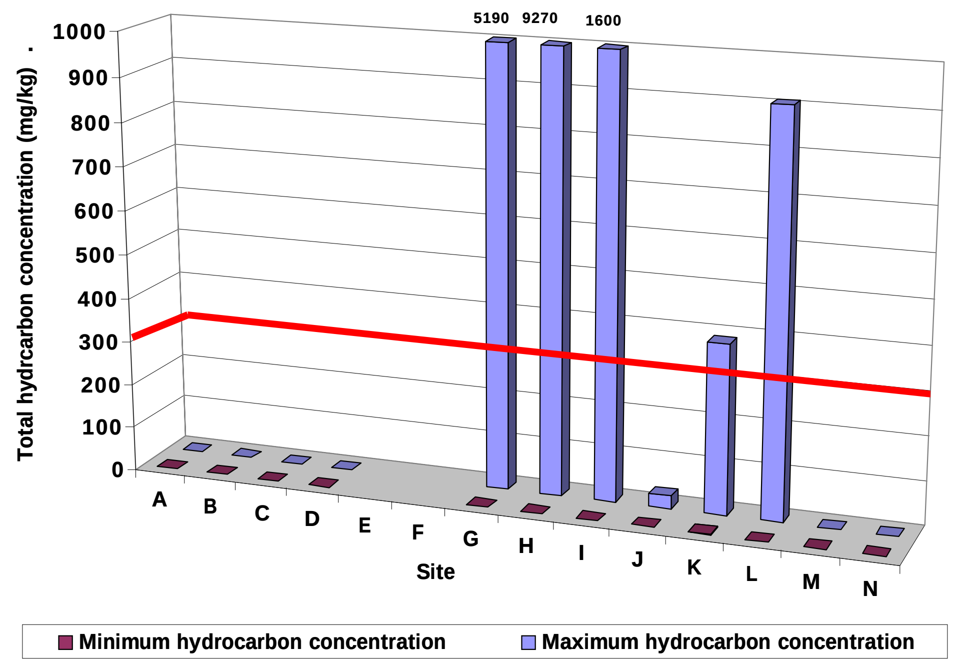

Figure 4.26 Maximum and minimum concentrations of total hydrocarbons in soil at each of the 14 POLMIT sites

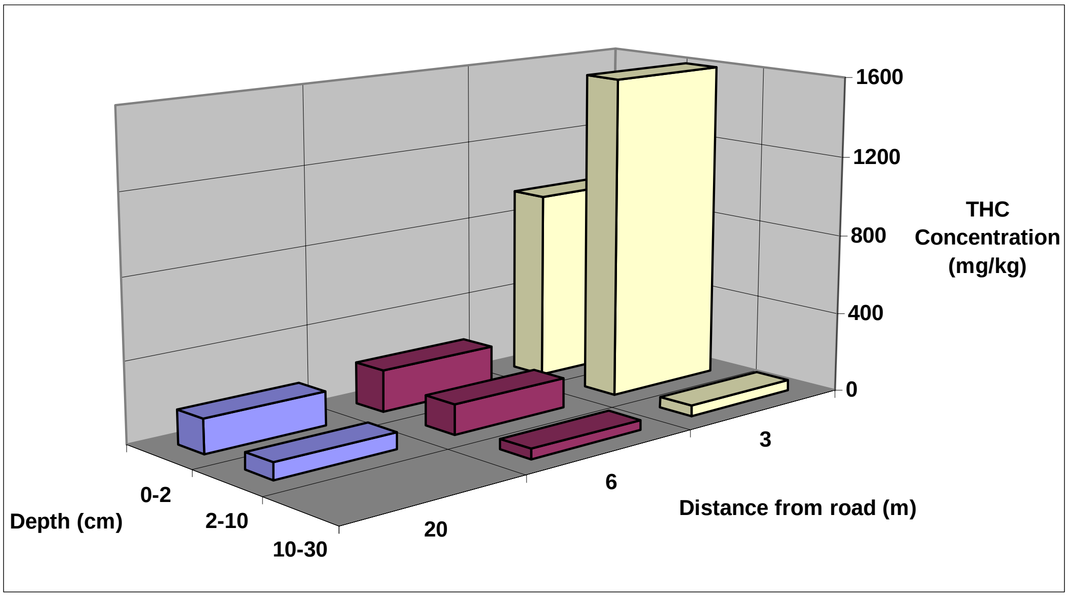

Figure 4.27 Concentration of THC in soil, at varying distance and depths form the road, at site I in Denmark

Soil solution and groundwater

As only sporadic samples of soil solution were obtained, no trends could be identified. However, Figure 4.28 Shows the minimum and maximum concentrations of THC in groundwater at each of the 14 sites. Most were below detection limits, but where concentrations were detected, they were far in excess of the threshold level. The elevated concentrations found in Site I in Denmark and Site L in France probably result from a road/vehicle source, as indicated by the elevated concentrations found in runoff, total deposition and soil. However, the elevated concentrations at Site H in Finland and sites M and N in Portugal are thought to result from non-road sources.

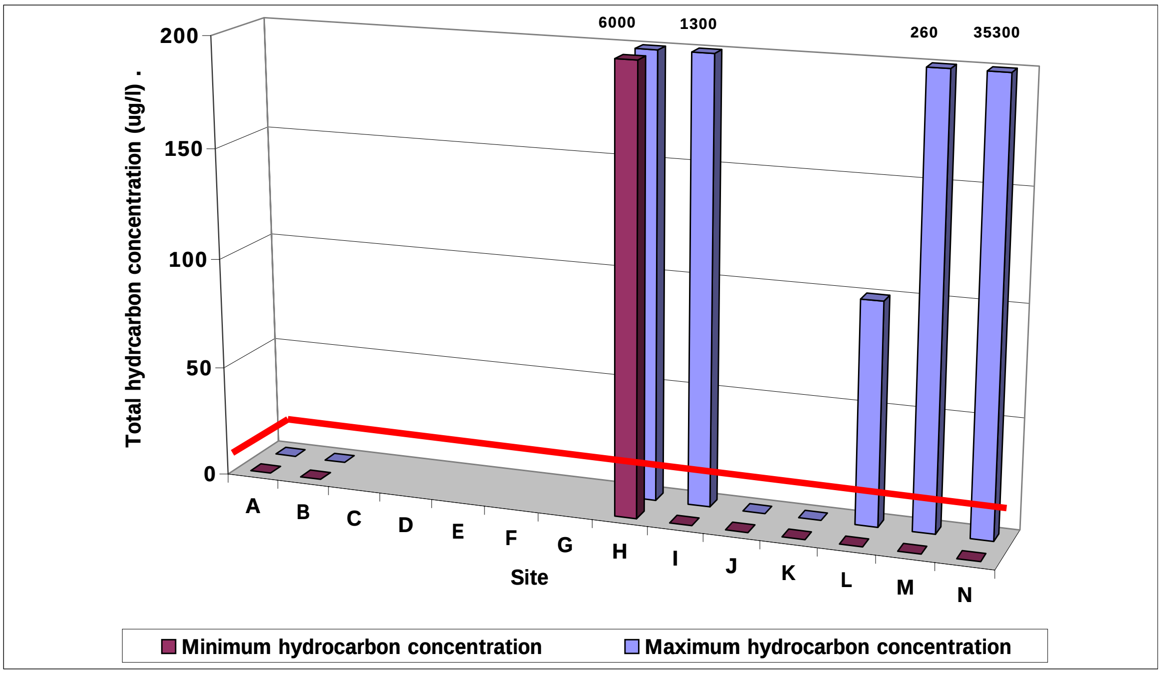

Figure 4.28 Maximum and minimum concentrations of total hydrocarbons in groundwater at each of the 14 POLMIT sites

Problems were encountered with the determination of both total hydrocarbons (THC) and PAHs. The detection limit of THC used was, in some cases, higher than the threshold level for groundwater. Consequently, although many water samples had concentrations of THC below the detection limit, it was not certain whether THC was present in concentrations regarded as being polluting.

PAH determinations were also often below detection limits. However, it was not certain whether PAHs were degrading naturally in the roadside environment prior to sample collection, whether PAHs were degrading during sample storage, or whether they were simply not present in the samples. Consequently, no general assumptions could be made about their movement into or within the local roadside environment. The degradation of PAHs was investigated further as part of the Special Studies, and sites where PAHs were determined are reported in the POLMIT report "Pollution from Roads and Vehicles and Dispersal into the Local Roadside Environment: Monitoring of 14 case study sites".

CHAPTER 5:

POTENTIAL POLLUTANTS AND POLLUTION CONTROL

Potential Pollutants in soils and groundwaters

Pollutant mass balances

Pollution control

5.1 IDENTIFICATION OF POTENTIAL POLLUTANTS IN SOILS AND GROUNDWATERS

Dutch intervention levels and target levels for soils and groundwaters were used to determine the potential for each of the elements/compounds investigated to cause pollution. No attempt was made to determine actual impacts on terrestrial or aquatic fauna and flora. A copy of the Intervention and target values can be found in Annex A.

The results of the field monitoring (See Chapter 4) clearly showed that some of the elements/compounds determined exceeded the recognised threshold concentrations in soil and/or groundwater on one or more sampling occasions. Those compounds exceeding intervention and target concentrations are summarised in Table 5.1 below. Depending on the frequency with which the intervention concentrations were exceeded, these compounds could be considered as pollutants. A summary of the frequency with which threshold levels were exceeded is given below. More detailed information is given in the POLMIT report ‘Pollution from Roads and Vehicles and Dispersal into the Local Environment: Mass Flux and Mass Balance Calculations; Assessment of Pollution of Groundwater and Soils by Road and Traffic Sources’.

5.3.1 Soil pollutants

Heavy metals

Lead was found to exceed the soil intervention level of 530 mg/kg at two sites (see table 5.1). The target level of 85 mg/kg was exceeded in most of the remaining sites. However, the area of soil polluted by lead lay directly adjacent to the road, and in the surface 10 cm of soil. Concentrations rapidly decreased with increasing distance from the road and depth from the surface, reflecting the strong adsorption capacity of this element. Soils with high pH encouraged this adsorption process.

Although soil intervention levels for cadmium, copper and zinc were not exceeded, many of the sites had concentrations of these metals above the target levels (0.8 mg/kg, 36 mg/kg and 140 mg/kg respectively). In a similar manner to lead, however, these elevated concentrations were only found in surface soils adjacent to the road.

Total hydrocarbons

Inconsistencies in total hydrocarbon analyses made assessment of this group of compounds difficult. At the majority of sites where hydrocarbons were detected, a clear pathway of movement, through highway runoff, aerial deposition, soil and eventually into groundwater, could be identified. Detection of total hydrocarbons in any medium was not, however, related to traffic density. It is possible that hydrocarbons are only detectable and therefore a potential problem where oil/fuel has been deposited or spilt as a result of e.g. an accident. Where detected, concentrations in soil often greatly exceeded the intervention level of 300 mg/kg. At two sites, the concentrations in soil were up to 30 times the intervention level. However, as no elevated concentrations were found in highway runoff or atmospheric deposition at these sites, it is not certain whether the elevated soil concentrations were derived from a past vehicle spillage or another non-road/vehicle source.

5.3.2 Groundwater pollutants

Chloride

Concentrations of chloride above the groundwater intervention level (200 mg/l) were found at just over half of the POLMIT sites. At some sites the maximum recorded concentration was almost 5 times the intervention level (see Chapter 4). Elevated concentrations were directly related to the application of de-icing salts during winter months. In a similar manner to metals in soils, however, chloride concentrations in groundwater rapidly decreased with distance away from the road. Concentrations also decreased rapidly when the application of de-icing salts was suspended. This demonstrates the ability of groundwaters to rapidly dilute the seasonal load of chloride. Drinking water abstraction points located away from roads do not currently appear to be polluted by chloride derived from de-icing salts. It is not known, however, how long de-icing salts can continue to be applied before more prolonged elevated concentrations of chloride are detected in groundwaters.

