IMPROVED DETERMINATION OF POLLUTANTS IN HIGHWAY RUNOFF PHASE 2

FINAL REPORT

WRc Ref: UC7697
AUGUST 2008

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Highways Agency Contract Reference 3/376

Report No.: UC7697

August 2008

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Contract No.: 13541-0

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SUMMARY

Highway surface runoff discharges may contain pollutants that have accumulated on the carriageway, particularly following periods of dry weather. These pollutants can then be transported via the highway drainage system to discharge to ground or receiving watercourses. Previous studies have demonstrated that highway runoff affects the quality of waters and sediments. Increased concentrations of metals, hydrocarbons and anions are associated with changes in the structure and functioning of biological communities.

In the UK, the Highways Agency is responsible for operating, maintaining and improving the strategic road network in England. The focus of the Highways Agency's ongoing research into the nature and impact of highway runoff is aimed at developing environmental assessment techniques that contribute towards sustainable development, whilst also ensuring that the Highways Agency will meet the requirements of the EU Water Framework Directive.

In late 2003, the Highways Agency commissioned WRc, with the Field Studies Council (FSC) as the main data collection subcontractor, to carry out Phase 2 of a study entitled 'Improved Determination of Pollutants in Highway Runoff' – subsequently referred to as 'ID2'. The purpose of the study can be summarised as:

1. to improve significantly the reliability and extent of existing data for pollutant concentrations found in highway runoff under a range of different site conditions; and,

2. to develop a more robust prediction procedure for the concentrations of pollutants in highway runoff in order that better guidance can be provided to designers.

This Report presents a synthesis of the outcome of this study. The study was carried out in conjunction with two further studies jointly funded by the Highways Agency and the Environment Agency:

- Effects of soluble pollutants on the ecology of receiving waters, carried out by Kings College, London and WRc; and,

- Accumulation and dispersal of suspended solids in watercourses, carried out by the University of Sheffield.

The key objectives of the ID2 study can be summarised as:

1. to undertake a comprehensive programme of field monitoring to obtain data, to identify the key contaminants and to determine the physical form (soluble/insoluble) and concentrations of pollutants in routine highway runoff throughout England;

2. to determine the influence of traffic flows and climate on the concentrations of key contaminants in highway runoff;

3. to investigate and determine the relationship between contaminants found within highway runoff and to identify the existence of any indicator substances that may be taken as indicative of a range of other pollutants; and,

4. to devise a robust pollutant concentration prediction model for highway runoff under a range of conditions.

Originally, the study was to have been undertaken in 4 stages over a 40-month period, with completion by December 2006. However, the original Stage 3 phase was extended by 3 months due to delays in site identification and, also, data capture resulting from abnormally dry conditions throughout the Stage 3 monitoring period. On completion of Stage 4, in March 2007, the study was extended with a fifth Stage to develop a prototype risk assessment tool for highway runoff impacts based on the results of all three research studies.

Stage 1 of the study included a literature review on pollutants in highway runoff, the development of a project database, the identification of site selection criteria and the development of protocols for highway runoff data collection. The results from earlier research indicated that non urban highway runoff could be related to regional climate, highway characteristics and rainfall event conditions. Four climate regions in England were defined on the basis of annual average rainfall (wet >800 mm and dry <800 mm) and annual average winter temperature (warm $>3^{o}C$ and cold $<3^{o}C$). Six non urban sites were identified in each climate region to represent the observed range of traffic flows in each of six traffic flow bands defined in agreement with the Highways Agency. These ranged from less than 15,000 to greater than 120,000 vehicles per day (VPD) annual average two way daily traffic (AADT). Geographically, the defined climate zones approximate to:

- the South East – warm/dry;
- the South West – warm/wet;
- the North West – cold/wet and,
- the North East – cold/dry.

Sites were selected where untreated highway runoff could be collected. Safe access from off the highway, safe site working conditions and equipment security were major factors in site selection. Site monitoring involved continuous rainfall and runoff flow monitoring (depth and velocity) and automatic or remote, telemetry triggering of a 24 bottle auto-sampler when the flow in the highway drain reached a site defined threshold. Rainfall event selection criteria aimed to capture runoff from events representing the full range of seasonal conditions for rainfall intensities and totals. Event selection was based on a minimum antecedent dry weather period (ADWP) of 24 hours. Samples were prepared from the individual auto-sampler bottle samples to produce a flow weighted event mean concentration (EMC) sample for subsequent analysis for a range of pollutants. This allowed for direct comparison with the results from previous studies that had identified a number of ‘key pollutants’ found in highway runoff on the basis of their presence at concentrations of more than 50% above the specified analytical limit of detection (LOD) in more than 50% of samples.

Stage 2 monitoring was carried out between June 2004 and September 2005 at four sites. Each site was selected to represent the highest traffic band in one of the 4 climate regions. The aim of Stage 2 was to confirm the selection of key pollutants for the subsequent, larger, Stage 3 monitoring programme and to obtain data from sites with the highest traffic flows. Ten events were captured at each site for rainfall, runoff and EMC pollutant concentrations of 56 pollutants, including a range of total and dissolved metals and PAHs, MTBE, Cyanide, BOD, COD, de-icing salt, Nitrate and Total Suspended Solids (TSS), plus particle size distribution of the TSS. The results from all four sites indicated higher pollutant concentrations than those found previously at lower traffic density sites and confirmed the selection of key pollutants for the more comprehensive Stage 3 monitoring.

Stage 3 included data collection at a total of 24 sites, including the four Stage 2 sites. Ten events were captured at each site. In addition, 'time determined' within event runoff monitoring was carried out at the four Stage 2 sites to assess the significance of any 'first flush' in highway runoff pollution responses. EMCs were collected from each event and analysed for 36 pollutants, on the basis of those routinely detected in highway runoff in Stage 2 and at concentrations that may present an ecological risk. This was based on the results from the two associated studies investigating the potential ecological impacts of soluble and insoluble pollutants. Based on the Stage 2 monitoring results, these pollutants, termed 'significant pollutants' included dissolved Copper, dissolved Zinc, total Copper, total Zinc, total Cadmium, total Pyrene and total Fluoranthene. Summary statistics from the monitoring data for these pollutants, plus total PAHs and total Suspended Solids were:

Determinand	**Units**	**LOD**	**Average EMC**	**Median EMC**	**Average Event Load/1000m^2**	**Runoff Load Units**
Total Cu	ug/l	0.3	91.22	42.99	0.66	g
Dissolved Cu	ug/l	0.3	31.31	23.30	0.16	g
Total Zn	ug/l	0.6	352.63	140.00	2.44	g
Dissolved Zn	ug/l	0.6	111.09	58.27	0.50	g
Total Cd	ug/l	0.01	0.63	0.29	0.00	g
Total Fluoranthene	ug/l	0.01	1.02	0.30	0.01	g
Total Pyrene	ug/l	0.01	1.03	0.31	0.01	g
Total PAHs (Total)	ug/l	0.01	7.52	3.33	0.04	g
Total Suspended solids TSS	mg/l	2.0	243.87	139.00	1.69	kg

LOD – Analytical limit of detection EMC – Event Mean Concentration

Correlations between metals and other substances (excluding PAH) were generally poor. However, there were strong correlations both between individual total PAH and individual total PAH with total PAHs. The results showed that, with the exception of total PAH as an indicator of concentrations of other total PAHs, there was no evidence to support the use of one or more indicator substances as a surrogate for others in developing the Stage 4 model to predict highway runoff pollutant concentrations.

The data indicated a trend with pollutant concentrations increasing with AADT and also a greater variability within traffic bands as AADT increases. There was no trend for higher or lower metals concentrations in the different climate regions. However, there appeared to be higher PAH concentrations in the Cold/Wet and Cold/Dry regions. Therefore, traffic density appeared to be the main site factor in terms of pollutant concentrations. However, the analysis confirmed that there were no simple relationships between pollutant concentrations and the individual site or event characteristics.

Stage 4 included further statistical investigation of the individual factors and their relative importance in relation to pollutant concentrations, the creation and testing of predictive models for each of the significant pollutants, and, a specification to incorporate these models in to a new tool for assessing the impact of highway runoff. The original intention was to develop a deterministic model, based on representing the build up and wash off of pollutants from the highway surface driven by a long rainfall time series, to predict event based concentrations for the significant pollutants. However, building on the initial data analysis, it became apparent that this approach would be unsuccessful. Therefore, subsequent model development focused on a statistical approach using multiple linear regression (MLR) analysis to assess the relative importance of the different potential explanatory factors and to provide regression equations to explain the variability observed in the data for each of the significant pollutants.

The MLR analysis identified that, for Copper and Zinc, only two site characteristics (AADT and climatic region) and three event characteristics (month, maximum hourly rainfall intensity and antecedent dry weather period) had some significant influence on the pollutant concentrations. The MLR analysis provided predictive equations for these pollutants that represented some of the observed variability based on explanatory factors but most of the variability by a random error term. Due to the highly variable nature of the data for total Cadmium and total PAHs, these models were developed from non-parametric distributions based on the observed data. In addition to total PAHs, models were produced for total Pyrene, and total Flouranthene. These were produced from simple linear regression models based on the total PAHs as they were closely correlated to the total PAHs concentrations.

The final task in Stage 4 was to specify how these statistical models could be incorporated into a new Highways Agency Water Risk Assessment Tool. The purpose of this tool, to be used in support improved guidance for highway design, will be to help highway designers decide whether or not pollution mitigation measures are needed in specific circumstances. A User Specification for this tool was developed in discussion with the Highways Agency, based on the following core features:

- It should require relatively little site specific data to make an assessment.
- It should incorporate a tiered approach to assessment whereby unnecessary work is avoided if the impact can be shown to be low.
- It should use a ‘traffic light’ reporting method whereby:
    - **Red** indicates an unacceptable impact;
    - **Amber** indicates a need to carry out further stages of assessment or to refer the situation to specialist judgement, and;
    - **Green** indicates an acceptable impact with no need for any further investigation.
- It should incorporate the statistical models for highway runoff quality developed in Stage 4.
- It should incorporate the use of both the ecologically-based Runoff Specific Thresholds (RSTs) for assessing the acute impacts caused by dissolved Copper and dissolved Zinc; and, the risk based procedure for assessing the chronic impacts caused by polluted by sediments from highway runoff, as developed in the two supporting research projects.

This Report is focused on the work carried out under the original four stages of the study. The development of the tool will be described elsewhere, in due course, upon completion of its development beyond the scope of the original study.

1. INTRODUCTION

1.1 Study outline

Highway surface runoff discharges may contain pollutants that have accumulated on the carriageway, particularly following periods of dry weather. These pollutants can then be transported via the highway drainage system to discharge to ground or receiving watercourses. Previous studies carried out by the Highways Agency[(1)] have demonstrated that highway runoff affects the quality of waters and sediments. Increased concentrations of metals, hydrocarbons and anions are associated with changes in the structure and functioning of biological communities.

In the UK, the Highways Agency is responsible for operating, maintaining and improving the strategic road network in England. The focus of the Highways Agency's ongoing research into the nature and impact of highway runoff is aimed at developing environmental assessment techniques that contribute towards sustainable development, whilst also ensuring that the Highways Agency will meet the requirements of the EU Water Framework Directive.

In late 2003, the Highways Agency commissioned WRc, with the Field Studies Council (FSC) as the main data collection subcontractor, to carry out Phase 2 of a study entitled 'Improved Determination of Pollutants in Highway Runoff' – subsequently referred to as 'ID2'. The purpose of the study can be summarised as follows:

- to improve significantly the reliability and extent of existing data for pollutant concentrations found in highway runoff under a range of different site conditions; and,

- to develop a more robust prediction procedure for the concentrations of pollutants in runoff in order that better guidance can be provided to designers.

This Report presents a synthesis of the outcome of this study.

The ID2 study was carried out in conjunction with two further studies jointly funded by the Highways Agency and the Environment Agency. These studies are reported elsewhere:

- Effects of soluble pollutants on the ecology of receiving waters carried out by Kings College, London and WRc [(2)]; and,

- Accumulation and dispersal of suspended solids in watercourses (carried out by the University of Sheffield) [(3)].

The original objectives of the ID2 study can be summarised as:

i) to undertake a comprehensive programme of field monitoring to obtain data, to identify the key contaminants and to determine the physical form (soluble/insoluble) and concentrations of pollutants in routine highway runoff throughout England;

ii) to determine the influence of traffic flows and climate on the concentrations of key contaminants in highway runoff;

iii) to investigate and determine the relationship between contaminants found within highway runoff and to identify the existence of any indicator substances that may be taken as indicative of a range of other pollutants;

iv) to determine the design storm likely to give the worst case scenario for pollutant concentrations at a given location for a given range of conditions;

v) to devise a robust pollutant concentration prediction model for highway runoff under a range of conditions; and,

vi) if required, to revise and/or update the existing assessment and prediction procedure in DMRB Vol. 11 Section 3.10 for the determination of pollutants arising from highway runoff.

In practise, the project was not required to address objectives (iv) and (vi). Objective (iv) was superseded as the pollutant prediction model developed under objective (v) was based on the use of a long rainfall timeseries simulation rather than specific design storms.

Originally, the study was to have been undertaken in 4 stages over a 40-month period, with completion by December 2006. However, the original Stage 3 was extended by 3 months due to delays in site identification and, also, data capture resulting from abnormally dry conditions, throughout the Stage 3 monitoring period. This also resulted in an overlap between Stage 3 and Stage 4. Stage 4 was extended to include additional data analysis and the development of a range of statistical models plus a specification for a prototype design support tool to support the Highways Agency in addressing the original objective (vi). The revised programme was as follows:

Stage	Description	Start	End
Stage 1	Literature review and identification of study sites	Sept 03	May 04
Stage 2	Identification of the key contaminants in highway runoff and the investigation and determination of substances that might be indicative of a range of other pollutants	Feb 04	Jan 06
Stage 3	Study of the influence of site-specific factors and the importance of the first flush on the pollutants after a rainfall event	April 05	Dec 06
Stage 4	Recommendations for design assumptions of pollutant concentrations for use in estimating the impact of highway runoff	Sept 06	Mar 08

1.2 Interim Project Outputs

The following Interim Reports were produced from Stages 1 to 4 of the ID2 project:

- Stage 1 Report, WRc Ref. UC6475[4];
- Stage 2 Report, WRc Ref. UC7043[5];

- Stage 3 Report, WRc Ref. UC7309[6]; and,
- Stage 4 Report, WRc Ref. UC7405[7].

Under the original study programme, the full results from Stage 2 would have been available to inform decisions regarding the Stage 3 programme and the requirements for sample analysis (the specified Analysis Suites 2 and 3). One of the main objectives of Stage 2 monitoring and analysis was to identify 'key contaminants' in routine highway runoff. These key contaminants would then define the sample analysis suite for Stage 3 data collection. However, in the course of Stage 2, it became clear that it was necessary to identify the Stage 3 sample analysis suites before the completion of all Stage 2 sample collection and data analysis. Also, it became apparent that a modified approach to Stage 3 would be required to reduce the risk of slippage in the overall programme and to ensure that the outputs were available to the Highways Agency in time to support further planned activities. An initial evaluation of data from the first 21 samples was used to specify more comprehensive Stage 3 sample analysis suites that were directly compatible with the results from Stage 2. As a consequence, it was agreed to reduce the original scope of the Stage 2 data analysis and reporting and to focus the Stage 3 data analysis on the combined data set from Stage 2, Stage 3 and the data from the previous 'Long term Monitoring' study[1] for model development in Stage 4.

1.3 Report Structure and Contents

This report provides a synthesis of the work carried out in the course of the four Stages of the ID2 project. The Interim Reports plus the individual Site Reports (as Annexes to the Stage 3 Report) and the Project Database are provided in electronic format, elsewhere.

Specifically, this report covers:

Section 1. Introduction.

Section 2. Stage 1 Literature Review and Development of the Data Collection Programme.

Section 3. Stage 2 Data Collection Programme.

Section 4. Stage 3 Data Collection and Preliminary Data Analysis.

Section 5. Stage 4 Data Analysis and Model Development.

Section 6. Overall Conclusions and Recommendations to support DMRB Vol. 11 Section 3.10 for the determination of pollutants arising from highway runoff.

1.4 Acknowledgement

The authors wish to acknowledge the data collection support provided by Andrew Turney and colleagues at the FSC centres who were responsible for the bulk of the highway runoff sample collection under WRc's supervision.

All Stage 2 samples were analysed by WRc. All Stage 3 samples were analysed by Severn Trent Laboratories under subcontract to WRc.

2. STAGE 1 LITERATURE REVIEW AND DEVELOPMENT OF THE DATA COLLECTION PROGRAMME

2.1 Overview of Stage 1

The following key tasks were undertaken during Stage 1:

- produce an update to the review of literature on pollutants in highway runoff;
- develop and agree a specification for the project database design and subsequent creation of an operational database;
- produce and agree the specification for the site selection procedure; and
- carry out site visits and information collection leading to recommendations for the selection of 4 sites for Stage 2 and the provisional identification of potential sites for Stage 3.

This Stage 1 Report[(4)] presents the outcome of these tasks.

2.2 Literature Review

Highway surface runoff discharges may contain pollutants that have accumulated on the carriageway, particularly following periods of dry weather. These pollutants can then be transported via the surface water drainage system to discharge to ground or receiving watercourses. The potential for the impact of highway runoff on receiving waters is likely to increase and previous studies have demonstrated that highway runoff affects the quality of waters and sediments. Vehicles, road construction and road maintenance produce a range of potentially toxic contaminants that originate from a variety of sources. These include fuel combustion, vehicle corrosion and tyre, road and brake wear. Contaminants may also come from atmospheric deposition. Contaminants found in highway runoff can be divided into the following categories:

- **Sediments** can act as an important transport mechanism for pollutants, as a number of contaminants will associate with sediment particles. Sediments, therefore, often contains metals and high molecular weight organics that can subsequently be removed from the highway surface to aquatic systems by runoff.
- **Hydrocarbons** in highway runoff may be derived from lubricating oils, fuels, hydraulic fluids, tyre wear, anti freeze products and exhaust emissions from vehicles, road wear and herbicides arising from weed control.
- **Metals** in highway runoff can arise from a wide range of sources including vehicle corrosion and wear, break linings, oil additives, catalytic converters, paints and rubber.
- **Salts and Nutrients** Sodium Chloride is the main chemical used for de-icing of road surfaces, though in some areas, such as around metal structures, calcium chloride, or urea may also be used to minimise corrosion. Other alternative de-icing chemicals include glycols and calcium magnesium acetate. Nutrients can indirectly affect stream

communities by accelerating the growth of organisms resulting in a decline in the water quality and an adverse impact on other members of stream communities. Nitrates can have an adverse impact on groundwater quality.

- **Bacteria** Microbial contaminants in highway runoff are usually associated with particulate material arising from the decay of organic matter.

- **Others** including herbicides used for routine vegetation control on roadside verges.

While some of the more volatile contaminants may enter the atmosphere, the remaining contaminants will collect on or near the road surface and will be washed off during periods of rainfall. The runoff is then collected by kerbs, drains and ditches and conveyed via pipes to receiving waters or retention ponds. Increasingly, some form of treatment is incorporated into the drainage system to remove contaminants.

The Literature Review focused on recent research funded by the Highways Agency as this was most relevant to the study. The inconsistencies in both monitoring strategies and the reporting of results for pollutant concentrations and loads between the recent studies have restricted direct numerical comparisons between studies. However, there are similarities in the relationships found between pollutants in runoff and other factors. Previous research[1,7] has indicated that, in general, pollutant concentrations in highway runoff are low and often close to analytical limits of detection. However, under certain conditions related to the nature and characteristics of the highway, the rainfall/runoff event and the receiving water, it is possible that the pollutants in highway runoff may exert an acute or chronic impact on the chemical and ecological status of the receiving water. The results of previous research into pollutant levels and their causative relationships with rainfall event and highway characteristics have been inconclusive[1]. However, traffic flow, climate and antecedent dry weather are considered to be potentially important, as are rainfall event intensity and duration.

The following conclusions were drawn from the recent studies of sites in the UK and Europe:

- recent studies carried out to assess pollutants in highway runoff have adopted a piecemeal approach to monitoring and reporting of results that limits direct comparisons of observed concentrations and loads between studies;

- there is a positive relationship between metals and PAH in highway runoff;

- concentrations of pollutants have been found to be higher in runoff from urban highways compared to non-urban highways. This appears to be due to a combination higher atmospheric deposition of pollutants and urban traffic flow characteristics;

- porous highway surfaces appear to reduce the level of contaminants in highway runoff;

- first flush effects appear to be related to antecedent dry weather period and event rainfall characteristics; and,

- there is a relationship between winter conditions and elevated concentrations of metals and PAHs in highway runoff. Salting may be a factor in increasing the availability of pollutants in runoff. Runoff from snowmelt is also likely to have elevated concentrations of pollutants.

It was recommended that Stage 2 data analysis should focus on seeking to confirm and quantify these relationships.

The use of gully pots as an interface between the highway surface and the highway drainage system is widespread in the UK and is likely to remain so for the foreseeable future. It was agreed that site selection could, in principle, include sites with gully pots, as the cost of the infilling of gully pots at otherwise suitable sites would be prohibitive. However, it was recognised that gully pots, to a degree, provide treatment of runoff and any results would be inconsistent with sites without gully pots. In practice, it was possible to identify all suitable sites without gully pots.

The Highways Agency's own research programme[(1)]) has identified that some aspects of the recently updated methodology for assessing the impacts of highway runoff[(9)], whilst representing the current best practice, are largely derived from earlier guidance[(10)] and in some aspects based on data that may not be representative of the pollutants and concentrations currently found in highway runoff.

2.3 Site Selection

The overall aim of the monitoring programme was to collect data to examine the effects of regional climate and traffic conditions on pollutants in runoff from non urban highways with free flowing traffic. This excluded all sites in the vicinity of junctions and less than 1km away from urban development. All data collection was carried out on the Highways Agency's trunk road network in England. Sites selected met the following criteria:

- runoff could be collected prior to any form of treatment;
- the highway drainage catchment had a minimum impermeable area of 1000 m^2;
- the highway surface was formed from hot rolled tarmac;
- there was no planned major maintenance activity at the site for the proposed monitoring period; and,
- site access and all routine data collection and site servicing could be carried out without direct access from the highway.

Four geographical areas were selected to represent regional climates in England, as shown in Figure 2.1. These were based on annual rainfall with a threshold of 800 mm and an average winter temperature with a threshold of 3^{o}C. The four zones were:

- South West – average winter temperature >3^{o}C and annual rainfall >800 mm – warm-wet;
- South East – average winter temperature >3^{o}C and annual rainfall <800 mm – warm-dry;
- North West – average winter temperature <3^{o}C and annual rainfall >800 mm – cold-wet; and,
- North East – average winter temperature <3^{o}C and annual rainfall <800 mm – cold-dry.

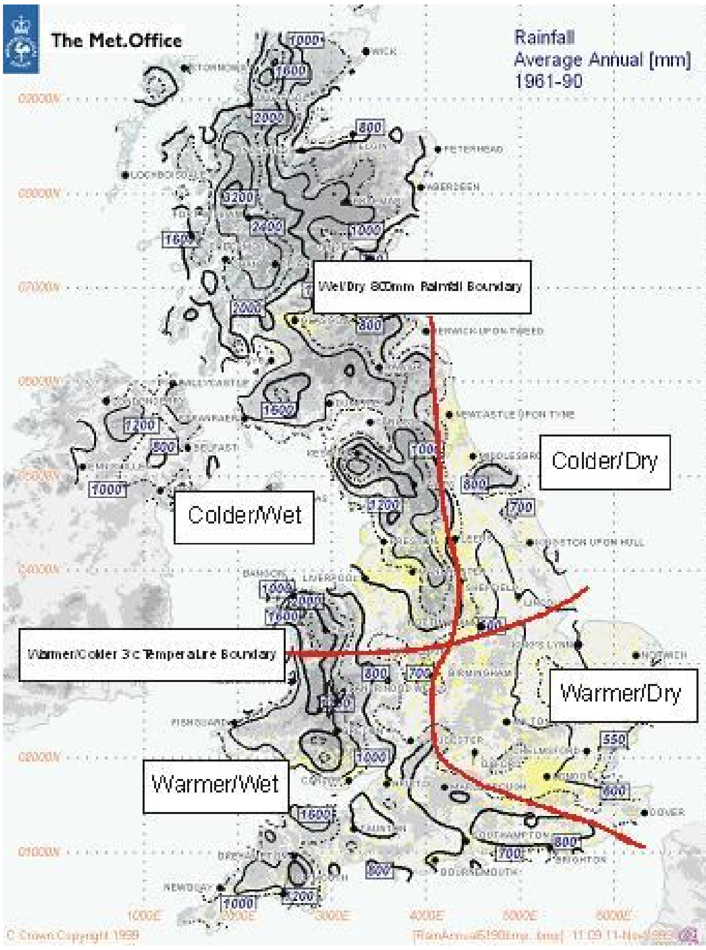


Figure 2.1 Defined Climate Zones

Six traffic density bands were agreed with the Highways Agency to characterise traffic flows, as shown in Table 2.1. The bands relate to the number of vehicles per day (vpd), derived from Highways Agency's monitoring of 2-way Annual Average Daily Traffic (AADT). This includes heavy goods vehicles.

Table 2.1 Highways Agency Traffic Bands

Traffic Band	AADT (vpd)
1	5000 - 14999
2	15000 - 29999
3	30000 - 49999
4	50000 - 79999
5	80000 - 119999
6	120000 - 200000

In practice, site selection continued through out Stage 1 and Stage 2. The final list of sites used in Stage 2 and Stage 3 is presented in Table 2.2 and the locations are illustrated in Figure 2.2.

