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Mapping hazard from urban non-point pollution: A screening model to support sustainable urban drainage planning

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Abstract

Non-point sources of pollution are difficult to identify and control, and are one of the main reasons that urban rivers fail to reach the water quality objectives set for them. Whilst sustainable drainage systems (SuDS) are available to help combat this diffuse pollution, they are mostly installed in areas of new urban development. However, SuDS must also be installed in existing built areas if diffuse loadings are to be reduced. Advice on where best to locate SuDS within existing built areas is limited, hence a semi-distributed stochastic GIS-model was developed to map small-area basin-wide loadings of 18 key stormwater pollutants. Load maps are combined with information on surface water quality objectives to permit mapping of diffuse pollution hazard to beneficial uses of receiving waters. The model thus aids SuDS planning and strategic management of urban diffuse pollution. The identification of diffuse emission ‘hotspots’ within a water quality objectives framework is consistent with the ‘combined’ (risk assessment) approach to pollution control advocated by the EU Water Framework Directive.

Keywords: Stormwater; Diffuse pollution; Sustainable Drainage System; River basin planning.

1 Introduction

Pollution from urban non-point sources is one of the main reasons that rivers fail to reach their water quality objectives. In Scotland, for example, 20 % of all water quality failures are attributed to urban non-point sources (SEPA, 1996). Sustainable drainage systems (SuDS) able to reduce diffuse pollution are available, including structural source controls (e.g. swales, filter drains, permeable surfaces, wetlands) and 'good housekeeping' best management practices, with advice on their implementation now available in the form of design manuals (CIRIA, 2000). Understandably, SuDS practice has focussed on new urban developments, as these offer opportunities to consider SuDS at the earliest planning and design stages. However, the majority of diffuse urban loads draining to surface waters come from existing developments; hence consideration must be given to retro-fitting these areas with SuDS if diffuse pollution impacts are to be reduced.

Advice is available on identifying sites in existing built areas where SuDS implementation is feasible (Makropoulos *et al*., 1998) or acceptable (Ellis, 1998), the latter considering criteria such as groundwater quality objectives. However, whilst it has long been known that diffuse urban loadings can vary by an order of magnitude or more between ‘clean’ and ‘dirty’ urban catchments (Ellis, 1991), little effort has been made to identify sites that are significant in terms of load and potential impact on receiving waters, and hence which deserve further detailed assessment and possible SuDS implementation. This omission is significant within the context of the EU Water Framework Directive (2000/60/EC), which requires that all emissions to water be identified, quantified and managed.

This paper reports on the development of a nonpoint source preliminary planning and assessment model designed for application to urbanised river basins, particularly those in NW Europe and the UK. The model is consistent with the EU Water Framework Directive’s combined approach to pollution that seeks a reduction of emissions within limits defined by water quality objectives, and which operates at the river basin scale. The model can: (a) quantify diffuse urban emissions, and map the location of areas producing the poorest stormwater quality runoff within a river basin; (b) identify areas which present the greatest hazard to the beneficial uses of receiving waters; and (c) assess the impact of land use change on diffuse loads. Thus the model can be used to identify urban areas where desired development presents the least risk to runoff quality, and more importantly can assist in prioritising existing built sites for further detailed assessment with a view to possible SuDS implementation.

2 Pollutants Addressed

Pollutants to be addressed in the model were selected using a simple risk assessment, consistent with the approach subsequently recommended in the EU Water Framework Directive for identifying pollutants of "management concern". Firstly, evidence of widespread contamination was assessed through literature review, including evidence from the US nation-wide urban runoff programme (NURP) (US EPA, 1983). Second, intrinsic hazard was assessed through a review of pollutant toxicity, and the frequency with which urban stormwater fails ecological and human health standards, based on the NURP priority pollutant programme (Cole *et al.*, 1984). Failure of water quality standards in UK urban rivers provided further evidence of possible contamination. The resultant provisional list was further refined through consultation with prospective end users in the UK (including the Environment Agency, Scottish Environmental Protection Agency, Water Research Centre, Water Utilities, and local authority urban drainage practitioners), and following definition of the stormwater quality modelling approach.

The pollutant parameters addressed are: total suspended sediment, BOD, COD, total metals (cadmium, chromium, copper, iron, lead, mercury, nickel and zinc); nutrients (total nitrogen, total kjheldahl-nitrogen, total phosphorous, soluble phosphorous and ammoniacal-N); and oil and grease.

