A geographic information system screening tool to tackle diffuse pollution through the use of sustainable drainage systems

Zorica Todorovic and Neil P. Breton

ABSTRACT

Sustainable drainage systems (SUDS) offer many benefits that traditional solutions do not. Traditional approaches are unable to offer a solution to problems of flood management and water quality. Holistic consideration of the wide range of benefits from SUDS can result in advantages such as improved flood resilience and water quality enhancement through consideration of diffuse pollution sources. Using a geographical information system (GIS) approach, diffuse pollutant sources and opportunities for SUDS are easily identified. Consideration of potential SUDS locations results in source, site and regional controls, leading to improved water quality (to meet Water Framework Directive targets). The paper will discuss two different applications of the tool, the first of which is where the pollutant of interest is known. In this case the outputs of the tool highlight and isolate the areas contributing the pollutants and suggest the adequate SUDS measures to meet the required criteria. The second application is where the tool identifies likely pollutants at a receiving location, and SUDS measures are proposed to reduce pollution with assessed efficiencies.

Key words | GIS, screening, SUDS, water quality

Zorica Todorovic (corresponding author)
Neil P. Breton
Atkins,
Warrington,
Cheshire,
United Kingdom
E-mail: *zorica.todorovic@atkinsglobal.com*

INTRODUCTION

Diffuse pollution has been recognised as a significant threat to achieving good status under the Water Framework Directive (WFD) (CEC 2000); indeed in the UK, the Environment Agency (EA) and Natural Resources Wales has estimated that diffuse pollution poses a greater risk to rivers, lakes and ground waters than point source pollution (Environment Agency 2007). Whilst there has been steady progress in addressing point sources such as industrial sites and wastewater treatment works, diffuse sources have proved much harder to tackle. Sources of diffuse pollution can be difficult to locate and control, particularly in urban areas which are spatially and temporally dynamic (Lundy *et al.* 2011).

There are not necessarily clear processes in place to tackle urban diffuse pollution as it originates from a wide-ranging base including atmospheric deposition, wear and tear of cars, car washing, roof runoff and especially industrial estates. If research can demonstrate the benefits of acting on defined sources, then this may go some way in facilitating informed discussions between the different stakeholders so a clear, proportionate response to urban diffuse pollution can be made. A geographic information system (GIS) allows geospatially referenced datasets to be combined to overlay consideration of multiple issues affecting the same geographic location. The combined dataset allows consideration of a range of different parameters in a consistent way to inform decision making for any specific geographic location at a range of scales. This paper describes a GIS tool that rapidly identifies areas contributing to different types of pollution and identifies source–pathway–receptor relations. The outputs of the GIS allow locations to be screened for the suitability of sustainable drainage systems (SUDS) to be applied to mitigate pollution.

MATERIAL AND METHODS

A number of readily available industry standard georeferenced datasets, such as vector map datasets produced by Ordnance Survey, and pollution sampling information captured by the EA have been used during the screening process. These GIS layers allow the locations of various constraints to be mapped and their spatial relationships

doi: 10.2166/wst.2014.075

identified. The authors used the same GIS approach for flood risk management and identification of opportunities to retrofit SUDS in order to reduce flood risk and improve capacity within the existing drainage network (Breton *et al.* 2013). That approach forms the basis for this work. The GIS tool has successfully been applied on a variety of projects for clients including water companies and local authorities in the UK, and provided a framework for development to incorporate water quality considerations. The existing tool operates at a variety of scales using georeferenced datasets to identify both large-scale opportunities to remove storm water from the combined sewer network, as well as individual dwelling-scale opportunities. Constraints such as underlying geology, distance to receiving open spaces, presence of floodplain, availability of nearby watercourse to discharge to, and location of utility services are considered through specified geospatial criteria. This information is then considered against data on land uses, location of flooding and pollution incidents, sewer records and catchments, WFD water quality classification, storm water drainage and highways drainage discharge points, etc. Different types of SUDS are screened for their suitability for each target location, and costs derived for the installation and annual maintenance of each SUDS. Costs have been calculated based on national CIRIA (Construction Industry Research and Information Association) guidance (CIRIA 2007) and estimates provided by a quantity surveyor for SUDS in London. These allow estimates of potential costs to be provided, along with an indication of comparative costs of different options.

The tool uses GIS techniques to identify different land uses and associated sources of pollutants. Once sources are identified, they are assigned to fluvial or sewer catchments, depending on whether the site drains to the sewer or fluvial system. Standard loads (Davis *et al.* 2001; Gromaire *et al.* 2001; Rule *et al.* 2006; Park & Stenstrom 2008; McKenzie *et al.* 2009; Bacci *et al.* 2010) are applied depending on the type of source, producing an estimate of pollutant loads based on the area of the sources identified. This allows the likely relative contribution of all sources in the catchment to be calculated, building up a map of sources for different pollutants across an area or region.