Table 2.2 Monitoring Site Characteristics

A) Warm Dry Region

Site Name	Highway Site Code	AADT (vpd)	Highway	Drainage Type	%HGV	No. of lanes	Catchment length (km)
Luton Group A Site	M1J9	146000	M1	Concrete V Channel	11	4	2.6
Redhill	M25J8	159400	M25	Kerb & Gully	10	9	1.2
Swindon	M4J16	80000	M4	Kerb & Gully	14	3	0.3
Marks Tey	A12	73000	A12	Concrete V Channel	10	4	1.4
Claydon	A14	30000	A14	Kerb & Gully	12	4	1.3
Ware	A10	18000	A10	Concrete V Channel	8	4	1.8

B) Warm Wet Region

Site Name	Highway Site Code	AADT (vpd)	Highway	Drainage Type	%HGV	No. of lanes	Catchment length (km)
Bromsgrove Group A Site	M5J4a	106000	M5	Kerb & Gully	16	3	0.2
Wootton Bassett	M4J17	80000	M4	Kerb & Gully	12	3	0.6
Plympton	A38	57000	A38	Concrete V Channel	7	5	1.5
Okehampton	A30Oke	18000	A30	Concrete V Channel	12	4	1.6
Cirencester	A417	27000	A417	Concrete V Channel	5	4	1.9
Honiton	A30Hon	27000	A30	Concrete V Channel	6	4	0.7

C) Cold Dry Region

Site Name	Highway Site Code	AADT (vpd)	Highway	Drainage Type	%HGV	No. of lanes	Catchment length (km)
Leeds Group A Site	A1MJ45	104000	A1M	Concrete V Channel	22	8	2.5
Boroughbridge	A1MBB	67000	A1M	Concrete V Channel	18	6	0.7
Garfoth	A1M1	74000	A1M1	Concrete V Channel	21	6	2.8
Tadcaster	A64Tad	44000	A64	Kerb & Gully	7	4	0.8
Doncaster	A1MDon	57000	A1M	Kerb & Gully	22	4	1.4
Micklefield	A1Mick	42000	A1	Concrete V Channel	27	6	2.6

D) Cold Wet Region

Sit Name	Highway Site Code	AADT (vpd)	Highway	Drainage Type	%HGV	No. of lanes	Catchment length (km)
Lymm Group A Site	M6J20	135000	M6	Beaney Blocks	22	4	0.5
Holme	M6J36	60000	M6	Kerb & Gully	23	6	1.5
Garstang	M6J32	68000	M6	Kerb & Gully	22	6	1.9
Southwaite	M6J41	44000	M6	Kerb & Gully	26	6	0.8
Brough	A66Brough	15000	A66	Kerb & Gully	23	4	1.0
Flusco	A66Flusco	11000	A66	Kerb & Gully	13	4	0.5

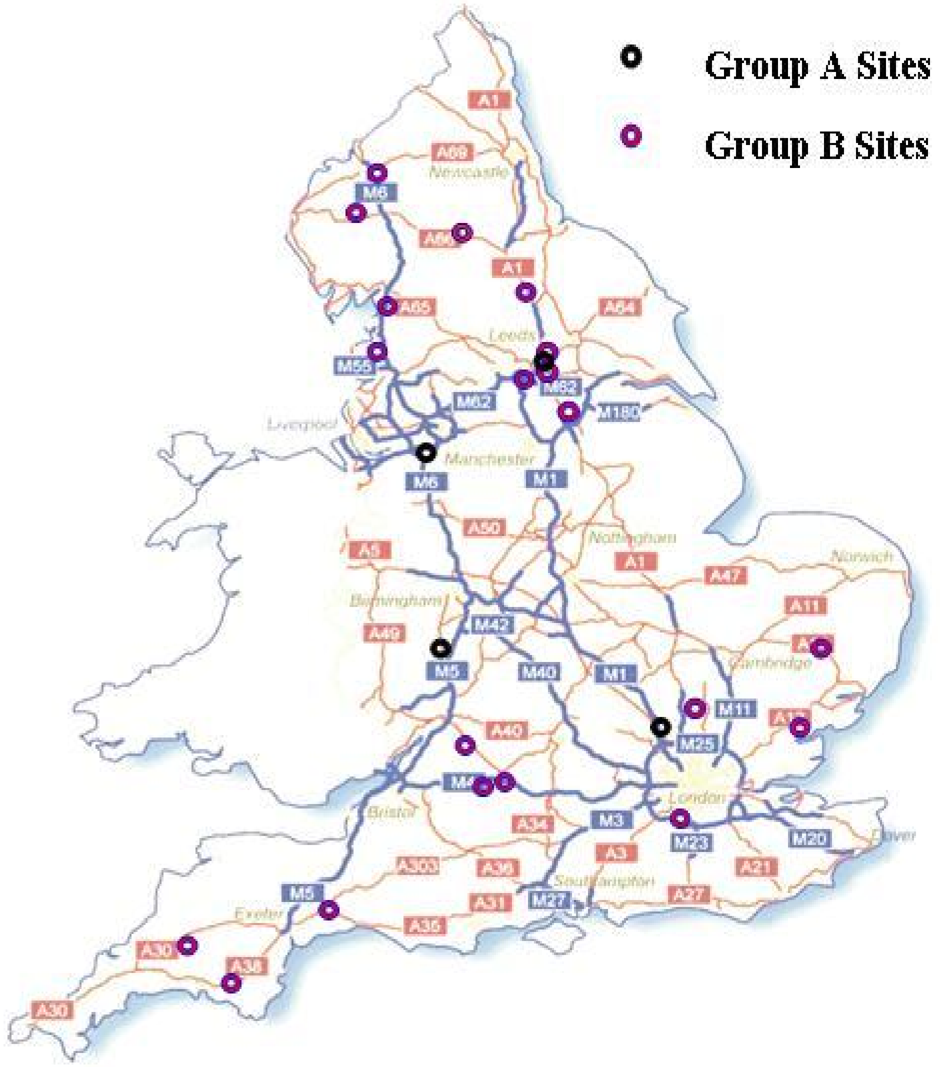


Figure 2.2 Location of Monitoring Sites

Data collection was carried out in Stages 2 and 3. Stage 2 data collection was based on the 4 sites (Group A sites) that represented the highest traffic density in each climate zone. Group B sites represent the lower traffic bands in each climate zone. In practise it was not possible to identify suitable monitoring sites for all of the traffic bands in each Climate Region. Table 2.3 shows the final breakdown of sites by traffic band and Climate Region. In particular, there was only one Band 1 site (Flusco) and 3 Band 6 sites. There were Band 4 monitoring sites in each Climate Region. All Climate Regions had some duplication of traffic bands. Brough, with 15000vpd is a borderline Band 2 site. The final site selection was a reflection of regional and national characteristics for traffic flows and highway construction.

Table 2.3 Stage 3 Monitoring Sites – Traffic Bands and Climate Regions

Traffic Band	AADT (vpd)	Sites Warm Dry	Sites Warm Wet	Sites Cold Dry	Sites Cold Wet	Sites Total
1	5000 - 14999				1	1
2	15000 - 29999	1	3		1	5
3	30000 - 49999	1		2	1	4
4	50000 - 79999	1	1	3	2	7
5	80000 - 119999	1	2	1		4
6	120000 - 200000	2			1	3

2.4 Monitoring Protocols

The basic site monitoring procedure used in the Stage 2 and Stage 3 data collection programmes was based on the protocols developed during the previous study(1) This allowed data from that study to be incorporated in the subsequent data analysis.

2.4.1 Monitoring Equipment

The Stage 2 Report(5) presents a general description of site instrumentation and the operation of monitoring equipment for rainfall and flow; highway runoff sampling; and, the telemetry system used control this equipment and download the data. The individual Site Reports identify the specific equipment deployed at each site. In general, site monitoring involved continuous rainfall and runoff flow monitoring (depth and velocity) and automatic or remote telemetry triggering of a 24 bottle auto-sampler when the flow in the highway drain reached a site defined threshold. Rainfall event selection criteria aimed to capture runoff from events representing the full range of seasonal conditions for a range of rainfall intensities and totals.

2.4.2 Event Selection Criteria

Highway runoff events were to be collected over a range of seasons at each site to try to capture both summer storms and winter events after salt application. Previous studies have indicated that these may produced the highest pollutant concentrations in highway runoff. The highway drainage discharge data were downloaded weekly and weather forecasts were monitored for potential rainfall events. The monitoring equipment was remotely activated for events that were expected to meet the required event characteristics. Samplers were triggered either remotely or automatically by the telemetry system once preset ‘alarm’ flow thresholds had been reached in the highway drain.

The key event selection criteria were:

- a minimum antecedent dry weather period (ADWP) of 24 hours;
- sampling had commenced at the start of the drainage system’s response to the event;

- the majority of the storm runoff was monitored in the sampling period;
- the total event rainfall had to vary between small (less than 5 mm), medium (between 5 and 10 mm) and large storms (greater than 10 mm);
- the mean event rainfall intensity had to fall into low (<4 mm per hour), medium (4-12 mm per hour) or high intensity (>12 mm per hour); and,
- runoff from snowmelt was not required.

A sample that satisfied the above criteria was sent for analysis. A range of events at each site had to be captured to cover as many of these requirements as possible.

2.4.3 Sample preparation

The sample was collected by an auto-sampler. Once sampling had finished, a site visit was made to collect the samples and reset the equipment. The auto-sampler collected 24 1 litre samples in separate bottles at a fixed sampling interval ranging from 6 to 30 minutes depending on the site characteristics and the forecast rainfall duration. A flow weighted composite sample from each event was created for subsequent analysis to determine the event mean concentration (EMC) of specified pollutants. A standard protocol was adopted in preparing the flow weighted composite sample. This was based on extracting 500 ml from the individual sample collected at the peak flow measured in the highway drain. Proportionally smaller sample volumes were extracted from the remaining samples based on the ratio of the flow at the time of sampling to the peak flow. The flow weighted composite sample was used to fill a 2 litre brown glass bottle and a 250 millilitre clear glass bottle (for PAH analysis). All sample bottles were new and pre-cleaned.

An example of the make up of a composite sample is shown in Figure 2.3. This illustrates the flow in the highway drain during sampling and how much of each individual sample bottle was included in the flow weighted composite sample.

Sample bottles were packed in 'Cool Boxes' and sent by courier, within 24 hours of sample collection, to the laboratory for analysis.

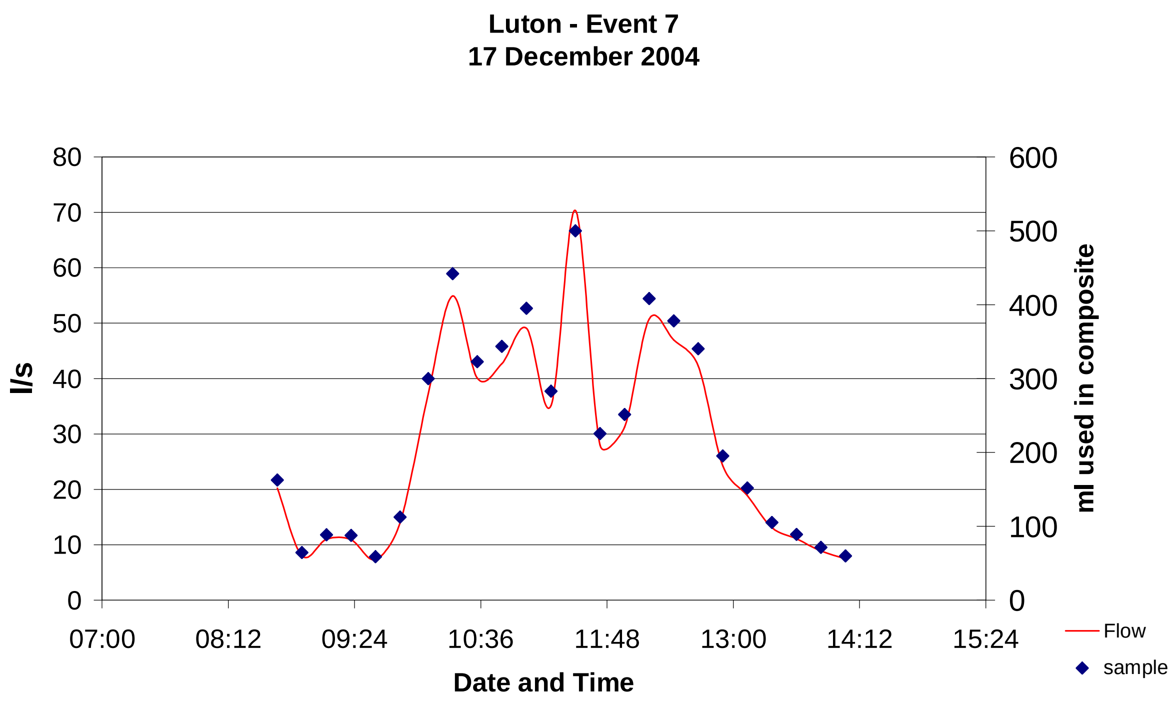


Figure 2.3 An Example of the Make Up a Flow Weighted Composite Sample

3. STAGE 2 DATA COLLECTION

3.1 Overview of Stage 2

The following tasks were undertaken during Stage 2:

- site visits and information collection leading to the firm selection of the 4 Group A sites for Stage 2 monitoring and the provisional identification of the additional 20 Group B sites for Stage 3;
- installation of the 4 Group A sites for event monitoring;
- sample collection of 10 events at each of the 4 Group A sites;
- population of the database with sampling results;
- data analysis of the results;
- comparison of event characteristics; and,
- identification of the analysis suite for Stage 3.

In the course of Stage 2 it became clear that it was necessary to identify the Stage 3 sample analysis suites before the completion of all Stage 2 sample collection and data analysis. Therefore, an initial evaluation of data from the first 21 samples was used to specify the Stage 3 sample analysis. As a consequence of this, it was agreed to reduce the original scope of the Stage 2 data analysis and reporting and to focus the data analysis on the combined Stage 2 and Stage 3 data set for subsequent model development in Stage 4. The revised requirement for the Stage 2 data analysis became:

- to confirm the identification of key determinands; and,
- to identify any potential relationships between determinands and site characteristics.

3.2 Data Collection

The aim of Stage 2 was to collect data on pollutants in highway runoff from 4 Group A sites for 10 events per site for the specified Analysis Suite 1 determinands, including total (unfiltered sample) and dissolved (filtered sample) determinations(1). The 4 Group A study sites represent the conditions under which the greatest potential pollution loadings within each of the four defined climate regions were considered to be most likely to occur. The 4 Group A sites, as shown in Table 2.2 were:

- Cold/dry – A1(M) Leeds (Aberford)
- Warm/Wet – M5 Bromsgrove
- Warm/dry – M1 Luton

- Cold/wet – M6 Lymm.

Ten events were captured at each site during the period June 2004 to September 2005. Samples were collected in a range of seasons to try to capture both summer storms and winter events after salt application. Flow weighted event mean composite samples were analysed for the specified Suite 1 determinands, as shown in Table 3.1. A sub sample was filtered through a 45um glass fibre filter, following standard protocols(1). The resulting filtrate was analysed to produce a 'dissolved' (soluble) fraction result. The unfiltered sample analysis produced a 'total' (insoluble and soluble fraction) sample result. Reporting of 'de-icing salt' is based on the concentration of Chloride (Cl^-) in highway runoff to allow for comparison with other Highways Agency data.

All Stage 2 samples were analysed by WRc Laboratories.

Table 3.1 Suite 1 Sample Analysis

Determinand	Limit of Detection
Metals: total and dissolved	
Cu	0.3 ug/l
Zn	0.6 ug/l
Cd	0.01 ug/l
Al	0.4 ug/l
Ni	0.01 ug/l
Cr	0.3 ug/l
Pb	0.1 ug/l
Pd	0.5 ug/l
Pt – total only	0.5 ug/l
Organics: total and dissolved	
Total Hydrocarbons	5.0 ug/l
Naphthylene	0.01 ug/l
Acenapthylene	0.01 ug/l
Acenapthene	0.01 ug/l
Fluorene	0.01 ug/l
Phenanthrene	0.01 ug/l
Anthracene	0.01 ug/l
Fluoranthene	0.01 ug/l
Pyrene	0.01 ug/l
Benzo(a)anthracene	0.01 ug/l
Chrysene	0.01 ug/l
Benzo(b)fluoranthene	0.01 ug/l
Benzo(k)fluoranthene	0.01 ug/l
Benzo(a)pyrene	0.01 ug/l
Indeno(1,2,3-cd)pyrene	0.01 ug/l
Dibenzo(a,h)anthracene	0.01 ug/l
Benzo(g,h,I)perylene	0.01 ug/l
MTBE	0.2 ug/l

Determinand	Limit of Detection
De-icing Agents:	
Na	0.05 mg/l
Cl	0.2 mg/l
Free Cyanide	10 ug/l
Others:	
Suspended Solids	2 mg/l
Nitrate – dissolved only	0.1 mg/l
Particle Size Analysis	n/a

3.3 Stage 2 Data Analysis

The main objectives of the Stage 2 data analysis were:

- to repeat the analysis for key pollutants in highway runoff and update the list of key determinands based on the previous study(1); and,
- to look for any strong relationships between key determinands and, hence, potentially to define a subset of 'primary' key determinands for model development.

The outcome of the Stage 2 data analysis identified:

1. Higher average and a greater range of pollutant concentrations were found at the Group A sites compared to the previous study. This appears to be a reflection of the higher traffic densities.
2. The Stage 2 data analysis identified a wider range of key determinands:
    - total and dissolved Copper;
    - total Zinc;
    - dissolved Aluminium;
    - total and dissolved Cadmium;
    - total Lead;
    - dissolved Chromium;
    - total PAHs and the 16 specific total PAH;
    - TSS; and,
    - De-icing Salt (Na+Cl).
3. Correlation analysis identified that relationships between key determinands were generally poor with the exception of those between the PAHs and Total Zn with filtered Cu. The analysis also suggests that relationships between determinands are not dependent on site or climate characteristics.
4. Previous studies have inferred relationships between determinands such as dissolved Copper and total Zinc; metals and PAH; and, the potential to identify surrogate indicator

substances. The statistical analysis carried out in Stage 2 did not substantiate these proposed relationships.

5. Comparison of trends in the data showed no elevation of concentrations in the winter and following salting as was the case in the previous study. This may be due to a bias in the Stage 2 data resulting from few events being captured during the winter of the Stage 2 monitoring period. The Stage 2 data show no relationships between pollutant concentrations and ADWP, total event rainfall and event average rainfall intensity.

6. A small number of events produced total Zinc concentrations that were much higher than those for the majority of events.

The following recommendations were made for developing proposals for the subsequent Stage 3 data analysis:

- confirm the identification of levels of all key determinands using the full data set available and re assess the use of EQS values in the selection;

- confirm potential relationships indicated by the Stage 2 and previous data in relation to causative factors in pollutant concentrations and if necessary take into account any potential bias due to low numbers of winter events;

- consider using total PAHs as a surrogate for levels of individual PAH based on the correlation between individual PAH; and,

- identify any factors producing the high runoff concentrations found in 2 events for total Zinc.

4. STAGE 3 MONITORING AND DATA ANALYSIS

4.1 Overview of Stage 3

The objective of Stage 3 was to study the influence of site specific factors and variables, including traffic flows and climate conditions on highway runoff pollutant concentrations; and, to assess the importance of the 'first flush' of pollutants in response to a rainfall event. The original programme for Stage 3 included the following tasks.

- To identify and instrument 20 Group B sites in addition to the 4 original Group A sites monitored in Stage 2. These sites were to be selected to cover each of the 6 potential traffic bands in each climate region, as defined in Stage 2.

- To carry out a field monitoring programme to capture 10 events for a range of seasonal conditions and storm event characteristics over a minimum monitoring period of 12 months at each Group A and Group B site.

- To collect EMC samples, as defined in Stage 2, from each event and analyse the samples for the defined Analysis Suite 2. This specified analysis for total and dissolved Zinc, Copper, Cadmium and the PAH, Pyrene and Fluoranthene. In addition, TSS and particle size distribution were also required.

- To carry out additional 'time determined' sample collection and analysis for 2 of the 10 Stage 3 events at each site. This requirement specified the collection and analysis of a minimum of 12 discrete samples during the event to characterise any 'first flush'. Discrete samples were to be analysed for a reduced parameter suite, Analysis Suite 3. This specified analysis for total and dissolved Zinc, Copper, Pyrene and Fluoranthene. Determination of TSS and particle size analysis was also specified for Suite 3.

- To carry out a statistical analysis of the data collected to identify:

    - the relationships between pollutant concentrations, traffic flow and other site characteristics;

    - the worst case 'design storm' for each climate region – the type of rainfall event under which the maximum amount of pollution is likely to occur;

    - the significance and characteristics of the 'first flush'; and

    - to produce a report on the outcome of Stage 3.

4.2 Data Collection

Stage 3 data collection was based on capturing 10 events at each of the 24 Group A and Group B monitoring sites as identified in Table 2.2 and Figure 2.2. Data capture was based on the same protocols established for Stage 2 monitoring. In addition to EMC event data capture at all Stage 3 sites, the original specification identified a requirement to collect 2 discrete time determined sample events at each site. These were to be used to support an assessment of the significance of 'first flush' pollutant responses to rainfall. The Group A sites represent the highest traffic bands in each climate region and the initial Stage 2 Group A site monitoring results indicated higher levels of pollutants than those found from the lower traffic band sites in the previous study[1]. Therefore, it was postulated that it was highly probable that 'first flush' effects and potential impacts would be highest at the Group A sites. As a consequent, it was agreed that all the time determined sampling would be carried out in conjunction with the EMC sampling for the 40 Group A site events. It was also agreed that the 12 discrete samples per event would be based on subsampling from the first 12 of the 24 individual 1 litre event samples collected by the auto-sampler.

4.2.1 Stage 3 Sample Analysis Suites

The original Stage 3 EMC and time determined sample analysis suites represented a reduction in sample analysis compared to the Stage 2 Suite 1. However, in the course of Stage 2, it became apparent that the Stage 3 analysis suites would need to be based on the initial results from Stage 2 to avoid programme slippage. This allowed a rolling start to Stage 3 as Stage 2 sampling was completed at each Group A site with sample analysis based on the outcome of Stage 2 plus additional determinands to be monitored to support other Highways Agency research as shown in Table 4.1 for both EMC and discrete samples. This approach maximised the number of results available for the Stage 3 data analysis by maintaining compatibility with the Stage 2 data and the data from the previous study[1].

Table 4.1 Stage 3 Sample Analysis

Determinand	Limit of Detection	Dissolved (Filtered Sample)	Total (Unfiltered sample)
Metals:			
Cu	0.3 ug/l	X	X
Zn	0.6 ug/l	X	X
Cd	0.01 ug/l	X	X
Al	0.4 ug/l	X	N/A
Cr	0.3 ug/l	N/A	X
Pb	0.1 ug/l	X	X
Organics:			
Total PAHs	5.0 ug/l	N/A	X
Naphthalene	0.01 ug/l	N/A	X
Acenapthylene	0.01 ug/l	N/A	X
Acenapthene	0.01 ug/l	N/A	X
Fluorene	0.01 ug/l	N/A	X
Phenanthrene	0.01 ug/l	N/A	X
Anthracene	0.01 ug/l	N/A	X
Fluoranthene	0.01 ug/l	N/A	X
Pyrene	0.01 ug/l	N/A	X
Benzo(a)anthracene	0.01 ug/l	N/A	X
Chrysene	0.01 ug/l	N/A	X
Benzo(b)fluoranthene	0.01 ug/l	N/A	X
Benzo(a)pyrene	0.01 ug/l	N/A	X

Determinand	Limit of Detection	Dissolved (Filtered Sample)	Total (Unfiltered sample)
Indeno(1,2,3-cd)pyrene	0.01 ug/l	N/A	X
Dibenzo(a,h)anthracene	0.01 ug/l	N/A	X
Benzo-k-fluoranthene	0.01 ug/l	N/A	X
Benzo(g,h,i)perylene	0.01 ug/l	N/A	X
De-icing Agents:			
Sodium	0.05 mg/l	N/A	X
Cl^-	0.2 mg/l	N/A	X
Others:			
Total Suspended Solids	2 mg/l	N/A	X
Particle Size Analysis		N/A	X*
BOD_5(ATU)	1 mg/l	X	X
COD	10 mg/l	X	X

N/A – not analysed

* excluded for time determined discrete samples from Group A sites

4.2.2 Data Collection Programme

Stage 3 data collection commenced in May 2005 as the Stage 2 data collection at the Group A sites was completed and event capture continued for Stage 3. The Group B sites became operational in a rolling programme of site instrumentation and activation. Data capture at a number of sites was restricted or delayed by roadworks during the monitoring period. The M1, Luton Group A site was abandoned after 16 events due to a major road widening scheme commencing earlier than originally planned. As a result, 4 time determined events were captured at the M25 Redhill Group B site as this was also a traffic band 6 site. Other sites where the data collection was delayed by external factors, including roadworks, permission to access the site and the identification of site drainage included Bromsgrove, Honiton, Holme, Garstang, Micklefield and Tadcaster. As a consequence, monitoring at some sites was limited to less than 12 months. In particular, monitoring at the Tadcaster and Doncaster sites, in the Cold/Wet region, did not commence until the summer of 2006. Stage 3 data collection was not completed until December 2006.

Figure 4.1 shows the rate of progress with Stage 3 data collection. The Stage 3 data collection period was characterised by 2 dry, mild winters and hot, dry summers. The limited number of winter events captured compared to summer events is a reflection of the general weather pattern over the monitoring period and may have resulted in a bias in the database in terms of the effects of winter conditions and winter salting on pollutant concentrations. This is discussed further in Section 4.3.

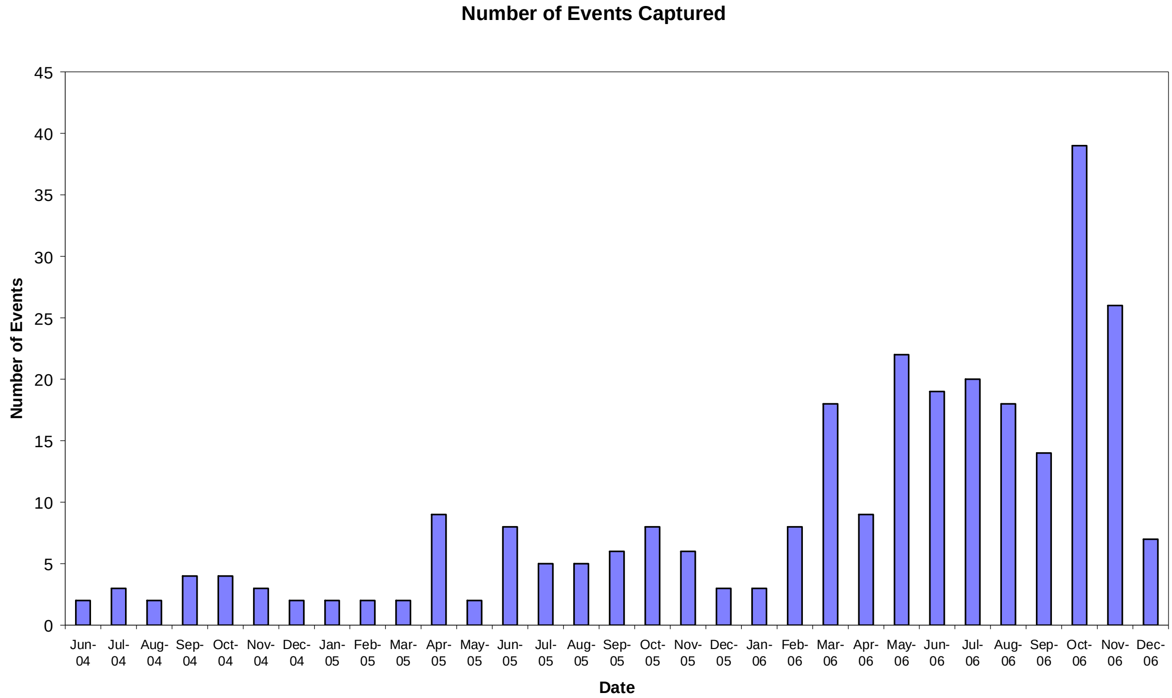


Figure 4.1 Data Capture

4.3 <u>Data Analysis</u>

4.3.1 Objectives

The revised objectives for the Stage 3 data analysis were to undertake a statistical analysis to determine:

- the relationship between pollutant concentrations, traffic flow and other site characteristics; and,
- the significance and characteristics of the first flush.