3 Modelling Approach

There are numerous approaches to estimating urban stormwater loadings. These include databases, regression analyses, unit load, sediment potency, volume-concentration and build-up and wash-off methods (Marsalek, 1991). There is no universal 'best' approach, and current advice is to match the modelling effort to the study objectives, avoiding the use of large complex models when smaller simpler ones will suffice (FWR, 1994). This study aimed to develop a preliminary planning and assessment model suitable for identifying urban diffuse pollutant 'hot spots' within a river basin, for a wide range of pollutants. Considering this objective, advice on model selection (Reckhow *et al.*, 1985), and a literature review of stormwater modelling (Mitchell *et al.*, unpublished), it was decided to develop a semi-distributed stochastic model with annual load modelled as the product of runoff volume and a pollution concentration variable, the site mean event mean concentration. The event mean concentration (EMC) is the total mass load of a chemical yielded from a storm, divided by the total storm discharge. A storm EMC is thus calculated as the area under the loading rate curve divided by the area under the flow rate curve (or is simply taken as the flow weighted mean concentration in sampling programmes). The mean value from multiple storms monitored at the same location is the site mean EMC, and is the parameter used in the load assessments.

This modelling approach was adopted for several reasons. First, volume-concentration methods often perform better than regression models (Brown, 1987; Pandit, 1997), and give load estimates comparable to, and in some cases better than those of complex build-up and wash-off models (Chandler, 1994; Charbeneau and Barrett, 1998). For example, application of a volume-concentration model in the USA, showed that 77 % of 124 load estimates were within a factor of two of the estimates derived using deterministic models (HSP-F and SWMM), and with 90 % certainty, were within 95 % of observed loads, for catchments up to 2 000 km^2 (Chandler, 1994). Such studies indicate that volume-concentration methods, if applied with sensitivity to local conditions, can provide load estimates of sufficient accuracy to inform SuDS planning, and at a fraction of the cost of more complex models.

Secondly, observations from the UK (Mance and Harman, 1978; Moy *et al*., 2003), USA (US EPA, 1983) and France (Hemain, 1986) have shown that the mean EMC of a site is not correlated with annual runoff volume, simplifying the modelling exercise as interactions between runoff volume and pollutant concentration could be ignored. Third, many pollutants can be addressed, and new ones easily added as EMC data become available. Fourth, EMC application allows uncertainty in loads estimation to be assessed through probabilistic methods, and finally, basin scale applications are possible whist maintaining a useful spatial unit of analysis. Once the approach was determined, site mean EMC values and a runoff model appropriate to a UK application were required. As land use is a determinant of both runoff and EMC, the model design proceeded iteratively until a land use structure suited to both the runoff model and the EMC database emerged.

Whilst the volume-concentration approach has been applied before, notably in the USA, no urban diffuse pollution screening model (of any sort) suitable for basin scale application in Europe is available. This paper presents the first such model. The study applies the volume-concentration approach, applying a runoff model validated for use in Europe, and derives European (and UK) specific EMC values via a review of 678 monitored urban catchments. The hazard mapping capability (see 6 below) also permits a simple assessment of diffuse loading hazard to receiving waters. The model thus supports management initiatives seeking to control emissions at source within a water quality standards framework, whilst also providing a basin scale assessment, both requirements of the Water Framework Directive.

4 Model Construction

4.1 Runoff Model

The requirements of the runoff model are: (a) an ability to quantify annual runoff volume (event runoff estimation was unnecessary); (b) applicability at the basin scale with a spatial unit of analysis <500m^2; (c) sensitivity to spatial variability in annual rainfall; (d) response to change in land use or land cover; (e) applicability to the UK study area; and (f) ability to be implemented at low cost within a desktop Geographic Information System (GIS), making it suitable for screening level applications.

A review of urban runoff models showed that statistical rainfall-runoff methods were most appropriate. From over a hundred such methods reported in the literature, the runoff volume algorithm (RUNVOL) of the Wallingford Modified Rational Method (DoE, 1981) was selected. This function has the form:

$$\mathrm{RUNVOL} = ((0.829\ \mathrm{PIMP} + 25.0\ \mathrm{SOIL} + 0.078\ \mathrm{UCWI} - 20.7) / 100) \times P \times A$$

Where: RUNVOL is annual runoff (mm)

PIMP is the coverage by impervious surfaces connected to a storm sewer (%).

SOIL is a unitless variable developed during the UK Flood Studies Report research (NERC, 1975). The index is based on winter rainfall acceptance, a soil hydrologic characteristic which is broadly infiltration potential and the reverse of runoff potential. Soil surveyors allocate SOIL values considering permeability, groundwater level, and slope.

UCWI (Urban Catchment Wetness Index), is antecedent wetness (mm).

P is annual rainfall (mm).

A is catchment area.

RUNVOL matches the requirements of the runoff model detailed above. It has been derived from the largest UK urban runoff database, comprising 510 storm events from 17 catchments, and is used to quantify runoff volume inputs to complex deterministic models (e.g. WASSP, WALLRUS) that are currently used in UK sewer design. Thus the method is proven, with potential for application in a basin scale distributed model.

