PERSISTENT POLLUTANTS URBAN RIVERS SEDIMENT SURVEY: IMPLICATIONS FOR POLLUTION CONTROL

Wilson C[1], Clarke R[1], D'Arcy BJ[1], Heal KV[2] and Wright PW[1]

[1] *Scottish Environment Protection Agency, 7 Whitefriars Crescent, Perth, PH2 0PA, UK. Email brian.darcy@sepa.org.uk*

[2] *University of Edinburgh, School of GeoSciences. k.heal@ed.ac.uk*

ABSTRACT
The impacts of diffuse urban sources of pollution on watercourses are quantified. A survey of nine urban streams in Scotland for persistent pollutants in stream sediments is described, together with sediments from SUDS ponds. Determinands reported are: PAHs, total hydrocarbons, and toxic metals (As, Zn, Ni, Pb, Cu, Cr, Cd). Results highlight hydrocarbons as a major urban pollutant, and show significant sediment contamination by toxic metals. The metals that occurred in the highest concentrations varied across the nine streams, but Pb, Cr, Ni, Zn and Cu most frequently present exceeded sediment quality standards. The pattern of contamination by PAHs suggested that pyrolytic sources were more ubiquitous and present in greater quantities than oil spill sources in these urban catchments. Exceptions were the sites below industrial estates. The findings indicate that four levels of activity will be needed to control urban diffuse sources of pollution: reductions in quantities of toxic pollutants used by manufacturers in the motor and construction industries; housekeeping measures to minimise storage and handling risks for oil and chemicals; public engagement to minimise polluting activities such as dumping oil and chemicals, and private car use; use of SUDS technology, including retro-fits in the worst affected urban areas.

KEY WORDS diffuse pollution, PAHs, toxic metals, hydrocarbons, sediment, SUDS, urban runoff.

INTRODUCTION
In Scotland 500 km of urban watercourse are downgraded by diffuse pollution from urban sources (SEPA 2002). The impact of contaminated runoff in urban areas is evident from low scores for field biological assessments in urban streams. However the sources of pollution are difficult to identify since there are no known major point sources, such as industrial effluent or sewage works discharges, that can be implicated. Under the EU Water Framework Directive, it will be required by 2004 to characterize pressures and impacts on the water environment and a better understanding of the causes and characteristics of urban pollution is needed. Concerns about toxic metals and hydrocarbons (D'Arcy *et al*. 2000, Mitchell *et al*. 2001) that are transported predominantly with particulates, suggested that a survey of urban stream sediments offered the best prospect of characterizing urban diffuse pollution.

THE SCOTTISH URBAN RIVERS SURVEY
In 2002, a survey was undertaken of nine streams across Scotland, primarily receiving runoff from urban areas. Watercourses with known sewage or industrial effluent inputs were ruled out of the study, so that contamination from diffuse sources would predominate. Sediment was sampled at three points along each watercourse, with the aim that the first would be a cleaner upstream site. In practice, several of the streams originated from oily runoff from a motorway (e.g. Lyne Burn), or from a culvert below an industrial estate (e.g. Caw and East Tullos Burns). The test sites are listed in Table 1, along with the classification of the river stretch (class A is the best and class D the worst quality). Concentrations of toxic metals, hydrocarbons and PAHs were measured by standard methods in all sediment samples. Analysis details are reported elsewhere, together with consideration of the implications for monitoring diffuse urban sources of pollution (Wilson and Clarke 2002).

Summary results are shown in Figures 1-3. Hydrocarbons were consistently the most severe type of contamination, although different toxic metals were prominent in the various watercourses. Among the toxic metals, zinc and nickel were most often found in concentrations exceeding both the UK ICRCL Threshold Concentrations (ICRCL, 1987) and Ontario Provincial Sediment Quality Guidelines (Ontario Ministry of Environment, 1993). Aquatic sediments containing these concentrations are considered heavily polluted and likely to affect the health of sediment-dwelling organisms.

High levels of sediment contamination were measured: if dredged, sediment from four of the nine streams would be classed as special waste in the UK because of the high hydrocarbon content. Sediments containing contaminant concentrations in excess of recognized threshold levels are shown in Table 2. Many of the metals found are associated with road run-off, specifically from tyre and brake lining wear and combustion of lubricating oils (Makepeace *et al*. 1995). Other sources of these metals in the urban environment include paints and metal surfaces, and particular industries on industrial estates

Table 1. Characteristics of the urban river study sites (BMWP scores are biological indications of water quality; the higher the numerical value the better the quality (Biological Monitoring Working Party 1978))