Total hydrocarbons

In a similar manner to soils, concentrations of total hydrocarbons in groundwater varied greatly from site to site, with the intervention level of 10 μg/l being exceeded at five sites. Three of these sites also had elevated concentrations in soil. However, two sites had excessively high concentrations (over 30,000 μg/l) in groundwater alone, possibly indicating a non-road source. The large variation in concentrations reflects the probable accidental nature of the source of these pollutants.

Heavy metals

Concentrations of cadmium, chromium, zinc and, to a lesser extent, lead were found to exceed target levels at many sites. This indicates that a proportion of the heavy metals do migrate down through the soil profile. Migration into groundwaters was found to be facilitated in sites to which large amounts of de-icing salts were applied. Soil texture and structure was also found to influence the downward movement of heavy metals, with porous soils facilitating greater movement into groundwaters. N.B. polluting concentrations of chromium and copper found in groundwaters at sites M and N in Portugal are thought to be derived from a non-road/vehicle source (see Chapter 4).

Table 5.1: Elements/compounds exceeding the Dutch Intervention Level (✓) or Target Level (#)

Site		Pollutants in soil							Pollutants in Groundwater						
		Cd	Cr	Cu	Pb	Zn	Cl	THC	Cd	Cr	Cu	Pb	Zn	Cl	THC
A	Reading (UK)			#	#	#			#					✓	
B	Oxford (UK)			#					#					#	
C	Nieuwegein (NL)	#		#	#	#			#	#		#	#	✓	
D	Spaarnwoude (NL)	#		#	✓	#			#	#		#	#	✓	
E	Svaneberg (SE)			#	#	#				#	#		#	✓	
F	Norsholm (SE)			#		#				#				✓	
G	Lohja (FI)				#			✓	-	-	-	-	-	-	-
H	Utti (FI)				#			✓	#	#				#	✓
I	Vejenbrød (DK)	#		#	#	#		✓	#	#				✓	✓
J	Rud Kirke (DK)								#	#	#	#	#	✓	#
K	Erdre (FR)			#	#	#		#						#	
L	Houdan (FR)	#		#	✓	#		✓					#		✓
M	Recta do Cabo (PT)		#	#	#	#				✓	✓	#	#	✓	✓
N	Vila Real (PT)										✓	#	#	✓	#

5.2 POLLUTANT MASS BALANCES

Once emitted, pollutants can be transported by a number of different pathways into various parts of the environment, including the atmosphere where pollutants are subject to long-distance transport processes. Consequently, the emission rate for various pollutants is no sure guide to the actual impact these pollutants may have on the terrestrial environment. It is also not possible to undertake expensive field monitoring on a frequent basis and/or at a large number of locations to determine impacts on the environment. To address this, a mass balance approach was used to analyse the POLMIT data to determine whether the proportion of the calculated pollutant emissions entering the local terrestrial roadside environment was consistent. If so, this knowledge could be used to develop a decision-making tool, in which emission rates could be calculated and transfer factors (to separate parts of the environment) could be utilised to assess potential environmental impacts. This could then be used to determine the most appropriate mitigation measures to be incorporated.

Table 5.2 shows the combined mass flux (runoff and total deposition) for each species investigated, and Table 5.3 shows the mass fluxes expressed as a percentage of the calculated emissions (given in Chapter 3). The values used apply to quantities emitted from, and transported into, one carriageway only.

5.3.1 PAHs

For PAHs many of the calculated percentages are expressed as 'less than', which makes any interpretation more difficult. Except for a few individual PAHs (indeno-1,2,3-pyrene and benzo-k-fluoranthene) the mass fluxes were generally below 10% of the emissions, showing a low recovery of the components in the vicinity of the road. PAHs are released through exhaust gas and are probably dispersed into the atmosphere, which could account for the low recovery in run-off and total deposition. As indicated in Chapter 4, natural degradation or degradation during sample processing could also explain the low values of the calculated mass fluxes, and the recovery rates should be viewed with caution.

5.3.2 Heavy metals

With respect to heavy metals, large variations in the calculated percentages were observed. The magnitude of the recoveries for the different heavy metals have been classified for each site in decreasing order of recovery (Table 5.4).

Table 5.2 Total mass fluxes (runoff + total deposition) at all 14 POLMIT sites

Parameter	**Unit**	**Great Britain**		**The Netherlands**		**Sweden**		**Finland**		**Denmark**		**France**		**Portugal**	
		Site A Reading	Site B Oxford	Site C Nieuwegein	Site D Spaarnwoude	Site E Svaneberg	Site F Norsholm	Site G Lohja	Site H Utti	Site I Vejenbrød	Site J Rud	Site K Erdre	Site L Houdan	Site M Recta	Site N Vila
Total PAH	g/km.yr	< 9	< 10	27	1.3	0.49	0.50			6.9	3.4	< 0.28	< 2.6	0.015	< 0.14
Fluoranthene	g/km.yr	< 9	< 10	1.5	0.12	0.08	0.06			1.3	1.2	< 0.09	< 0.36	0.004	< 0.028
benz-a-pyrene	g/km.yr	< 9	< 10	1.5	0.0	0.01	0.01			0.41	0.34	< 0.02	< 0.07	0.001	< 0.02
indeno-1,2,3-pyrene	g/km.yr	< 9	< 10	1.5	0.0	0.02	0.01			1.5	0.51	< 0.03	< 0.22	0.003	< 0.035
benzo-g,h,I-perylene	g/km.yr	< 9	< 10	1.5	0.0	0.07	0.04			3.0	0.44	< 0.09	< 0.36	0.003	< 0.026
Benzo-k-fluoran-thene	g/km.yr	< 9	< 10	1.5	0.0	-	-			0.73	0.86	< 0.05	< 0.15	0.001	< 0.034
Naphthalene	g/km.yr	< 9	< 10	5.3	0.49	n.a.	n.a.			0.07	0.06	n.a.	< 1.5	n.a.	n.a.
Cd	g/km.yr	6	< 12	37	2.9	4.0	4.5			2.6	2.4	< 4.3	< 1.9	0.3	< 72
Cr	g/km.yr	1	< 234	161	7.8	12	45			35	23	< 6.6	< 10	0.8	23
Cu	g/km.yr	1,201	363	653	82	274	852			595	320	< 224	174	12	1.2
Pb	g/km.yr	1,115	258	604	184	72	208			164	118	188	< 154	14	40
Zn	g/km.yr	4,022	1,471	3,505	297	1,275	2,501			1,074	1,272	2208	720	111	8
Cl	kg/km.yr	2,241	992	10	2,8	5,045	11,755			5,115	2,269	830	< 321	0.055	0.018
Traffic density	10^3 veh./yr	17,922	14,180	27,375	16,425	1,341	3,292			4,471	3,212	4,380	3,833	3,887	1,540

Note: n.a.: not analysed

Table 5.3 Mass balance calculations: Total mass fluxes expressed as a percentage of calculated emissions

Parameter	Unit	**Great Britain**		**The Netherlands**		**Sweden**		**Finland**		**Denmark**		**France**		**Portugal**	
	%	Site A Reading	Site B Oxford	Site C Nieuwegein	Site D Spaarnwoude	Site E Svaneberg	Site F Norsholm	Site GLohja	Site H Utti	Site I Vejenbrød	Site J Rud	Site K Erdre	Site L Houdan	Site M Recta	Site N Vila
Total PAH		< 1.2	< 1.8	0.76	0.04	0.16	0.07			7.3	5.2	< 0.17	< 1.7	0.003	< 0.09
Fluoran-thene		< 2.7	< 4.0	0.23	0.02	0.16	0.05			2.8	3.8	< 0.10	< 0.45	0.01	< 0.11
benz-a-pyrene		< 26	< 37	2.4		0.20	0.09			7.9	9.2	< 0.25	< 0.88	0.01	< 0.83
indeno-1,2,3-pyrene		< 43	< 63	3.9		0.67	0.14			48	26	< 0.50	< 4.4	0.07	< 2.2
benzo-g,h,I-perylene		< 7.5	< 10	0.68		0.35	0.10			16	3.1	< 0.36	< 1.6	0.01	< 0.31
Benzo-k-fluoranthene		< 27	< 39	2.6						24	41	< 0.63	< 2.1	0.01	< 1.5
Naphthalene		< 4.7	< 6.9	1.5	0.16					0.39	0.5		< 4.4		
Cd		99	< 243	370	32	400	150			163	126	< 215	< 95	20	
Cr		1.1	< 323	99	5.5	86	132			152	96	< 24	< 40	4.0	319
Cu		2.0	0.8	0.60	0.09	2.8	3.7			6.4	5.3	< 1.5	1.3	0.09	0.02
Pb		2.3	0.6	0.55	0.17	0.72	0.74			0.79	0.89	2.5	< 2.4	0.09	0.66
Zn		14	6.6	6.8	0.67	24	21			28	51	29	9.8	1.6	282
Cl		150	81			76	77			59	34	27	< 11		
Traffic density	10^3 veh./yr	17,922	14,180	27,375	16,425	1,341	3,292			4,471	3,212	4,380	3,833	3,979	1,551

Table 5.4 Classification of the heavy metal recovery at each site

% recovery	Site													
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
High	Cd	Cr	Cd	Cd	Cd	Cd			Cd	Cd	Cd	Cd	Cd	Cd
↓	Zn	Cd	Cr	Cr	Cr	Cr			Cr	Cr	Zn	Cr	Cr	Cr
	Pb	Zn	Zn	Zn	Zn	Zn			Zn	Zn	Cr	Zn	Zn	Zn
	Cu	Cu	Cu	Pb	Cu	Cu			Cu	Cu	Pb	Pb	Pb	Pb
Low	Cr	Pb	Pb	Cu	Pb	Pb			Pb	Pb	Cu	Cu	Cu	Cu

The classification of heavy metal recovery shows great similarities between the sites, despite differences in traffic density, traffic distribution, climate and topography. This indicates similarities in the dispersal mechanism and environmental behaviour of heavy metals near roads.

In most cases the recoveries of Cd were higher than 100%, which would suggest that the emissions were underestimated (e.g. a source was lacking in the calculation), or that sources of Cd other than roads and vehicles (e.g. atmospheric deposition) contributed to the measured fluxes. The metal content of ‘background’ atmospheric deposition (determined in a study carried out by Alloway *et al.,* 1997), in the vicinity of Sites A and B in the UK, showed that significant inputs of both Cd and Cr were derived from the atmosphere rather than directly from the road.

Approximately twice as much Cd was deposited from the atmosphere as was emitted by roads and vehicles. (Other metals investigated were deposited from the atmosphere in amounts which were much smaller than the quantities emitted by roads and vehicles). Based on the detected recoveries, it seems that the majority of the emissions of Cd from roads and vehicles end up in the verge of the road.

The variation in Cr percentage recovery between the sites was great, but again they were generally high. The same explanation proposed for Cd could, therefore, be responsible for the observed Cr recovery rates. Dispersion to the verge of the road also appears to be the main transport route for Cr. The total annual loading of both Cd and Cr were low in comparison with the other metals.

Much larger quantities of Zn, Cu and Pb were transported though run-off and deposition, but with much smaller recovery rates for Cu and Pb (less than 10% and 5% respectively) compared to the calculated emissions. The recovery of Zn was greater, though still below 50% in most cases. Zn is derived primarily from tyre wear, and the particles of Zn released from tyres might be sufficiently large to result in a significant proportion settling onto the road surface and being transported into the terrestrial environment without being dispersed into the atmosphere.

The low recovery rates for Pb may have be due to the fact that Pb is primarily emitted from vehicle exhaust in form of fine particulate matter. The particulate matter would easily be dispersed into the atmosphere, and would not end up in run-off or be deposited locally. Cu, derived primarily from the wear and tear of brakes, was expected to be deposited locally and on the road, and then become incorporated in run-off. However, since brakes are seldom used on motorways, overestimation of the Cu-emission could be a sound explanation for the low recovery rates.