4.2 GIS database

To support annual runoff volume and load modelling, a GIS database was developed to address:

(a) Impervious area (PIMP). This impermeability variable was estimated using land use data (see b below), and corresponding land use-impermeability coefficients derived from surveys of NW London, Bolton, Nottingham and Dundee (Ellis, 1986; Ellis, *pers. comm.*), conducted as feasibility preparation for the MOSQUITO sewer quality model. This approach was used as other methods such as map interpretation, field or air photo survey are prohibitively costly at the basin scale, and hence not suited to a screening model. From the surveys, typical impermeability values were obtained for 12 urban land use and residential density classes. Values for motorways were drawn from the CIRIA 142 report (Luker and Montague, 1994).

(b) Urban land use. Through the CORINE project the European Environment Agency provides digital land use data for Europe, collected through remote sensing, air photo interpretation and field verification (EEA, 2000). Data is classified in a hierarchical structure, with 44 land uses (11 are urban) at the most resolved tier. Data is available in vector format (the smallest polygon is 25 ha) and as a raster image (the smallest unit is 25 m) based on the vector data. Using the raster data, a map was developed to address the land use categories of the EMC and impermeability databases. Main highway areas were delineated using OS Meridian road centre line data and the standard design width by road type.

(c) Residential density data was required to permit appropriate selection of the impermeability coefficient described in (a) above, and potentially a density dependent EMC value. This data was drawn from the SURPOP database (Anon, 1999), an ESRC facility in which demographic census data has been subject to surface population modelling, a standard demographic technique designed to overcome the problem of false spatial representation of demographic data when using administrative boundaries. From the SURPOP database, residential density data is available on a 200 x 200 m grid for the entire UK.

(d) The rainfall acceptance potential variable SOIL was mapped by digitising the SOIL map presented in the UK Flood Studies Report (NERC, 1975);

(e) Annual rainfall. Daily rainfall for up to forty years was derived for Meteorological Office records for 600 sites in the study region. For each site, annual and return period annual averages were determined, and subject to area weighted Theissen polygon modelling so as to generate rainfall maps for the river basin;

(f) The UCWI data was derived using the Wallingford method recommended procedure, which relates UCWI to annual average rainfall via a power function

(DoE, 1981). Using this function, and the appropriate rainfall map described above (e), a UCWI map was generated for the basin.

(g) Catchment area. Determined by the grid cell size adopted in the GIS.

4.3 EMC database

Site mean EMC values are recommended by the US EPA for use in pollutant discharge assessment, a local government requirement under the Clean Water Act. They form the basis, for example, of Department of Commerce National Oceanic and Atmospheric Administration assessments of non point source loadings to coastal waters, part of the National Coastal Pollution Discharge Inventory. However, US values are potentially inappropriate in a European or UK context due to differences in urban structure and land use activities. EMC values for UK and northern European applications were therefore derived through analysis of an EMC database, constructed through literature review (Mitchell, *unpublished*). In total, 160 urban stormwater quality studies were included in the database, addressing 678 monitored catchments. Of these, 242 catchments were in northern Europe (Denmark, Finland, France, Germany, Norway, Russia, Sweden, Switzerland and the Netherlands); and 71 in the UK. The majority of the non-European data was drawn from the USA, Japan, New Zealand and Australia. The database was used to: (a) assess normality in site EMC data; (b) identify any differences in site EMC by land use; and (c) recommend EMC values for use in UK and northern European urban stormwater screening analyses.

Analysis demonstrated that, for most pollutants, the site mean EMC conforms very well to a predictable (log-normal) distribution, as indicated by Q-Q plots (e.g. Figure 1) and Shapiro-Wilk normality tests. This finding, not previously demonstrated for European site mean EMC data, allows reliable selection of probabilistic and central tendency site EMC values. Differences in site mean EMC by land use are *a priori* assumed to occur in the literature, but land use specific EMC values are often used without statistical justification. Difference tests show that significant differences in EMC do occur between land use classes in the northern European data set ($P_{t\text{-stat}} > 0.05$), but not always in the UK data (sample size was often prohibitively small) or in the global (all countries) data, where confounding effects across continents are assumed to vary more than within northern Europe, masking the influence of land use.

Figure 1 about here

Given these significant differences, site mean EMC values could be recommended for most pollutants for different land uses (residential, industrial and commercial, multi-lane highways, other main roads, urban open) or combinations of these land uses (e.g. all roads). However, for several pollutants (Cd, Cr, Fe and Hg) a small sample size meant that only a single EMC value addressing all urban land could be recommended (Table 1). Clear differences in EMC were not found by residential density class, but were found between commercial and industrial land uses. However, the latter categories were not treated separately in the GIS-model as they could not be resolved in the available land use data.