The tool has the functionality to obtain a list of suitable SUDS depending on site constraints. SUDS treatments are selected from the toolkit to target reduction of specific pollutants from the source, or to effect a wide-ranging improvement in water quality. Suitable SUDS techniques are selected for each site depending on the site constraints and are selected based on the treatment efficiency of each SUDS (Stenstrom & Strecker 1993; Schueler 1994; Barrett *et al.* 1998; Bäckström 2003; Escarameia *et al.* 2006; Susilo *et al.* 2006; Park *et al.* 2007, 2008; Stein *et al.* 2007). This allows SUDS to be selected to provide the best treatment at source, site and regional level. Geospatial analysis of large areas also allows strategic planning of SUDS, with the potential to create large-scale SUDS treatment trains to provide a broad spectrum of water quality improvement. Once potential locations have been identified, SUDS are sized based on the treatment required, and the size of area contributing runoff to them. The appropriately sized SUDS are then costed using the previously described functionality of the tool.

Where the pollutant of interest is known, the outputs of the tool highlight and isolate the areas contributing the pollutants (Scenario 1); alternatively the tool can be used to identify likely pollutants at a receiving location (Scenario 2). In the first scenario, the contaminant load database can be used to identify types of land use contributing high levels of the pollutant of interest. The contaminant load database was compiled from a literature review (including Göbel *et al.* 2007; Kayhanian *et al.* 2007; Helmreich *et al.* 2010; Gromaire *et al.* 2011; Bressy *et al.* 2012; Brezonik & Stadelmann 2012; Lundy *et al.* 2012) of internationally available information on contaminant loads in runoff, and is subject to regular update as new data becomes available. The contaminant load database thus forms the primary method of identifying potential contaminant sources, subject to the findings of a historic analysis of potential sources of contaminants. Areas of the land uses of interest that drain to the point of interest can then be quickly and easily identified.

Case study 1: pollutants known

In the example in Figure 1, analysis of sediment from a lake had indicated high levels of zinc and cadmium in the silt, corresponding to scenario one outlined above where the pollutant of interest is known. The project objective was to identify SUDS options that enabled both source control and regional treatment, with particular focus on sediment control and reduction in heavy metal loads. The pollutant database developed through the literature review indicated that the surrounding road networks were likely to be significant sources of both zinc and cadmium, through dust from brakes (McKenzie *et al.* 2009; Marsalek & Viklander 2011) and zinc from brakes, tyres, oil and exhaust emissions (Napier *et al.* 2008; McKenzie *et al.* 2009; Bacci *et al.* 2010; Marsalek & Viklander 2011). A review of historic land use indicated little potential for aerial sources of either metal, and therefore a gradual build-up of concentrations from