Previous studies into the impact of soluble and insoluble pollutants found in routine highway runoff have identified a range of pollutants that have been found in highway runoff at concentrations that pose a risk of short-term acute impacts and/or long term chronic impacts on ecosystems. A list of potential 'significant pollutants' was agreed between the Highways Agency and the Environment Agency, based on the Stage 2 results plus information from the 2 supporting projects[2,3]. These were:

- total and dissolved Copper;
- total and dissolved Zinc;
- total Cadmium; and,

- total Fluoranthene, total Pyrene and total PAHs.

4.3.2 Data Analysis Approach

The objective of the Stage 3 data analysis was to identify the factors and variables that influence pollutant concentrations in routine highway runoff. The statistical methods adopted for the Stage 3 data analysis were based on those used in Stage 2 [(5)].

The Stage 3 data analysis was carried out in 5 phases:

- Phase 1 –outlier identification and removal, plus application of agreed protocols for less than values;

- Phase 2 – assessment of event characteristics and within site data analysis to generate site summary Tables for inclusion in the individual Site Reports;

- Phase 3– generation of pollutant summary statistics for all data, by climate region and traffic band, plus analysis for dissolved (soluble) significant pollutants against the proposed ecological standards;

- Phase 4 – initial analysis of the behaviour of significant pollutants for model development, including potential relationships with climate, site and event characteristics; and,

- Phase 5 – analysis of Stage 3 Group A site EMC and time determined data for within event pollutant concentration and load variations and peaking factors in relation to event characteristics.

Compatible event characteristics and pollutant data for the following determinands were included in the database for a total of 340 storm events at 30 sites following the inclusion of data from the previous study[(1)]. These were:

- Metals – total and dissolved Copper, total Zinc, total Cadmium and total Lead;
- total PAHs and 16 individual total PAH; and,
- TSS and Cl^-.

Table 4.2 gives a breakdown of all 30 sites by climate region and traffic flow.

Table 4.2 All Monitoring Sites – Traffic Bands and Climate Regions

Traffic Band	AADT (vpd)	Sites Warm Dry	Sites Warm Wet	Sites Cold Dry	Sites Cold Wet	Sites Total
1	5000 - 14999				1	1
2	15000 - 29999	1	4		1	6
3	30000 - 49999	1	1	2	1	5
4	50000 - 79999	2	1	3	2	8
5	80000 - 119999	3	3	1		7
6	120000 - 200000	2			1	3

4.3.3 Phase 1: Removal of Outliers

Outliers are data values that appear to be outside the normal range in terms of a consistent data set. Outliers may be a result of unusual site/event conditions, analytical error or data entry error. The whole database was checked for outliers in individual results for EMC and time determined samples. The identification of outliers was based on extreme high values as many values were close to the limit of detection (LOD) or exhibited a broadly consistent range of concentrations. The majority of potential outliers were identified as being a result of analytical or reporting error. However, a relatively small number of extreme values were identified as being likely to be true results. Similar results have been found in a comparable study carried out in the USA[11]. It was considered that these results were related to non routine pollutant build up, for example, due to spillages or release as a result of accidental damage. Figure 4.2 illustrates an example of this phenomenon.

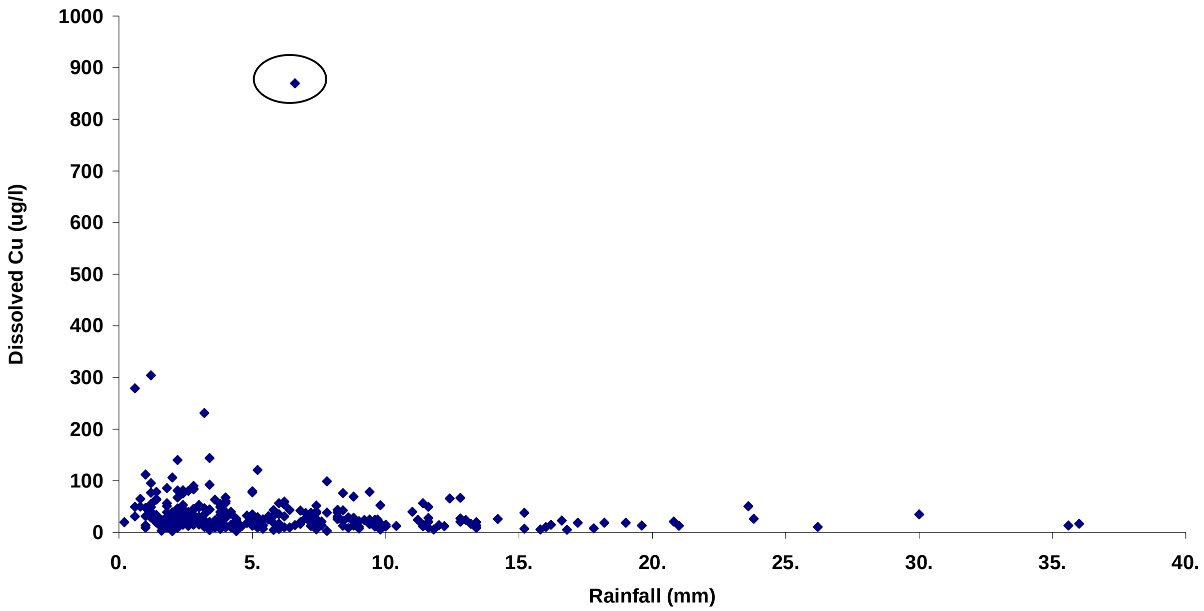


Figure 4.2 EMC Outlier for Dissolved Copper

4.3.4 Rainfall Event Characteristics

The overall pattern of rainfall events captured shows a range of event characteristics covering the need for variability in the size of event (total rainfall) with ADWP, mean rainfall intensity and peak rainfall intensity. The range of events would, therefore, appear to be typical of rainfall patterns in England. There were relatively few extreme events, despite the relatively low rainfall during the Stage 2 and Stage 3 monitoring period that may have produced events with more extreme characteristics, such as ADWP. General relationships between runoff event characteristics showed:

- a range of events for each climate zone;
- the largest individual events and range of events occurred during the late Spring to early Autumn;
- the winter events had the smallest range of total rainfall;
- 86% of events have a total rainfall <10 mm;
- 87% of events had an ADWP < 15 days;
- 88% of events had a mean rainfall intensity <5 mm/hr;
- 90% of events had a peak rainfall intensity <30 mm/hr;
- 23% of events occurred on Saturday-Sunday;
- 73% of events occurred between 7 am and 7 pm (including those that started before 7 am and finished after 7 pm);
- 64% of events occurred within the periods 7 am to 10 am and 4 pm to 7 pm, representing the likely most heavily trafficked periods; and,
- the average event duration was 5.6 hours.

In terms of event characteristics in relation to the 4 defined regional climate zones:

- the largest events occurred in the Warm/Dry and Warm/Wet regions;
- the lowest ranges of ADWP, mean intensity and peak intensity occurred in the Cold/Wet region;
- the greatest range of ADWP occurred in the Warm/Wet region; and,
- the greatest range of mean and peak rainfall intensity occurred in the Cold/Dry region.

Figure 4.3 illustrates the spread of rainfall events in relation to event rainfall and ADWP.

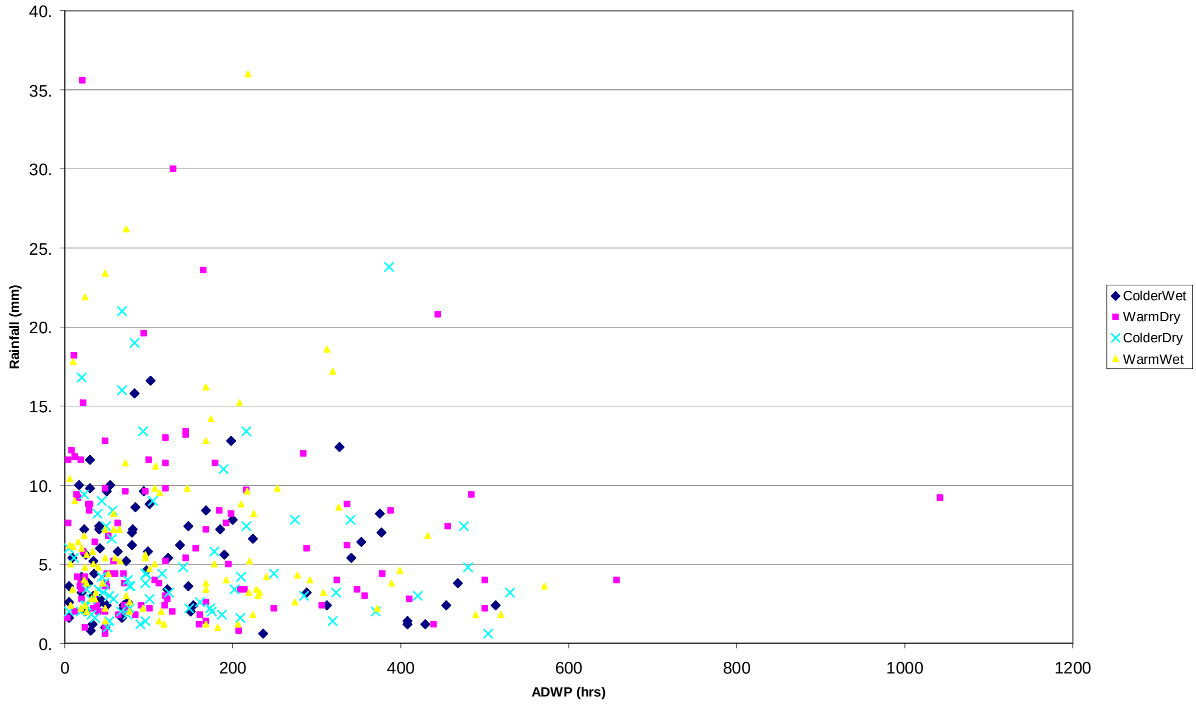


Figure 4.3 Event rainfall and ADWP (hrs)

4.3.5 Within Site Data Analysis

All within site event data and summary results for EMCs and Group A site time determined samples are presented in the individual Stage 3 Site Reports. Data analysis of the EMC event results for each event adopted the following protocols:

1. if the determinand analysed was only detected at values of less than the limit of detection (<LOD) it was reported as Not Detected (ND);

2. if the determinand analysed was detected at values above the limit of detection for some events but was also detected at <LOD for others, then the values recorded as <LOD were given a value of the LODx0.5;

3. all identified outliers were excluded from the data analysis; and,

4. summary statistics have been generated for average event pollutant loads based on the average of loads from the individual events.

The load for each event is the product of the EMC and the volume of highway runoff. The main source of elevated Sodium and Chloride concentrations in highway runoff is winter salt application. Average event loads have not been calculated for these determinands as the observed concentrations are the result of an intermittent maintenance activity.

4.3.6 Phase 3 Summary Statistics for Pollutant Concentrations in Highway Runoff

Summary Statistics for Event Mean Concentrations

MTBE and Free Cyanide were only measured in the 40 Stage 2 events. MTBE was only detected above LOD for 1 event. Dissolved Dibenzo[a,h]anthracene and Free Cyanide were not detected above the LOD. The results for the majority of dissolved PAHs, also only measured in Stage 2, were below the analytical limit of detection (0.01 ug/l) as shown in Table 4.3.

Table 4.3 Dissolved PAH Results above LOD

Determinand Name	Total No. of Samples	No of Samples greater than LOD
Dissolved Acenaphthene	40	12
Dissolved Acenaphthylene	40	8
Dissolved Anthracene	40	5
Dissolved Benz[a]anthracene	40	4
Dissolved Benz[g,h,I]perylene	40	5
Dissolved Benzo[a]pyrene	40	3
Dissolved Benzo[b]fluoranthene	40	6
Dissolved Benzo[k]fluoranthene	40	3
Dissolved Chrysene	40	15
Dissolved Dibenzo[a,h]anthracene	40	0
Dissolved Fluoranthene	40	36
Dissolved Fluorene	40	5
Dissolved Indeno[1,2,3-c,d]pyrene	40	3
Dissolved Naphthalene	40	17
Dissolved Phenanthrene	40	17
Dissolved Pyrene	40	36

Table 4.4 presents a summary of the EMCs for all 340 events. The significant pollutants are highlighted. TSS is also highlighted, as this determinand was used to estimate event loads for insoluble pollutants for other Highways Agency studies[(3)].

In general, these results were higher than those from the previous study[(1)] that included data from sites in Traffic Bands 2-5. However, they tended to be lower than those from the Stage 2 monitoring data that were from Traffic Bands 5-6.

Table 4.4 Summary of All Event Mean Concentrations

Determinand	Units	LOD	Smallest EMC	Average EMC	Median EMC	Largest EMC	Average Event Load/1000m^2	Runoff Load Units
Total Cu	**ug/l**	**0.3**	**4.00**	**91.22**	**42.99**	**876.80**	**0.66**	**g**
Dissolved Cu	**ug/l**	**0.3**	**2.15**	**31.31**	**23.30**	**304.00**	**0.16**	**g**
Total Zn	**ug/l**	**0.6**	**9.73**	**352.63**	**140.00**	**3510.00**	**2.44**	**g**
Dissolved Zn	**ug/l**	**0.6**	**4.99**	**111.09**	**58.27**	**1360.00**	**0.50**	**g**
Total Cd	**ug/l**	**0.01**	**<0.01**	**0.63**	**0.29**	**5.40**	**0.00**	**g**
Dissolved Cd	ug/l	0.01	<0.01	0.26	0.13	3.12	0.00	g
Total Al	ug/l	0.4	103.00	2593.10	1310.00	11040.00	13.77	g
Dissolved Al	ug/l	0.4	<0.4	80.07	24.88	957.00	0.40	g
Total Ni	ug/l	0.01	0.73	10.31	7.10	47.20	0.05	g
Dissolved Ni	ug/l	0.01	0.66	3.28	2.74	12.90	0.02	g
Total Cr	ug/l	0.3	<0.30	7.00	3.82	60.70	0.05	g
Dissolved Cr	ug/l	0.3	<0.30	5.27	4.08	24.30	0.05	g
Total Pb	ug/l	0.1	<0.10	37.68	9.50	378.90	0.31	g
Dissolved Pb	ug/l	0.1	<0.10	3.81	0.55	176.00	0.02	g
Total Pd	ug/l	0.2	<0.20	0.21	0.20	0.90	0.00	g
Dissolved Pd	ug/l	0.2	<0.20	0.16	0.10	0.25	0.00	g
Total Pt	ug/l	0.2	<0.20	0.15	0.10	0.25	0.00	g
Total Petroleum Hydrocarbons (Total)	ug/l	5.0	810.00	6958.00	4820.00	19900.00	34.18	g
Total Petroleum Hydrocarbons (Dissolved)	ug/l	5.0	146.00	746.76	500.00	3310.00	3.39	g
Total Naphthalene	ug/l	0.01	<0.01	0.06	0.00	0.92	0.00	g
Dissolved Naphthalene	ug/l	0.01	<0.01	0.06	0.03	0.25	0.00	g
Total Acenaphthylene	ug/l	0.01	<0.01	0.03	0.00	0.33	0.00	g
Dissolved Acenaphthylene	ug/l	0.01	<0.01	0.01	0.01	0.07	0.00	g
Total Acenaphthene	ug/l	0.01	<0.01	0.03	0.00	0.58	0.00	g
Dissolved Acenaphthene	ug/l	0.01	<0.01	0.02	0.01	0.12	0.00	g
Total Fluorene	ug/l	0.01	<0.01	0.04	0.01	1.00	0.00	g
Dissolved Fluorene	ug/l	0.01	<0.01	0.01	0.01	0.03	0.00	g
Total Phenanthrene	ug/l	0.01	<0.01	0.35	0.13	3.63	0.00	g
Dissolved Phenanthrene	ug/l	0.01	<0.01	0.02	0.01	0.11	0.00	g
Total Anthracene	ug/l	0.01	<0.01	0.08	0.03	0.81	0.00	g
Dissolved Anthracene	ug/l	0.01	<0.01	0.01	0.01	0.02	0.00	g
Total Fluoranthene	**ug/l**	**0.01**	**<0.01**	**1.02**	**0.30**	**12.50**	**0.01**	**g**
Dissolved Fluoranthene	ug/l	0.01	<0.01	0.04	0.03	0.09	0.00	g
Total Pyrene	**ug/l**	**0.01**	**<0.01**	**1.03**	**0.31**	**12.50**	**0.01**	**g**
Dissolved Pyrene	ug/l	0.01	<0.01	0.04	0.03	0.09	0.00	g
Total Benz[a]anthracene	ug/l	0.01	<0.01	0.54	0.25	5.13	0.00	g
Dissolved Benz[a]anthracene	ug/l	0.01	<0.01	0.01	0.01	0.02	0.00	g

Determinand	Units	LOD	Smallest EMC	Average EMC	Median EMC	Largest EMC	Average Event Load/1000m^2	Runoff Load Units
Total Chrysene	ug/l	0.01	<0.01	0.76	0.29	7.40	0.00	g
Dissolved Chrysene	ug/l	0.01	<0.01	0.01	0.01	0.03	0.00	g
Total Benzo[b]fluoranthene	ug/l	0.01	<0.01	1.02	0.50	8.78	0.01	g
Dissolved Benzo[b]fluoranthene	ug/l	0.01	<0.01	0.01	0.01	0.03	0.00	g
Total Benzo[k]fluoranthene	ug/l	0.01	<0.01	0.36	0.16	3.50	0.00	g
Dissolved Benzo[k]fluoranthene	ug/l	0.01	<0.01	0.01	0.01	0.02	0.00	g
Total Benzo[a]pyrene	ug/l	0.01	<0.01	0.69	0.33	6.56	0.00	g
Dissolved Benzo[a]pyrene	ug/l	0.01	<0.01	0.01	0.01	0.02	0.00	g
Total Indeno[1,2,3-c,d]pyrene	ug/l	0.01	<0.01	0.56	0.27	5.61	0.00	g
Dissolved Indeno[1,2,3-c,d]pyrene	ug/l	0.01	<0.01	0.01	0.01	0.02	0.00	g
Total Dibenzo[a,h]anthracene	ug/l	0.01	ND	ND	ND	ND	ND	
Dissolved Dibenzo[a,h]anthracene	ug/l	0.01	<0.01	0.01	0.01	0.02	0.00	g
Total Benz[g,h,I]perylene	ug/l	0.01	<0.01	0.59	0.25	5.70	0.00	g
Dissolved Benz[g,h,I]perylene	ug/l	0.01	<0.01	0.01	0.01	0.03	0.00	g
Total PAHs (Total)	**ug/l**	**0.01**	**<0.01**	**7.52**	**3.33**	**62.18**	**0.04**	**g**
Total PAHs (Dissolved)	ug/l	0.01	0.10	0.27	0.25	0.54	0.00	g
De-icing Salt (as Cl^-)	mg/l	0.2	5.00	349.53	66.00	9760.00		
Free Cyanide	ug/l	10.0	ND	ND	ND	ND		
Sodium	mg/l	0.05	3.90	261.12	51.90	5400.00		
Nitrate (as N)	mg/l N	0.05	0.05	1.29	1.25	4.68	0.01	kg
Total Suspended solids TSS	mg/l	2.0	1.00	243.87	139.00	2030.00	1.69	kg
MTBE*	ug/l	0.2				0.80		
BOD (ATU, 5 day) Total	mg/l	1.0	<1.0	6.11	4.00	57.00	0.03	kg
BOD (ATU, 5 day) Dissolved	mg/l	1.0	<1.0	2.27	2.00	21.00	0.01	kg
COD (Total)	mg/l	1.0	10.00	201.93	128.00	1900.00	1.36	kg
COD (Dissolved)	mg/l	1.0	10.00	47.79	35.00	475.00	0.25	kg

LOD – Analytical limit of detection   ND - Not detected above LOD
*only detected above LOD in 1 event.

The results from the previous study[1] showed higher levels of some pollutants than the values provided in the then current ranges of pollutant levels presented in DMRB 11.3 part 10 (1998)[10] for rural highways with AADT < 30,000 vpd and used to estimate annual pollutant loading rates for dissolved Copper and total Zinc. The results from the previous study[1] are used in current guidance, as identified in DMRB 11.3 part 10 – HA216/06 (2006)[9]

Table 4.5 compares the previous ranges of EMC values with those derived from all 340 events. With the exception of total Lead, both the 2 sets of DMRB values are smaller and have a smaller range than those from the current study. The original DMRB data for total Lead are based on data from the 1980s, whereas the more recent data are considerably lower and reflect the benefits of removing Lead based additives from petrol.

Table 4.5 Comparison of ranges of pollutant EMCs

Pollutant	Original DMRB Median EMC* Range[10]	Median EMC Range[*] Long Term Monitoring Study[1]	Median EMC* Range All Data
Total Copper (ug/l)	10 - 50	13 - 87	13 - 242
Total Zinc (ug/l)	35 - 85	40 - 317	34 - 903
Total Lead (ug/l)	24 - 272	0.13 – 4.00	0.46 - 114
Total COD (mg/l)	28 - 85	41 - 149	48 - 411
Total Suspended Solids (mg/l)	12 - 135	27 - 201	40 - 612

* value exceeded by 10% and 90% of sites respectively

Dissolved Copper and Zinc have been identified as significant pollutants in terms of potential ecological risk. Dissolved Cadmium and dissolved Pyrene and Fluoranthene were also considered to be a potential risk. However, comparison of all the data with Risk Specific Thresholds (RSTs) developed under another Highways Agency research project into the effects of soluble pollutants in receiving waters[2] demonstrated that no observed highway runoff EMCs for dissolved Cadmium, Pyrene and Flouranthene exceeded the proposed event thresholds for receiving waters. Table 4.6 shows the %age of events failing the RST_{6hr} and RST_{24hr} thresholds potentially impacting on 5% of species in the receiving water as an emission standard applied to the untreated/undiluted runoff. However, the observed runoff EMCs for both dissolved Copper and dissolved Zinc exceeded the RST_{24hr} and RST_{6hr} thresholds for around 50% and 20% of events, respectively.

Table 4.6 Exceedence of Runoff Specific Thresholds for Soluble Pollutants – All Event Data

Parameter	Values for substance of interest				
	Cadmium (RST_{24h} = 40 ug/l, RST_{6h} = 80 ug/l)	Copper (RST_{24h} = 21 ug/l, RST_{6h} = 42 ug/l)	Zinc (RST_{24h} = 60 ug/l, RST_{6h} = 120 ug/l)	Fluoranthene (RST_{24h} = 1.3 ug/l,	Pyrene (RST_{24h} = 1.3 ug/l,
Number of EMC values exceeding the RST_{24h} value (% of total)	0	184 (53.9)	155 (45.5)	0	0
Number of EMC values exceeding the RST_{6h} (% of total)	0	74 (21.7)	70 (20.5)	0	0

Table 4.7 presents the summary statistics for the Significant Pollutants.

Table 4.7 Summary Statistics for Significant Pollutants - All Event data

Determinand	Units	LOD	Average EMC	Median EMC	Average Event Load/1000m^2	Runoff Load Units
Total Cu	ug/l	0.30	91.22	42.99	0.66	g
Dissolved Cu	ug/l	0.30	31.31	23.30	0.16	g
Total Zn	ug/l	0.60	352.63	140.00	2.44	g
Dissolved Zn	ug/l	0.60	111.09	58.27	0.50	g
Total Cd	ug/l	0.01	0.63	0.29	0.00	g
Total Fluoranthene	ug/l	0.01	1.02	0.30	0.01	g
Total Pyrene	ug/l	0.01	1.03	0.31	0.01	g
Total PAHs (Total)	ug/l	0.01	7.52	3.33	0.04	g
Total Suspended Solids (TSS)	mg/l	2.00	244.00	139.00	1.69	kg

4.4 Phase 4 Potential Relationships Between Determinands, Site Factors and Event Characteristics

4.4.1 Relationships Between Determinands

One of the original project objectives was to investigate and determine any relationships between individual contaminants found in highway runoff and to identify the existence of any substances that may be taken as indicative of a range of other pollutants. Stage 2 data analysis identified that relationships between determinands were positive, but generally poor, except between some individual PAH and between total Zinc and dissolved Copper. Analysis was based on a linear regression analysis to test for any significant correlations between determinands on the basis of estimating the 'least squares' fit. A summary of the results for the significant pollutants is presented in Table 4.8. These show the r^2 value for each regression equation. An r^2 value close to 1 indicates a very high correlation between 2 sets of data, while a value close to 0 shows little or no correlation between the datasets.

Table 4.8 Correlations (r^2) between Significant Pollutants

	Total Cu ug/l	Dissolved Cu ug/l	Total Zn ug/l	Dissolved Zn ug/l	Total Cd ug/l	Total Pyrene ug/l	Total of individual total PAH ug/l	Total Fluoranthene ug/l
Dissolved Cu ug/l	0.16							
Total Zn ug/l	0.75	0.06						
Dissolved Zn ug/l	0.08	0.21	0.23					
Total Cd ug/l	0.08	0.00	0.07	0.00				
Total Pyrene ug/l	0.11	0.02	0.13	0.02	0.02			
Total of individual total PAH ug/l	0.09	0.01	0.12	0.02	0.12	0.97		
Total Fluoranthene ug/l	0.11	0.02	0.13	0.03	0.02	0.97	0.96	
Suspended solids TSS mg/l	0.28	0.00	0.27	0.00	0.17	0.13	0.14	0.15

These results show that, with the exception of total PAHs s an indicator of concentrations of other individual total PAH, there is no evidence to support the use of one or more indicator substances as a surrogate for others. The results indicate that total PAHs could use as an indicator of total Pyrene and total Fluoranthene.