Mass balance considerations for chloride are of interest in the countries in which de-icing procedures were applied during the sampling period. Chloride is normally a good tracer as it is not subjected to sorption or degradation processes and is easy to determine in samples. Furthermore, actual de-icing application rates and times are usually known, and the chloride emission should consequently be relatively accurate. In addition, the quantities applied are relatively large, enabling more accurate flux calculations. It can be seen from Table 2.5 that, apart from in France, the recoveries were high. This indicates that chloride was mainly transported into the terrestrial environment through run-off and total deposition.

Explanations for the low recovery rates at the other sites could be that chloride (and other dissolved pollutants) is transported as aerosols over quite long distances. Most sites had problems with overflow in run-off sampling which, even after correction, can lead to an underestimation of the immissions, especially if the overflow occurred during the winter period. Finally, as a result of poor application methods, salt could be thrown into the local roadside and not be incorporated in run-off or collected in the total deposition samplers.

There are several other explanations for the discrepancies in the recovery rates of all the pollutants investigated One such explanation could be related to the problems with sampling, such as overflow, lack of data, or high detection limits due to insufficient amounts of water and so on (see chapter 2.2.2 Detection of problems). Another could be the uncertainties relating to the methodology applied to the mass flux calculations. A particular problem was the calculation of mass fluxes through total deposition, which was based on integration of 3 values over their respective distances from the road without any accurate knowledge on the spatial or temporal variation of the current parameter in that particular medium (see POLMIT report ‘Pollution from Roads and Vehicles and Dispersal into the Local Environment: Mass Flux and Mass Balance Calculations; Assessment of Pollution of Groundwater and Soils by Road and Traffic Sources’ for more details).

In the emission calculations it has been assumed that 100% of the metals contained in fuel are emitted in exhaust gas. Generally, according to the literature, only 75% of lead is emitted in vehicle exhaust gas. However, in addition to the metal content of fuel itself, metals are released as a result of the wear of engine components. Ntziachristos (personal communication, 2000) suggests that emission of metals from this source are greater than those derived from fuel alone.

Despite the range of uncertainties included in the mass balance calculations, it has been possible to demonstrate and extract some general trends about the magnitude of the fluxes and the transport routes of the investigated pollutants. It is clear that aerial dispersal can be a significant mechanism by which some pollutants (especially Zn and Cl) are transferred into the local roadside environment. The mechanism of transfer has implications for the type and effectiveness of pollution control strategies currently employed. This is addressed in more detail in the following section.

5.3 POLLUTION CONTROL

Where an assessment has indicated the need for treatment of road and vehicle pollution, selection of the most appropriate type of treatment will have to take account of the type of pollutant, the transport mechanism by which this pollutant enters the roadside environment, availability of land, and physical characteristics of the site, such as topography and the nature and type of receiving environment (surface water, soil etc). The majority of treatment systems are designed for the treatment of highway runoff, and are often developed as part of a standard road drainage system.

Best Management Practice (BMP) guidelines to control pollution runoff can be either structural or non-structural. Structural BMPs operate by physically trapping runoff until pollutants settle out or are filtered through the underlying soils. The basic mechanisms for pollutant removal are gravity settling, infiltration of soluble nutrients through soil or filters, or biological and chemical processes. Non-structural BMPs, are source control practices such as street sweeping, land use planning, vegetated buffer areas, and fertiliser application controls. They are used to reduce the initial concentration and accumulation of contaminants in runoff. (Non-structural BMPs may reduce the need for costly structural controls).

Some BMPs can operate effectively regardless of weather condition while others can not. Structural BMPs are not always suitable for areas where land space is limited, as in urban settings, while non-structural BMPs can be implemented just about anywhere, even where space is a constraint. Table 5.5 summarises the major functions and water quality attributes (i.e. contribution to improvement of water quality) of drainage system components currently in use.

Table 5.5 Functions and water quality attributes of road drainage methods (Luker & Montague, 1994).

Method	Primary function	Secondary function	Water quality attributes
Kerbs & Gully pots	Collection of surface water	Sediment removal (gullies)	Can remove pollutants associated with sediment but can also generate polluted liquor
Filter drains	Collection and conveyance of surface water	Collection of sub-surface water	Can remove pollutants associated with sediment but may be a risk to groundwater quality
Surface water channels	Collection of surface water	Conveyance of surface water	None
Porous surfacing	Collection of surface water		Unknown
Informal verge systems	Collection of surface water	none	Can remove pollutants associated with sediment
Fin drains	Collection of sub-surface water	none	Associated geotextiles may remove pollutants associated with sediment
Infiltration pavements	Collection and disposal of surface water	Sediment and pollutant removal	Can remove pollutants associated with sediment and dissolved pollutants
Catchpits & Grit traps	Sediment removal	Pollutant removal	Can remove pollutants associated with large sediments
Oil separators	Pollutant removal	none	Can remove oil and other liquids that float on water
Swales & Ditches	Conveyance of water	Storage; sediment and pollutant removal; disposal	Can remove suspended and possibly dissolved pollutants but may be a risk to groundwater quality if not sealed
Infiltration basins	Disposal of surface water	Storage; sediment and pollutant removal	Can remove suspended and possibly dissolved pollutants but may be a risk to groundwater quality
Soakaways & Infiltration trenches	Disposal of surface water	Storage; sediment and pollutant removal	Can remove suspended and possibly dissolved pollutants but may be a risk to groundwater quality
Detention tanks	Storage of surface water	Sediment and pollutant removal	Can remove pollutants associated with sediments
Storage ponds	Storage of surface water	Sediment and pollutant removal	Can remove pollutants associated with sediments and provide some biological treatment
Sedimentation tanks	Sediment removal	Pollutant removal	Can remove pollutants associated with sediments and liquids not miscible with water
Lagoons	Pollutant removal	Sediment removal; storage	Can remove pollutants associated with sediments; vegetation can provide further treatment
Wetlands	Pollutant removal	Storage	Can remove and treat various pollutants

5.3.1 Non-structural measures

Non-structural source mitigation measures such as litter control and control of chemical applications attempt to reduce the amount of pollution available on the road surface. These measures are not directed towards site-specific problems, although they can be used in conjunction with effective site-specific measures. They address minor storms as well as major storms since overall pollution accumulations are reduced. First flush effects are reduced because these measures tend to reduce the accumulation of particulates that contribute to shock loadings (Dorman *et al*., 1996). The practices are relatively low-cost and can be incorporated into existing road design procedures and maintenance programmes.

Generally, the pollutant load from roads is transported by stormwater runoff from the road along kerbs. Most of the pollutant load in the runoff is carried as suspended solids or adsorbed to suspended solids. Therefore, management measures are usually intended to reduce the volume of particulates available for transport by runoff or to filter and settle out suspended solids. The measures, which fall into these two categories are:

- Litter Control
- Street Cleaning
- De-icing Chemical Use Management
- Pesticide / Herbicide Use Management
- Reduce Direct Discharges
- Reduce Runoff Velocity
- Control of Pervious Areas
- Control of Construction Sites
- Establishment and Maintenance of Vegetation

5.3.2 Structural measures

There are five management measures considered cost-effective for pollutant removal from road runoff. These management measures can be used alone or in combination to address site-specific road runoff pollution problems. These are:

- Vegetative controls
- Wet detention basins
- Dry extended detention basins
- Infiltration / retention systems
- Wetlands

There are a few stormwater runoff pollution management measures occasionally recommended as BMP's which are found to be less effective at reducing pollutant loads in road runoff (Dorman *et al.,* 1996). These less effective measures are:

- Catchbasins
- Porous pavements
- Filtration devices for sediment control

5.3.3 Effectiveness of control strategies

Table 5.6 summarises the potential effectiveness of several control strategies that have been used to immobilise pollutants transported in road runoff. Here, effectiveness is defined as the efficiency of the device at trapping pollutants (Malcom, 1989).

Table 5.6 Effectiveness of treatment control strategies (Schueler, 1987; DOT, 1994).

Treatment System	Removal Efficiency (%)					
	Zinc (Total)	Copper (Dissolved)	Iron	Lead	Suspended Solids	Hydro-carbons
Gully/ Carrier Pipe System	10 - 30					
Porous Pavement	-	-	-	-	90 - 100	-
Combined Filter / French Drains	70 – 80	10 - 30	80 - 90	80 - 90	80 - 90	70 - 90
Filtration Basin	70 – 80	10 - 30	80 - 90	80 - 90	60 - 90	70 - 90
Sedimentation Lagoon/ Settling Pond	60 – 80	20 - 30	90 +	80 - 90	60 - 90	70 - 90
PET	-	-	-	-	70 - 100	80 - 100
Sedimentation Tanks & Oil Separators	30 – 50	< 10	30 - 40	40 - 60	30 - 80	40 – 99
Balancing Ponds						
Dry	35 – 45	< 10	20 – 30	30 – 50	30 – 60	30 – 60
Wet	30 – 40	< 10	30 - 50	40 - 60	40- 70	30 - 60
Detention Basin	-	-	-	-	40 - 60	-
Retention Basin	-	-	-	-	80 - 100	-
Swales / Grassed Ditches	70 - 90	50 - 70	90 +	80 - 90	60 - 90	70 - 90
Biofiltration Techniques	50 - 80					

Table 5.7 summarises the cost implications and maintenance needs of each control strategy. Such information is important as lack of routine maintenance can have significant impacts on the effectiveness of treatment systems.

Table 5.7 Capital and maintenance costs for treatment control systems (adapted from DOT, 1994).

Treatment System	Capital Cost	Maintenance Cost	Comments
Gully/ Carrier Pipe System	high	high	Regular de-silting of gullies
Containment Facilities (Oil separators)	low	low	Regular de-silting of separator
Combined Filter / French Drains	high	high	Low annual maintenance Requires stone replacement or cleaning after 10 – 20 years
Filtration Basin	low	high	Low annual maintenance Assume sand replaced every 5 years
Sedimentation Lagoon/ Settling Pond	low	high	Low annual maintenance De-silting after 5 years
Sedimentation Tanks	medium	low	Annual de-silting
Balancing Ponds **Dry** **Wet**	low	low	Assume no maintenance in first 5 years
Swales	low	low	Assume no off-site disposal of cuttings
Biofiltration Techniques	low	high	Annual maintenance in first 3 years

Besides efficiency of trapping pollutants, the applicability of each control strategy to particular road conditions is important. Urban roads often have relatively narrow rights-of-way. Therefore, control devices with long linear configurations, such as a partial exfiltration trench (PET) or an infiltration trench, may be the most suitable alternatives. In less confined areas where sufficient shoulder or median space is available, a vegetated swale may be the preferred control strategy, depending on the soil cover conditions, infiltration characteristics and slope (Sansalone et al., 1995).

Taking into consideration the range of potential pollutants derived from roads and vehicles, the annual mass flux of these pollutants, the mechanism by which they are transported into the local roadside environment, and any factors that influence the methods by which these pollutants are transported, a first draft of a Best Practice Handbook for the assessment of potential pollution problems and identification of the most appropriate treatment strategy(s) has been produced. This handbook is provided as Annex A of this report. To develop this handbook into a practical guide for engineers and consultants, further work would be needed to address some of the inconsistencies found in the experimental data and to identify clear thresholds within the decision making process.

CHAPTER 6:

CONCLUSIONS

6.1 POLLUTANT EMISSIONS

Emission values calculated for the 14 POLMIT monitoring sites are summarised in Table 6.1 below. Due to the lack of reliable data, these values were regarded only as broad estimates of actual emissions. Metal emission rates were primarily dependant on traffic volume, PAH emission rates primarily on traffic volume and road type, and chloride emission rates primarily on the severity of the winter during the monitoring period, and hence on the application of de-icing salts during the period.