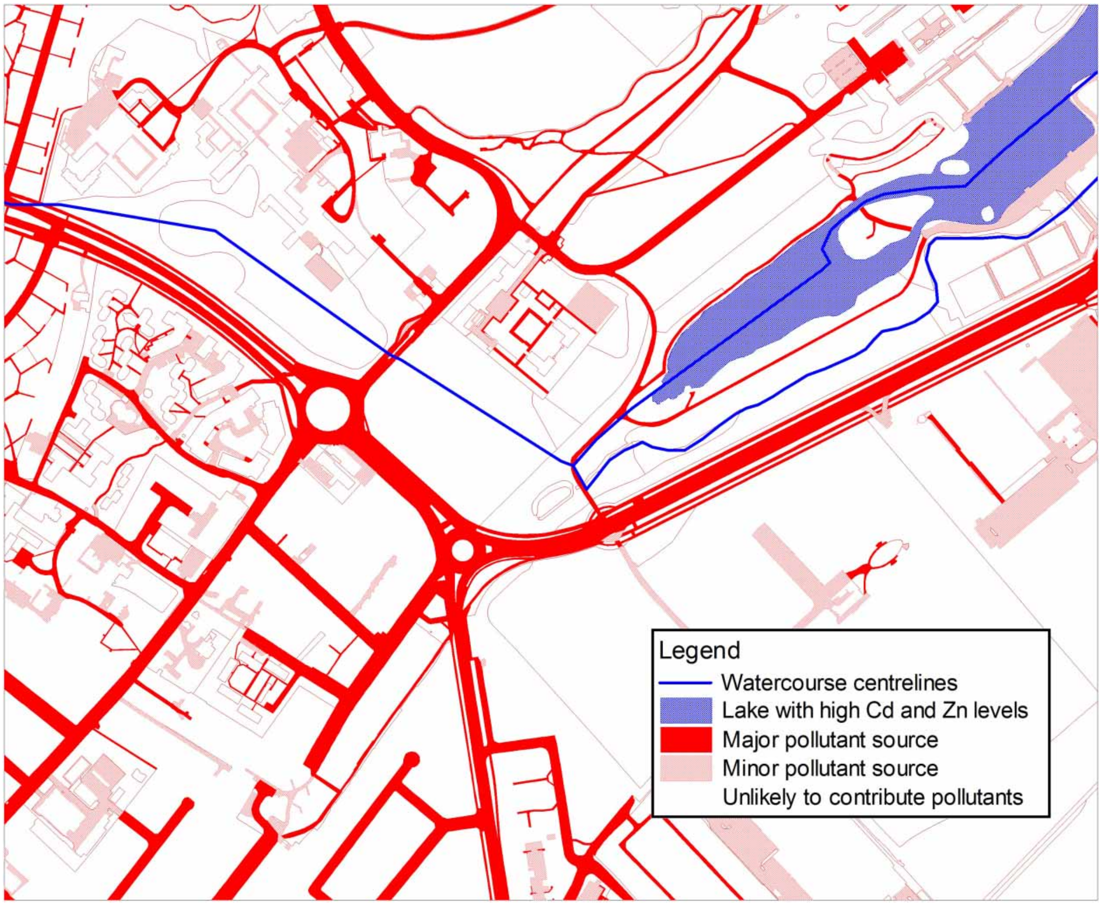

Figure 1 | Output of the tool identifying pollutant source areas.

historic aerial sources was discarded. As highways are the likely source of the metals found in the sediment, it was likely that they will also be the source of the sediment itself, although some sediment was likely to be from decomposed leaf fall and other vegetation around the pond itself.

Case study 2: pollutants unknown

A more complex example of where pollutants are not known can be demonstrated through application of the tool to a series of seven industrial estates in the Midlands of England. The study area was a small urban conurbation containing a number of industrial estates discharging storm water to a receiving watercourse which passed through a Site of Special Scientific Interest and was thought to fail WFD water quality targets.

Land uses around the catchment were identified and potential diffuse pollution contributions were clustered. This was achieved through a GIS analysis which also merged with GIS sewer records and catchments, WFD water quality classification, storm water drainage and highways drainage discharge points. Combining this data enabled both geospatial representation of the different potential sources of diffuse pollutants and alignment of the sources to the areas with worst water quality. The *Flood Estimation Handbook* (CEH 1999) was then used to identify fluvial catchment outlines, and GIS layers of sewer catchments to define sub-catchments.

The sub-catchments were overlain on the GIS analysis to identify potential sources, which were then screened to identify potential commercial/industrial areas for targeted retrofitting of SUDS. Different land use areas were assigned associated risks of pollution, categorised into low, medium and high risk areas in line with a previously developed methodology (Figure 2) for assessing risk of storm water pollution from different industrial estates across Scotland (Todorovic *et al.* 2010). Industrial estates were split into zones created by an analysis of where industrial area drainage discharges to the watercourse. This analysis was based primarily on sewer system records provided by the water company and