Figure 4.4 and Figure 4.5 show the relationships between:

- total Zinc and total Copper; and,
- total Fluoranthene and total PAHs, respectively.

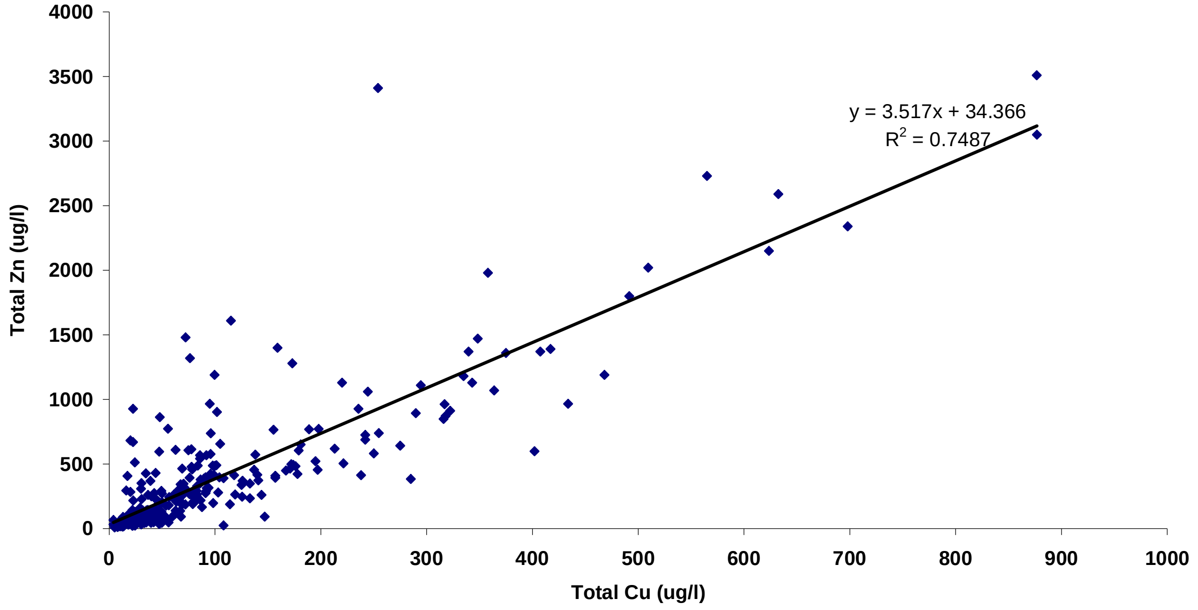


Figure 4.4 Relationship between Total Zinc and Total Copper

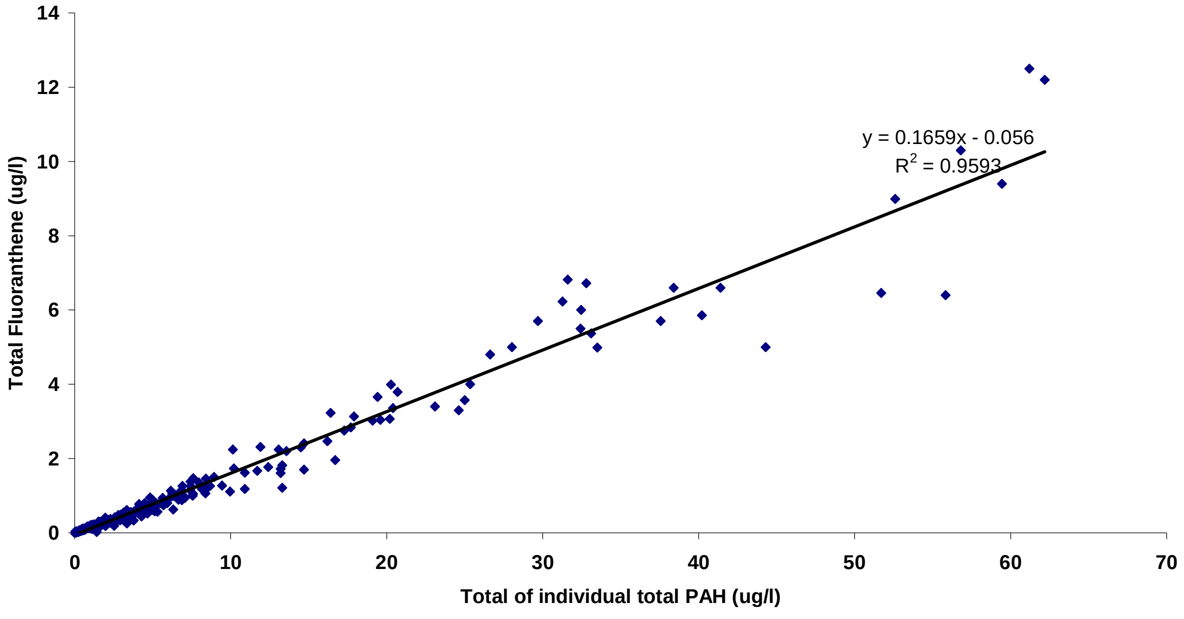


Figure 4.5 Relationship between Total Fluoranthene and Total PAHs

There were no relationships found between the significant pollutants, as illustrated for total Copper and TSS in Figure 4.6. Consequently, TSS could not be used as a surrogate for the significant pollutants.

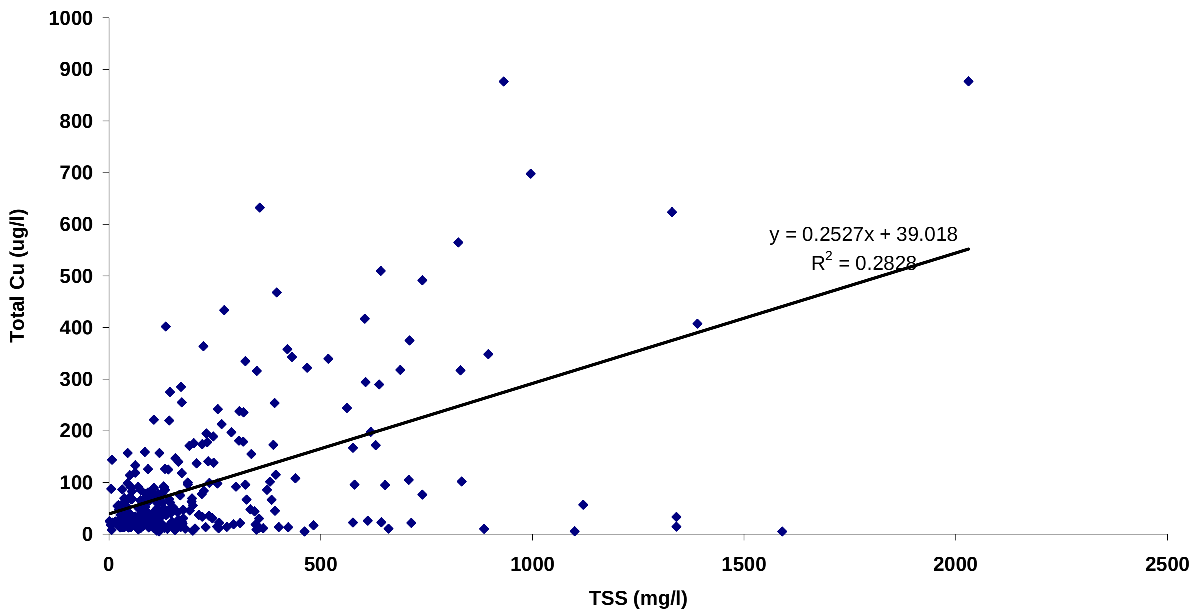


Figure 4.6 Correlation between Total Copper and TSS

4.4.2 Relationships between Significant Pollutants and Site Factors

The 30 monitored sites can be categorised by both Traffic Band and Climate Region as site factors. Figure 4.7 to Figure 4.9 present 'Box Plots' to illustrate the relationships between the Significant Pollutants and AADT. These plots show the minimum and maximum concentrations found, the upper and lower quartiles and the mean values. The results indicate a trend with pollutant concentrations increasing with AADT and also a greater variability within traffic bands as AADT increases. A similar analysis for climate region did not show any trend although there appeared to be higher PAH concentrations in the Cold/Wet and Cold/Dry regions.

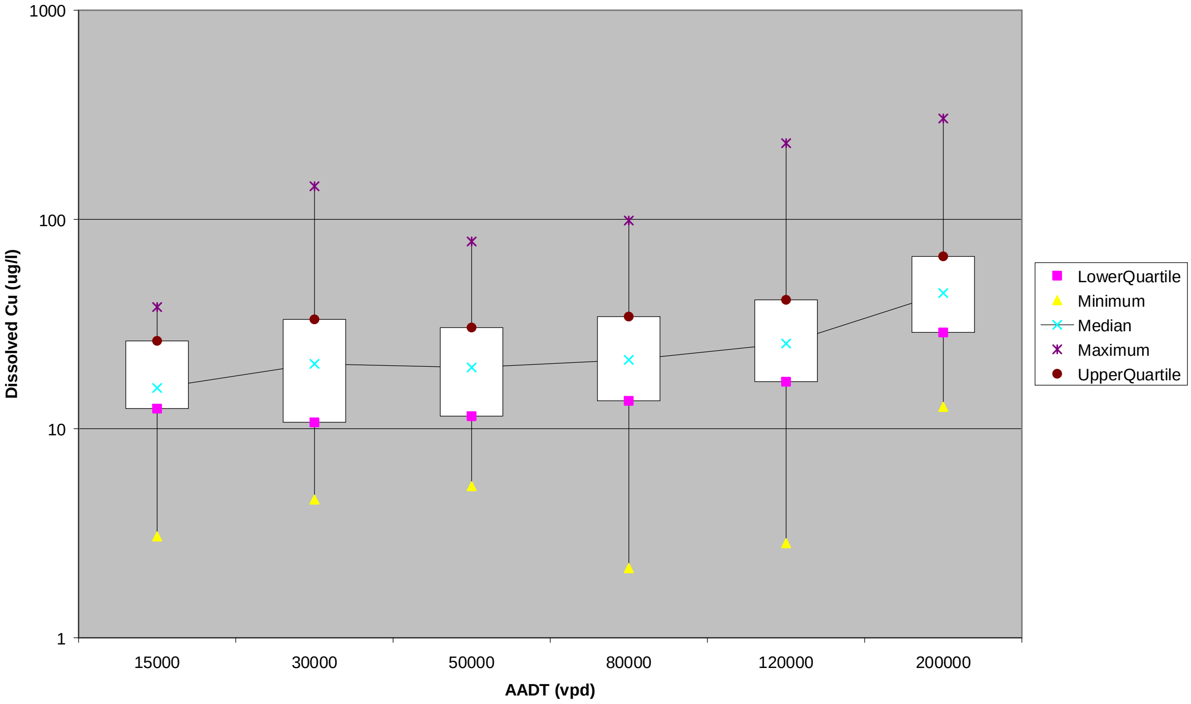


Figure 4.7 Dissolved Copper and AADT

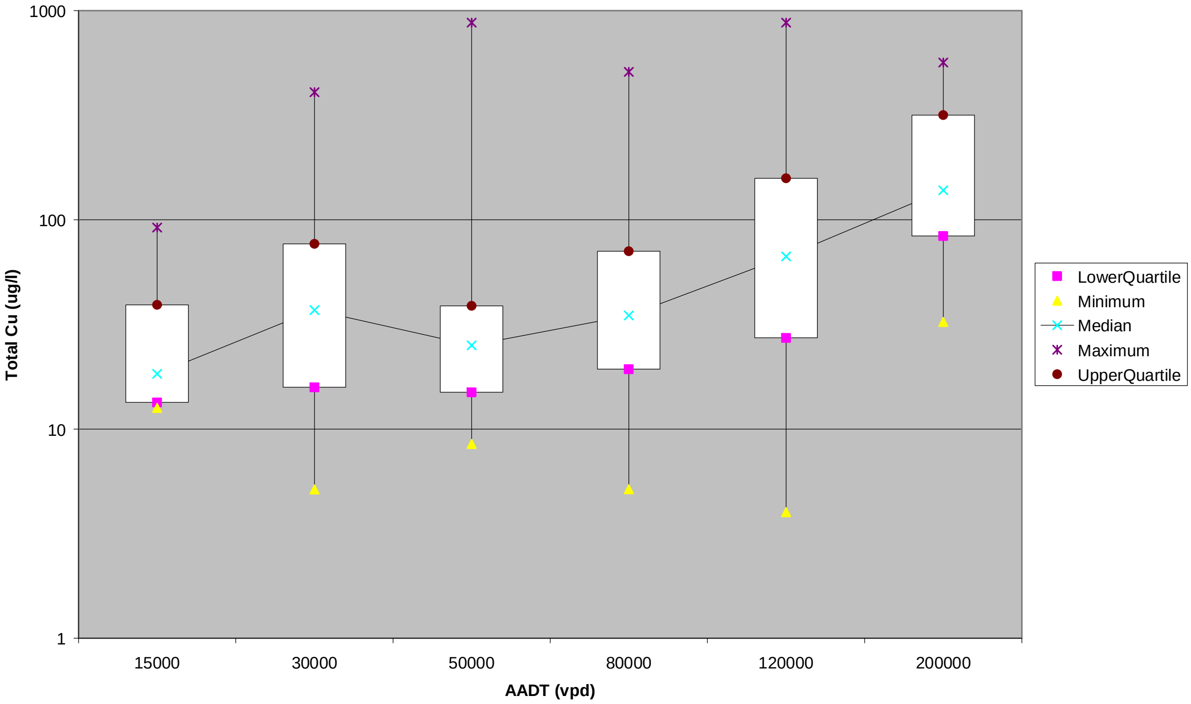


Figure 4.8 Total Copper and AADT

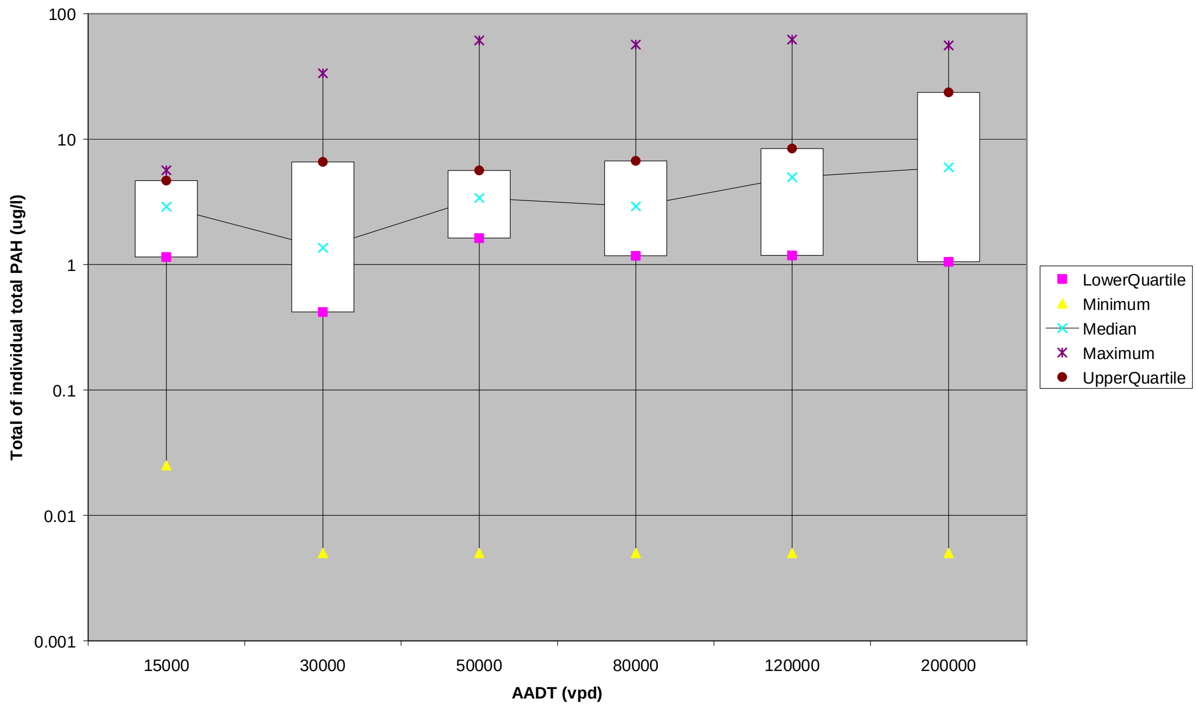


Figure 4.9 Total PAHs and AADT

The assessment of compliance against the soluble pollutant thresholds - RSTs(2) - by event for the Traffic Bands and Climate Regions gives an indication of the significance of any differences in EMCs. Table 4.9 presents the %age of events failing the RSTs as an emission standard applied to the untreated/undiluted runoff by Traffic Band. Table 4.10 presents the %age of events failing by Climate Zone. The results are summarized for the RSTs potentially impacting on 5% of species in the receiving water.

Table 4.9 Percent of Events Failing RSTs by Traffic Band

Traffic Band	Dissolved Cu RST_{24h} value (21 ug/l)	Dissolved Cu RST_{6h} value (42 ug/l)	Dissolved Zn RST_{24h} value (60 ug/l)	Dissolved Zn RST_{6h} value (120 ug/l)
1 (5000-14999)	40.0	0.0	10.0	0.0
2 (15000-29999)	43.3	13.3	31.7	10.0
3 (30000-49999)	41.2	15.7	35.3	15.7
4 (50000-79999)	51.8	5.7	45.8	13.3
5 (80000-119999)	58.2	21.9	47.3	20.9
6 (120000-200000)	80.4	54.3	86.9	56.5

The pattern of failure in Table 4.10 increases with AADT and there is a greater increase between Band 5 and Band 6 than between Bands 1 to 5. This implies that there is a greater increase in ecological risk above Bands 5 than between all the lower traffic bands.

Table 4.10 Percent of Events Failing RSTs by Climate Zone

Climatic Region	Dissolved Cu RST_{24h} value (21 ug/l)	Dissolved Cu RST_{6h} value (42 ug/l)	Dissolved Zn RST_{24h} value (60 ug/l)	Dissolved Zn RST_{6h} value (120 ug/l)
Cold/Dry	54.9	14.1	47.9	18.3
Cold/Wet	57.7	21.1	47.9	22.5
Warm/Dry	53.8	24.5	44.3	20.8
Warm/Wet	50.5	24.7	47.3	20.4

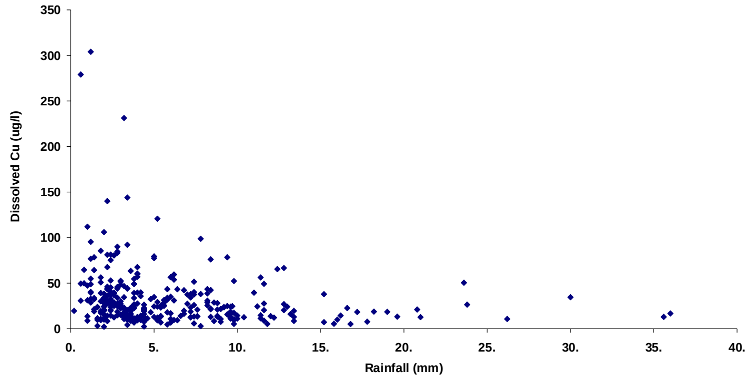
There is little change in the percentage of events failing the RSTs across the Climate Zones, as indicated in Table 4.10. Therefore, the traffic density appears to be the main site factor in terms of pollutant concentrations, with a greater risk of impact above Band 5.

4.4.3 Relationships between Significant Pollutants and Event Characteristics

Scatter Plots and Box Plots were used to identify potential relationships between EMC concentrations of significant pollutants and a range of event characteristics that could be investigated further in the detailed Stage 4 analysis for model development. This analysis used all the event data and, based on the Stage 2 analysis, has considered:

- total event rainfall;
- mean event rainfall intensity;
- peak rainfall intensity;
- ADWP;
- seasonality (month sample collected); and,
- salting.

The results suggest a similar pattern for all the significant pollutants. Therefore, the results for dissolved Copper and Total PAHs are presented for illustration in Figures 4.10 to 4.14.



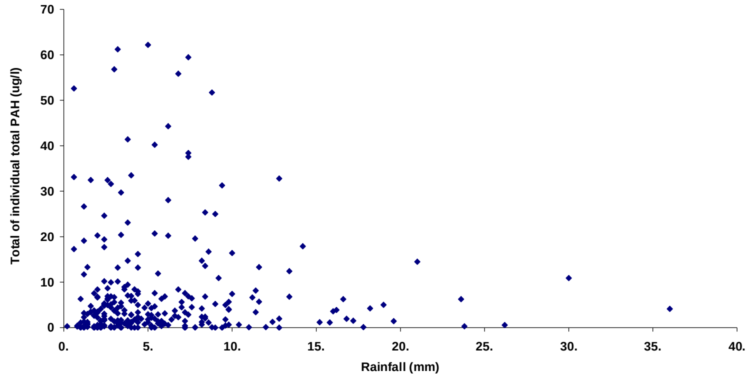
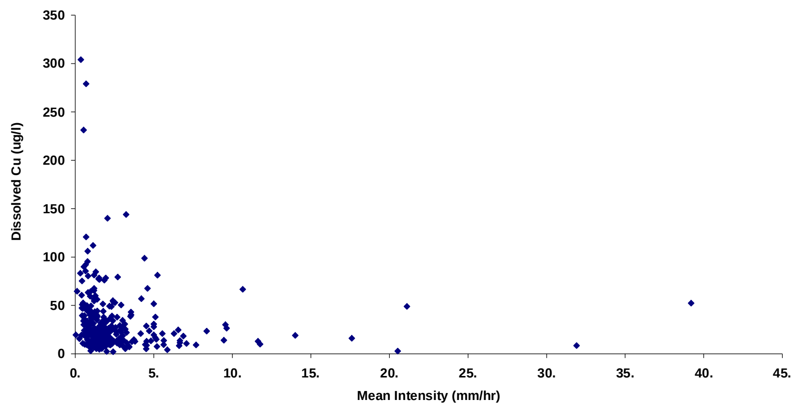


Figure 4.10 Dissolved Copper and Total PAHs v Event Total Rainfall

Figure 4.10 indicates that there is no simple relationship between pollutant concentrations and total event rainfall, as similar concentrations occur across the range of events.



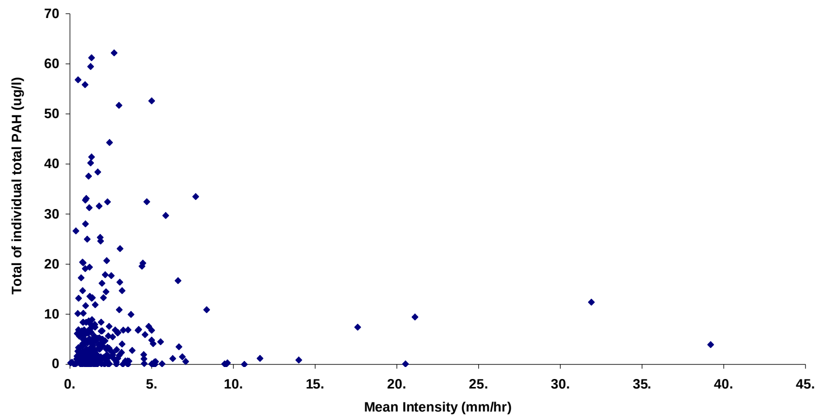
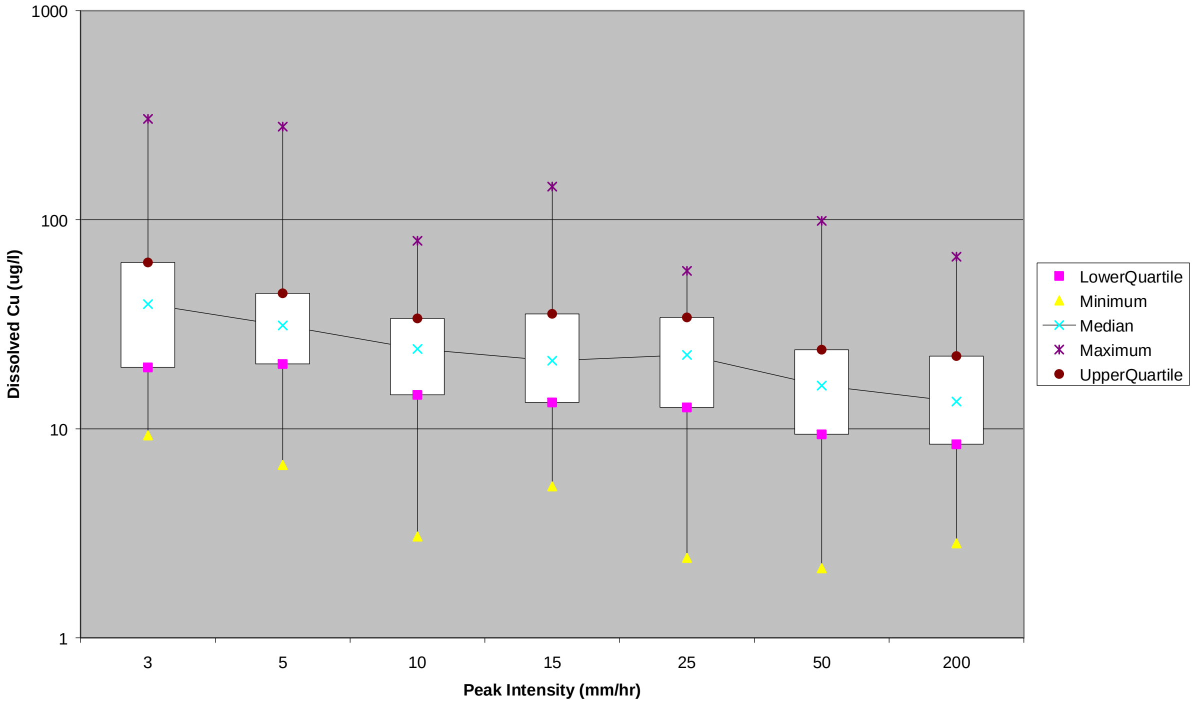


Figure 4.11 Dissolved Copper and Total PAHs v Event Mean Rainfall Intensity

Figure 4.11 shows a large scatter of concentrations for similar intensities.



