A Critical Review of Urban Diffuse Pollution Control: Methodologies to Identify Sources, Pathways and Mitigation Measures with Multiple Benefits

Stage 1 - A critical review of methodologies to identify the sources and pathways of urban diffuse pollutants

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EXECUTIVE SUMMARY

Background to Research

On behalf of the Scottish Government, the Centre for Expertise for Waters (CREW) commissioned 'A critical review of urban diffuse pollution control: Methodologies to identify sources, pathways and mitigation measures with multiple benefits'. The project was carried out in three stages:

1. A critical review of available methods for identification of sources and pathways of diffuse pollutants in urban environments
2. A critical review of mitigation measures, from source to end of pipe, for diffuse pollution prevention, and an assessment of their multiple benefits
3. A case study of a typical Scottish urban environment, utilising available information of pollutant sources and geographical details, incorporating scenario testing of sustainable mitigation measures and their multiple benefits.

This report presents the findings of the first stage, a review of available methods for identification of sources and pathways of diffuse pollutants in urban environments.

An overview is presented of the current level of scientific understanding associated with the range of approaches available to support practitioners in identifying the sources and pathways of urban diffuse pollutants at a local, catchment or regional scale. This report highlights key strengths and weakness of available urban diffuse pollution evidence bases, methodologies and their associated levels of implementation.

Whilst varying on a site-by-site basis, the key sources of urban diffuse pollution are identified as road traffic, misconnections, contaminated land and industrial estates. The specific pollutants typically associated with each source are presented, processes resulting in their mobilisation discussed and the subsequent pathways to surface and groundwaters described. This review provides information which underpins Stage 2 and Stage 3 research within this project.

Key Findings

Key findings regarding urban diffuse pollution and its sources:

- Due to a greater number of sources, urban diffuse pollution is typically more complex in terms of number of pollutants than diffuse pollution generated in rural areas.
- Key urban diffuse pollutants include particulate matter, metals (e.g. Cd, Pb, Cu and Zn), hydrocarbons (e.g. PAHs), herbicides, pesticides, and faecal coliforms.
- Many of the EU WFD (2000) priority (hazardous) substances have been detected in urban surface and/or groundwaters with urban diffuse pollution identified as contributing to the failure of WFD environmental quality standards.

- Primary sources of urban diffuse pollution are typically roads, misconnections, industrial estates and/or land which may be contaminated.
- Urban diffuse pollutants are mobilised by rainfall and snow melt.
- Mobilised diffuse pollutants may directly discharge to surface waters via SWO, infiltrate into land (which may or may not be contaminated) and subsequently migrate downwards to groundwater or laterally to surface water bodies. Recharge of surface waters by contaminated groundwaters may act as a further bi-directional pathway.
- The urban diffuse pollution evidence base is strongest with regard to the sources, scale and pollutants load associated with road traffic activities.
- Considerable data sets exist on contaminated land with regard to locations and concentrations of a wide range of pollutants. However, the relative contribution it makes to the diffuse pollutant load of urban surface and groundwaters is not established.
- Further data are required to enable the scale, severity and pollutant loads associated with misconnections and diffuse emissions from industrial estates to be quantified at either a regional or national scale.

Key findings regarding methods to identify sources and pathways of urban diffuse pollutants:

- Many methods and tools exist which are designed to identify sources of diffuse pollutants (see Appendix 1). These range from low-cost mapping exercises to determine potential sources and pathways (e.g. maps of traffic routes), locations of surface water outfalls and audits of current and historic land use, to in-depth water and sediment sampling and analysis programmes, and to the use of theoretical models which predict generation of pollutant loadings at local to regional scales.
- A range of urban diffuse pollutants can be linked to current and/or historic land use type or activity e.g. roads, residential, industrial. Different activities are likely to produce different pollutants at differing loading levels.
- Urban diffuse pollution is typically a ‘cocktail’ or mixture of pollutants from multiple sources.
- Where a specific pollutant is identified (e.g. from stream chemistry samples) it may be possible to identify the types of activity in the catchment that are likely to yield (be a source of) that pollutant and to track the pollutant pathway using methods identified in Appendix 1. However, as individual pollutants may be transformed during their transit through the catchment, source identification and allocation remains a challenging and problematic area.

The materials reviewed for this stage are presented in an overview table of methodologies which can help decision-makers with identification of the sources and pathways of diffuse urban pollutants. These are presented in the Appendix to the Stage 1 report.

Key words
Urban diffuse pollution, sediment, water, soil quality

1.0 INTRODUCTION

In 2012 the Scottish Government via the Centre of Expertise for Waters (CREW) commissioned a project entitled 'A critical review of urban diffuse pollution control: Methodologies to identify sources, pathways and mitigation measures with multiple benefits'. The project is being carried out by a consortium of research providers including:

- University of Abertay, Dundee (Project Leader)
- The James Hutton Institute (JHI), Aberdeen
- British Geological Survey (BGS), Edinburgh
- Middlesex University, London
- University of Dundee
- Creative Drainage

The project involves three stages:

Stage 1: Research that critically reviews available methods for identification of sources and pathways of diffuse pollutants in urban environments, including a research summary.

Stage 2: Research that critically reviews mitigation measures, from source to end of pipe, for diffuse pollution prevention allied with an assessment of their multiple benefits.

Stage 3: A case study of a typical Scottish urban environment, utilising available information of contaminant sources and geographical details, incorporating scenario testing of sustainable mitigation measures and their multiple benefits.

This report presents the findings of the first stage, a review of available methods for identification of sources and pathways of diffuse pollutants in urban environments.

An overview is presented of the current level of scientific understanding associated with the range of approaches available to support practitioners in identifying the sources and pathways of urban diffuse pollutants at a local, catchment or regional scale. This report highlights key strengths and weakness of available urban diffuse pollution evidence bases, methodologies and their associated levels of implementation.