Site	BMWP score	Classification	Site	BMWP score	Classification
East Tullos 1	-	-	Dedridge Burn 1	26	C
East Tullos 2	-	C	Dedridge Burn 2	31	C**
East Tullos 3	-	C	Dedridge Burn 3	22	NC
Town Loch 1	-	-	Findon Burn 1	-	A2
Town Loch 2	-	-	Findon Burn 2	25	D
Town Loch 3	-	B	Findon Burn 3	-	-
Red Burn 1	-	C	Kittoch Water 1	-	C
Red Burn 2	52	B***	Kittoch Water 2	37	C
Red Burn 3	53	B	Kittoch Water 3	64	C
Lyne Burn 1	-	C	White Cart Water 1	67	C
Lyne Burn 2	-	C	White Cart Water 2	100	B
Lyne Burn 3	25	C*		* Data from November 1997	
Caw Burn 1	-	C		** Data from April 1999	
Caw Burn 2	34	C		*** Data from November 1998	
Caw Burn 3	48	C		NC – Not classified	

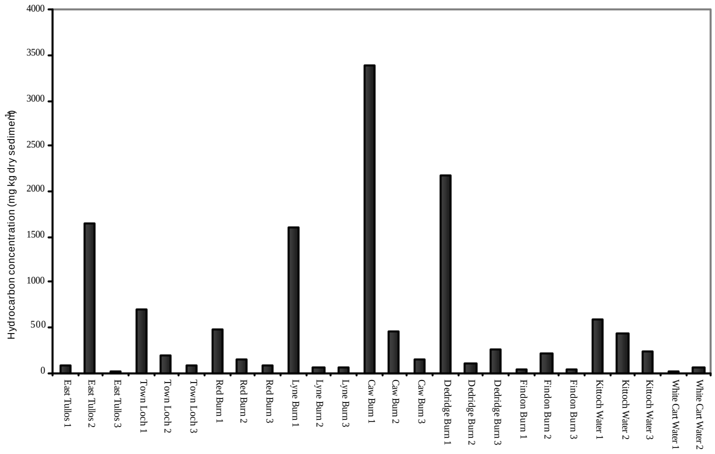

Figure 1. Total Hydrocarbon Concentration

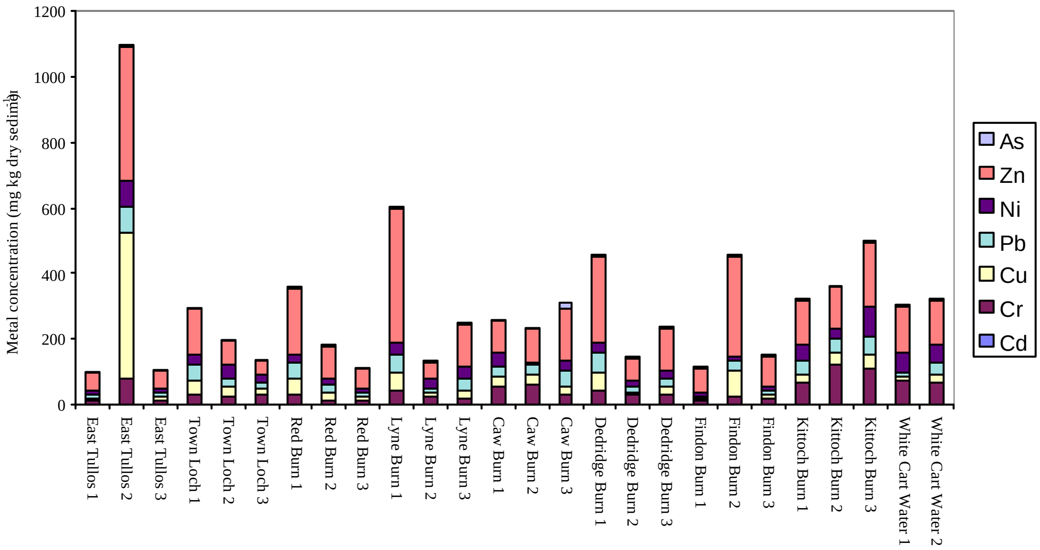

Figure 2. Toxic Metal Contamination

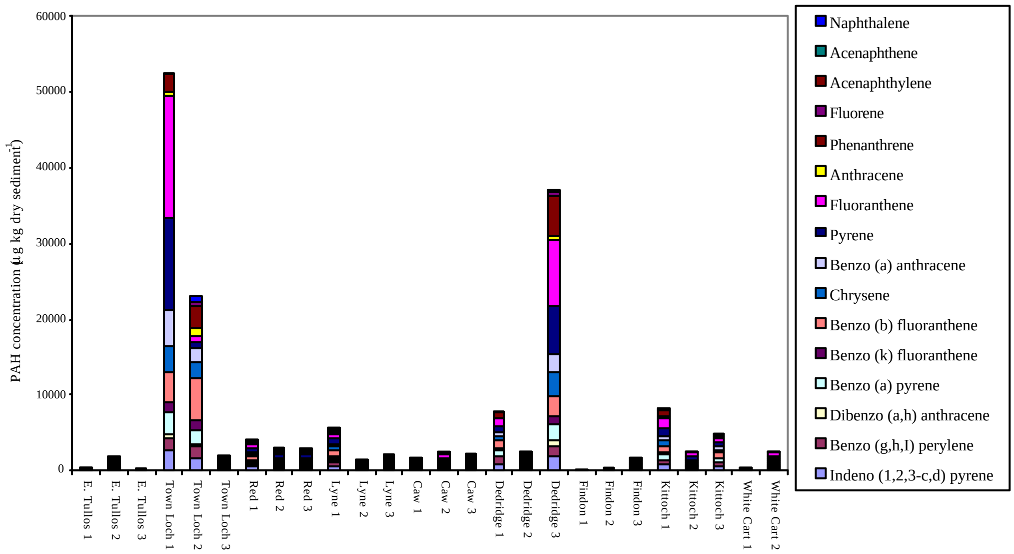

Figure 3. Total PAH Contamination

Table 2. Sites with sediment contamination exceeding ICRCL and/or Ontario Provincial Sediment Quality Guidelines Severe Effect Levels, plus Special Waste Regulations.

Site	Determinand	ICRCL Lower Threshold Concentration (mg kg^{-1})	Ontario Provincial Sediment Quality Guidelines -Severe (mg kg^{-1})	Standard Exceeded	Concentration (mg kg^{-1})
East Tullos 2	Copper Nickel Zinc	130 70 300	110 75 820	Both Both ICRCL	440.6 80.9 407.0
Kittoch Water 3	Nickel	70	75	Both	192.8
Lyne Burn 1	Zinc	300	820	ICRCL	411.7
Findon Burn 2	Zinc	300	820	ICRCL	303.0
Caw Burn 3	Arsenic	10*	33	ICRCL	17.65
