Characterisation of highway stormwater pollution in the highly urbanised Greater London area

Caractérisation de la pollution des eaux de ruissellement routier dans le secteur fortement urbanisé du Grand Londres

J Bryan Ellis*, D Michael Revitt*, Lian Lundy*, Rosie Nelson**, John Brydon**

*Urban Pollution Research Centre, Middlesex University, The Burroughs, Hendon, London. NW4 4BT. UK. (B.Ellis@mdx.ac.uk).
**Thames 21, Bow Locks, Navigation Road, London. E3 3JY. UK.

RÉSUMÉ

Une nouvelle méthodologie est présentée, qui permet de prédire les concentrations de polluants et les charges associées aux différents types d'autoroutes, conditions de circulation et de conduite rencontrées dans une zone métropolitaine très urbanisée telle que le Grand Londres. La procédure innovante combine des calculs de charge de polluants des véhicules à la source avec des facteurs d'émission de trafic tels que le type et les densités de véhicules, les encombrements et les formats d'autoroutes pour créer une approche de filtrage générique originale. Les concentrations et les charges prévues peuvent ensuite être cartographiées géospatialement à l'aide d'ArcInfo GIS pour fournir un affichage visuel de leur distribution et de leur ampleur, servant de base au développement d'options de drainage et de gestion durables appropriées.

ABSTRACT

A novel methodology is presented which enables the prediction of pollutant concentrations and loadings in runoff associated with differing highway types, typical of the traffic and driving conditions encountered within a highly urbanised metropolitan area such as Greater London. The innovative procedure combines vehicle flow characteristics with source-based vehicular pollutant emission factors to derive deposition loadings for zinc, copper and cadmium. Subsequently, the concentrations in highway runoff are estimated and are geospatially mapped using ArcInfo GIS to provide a visual display of their distribution and magnitude across the highway network. This provides a basis for the development of appropriate sustainable drainage and management options in order to minimise the risk to receiving environments.

KEYWORDS

Geospatial mapping, highway pollutant loadings, risk assessment, vehicle emissions

1. INTRODUCTION

Methods of predicting highway pollutant runoff concentrations have traditionally used statistical analysis of monitored data to develop correlated relationships between traffic volumes and representative pollutant concentrations, normally expressed in terms of the mean or median event mean concentration (EMC value). Predictions of runoff concentrations can then be made for any given site based on its traffic and storm event characteristics. This is the fundamental basis of the US FHWA and UK HA approaches (Driscoll et al 1990; HA, 2009). Whilst these approaches do enable pollutant concentration/load predictions in relation to traffic volumes, they do not take account of the influence of other dominant traffic process factors and highway characteristics such as vehicle type and exhaust emissions, brake/tyre wear, road surface wear, highway type etc. This is of particular relevance given the growing concerns regarding public health and receiving water risks arising from elevated vehicle emissions and critical depositional highway loadings within highly urbanised metropolitan areas (Colman et al., 2001). An innovative and novel approach combining the physico-chemical source processes associated with highway and storm event conditions is being tested within the Greater London area by a research consortium comprising Middlesex University, Thames 21, Greater London Authority (GLA), Transport for London (TfL) and the Environment Agency (EA). The objective is to develop a first-order screening methodology to address the following question: *What pollutant runoff concentrations are associated with differing highway types and conditions within the Greater London region?* Geospatial distribution mapping of the predicted concentrations enables their distribution and magnitude to be visually displayed and to highlight «hotspots» for priority attention.

2. METHODS

The research consortium has developed an approach which combines road characteristics (length, width, vehicle kilometre travelled; Stage 1 analysis) with different traffic source based emission factors (Stage 2 analysis) to derive a highway surface pollutant loading. Stage 3 analysis incorporates the runoff volumes to allow an estimation of the discharged runoff concentrations. A later stage of the project will incorporate drainage pathway loading reductions brought about by flow/drainage mitigation controls following source discharge from the highway surface. The developed methodology uses a benchmarking approach which combines pollutant source strength (as defined by vehicle emission factors) with driving and road characteristics. The derived emissions from 10 different vehicle types are estimated for each highway section and then adjusted for the impact of traffic congestion on the deposition capability and then converted into runoff concentrations using the drainage characteristics. Individual highway section values can then be summed for each sub-catchment.