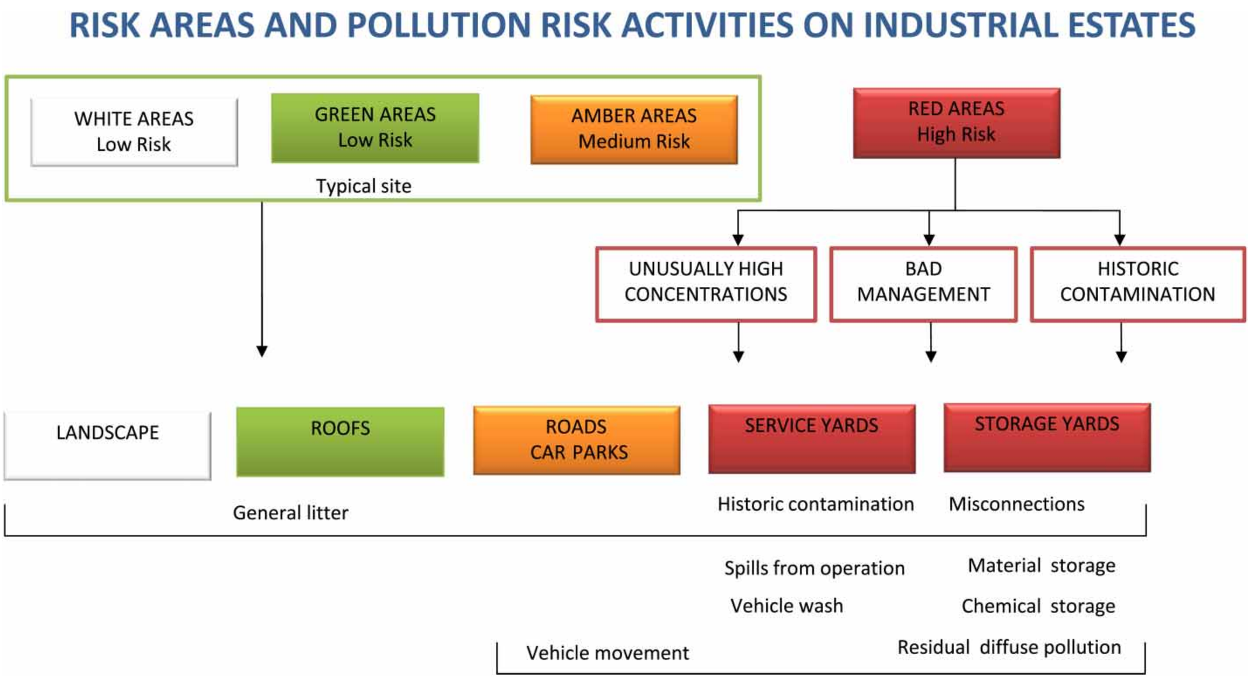

Figure 2 | Flowchart of mitigation risk assessment.

the site visit which confirmed outfall locations. Each zone was then assessed for its potential to contribute pollutants to the watercourse, through visual inspection during the site visit and analysis of aerial photography.

General approach

The industrial estates were first classified into high, medium and lower risk zones, where each zone was a discrete industrial estate or collection of buildings and surrounding hardstandings. The classification was undertaken based on observations from the site visit of the type of industry being undertaken in each zone, and also the state of the buildings and work areas at each.

Following on from this general classification, storm water contamination risk arising from trader activities was prioritised in accordance with the following hierarchy.

High risk (red): contamination is very likely to occur. These areas are usually related to inadequate site management practices on site that affect areas of chemical and material storage and areas of operational spill risks. Key hot spot areas on industrial estates are storage and service yards, contaminated land and any areas with illegal waste disposal and general industrial litter. Also sewer misconnections are considered high risk of contamination with raw sewage and the possibility of blockages in the storm water drainage network and related risk of localised flooding.

Medium risk (amber): contamination is likely to occur. Traders' operations and other site activities identified as having medium risk need to be checked on site and further reference literature data need to be gathered to assess the requirement for treatment by SUDS. These areas include mainly car parks and roads. Key activities that bring attention to possible storm water pollution are ad hoc uncontrolled car washing, vehicle movement and impermeable storm runoff during a storm event.

Lower risk (green): contamination is not likely to cause concern; no further studies required. Usually these areas are associated with roofs and building sidings (depending on the type of materials and age, they could be considered as medium risk) and landscape areas. Additionally, storage and service yards of well-managed traders that can give rise to some residual diffuse pollution are considered low risk areas.

SUDS are suitable pollution mitigation measures for low to medium risk areas of pollution. That means that they could assist in mitigating pollution from a typical light industrial estate which is well managed and has no historical problems with contamination. Lack of, or insufficient pollution mitigation measures, for high risk areas could jeopardise the efficiency of the SUDS measures applied for the site in general. Consequently the recommendations for high risk estates include the introduction of best management practice training and information to reduce the overlying risk from high to medium; so ponds and other SUDS become a suitable mitigation approach.

RESULTS AND DISCUSSION

Case study 1

The screening indicated a number of potential SUDS locations to treat the pollutants associated with highways sources. The primary location identified was a paddling pool located upstream of the lake. This area was used to divert low flows from the incoming stormwater sewer and to serve as a pretreatment for the first-flush volume, which contains a high proportion of pollutants and sediment. Consequently the incoming flows to the lakes could be directed to the paddling pool area to settle out and undergo bioremediation. In addition, a part of the lake/wetland was designed to be a forebay to allow settling of sediment and easy de-siltation of that area in the case where higher flows bypass the pretreatment area and bring sediments to the lake. This solution made good use of the existing feature to provide a catchment-scale SUDS option, mitigating sediment and metals from all sources upstream of the paddling pool.

With respect to maintenance, research on lakes in Scotland (Heal *et al.* 2006) indicated that removal of sediment from ponds is likely to be driven by loss of volume due to siltation rather than concerns over aquatic environment quality. This has the benefits of reducing the required maintenance frequency and minimising disturbance to the lake environment.