Table 6.1 Pollutant emission rates

Potential pollutant	Calculated emission rates (mass/km road/year)	
Total PAHs	65 - 721	g/km/yr
Cd	1 – 10	g/km/yr
Cr	14 - 162	g/km/yr
Cu	9,248 - 108,893	g/km/yr
Pb	7,391 - 110,984	g/km/yr
Zn	2,479 - 51,369	g/km/yr
Cl	1,225 – 15,249	kg/km/yr

**One carriageway (downwind side) only*

Comparisons with emissions from other sources were difficult to make due to the lack of systematic monitoring/reporting of PAHs and heavy metals undertaken in Europe at the present time. Comparisons of reported atmospheric emissions in the UK indicate that road transport contributes little (if any) Cd or Cr, very small amounts of Cu (2%), but significant amounts of Pb (59%) and Zn (23%). To determine the significance of roads and vehicles to soil and groundwater pollution, concentrations of road/vehicle derived substances reaching surrounding soil and groundwaters were compared with recognised threshold levels (Dutch Intervention and Target levels) to determine their ‘polluting potential’.

6.2 MECHANISMS OF MOVEMENT

Once released, pollutants are transported into the local roadside environment either by highway runoff or short distance aerial dispersion followed by deposition. Monitoring of the total annual movement of pollutants by each of these mechanisms was undertaken at each of the 14 sites. The total annual transfer rate of each pollutant, by both highway runoff and aerial dispersal, was calculated. The range of transfer rates for each pollutant are summarised in Table 6.2 below.

Table 6.2 Pollutant transfer rates

Pollutant	**Transfer rates (g/km road/yr)***	
	Highway Runoff	**Aerial dispersal**
Total PAHs	< 1 - 7	< 1
Cd	< 3 - 6	< 1 - 35
Cr	< 1 - 30	< 1 - 156
Cu	< 1 - 1,125	< 26 - 539
Pb	14 - 1,115	< 10 - 541
Zn	111 - 8,091	< 98 - 2,447
Cl* (kg/km/yr)	< 1 - 9,261	< 1 - 2,523

A mass balance approach was used to determine what proportion of the calculated pollutant emissions entered the local terrestrial roadside environment. It was appreciated that, due to difficulties encountered in field monitoring, and recognised weaknesses in the emission calculations, the recovery rates for each pollutant varied greatly from site to site and only general interpretations could be made.

6.2.1 PAHs

Except for a few individual PAHs (indeno-1,2,3-pyrene and benzo-k-fluoranthene) the total transfer rates (mass fluxes) were generally below 10% of the emissions, showing a low recovery of the components in the vicinity of the road. However, problems were encountered during the analysis of these compounds, and it was difficult to determine whether the low concentrations of PAHs recovered were due to natural degradation in the environment (in the presence of sunlight) or degradation during sample storage. Further investigation is needed to decide whether or not PAHs are transported into the local roadside environment in significant concentrations.

6.2.2 Metals

Of the metals, Zn was transported in the greatest quantities followed by Cu and Pb (although the positions of these two elements were sometimes reversed) and finally by Cr and Cd. This generally reflected the magnitude of the emissions of these elements, except in the case of Pb. As Pb is primarily released in fine particulate form from exhaust emissions, it is prone to long distance transport and hence a smaller proportion is found in the local roadside environment.

Strong correlations were found between traffic volume and metal transport, reflecting the vehicle sources of these pollutants. However, road surface type had a marked influence on quantity of metals transported in highway runoff, with porous asphalt appearing to trap sediment in highway runoff, reducing the total quantity of pollutants transported into the local roadside environment.

In most cases the recoveries of Cd were greater than 100%, suggesting that either the emissions were underestimated, or that sources of Cd other than roads and vehicles (e.g. atmospheric deposition) contributed to the measured fluxes. This was supported by the fact that greater quantities of Cd were found in atmospheric deposition compared to highway runoff.

The variation in Cr percentage recovery between the sites was great, but again ranged to over 100%. In a similar manner to Cd, greater quantities of Cr were found in atmospheric deposition compared to highway runoff. A similar explanation to that proposed for Cd could, therefore, be responsible for the observed Cr recovery rates.

Recovery rates for Cu and Pb were relatively low (less than 10% and 5% respectively of the calculated emissions). As Pb is emitted primarily as fine particulates from vehicle exhausts, this material is easily transported large distances, away from the local roadside environment. Cu is derived primarily from the wear of brakes and hence would be expected to be transported in highway runoff following deposition onto the road surface. However, the amount of braking used in motorway driving is much less than that in urban driving. It is possible that the emission rates calculated overestimated the amount of Cu released at the POLMIT sites, leading to a lower apparent recovery rate for Cu.

The recovery of Zn varied greatly, but was generally below 50% of the calculated emission rates. Zn is derived primarily from tyre wear, and released in the form of particulate material deposited on the road surface. However, the particle size range of worn rubber is unknown and significant proportion could be released in the form of fine particulates and transported away from the local roadside environment in a similar manner to Pb.

6.2.3 Chloride

At sites where salt was applied, recovery rates again varied, with recovery rates being 60% or greater where large applications were made, and less than 35% where smaller applications were made. Although the majority of the applied chloride was transported by highway runoff, significant proportions of chloride were also transported by aerial dispersal. However, poor application methods can result in salt being thrown directly into the local roadside environment. Explanations for the low recovery rates at some sites could be that chloride is transported as aerosols over quite long distances, away from the local roadside environment.

6.2.4 Hydrocarbons

Although total hydrocarbon (THC) concentrations were monitored at each of the 14 sites, trends were difficult to distinguish as different methods of analysis were used by some partners, and/or concentrations were below detection limits. Consequently, detailed results were described only for a small number of sites. Wide variations found between sites were thought to be the result of possible accidental spills.

6.3 SOIL AND GROUNDWATER POLLUTION

Concentrations of pollutants in soil and groundwater samples were monitored at each of the 14 sites to determine whether they exceeded recognised threshold levels (Dutch intervention levels and target levels) for soil and groundwater quality.

6.3.1 Soil pollution

Soil Intervention levels were only exceeded for Pb, with most of the Pb probably having been deposited when leaded fuel use was at a peak. At some sites Cu and Zn concentrations did approach Intervention levels, but were thought to be derived from the presence of nearby crash barriers, rather than roads/vehicles directly.

Problems were encountered with the determination of both total hydrocarbons (THC) and PAHs in soils. Consequently, although the concentrations of THC and PAHs appeared to be low in many sites, it was not certain whether this was representative of the actual situation.

6.3.2 Groundwater pollution

In general, concentrations of heavy metals found in groundwaters were low even in areas located close to and downstream of the road. Most of the metal concentrations were well below the Dutch Intervention levels for groundwater. Metals are strongly adsorbed to soil surfaces, and are difficult to leach down the soil profile into groundwater. However, elevated concentrations were found when large amounts of de-icing salts were applied, indicating that Cl does facilitate the movement of adsorbed metals.

The Intervention level for chloride was exceeded at most sites at which de-icing salts were applied. At some sites the maximum recorded concentration was almost 5 times the Intervention level. However, concentrations rapidly reduced to below the Intervention level during the summer months when de-icing salts were no longer applied.

In a similar manner to soils, concentrations of total hydrocarbons in groundwater varied greatly from site to site, with the Intervention level being exceeded at five sites. Three of these sites also had elevated concentrations in soil. However, two sites had excessively high concentrations (over 30,000 ug/l) in groundwater alone, possibly indicating a non-road source. The large variation in concentrations reflects the probable accidental nature of the source of this pollutant.

6.4 METHODS OF CONTROL

Currently, treatment systems are designed to reduce the concentration of pollutants found in highway runoff. The range of systems available, and their relative efficiencies at removing pollutants, have been reviewed. However, no treatment systems currently exist for those pollutants transported by aerial dispersal. Although not the predominant mechanism of transfer into the local environment, significant quantities of especially zinc and chloride were transported by aerial dispersal. The presence of porous road surfaces was shown to reduce transfer rates by this mechanism, however, at present, the only effective method of treatment currently available for pollutants transported by aerial dispersal is source control.

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ANNEX A:

PRACTICAL GUIDE FOR MITIGATING POLLUTANT DISPERSAL INTO THE ENVIRONMENT

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APPENDIX

Reference Values

1 INTRODUCTION

Throughout the working life of a road, both the road and vehicles using it produce compounds that contaminate the environment. These are derived from the combustion of fuel, wear of vehicle components, wear of road furniture (e.g. crash barriers), degradation of road surfaces, and the application of road maintenance chemicals (mainly de-icing salts).

Gaseous and fine particulate material are released into the atmosphere through vehicle combustion processes, and impact on local, regional and global air quality. This in turn has been linked directly to human health. As well as air pollution, traffic causes soil and groundwater pollution in the verges of highways and main roads by means of dry deposition, vehicle spray and runoff.

The aim of this Practical Guideline is to give insight into the causes and remedies of the pollution of groundwater and soil by road and traffic sources, and how to reduce the flux and the impact of this pollution. Much of the information is based on the findings of the 4th FP research project POLMIT. In that project, pollution of soil and water was measured at 14 highway sites in 7 European countries.

The POLMIT research has resulted in an extensive dataset on pollution. Mass balances were calculated which provided information on the pathways and mechanisms of dispersion of pollutants to soil and groundwater. Also a wide range of mitigation measures have been described.

Detailed information on the POLMIT work is contained in a series of reports on the project:

- Pollution from Roads and Vehicles and Dispersal into the Local Environment: A Literature Review
- Pollution from Roads and Vehicles and Dispersal into the Local Environment: Experimental Case Study Results
- Pollution from Roads and Vehicles and Dispersal into the Local Environment: Pollutant Mass Fluxes and Mass Balances

These reports can be found on the POLMIT web site:

trl.co.uk/europeanprojects/polmit/index.htm

Based on these results, this Practical Guideline will provide a tool that, on the basis of location specific properties and utilisation characteristics of the road, identifies the following:

- Which specific pollutant may be emitted
- The likely amounts of pollutants emitted
- A scheme to assess the pathway of the pollutant into the local roadside environment
- A scheme to assess if mitigation measures are necessary
- A list of mitigation measures

With this Guideline, road construction/maintenance engineers and implementers of policies relating to road and vehicle pollution (e.g. road authorities, national environment agencies) will be able to evaluate whether mitigation measures are necessary on the basis of specific site data and immission standards and which measures would be effective in each specific case.

In the Guideline it is made clear which pathways and mechanisms are of importance for the dispersion of pollutants and which pollutants are the most threatening for the environment.

Understanding the impacts of road and vehicle pollution on the terrestrial environment, and identification of effective mitigation measures will inform those who are responsible for protecting the environment and will enable them to utilise their time and efforts more productively.

The Practical Guideline will provide a practical tool to enable this understanding to be communicated efficiently and effectively to road construction/maintenance engineers. It will not give a detailed technical description of mitigation measures but it will offer the possibility to quickly focus on the relevant measures to be taken.

This Guideline focuses mainly on diffuse sources. Another important source of contamination are accidents with, for instance, tanker trucks, which cause acute problems for the environment. This source was not investigated in the POLMIT research and is not, therefore, evaluated in the Guideline.

2 SOURCES, PATHWAYS AND MECHANISMS

The pollution of soil and groundwater is caused by several, mostly diffuse, sources. Figure 2.1 shows the most important sources and transportation mechanisms near highways.