1.1 Background

What directly links cars, contaminated land and misconnected foul drainage? From an environmental management perspective, the key connection is that they are all sources of urban diffuse pollution. The same can be said of roads, pavements, roofs, car parks, car washes, building materials, railway sleepers, current and historical industry, energy generation, waste management, air quality and deposition and numerous other commodities and activities (Lundy et al., 2012; Boussu et al., 2007; Blocken et al., 2013; Mateus et al., 2008; Thierfelder and Sandstrom 2008). From the moment we are born, our life styles are dependent on the use of a range of products and processes that result in the release of a diversity of substances in an abundance that far exceeds background environmental concentrations or, with regard to synthesised compounds, substances that are not found in nature (Donner et al., 2009).The mobilisation of these released pollutants by rainfall (and snow melt), as it travels over impermeable surfaces or over and through permeable substrates, provides a major pathway through which a range of European Union (EU) Water Framework Directive (WFD) priority (hazardous) substances may be discharges to receiving waters (EU WFD, 2000). Further key pathways for the transportation of urban diffuse pollution include groundwater base flow and leaching from surrounding land.

Whilst the pollutant types and loads released from these disparate sources will vary greatly, each one is a potential cause of environmental pollution and hence a challenge for environmental management (Donner et al., 2009). Nowhere is this more the case than in our urban areas.

1.2 Definition of diffuse pollution concepts

The EU WFD (2000) requires the development of 'Programmes of Measures' which address both point and diffuse sources of pollution as a key way to enable good ecological status to be achieved in all surface, ground and coastal water bodies (EU WFD, 2000). SEPA (2013) defines diffuse pollution as "the release of potential pollutants from a range of activities that individually may have no effect on the water environment, but at the scale of a catchment can have a significant impact (i.e. reduction in water quality, decrease in wildlife, etc.)". Pollution can be considered to originate from sources in the landscape (e.g. traffic, building materials), be moved from those sources via series of pathways(e.g. runoff events, misconnections) and eventually reach a receptor, such as a surface or ground water body, human populations or buildings (SEPA, 2011; Luo et al., 2009).

The 'source-pathway-receptor' (SPR) model is a useful concept in understanding how pollutants can impact negatively on receptors. It also makes clear that for a pollutant to have an impact on a identified receptor a complete SPR chain is required (Luo et al., 2009). For example, a pollutant, however hazardous, poses no risk to a potential receptor if there is no exposure route (i.e. pathway) directly linking the source to the receptor. The SPR model is also a useful framework in supporting the development of diffuse pollutant mitigation measures as:

- The identification of the sources is an essential component of effective sector engagement, in persuading sectors that they are involved in the problem and hence have a role in solving it (D'Arcy, 2013).
- it supports understanding of varying patterns of pollutant release (e.g. continuous, daily, intermittent) and their subsequent movement through the landscape
- it can support prioritisation of particular sources, pathways and/or receptors with regard to e.g. particular pollutants or receptors of concern, providing transparent justification for the allocation of resources.
- it can support the screening of mitigation measures in relation to:
    - their potential to break the SPR chain

- their location of application i.e. upstream (applied to source), mid-stream (breaks the chain between pathway and receptor) downstream (post-receptor), facilitating the evaluation of potential mitigation measures within a wider socio-economic context.

1.3 Categorisations of urban diffuse pollutants

When identifying urban diffuse pollutants which may be prevalent at a particular site, one of two broad approaches is commonly utilised:

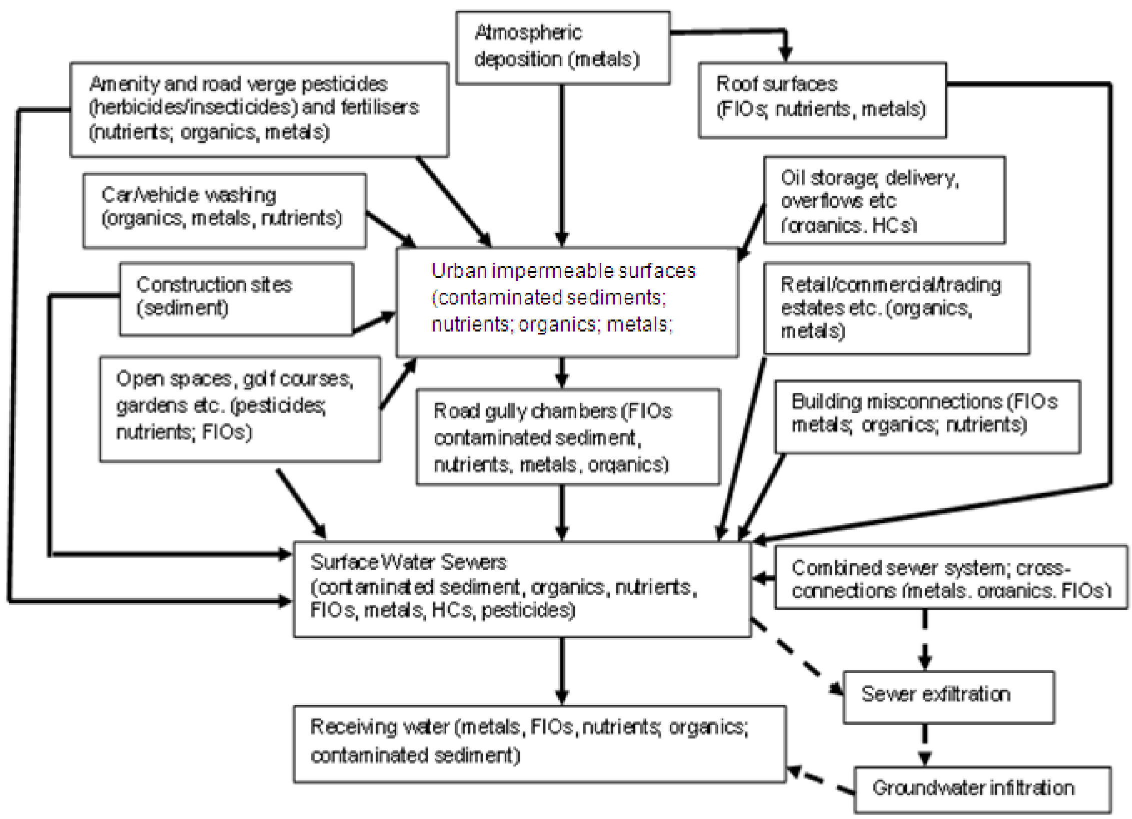
- Identification of urban pollutants based on an assessment of current and historic land use types/activities (certain pollutants are known to be associated with particular types of land use and/or activities; see Figure 1.1 and Table 2.2)
- Consideration of pollutants which may be present based on a grouping of pollutants by broad type (e.g. metals in an urban area are likely to include Cd, Zn, Pb and Cu, key constituents of urban hydrocarbon loadings would be expected to include several polyaromatic hydrocarbons; PAHs)