In addition to the regional-scale control identified above, opportunities for site and source controls via an

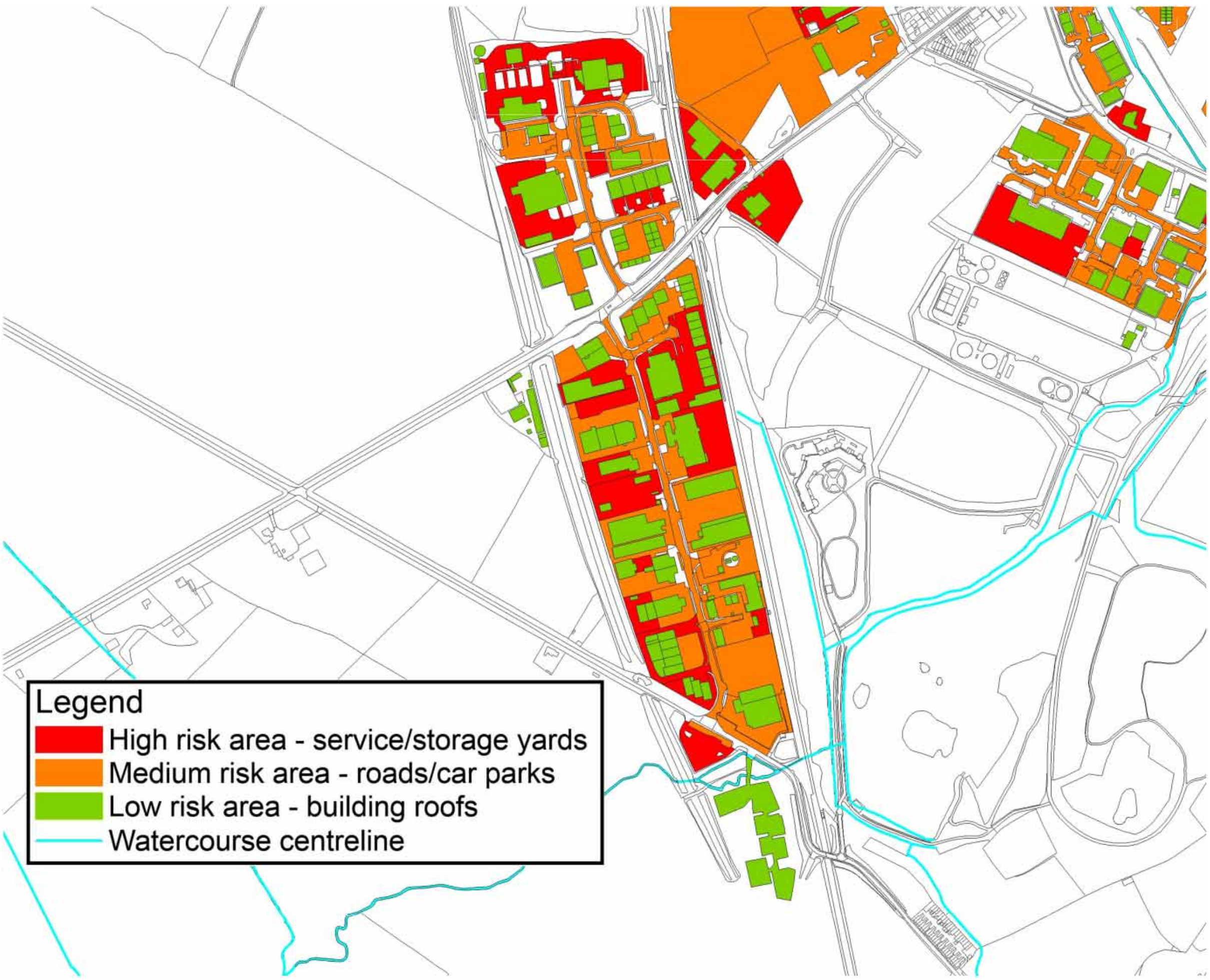

Figure 3 | Classification of industrial estate land uses.

open space at some other areas along the road network have been identified.

These areas were examples of small areas of natural surface adjacent to the highway, which could be used for SUDS tree planters. Whilst small in size, the combination of many of these SUDS, installed as the road or pavement area is resurfaced or maintained, would contribute over time to reductions in sediment loads and improvements in water quality downstream of the locations at which they are installed. Porous pavements, tree planters or filter drains were deemed particularly suitable for these densely populated areas, where use of large swales or ponds is prohibited due to limited availability of land.