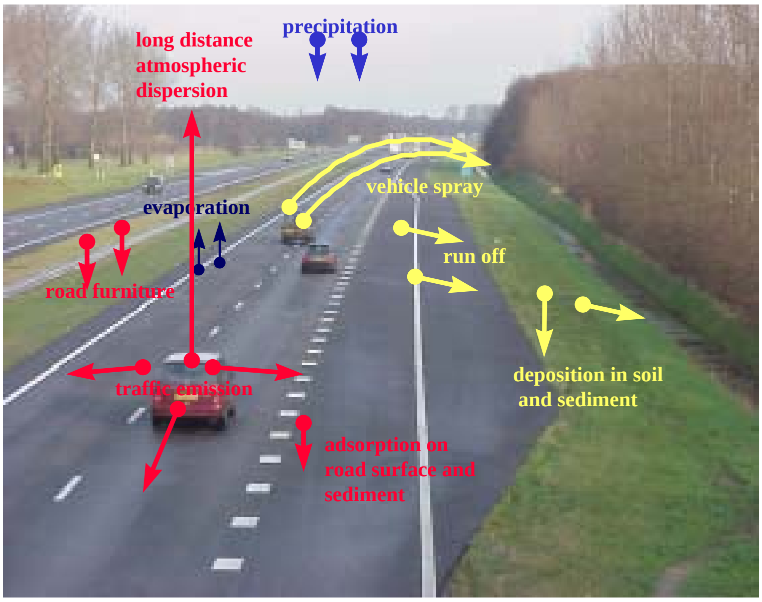

Figure 2.1 Sources and pathways

2.1 Sources

Pollution from vehicles and roads arise from a variety of individual sources. The main sources of contamination of soil and groundwater near roads are:

- Traffic emissions
- De-icing salt and other chemicals e.g. herbicides if applied
- Wear of road surface
- Road furniture
- Accidents

Traffic emissions

Traffic produces potential pollutants in gaseous, liquid or solid state. Examples are:

- *Gaseous*: exhaust gases containing incomplete burnt fuel, carbon monoxide, carbon dioxide and nitrogen oxides
- *Liquid*: oil and fuel leakage and accidental spills
- *Solid*: corrosion of metal parts, particles in exhaust gases, wear of tyres

De-icing salt

During the wintertime, de-icing salts are spread in large amounts in most Northern European countries to clear ice and snow. These salts contain the highly soluble NaCl and therefore large amounts of chloride-ions, which can easily form chloride-metal complexes. Through the melting water these end up in the verges of the road. Because these complexes are highly mobile, metals tend to disperse in the soil more easily until a new equilibrium is established. Another effect is that soil and groundwater become more brackish.

Wear of road surface

Traffic causes wear of the road surface. A study by the Dutch ministry of Housing, Spatial Planning and Environment (VROM 1997) shows that, in the Netherlands, new open asphalt contains only very small amounts of PAH and heavy metals. Re-used open asphalt and open asphalt used in roads also show small PAH-content, but chromium and nickel content has increased. POLMIT concluded that there is a certain leaching of various chemicals through degradation and weathering of the road material, not least in the passage of water through cracks. In those cases where road material contains waste products such as blast furnace slags, steel slags, fly ashes and bottom ashes, leaching of heavy metals may occur (Bjelkas & Lindmark, 1993). Bitumen, used in asphalt, is a considerable source of organic pollution (Bjelkas & Lindmark, 1993). Road markings may give rise to runoff pollution with organic compounds (Pala et al., 1992).

Road furniture

Most crash barriers, traffic signal systems and lamp posts are made of galvanised steel. This is an important source of zinc and cadmium contamination.

Accidents

During road accidents many chemicals may be released and disperse into the soil. Although minor in terms of overall loading, spillages resulting from individual accidents are potentially the most serious source of contaminants associated with roads. Accidental spillages can range from minor losses of fuel from vehicles to major losses from fractured tanker vehicles, but their effects can be serious because of the unpredictable nature of the materials involved (POLMIT).

Table 2.1 summarises the sources of some of the constituents and provides concentration values for some of the parameters found in urban road runoff (from POLMIT; Gupta *et al,* 1981).

Table 2.1 Road pollutants and sources (POLMIT)

Pollutant Groups	**Examples**	**Sources**	**Parameters**	**Concentrations (mg/l)**	
				Average	**Range**
Particulates	Dust, stones, sand, gravel, grain, glass, plastics, metals, fine residues	Tyre, brake & pavement wear, car exhaust, mud & dirt accumulated on vehicles	Total solids Total volatile solids Total suspended solids Volatile suspended solids	1147 242 261 77	145-21640 26-1522 4-1656 1-837
Heavy metals	Lead, zinc, iron, copper, nickel, cadmium, mercury	Use of leaded fuels, tyre and brake wear, motor oil additives, rust	Lead Zinc Iron Copper Nickel Cadmium Chromium	0.96 0.41 10.3 0.103 9.92 0.04 0.04	0.02-13.1 0.01-3.4 0.1-45.0 0.01-0.88 0.1-49 0.01-0.4 0.01-0.14
Organic matter	Vegetation, dust & dirt, humus, oils, fuels	Vegetation, litter, animal droppings, motor fuels & oils	$BOD_{5\text{ (days)}}$ (biological oxygen demand) TOC (total oxygen demand) COD (chemical oxygen demand) Oil / grease	24 41 14.7 9.47	2-133 5-290 5-1058 1-104
Pesticides / herbicides	Weed killers	Right-of-way maintenance	Dieldrin Lindane PCB's (poly chlorinated biphenyls)	(µg/l) 0.005 0.04 0.33	0.002-0.007 0.03-0.05 0.02-8.89
Nutrients	Nitrogen, phosphorus	Fertilisers, motor fuels & oils	TKN (total kjeldahl nitrogen) NO_2 +NO_3 PO_4 (phosphate)	2.99 1.14 0.79	0.1-14.0 0.01-8.4 0.05-3.55
Pathogenic bacteria (indicators)	Coliforms	Soil, litter, excreta, bird & animal droppings	TC (total coliform) FC (faecal coliform)		

2.2 Pathways and mechanisms

Figure 2.2 shows the pathways and mechanisms for transport and dispersion of pollutants in the environment. Emissions are divided into emissions to the air and to the road surface. Emissions to the air are incompletely burnt exhaust gases and particles (mostly from diesel engines) which directly contribute to the background concentration in the atmosphere and are deposited directly to the vegetation or soil surface without the aid of precipitation.

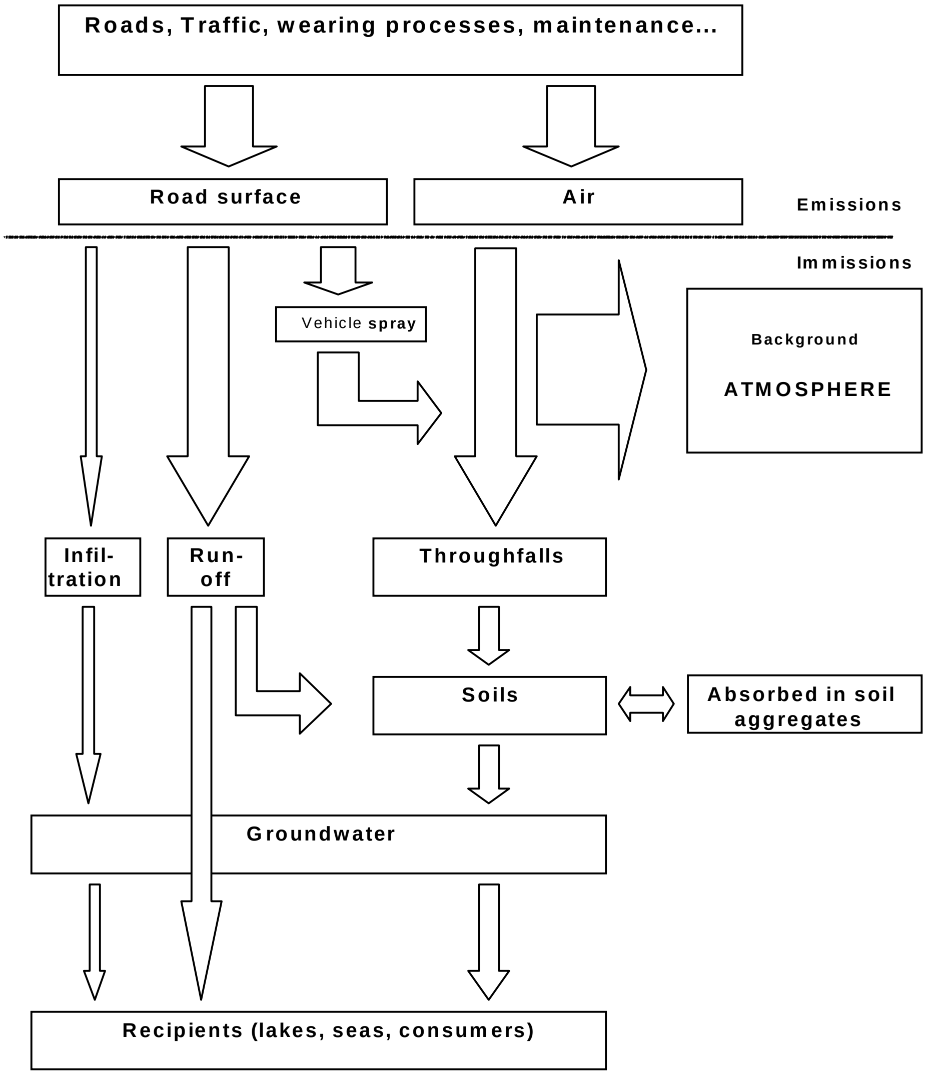

Figure 2.1 Mass fluxes at the road/environment system

However, part of this so-called dry deposition ends up in the soil and groundwater by means of subsequent precipitation. As a result, pollutants originating from roads and vehicles are deposited on the surface of the road and transported into the local roadside environment by two main mechanisms:

- Highway runoff
- Aerial dispersion

The latter involves the transportation of material by wind in dry weather, or by vehicle splash and wind-blown spray in wet weather. Long-distance atmospheric dispersion is another major mechanism of transportation, particularly of gaseous and fine particulate material. However, as this impacts mainly on the atmospheric rather than the terrestrial environment, it is not addressed in any detail here.

The actual mechanism by which a particular pollutant is transported depends on the physical form in which the pollutant is emitted, the chemical properties of the pollutant, the climatic conditions and, to some extent, the type of road pavement. For example, the main transportation processes for liquid pollutants deposited on the road surface will be highway runoff or evaporation. They may, however, be subject to some aerial deposition in wet weather due to vehicle spray. In contrast, particulate material is prone to be wind blown in dry weather. Consequently, the relative importance of each mechanism is dictated by the climatic conditions in any given period: continual rainfall will promote transport by runoff; dry periods will encourage more transport by aerial dispersion.

As highway runoff is the predominant transport mechanism for most pollutants, and as quantification of the source(s) of road and vehicle pollutants is very difficult, many past studies have focused on determining the concentrations of pollutants in highway runoff. Consequently, concentrations of pollutants in highway runoff have often been used as surrogate indicators of the quantities of pollutants emitted from roads and vehicles.

The intensity of the precipitation influences the runoff volume and pollutant concentrations. E.g. the 'first flush' may often have a pronounced shock effect on the biota in those waters receiving the runoff. Less intense and more prolonged rainfall has less impact due to the greater dilution of pollutants in the runoff and greater flows in the receiving watercourse. Rainwater and snowfall can add its own adsorbed and dissolved pollutants to the loads carried by highway runoff. Consequently, the pollutants found in highway runoff may be derived from sources other than roads and vehicles. The first rain after a long dry period may be particularly heavily laden with air pollutants, derived from a variety of sources, which can be deposited onto the road surface and form part of the highway runoff pollutant load.

Aerial dispersion

After release, some particulate material will be dispersed in the atmosphere by turbulent air currents that prevail in the vicinity of moving traffic. Fine particulate material (between 0.1 and 25 μm) will remain suspended in the atmosphere and impact on the atmospheric environment.

Larger particulate material will be subject, however, to gravitational settling. All particles can be subject to one of three deposition processes:

- Gravitational settling: removal of most of the particles greater than 25 μm in diameter
- Dry deposition: this is dependent upon the concentration gradient between the surface and the atmosphere and the properties of both the pollutant and the surface
- Scavenging by precipitation or wet deposition: pollutants carried up into the clouds by convection motion may become droplet nuclei or be dissolved in cloud water and transported back to the surface via rain or snow. Below the cloud, precipitation can also intercept particles and deposit them on the surface.