Within each of these approaches, there are many methods available for identifying or assessing sources (see Table A1.1. in Appendix 1 for an overview of methods benchmarked to reflect their level of development/use in practice). However, it should be noted that whilst it is possible to identify potential sources within a particular field site, attributing specific loads to each source remains highly problematic. This is primarily due to the fact that many sources and types of pollutants are present in urban areas. Once released, these quickly become mixed during both above and below ground transportation producing a 'cocktail' of pollutants within which further array of biological and physic-chemical transformations can take place.

Policy makers currently seek to meet these challenges with regulations such as the EU Water Framework Directive (EU WFD, 2000), European REACH regulation (EU REACH, 2006) the EU Integrated Pollution Control Directive (EU IPPC, 2008), the EU Environmental Liability Directive (EU, 2004) and the EU soil thematic strategy (EU, 2012), reflecting the need to protect both human health and the environment from adverse effects. The inherent properties of diffuse pollutants (e.g. solubility, volatility, biodegradability etc.) are just as varied as their potential sources, and the behaviour of different substances upon release to the environment varies accordingly (see Bester et al., 2007 for background information on the fate of a range of substances in the environment).

1.4 Pathways for urban diffuse pollutants

Once present within a catchment, urban diffuse pollutants can be mobilised during rainfall events (Eriksson et al., 2007). As rainfall runoff travels over impermeable (and to a lesser extent permeable) surfaces, it can mobilise and transport pollutants from a range of sources (including those identified above) and can carry pollutant loads comparable to those reported for raw sewage (Herngren et al., 2006). Infiltration of surface water can also mobilise pollutants within soils leading to their migration laterally and vertically downwards to surface waters and groundwaters, respectively. Key factors influencing the load of pollutants mobilised during a particular event include current and historic land use activities (e.g. industrial, commercial, highways, residential), nature of the catchment surfaces (e.g. permeable, impermeable, surface texture and depth), the intensity and frequency of storms and the weather conditions between storms as well as the inherent biological and physico-chemical characteristics of the pollutants themselves. Hence, the quantity of urban diffuse pollution mobilised can be highly variable, even within a single catchment area (Lundy et al., 2012). Figure 1.1 gives a generic overview of the range of the pollutant types typically reported in urban runoff, the sources of these pollutants and the routes by which urban surface runoff (and its associated pollutant load) may impact on surface and sub-surface urban water bodies.



Key: FIOs = faecal indicator organisms; HC = hydrocarbons

Figure 1.1 Principal urban pollutant sources, types and pathways (modified from Lundy et.al. 2012)

Whilst point source pollutants are relatively easy to identify, sources of diffuse pollutants can be more difficult to locate and control, particularly in urban, areas which are spatially and temporally dynamic. As noted above, further transformations of pollutants may occur as they reside within and move between the pollutant sources and sinks identified in Figure 1.1, with their environmental behaviour and subsequent fate being further complicated by the fact that several of the identified receptors e.g. highway surfaces, road gullies and pipe drains, can act as both pollutant sinks and sources in response to natural and anthropogenic changes within a particular catchment. As a result, identifying specific sources of pollutants found within receiving waters can be difficult as the pollutant loadings within a particular discharge may be more indicative of the nature of the flow properties of the individual event rather than the characteristics of the sources and their patterns of emission (Lundy et al., 2012).

Identifying sources and pathways of diffuse pollutants in urban areas is potentially more complicated than in agricultural areas due to the elevated numbers of potential sources associated with the greater population densities, and the mixture of pollutants is hence more complex. An overview of the impact of urban diffuse pollution on the Scotland River Basin District (SEPA, undated) and measures currently proposed for its mitigation is given in Appendix 2.

2.0 URBAN DIFFUSE POLLUTANTS ASSOCIATED WITH SPECIFIC LAND USE TYPES/ ACTIVITIES

Table 2.1 identifies the sources of a range of organic and inorganic pollutants frequently detected in urban surface runoff, an overview of the concentrations at which they have been reported in the literature and an indication (where available) of the % EU WFD failures attributable to an identified source category. Whilst many of the pollutants identified in Table 2.1 may be present in either the dissolved or particulate phase, it is widely reported that the majority of the urban pollutant load is associated with particles (e.g. Lee et al., 1997; Vaze and Chiew 2002 and 2004; Bjorkland, 2011) and that the particles 'carry' a range of pollutants (Herngren et al., 2006; McKenzie et al., 2008).

Sources of particulate matter deposited on urban surfaces can include traffic, industrial emissions, roofing materials and street furniture, general street litter, accidental spills and erosion of soils from surrounding areas (Gunawardana et al., 2012) via both direct and indirect deposition routes (e.g. short- and long-distance aerial transport and resuspension of previously settled particles). Whilst the impacts of urban diffuse pollution on groundwater are not well understood in terms of processes, the fact that urban areas negatively impact on groundwater is well established (e.g. see Foster et al., 1999; Lerner et al., 2008, Wolf, 2007).