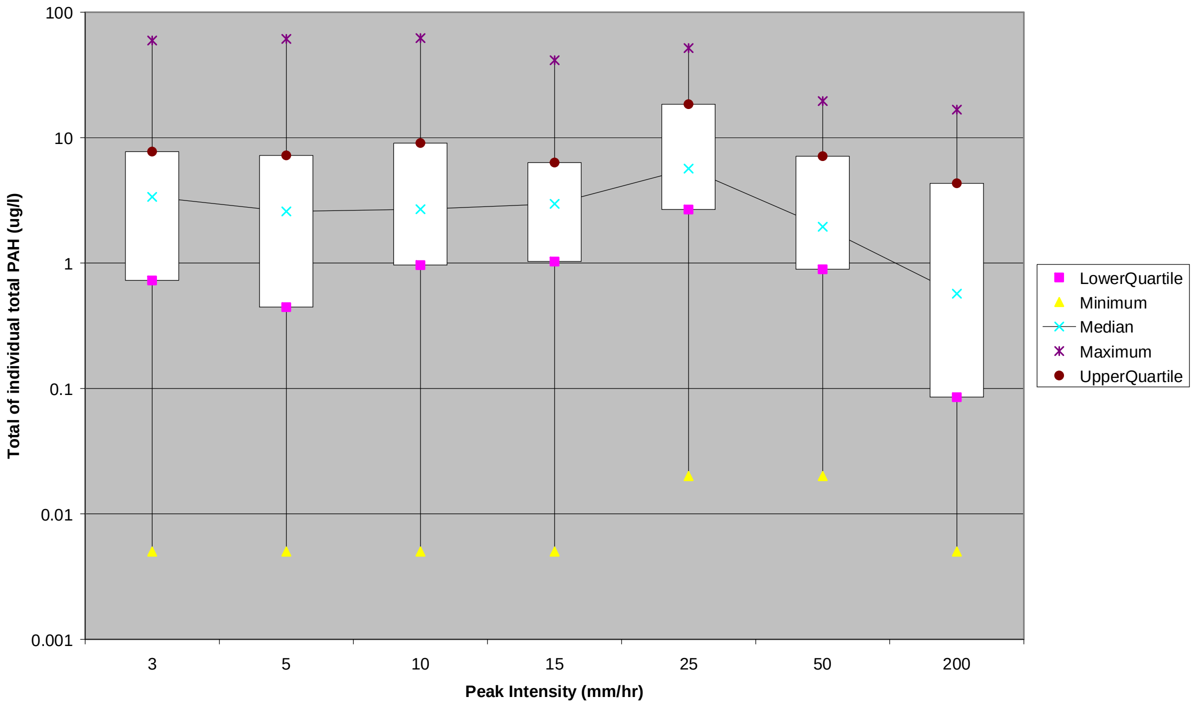
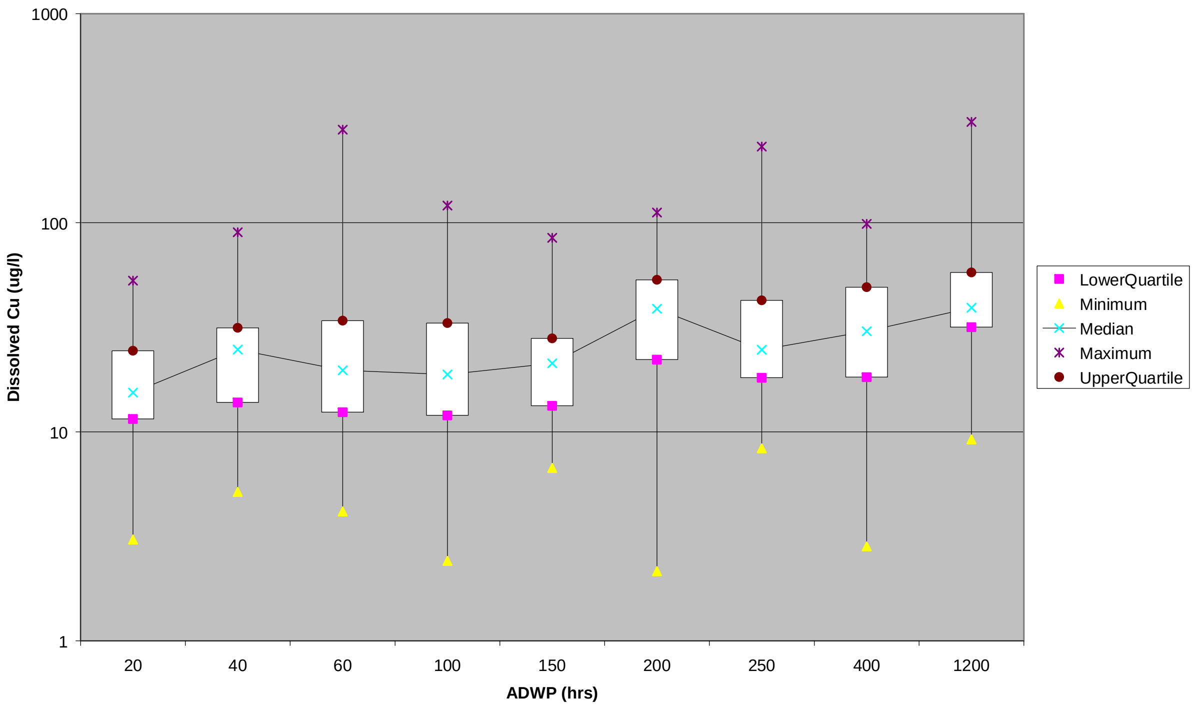


Figure 4.12 Dissolved Copper and Total PAHs v Event Peak Rainfall Intensity

Figure 4.12 indicates a possible trend of concentrations decreasing with event peak rainfall intensity.



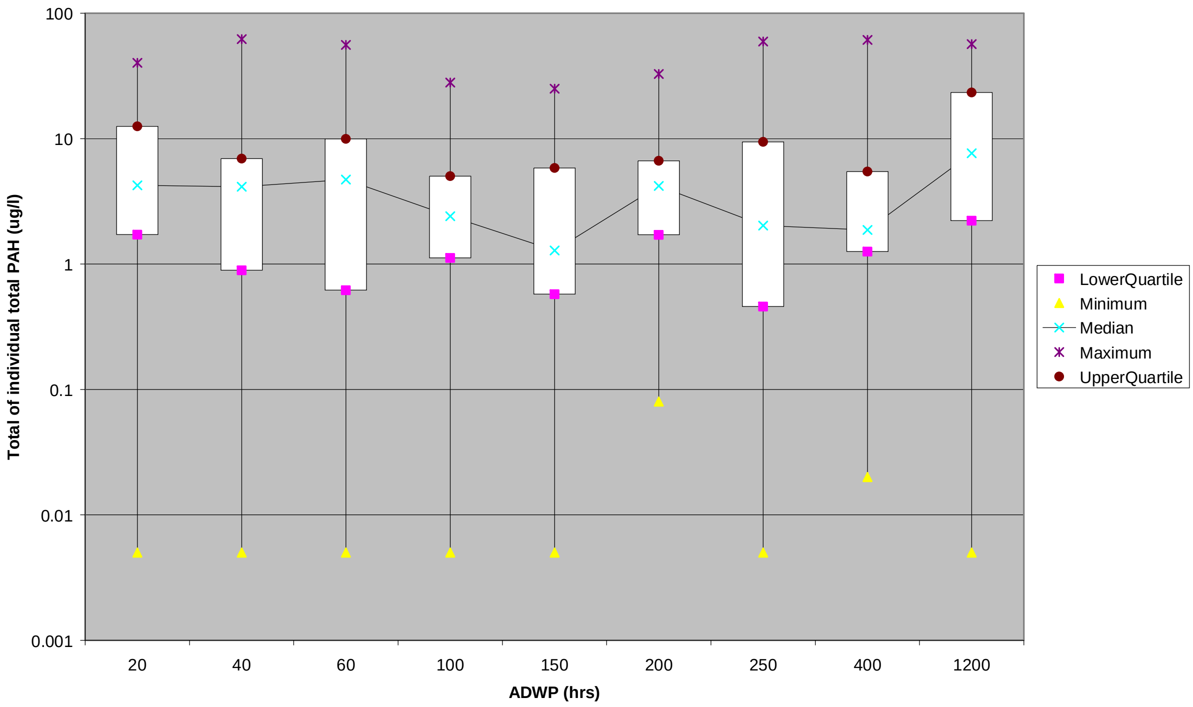


Figure 4.13 Dissolved Copper and Total PAHs v ADWP

Figure 4.13 indicates a possible trend of dissolved Copper concentrations increasing with ADWP. This trend is not present in the total PAHs data.

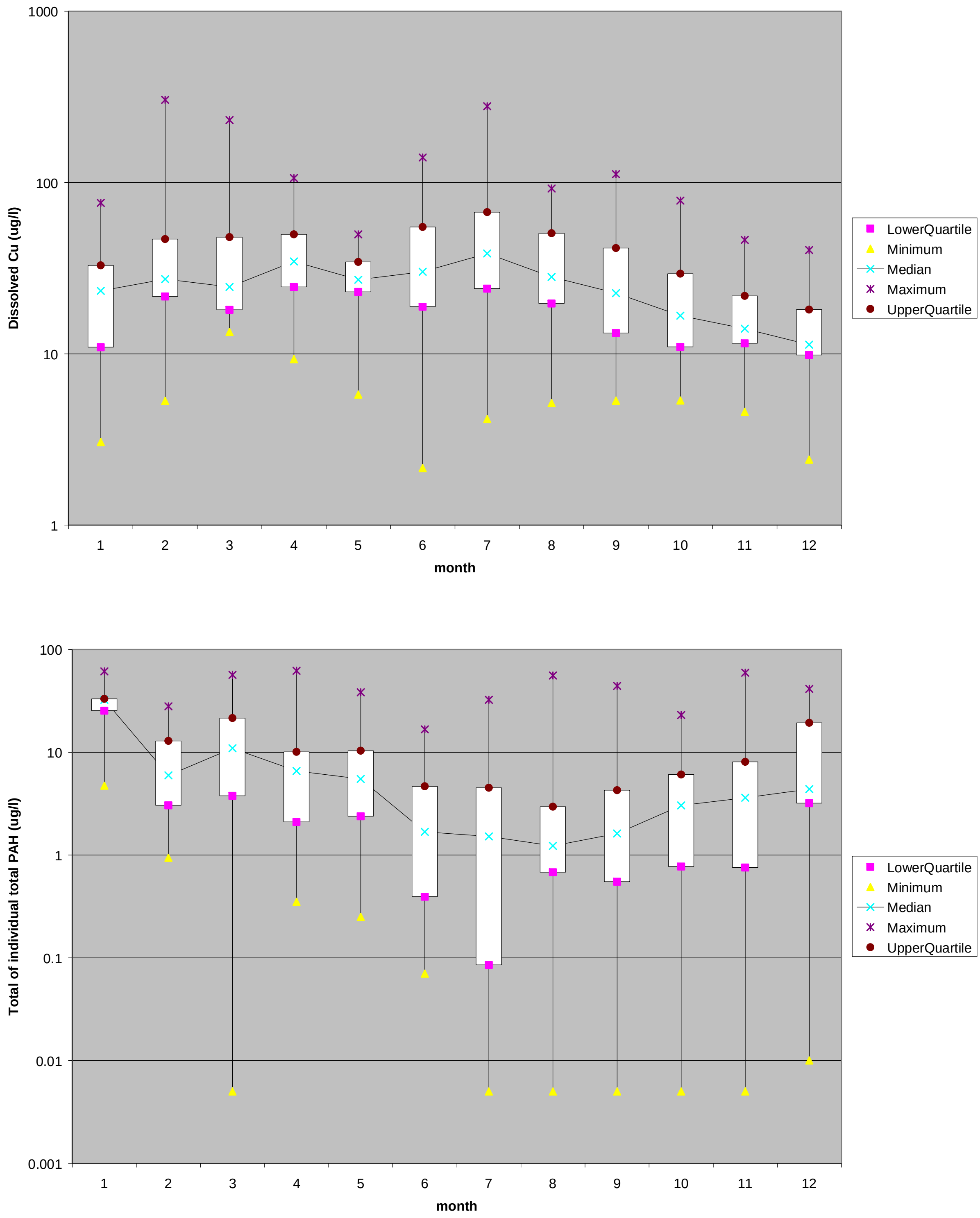


Figure 4.14 Dissolved Copper and Total PAHs v Seasonality

Figure 4.14 shows the effect of seasonality (represented by the month of data capture, with January being month 1) on pollutant concentrations. The results suggest that higher values of dissolved Copper occurred during the summer months and that total PAHs were higher in the winter.

4.4.4 Relationships between Significant Pollutant Concentrations and Winter Salting

Previous studies[1, 5] proposed possible relationships between pollutant concentrations and winter conditions and that this effect could be caused by applying salt as a de-icing agent. Figure 4.15 presents a summary of average monitored Chloride concentrations by month of the year. Primarily, the effect of high Chloride concentrations is thought to increase metals concentrations in highway runoff in the winter. Figure 4.16 illustrates the effect of winter salting using Chloride as a measure of the application of de-icing salt. While there is considerable scatter in the data, a small number of events had high concentrations of both the significant pollutants and Chloride.

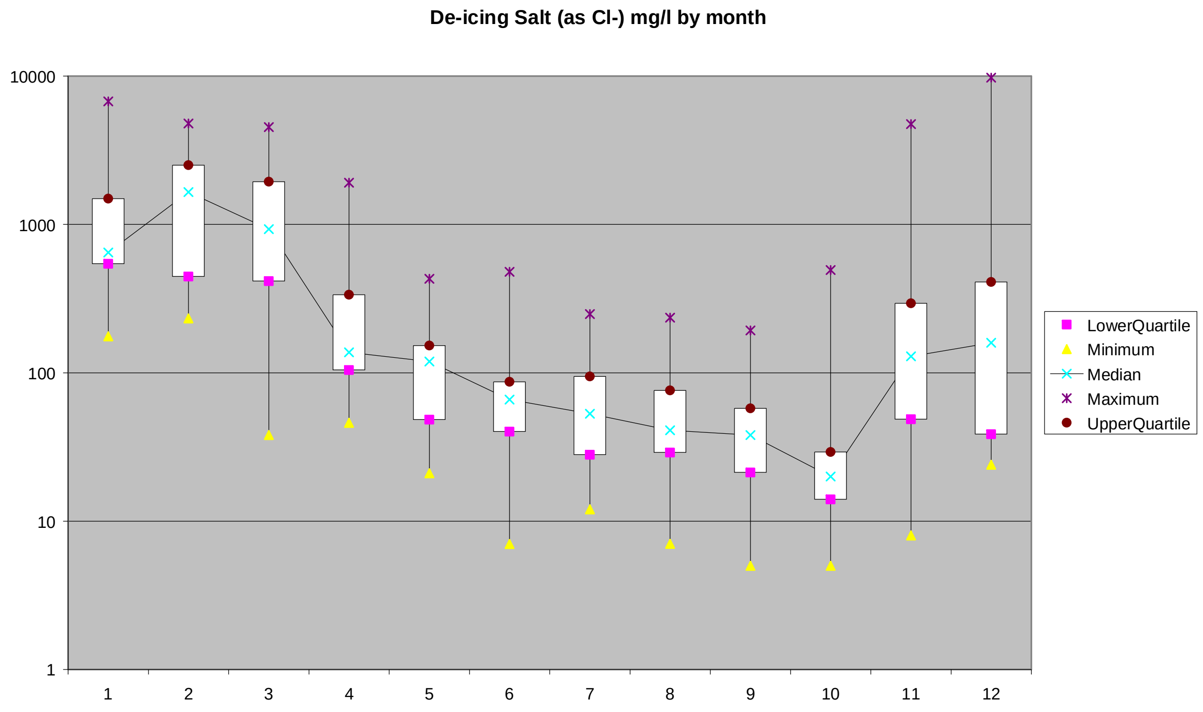


Figure 4.15 Seasonal variations in Chloride Concentrations in Highway Run

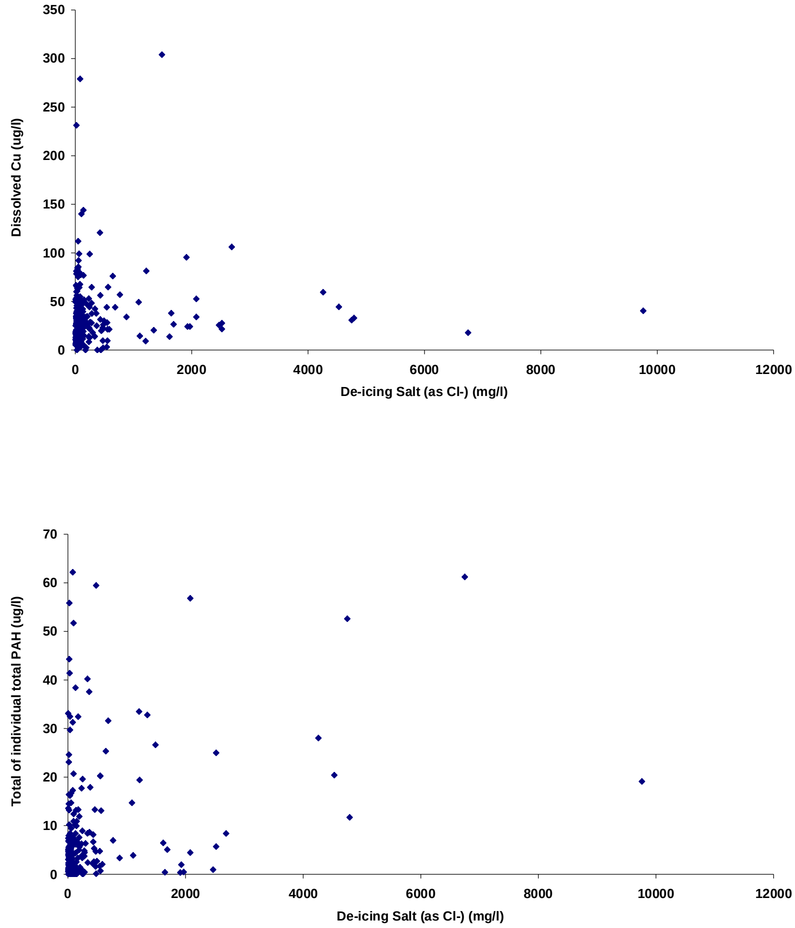


Figure 4.16 Dissolved Copper and Total PAHs v Chloride

In the course of the study, Chloride has been monitored in highway runoff events and information has been provided for salt applications from 21 of the 24 sites. Attempts to relate Chloride concentrations in runoff events directly to pre event salt application loads have not been possible due to uncertainty in the interpretation of winter maintenance records and other factors, such as loses due to the wind and traffic dispersal.

Winter salting is an essential maintenance activity and is, therefore, an intermittent seasonal activity linked primarily to inter runoff event periods. Application policy can lead to a build up of salt on the carriage way prior to a runoff event. In this study, the results showed high concentrations of Chloride in highway runoff after salt application. A small number of these events showed high concentrations of significant pollutants, but not all events. Therefore, it would appear that other factors are associated with this effect that may be event specific. The relatively few data for these events limits understanding of this phenomenon and was outside the scope of the current study where the focus was on routine highway runoff.

The UKTAG Report on UK Water Quality Standards for the Water Framework Directive(12) identifies a need to consider the development of standards to control salinity in rivers caused by highway runoff. Therefore, it is possible that salting effects will need to be considered in greater detail in the future.

4.5 Assessment of within event variations in pollutant concentrations in highway runoff

One of the original Stage 3 tasks was to identify the significance and characteristics of the 'first flush' in relation to the derivation of a worst case design storm approach for predicting pollution risk from highway runoff. However, in the course of the study, the concept of a design storm approach was superseded by a rainfall time series approach proposed by WRc and accepted by the Highways Agency for the Stage 4 model development. As there were only data available for 40 time determined events this was recognised as being insufficient to support the development of a model capable of representing within event pollutographs. This was also considered to be appropriate in relation to the risk of environmental impact from short duration exposure to higher levels of pollutants within a highway runoff discharge event.

The concept of the 'first flush' phenomena in sewers and drains has been the subject of much recent research in the UK and overseas in relation to improving the design of these systems to reduce their environmental impact. While there remains considerable debate over the precise definition of a 'first flush', the basic concept is that pollutant concentrations and, potentially, pollutant loads are highest at the onset of flow in the sewer or drain in response to rainfall. Early research indicated that the 'first flush' in combined sewers is produced by the erosion of fine sediment deposits in the sewer at the onset of stormflow conditions[13]. These fine, highly mobile, highly polluting, largely organic sediments are generated from the deposition of sewage solids in the dry weather flow on the invert of the sewer. Other factors, such as rainfall event and catchment characteristics also influence the magnitude and nature of the first flush.

The characteristics of highway drains are different to those of combined sewers and, as a result, the concept of the 'first flush' is less appropriate and, potentially, less significant. Prior to a rainfall event, pollutants will accumulate on the highway surface and there may be a store of polluted sediment deposited in the pipe network from previous events. However, the nature of this material (largely mineral rather than organic) is less polluting than sediments in a combined sewer. Similarly, its erosion and transport is more influenced by peak rainfall within an event in terms of surface wash off and erosion and transport by in-pipe flows. A key factor in any within event variability in sediment attached pollutants will be the timing of the peak rainfall intensity rather than the initial rainfall intensity. Therefore, assuming that the discharge of sediments and pollutants is limited by the transport capacity of the flow, a flush, or the peak discharge loading rate, may occur at any time in the runoff hydrograph in relation to the variation in rainfall intensity and discharge flow. If, however, the pollutant load is limited by the availability of sediment and pollutants on the carriageway and in the drainage system, then the peak load is more likely to occur towards the beginning of the event before the available store of material is depleted.

Within the Stage 3 highway runoff monitoring programme, 10 events at each of the four Group A Sites were monitored for within event variability. The first 12 discrete samples collected in these 10 events were subsampled for individual analysis for the full range of pollutants. Event sampling intervals varied from 6 to 30 minutes depending on the forecast rainfall event characteristics. However, in some cases this did not allow the full runoff event to be monitored. Figure 4.17 and Figure 4.18 illustrate a relatively simple response to a short, high intensity rainfall event on the M6 in the North West of England. Figure 4.18 compares the event EMC concentrations with the discrete sample results. Of the 40 events with discrete sample data, 26 showed similar patterns of pollutant loading rates as the event illustrated in Figure 4.18:

- concentrations of dissolved metals increased during the event with the lowest concentrations during the peak flow;
- concentrations of total metals and TSS peaked at the hydrograph peak at the beginning of the event and then decreased;
- loading rates for metals were lower during the hydrograph peak and increased as flows decreased toward the end of the event; and,
- both concentrations and loading rates for PAHs showed a less consistent trends than the metals but were, typically, lower at the hydrograph peak and then increased. This is believed to be a reflection of the high variability in the observed data for PAHs.

Only seven events had the highest loading rates at the beginning of the event. There are significant implications for the design of highway runoff treatment systems if these patterns of runoff and pollutant behaviour are common place.

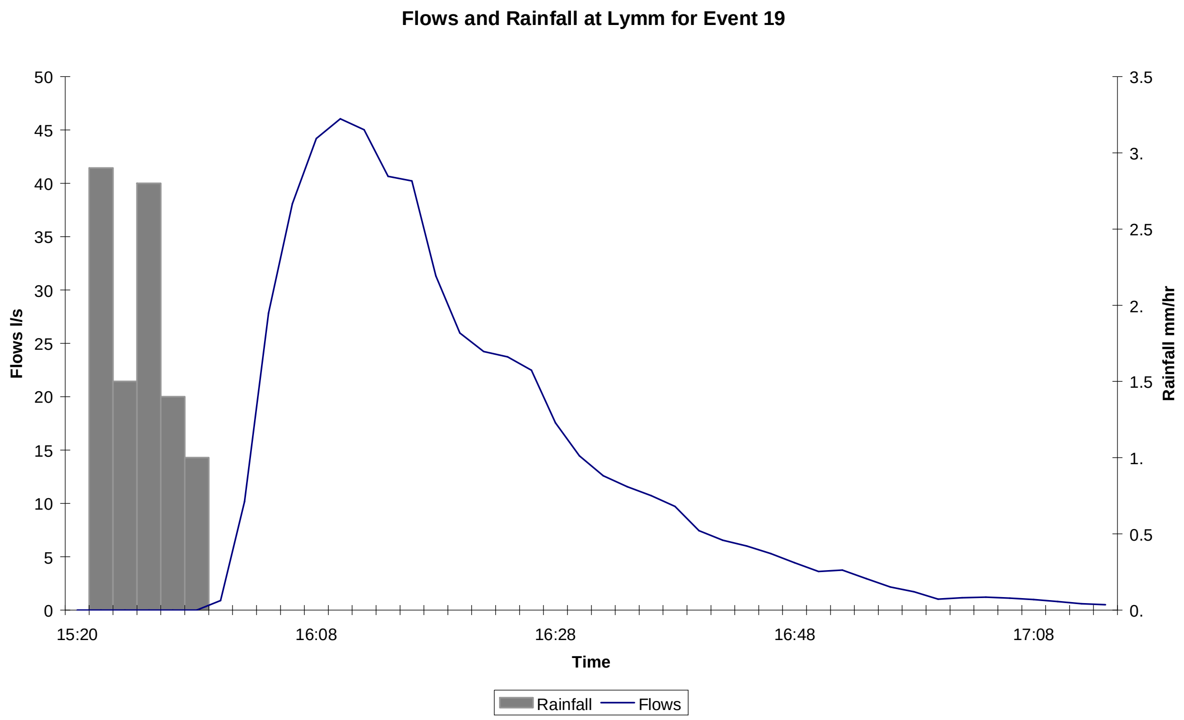


Figure 4.17 Rainfall Intensity and Flow at Lymm: Event 19

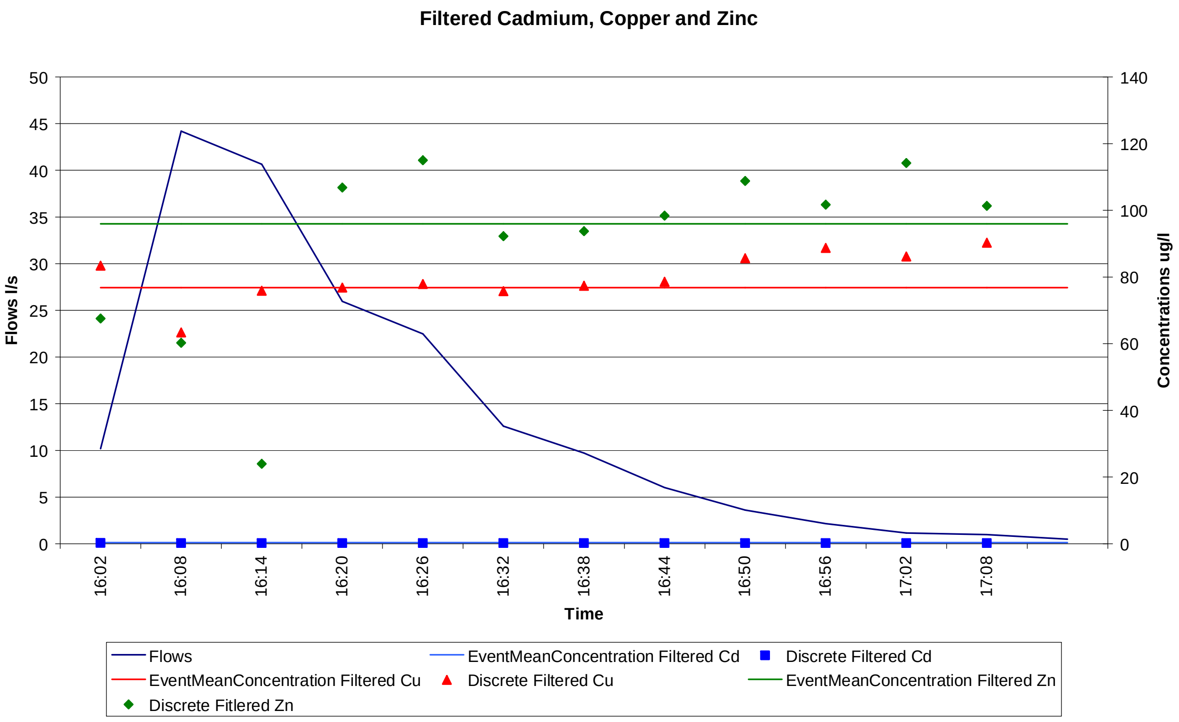


Figure 4.18 Dissolved Cadmium, Dissolved Copper and Dissolved Zinc Concentrations at Lymm: Event 19

4.6 Outcome of Data Collection and Analysis

4.6.1 Conclusions from Stage 3 Data Analysis

The main objective of Stage 3 was to study the influence of site specific factors and variables, including traffic flows and climate conditions, on highway runoff pollutant concentrations; and, to assess the importance of the 'first flush' of pollutants in response to a rainfall event. The Stage 3 data analysis was based on the previous Stage 2 data analysis(5) and included the estimation of pollutant summary statistics for each traffic band and climate region; a correlation analysis between determinands, site factors and event characteristics; and, an assessment of within event variability of pollutant concentrations. The results from the Stage 3 data analysis formed the basis for a more detailed analysis in Stage 4 to support the development of a rainfall time series based model to predict pollutant concentrations in routine, non urban, highway runoff.