Town Loch 1	Total PAHs	50	-	ICRCL	52.5
Caw Burn 1	Total hydrocarbons	1000	-	Special Waste Regs (1996)	3382
Dedridge Burn 1	Total hydrocarbons	1000	-	Special Waste Regs (1996) UK	2175
East Tullos 2	Total hydrocarbons	1000	-	Special Waste Regs (1996) UK	1641
Lyne Burn 1	Total hydrocarbons	1000	-	Special Waste Regs (1996) UK	1603

* Threshold for domestic gardens and allotments.

The ratios of different PAHs can be used to infer the likely source of PAH contamination. For example, phenanthrene (P) and anthracene (A) are structural isomers, but anthracene originating from oil spills (petrogenic) degrades more rapidly than from combustion (pyrolytic) sources. This is not the case for phenanthrene. Therefore a low P/A ratio (<10) suggests that a greater proportion of the PAH contamination originates from pyrolytic sources. The ratio of chrysene (C) to benzo(a)anthracene (BaA) can be used in a similar manner. As chrysenic derivatives are more stable than benzanthrenic ones, a higher proportion of PAHs from combustion sources are benzanthrenic. Therefore, a C/BaA ratio <1 indicates that PAHs are derived mainly from pyrolytic sources (Wilson & Clarke 2002). The P/A and C/BaA ratios occurring in the stream sediment samples are shown in Fig. 4. They suggest that combustion sources were more ubiquitous and present in greater quantities than oil spill sources, i.e. motor vehicle engines and oil-fired boilers were more important sources of urban contamination than oil spills.