Table 2.1 Urban diffuse pollutants: sources, event mean concentrations and impacts (modified from Lundy et al., 2012)

Pollutant pressure	Pollutant source	Event mean concentrations	% WFD failures attributable to pollutant source
Nutrients (mg/l)	Misconnections	Total P:39; NH_4:5	<2% (3-5% Dwellings)
	Urban amenity fertiliser	Total P: 0.02-14.3; Total N: 0.4-20; NO_3: 0.1-4.7	2%-8%(Housing; Roads; Golf courses)
	Residential	Total N:0-6; NH_4:0.4-3.8	2%-3%
	Highways and motorways	Total N:0-4	
	Commercial	NH_4:0.2-4.6	
	Industrial	NH_4: 0.2-1.1	
	Roofs	NH_4: 0.4-3.8	
	Gully Liquors	Total N:0.7-1.39	
FIOs: *E. coli*	Misconnection	10^3-10^6	
(MPN/100ml)	Roofs, roads and parks	40-10^6	N/A
Metals (µg/l)*	Motorways and major roads	Pb: 3-2410; Zn: 53-3550; Ni:4-70; Cd: 0.3-13	~5%(Highways
Pb			
Cd	Urban distributor roads	Pb:10-150; Zn: 410; Cd:0.2-0.5	<14%
Zn	Suburban roads	Pb:10-440; Zn: 300	
Ni	Commercial estates	Ni: 2-493	~5% trading estates/car washing
Cu	Residential	Cd: 0-5; Zn: 150; Pb: 0-140	
	Roofs	Pb:1-30	
	Gully Liquors	Pb:100-0.850	
Total suspended solids (mg/l)	Residential		
	High density	55-1568	5%-6%
	Low density	10-290	
	Motorways & major Roads	110-5700	
	Urban roads	11-5400	
	Roadside gully chambers	15-840	
	Industrial	50-2582	
	Commercial	12-270	
	Roofs	12.3-216	
	Misconnections	300-511	
Hydrocarbons (µg/l)	Residential		
	High density	Total HC:0.67-25.0	
	Low density	Total HC: 0.89-4.5	
	Motorways & Major Roads	Total HC:7.5-400; PAH:0.03-6	
	Urban roads	Total HC: 2.8-31; PAH: 1-3.5	
	Commercial	Total HC:3.3-22; PAH:0.35-0.6	
	Industrial	Total HC:1.7-20	

Key: *= metalled roofs not included; HC = hydrocarbons; PAH = polyaromatic hydrocarbons.

2.1 Roads, highways and motorways: key trends and concepts

Amongst the wide range of sources of urban diffuse pollution, road traffic has been identified as an important contributor (Herngren et al., 2006, Thorpe and Harrison, 2008). Specific traffic-related sources of pollution include wear and tear of car bodies and engines, abrasion of brakes and tyres, exhaust emissions, friction-assisted break-up of paving and road materials, degradation of street furniture (e.g. streetlights, crash barriers and signage) and de-icing/anti-skid materials (Sorme, 2003, Westerlund, 2005, Gunawardana et al., 2012).Road traffic is frequently identified as an important source of a diverse array of organic and inorganic pollutants in the urban environment (Sorme, 2003; Thorpe and Harrison, 2008; Ellis and Revitt et al., 2008; Lundy et al., 2012). At locations heavily influenced by traffic, this source can be a more important source of key urban diffuse pollutants than industrial emissions in association with both direct deposition and subsequent resuspension processes.

The Highways Agency (HA) has made significant efforts in recent years to define the diffuse pollution problem associated with highways and roads and has worked in conjunction with other organisations and experts to develop a method for assessing environmental risk from road derived pollutants (Whitehead and Crabtree, 2007). Their findings add useful evidence to the overall analysis of urban diffuse pollutant sources. HA research findings include the following conclusions:

- Traffic density has greatest effect on organic and inorganic pollutant concentrations
- Some climate effects for PAHs (higher in cold regions) were noted
- Seasonality trends for some parameters e.g. metals concentrations higher in summer, PAH concentrations higher in winter
- No simple relationship between pollutant concentrations and rainfall event characteristics were apparent

In a 5 year study undertaken by the University of Sheffield, ECUS and the University of Warwick (Guymer and Gaskell, 2008) on the impact of highway derived sediments on receiving water ecology, researchers reported that:

- Highway-derived particles may be contaminated with metals and PAHs at concentrations that exceed selected toxicity thresholds.
- Highway-derived contaminants may accumulate in river bed sediments and can reach potentially toxic concentrations.
- Metals and PAHs are bio-accumulated by fish and invertebrates, especially at sediment accumulating sites.
- Highway-runoff is associated with changes in in-stream community composition, especially at sediment accumulating sites.
- Highway discharges can be toxic to invertebrates deployed *in-situ*.
- Toxicity of contaminated sediment was confirmed by laboratory toxicity tests.
- PAHs are the key contaminants driving toxicity.

With respect to methods used to determine diffuse pollution for roads and highways, the following water and sediment quality considerations are used:

- Runoff Specific Thresholds (RSTs): RSTs are values defined with regard ensuring the protection of receiving water organisms from short-term exposure to soluble pollutants in highway runoff to account for the fact that, due to the intermittent nature of highway runoff, soluble pollutant concentrations may be high but only for short periods (Crabtree et al., 2007).
- Sediment Quality Guidelines (SQGs) values (e.g. CCME, 2001) were identified to protect the healthy functioning of aquatic ecosystems. Research has shown that SQGs are commonly exceeded in highway derived sediments. As such, the real test is whether sediment will disperse within basal sediments in receiving water environments or whether it will accumulate in quantities that might have an adverse effect on riverine ecologies.
- Environmental Quality Standards (EQS) are stringent receiving water quality standards for a wide range of physic-chemical parameters which have been derived by all Member States according to methods set out in the EU WFD (2000).
- EQSs are the means by which the EA assess water quality so that, while RSTs are arguably more appropriate for intermittent highway runoff, the EQSs must also be complied with.

Further data on specific sources and loads of organic and inorganic diffuse urban pollutants are reported in Appendix 3.