A list of 'significant pollutants' that pose a risk of short-term acute impacts and/or long term chronic impacts on ecosystems has been agreed between the Highways Agency and the Environment Agency. These are:

- total and dissolved Copper;
- total and dissolved Zinc;

- total Cadmium;

- total Fluoranthene, total Pyrene and total PAHs.

The Stage 3 data analysis was focused on understanding the behaviour of these pollutants for their potential inclusion in the Stage 4 model.

The outcome of the Stage 3 data collection and data analysis identified the following.

1. In general, overall EMC results are higher than those from the previous study[1] that included data from sites in Traffic Bands 2-5. However, they tend to be lower than those from the Stage 2 monitoring data that were from Traffic Bands 5-6.

2. MTBE was only detected above the LOD in 1 event and Free Cyanide was not detected above LOD for any event. Total Platinum and total and dissolved Palladium were only found at concentrations above LOD for a very small number of events. Also, dissolved PAHs were not found above the LOD for a large proportion of events.

3. A direct comparison of the results with previous Highways Agency guidance[9,10] for pollutant concentrations in highway runoff shows that, with the exception of total Lead, the Stage 3 results had a greater range of concentrations.

4. The results show that, with the exception of total PAHs as an indicator of concentrations of other total PAH, there is no evidence to support the use of one or more indicator substances as a surrogate for others.

5. The results indicate a trend with pollutant concentrations increasing with AADT and also a greater variability within traffic bands as AADT increases.

6. The results show no trend for higher or lower metals concentrations in the different climate regions. However, there appear to be higher PAH concentrations in the Cold/Wet and Cold/Dry regions.

7. The results suggest that dissolved metals concentrations may be higher in the summer and that PAHs are higher in the winter.

The key conclusions arising from the data collection and analysis for the subsequent Stage 4 model development were:

- the investigation of the effects of site characteristics on pollutant concentrations suggests that there are no simple relationships and that individual event EMCs are a result of a combination of traffic density and a number of interacting event specific variables, including rainfall, ADWP and seasonality. This conclusion is similar to the findings of a recent study carried out in the USA[14].

- traffic density appears to be the main site factor in terms of pollutant concentrations.

- there is no simple relationship between pollutant concentrations and total event rainfall, event peak rainfall intensity and ADWP, as similar concentrations occur across the range of rainfall event characteristics; and,

- there are insufficient data to support the development of a model capable of representing within event pollutographs.

4.6.2 Recommendations for Stage 4 Model Development

Based on the results form the Stage 3 data analysis, it was recommended that the Stage 4 detailed data analysis and model development should:

1. examine relationships between the concentrations of Significant Pollutants and traffic density in more detail as the main factor for model development. This should include a re-assessment of the original traffic bands to reflect the increase in pollutant concentrations between bands 5 and 6;

2. consider other potential factors that may influence pollutant concentrations; for example, the time of day an event occurs in relation to temporal variation in traffic flows throughout the day;

3. examine relationships between the concentrations of Significant Pollutants and interactions between rainfall event characteristics;

4. investigate potential seasonal effects further, particularly higher PAH concentrations in winter and higher dissolved metals concentrations in summer;

5. investigate the possible causes of higher PAH concentrations in the Cold/Wet and Cold/Dry climate regions;

6. consider the use of total PAHs as a surrogate indicator for total Pyrene and total Fluoranthene;

7. consider excluding data from post salting events, as these are potentially influenced by an intermittent maintenance related activity rather than normal highway running conditions;

8. model EMCs for soluble Significant pollutants;

9. include TSS as a model parameter to allow results for the total fraction of the significant pollutants to be produced as event mean loading rates (EMLRs); and,

10. use the peaking factors from the time determined results to produce event maximum loading rates (EMaxLRs) for the total fraction of the Significant Pollutants. However, it is unlikely that the model will be able to predict when within an event the EMaxLR occurs.

4.6.3 Additional Recommendations

The following recommendations, not directly related to the Stage 4 model development, relate to potential issues for highway design and maintenance.

Design of Runoff Treatment Systems

The timing of the peak runoff load has potential implications for the design of runoff treatment systems and the concept of a ‘first flush’ may not be an appropriate design model. It is recommended that the Stage 3 time determined monitoring data should be examined in more detail to improve the understanding of within event variations of pollutant concentrations and loads in relation to the rate of discharge flow. Depending on the outcome, it may be appropriate to consider a further specific data collection programme to investigate this issue and its significance in more detail.

Winter Salting

Winter salting is an essential maintenance activity and is, therefore, an intermittent seasonal activity linked primarily to inter runoff event periods. Application policy can lead to a build up of salt on the carriage way prior to a runoff event. In the course of the study, Chloride has been monitored in highway runoff events and information has been provided on salt application for 21 of the 24 sites. Attempts to relate Chloride concentrations in runoff events directly to pre event salt application loads have not been possible due to uncertainty in the interpretation of winter maintenance records and other possible factors, such as loses due to the wind and traffic.

The highest observed EMC for Chloride in a post salting event was 9760 mg/l against a background level generally between 50-100 mg/l, or less. A number of closely spaced events showed a carry-over effect from salting prior to the first event. Monitoring of runoff from snowmelt, which may have been associated with salting, was outside the scope of the study, but could produce similar Chloride concentrations in highway runoff. Further understanding of (and the development of guidance related to) salting effects was beyond the scope of the current study. It is recommended that further specific data collection should be carried out to establish a better understanding of the relationships between salting and the concentrations of Chloride and other pollutants in subsequent highway runoff.

It is possible that salting effects on the aquatic environment will need to be considered in greater detail in the future to ensure compliance with the WFD requirements for good ecological status. Current water quality standards are based on annual statistics that would be inappropriate as a measure of the ecological risk of intermittent highway runoff discharges. Therefore, it is recommended that the Highways Agency should consider an assessment of the ecological risk, in terms of potential RSTs for salinity, that take account of the nature of the discharge, receiving water conditions and the life cycle of the fauna and flora that would be present under winter flow conditions.

5. STAGE 4 MODEL DEVELOPMENT

5.1 Overview of Stage 4

The main objective of Stage 4 was to carry out the development and testing of models to predict concentrations of the significant pollutants in highway runoff. It was agreed that the models should focus on the significant pollutants in the following forms only:

- Solubles: Event mean concentrations (EMCs in µg/l) for dissolved Copper and Zinc, and;

- Insolubles (total of dissolved and sediment attached fractions): Event Mean Loading Rates (EMLRs in mg/kg) for total Copper, Zinc, Cadmium, Pyrene, Fluoranthene, Anthracene, Phenanthrene and total PAHs. (EMLRs are also referred to as Event Mean Sediment Concentrations (EMSCs)).

Dissolved Cadmium, Pyrene and Fluoranthene were excluded from the model development because the data collection found no samples with concentrations exceeding the Runoff Specific Thresholds (RSTs)[2] for these pollutants. Total Anthracene and total Phenanthrene were included with the significant pollutants at this stage as a result of research in to highway runoff sediment toxicity[3].

The work in Stage 4 built on the initial analysis in Stage 3 that indicated where there may be relationships between runoff concentrations and different site and event factors. The main tool used for the model development was multiple linear regression (MLR) analysis. MLR was used to assess the relative importance of the different explanatory factors and provide regression equations to explain some of the variability observed in the data.

Originally, it had been intended that a more deterministic approach would be used based on representing the build-up and washoff of pollutants in a timeseries model. This was attempted but, at an early stage, it became apparent that this approach was not going to be successful. It was clear that, with the available data, a deterministic approach was not able to provide any better explanation of the variability observed.

The tasks carried out in Stage 4 were:

1. to undertake further examination of individual factors using the same procedures as in Stage 3;

2. to use statistical methods to identify and evaluate the relative importance of factors that appeared to have a significant effect on concentrations;

3. to use the results from this analysis to create and test predictive models for each specified pollutant; and;

4. to specify how these models could be incorporated into a new tool for assessing the impact of highway runoff, with particular reference to the work of the associated projects on ecological impacts [2,3].

5.2 Further Investigation of Data

Before proceeding to develop statistical models, some aspects of the data, identified earlier during Stage 3 but not investigated at that time, were examined. These aspects were as follows.

1) Some unusual trends in the ratio of the dissolved/total EMCs for Copper and Zinc had become apparent. There was concern that these may create a bias in the analysis. A decision was needed on whether or not to exclude some data from the model development work.

2) Some particularly high EMLRs had been noted but not excluded from the Stage 3 analysis. A decision was needed on whether or not to exclude them from the development of statistical models.

3) A hypothesis had been put forward that different levels of traffic activity (that occur at different times of the day) might in some way affect the mobilisation of contaminants and hence the runoff concentrations. It was decided to test this hypothesis by seeing if there was any apparent relationship between ‘time of day’ and runoff concentrations that would suggest that ‘time of day’ would be candidate as an explanatory factor in the subsequent model development.

During the Stage 3 investigation, it became apparent that there were some unusual trends in the metals data. For most periods the ratios of dissolved/total EMCs show a similar variation but in the autumn 2006 period the ratios are clustered around 1. This raised concerns that there may have been some analytical problem at that time. In order to avoid any possible bias in the subsequent analysis it was agreed that the dissolved metals data for the period from September – December 2006 would not be included in the model development. The total metals data were retained.

A second issue was the occurrence of some particularly high EMLR values, as identified in Section 4.3.3. As such they were seen as outliers that could unduly bias the statistical models and were excluded from the subsequent analysis.

Box plots were prepared using ‘time of day’ of an event to categorise the data and help look for any patterns or trends. An example is shown in Figure 5.1 which indicates some increase in dissolved Copper concentrations around the morning traffic peak times. However, in general, there were no consistent patterns that would justify the inclusion of ‘time of day’ as an explanatory factor in the subsequent work.

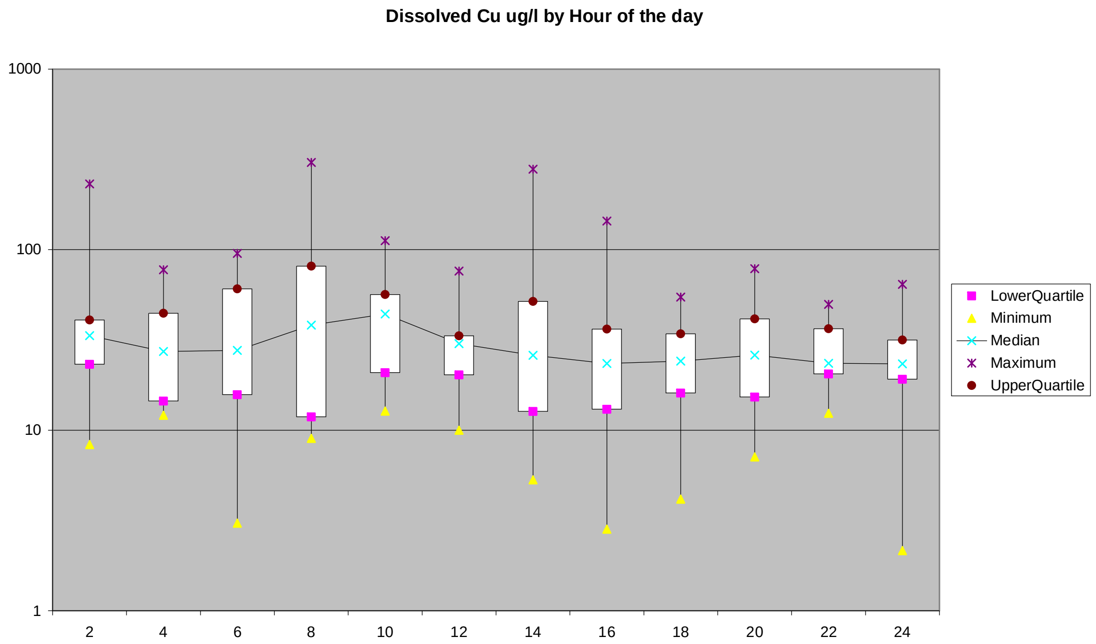


Figure 5.1 Box plots for dissolved copper EMCs by hour of day of the event

Following these revisions, the data were re-analysed using box plots and distribution plots. The revisions to the data did not indicate any major changes from the conclusions drawn in Stage 3[(6)].

- the results indicated a trend with metal concentrations increasing with AADT and also a greater variability within traffic bands as AADT increased. PAH concentrations did not appear to be related to traffic density;

- the increase in metal concentrations between traffic bands 5 and 6 was greater than the increase between bands 1 and 5;

- the results showed no trend for higher or lower metals concentrations in the different climate regions. However, there appear to be higher PAH concentrations in the Cold-Wet and Cold-Dry regions;

- the results suggested that dissolved Copper concentrations may be higher in the summer and that PAHs were lower in the summer;

- the dissolved metals concentrations and EMLRs tended to decrease with increasing rainfall intensity but the effect was slight; and,

- the dissolved metals concentrations tended to increase with increasing Antecedent Dry Weather Period (ADWP), but again the effect was slight.

Further investigation confirmed that there were no simple relationships between EMCs or EMLRs and the individual site or event characteristics. The next stage was to use MLR to see if this analysis technique could bring out any stronger relationships when the combined effects of different factors were taken into account.

5.3 <u>Development of Statistical Models</u>

5.3.1 MLR Models

Model Development

MLR analysis was used to investigate the combined effect of the different explanatory factors identified by the earlier analysis and to see how much of the variability in the data could be explained in this way.

For the MLR analysis it was important to work with normally distributed data. Logs of the pollutant data were taken and it was established that the logged data for the EMCs could be represented reasonably well by a normal distribution. The logs for the EMLRs were not normally distributed and other transformations were tried. For the copper and zinc EMLRs, the fourth root of the values was satisfactory. However, no suitable transformation was found for the EMLRs for cadmium and total PAH and these were not investigated using MLR.

The various factors were divided into those that could be expressed as *continuous variables* (e.g. rainfall intensity) and those that could be described as discrete *category variables* (e.g. climatic region). Hence, the basic equation used in the MLR analysis was:

Y = constant + C1 +C2 +……….. aX_1+bX_2 + ... + error

Where Y = transformed (log or fourth root) value of the pollutant concentration

C1, C2 = constants for category variables

X_1, X_2 = values of factors that are continuous variables

a, b, = coefficients

error = error term to express unexplained variability

In the analysis, the 95% confidence level was used for judging whether of not a factor had a significant effect upon explaining the pollutant concentrations. The GenStat® (15) statistical package, was used for the analysis. Initially, all potential factors from the project database were considered in the analysis. The analysis was limited to the following pollutants:

- Event Mean Concentrations (EMCs in µg/l) for dissolved Copper and Zinc and for total Copper, Zinc, cadmium, and TSS, and;
- Event Mean Loading Rates (EMLRs in mg/kg) for total Copper, and total Zinc.

First, the results using all the factors were examined and any factors that consistently failed the significance test were removed. In addition, some factors that were strongly correlated with other factors were also removed.

Backward elimination was used in the second stage,. The shortlisted factors were included in the model and then the factors were dropped from the model one at a time. The factor that had the smallest standard error when dropped in each round was taken out the model. The process was repeated until all the factors left in the model met the significance criteria.

This process produced a shortlist of factors as shown in Table 5.1.

Table 5.1 Shortlisted factors

Factor	Units	Factor type
AADT	veh/day	Category
Climatic Region		Category
Month		Category
Max Hourly Intensity	mm/hr	Continuous
Preceding Rain10 day	mm	Continuous
Preceding Rain 20 day	mm	Continuous
ADWP	hours	Continuous

The event characteristics Preceding Rain10 day, Preceding Rain 20 day and ADWP are all correlated to some degree. Therefore, the model was forced to use only one of these three factors for any given pollutant.

Climatic Region and Month were treated as category variables – with the 4 categories for Climatic Region and 12 categories for the months. AADT was treated as a category variable and various categorisations were tried. Mostly, there was little justification for using more than 2 categories (<100,000 and >100,000) but for the final model three categories were used (<50,000, 50,000-100,000, >100,000) because the extra category showed some significance for the EMLRs.

Overall, the results for the final MLR models showed few common patterns between the different pollutant models and, at best, only a small degree of the observed variability is being explained. The best degree of explanation was for the total metal EMCs – Copper (59.5%), Zinc (51.3%) and Cadmium (40.4%). However, these figures reduced when the total metal EMLRs were considered – Copper (35.9%) and Zinc (31.2%). For dissolved metal EMCs the figures were Copper (37.8%) and Zinc (24.9%).

The analysis was also carried out with the data from the previous study(1) excluded. This was to test whether differences in event characteristics or analytical procedures between the two studies might have created some additional variability. However, as shown in Table 5.2, the percentage variance accounted for was not improved by excluding these data.

Table 5.2 The effect of including/excluding the long-term monitoring data in the MLR models

	Percentage variance explained		
	Dissolved Cu	**Dissolved Zn**	**Total Cu**
Including long-term monitoring study data	37.8	24.9	59.5
Excluding long-term monitoring study data	38.3	22.6	59.5

The overall form of the MLR models is illustrated by the example below for dissolved copper:

log Copper = 1.008
+ constant for climatic region
+ constant for AADT
+ constant for month
- 0.034 x Max Hourly Intensity (mm/hr)
+ 0.005 x Antecedent Dry Weather Period (hours)
+ error term

e.g.	<50,000	0
	50,000-100,000	0.085
	>100,000	0.323

The error term is a normally distributed random variable to reflect the unexplained variability. Figure 5.2, for a site in the colder/wet region and with AADT>100,000, compares the predictions for dissolved copper, based on a 10 year rainfall time series simulation with the observed data for sites in this category. The day number identifies the time of year of each model event simulation and the observed events (day 1 = 1 January). The results are plotted on a log scale and show how the error term produces a degree of variation which is broadly consistent with the observed data.

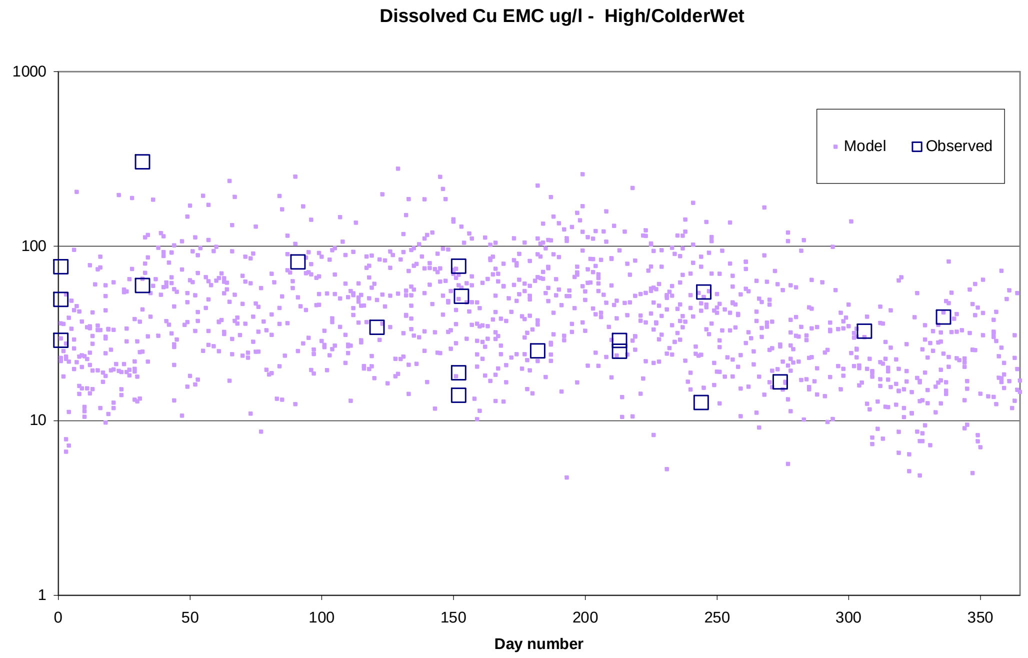


Figure 5.2 Comparison of MLR model results with observed data – for dissolved Copper for a site in the highest traffic band and the Colder/Wet climatic region

Individual MLR Models

1. Dissolved Copper

Whether AADT was greater or less than 100,000 had a highly significant effect in the dissolved Copper model. AADT below 100,000 was not a significant factor. The Cold Dry climatic (North East) region gave significantly lower dissolved Copper levels than the other climatic regions. The analysis also showed that dissolved Copper levels had a significant seasonal pattern with generally higher levels in the February – August period. Maximum hourly intensity and ADWP also emerged as highly significant factors. Dissolved Copper had the highest percentage variance accounted for.

2. Dissolved Zinc

Traffic density also had a highly significant effect on dissolved Zinc levels. Climatic region was also important but it was the Warm Wet (South West) region that had significantly higher dissolved Zinc levels than the other three regions. There was no strong seasonal pattern for dissolved Zinc and no significant relationship with rain intensity or antecedent conditions.

3. Total Copper EMLR

The significant factors for total Copper EMLR were much the same as those for dissolved Copper EMC, except that ADWP did not emerge as being significant.

4. Total Zinc EMLR

For the total Zinc EMLR, the difference relative to the lower AADT category, was significant for the middle category and highly significant for the upper category. The Cold Dry climatic (North East) region stood out as giving significantly lower total Zinc EMLRs than the other regions. There was a more significant seasonal pattern for total Zinc EMLR, than for dissolved Zinc EMC, with generally higher levels in the February – July period. Maximum hourly rainfall intensity also emerged as a highly significant factor.

5.3.2 Principal Component Analysis (PCA)

A brief PCA investigation was undertaken The conclusion reached was that the results were similar to those from the MLR analysis, both in terms of the significant explanatory factors, and in terms of the % of variance explained. One drawback of using PCA is that the link between the pollutant concentrations and the original factors becomes less clear. As a consequence, it was agreed that further model development would be based on the MLR models.

5.3.3 Distribution Based Models

Total Cadmium and Total PAH

No suitable transformation could be found to allow the total Cadmium and total PAHs EMLRs to be handled in the MLR analysis. Therefore, it was decided to create non-parametric distributions for these pollutants by grouping the data according to the main explanatory factors identified in the statistical analysis.

For the total Cadmium EMLRs, the results showed that AADT and season were relevant factors. Based on these patterns, AADT was divided into three categories (as used for the MLR analysis) and the year was divided into two seasons (January–June and July-December) giving 6 categories in total. For each of these, the data distributions were calculated separately, as illustrated in Figure 5.3. The distributions for the July-Dec period showed a consistent pattern for the 3 traffic categories, with higher EMLRs as the traffic density increased. For the January-June period, the same pattern was evident for the low and medium traffic densities, both of which had higher levels than for the July-December period. However, the pattern for the High AADT category in the Jan-June period did not fit with this overall trend.