In wet conditions, vehicle spray can also aid in the aerial dispersion of road and vehicle pollutants. The amount of spray thrown up depends on the vehicle, its tyres, the vehicle speed and the nature of the road surface; spray generated by vehicles becomes more acute as traffic increases both in intensity and speed. Little information is available on quantities of pollutants that are dispersed in this manner. However, the spray thrown up from vehicle tyres in wet conditions is noticeably reduced with pervious surfacing such as porous asphalt.

For POLMIT it was decided to concentrate on determining the total annual loading (mass flux) of pollutants transported by both highway runoff and aerial dispersion. By concentrating on mass flux calculations and subsequent movement within the local roadside environment, POLMIT would gain a better insight into:

- The dispersal of traffic-generated compounds to the soil and groundwater in the vicinity of the road
- The transport mechanisms involved
- The transport mechanisms that would need to be targeted to ensure effective treatment

The calculated emissions from the road due to vehicle exhaust, wear processes, maintenance, etc. result in a mass flux of pollutants that will spread into different environmental compartments. Each mass flux that enters a specific environmental compartment (e.g. soil, groundwater) is called an immission. The mass flux of the road emissions, which results in immissions, is shown in Figure 2.2.

The main pathways for pollutants to disperse from the road surface into soil and groundwater are:

- Vehicle spray (dispersion, aerosols)
- Runoff
- Dry deposition through the air

The most important factors for the transportation of contaminants are:

- Type of road surface
- Precipitation characteristics
- Soil type

Type of road surface

Table 2.2 shows that with a porous asphalt road surface (as shown in Fibure 2.3), evaporation of rainwater is much higher than with conventional road surfaces. This is caused by the large surface area of porous asphalt compared with impervious asphalt, which increases the rate of evaporation. Consequently, both vehicle spray and runoff are much reduced compared to impervious asphalt.

Table 2.2 Estimation of different mechanisms contributing to transfer of pollutants

	Porous asphalt	**Normal asphalt/ impervious asphalt**
Evaporation of rainwater	81%	15%
Runoff of non-evaporated rainwater	13%	24%
Vehicle spray of non-evaporated rainwater	6%	61%
Total	100%	100%

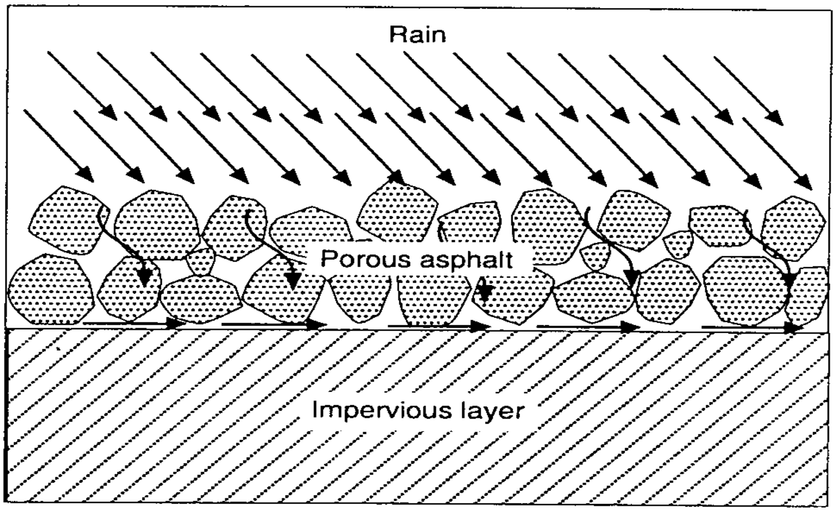

Figure 2.3 Schematic of a porous asphalt-wear course

Figure 2.4 also shows that for pollutants, especially heavy metals but also PAH, runoff is the main mechanism of distribution to the verge for porous asphalt, while for impervious asphalt the spray deposition (vehicle spray) is dominant. For both impervious asphalt and for porous asphalt the infiltration of water through the road surface into the soil is almost negligible.

Figure 2.4 Runoff and vehicle spray (blowing away) characteristics of porous asphalt-(ZOAB) and impervious asphalt (DAB)

Another important mechanism is the adsorption of pollutants to solids (sediment, tyre wear, road wear and dust particles). Due to this mechanism, contaminants can be transported through the solid state phase by means of contaminants adsorbed to sediment particles, as well as in solution. The adsorption depends on the type of road surface and on the type of contaminant, shown in Figure 2.5 From this figure it is clear that in all cases, salt is dissolved in water, while PAHs are mainly adsorbed to sediment particles. Heavy metals are transported both dissolved in liquid as well as adsorbed on sediment.

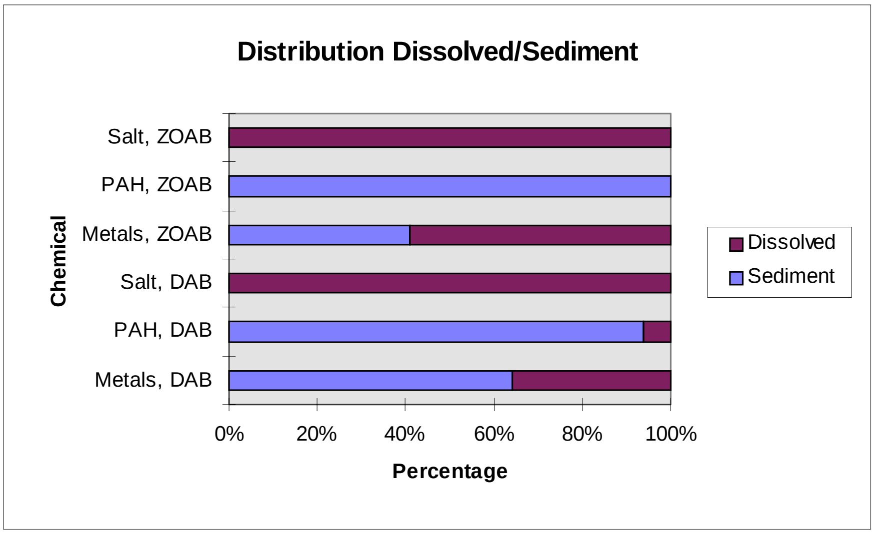

Figure 2.5 Distribution of selected pollutants between the dissolved and sediment fractions

(ZOAB - porous asphalt, DAB - impervious asphalt)

Precipitation characteristics

It is clear that high precipitation increase the possibility of contaminant transport. Therefore, in dry areas the dry deposition will be of more importance, while in wet areas runoff, dispersion and infiltration will be dominant.

Soil type

Contaminants are slowly transported to the deeper soil by means of adsorption and desorption. The velocity of this process is highly dependent on the type of pollutant and the amount of organic matter in the soil; the more organic matter the higher the adsorption of the contaminant and the slower the dispersion. This means that sandy soils with low organic fractions are the most vulnerable in this respect.

Table 2.3 shows the general soil types for each POLMIT site.

Table 2.3 Soil type at each POLMIT site

Site	Soil
A, Reading, Great Britain	Sandy clay loam
B, Oxford, Great Britain	Sandy clay
C, Nieuwegein, Netherlands	Clay loam
D, Spaarnwoude, Netherlands	Silt loam
E, Svaneberg, Sweden	Sand+silt (1 m) on clay
F, Norsholm, Sweden	Clay
G, Lohja, Finland	Sand, gravel
H, Utti, Finland	Sand, gravel
I, Vejenbrod, Denmark	Boulder clay
J, Rud, Denmark	Boulder clay
K, Erdre, France	Silt-sand
L, Houdan, France	Silt-sand
M, Recta, Portugal	Sand and clay
N, Vila, Portugal	Material from weathered granites

The rapid transport in coarse-textured or otherwise permeable soils was demonstrated in the French POLMIT sites where heavy metals were found to migrate deeper in sandy than in loamy-sandy soil. At Site L in France, where the soil is sandy, Cu, Pb and Zn were found to move down to 30 cm. Figure 2.6 shows relatively high concentrations of Zn even at a depth of 10-30 cm, demonstrating the migration of Zn down through the profile at this site.

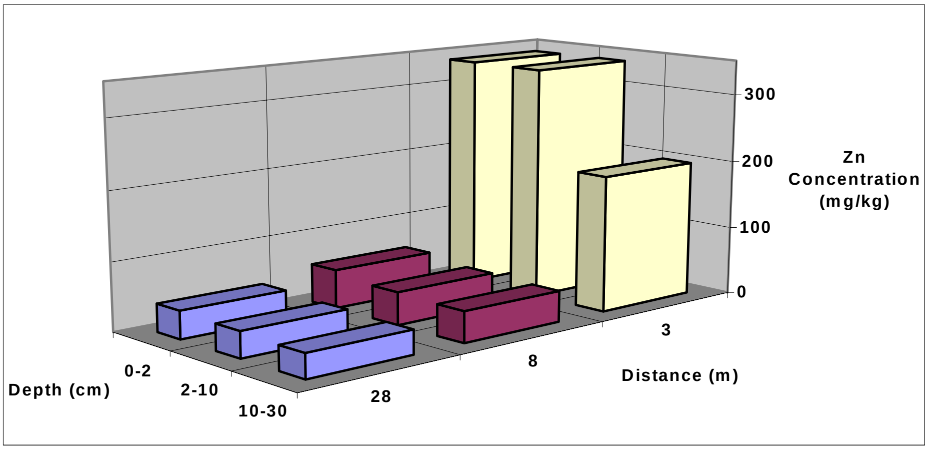

Figure 2.6 Zn concentrations in soil at Site L in France

Heavy-metal concentrations were usually highest in topsoil closest to the roads, decreasing down the soil profile and away from the road edge. This trend was most marked at sites where the traffic density was high and/or the road was relatively old. Figure 2.7 shows a typical example at site A in the UK.

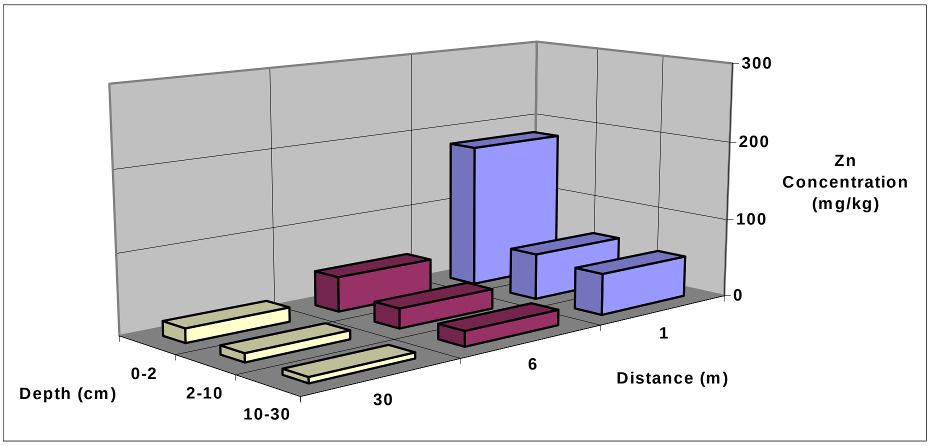

Figure 2.7 Zn concentrations in soil at Site A in the UK

Another important factor is the groundwater level. High groundwater levels result in shorter travel time of the contaminant to the saturated zone, therefore contaminant transport will be quicker.

2.3 The pollution process, as indicated by the POLMIT research results

Once emitted, pollutants can be transported by a number of different pathways into various parts of the environment, including the atmosphere where they are subject to long-distance transport processes. Consequently, the emission rate for various pollutants is no sure guide to the actual impact they may have on the terrestrial environment. It is also not feasible to undertake expensive field monitoring on a frequent basis and/or at a large number of locations to determine impacts on the environment. To address this, a mass balance approach was used to analyse the POLMIT data to determine whether the proportion of the calculated pollutant emissions entering the local terrestrial roadside environment was consistent.