2.2 Industrial estates: key issues and concepts

Whilst playing a key role in the socio-economic development of an area through the provisions of goods and employment, industrial estates can also place a significant negative environmental burden on the immediate and surrounding areas in terms of the generation of air, water, soil and solid pollution loads. The activities of industrial estates can impact on diffuse pollutant loadings of adjacent receiving waters via two key routes:

- The misconnection of effluent wastewaters to surface water drainage piped systems
- The discharge of surface water runoff from industrial estates

Industrial wastewaters generated through the business activities located on-site can contain a range of contaminants representing the compounds involved at each stage of the particular manufacturing/development process involved e.g. un-reacted starting materials, intermediate compounds and unwanted by-products (Revitt et al., 2009). Additional wastewater streams requiring treatment can be generated from other on-site sources such as scrubbing of exhaust gases from incineration and combustion, bleed from boiler feed water systems and back-washing of filters. Hence the implications of a misconnection resulting in the direct discharge of untreated or partially treated industrial effluents to surface water pipe and, subsequently, receiving waters can be profound with respect to resulting impacts on its ecology.

With regard to the pollutant load carried by industrial estate derived surface runoff, together with the pollution loads associated with traffic activities (common to other impermeable urban surfaces), there are further specific activities and practices that can result in industrial estate surface runoff discharging higher pollutant loads than that which may be predicted based on a consideration of impermeable surface area alone (D'Arcy, 2011). This is primarily associated with the fact that the quantities and variety of potential pollutants handled and utilised within industrial estates is greater than that on other urban surfaces. Specific activities include leaks and spills (e.g. a wide range of chemicals), cleaning activities (detergents), weed and pest control (herbicides and pesticides), food and drink wastes (e.g. elevated organic loadings) and elevated loads of sediments (Todorovic et al., 2011). A high potential for misconnections (see section 2.3) on industrial estates whereby, for example, industrial effluents are illegally discharged into surface water drainage systems, has also been suggested (Tedorovic et al., 2011).

Characteristics of runoff discharging from industrial estates are reported to include low levels of dissolved oxygen and high levels of biochemical oxygen demand, nutrients, metals and total coliform bacteria (Rule et al., 2006a; Todorovic et al., 2011). In a survey of runoff from a range of land-use types including light industry, old and new housing, Rule et al. (2006a) reported that average metal concentrations were generally higher in industrial runoff samples than in those associated with residential areas, with highest concentrations reported in samples collected at the start of rainfall events. A separate paper by the same authors reported a similar trend for nonylphenol ethoxylates in runoff (Rule et al., 2006b). However, an opposite trend was reported for polybrominated diphenylethers and diethylhexyl phthalate (i.e. concentrations were greater in residential than light industrial runoff), indicating that urban diffuse pollution loads may vary on a source by source basis that is highly spatially complex.

2.3 Misconnections: overview and challenges

The term 'misconnections' is typically used to refer to the incorrect connection of pipes carrying domestic wastewater (e.g. toilets, sinks, washing and dishwashing machines) to surface water piped systems which can occur as a result of poor plumbing practices(Butler et al., 1995). However, it can also refer to the incorrect cross-linkages of pipes carrying industrial and commercial effluents to surface water piped systems, as well as the connection of surface water pipes into foul water sewers. Surface water piped systems are designed to collect and drain surface water to the nearest receiving water following a rainfall event. Hence, incorrect cross-linkages between drainage systems results in the direct discharge of untreated sewage and industrial/commercial effluents to receiving waters. In contrast, the misconnection of surface water drainage into wastewater pipes can lead to hydraulic overloading, surcharging and flooding (Ellis, 2013).

A study of the potential polluting impact of domestic misconnections indicated that key pollutants of concern are nitrates, phosphates, ammonia and bacteria with industrial/commercial misconnections potentially introducing a range of hydrocarbons, solvents and other EU WFD priority (hazardous) substances to receiving waters (Royal Haskoning, 2007 and 2010). In a recent evaluation of the scale and polluting impact of misconnections in England and Wales, Ellis (2013) reported that, whilst the issue of misconnections is widely referred to as being 'ubiquitous', there are little hard data on which to base evaluations of the scale, severity and impact of misconnections on receiving water quality. A key factor in this is understood to be the high number of unknown/unmapped surface water outlets. Key conclusions of the review by Ellis (2013) include:

- There is a lack of data on the numbers of misconnections and their potential pollution impact on receiving watercourses in England and Wales, with this trend thought to prevail in other parts of Europe and North America
- Average misconnection rates are reported to vary from 1% - 9% of the sewer network.
- Domestic misconnection rates are reported to contribute to 5-8% of the failure of freshwater EU WFD standards in and up to 25 failures per annum of bathing water standards.
- A sample survey of 416 houses indicates substantial differences in pollution potential for differing household appliances which yields estimates for annual BOD loading to urban receiving waters varying between 2 – 1500 tonnes per annum depending on the choice of regional or national data respectively.
- Survey, inspection and rectification costs at the regional level would suggest total overall costings substantially exceeding current national annual estimates of £235M per year.

2.4 Land Contamination: sources and pathways

The UK's long history of industrialisation is evidenced in many facets of our major cities, from their location close to natural resources (such as coal and waterways) to the grand architecture and cityscapes it funded. However, our industrial past has also left many cities with a legacy of land contamination (Luo et al., 2009). While estimates of the extent and number of contaminated sites that exist in the UK vary, SEPA estimate that 82,034 hectares could be affected by land contamination (SEPA, 2008) with predictions for England and Wales ranging from 50,000-300,000 hectares (EA, 2002) an area representing 0.4-0.8% of the UK's total land surface. Due to a combination of limited availability of space in cities, increased demand for new urban housing stock and a new understanding of the value of protecting our rural heritage, the drive to redevelop previously used land (i.e. brownfield sites which may or may not be contaminated) is increasing. This approach is strongly supported by Scottish, English and Welsh government departments through a combination of policies and financial incentives (SEPA, 2008; EA, 2002).