Once solutions had been selected and correctly sized, CIRIA (2007) guidance and estimates from quantity surveyors for unit costs were applied to generate estimates of the cost of retrofitting the selected SUDS. These provided a useful indication of the potential scheme costs, although they remained subject to site-specific investigations to identify any remaining constraints.

Case study 2

Seven industrial estate zones were identified as potential sources of pollutants, based on their likely drainage. Following application of the previously described approach, classifications of land use were made as shown in Figure 3. This then informed the choice of SUDS to address likely pollutant from each unit.

A range of SUDS were applied as source or site control options, taking advantage of existing features where possible. Primarily, disconnection and green roofs were considered for buildings, with filter drains and permeable paving used for

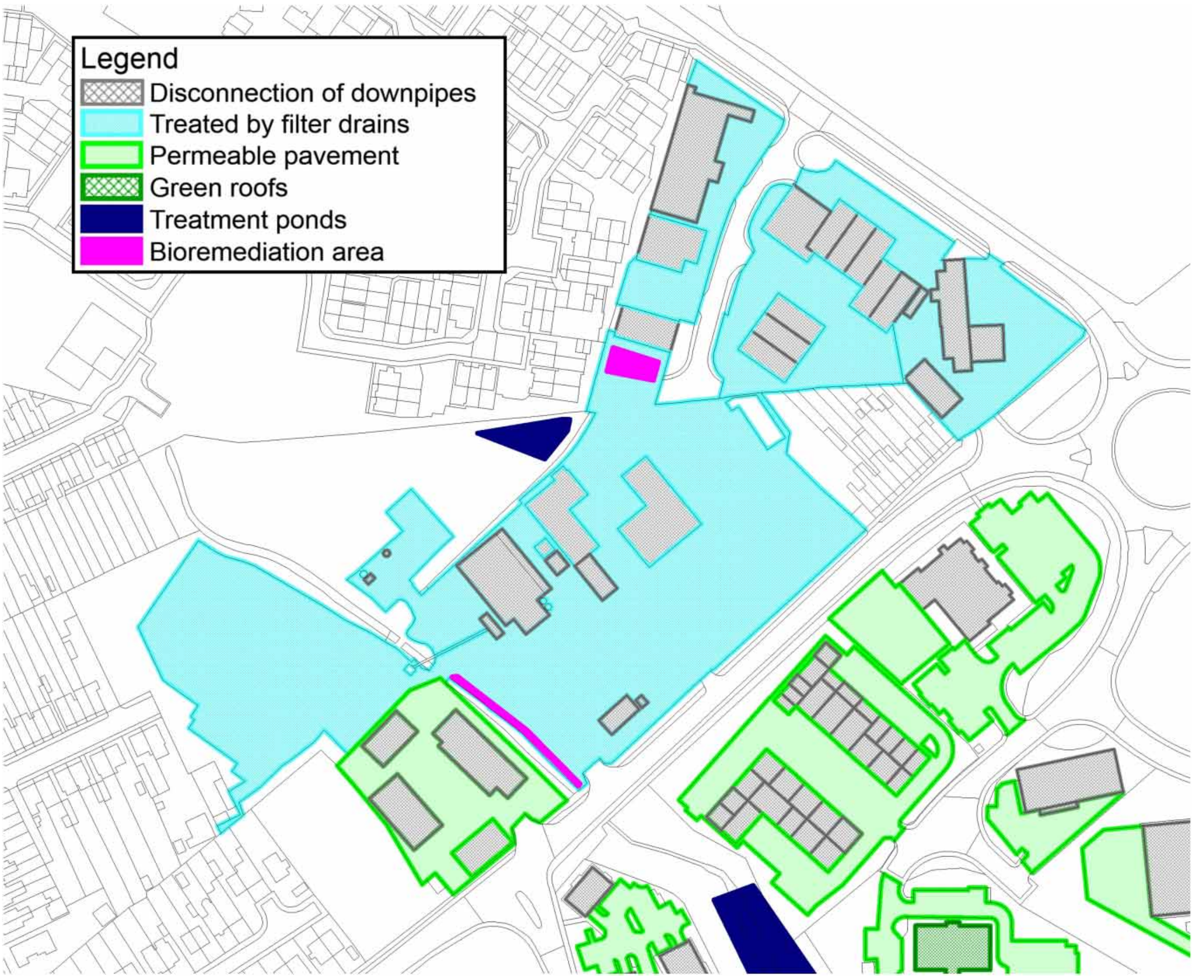

Figure 4 | Areas suitable for different types of SUDS treatment at an industrial estate.

yard areas, car parks and road surfaces where appropriate. Ponds and bioremediation areas were used with swales to offer regional solutions at four of the estates.