Table 1 about here

5 Model Implementation

5.1 Probabilistic Load Mapping

The diffuse pollution screening model was applied to the Aire basin, Yorkshire, an area of 2 057 km^2 drained by the Aire and Calder rivers and their 24 main tributaries. The basin includes the urban centres of Leeds, Bradford, Huddersfield and Halifax, and has a population of 1.9 million people. The model was developed using the GIS MapInfo$^©$ with the grid algebra extension Vertical Mapper$^©$, but could readily be implemented with any GIS with a grid algebra capability. All data was converted to a grid format with a default cell size of 200 x 200 m, or 10 x 10 m if roads were addressed.

For each pollutant, the GIS-model was applied to calculate runoff volume per grid cell, which was then coupled with an EMC value appropriate to the land use, so as to generate a pollutant unit area load (UAL) in kg $ha^{-1}yr^{-1}$. Figure 2 illustrates the annual non-point source loading of copper for a part of the Aire basin. Observed data to test the validity of these loadings is not available (a motivation behind the model development), but results are within the range of observed UAL's reported in the literature for northern Europe.

Figure 2 about here

Loadings under non-average conditions can also be determined. The EMC data is log-normally distributed, so an EMC value can be determined for any probability of occurrence. Similarly, from the rainfall records, it was possible to generate ten year return period annual rainfall maps, in a similar manner to flood frequency analysis. As runoff volume is independent of EMC, percentile values representative of non-average conditions can be chosen for both parameters (or just one if desired), and applied to assess the effect of extremes of pollutant concentration and runoff on diffuse loadings.

5.2 Land Use Change Impact

The model was run to assess the effect of land use change on diffuse loads. Calderdale Council, one of four local authorities in the Aire basin provided digital 'before' and 'after' land use maps for their district. The 'after' map represents land use and residential densities in the area, assuming all of the permitted developments detailed in the 2005-2016 Unitary Development Plan are executed. This includes provision of 1 800 new residential properties in the area, although many are on brownfield sites. The analysis indicates, for example, that this level of development would contribute an additional 530 kg yr^{-1} of copper to the river Calder. This is a relatively modest amount in the context of a basin load of over 19 tonnes yr^{-1} (Neal, 2000), but indicates that anticipated land use change in the basin can be expected to significantly raise total diffuse inputs.

5.3 UAL Mapping

The distributed load maps, superimposed over an OS 1:50 000 scale map, are used to identify sites that merit further investigation and possible SuDS implementation.

However, these maps have a spatial resolution that makes manual identification of 'hot spots' difficult at the basin scale. To address this problem, area averaging techniques, such as the moving window average, were considered, but it was decided to sum cell based data by small catchment, as this would assist with the subsequent hazard mapping phase. For the Aire basin, 840 sub-catchments were identified using Hydrologic Modelling 1.1, an Arc View routine that uses digital elevation data to determine flow paths for incident rainfall, supported by manual vector editing. Improved catchment boundaries could be defined through application of Standing Technical Committee 25 sewer network data, but the process was considered adequate for preliminary planning purposes. For each catchment, results were mapped as the UAL, and as percentile UAL (e.g. the top 5 % of catchments in load terms).

6 Hazard Mapping

To enhance the utility of the GIS-model, a simple risk assessment was conducted relating modelled annual load to environmental quality standards (EQSs) for receiving waters. The Aire basin was subdivided into separate catchments for which observed annual discharge data is available from undisturbed gauging stations. From the catchment area and discharge data, and the required EQS (the permitted maximum pollutant concentration), a maximum acceptable unit area load (UAL_{Max}) was determined. In effect, the UAL_{Max} is a quantitative expression of the annual cumulative environmental carrying capacity of the receiving waters, ignoring short term acute effects. For each pollutant, hazard maps are then generated simply as UAL / UAL_{Max} for each sub-catchment, giving a unitless hazard score.

Hazard mapping adds new information to the appraisal, as the UAL_{Max} variable recognises spatial variability in the environmental quality objectives of receiving waters (e.g. upstream waters have higher quality standards). The hazard of diffuse pollution to alternative uses of receiving waters can also be mapped. Beneficial use classes (e.g. Cyprinid fishery, Salmonid fishery, Potable water abstraction) are defined by water quality standards for a combination of pollutants, where the range of pollutants and/or the quality standard vary according to the use class. By averaging hazard maps for each pollutant within a beneficial use class (using the appropriate EQO), it is possible to map the hazard posed to that beneficial use from diffuse urban sources. As with the load maps, the scores for hazard to beneficial use can also be expressed in percentile classes to identify those diffuse source areas posing the greatest hazard to the relevant beneficial use. Figure 3 shows, for the Aire basin, the hazard to the Salmonid beneficial use class. For each parameter addressed by the model, and included in the Salmonid use class classification, hazard maps were developed. These parameter specific hazard maps (each with a unit less score) have then been averaged, to indicate hazard to the Salmonid environmental quality objective.