Land contamination can contribute to the diffuse pollutant load of receiving waters through a range of direct and indirect routes. These include:

- leaching of pollutants from surface areas of land contamination which are subsequently mobilised by rainfall runoff and enter the surface water drainage system

- leaching of pollutants from land contamination downwards or laterally into surrounding soils which can then migrate into receiving water bodies e.g. through the vadose zone
- leaching of pollutants from land contamination into groundwater bodies and their subsequent migration upwards to receiving water bodies

A key process governing the movement of pollutants from land contamination areas to surface and ground waters is the leaching behaviour of the pollutants which in turn is influenced by a wide range of physico-chemical and site specific properties, from the soil type and pH to depth to groundwater and the inherent properties of the pollutants themselves (e.g. adsorption capacity, solubility and volatility etc). However, not all sources of land contamination are historic with a range of current activities such as gas works, waste disposal, petrol distribution and dry cleaning also cited as potential sources of land contamination (SEPA, 2008). Table 2.2 gives an overview key pollutant types associated with common types of historic industries in the UK.

Table 1.2 An overview of common historic industries and selected frequently associated contaminants (taken from SEPA 2008)

Industry	Frequently associated contaminants
Steel making and rolling	Metals Coke making contaminants such as cyanides, polycyclic aromatic hydrocarbons (PAHs) Fuels and oils
Gas works	PAHs Cyanides Phenols
Shipbuilding	Metal pigments Oils Paints and solvents Asbestos
Textile and dye works	Metals Chlorinated and non-chlorinated solvents Pesticides
Oil refining and bulk storage	Fuel oils (e.g. aviation, diesel, petroleum) Organo lead compounds

3.0 KEY-FINDINGS

Key findings regarding urban diffuse pollution and its sources:

- Due to a greater number of sources, urban diffuse pollution is typically more complex in terms of number of pollutants than diffuse pollution generated in rural areas.
- Key urban diffuse pollutants include particulate matter, metals (e.g. Cd, Pb, Cu and Zn), hydrocarbons (e.g. PAHs), herbicides, pesticides, and faecal coliforms.
- Many of the EU WFD (2000) priority (hazardous) substances have been detected in urban surface and/or groundwaters with urban diffuse pollution identified as contributing to the failure of WFD environmental quality standards.
- Primary sources of urban diffuse pollution are typically roads, misconnections, industrial estates and/or land which may be contaminated.
- Urban diffuse pollutants are mobilised by rainfall and snow melt.
- Mobilised diffuse pollutants may directly discharge to surface waters via SWO, infiltrate into land (which may or may not be contaminated) and subsequently migrate downwards to groundwater or laterally to surface water bodies. Recharge of surface waters by contaminated groundwaters may act as a further bi-directional pathway.
- The urban diffuse pollution evidence base is strongest with regard to the sources, scale and pollutants load associated with road traffic activities.
- Considerable data sets exist on contaminated land with regard to locations and concentrations of a wide range of pollutants. However, the relative contribution it makes to the diffuse pollutant load of urban surface and groundwaters is not established.
- Further data are required to enable the scale, severity and pollutant loads associated with misconnections and diffuse emissions from industrial estates to be quantified at either a regional or national scale.

Key findings regarding methods to identify sources and pathways of urban diffuse pollutants:

- Many methods and tools exist which are designed to identify sources of diffuse pollutants (see Appendix 1). These range from low-cost mapping exercises to determine potential sources and pathways (e.g. maps of traffic routes), locations of surface water outfalls and audits of current and historic land use, to in-depth water and sediment sampling and analysis programmes, and to the use of theoretical models which predict generation of pollutant loadings at local to regional scales.
- A range of urban diffuse pollutants can be linked to current and/or historic land use type or activity e.g. roads, residential, industrial. Different activities are likely to produce different pollutants at differing loading levels.
- Urban diffuse pollution is typically a 'cocktail' or mixture of pollutants from multiple sources.
- Where a specific pollutant is identified (e.g. from stream chemistry samples) it may be possible to identify the types of activity in the catchment that are likely to yield (be a source of) that pollutant and to track the pollutant pathway using methods identified in Appendix 1. However, as individual pollutants may be transformed during their transit through the catchment, source identification and allocation remains a challenging and problematic area.

4.0 SUMMARY

This report gives a succinct overview of the current level of scientific understanding associated with the range of approaches currently available to support practitioners in identifying the sources and pathways of urban diffuse pollutants at a local, catchment or regional scale. With a strong focus on accessibility (in terms of both language and referenced materials), this report highlights key strengths and weakness of available urban diffuse pollution evidence bases, methodologies and their associated levels of implementation.

Whilst varying on a site-by-site basis, the key sources of urban diffuse pollution are identified as road traffic, misconnections, contaminated land and industrial estates. The specific pollutants typically associated with each source are presented, processes resulting in their mobilisation discussed and the subsequent pathways to surface and groundwaters described. This review underpins Stage 2 and Stage 3 research.

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Appendix 1

Table A.1.1 presents an overview of methods developed to identify the sources and pathways of urban diffuse pollutants. Note that some methods also identify the sensitivity of the receiving water, explicitly acknowledging a route (pathway) for the pollutant through the catchment and takes into consideration the condition of the water body (e.g. stream, river, groundwater) and human population which will be impacted by the diffuse pollution.