The site control SUDS proposed for the industrial estates utilise existing ditches and ponds as the basis for the SUDS treatment to provide treatment to a wide range of potential pollutants. The ditch at the industrial estate shown in Figure 3 was in very poor condition and contained large amounts of detritus. A distinct odour at this location also indicated the likelihood of misconnections discharging in to the ditch. These would need to be addressed before using the ditch and pond for SUDS. The pond volumes were checked to ensure that they were of a suitable size to treat the first flush of pollutants from the respective industrial estates (using a first-flush rainfall depth of 12.5 mm (Todorovic *et al*. 2008). The inclusion of programmes to disconnect roofs to soakaways and introduce filter drains and permeable paving where appropriate would reduce the runoff to the ponds and offer an important level of source control, providing a preliminary treatment before the potentially heavily polluted flows reach the ponds.

As with case study 1, unit costs for each type of SUDS generated from CIRIA (2007) and quantity-surveyed estimates were applied to the correctly sized SUDS to generate costs for installation of the proposed schemes.

For the trading estate in Figure 4, a combination of a pond and two bioremediation areas was included. These were sized based on the total first-flush runoff that may be expected. The areas of blue shading are proposed to be treated with filter drains located to treat run off, providing a first level of treatment for these areas.

CONCLUSIONS

This work represents a step forward in rapidly identifying and quantifying pollutants and identifying suitable mitigation measures to tackle identified pollutants, with particular focus on the requirements of the European WFD. The tool allows both a detailed analysis of small areas such as industrial estates and their surrounds, and large-scale screening of towns and regions.

Two different applications of the tool are presented. Firstly, where the pollutant of interest is known, the outputs of the tool highlight and isolate the areas contributing the pollutants, and suggest the adequate SUDS measures to meet the required criteria. Secondly, where the tool identifies likely pollutants at a receiving location, SUDS measures are proposed to reduce pollution with assessed efficiencies.

The tool could be used to compare different options for their efficiency in terms of cost, land use and treatment. Additionally, the use of costing data for different types of SUDS means the costs of various treatment approaches can be generated at an early stage to allow funds to be secured.

REFERENCES

Bacci, F., O'Reilly, S., Morgan, G., Heffron, J. J., O'Halloran, J. & Foley, A. M. 2010 Abatement technologies for road surface run-off. *Proceedings of ITRN 2010*, University College Dublin, Dublin, Ireland.

Bäckström, M. 2003 Grassed swales for stormwater pollution control during rain and snowmelt. *Water Sci. Technol.* **48** (9), 123–134.

Barrett, M. E., Walsh, P. M., Malina Jr, J. F. & Charbeneau, R. J. 1998 Performance of vegetative controls for treating highway runoff. *J. Environ. Eng. ASCE* **124**, 1121–1128.

Bressy, A., Gromaire, M.-C., Lorgeoux, C., Saad, M., Leroy, F. & Chebbo, G. 2012 Towards the determination of an optimal scale for stormwater quality management: Micropollutants in a small residential catchment. *Water Res.* **46**, 6799–6810.

Breton, N., Todorovic, Z. & Crayston, F. 2013 Screening tool for water quality improvements, flood risk management and urban regeneration through surface water flood reduction at a regional scale. *Novatech 2013 Proceedings* (J. L. Bertrand-Krajewski & T. D. Fletcher, eds), GRAIE, Lyon, France.

Brezonik, P. L. & Stadelmann, T. H. 2012 Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA. *Water Res.* **36**, 1743–1757.

CEC 2000 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *OJ* **L327**, 22 December, 1–73.

Centre for Ecology and Hydrology 1999 *Flood Estimation Handbook*. Centre for Ecology and Hydrology, Wallingford, UK.

CIRIA 2007 *The SUDS Manual* (C697), CIRIA, London.

Davis, A. P., Shokouhian, M. & Ni, S. B. 2001 Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere* **44**, 997–1009.

Environment Agency 2007 *The Unseen Threat to Water Quality Diffuse Water Pollution in England and Wales Report.* http://www.environment-agency.gov.uk/research/library/publications/33983.aspx (accessed 26 March 2014).

Escarameia, M., Todd, A. J. & Watts, G. R. A. 2006 *Pollutant Removal Ability of Grassed Surface Water Channels and Swales: Literature Review and Identification of Potential Monitoring Sites*. Highways Agency, Wokingham, UK.

Göbel, P., Dierkes, C. & Coldewey, W. G. 2007 Storm water runoff concentration matrix for urban areas. *J. Contaminant Hydrol.* **91**, 26–42.