Figure 3 about here

The hazard assessment is not a full risk assessment, as the model does not address short term acute effects, and ignores factors of gully pot and in pollutant amelioration (or enhancement) resulting from dilution or sedimentation. Exposure pathways, dilution in the receiving waters, and impact recovery potential are also ignored. Addressing these factors requires application of more complex (e.g. mixing) models, which is considered incompatible with the preliminary planning objective of the hazard mapping model. Rather, the results of the 'hotspot' and hazard mapping procedures are intended to assist in identifying sites which particularly merit more detailed appraisal using site specific procedures recommended in guidance such as that produced by CIRIA (2000). Decisions over the most appropriate form of management (including application of SuDS or other regulatory controls) and considering site constraints can then be made.

7 Retrofitting Cities with SuDS

New urban developments are increasingly being addressed by SuDS, and this is to be welcomed. However, at best, this can only prevent further increase in non-point urban loads. To address current water quality failures attributed to diffuse sources, it is essential to implement SuDS in existing built areas. This is a major challenge, as existing developments place physical and design constraints on SuDS implementation, although advice to support this process is emerging (Ellis, 1998; Makropoulos *et al*., 1998).

Where retrofitting urban areas with SuDS has been considered, evaluations have shown that there are many opportunities to install SuDS, and that doing so can have positive effects on the quality of urban runoff. Sieker and Klein (1998), for example, report that surface water discharges in a large Berlin catchment could no longer be addressed using conventional end of pipe treatment due to insufficient space for settling tanks, unfavourable hydraulic conditions and a high cost to address the whole catchment. SuDS, including a variety of infiltration systems, were considered as an alternative. For the entire city of Berlin, it was concluded that a disconnection of 30 % of the impervious area could be easily achieved using SuDS, and that the resulting reduction in discharge made it possible to convert existing retention tanks to soil filter tanks, with a much improved overall purification efficiency than with settling tanks alone.

8 Conclusions

Diffuse urban pollution is a significant problem requiring retrofitting of existing built areas with sustainable urban drainage systems (SuDS). However, prioritising locations for possible SuDS implementation is constrained by the difficulty of assessing diffuse loadings on a basin scale. To address this problem, a GIS-model has been developed which can be used in urban diffuse pollution appraisal and SuDS planning. The model can: (a) map the location of diffuse pollution 'hotspots', under a range of probabilistic conditions; (b) identify those areas which present the greatest hazard to beneficial uses of receiving waters; and (c) assess the impact of land use change on non-point source runoff quality. The model is intended to act as a screening tool to guide subsequent site appraisal using more detailed modelling or monitoring. The requirements of the EU Water Framework Directive are addressed by the model which facilitates pollution appraisal at the river basin scale, aids investigative monitoring, and supports management of emissions at source within a water quality standards framework.

Pollutant loads are quantified using a volume-concentration technique, which has been shown to perform as well or better than more complex and costly deterministic models. From a review of 160 stormwater quality studies reported in the published and grey literature, site mean event mean concentration (EMC) coefficients for 18 urban nonpoint source pollutants were identified for the UK and/or northern Europe. Where sample size permitted, analysis of the EMC database revealed log-normality in both UK and northern European stormwater quality data, allowing derivation of mean and percentile EMC coefficients, and screening assessments using probabilistic modelling. In addition, statistically significant differences in pollutant site mean EMC by land use were identified for northern European data, introducing greater spatial heterogeneity into urban diffuse pollution screening assessments.

Finally, the recommended EMC coefficients are applicable to any northern European runoff volume-pollutant concentration assessment. However, the model is particularly well suited to a UK application, as it uses an established and widely accepted UK runoff algorithm. The model can be implemented using readily available, low cost data, and any desktop GIS with a grid algebra capability.

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Figure 1. Log-normality of site mean EMC: Oxidised nitrogen for industrial and commercial land use in northern European cities.

Figure 2. Total diffuse urban copper load (kg $ha^{-1}yr^{-1}$) in the Brighouse area of the Aire basin, Yorkshire, UK.

Figure 3. Urban nonpoint source hazard to the Salmonid beneficial use class in the river Aire basin, Yorkshire, UK.