Figure 1 illustrates the general methodology for the estimation of highway pollutant loads and runoff concentrations based on such a three stage structural framework for pollutant source and drainage pathway components. The modelling approach involves a basic Excel spreadsheet designed to initially allow the input of data relating to the detail of the highway (length, carriageway width etc.), traffic type and volume (AADT) in order to calculate daily vehicle kilometre travelled (Stage 1). The capacity for any given road type is derived from the look-up tables for differing road and traffic types in the Greater London area as provided in Transport for London Technical Note 10 (TfL, 2011) based on the ratio of traffic volume to road design capacity. This enables the derivation of maximum hourly traffic flows for differing urban highway types within London. The pollutant traffic emission factors for exhaust, brake, tyre and road surface wear are included taking into account the highway usage/condition levels (i.e. traffic congestion and driving modes). By combining the emission factors for the different pollutant sources with the pollutant concentration in the source material, the methodology derives daily emission loads for each source and subsequently the deposited load (mg per vehicle kilometre travelled; mg/vkm). To provide a representation of the pollutant load deposited on a road surface during an extended dry period, monthly deposition emissions are calculated (Stage 2). Based on the annual rainfall statistics, average monthly rainfall depths are obtained and used to predict the average monthly rainfall volumes possible for the stretch of road under consideration. This, in turn, yields the monthly average pollutant concentration in highway runoff (µg/L; Stage 3).

The predicted pollutant highway runoff concentration distributions, as calculated from the Excel spreadsheet provides the input data for the ArcInfoGIS mapping of the differing highway types in the metropolitan area. The resulting visual display of the geospatial highway runoff pollutant concentrations enables identification of pollution ‘hotspots’ to be preferentially targeted in terms of the introduction of control measures. Initial analysis has focussed on three metals (zinc, copper and cadmium) all of which are indicators of vehicle derived emissions, although to different extents. It is anticipated that a later stage in the project will focus on the relevant drainage mitigation controls (such as roadside gully chambers, grass verges etc.) which can be introduced to reduce the potential impact of highway runoff on receiving waters.