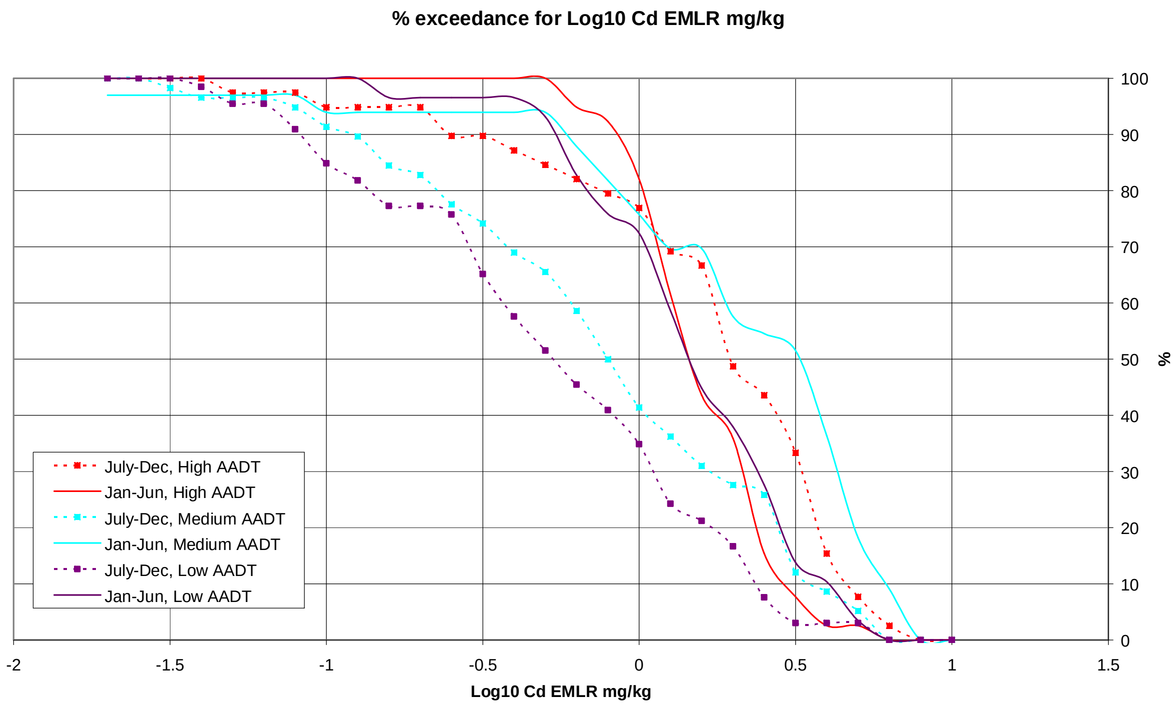


Figure 5.3 Distributions of log10 observed EMLRs for Total Cadmium by category

For the total PAHs EMLRs, the data indicated that climatic region and season were relevant factors. Based on these patterns, the climatic regions were divided into warm or cold and the year into two seasons (June-September, October - May) to give four overall categories. Then the data distributions in each of these 4 categories were calculated, as shown in Figure 5.3. These distributions showed the large difference between the high total PAHs concentrations in the winter from the Cold regions compared with the summer concentrations from the Warm regions, with the other 2 categories generally giving intermediate values.

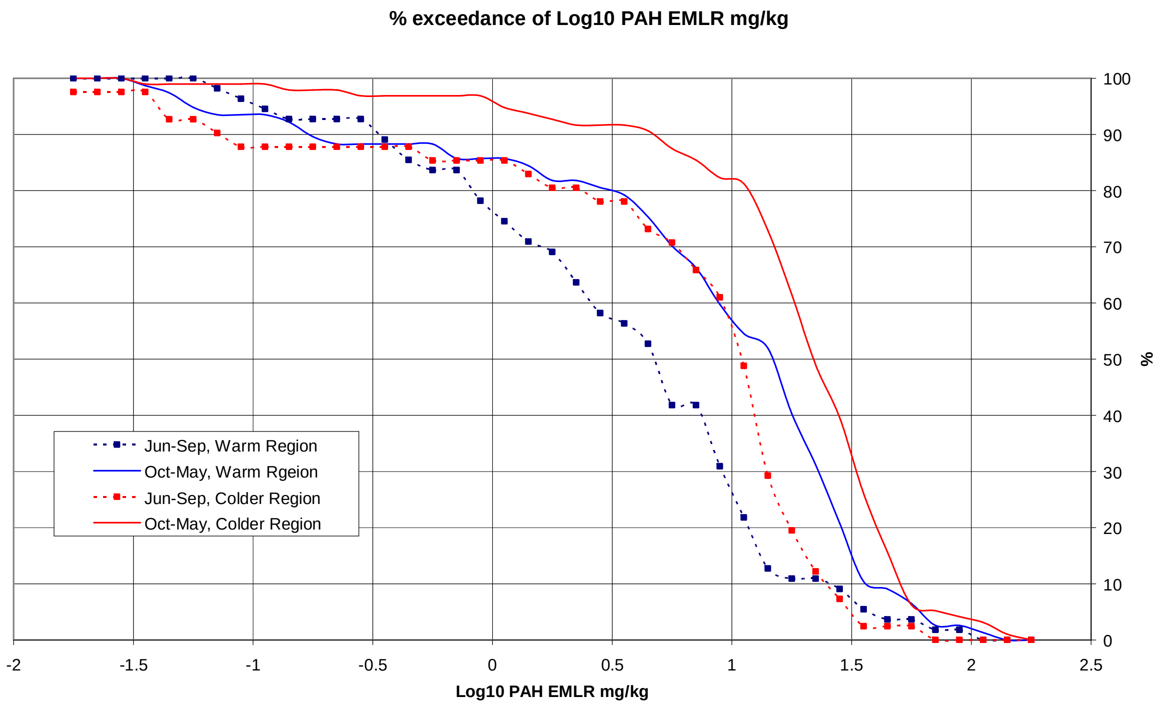


Figure 5.4 Distributions of log10 observed EMLRs for Total PAH by category

Pyrene, Fluoranthence, Anthracene and Phenanthrene

In addition to total PAHs, models were required for four individual PAH – Pyrene, Flouranthene, Anthracene and Phenanthrene – as EMLRs. Individual distributional analyses were not carried out for these PAHs because the Stage 3 analysis(6) had shown that these could be predicted from total PAHs using simple linear regression models. These are

The relationships between these individual the four individual PAH and total PAHs were:

total Pyrene = 0.169 * total PAHs;

total Fluoranthene = 0.164 * total PAHs;

total Anthracene = 0.011 * total PAHs; and,

total Phenanthrene = 0.047 * total PAHs.

5.4 Comparison of the Statistical Model Predictions with Observed Data

5.4.1 Introduction

The statistical models were used to generate long-term predictions of runoff quality for the sites where there were observed data. By comparing the predictions with these data it was possible to provide evidence that the models were giving representative results and thereby, increasing confidence in their use for future assessment work. The two sets of observed data available were:

- the original data used to derive the statistical models, and;
- independent data collected under one of the parallel investigations[3].

The University of Sheffield[3] collected runoff samples from six sites and analysed these for metals and PAH concentrations (µg/g) for around 10 events. For each event, there were about 10 samples collected over a 2 hour period. These data provided an opportunity to help validate the statistical models using information that had not been used in the original development of the models.

5.4.2 Approach

The MLR analysis provided regression equations that explained some of the variability observed in the pollutant runoff data. Given a particular rainfall event (characterised by month, maximum hourly rainfall intensity and preceding rainfall conditions) at a given highway site (characterised by AADT and Climatic Region), the equations can provide an estimate of runoff quality. However, there were wide error bands to these estimates and this uncertainty must also be taken into account.

Therefore, given a large set of rainfall events (representative of, say, 10 years), the models can estimate EMCs and EMLRs in the highway runoff, for each event, using the MLR equations and a random element based on the standard errors from the MLR analysis. For the EMLRs for total Cd and PAHs, the estimates can be based on a random selection from the relevant category distribution – in this way the values generated will have a similar distribution to the observed data.

Average concentrations were calculated as simple arithmetic means of the sample results for each event using the data provided[3]. Flow weighted event mean data were not available. However, it was possible to compare the flow weighted means with the simple arithmetic means for sites/events where flow data were provided.

WRc's STORMPAC® Software[15] was used to generate fourteen 10 year hourly rainfall sites to represent different rainfall patterns around England. STORMPAC® was then used to identify all rainfall events for each site and to characterise these events in terms of date, rainfall total, rainfall duration, maximum hourly intensity and antecedent conditions (ADWP, rainfall in preceding 10 days and 20 days). All events greater than 1 mm were included.

5.4.3 Results Compared with Original Data

Scatter plots were created from the 10 year model results to illustrate the full range of predictions compared to the limited observed data for each site. An example is illustrated in Figure 5.5. This is for a site monitored in the course of the study and shows that the statistical models are able to reproduce the general patterns of variability in the original observed data.

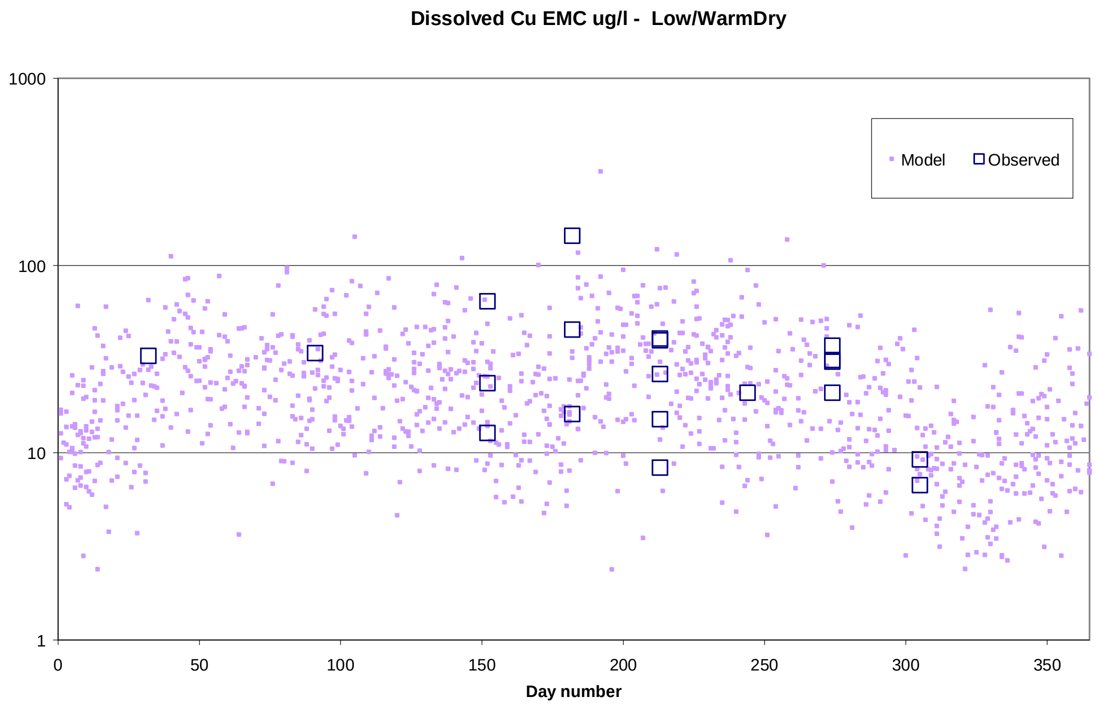


Figure 5.5 Comparison on model predictions and observed data for dissolved Copper EMCs – AADT<50,000, Warm Dry region

Figure 5.6 illustrates the model results produced for one of the University of Sheffield sites[(3)]. The results show that the model predictions are consistent with the observed event data. It should be recognised that the model results are from a large number of simulated events (generally above 1000 individual events, depending on site location) and will include a higher range of variability in event characteristics than those in the relatively small number of observed events. It is also important to note that the limitations of the models are largely due to the limited data available, particularly in relation to events with a long return period.

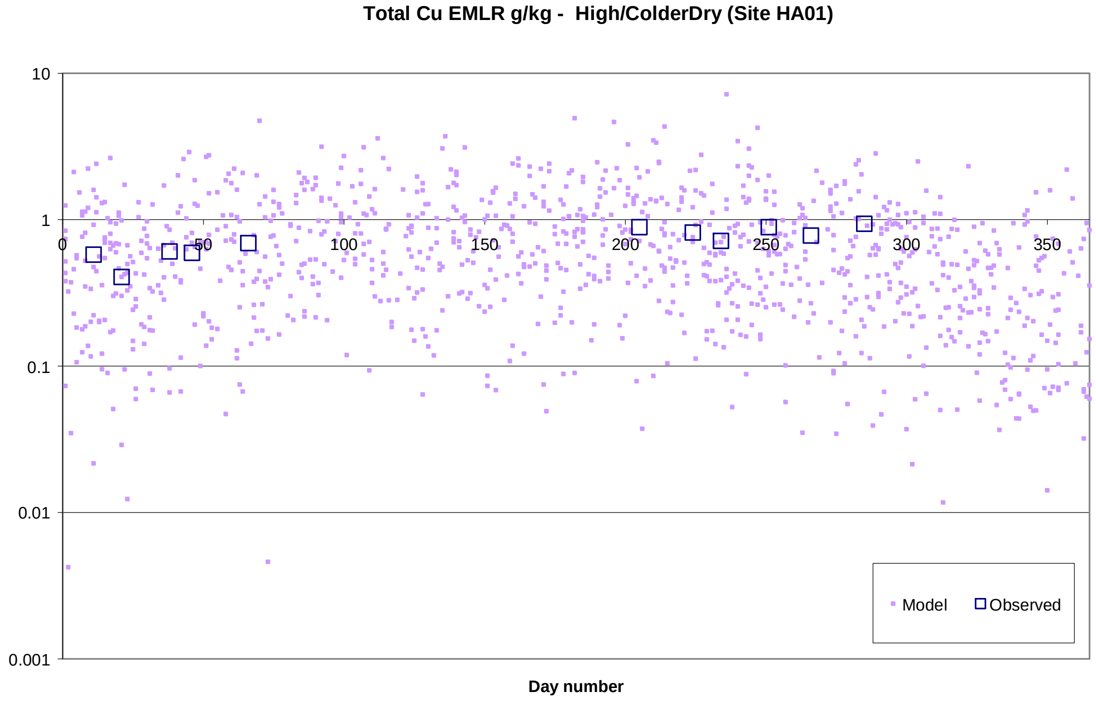


Figure 5.6 Comparison on model predictions and University of Sheffield data for total Copper - Site HA01

Following detailed discussions between the Highways Agency and the Environment Agency, it was agreed that the models were acceptable for inclusion in the future development of improved design guidance to manage the pollution impact risk from highway runoff.

5.5 Design Tool Specification

5.5.1 Introduction

One of the main objectives of the overall research programme commissioned by the Highways Agency, in conjunction with the Environment Agency was to develop an environmental assessment tool to predict the impact of highway runoff discharges on the ecology of receiving waters and assist in the future design of highway drainage schemes to meet environmental requirements.

Hence, the final task in Stage 4 was to specify how the statistical models for highway runoff concentrations could be incorporated into a new Highways Agency Water Risk Assessment Tool (HAWRAT). The purpose of this tool will be to support the improved guidance on how to assess and control the impact of highway runoff on receiving waters and to assist in the future design of highway drainage schemes.

5.5.2 User Specification

A User Specification for this too, to be based on an EXCEL application, was developed in discussion with the Highways Agency based on the following core features.

- It should require relatively little site specific data to make an assessment.
- It should incorporate a tiered approach to assessment whereby unnecessary work is avoided if the impact can be shown to be low.
- It should use a 'traffic light' reporting method whereby:
    - **Red** indicates an unacceptable impact;
    - **Amber** indicates a need to carry out further stages of assessment or to refer the situation to specialist judgement, and;
    - **Green** indicates an acceptable impact with no need for any further investigation.
- It should incorporate the statistical models for highway runoff quality developed in Stage 4(7).
- It should use the ecologically-based Runoff Specific Thresholds (RSTs) for assessing the acute impacts caused by dissolved Copper and dissolved Zinc(2).
- It should incorporate the risk based procedure for assessing the chronic impacts caused by polluted sediments from highway runoff(3).

As well as predicting the pollutant concentrations in highway runoff, the assessment tool should incorporate models for predicting the subsequent impact on rivers and streams. For the soluble pollutants that cause acute impact this involves a simple mass balance approach taking account of river flows. The river flows can be generated by a simple hydrological model using the same rainfall series as that used for the highway runoff predictions. The predicted river flows at the start of an event, and thus reflecting the rainfall history up to this point, can be used for the dilution calculations – any increased river flows during an event should be ignored on the basis that the river catchment will respond more slowly than the highway catchment.

For the insoluble pollutants that cause chronic impact, the impact models should consider both the likelihood and extent of sediment accumulation. This involves hydraulic calculations related to the channel dimensions and river flows at the time of discharge.

The assessment tool should incorporate a number of ecologically-based pollutant thresholds(2,3). The tool should compare the predicted impacts with these thresholds to evaluate exceedance frequencies which, in turn, are compared with 'acceptable' frequencies. This comparison should then reported by the traffic light system.

The tiered approach should be used in the assessment tool, as proposed in Figure 5.7, involving 3 main steps.

Step 1. Check whether the untreated pollutant concentrations in the highway runoff, at the point of discharge prior to any dilution from receiving waters, are acceptable or not. This is a conservative emission standard test. If acceptable at this step, then no further assessment is required.

Step 2. Check whether the impacts of the untreated pollutants on the receiving watercourse are acceptable or not. If acceptable at this step, then no further assessment is required.

Step 3. Check what degree of mitigation would be required to bring pollutant concentrations back to within acceptable limits.

The tool should have a simple User Interface that will mimic this tiered approach.

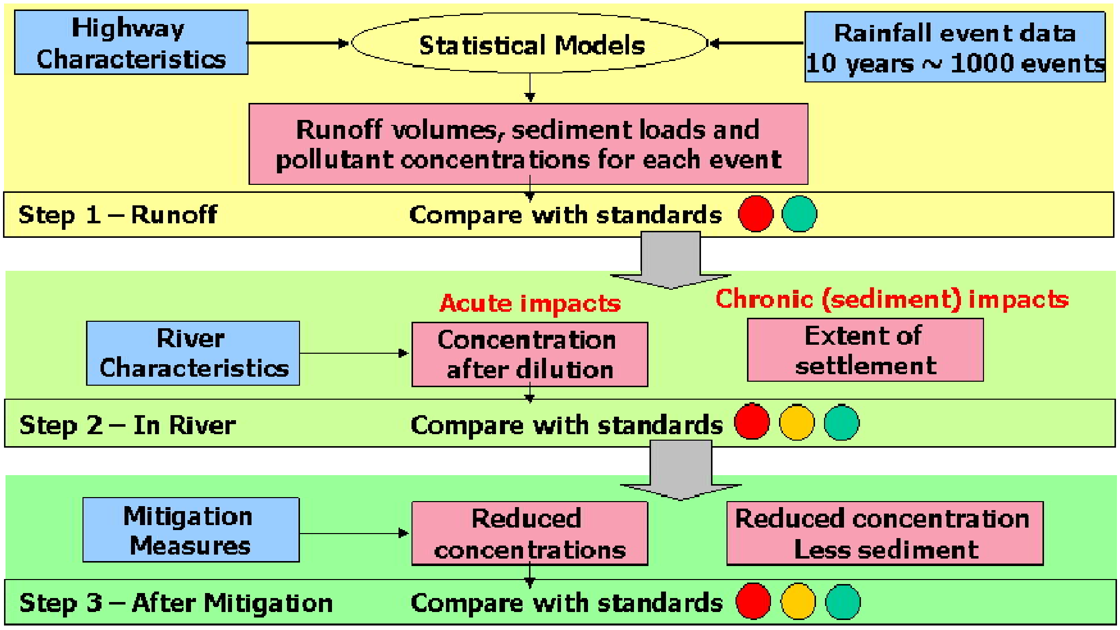


Figure 5.7 Flow chart for the Highways Agency Water Risk Assessment Tool

The tool will not be directly applicable for:

- urban highways;
- highways outside England;
- highways with an AADT outside the range of sites monitored for the model development (<11,000 and >150,000 VPD); and,
- highway discharges to lakes and tidal water courses.

The full User Specification developed is presented in Appendix A.

6. SUMMARY CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In the course of the study data have been collected for 280 highway runoff events from 24 sites across England. These sites represent the range of regional climates and traffic densities found on the Highways Agency's trunk road network. Data have been collected for EMCs and EMLRS for a wide range of soluble and insoluble pollutants found to be routinely present in highway runoff. In addition, 40 events from sites representing the highest traffic densities in each of the 4 defined climate zones included discrete sampling within the event to examine the variability of pollutant concentrations and loads within an event. The resulting data were combined with compatible data from a previous study[(1)] to produce a database of 320 events from 30 sites.

The data analysis in Stage 3 of the study confirmed a list of 'significant pollutants' that may, potentially, pose a risk of short-term acute impacts and/or long term chronic impacts on ecosystems. These have been agreed between the Highways Agency and the Environment Agency. The significant pollutants are:

- total and dissolved Copper;
- total and dissolved Zinc;
- total Cadmium;
- total Fluoranthene, total Pyrene and total PAHs.

The Stage 3 data analysis was focused on understanding the behaviour of these pollutants for their potential inclusion in the Stage 4 model development.

The outcome of the Stage 3 data collection and data analysis identified the following conclusions.

- MTBE was only detected above the LOD in 1 event and Free Cyanide was not detected above LOD for any event. Total Platinum and total and dissolved Palladium were only found at concentrations above LOD for a very small number of events. Also, dissolved PAHs were not found above the LOD for a large proportion of events.
- A direct comparison of the results with previous Highways Agency guidance[(9,10)] for pollutant concentrations in highway runoff shows that, with the exception of total Lead, the Stage 3 results have a greater range of concentrations.
- Correlations between metals and other substances (excluding PAHs) were generally poor. There were no relationships between dissolved metals.
- There are strong correlations between both individual total PAH and individual total PAH with total PAHs.

- The results showed that, with the exception of total PAH as an indicator of concentrations of other total PAHs, there was no evidence to support the use of one or more indicator substances as a surrogate for others.

- The results indicated a trend with pollutant concentrations increasing with AADT and also a greater variability within traffic bands as AADT increases.

- The time determined sampling results suggested that total pollutant concentrations were higher at the hydrograph peak and dissolved pollutant concentrations were lower. Loading rates for total pollutants increased during the event for over 26 of the 40 time determined events. The timing of peak concentrations and loads within an event has significant implications for the design of highway runoff treatment systems.

Key conclusions for Stage 4 model development were:

- the investigation of the effects of site characteristics on pollutant concentrations suggests that there are no simple relationships and that individual event EMCs are a result of a combination of traffic density and a number of interacting event specific variables, including rainfall, ADWP and seasonality;

- traffic density appears to be the main site factor in terms of pollutant concentrations;

- there is no simple relationship between pollutant concentrations and total event rainfall, event peak rainfall intensity and ADWP, as similar concentrations occur across the range of rainfall event characteristics; and,

- there are insufficient data to support the development of a model capable of representing within event pollutographs.

In Stage 4, the original intention was to develop a deterministic model, based on representing the build up and wash off of pollutants from the highway surface driven by a long rainfall time series, to predict event based concentrations for the significant pollutants. However, building on the initial data analysis, it became apparent that this approach would be unsuccessful. Therefore, subsequent model development focused on a statistical approach using multiple linear regression (MLR) analysis to assess the relative importance of the different potential explanatory factors and to provide regression equations to explain the variability observed in the data for each pollutant. The following pollutants were included in the analysis:

- Acute impacts (soluble pollutants)
    - Dissolved Copper
    - Dissolved Zinc

- Chronic impacts (sediment attached, insoluble pollutants)
    - total Copper
    - total Zinc
    - total Cadmium
    - total PAHs
    - Other PAH

The MLR analysis identified that only two site characteristics (AADT and climatic region) and three event characteristics (month, maximum hourly rainfall intensity and antecedent dry weather period) had some significant influence on the pollutant concentrations for Copper and

Zinc. The MLR analysis provided predictive equations for these pollutants that represented some of the observed variability based on explanatory factors but most of the variability by a random error term.

For MLR analysis it was important to work with normally distributed data and this was possible for the Copper and Zinc pollutants, after suitable transformations. However, no suitable transformations were found for total Cadmium and total PAHs and these were modelled by developing non-parametric distributions based on the observed data. Predictions were then made by random sampling from these distributions. In addition to total PAHs, models were developed for four individual PAH – Pyrene, Flouranthene, Anthracene and Phenanthrene. It was possible to develop simple linear regression models to make predictions as the concentrations of these individual PAH were closely correlated to the total PAHs concentrations.

The statistical models were developed to be used with a database of rainfall events that are representative of the long term rainfall conditions for a particular highway discharge location. Runoff concentration is predicted for each event. These results provide a distribution of predicted concentrations which can then be compared directly with runoff standards or used in an impact assessment for a receiving water course(2,3). The models were run for 10 years of rainfall events for the sites used in the study as a check. Comparison plots confirmed that the model results reflected the general patterns in the observed data used to develop the models.

The models were run for additional sites that had been monitored for the sediment attached pollutants in another project(3) to provide validation against independent data. The comparisons showed that the central tendency of the model results were in line with the observed data.

6.2 Recommendations for the Development of a Risk Assessment Tool

The final task in Stage 4 was to specify how these statistical models could be incorporated into a new Highways Agency Water Risk Assessment Tool (HAWRAT). The purpose of this tool, that will underpin the application of improved user guidance in a proposed update to the current 'Section HA216 Road Drainage and the Water Environment', DMRB 11.3.10(10) will be to help highway designers decide whether or not pollution mitigation measures are needed in specific circumstances.

A User Specification for this tool was developed and agreed in discussions between the Highways Agency and the Environment Agency on the basis of the following key features:

- it should require relatively little site specific data to make an assessment;
- it should incorporate a tiered approach to assessment whereby unnecessary work is avoided if the impact can be shown to be low;
- it should use the ecologically-based Runoff Specific Thresholds (RSTs)(2) for assessing the acute impacts caused by dissolved Copper and dissolved Zinc;
- It should incorporate the risk based procedure for assessing the chronic impacts caused by polluted sediments from highway runoff(3).

It is recommended that a prototype tool should be developed on the basis of the User Specification and then extensively tested and validated. This testing should include the following stages.

1. Initial testing for correct functionality against the User Specification by the developers (alpha testing).

2. Independent testing by potential users to check functionality of the user interface and reliability of results (beta testing).

3. Sensitivity testing – to investigate the ranges of results produced in relation to the assumptions used in the development of the underlying models and the potential interactions between specified ranges for ‘hard wired’ and user defined ranges for input parameter values.

4. Validation testing – to compare model predictions for a range of locations with observations of impact at the site.

It is recommended that the prototype tool should be reviewed on completion of the testing programme prior to final development and release. The release of the tool to users should be accompanied by a user training programme and supported by a Technical Manual that provides a detailed description of the underlying models and functionality. It is also recommended that the Highways Agency should consider how long term user support should be provided, including training, technical support, revisions and upgrades and performance assessment in relation to the associated improved design guidance and post construction project appraisal.

The models for predicting pollutant concentrations in highway runoff have been developed using data collected from the highway network in England. The results indicate that traffic is the more significant factor in determining pollutant concentrations compared to climate. On this basis, it would be possible to consider application of the tool by local highway authorities, the devolved administrations within the UK and possibly, to some extent, highways organisations outside the UK. This would require the inclusion of additional rainfall time series data for these regions. Any additional, compatible data on highway runoff pollutant concentrations could be used to revise the existing models or develop regionally specific models.

The prime purpose of the study has been to produce a methodology for managing the environmental risk from non urban highways. It is recognised that urban highways are likely to produce higher levels of pollutants due to traffic loadings, traffic flow patterns and higher levels of atmospheric deposition from the surrounding area. On this basis, the current models may underestimate pollutant loads but give results that could be factored in relation to risk assessments using compatible data from urban highways. In the longer term, subject to need, specific models for urban highways could be developed from targeted data collection to provide an ‘urban roads’ option in the design tool.