Gromaire, M. C., Garnaud, S., Saad, M. & Chebbo, G. 2001 Contribution of different sources to the pollution of wet weather flows in combined sewers. *Water Res.* **35** (2), 521–533.

Gromaire, M. C., Robert-Sainte, P., Bressy, A., Saad, M., De Gouvello, B. & Chebbo, G. 2011 Zn and Pb emissions from roofing materials – modelling and mass balance attempt at the scale of a small urban catchment. *Water Sci. Technol.* **63** (11), 2590–2597.

Heal, K. V., Hepburn, D. A. & Lunn, R. J. 2006 Sediment management in sustainable urban drainage system ponds. *Water Sci. Technol.* **53** (10) 219–227.

Helmreich, B., Hilliges, R., Schriewer, A. & Horn, H. 2010 Runoff pollutants of a highly trafficked urban road – correlation analysis and seasonal influences. *Chemosphere* **80**, 991–997.

Kayhanian, M., Suverkropp, C., Ruby, A. & Tsay, K. 2007 Characterization and prediction of highway runoff constituent event mean concentration. *J. Environ. Manage.* **85**, 279–295.

Lundy, L., Revitt, D. M., Eriksson, E. & Viavattene, C. 2011 Evaluation of alternative pollutant emission control strategies to urban water systems using substance flow analysis. *12th International Conference on Urban Drainage*, Porto Alegre, Brazil.

Lundy, L., Ellis, J. B. & Revitt, D. M. 2012 Risk prioritisation of stormwater pollutant sources. *Water Res.* **46**, 6589–6600.

Marsalek, J. & Viklander, M. 2011 Controlling contaminants in urban stormwater: linking environmental science and policy. *On the Water Front* **2**, 100–107.

McKenzie, E. R., Money, J. E., Green, P. G. & Young, T. M. 2009 Metals associated with stormwater-relevant brake and tire samples. *Sci. Total Environ.* **407**, 5855–5860.

Napier, F., D'Arcy, B. & Jefferies, C. 2008 A review of vehicle related metals and polycyclic aromatic hydrocarbons in the UK environment. *Desalination* **226** (1–3), 143–150.

Park, M. & Stenstrom, M. K. 2008 Comparison of pollutant loading estimation using different land uses and stormwater characteristics in Ballona Creek Watershed. *Water, Sci. Technol.* **57** (9), 1349–1354.

Park, M., Stenstrom, M. K. & Pincetl, S. 2007 *An Evaluation on the Effectiveness of Proposition O Projects for Water Quality Improvement*. Institute of the Environment, University of California, Los Angeles.

Park, M., Stenstrom, M. K. & Pincetl, S. 2008 Water quality improvement by implementation of Proposition O in the Los Angeles river watershed, California. *Water, Sci. Technol.* **58** (12), 2271–2278.

Rule, K. L., Comber, S. D. W., Ross, D., Thornton, A., Makropoulos, C. K. & Rautiu, R. 2006 Diffuse sources of heavy metals entering a wastewater catchment. *Chemosphere* **63**, 64–72.

Schueler, T. R. 1994 Performance of grassed swales along east coast highways. *Watershed Prot. Tech.* **1** (3), 122–123.

Stein, E. D., Tiefenthaler, L. & Schiff, K. 2007 Land-use-based sources of pollutants in urban stormwater. *Proceedings of 80th Water Environment Federation Technical Exhibition and Conference*, San Diego, CA, USA.

Stenstrom, M. K. & Strecker, E. W. 1993 *Annual Pollutants Loadings to Santa Monica Bay from Stormwater Runoff, Assessment of Storm Drain Sources of Contaminants to Santa Monica Bay*. Report No. UCLA ENGR 93-62, University of California, Los Angeles, CA, Vol. 1. (WEFTEC), San Diego, CA, USA, 13–17 October 2007.

Susilo, K. J., Steets, B., Leisenring, M. & Strecker, E. 2006 *Los Angeles County-Wide Structural BMP Prioritization Methodology*. Guidance Manual, GeoSyntec Project: LA0104, GeoSyntec, Los Angeles, USA.

Todorovic, Z., Reed, J. & Taylor, L. 2008 SUDS retrofit for surface water outfalls from industrial estates: Scotland case study. *11th International Conference on Urban Drainage*, Edinburgh, Scotland, UK.

Todorovic, Z., Barbarito, B., D'Arcy, B. & McLean, N. 2010 SUDS retrofit in Scotland to treat diffuse pollution from the industrial estates. *DIPCON 2010 Conference*, Quebec.

First received 28 October 2013; accepted in revised form 29 January 2014. Available online 7 March 2014