Table A 1.1 Overview table of methodologies to support identification of the sources and pathways of diffuse urban pollutants together with identification of users and information on level of development of method

Method	Supporting information	Actors/ stakeholders	Established/ piloted in the field/ theoretical	Reference
Risk based approach for regulation.	Process to identify high risk situations where General Binding Rules are surpassed and a licence is required in order to comply with WFD requirements.	Environmental protection agencies	Established	SEPA, 2011
Mapping of land uses associated with diffuse pollutant sources and pathways	Map resources and tools (including GIS) such as mapping current land use, geological information (surface geology, infiltration maps, bore hole and stream sediment data), historical land use. (The Contaminated Land Register (CLR) can be used in this process together with consultation of trade directories, SEPA permits and licenses etc.). Also mapping of traffic routes and traffic densities.	Local authorities, environmental protection agencies, highways agencies, consultants	Established. Used in practice and research	Many attempts, published and unpublished (grey literature and anecdotal)
Highways Agency Water Risk Assessment Tool (HAWRAT)	A three step process to assess the risk of highways to the water environment. Assessment process categorises level of risk and adequate mitigation measures.	Highways agencies, environmental protection agencies	Established. (Piloted, evaluated and revised).	DMRB, 2010; 11.3.10 – HD45
Identification of surface water outfalls and combined sewer outfalls	Use of drainage maps to identify locations of surface water receiving runoff from particular land outfalls use types/locations (e.g. industrial estates) and the location of combined sewer	Local authorities, environmental protection agencies, highways	Established	Planning Portal (undated)

	outfalls	agencies, consultants		
Detection of misconnections	Water companies currently promoting campaigns to locate and tackle misconnections e.g. the connect right stop pollution and the sewer network action programme	Local authorities, environmental protection agencies	Established	Water UK (undated)
Traffic density data	Traffic widely identified as key source of diffuse pollution; use data available on road traffic density as an initial screening tool to identify priority roads/stretches of roads	Local authorities, environmental protection agencies, highways agencies, consultants	Established	DoT (undated)
Desk based reviews of literature	>40 years of data on diffuse pollutant concentrations and loads associated with differing land-use types from e.g. peer-reviewed and non-peer reviewed papers, national and 'in house' field databases; varying levels of quality control applied	Local authorities, environmental protection agencies, highways agencies, consultants	Established	D'Arcy, 2013
Air quality and emissions databases	E.g. data on current and historic emissions of a range of pollutant s emitted to air including generic information on transportation and deposition behaviours.	Local authorities, environmental protection agencies, highways agencies, consultants	Established	Air quality in Scotland
Risk prioritisation of storm water pollutant sources.	A pollutant risk prioritisation methodology for the comparative assessment of stormwater pollutants discharged from differing land use types and activities	Local authorities, environmental protection agencies, highways agencies, consultants	Theoretical	Lundy et al., 2011
STTAT tool	Proposes a mechanism to assess pollutant risk and nature of receiving water so that mitigation (SUDS) can be suitably designed. Land use category includes	Local authorities, environmental protection agencies,	Piloted	Jefferies et al., 2009

	application to main (trunk / motorway) road junctions.	consultants		
SAGIS (source apportionment – GIS	Builds on the SIM-CAT tool River source apportionment model by including diffuse pollution; used to identify and quantify sources of pollution and to predict the impacts of applying mitigation measures in order to meet WFD expectations for water quality	Local authorities, environmental protection agencies, consultants	Piloted	UKWIR, 2012
Development of unit area loadings linked to land use type	A simple modelling approach to identify and quantify unit area pollution loads (UALs) associated with differing urban land uses on a catchment scale. Development of predictive approaches for hazard assessment and locating mitigating technologies	Local authorities, environmental protection agencies, consultants	Piloted	Ellis and Revitt, 2008.
Substance flow analysis	An evaluation of the movement of a substance within a defined system including identification and quantification of inflows, stocks and outflows (e.g. exports and environmental emissions)	Local authorities, environmental protection agencies, consultants	Established	Bjorklund et. al., 2011
Mapping diffuse pollutant sources and pathways	Development of a GIS-model to map small-area basin-wide loadings of a range of 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.	Local authorities, environmental protection agencies, highways agencies, consultants	Piloted	Mitchell, 2005.
Aberdeen National Soil Inventory Database for Scotland	Chemical quality data for rural soils collected at a scale of 1 per 10 km.	Local authorities, environmental protection agencies, highways agencies, consultants	Established	The James Hutton Institute (2013a)
National Waters Inventory for Scotland	Chemical quality data for surface waters and groundwater at selected monitoring sites across Scotland.	Local authorities, environmental protection	Established	The James Hutton Institute (2013b)

		agencies, highways agencies, consultants		
SEPA Scottish Pollutant Release Inventory	A database of annual mass releases of specified pollutants to air, water and land from SEPA regulated industrial sites.	Local authorities, environmental protection agencies, highways agencies, consultants	Established	SEPA, 2010
DoE Industry Profiles	Provides information on the types of chemical substances and waste associated with individual industries with regard to likely contamination.	Local authorities, environmental protection agencies, highways agencies, consultants	Established	EA, 2013
BGS Soil Chemistry for Environmental Assessments database:	Estimated ambient background concentrations for the soils of Great Britain as well as locations and concentrations (mg kg-1) of As, Cd, Cr, Ni and Pb in urban surface soil samples.	Local authorities, regulators, developers and the environmental consultancy industry	Established	BGS (undated c)
Product databases	E.g. >10 years worth of studies by the Danish EPA to identify chemical substances in a number of consumer products, such as toys, cosmetics, clothes, furniture etc.	Local authorities, environmental protection agencies, consultants	Established	Danish EPA, 2008
Chemical databases	E.g. TOXNET – access to Databases on toxicology, hazardous chemicals, environmental health, and toxic releases.	Local authorities, environmental protection agencies, consultants	Established	US HSDB, 2008.
European Pollutant Release and Transfer Register (E-PRTR)	The *E-PRTR* is a Europe-wide register that provides data on the amount of 91 pollutants released to air, water and land as well as off-site transfers of waste. Some	Local authorities, environmental protection agencies,	Established	E-PRTR, 2008.

	information on releases from diffuse sources is also available.	consultants		
NOSE-P (Nomenclature for sources of emissions - processes)	A standard statistical classification for industrial sources of emissions covering emissions and discharges to land, water and air.	Environmental protection agencies, consultants	Established	EEA (undated)
EU Risk Assessment Reports	Detailed risk assessments identifying the sources and impacts of a range of substances as required under EU risk assessment regulations related to new notified substances, existing substances and the placing of biocidal products on the market.	Local authorities, environmental protection agencies, consultants	Established	ECHA (undated).