Potentially, the HAWRAT design tool provides a user interface that could be developed further to include other types of risk assessment that would be carried out as part of the design process; for example, spillage risk assessment. A further potential area for development would be in relation to assessing the type of mitigation – attenuation or treatment of runoff, for example – that would be required to achieve the identified level of risk reduction for the receiving water impact. Additionally, it may be appropriate to consider including the capability to carryout specific risk assessments against the WFD environmental quality standards (for example, expressed as annual statistics) for the significant pollutants and any others, when required by the Environment Agency.

A capability could also be developed to include risk assessments based on projected climate change scenarios and increases in traffic density.

The R&D programme and the supporting development of the design tool will make a significant contribution to achieving the goals of the WFD in terms of understanding the relative apportionment of diffuse pollution arising from the road transport sector.

6.3 Further Recommendations

The following recommendations are not directly related to the development of the design tool but arise from the results of the data collection and data analysis in terms of implications for highway design and maintenance.

6.3.1 Design of Runoff Treatment Systems

The timing of the peak runoff load has potential implications for the design of runoff treatment systems and the concept of a 'first flush' may not be an appropriate design model. It is recommended that the Stage 3 time determined monitoring data should be examined in more detail to improve the understanding and potential significance of within event variations of pollutant concentrations and loads in relation to the rate of discharge flow and the potential implications for the design of mitigation measures. The need for further targeted data collection may be identified following this examination of the existing data.

6.3.2 Winter Salting

Winter salting is an essential maintenance activity. Application policy can lead to a build up of salt on the highway prior to a runoff event. Attempts to relate Chloride concentrations in runoff events directly to pre event salt application loads have not been possible due to uncertainty in the interpretation of winter maintenance records and other possible factors, such as loses due to wind and traffic effects.

It is recommended that further specific data collection should be carried out to establish a better understanding of the relationships between salting and the concentrations of Chloride and other pollutants. Current water quality standards and those being proposed to define WFD good ecological status are based on annual statistics that would be inappropriate as a measure of the ecological risk of intermittent highway runoff discharges. Therefore, it is recommended that the Highways Agency should consider an assessment of the ecological risk, in terms of potential RSTs for salinity, that take account of the nature of the discharge, receiving water conditions and the life cycle of the fauna and flora that would be present under winter flow conditions. This will help to inform discussion with the Environment Agency on the risk of impact from salting and the nature of any potential control measures. This could include the development of a further element in the HAWRAT tool to assess salting risk.

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APPENDIX A USER SPECIFICATION FOR THE WATER RISK ASSESSMENT TOOL

1. INTRODUCTION

This document provides a User Specification for the Highway Runoff Pollution Assessment Tool. The purpose of the assessment tool is to help highway designers decide whether or not pollution mitigation measures are needed in specific circumstances. The tool should have certain core features:

- It should require relatively little site specific data to make an assessment.
- It should incorporate a tiered approach to assessment whereby unnecessary work is avoided if the impact can be shown to be low.
- It should use a 'traffic light' reporting method whereby:
    - **Red** indicates an unacceptable impact;
    - **Amber** indicates a need to carry out further stages of assessment or to refer the situation to specialist judgement, and;
    - **Green** indicates an acceptable impact with no need for any further investigation.
- It should incorporate the statistical models for highway runoff quality developed in Stage 4.
- It should use the ecologically-based Runoff Specific Thresholds (RSTs) for assessing the acute impacts caused by dissolved Copper and dissolved Zinc[(4)].
- It should incorporate the risk based procedure for assessing the chronic impacts caused by polluted sediments from highway runoff[(5)].

1.1 Pollutants

The assessment tool should deal with the following pollutants:

Soluble pollutants associated with acute pollution impact: Expressed as Event Mean Concentrations (EMCs in ug/l) for dissolved copper and zinc, and;

Insoluble pollutants associated with Sediment pollution impact: Expressed as Event Mean Sediment Concentrations (EMSCs in mg/kg) for total Copper, Zinc, Cadmium, Pyrene, Fluoranthene, Anthracene, Phenanthrene and total PAHs. (NB. In the Stage 3 and Stage 4 reports, EMSCs have also been referred to as Event Mean Loading Rates (EMLRs).

1.2 Runoff pollution models

The assessment tool should use the statistically-based models for predicting the runoff quality for each pollutant, as described in the Stage 4 Report.

1.3 Impact models

The assessment tool should also incorporates models for predicting the impact of the runoff on receiving rivers and streams. For the soluble pollutants that cause acute impact this will involve a simple mass balance approach taking account of river flows and assuming minimal levels of the pollutants in the receiving waters.

For the insoluble pollutants that cause sediment impact, the impact models should consider both the likelihood and extent of sediment accumulation.

1.4 Threshold analysis

The assessment tool should incorporate a number of ecologically-based pollutant thresholds. The tool should compare the predicted impacts with these thresholds to evaluate exceedance frequencies which, in turn, should be compared with 'acceptable' frequencies. This comparison should then reported by the traffic light system.

1.5 Limitations

The tool will not be directly applicable for:

- urban highways;
- highways outside England;
- highways with an AADT outside the range used in the research upon which the runoff models were developed (about 11,000 to 146,000 veh/day), and;
- highways where the receiving water course is tidal.

1.6 Software

The assessment tool should be developed as an Excel application in Microsoft Excel 2003 under Windows XP. It should incorporate some Visual Basic code to help manage the User Interface. It should be tested for compatibility with version 2007 of Excel and with the Vista operating system.

2. TECHNICAL SPECIFICATION

2.1 General

The assessment tool will be an Excel based application with a number of elements. These are:

- the **core models** for predicting EMCs and EMSCs in highway runoff, based on the statistical models described in the Stage 4 report. These models and their associated parameters will be protected and only changed by the model developer.

- **Code** to manage the user interface, call up the models and display results. Again, this will be protected and only changed by the model developer. The functionality is described in Sections 2.4 and 2.5.

- **Default values** for various parameters and for the assessment thresholds (Section 2.2). This includes the rainfall series. These will be in look-up tables that could be edited by the Administrator (See section 2.5).

- The **User Interface**, accessible to the user for entering data, running the model and inspecting the results (Section 2.3).

2.2 Assessment Thresholds

Look-up tables will be developed that define the thresholds and the number of exceedances of these thresholds that would result in a Red/Amber/Green result. For acute pollution, these standards are Runoff Specific Thresholds (RST). For Sediment pollution, these are Threshold Effect Levels (TEL) and Probable Effect Levels (PEL).The threshold tables will take a form similar to that shown in Tables 2.1 and 2.2. The exceedances tables will take the form of those illustrated in Tables 2.3 and 2.4. Different tables may apply for discharges that will impact on conservation areas (e.g. SAC/SPA), as illustrated in Table 2.3.

Table 2.1 Assessment thresholds for acute pollution from highway runoff

Threshold Name		Zn ug/l		
		Hardness		
	Cu ug/l	Low	Medium	High
RST24hr	21	60	92	385
RST6hr	42	120	184	770

Low = < 50mg $CaCO_3$ l^{-1}
Medium = 50-200mg $CaCO_3$ l^{-1}
High = >200mg $CaCO_3$ l^{-1}

Table 2.2 Assessment thresholds for sediment pollution from highway runoff

Substance	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Unit	mg/kg	mg/kg	mg/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg
TEL	35.7	123	0.6	1684	53	111	46.9	41.9
PEL	197	315	3.5	16770	875	2355	245	515

Table 2.3 Exceedance thresholds for acute pollution from highway runoff

	Max number of exceedances allowed in 10 years		Traffic light assessment		
Likely to impact on a protected site for conservation	>RST24hr	>RST6hr	Both criteria met	RST24 criterion failed but RST6 criterion passed	RST6hr criteria failed
No	20	10	**Green**	**Amber**	**Red**
Yes	10	5	**Green**	**Amber**	**Red**

Table 2.4 Exceedance thresholds for sediment pollution from highway runoff

Unit	Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
exceedances allowed in 1 year	1	1	1	1	1	1	1	1

2.3 User interface

The use of the assessment tool will be through the user interface. On the interface the user will enter the details relating to the highway site to be assessed, the receiving water course and potential mitigation. There is a single button (or menu item) to execute an assessment run.

The interface will include an area showing the summary results from an assessment run. This will indicate, by pollutant, if the results are Red/Amber or Green. In addition there will be a separate Detailed Results sheet giving more statistics. This sheet will be accessible from a button or menu item. There will several other buttons or menu items for general file management.

Figure 2.1 is a mock up of the assessment tool interface illustrating the layout of the inputs and results. The details of each component on the interface and the related calculations are set out below.

2.3.1 Initialisation

The assessment tool will automatically initialise when it is first opened. The initialisation will populate the various drop-down menus and set default values for any parameters. If a parameter is at its default setting this will be identified by a 'D' adjacent to the entry box. This will disappear if the value is altered from its default setting.

2.3.2 Location Details

This area will allow a user to define the exact location of the outfall being assessed. The data will not required for the calculation procedure but will included in the saved results for documentation and auditing.

2.3.3 Tiered approach

Figure 2.1 illustrates the tiered approach with 3 steps:

Step 1. Check whether the untreated pollutant concentrations in the highway runoff, at the point of discharge prior to any dilution from receiving waters, are acceptable or not. This is a conservative emission standard test. If acceptable at this step, then no further assessment is required.

Step 2. Check whether the impacts of the untreated pollutants on the receiving watercourse are acceptable or not. If acceptable at this step, then no further assessment is required.

Step 3. Check what degree of mitigation would be required to bring pollutant concentrations back to within acceptable limits.

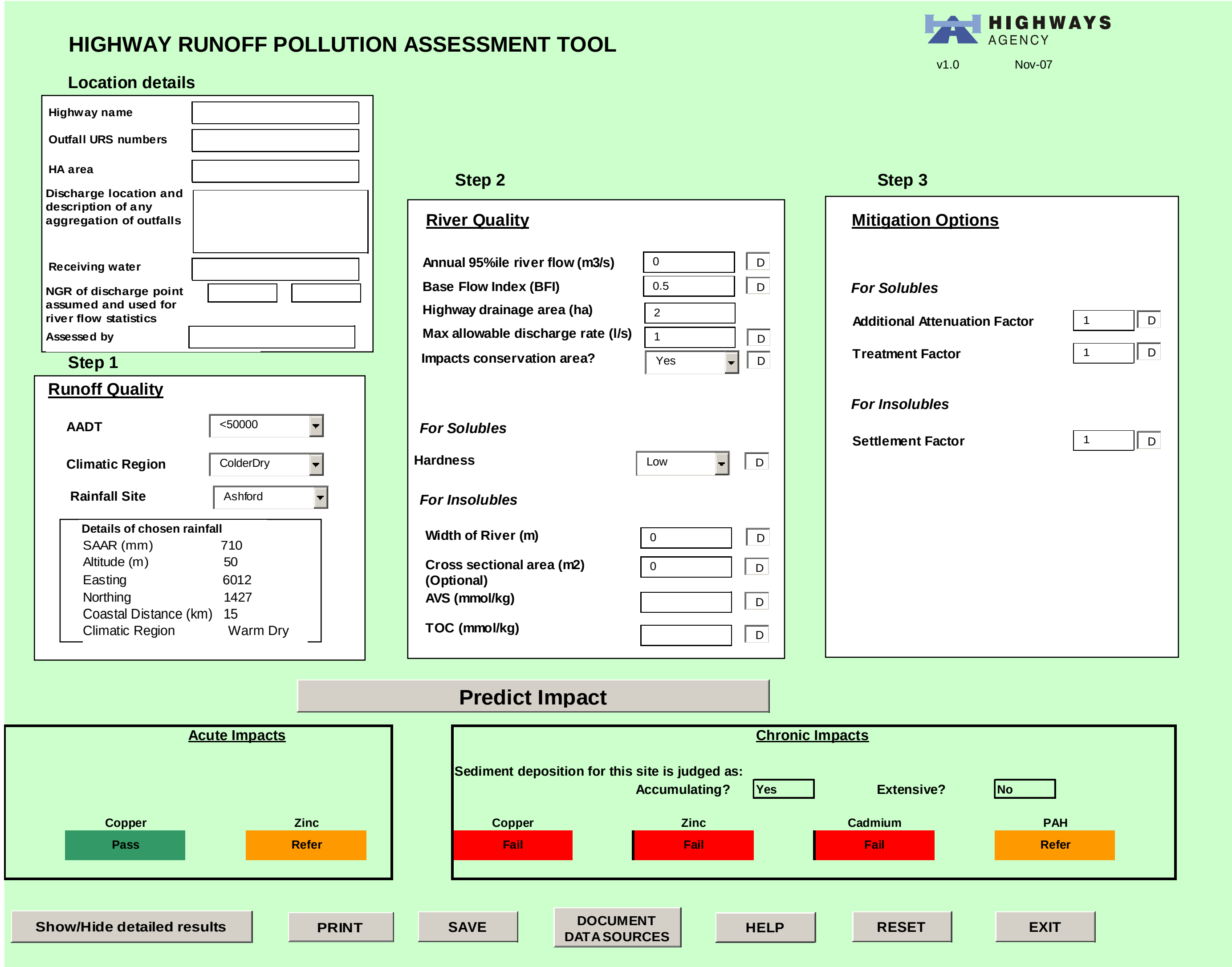

Figure 2.1 Illustration of the User Interface

DETAILED RESULTS Hide detailed results

Note: summer defined as April to September

In Runoff	Step1	Acute			Chronic							
		Copper	Zinc		Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Threshold 1	*RST24 (ug/l)*	*21*	*60*	*TEL mg/kg*								
	No. of exceedances/year											
	No. of exceedances/worst year											
	No. of exceedances/summer											
	No. of exceedances/worst summer											
Threshold 2	*RST6 (ug/l)*	*42*	*120*	*PEL mg/kg*								
	No. of exceedances/year											
	No. of exceedances/worst year											
	No. of exceedances/summer											
	No. of exceedances/worst summer											
	Statistics	ug/l	ug/l		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Mean											
	90%ile											
	95%ile											
	99%ile											

In River (Modified)	Step2	Acute			Chronic							
		Copper	Zinc		Copper	Zinc	Cadmium	Total PAH	Pyrene	Fluoranthene	Anthracene	Phenanthrene
Threshold 1	*RST24 (ug/l)*			*TEL mg/kg*								
	No. of exceedances/year											
	No. of exceedances/worst year											
	No. of exceedances/summer											
	No. of exceedances/worst summer											
Threshold 2	*RST6 (ug/l)*			*PEL mg/kg*								
	No. of exceedances/year											
	No. of exceedances/worst year											
	No. of exceedances/summer											
	No. of exceedances/worst summer											
	Statistics	ug/l	ug/l		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Mean											
	90%ile											
	95%ile											
	99%ile											
	% coverage of sediment				%							

In River (modified and after treatment)	Step3	Acute			Chronic
		Copper	Zinc		
	RST24 (ug/l)				
	No. of exceedances/year				
	No. of exceedances/worst year				
	No. of exceedances/summer				
	No. of exceedances/worst summer				
	RST6 (ug/l)				
	No. of exceedances/year				
	No. of exceedances/worst year				
	No. of exceedances/summer				
	No. of exceedances/worst summer				
	Statistics	ug/l	ug/l		
	Mean				
	90%ile				
	95%ile				
	99%ile				
	% coverage of sediment				%

Figure 2.2 Illustration of detailed results section

2.3.4 Step 1 Check runoff quality

When the tool is first opened the parameters will be set at their default values and the tool will be ready to carry out Step 1 – check runoff quality. This means that the river flow (in Step 2) is set to 0 and the mitigation factors (Step 3) are set to 1. If, at a later stage, the user wants to revisit Step 1 (runoff quality alone) these parameters will need to be reset to these defaults.

User Input

The user will be able to set up the highway site characteristics – AADT, climatic region and rainfall site by choosing the closest category/type from the drop-down lists:

AADT: <50000; >50000 and <100000; >100000

Climatic Region: Cold-Dry; Cold-Wet; WarmDry; WarmWet

The list of *rainfall sites* will comprise a range of typical sites around the country as illustrated in Table 2.5. Once selected, the site's Standard Annual Average Rain (SAAR) and location details will be displayed instantly on the interface to help the user confirm that the most appropriate site has been chosen.

The HELP button will give access to definitions for each item (e.g. a map of climatic regions) and advice about using the tool and interpreting the results.

Table 2.5 Rainfall sites built into the tool

Rainfall	Altitude	Easting	Northing	Coastal Distance(km)	SAAR	Climatic Region	Annual number of rainfall events
Ashford	50	6012	1427	15	710	Warm Dry	78
Ipswich	35	6164	2448	17	550	Warm Dry	68
London	20	5301	1795	45	600	Warm Dry	109
Huntingdon	15	5237	2716	100	600	Warm Dry	108
Lincoln	40	4976	3718	55	600	Colder Dry	111
Newcastle upon Tyne	75	4248	5648	18	680	Colder Dry	129
Penrith	200	3514	5304	45	900	Colder Wet	136
Keighley	200	4060	4410	70	1000	Colder Wet	97
Warrington	20	3610	3885	15	830	Colder Wet	91
Birmingham	120	4073	2872	120	750	Warm Dry	122
Bristol	70	3561	1754	10	850	Warm Wet	130
Southampton	25	3561	1754	10	820	Warm Wet	131
Exeter	70	2918	1924	15	1000	Warm Wet	141
Bodmin	110	2072	1670	20	1200	Warm Wet	151

Test/calculation (Predict Impact)

For acute impacts

The assessment tool will estimate the EMCs in the highway runoff for each event in the 10 year period, using the statistical models. The predicted EMCs will then be checked against RSTs and the number of exceedances will be counted and compared against allowable exceedance frequencies (Table 2.3). The 'headline' result will be presented as Pass/Refer/Fail for each pollutant.

To inspect the detailed results, the user can click on 'Show/Hide detailed results'. This will show the number of exceedances for the whole 10 year period and for the worst year and for summers. Summary statistics will also be shown. Figure 2.2 illustrates the type of results that the user will see on the detailed results table. By viewing the detailed results a user will get an idea of how far the predictions are above or below the criteria. In addition, the results will be used if the assessment needs to be referred for more specialist judgement. The detailed results can be hidden by toggling the 'Show/Hide detailed results' button.

For Sediment Impacts

The assessment tool will estimate the EMSCs in the highway runoff for each event in the 10 year period, using the statistical models.

The predicted EMSCs will then be checked against the TELs and the number of exceedances will be counted and compared against allowable exceedance frequencies (Table 2.4). This will be a 1 year RP test. The 'headline' result will be presented as Pass/Fail for each pollutant, except for the PAHs. For the PAHs, a single 'headline' result will be presented – Pass if all the individual PAH and total PAHs pass; Fail if any PAH fails.

As for the acute impact it will be possible to view more detailed results where the results for individual PAHs will be available (see Figure 2.2).

2.3.5 Step 2 Check river impact

User input

Annual 95%ile river flow (Q95)

Base Flow Index (BFI)

Highway drainage area (Impermeable and permeable)

Maximum allowable discharge rate

Likely to impact on a protected site for conservation?

For Zinc

Hardness (high, medium, low),

For Sediment impacts

Various parameters related to the Width of river or area

Test/calculation (Predict Impact)

For acute impacts

For predicting the likely river acute impacts, the tool will need an estimated river flow for dilution calculations. The user supplies an annual 95%ile low flow and Base Flow Index (BFI). The river flow when the event happens will be simulated using a simple two store hydrological model which incorporates the given BFI. The model will automatically calibrate to generate a flow series that has a 95%ile low flow equal to the given 95%ile flow. The estimated flow for a given event will be the river flow generated by the model at the start of the event – i.e. it will not be influenced by the event itself. This will be a conservative approach and recognises that the highway runoff response will generally be much faster than the river flow response.

The average highway runoff flow generated by each rainfall event will be calculated using the Highway Agency's method(s). It will be expressed as an average rate (in m^3/s) over the duration of the rainfall event. If this is greater than the 'Max allowable discharge rate', the Max allowable discharge rate will be used and the runoff duration will be adjusted accordingly to give the same total volume of runoff. (The user will supply the 'Max allowable runoff rate' based on the EA flood protection requirements for the site).

Finally, the pollutant concentrations in the receiving river will be calculated based on the following equation for each event in the 10 year period:

Concentration in river = (concentration in runoff x runoff flow + concentration in upstream river flow x river flow) / (runoff flow + river flow)

The number of threshold exceedances will be calculated as before and compared with the allowable frequencies. The thresholds for Zn may be different at this stage, depending on the hardness range selected (see Table 2.1). In addition, the allowable frequencies may also be different depending on whether or not the conservation area option is selected (see Table 2.3).

For Sediment impacts

The calculations will be based on the risk assessment procedure developed by Sheffield University(5).

The tool will first assess whether or not sediment is likely to accumulate under low flow conditions. The Sheffield procedure uses information on the channel shape and slope to estimate a flow velocity at either the Q95 or Q90 flow. This is then compared with a critical threshold (0.1 m/s). If the calculated velocity is greater than the threshold the sediment is judged to disperse and hence the result is Green (unless the discharge is likely to impact upon a protected site for conservation, in which case the result is Amber). If less than the threshold the result depends on the extent of sediment.

The tool will then assess the extent of the sediment deposition. The Sheffield procedure compares the amount of the stream width likely to be occupied by the predicted annual sediment volume against a test threshold (10%). The tool will make this calculation and provide a result as indicated in the table below (from the Sheffield procedure), also taking account of the predicted EMSCs:

	Is sediment coverage (relative to stream width) predicted to be:	
Is 1 year RP EMSC	<10%	>10%
<PEL	**Green**	**Amber**
>PEL	**Amber**	**Red**

2.3.6 Step 2a Bioavailability

The Sheffield procedure allows a further refinement whereby the sediment concentrations are compared with mechanistic Sediment Quality Guidelines (rather than the PELs) to take better account of bioavailability. The tool will incorporate these calculations also. This step will be optional if the result from Step 2 was Amber.

User Input

Total Organic Carbon (TOC)

Acid Volatile Sulphide (AVS)

Simultaneously Extracted Metals (SEM)

Calculation/Test (Predict Impact)

Using the TOC, AVS and SEM the sediment toxicity (1 year RP) will be compared with the mechanistic Sediment Quality Guidelines. If greater than the guidelines the Amber from Step 2 will become Red. If less than the guidelines, the Amber from Step 2 will become Green. Any Green or Red result from Step 2 will remain unchanged.

2.3.7 Step 3 Mitigation options

If the results from Step 2/2a are not Green, then the user will be able to explore the degree of mitigation needed to bring the pollutant concentrations back to within acceptable limits.

User Input

For acute impacts

Further Attenuation factor (0-1),

Treatment factor (0-1)

For Sediment impacts

Settlement factor (0-1)

Treatment factor (0-1)

Calculation/Test (Predict Impact button)

For acute impacts

The tool will allow the representation of two mitigation measures for pollutants causing acute impacts – further runoff attenuation and treatment.

The further attenuation factor will reduce the pollutant level in the river by further reducing the rate of highway runoff that gets mixed with the upstream river flow (this will be in addition to any attenuation already required to meet the 'Max allowable runoff rate' used in Step 2). The revised runoff flow will be calculated as:

Attenuated runoff flow (m^3/s) = runoff rate (from Step 2) * attenuation factor

The treatment factor (<1) will reduce the pollutant concentration in the highway runoff before it mixes with the upstream river flow, therefore, bringing down the pollutant level in the river.

Treated runoff EMC = Untreated EMC * treatment factor

So overall, the pollutant concentration in the river for each event will be adjusted to:

Concentrations in river = (concentration in runoff x *treatment factor* x runoff flow/*attenuation factor* + concentration in upstream river flow x river flow) / (runoff flow/*attenuation factor* + river flow)

The recalculated concentrations will be compared with thresholds and the results updated.

For Sediment impacts

The settlement factor (<1) will work by reducing the quantity of sediment discharged. Hence, it will affect the extent of the sediment coverage:

% coverage = % coverage without settlement option * settlement factor

The treatment factor (<1) will reduce the pollutant concentration in the highway runoff and thus affect the comparisons with the PELs and mechanistic sediment quality guidelines.

2.4 File management

The tool will have a number of file management options included in a new menu on the Excel toolbar.

2.4.1 Save

The assessment tool will allow the user to save the detailed results along with the parameters used as .csv files in a user defined location. By clicking the 'Save' button , the user will be able to name the .csv file and choose the folder in which the file is saved. The save date will be included.

2.4.2 Document data sources

This option will allow a user to both inspect the current User Parameter values and to provide notes to explain/justify any of the data entries. This is likely to be needed at a final stage in assessment to provide an audit trail. These notes, which will take a form similar to that shown in Table 2.6, will get saved when the save option is used.

Table 2.6 Table for the user to document data sources

Parameter	Units	Value	Default value	Notes

2.4.3 Print

The Print button will print a copy of the interface, as it currently appears, to the user's default printer. The detailed results will also be printed. The print date will be included on the print out.

2.4.4 Open

This will allow a user to identify an existing csv file that has been previously saved, and populate the tool with the previous saved values.

2.4.5 Reset

This will clear all existing user data on the tool and reset the tool to the default values (as if the tool had been opened). A warning message will be given.

2.5 <u>Protection/Security</u>

The assessment tool will be fully protected with 3 levels of accessibility – user, administrator, developer.

- The **user** will be able to use the tool to make assessments and manage input data and results, as described in this note. A user will have access to the User Interface and will be able to change data entry boxes there. The User will be able to view the User Parameters sheet and add notes about the source of data but will not be able to edit any other aspects of this sheet. The User will have 'Read only' access to the Detailed Results sheet and to the Assessment Parameters sheet (The user will not be able to adjust any of standards/thresholds or other default parameter settings on the Assessment Parameters sheet).

- The **administrator** will have the same access rights as the user. In addition, the Administrator can view and change the Assessment Parameters sheet that holds the default values for the standards/thresholds and other parameters. An administrator can also add worksheets for additional rainfall sites.

- The **developer** will have full access of the assessment tool including the programming code and the core models for runoff quality.

On opening up the application, a box will pop up asking for the user type. If 'user' is chosen from the dropdown list, no password will be required. If 'administrator' or 'developer' is chosen, passwords will be required before further actions can be taken.

2.6 Help

The HELP button will provide access to an online User Guide which will provde detailed advice and instructions on the overall purpose of the tool and on each stage.

2.7 Data entry validation

Each data entry box will have a validity range defined (minimum and maximum). Invalid entries will be flagged.