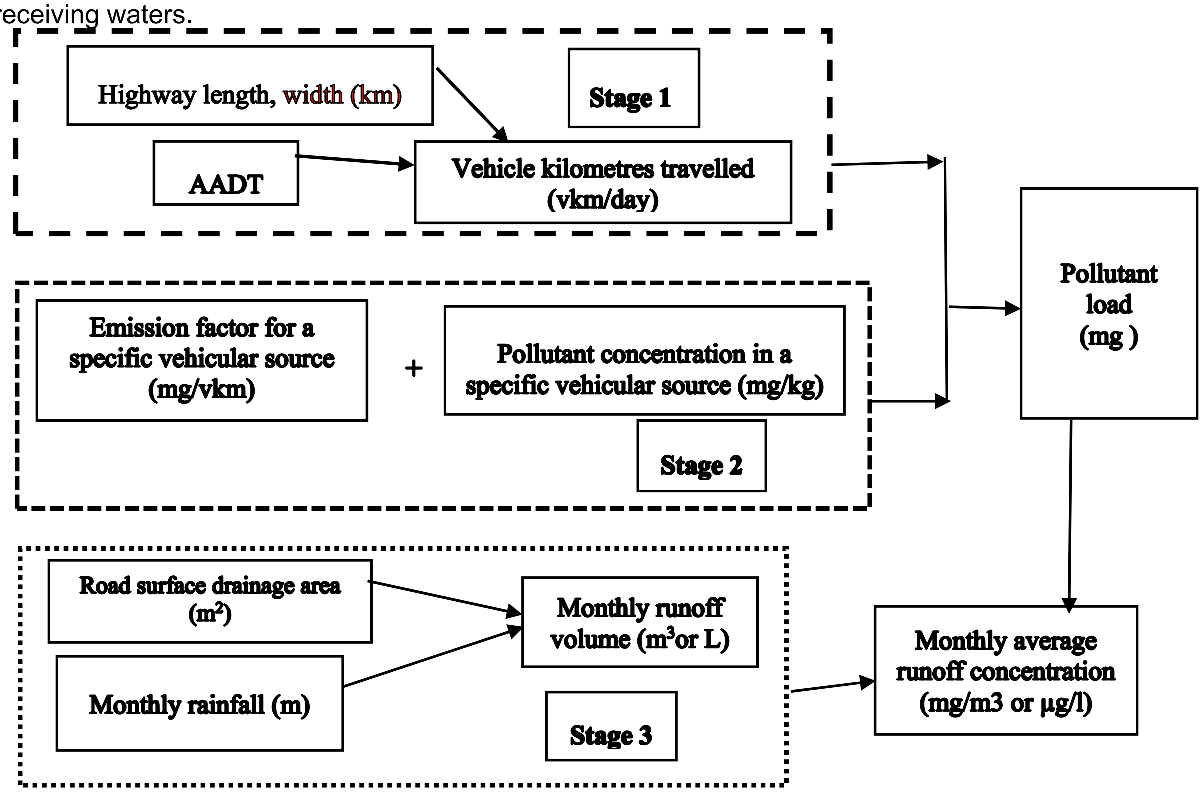

Figure 1. Outline of highway runoff pollutant concentration estimation

3. RESULTS AND DISCUSSION

The methodological approach has been initially trialled within the Borough of Enfield in NE London (UK) for a 134m dual carriageway section of the North Circular Road (NCR; London inner ring road). As an example of a larger data set Table 1 identifies the spreadsheet results for the accumulated Zn derived from different types of vehicle. Based on the integration of traffic and local rainfall data, the overall predicted monthly total Zn concentration is 599.43 µg/l. The marked deleterious impact of diesel-powered traffic on the emission and loading data is clearly identified contributing an overall 74% of the monthly concentrations. However, this is associated with the characteristics of the vehicles fuelled by diesel e.g. HGVs rather than being a function of the fuel itself.

Table 1. Vehicular zinc distributions for a 134m section of the North Circular Road in the London Borough of Enfield.

	AADT	Overall daily Zn emissions (mg)	Monthly average runoff concentration (ug/L)	% contribution
Petrol passenger cars	16245	1162.02	117.94	24.5
Diesel passenger cars	13838	989.64	100.45	20.8
Petrol LGVs	101	5.90	0.60	0.4
Diesel LGVs	5261	307.06	31.17	19.6
Diesel rigid axle HGVs	2109	2325.19	236.01	15.4
Diesel articulated HGVs	652	718.84	72.96	4.8
Motorcycles	311	13.20	1.34	0.2
Electric car	166	11.87	1.20	0.2
Electric LGVs	143	8.34	0.85	0.2
Taxis	3132	223.99	22.74	11.7
Buses	220	124.78	12.67	1.6
Coaches	79	14.92	1.51	0.6
Total for all vehicles	**42257**	**5905.74**	**599.43**	**100**