Table 1. Site mean EMC values applied in the diffuse pollution screening model

Table 1. Site mean EMC values applied in the diffuse pollution screening model

Pollutant	Land use [a]	Mean	1st Quartile	3rd Quartile	Data source [b]	N
TSS mg l^{-1}	UO	126.3	57.0	279.8	G	18
	IC	50.4	18.1	140.4	NE	34
	R	85.1	37.6	192.5	NE	37
	MLH	194.5	110.1	343.5	NE	16
	MH	156.9	62.2	396.3	NE	6
BOD mg l^{-1}	UO	7.9	3.5	18.2	G	4
	IC	9.9	5.9	16.7	NE	29
	R	8.5	5.1	14.1	NE	27
	H	23.9	17.5	32.6	NE	11
COD mg l^{-1}	UO	36.0	20.0	64.6	G	16
	IC	146.2	121.3	176.1	NE	6
	R	80.0	53.2	120.4	NE	20
	H	136.5	89.1	209.2	NE	9
Cd ug l^{-1}	All	2.2	1.3	3.7	NE	39
Cr ug l^{-1}	All	7.3	3.5	15.0	NE	19
Cu ug l^{-1}	UO	27.9	19.8	39.2	G	6
	DU	51.1	22.3	117.1	NE	44
	H	80.3	43.2	149.5	NE	21
Fe mg l^{-1}	All	2.98	1.42	6.28	G	77
Pb [c] ug l^{-1}	UO	60.6	28.8	127.4	G	11
	IC	132.6	55.8	315.4	NE	11
	R	140.5	91.6	215.5	NE	24
	MLH	330.1	197.7	551.1	NE	14
	MH	201.0	107.7	375.0	NE	10
Hg ug l^{-1}	All	0.27	0.10	0.74	G	25
Ni ug l^{-1}	UO	14.8	10.2	21.6	G	2
	DU	30.4	18.2	50.6	NE	13
Zn ug l^{-1}	UO	203.0	102.0	403.9	All	8
	IC	188.6	84.7	420.2	NE	13
	R	296.9	192.8	457.2	NE	25
	MLH	417.3	284.0	613.3	NE	14
	MH	253.1	97.7	655.5	NE	10

Table 1. / Cont.

Pollutant	Land use [a]	Mean	1st Quartile	3rd Quartile	Data source [b]	N
Total P mg l^{-1}	UO	0.22	0.08	0.58	G	21
	IC	0.30	0.16	0.54	NE	6
	R	0.41	0.24	0.72	NE	18
	MLH	0.28	0.15	0.52	G	35
	MH	0.34	0.17	0.67	G	21
Soluble P mg l^{-1}	UO	0.056	0.018	0.174	G	9
	IC	0.156	0.070	0.345	G	24
	R	0.198	0.109	0.359	G	45
	H	0.178	0.101	0.313	G	4
Total N mg l^{-1}	UO	1.68	0.86	3.27	G	14
	IC	1.52	0.89	2.60	G	54
	R	2.85	1.73	4.71	G	119
	H	2.37	1.52	3.71	G	26
TKN mg l^{-1}	UO	1.21	0.73	2.02	G	11
	IC	1.54	1.06	2.23	G	34
	R	2.40	1.54	3.74	G	84
	H	1.60	2.75	0.47	G	20
$NO_{2}+_{3}$ mg l^{-1}	UO	0.84	0.43	1.65	G	8
	IC	0.60	0.40	0.92	G	32
	R	0.98	0.50	1.91	G	68
	H	0.81	0.63	1.03	G	17
NH_4-N mg l^{-1}	UO	0.10	0.10	0.10	G	1
	DU	0.56	0.30	1.06	UK	37
Oil & Grease mg l^{-1}	UO	0.60	0.60	0.60	G	1
	DU	4.24	1.21	14.89	NE	18

[a] Land use: IC is Industrial and Commercial; R is Residential; UO is Urban Open; MLH is Multi-Lane Highway (Motorway); MH is Main Highway (excludes MLH); H is Highway (MLH + MH); (DU is Developed Urban (IC + R + not stated/mixed but excluding UO, MLH, MH and H); All is All urban land uses.

[b] Data regions: G is Global, using all countries in the database; NE is Northern European countries only; UK is United Kingdom data only.

[c] Due to the historical reduction in use of leaded petrol, the first quartile value was used to represent the mean EMC.