If so, this knowledge could be used to develop a decision-making tool, in which emission rates could be calculated and transfer factors (to separate parts of the environment) could be utilised to assess environmental impacts. This could then be used to determine the most appropriate mitigation measures to be incorporated.

Table 2.4 shows the combined mass flux (runoff and total deposition) for several species investigated, and Table 2.5 shows the mass fluxes expressed as a percentage of the calculated emissions (given in Chapter 3). The values used apply to quantities emitted from, and transported into, one carriageway only.

Table 2.4 Total mass fluxes (runoff + total deposition) at several POLMIT sites

Parameter	**Unit**	**Great Britain**	**Netherlands**	**Sweden**	**Denmark**	**France**	**Portugal**
		Site A Reading	Site C Nieuwegein	Site E Svaneberg	Site I Vejenbrød	Site K Erdre	Site M Recta
Total PAH	g/km.yr	<9	27	0.49	6.9	<0.28	0.015
Cd	g/km.yr	6	37	4.0	2.6	<4.3	0.3
Cr	g/km.yr	1	161	12	35	<6.6	0.8
Cu	g/km.yr	1,201	653	274	595	<224	12
Pb	g/km.yr	1,115	604	72	164	188	14
Zn	g/km.yr	4,022	3,505	1,275	1,074	2208	111
Traffic density	10^3 veh./yr	17,922	27,375	1,341	4,471	4,380	3,887

Table 2.5 Mass balance calculations: Total mass fluxes expressed as a percentage of calculated emissions

Parameter	Unit	Great Britain	Netherlands	Sweden	Denmark	France	Portugal
		Site A Reading	Site C Nieuwegein	Site E Svaneberg	Site I Vejen-brød	Site K Erdre	Site M Recta
Total PAH	%	<1.2	0.76	0.16	7.3	<0.17	0.003
Cd	%	99	370	400	163	<215	20
Cr	%	1.1	99	86	152	<24	4.0
Cu	%	2.0	0.60	2.8	6.4	<1.5	0.09
Pb	%	2.3	0.55	0.72	0.79	2.5	0.09
Zn	%	14	6.8	24	28	29	1.6
Traffic density	10^3 veh./yr	17,922	27,375	1,341	4,471	4,380	3,979

PAHs

For PAHs many of the calculated percentages are expressed as 'less than', which makes any interpretation difficult. Except for a few individual PAHs (indeno-1,2,3-pyrene and benzo-k-fluoranthene) the mass fluxes were generally below 10% of the emissions, showing a low recovery of the components in the vicinity of the road. PAHs are released through exhaust gas and are probably dispersed into the atmosphere, which could account for the low recovery in run-off and total deposition. As indicated in Chapter 4, natural degradation or degradation during sample processing could also explain the low values of the calculated mass fluxes, and the recovery rates should be viewed with caution.

Heavy Metals

With respect to heavy metals, large variations in the calculated percentages were observed. The magnitude of the recoveries for the different heavy metals has been classified for each site in decreasing order of recovery (Table 2.6).

Table 2.6 Classification of the heavy metal recovery at several POLMIT sites

	Site					
Recovery	**A**	**C**	**E**	**I**	**K**	**M**
High	Cd	Cd	Cd	Cd	Cd	Cd
↓	Zn	Cr	Cr	Cr	Zn	Cr
	Pb	Zn	Zn	Zn	Cr	Zn
	Cu	Cu	Cu	Cu	Pb	Pb
Low	Cr	Pb	Pb	Pb	Cu	Cu

The classification of heavy metal recovery shows great similarities between the sites, despite differences in traffic density, traffic distribution, climate and topography. This indicates similarities in the dispersal mechanism and environmental behaviour of heavy metals near roads.

In most cases the recoveries of Cd were higher than 100%, which would suggest that the emissions were underestimated (e.g. a source was lacking in the calculation), or that sources of Cd other than roads and vehicles (e.g. atmospheric deposition) contributed to the measured fluxes. The metal content of ‘background’ atmospheric deposition (determined in a study carried out by Alloway *et al.*, 1997) in the vicinity of Sites A and B in the UK showed that significant inputs of both Cd and Cr were derived from the atmosphere rather than directly from the road. Approximately twice as much Cd was deposited from the atmosphere as was emitted by roads and vehicles. (Other metals investigated were deposited from the atmosphere in amounts that were much smaller than the quantities emitted by roads and vehicles). Based on the detected recoveries, it seems that the majority of the emissions of Cd from roads and vehicles end up in the verge of the road.

The variation in Cr percentage recovery between the sites was great, but again the recovery rates were generally high. The same explanation proposed for Cd could, therefore, be responsible for the observed Cr recovery rates. Dispersion to the verge of the road also appears to be the main transport route for Cr. The total annual loading of both Cd and Cr were low in comparison with the other metals.

Much larger quantities of Zn, Cu and Pb were transported though run-off and deposition, but with much smaller recovery rates for Cu and Pb (less than 10% and 5% respectively) compared to the calculated emissions. The recovery of Zn was greater, though still below 50% in most cases. Zn is derived primarily from tyre wear, and the particles of Zn released from tyres might be sufficiently large to result in a significant proportion settling onto the road surface and being transported into the terrestrial environment without being dispersed into the atmosphere.

The low recovery rates for Pb may have be due to the fact that Pb is primarily emitted from vehicle exhaust in form of fine particulate matter. The particulate matter would easily be dispersed into the atmosphere, and would not end up in run-off or be deposited locally. Cu, derived primarily from the wear and tear of brakes, was expected to be deposited locally and on the road, and then become incorporated in run-off. However, since brakes are seldom used on motorways, overestimation of the Cu-emission could be a sound explanation for the low recovery rates.

Mass balance considerations for chloride are of interest in the countries in which de-icing procedures were applied during the sampling period. Chloride is normally a good tracer as it is not subject to adsorption or degradation processes and is easy to determine in samples. Furthermore, actual de-icing application rates and times are usually known, and the chloride emission should consequently be relatively accurate. In addition, the quantities applied are relatively large, enabling more accurate flux calculations. It can be seen from Table 2.5 that, apart from in France, the recoveries were high. This indicates that chloride was mainly transported into the terrestrial environment through run-off and total deposition.

Explanations for the low recovery rates at the other (French) sites could be that chloride (and other dissolved pollutants) is transported as aerosols over quite long distances. In addition, most sites had problems with overflow in run-off sampling which, even after correction, can lead to an underestimation of the immissions, especially if the overflow occurred during the winter period. Finally, as a result of poor application methods, salt could be thrown into the local roadside and not be incorporated in run-off or collected in the total deposition samplers (See POLMIT report ‘Pollution from Roads and Vehicles and Dispersal into the Local Environment: Mass Flux and Mass Balance Calculations; Assessment of Pollution of Groundwater and Soils by Road and Traffic Sources’ for more details).

Assessment of fluxes in relation to environmental impact

Given a certain concentration of a (potential) pollutant, a comparison can be made with quality standards (Dutch Target and Intervention Levels as presented in Appendix 1). This results in a matrix that gives the environmental risk (Table 2.7).

Table 2.7 Environmental Risk Matrix

Pollutant content	No risk	Possible risk	High risk
lower than	target value	intervention value	
higher than		target value	intervention value

This comparison was made for every POLMIT site. Table 2.8 shows the results of this comparison.

Table 2.8 Elements/compounds exceeding the Dutch intervention level (✓) or target level (#)

Site		Pollutants in soil							Pollutants in Groundwater						
		Cd	**Cr**	**Cu**	**Pb**	**Zn**	**Cl**	**THC**	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**	**Cl**	**THC**
A	**Reading (UK)**			#	#	#			#					✓	
B	**Oxford (UK)**			#					#					#	
C	**Nieuwegein (NL)**	#		#	#	#			#	#		#	#	✓	
D	**Spaarnwoude (NL)**	#		#	✓	#			#	#		#	#	✓	
E	**Svaneberg (SE)**			#	#	#				#	#		#	✓	
F	**Norsholm (SE)**			#		#				#				✓	
G	**Lohja (FI)**				#			✓	-	-	-	-	-	-	-
H	**Utti (FI)**				#			✓	#	#				#	✓
I	**Vejenbrød (DK)**	#		#	#	#		✓	#	#				✓	✓
J	**Rud Kirke (DK)**								#	#	#	#	#	✓	#
K	**Erdre (FR)**			#	#	#		#						#	
L	**Houdan (FR)**	#		#	✓	#		✓					#		✓
M	**Recta do Cabo (PT)**		#	#	#	#				✓	✓	#	#	✓	✓
N	**Vila Real (PT)**										✓	#	#	✓	#

A summary of the results is presented in Table 2.9. It is clear that hydrocarbons are pollutants in both groundwater and soil and chloride is a pollutant in groundwater. Other elements or compounds have the potential to become pollutants but were not regarded as so at the POLMIT sites.

These conclusions are based on results obtained from the POLMIT field sites. Although the sites were chosen to give a broad range of characteristics, it was not possible for every scenario to be considered. These conclusions should be viewed, therefore, in this context.

Table 2.9 Summary of qualitative assessment of the POLMIT field results

Parameter	**Potential pollutant**	**Pollutant**	
Degree of evidence	High	Medium	High
Soil	Cd, Cu, Zn, PAH	Pb	HC
Groundwater	Cd, Zn, PAH	Cr	Cl, HC

3 ASSESSMENT

When it is clear that there is a chance for contamination to occur at a specific site, one should consider the necessity of mitigation measures. This involves the development of a decision-making process that considers the important factors such as sources of pollution, mechanisms of movement, and other influencing factors.

The main pathways for pollutants to disperse from the road surface into soil and groundwater were identified as:
- Vehicle spray (dispersion, aerosols)
- Runoff
- Dry deposition through the air

The most important factors for the transportation of contaminants are:
- Type of road surface
- Precipitation characteristics
- Soil type

To be able to make the assessment it is necessary to obtain relevant information that is specific for the site:

- Road surface
- Meteorological data (precipitation characteristics)
- Soil type
- Groundwater information (protected area, groundwater table, quality)
- Traffic type and intensity
- Vegetation type

Figure 3.1 provides a basic decision support scheme to establish whether or not runoff and/or vehicle spray cause pollution risks to the immediate roadside environment. The scheme starts with 3 possible sources of pollution, which leads to an identification of the potential pollutants from each source. When the soil type and vulnerability of the area are taken into account, a conclusion can be drawn about the necessity for mitigation measures.