Appendix 2 Overview of current SEPA thinking on the sources, impact and mitigation of urban diffuse pollution (taken from SEPA, undated)

Diffuse pollution from urban areas includes the following pollutants:

- Metals, oil and other hydrocarbons such as polyaromatic hydrocarbons (PAHs) which are associated with hydrocarbon spills and especially with the combustion of hydrocarbons. These coatriver beds with a toxic film which kills invertebrates and fish.
- Herbicides used to control weeds along roadsides and pavements, and spillages of domestic pesticides kill plantsin rivers.
- Domestic sewage which is mistakenly and/or illegally connected to the surface waterdrainage piped system instead of the foul drain, and therefore is conveyed directly to the nearest watercourse withouttreatment. The result is bacterial contamination and lowoxygen levels caused by the breakdown of organic matter.

Diffuse pollution from urban development has been identified as a significant issue on rivers and coastal water bodies (see Table A2.1). The impacts of urban run-off on groundwater are not well understood as there are no groundwater monitoring sites under urban areas. It is currently thought that most pollutants from urban areas adhere rapidly to particles and willtherefore be held within the soil.

Table A 2.1 Extent of the impact of urban diffuse pollution in the Scotland river basin district

Category	Impacts more than 15% length/ 20% area of 'at risk' water bodies	Length/area impacted	Number of water bodies
River	✔	1,044 km	88
Loch	✘	1 km^2	2
Transitional	✘	77 km^2	4
Coastal	✔	98 km^2	2
Groundwater	✘	-	-

An overview of the current urban diffuse pollution mitigation measures (and additional measures which could be put in place) is given in Table A2.2 (below).

Table A 2.2 Measures to address the impact of diffuse pollution from urban areas

What are we already doing about this?	
Regulation	• Local authority development plans require SUDS • Local authority development control enforces the requirements for SUDS • General Binding Rule under Controlled Activities Regulations (CAR) requires all new surface water discharges to be treated by SUDS
Economics	• Scottish Executive is to develop a scheme of drainage charges based on the amount of impermeable area draining to sewer • Scottish Water is provided with funds under Quality and Standards to retrofit SUDS to surface water systems in industrial estates
Advice	• Scottish Water's technical manual specifies design requirements for SUDS
What additional measures could we put in place?	
Regulation	• Promote source control of polluted road drainage before its discharge into the public drainage system
Advice	• Promote the development of integrated surface water management planning in major urban areas • Pollution-reducing campaigns involving the National Advisory Group and Area Advisory groups

Appendix 3 Urban diffuse pollutant data: sources and loads

Overview of data from the literature identifying sources and loads of pollutants associated with a range of urban land-use activities and processes.

Table A 3. 1 Overview of metal concentrations determined in brake linings, brake dust and passenger car tyre treads (mg kg^{-1})

Metal	Car brake linings	Car brake dust	Passenger car tyre treads
As[1]	<2-18	<2-11	-
Cd[1]	<1-41.4	<0.06-2.6	<0.05-2.6
Cr[1]	<10-411	135-1320	<1-30
Cu[1]	11-234,000	70-39,400	1-490
Ni[1]	3.6-660	80-730	<1-50
Pb[1]	1.3-119,000	4-1,290	1-160
Sb[1]	0.07-201	4-16,900	<0.2-0.9
Zn[1]	25-188,000	120-27,300	430-9640
Cu[2]	52,100-119,000		1.8
Zn[2]	7200-28,800		10,000
Pb[2]	9,050-18700		6.3
Cr[2]	73-151		
Ni[2]	70-182		
Cd[2]			2.6

Key: [1] = taken from review by Thorpe and Harrison, 2008; [2] = taken from Sorme, 2003

Table A 3. 2 Combined concentrations of 16 PAHs in street dusts from sites with different characteristics and land uses.

Land use	Characteristics of site	Total PAH concentration (µg/g)
Non-Ferrous industrial site	Zn + traffic	69.32
	Non-ferrous	11.84
	Zn + rail road	184.03
Petrochemical industrial site	Refineries	45.53
	Petrochemical	73.32
	Terephthalate	49.15
Heavily trafficked	Highway	154.64
	City centre	67.15
	Riverside	53.76
Downtown area	City hall	52.45
	Old downtown	245.12
Residential	Urban	19.69
	Industrial	68.73
	Newly developed	48.83

Table A 3. 3 Concentrations of selected hydrocarbons in urban street dusts, lubricating oils, tyres, asphalt and exhaust emissions (Mostafa et al., 2009)

Source	ΣPAHs (ng/g)[1]	Σselect PAHs (ng/g)[2]
Residential street	32	3.2
Residential street	35	4.2
Residential street	27	3.0
Residential street	76	11
Heavily trafficked street	304	180
Heavily trafficked street	320	205
Heavily trafficked street	379	170
Heavily trafficked street	295	144
Heavily trafficked street	283	124
Fresh lube oil	2926	63
Used lube oil	1428	467
Asphalt	1596	420
Auto exhaust	1476	564
Tyre particles	364	225

Key: [1] = sum of the concentrations of Phenanthrene, C1-fluoranthene-pyrenes, Anthracene, Benz[a]anthracene, 3-Methylphenanthrene, Chrysene, 2-Methylphenanthrene, C1 chrysenes, 9-Methylphenanthrene, C2 chrysenes, 1-Methylphenanthrene, C3 chrysenes, C2 phenanthrenes–anthracenes, C4 chrysenes, C3 phenanthrenes–anthracenes, Benzo[b]fluoranthene, C4 phenanthrenes–anthracenes, Benzo[k]fluoranthene, Dibenzothiophene, Benzo[e]pyrene, C1 dibenzothiophenes, Benzo[a]pyrene, C2 dibenzothiophenes, Perylene, C3 dibenzothiophenes, 3 Indeno[1,2,3-cd]pyrene, Fluoranthene, Dibenz[ah]anthracene, Pyrene and Benzo[ghi]perylene. [2] = sum of the concentrations of pyrene, fluoranthene, benz[a]anthracene, chrysene, benzofluoranthenes, benzopyrenes, indeno[1,2,3-cd]pyrene, and benzo[ghi]perylene.

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