Fig 1

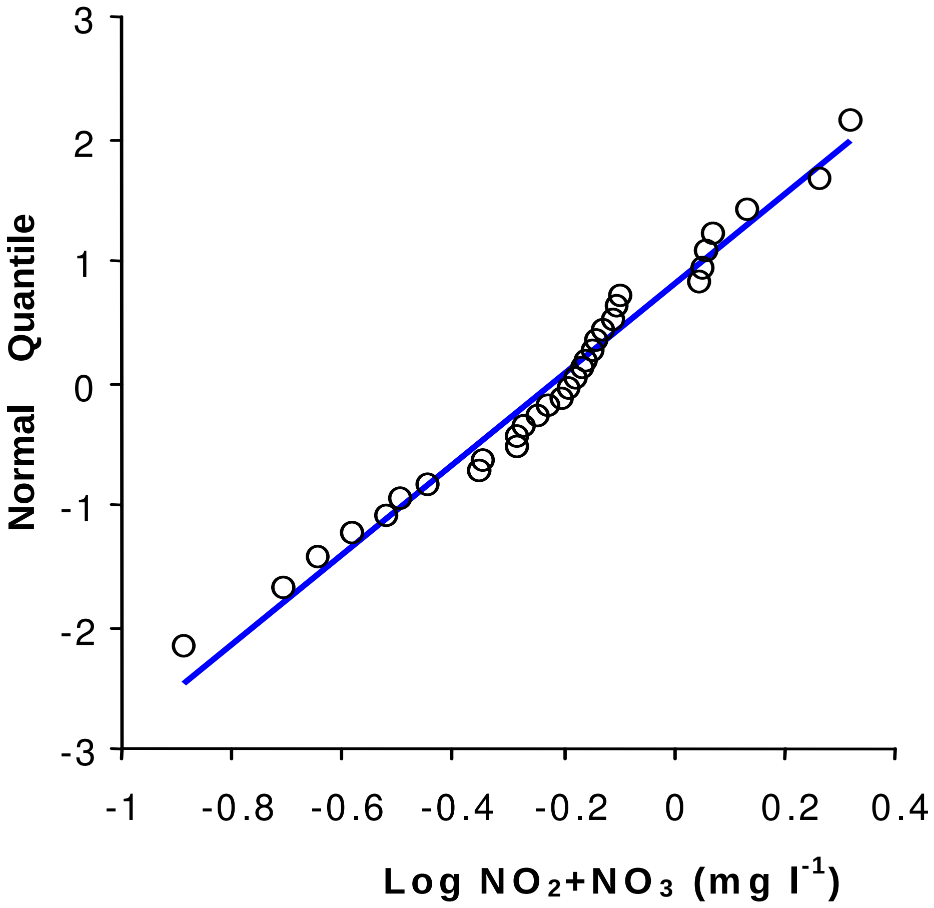


Fig 2

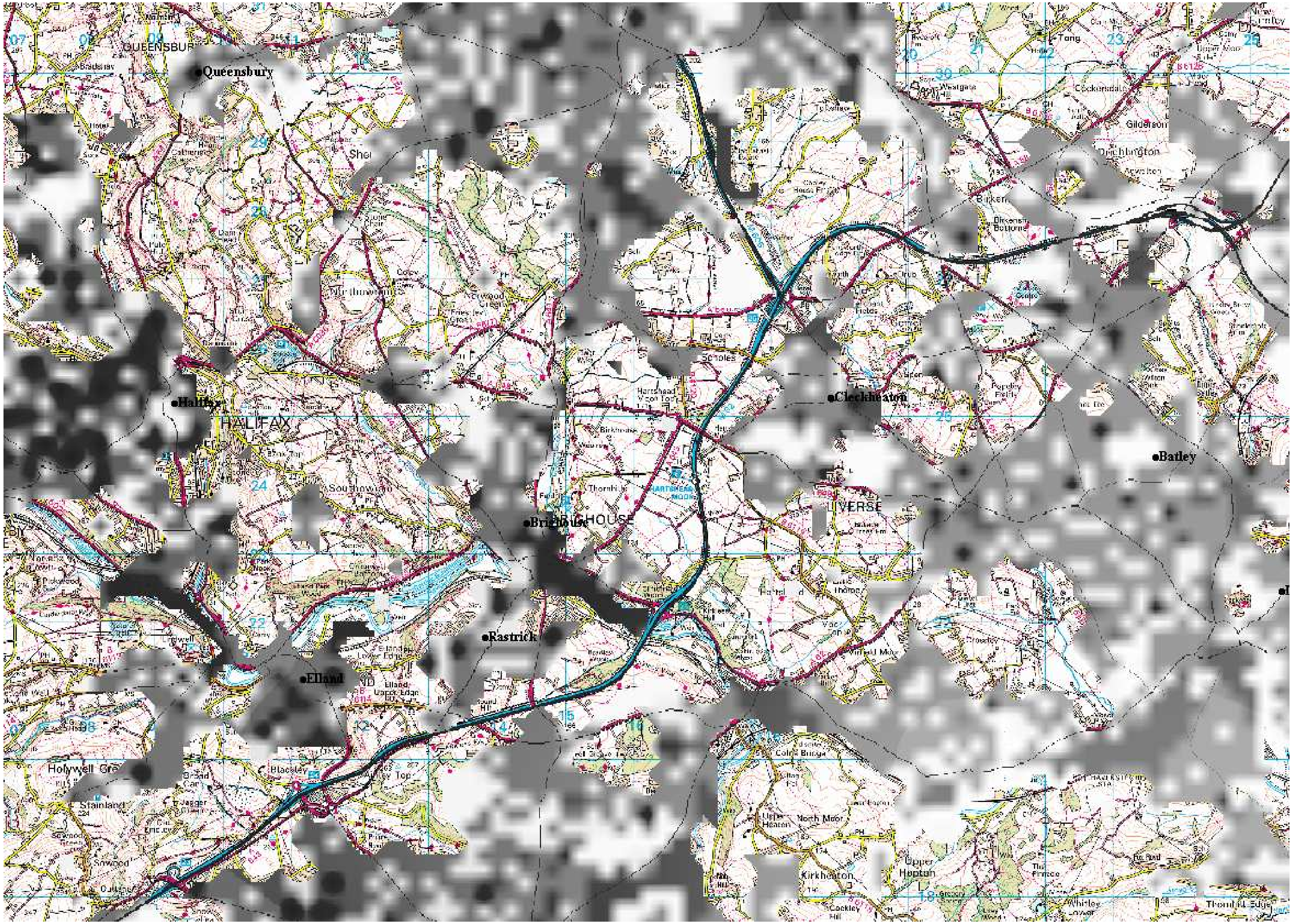
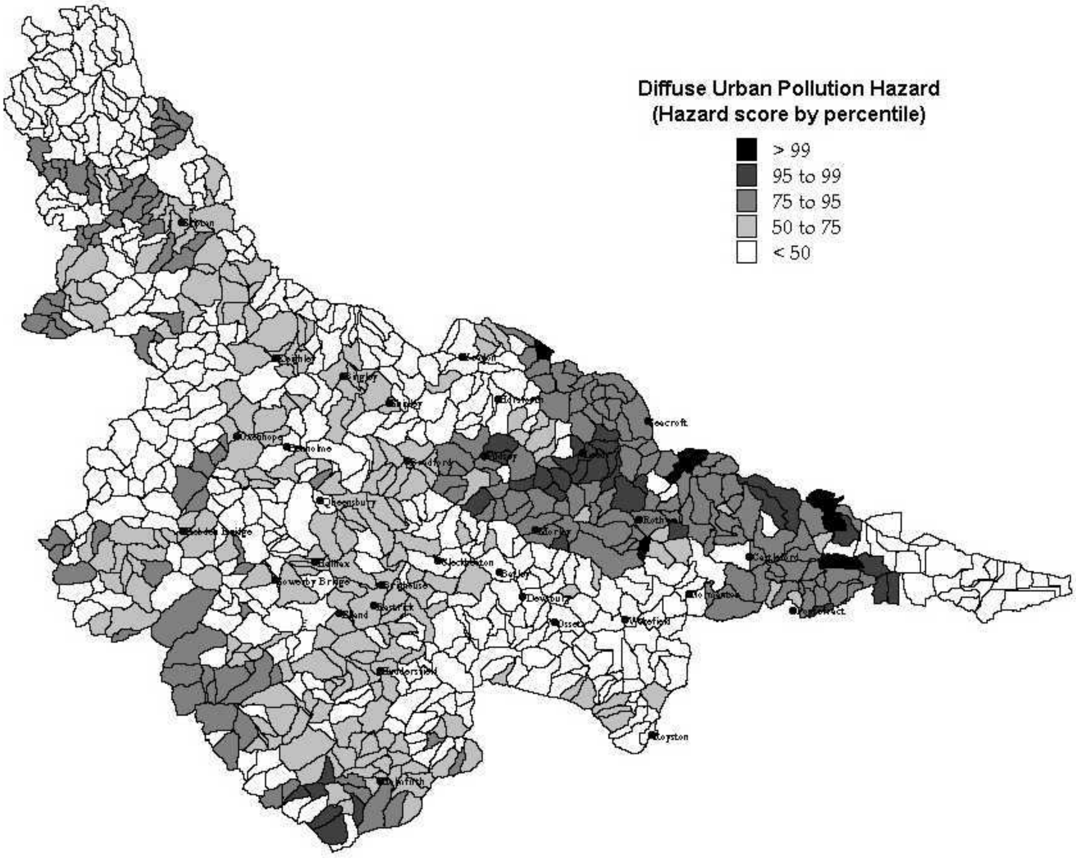

Queensbury
Halifax
Cleckheaton
Batley
Brighouse
Rastrick
Elland

Fig 2 Key

Annual diffuse load:
Total dissolved
copper (Kg ha^{-1} yr^{-1})

■	**> 1.0**
▓	**0.6 - 0.8**
▒	**0.4 --0.6**
░	**0.2 - 0.4**
□	**< 0.2**

Fig 3


Diffuse Urban Pollution Hazard
(Hazard score by percentile)
■ > 99
■ 95 to 99
■ 75 to 95
■ 50 to 75
□ < 50
Skipton
Keighley
Yeadon
Bingley
Shipley
Horsforth
Seacroft
Oxenhope
Denholme
Bradford
Pudsey
Leeds
Queensbury
Hebden Bridge
Rothwell
Morley
Halifax
Cleckheaton
Batley
Castleford
Sowerby Bridge
Brighouse
Dewsbury
Normanton
Rastrick
Elland
Ossett
Wakefield
Pontefract
Huddersfield
Royston
Holmfirth