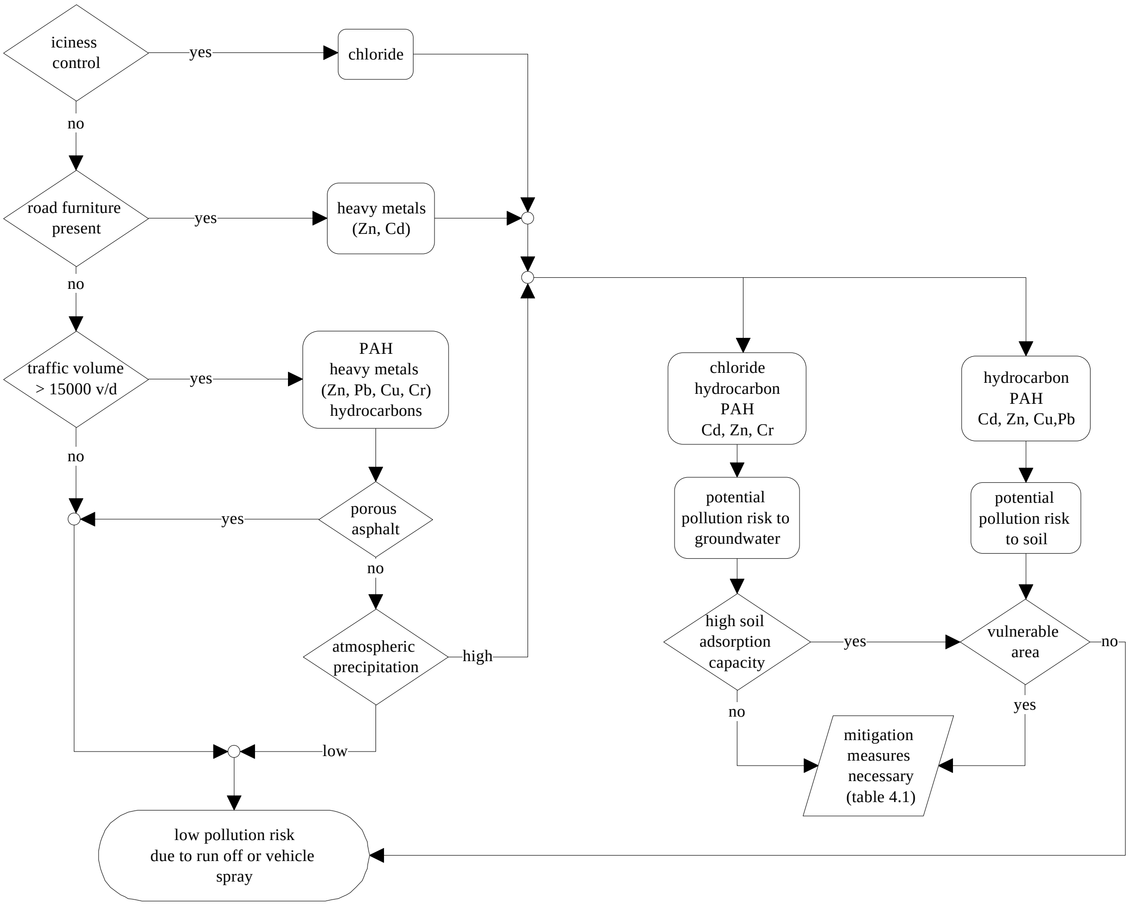

Figure 3.1 Pollution risk assessment

For such a risk assessment to be practical, further work would be required to define criteria such as ‘vulnerable area’, ‘high soil adsorption capacity’ and ‘high atmospheric deposition’. Further work would also be required to clarify the traffic volume threshold (currently presented as 15,000 vehicles/day) as only a limited number of sites with relatively large traffic volumes were monitored in the POLMIT project. The procedure would also need to be tested and refined using a number of existing roads with varying characteristics, and for which the pollution risk was already known (via direct monitoring).

However, as an initial decision-making tool to determine whether more detailed assessment might be required, the above procedure has the potential to be very useful.

4 MITIGATION MEASURES

4.1 General

Mitigation measures can be divided into source-based and effect-based measures. In this Guideline, source-based measures will be discussed briefly as they are mostly dependent on policy and regulation. Emphasis is laid on effect-based measures that can be applied at local sites.

4.2 Source-based measures

Some examples of source-based measures are:

- Introduction of speed limit (e.g. motorway 80 km/h, other roads, 60 km/h)
- Alternative materials for road barriers
- Alternative materials for brake linings to prevent Cu-pollution
- Alternative materials for tyre rubber to prevent Zn/Cd-pollution

4.3 Effect-based measures

At local sites, mitigation measures can be implemented, based on reducing the impact of of the various pollutants. The effect of the contamination is suppressed by using the following techniques:

- Porous asphalt
- Collection of water
- Conveyance of water
- Disposal of collected water
- Storage
- Coarse sediment removal
- Pollutant removal

Porous asphalt

One of the most important measures is the use of porous asphalt. This causes a large decrease of emissions from the road surface by means of:

- Less dispersion
- High retention/adsorption of contamination in remaining sediment, which has to be removed from time to time
- Increased evaporation of water, which results in a decreasing transport of pollutants

Collection of water

Surface water

The following systems are in common use for the collection of surface water:

- Kerbs and gullies (either trapped or un-trapped) including combined kerb and channel drainage units
- Filter drains
- Surface water channels and ditches
- Informal systems for dispersing water across or through a roadside verge
- Precast channel or slot drains

Sub-grade drainage

Sub-grade or sub-soil drains are usually designed to deal with small quantities of water which may percolate into the road construction, either through a poorly maintained road surface that would normally be impermeable, or by groundwater percolation.

Conveyance of water

Once the water has accumulated in the collection system it needs to be conveyed by a suitable means to the disposal point. With the exception of informal verge systems and open highway drainage ditches, the predominant method employed for conveyance is a pipe system.

Disposal

This is usually achieved by discharging the runoff to a receiving watercourse or a soakage system.

Table 4.1 summarises the major functions and water quality attributes (i.e. contribution to improvement of water quality) of drainage system components used in Britain, and Table 4.2 gives an indication of the pollutant removal efficiencies .

Table 4.1 Functions and water quality attributes of highway drainage methods

Method	Primary function	Secondary function	Water quality attributes
Kerbs & gully pots	Collection of surface water	Sediment removal (gullies)	Can remove pollutants associated with sediment but can also generate polluted liquor
Filter drains	Collection and conveyance of surface water	Collection of sub-surface water	Can remove pollutants associated with sediment but may be a risk to groundwater quality
Surface water channels	Collection of surface water	Conveyance of surface water	None
Porous surfacing	Collection of surface water		Unknown
Informal verge systems	Collection of surface water	None	Can remove pollutants associated with sediment
Fin drains	Collection of sub-surface water	None	Associated geotextiles may remove pollutants associated with sediment
Infiltration pavements	Collection and disposal of surface water	Sediment and pollutant removal	Can remove pollutants associated with sediment and dissolved pollutants but may lead to increase in nutrient levels
Catchpits & grit traps	Sediment removal	Pollutant removal	Can remove pollutants associated with large sediments
Oil separators	Pollutant removal	None	Can remove oil and other liquids that float on water
Swales & ditches	Conveyance of water	Storage; sediment and pollutant removal; disposal	Can remove suspended and possibly dissolved pollutants but may be a risk to groundwater quality if not sealed
Infiltration basins	Disposal of surface water	Storage; sediment and pollutant removal	Can remove suspended and possibly dissolved pollutants but may be a risk to groundwater quality
Soakaways & infiltration trenches	Disposal of surface water	Storage; sediment and pollutant removal	Can remove suspended and possibly dissolved pollutants but may be a risk to groundwater quality
Detention tanks	Storage of surface water	Sediment and pollutant removal	Can remove pollutants associated with sediments
Storage ponds	Storage of surface water	Sediment and pollutant removal	Can remove pollutants associated with sediments and provide some biological treatment
Sedimentation tanks	Sediment removal	Pollutant removal	Can remove pollutants associated with sediments and liquids not miscible with water
Lagoons	Pollutant removal	Sediment removal; storage	Can remove pollutants associated with sediments; vegetation can provide further treatment
Wetlands	Pollutant removal	Storage	Can remove and treat various pollutants

Table 4.2 Effectiveness of Treatment Control Strategies (Schueler, 1987; DOT, 1994)

Treatment System	**Removal Efficiency (%)**					
	Zinc (total)	**Copper (dissolved)**	**Iron**	**Lead**	**Suspended solids***	**Hydro-carbons**
Gully/ carrier pipe system	10 - 30					
Porous pavement	-	-	-	-	90 - 100	?
Combined filter / french drains	70 – 80	10 - 30	80 - 90	80 - 90	80 - 90	70 - 90
Filtration basin	70 – 80	10 - 30	80 - 90	80 - 90	60 - 90	70 - 90
Sedimentation lagoon/ settling pond	60 – 80	20 - 30	90 +	80 - 90	60 - 90	70 - 90
Pet	-	-	-	-	70 - 100	80 - 100
Sedimentation tanks & oil separators	30 – 50	< 10	30 - 40	40 - 60	30 - 80	40 – 99
Balancing ponds						
– dry	35 – 45	< 10	20 – 30	30 – 50	30 – 60	30 – 60
– wet	30 – 40	< 10	30 - 50	40 - 60	40- 70	30 - 60
Detention basin	-	-	-	-	40 - 60	-
Retention basin	-	-	-	-	80 - 100	-
Swales / grassed ditches	70 - 90	50 - 70	90 +	80 - 90	60 - 90	70 - 90
Biofiltration techniques	50 - 80					

** Where suspended solids are removed, it is likely that some heavy metals and hydrocarbons will also removed*

To provide practical guidance for the use of mitigation measures, a clearer link is required between the pollution risk, site characteristics and the type of mitigation required. Consequently, further study would be required to evaluate the effectiveness of current and future mitigation against a range of criteria, such as effectiveness at reducing metal pollutants in highway runoff etc. The result could be presented in the form of a matrix, allowing a range of mitigation measures to be selected for any set of site characteristics.

A provisional evaluation has been carried out to indicate the usefulness of such a technique. Nine criteria were considered in this evaluation:

1. Effective for collection and conveyance of runoff
2. Effective for collection and conveyance of dispersion
3. Effective for the removal of organic compounds
4. Effective for the removal of heavy metals
5. Technical practicability and traffic safety
6. Use of space (+: space consuming; -: space saving)
7. Practical experience (+: much experience; -: less experience)

8. Indication of relative implementation cost (high, medium or low)
9. Indication of relative usage cost (high, medium or low)

Each system was assessed to determine whether it had a positive (+), negative(-) or no (0) impact for each criteria (1-7) and whether it has a relatively high, medium or low cost for criteria 8-9. Table 4.3 summaries these results and gives an indication of which mitigation measures would be appropriate in particular circumstances.

Table 4.3 Assessment of treatment systems against 9 criteria

	Criteria								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Collection									
Gully/sewer	+	**0**	**0**	**0**	+	-	+	medium	low
Ditches	+	**0**	**0**	**0**	+	+	+	medium	low
Sedimentation tanks	+	+	+	+	+	+	-		
Algae	+	+	**0**	+	**?**	**?**	-		low
Purification systems									
Physical/chemical-purification	**+/0**	**+/0**	+	+	**+/0**	+	-	high	low
Wetlands/reed beds	+	**0**	+	+	+	+	-		low
Compost filter	+	**0**	+	**+/0**	+	+	-		
Sealing									
soil with clay/organic material	+	+	+	+	+	**0**	-	low	medium
Clay	+	+	+	+	+	**0**	-	medium	medium
Lining	+	+	+	+	+	**0**	-	medium	medium
Foil	+	+	+	+	**0**	**0**	-	low	medium
Soil fixation	+	+	+	+	**?**	+	-		
Vehicle barrier									
Metal crash barrier	-	-	**0**	-	+	-	+	medium	low
Concrete barrier	-	**0**	**0**	**0**	+	-	+	medium	low
Soil bank	-	+	**0**	**0**	+	+	+	high	medium
Miscellaneous									
Binding agent	+	+	+	+	+	**0**	-	medium	medium
Noise barrier	-	+	**0**	**0**	+	+	+	high	high
Windbreak	-	+	**+/0**	**+/0**	+	+	+	medium	medium
Hard shoulder	+	+	+	+	+	+	+		PM
Cleaning road surface	+	+	**0**	**0**	+	**0**	+		medium

It is this matrix that would form the final decision making element of the practical guide. However, the usefulness of such guides are often enhanced when case studies or examples are given of the decision making process and final outcome. Following further refinement and testing of the process, examples should be provided in an Appendix.

APPENDIX 1 REFERENCE VALUES

Table A.1 Dutch Target and Intervention quality standards for soil and groundwater

	Soil (mg/kg)		**Groundwater (µg/l)**	
	Target	*Intervention*	*Target*	*Intervention*
Total hydrocarbons	50	300		10
Fluorantene	1	40	0.005	1
Benz-a-pyrene			0.001	0.05
Indeno-1,2,3-pyrene			0.0002	0.05
Benzo-g,h,I-perylene			0.001	0.05
Benzo-k-fluoranthene			0.0004	0.05
Naphthalene			0.1	70
Chloride			25 000	200 000
Cd	0.8	12	0.4	6
Cr	100	380	1	30
Cu	36	190	15	75
Pb	85	530	15	75
Zn	140	720	65	800