For example, the largest source contribution comes from tyre wear (91.7%) followed by brake wear (6.7%) with rigid-axle HGVs representing 40% of the tyre wear source. Nearly 52% of the brake wear input can be sourced to light duty vehicles. The mass of materials emitted which then deposit on the road surface varies in relation to particle size which itself varies in relation to differing sources. Fine particulate matter (defined as ≤PM_{10}) and associated metals may be re-suspended by airborne turbulence and traffic deflation, although those particulates which remain in the immediate road environment will be washed out during rainfall events and transported together with road surface deposits. Results indicate that concentrations of both total Zn and Cu pose the greatest potential impacts with the possibility that UK TAG levels may be exceeded in an adjacent receiving water suggesting runoff should be treated to ensure compliance with EU WFD requirements. At current observed levels, the extremely high concentrations noted for highway runoff would imply that non-compliance could occur even after applying all tiers of assessment. It is clear that the level (and choice) of "background" concentrations will be critical to the overall assessment of receiving water compliance. Figure 2 shows the ArcGIS spatial distribution and magnitude of zinc highway runoff concentrations for the principal highway types occurring within the London Borough of Enfield with the North Circular Road (NCR), M25 (Outer Orbital Road) and A10 trunk road yielding the highest contributions. There are some methodological issues relating to the data categorisation given that the use of limited equal interval categories appears to result in data "clumping" which tends to mask detailed variation in the geospatial distribution.

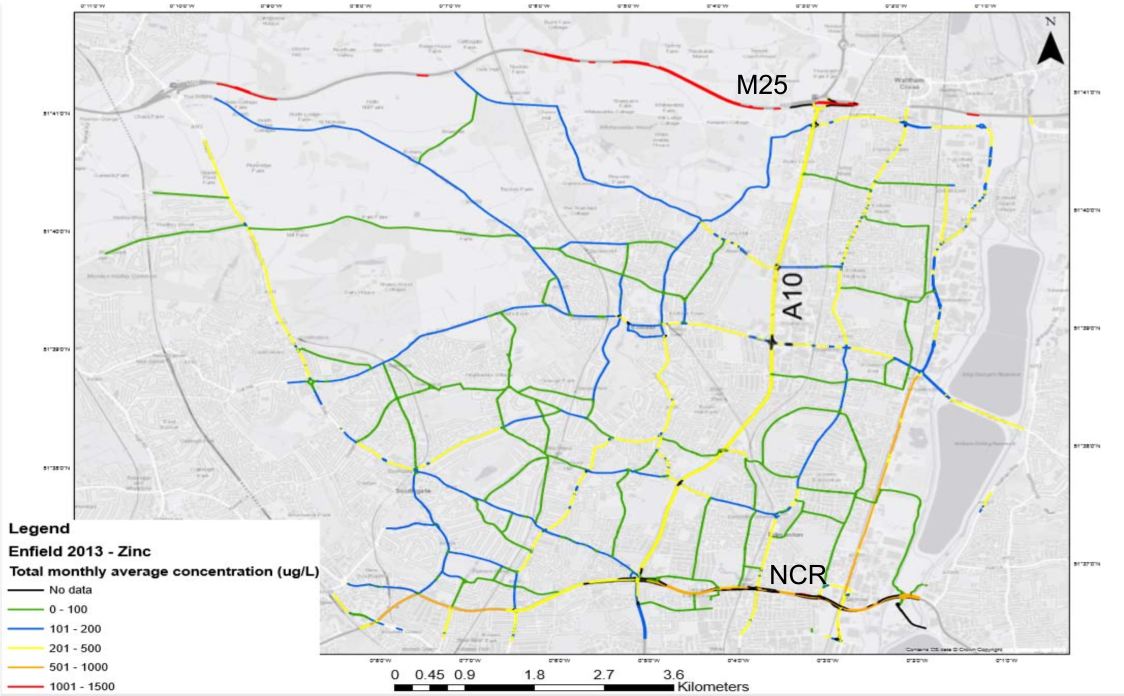

Figure 2. Spatial distribution of annual average zinc highway loadings for the London Borough of Enfield

4. CONCLUSIONS

The method is relatively simple being based on lumped averaging procedures but being largely founded on local data/evidence provides a robust comparative methodological approach suitable for preliminary decision-making on highway stormwater drainage options within a highly urbanised environment. The geospatial mapping of predicted pollutant distributions and magnitude will provide TfL, the GLA and EA staff with a better understanding of relative pollutant risks associated with surface water runoff from differing highway types within the Greater London region to support and assist drainage infrastructure investment decisions and enable prioritisation of follow-up investigations.

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