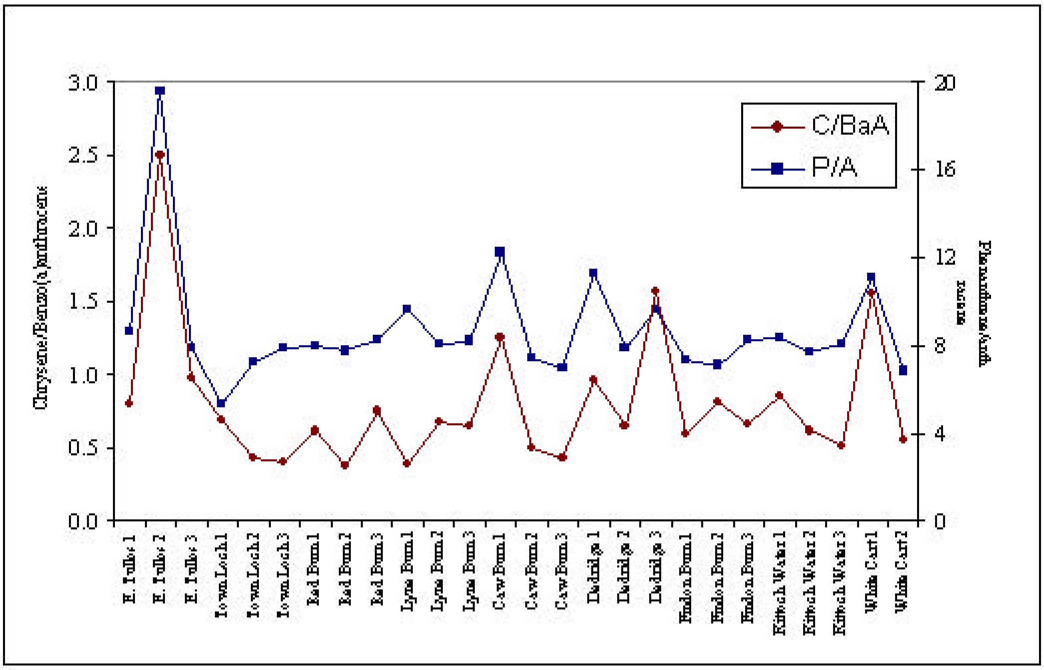

Figure 4. Presence of pyrolytic and petrogenic derived PAHs in Scottish urban watercourse sediments.

IMPLICATIONS FOR POLLUTION CONTROL

Intercepting persistent pollutants prior to discharge to receiving waters

Since urban drainage currently contains persistent pollutants, the retention of urban runoff in SUDS (Sustainable Urban Drainage Systems) to attenuate flood flows and improve water quality will result in the accumulation of pollutants within SUDS sediments. Table 3 summarises the results of analyses of sediments from five SUDS retention ponds in Central Scotland in 1999 and 2000. Sediment sampling procedures and analysis methods are described in Heal (2002). Claylands Pond was constructed in the 1970s as an agricultural pond and has been used as a SUDS since 1996, receiving runoff from a busy highway (48,000 vehicles per day) (McLean, 1998). The other SUDS were constructed in 1998 to receive runoff from roads, housing estates and retail outlets in a new urban development. Table 3 shows that sediment from Claylands Pond generally has higher metal concentrations than the other SUDS. This is probably caused by the heavier vehicle traffic near the Claylands site, resulting in the input of metals from the breakdown of tyres, brake pads, combustion of lubricating oils and corrosion of metal (Makepeace *et al*., 1995).

To assess the toxicity of the SUDS sediments to the aquatic environment, mean, minimum and maximum hydrocarbon and metal concentrations in sediment were compared with severe effect levels contained within the Ontario Provincial sediment quality guidelines. Table 3 shows that mean iron concentrations exceeded the severe effect level in Halbeath Pond, Linburn Pond and the Wetland and in some samples from Pond 7, although this may be due to the geochemistry of the geology and soils of the area. Some samples from Linburn Pond and Pond 7 exceeded the severe effect level for hydrocarbons. Although concentrations of pollutants in the SUDS sediments exceed background levels, the metal concentrations measured are not generally detrimental to aquatic life.

Comparison of mean, minimum and maximum metal concentrations with the UK ICRCL trigger values for contaminated land indicate the potential disposal routes for sediment excavated from SUDS ponds (e.g. spreading on land, landfill). Table 3 shows that trigger concentrations were only exceeded by some samples from Linburn Pond for nickel. Therefore, it appears that sediment from these SUDS could be disposed of by spreading on land at the moment. Alternative disposal routes may need to be considered for sediments from SUDS that have received polluted urban runoff (e.g. from heavily-trafficked areas) for many years. The levels of contamination that can be reached in urban watercourse sediments can be seen from the data presented in Table 2. It is fair to assume that these SUDS ponds will, after some years of operation, contain equivalent levels of contamination to these streams, as they are purpose built to receive similar, if not more polluting runoff. One of the major advantages of SUDS ponds is that contamination can hopefully be contained within a known area and managed in a less damaging way than if it were in the wider environment.

Table 3. Comparison of metal and hydrocarbons concentrations in SUDS sediments with standards for aquatic sediments/contaminated land
(All units mg kg^{-1} sediment dry weight except where indicated)

Metal	**Claylands**	HALBEATH	***Linburn***	**Pond 7**	WETLAND	Ontario Provincial sediment quality guidelines Severe effect level	UK ICRCL Threshold trigger concentration
Cd	0 (0-0)	0.09 (0-1.1)	0.08 (0-1.62)	0.06 (0-0.5)	0.03 (0-0.73)	10	15[a]
Cr	46.9 (27.7-59.7)	22.3 (7.5-44.0)	40.3 (14.2-109)	31.0 (17.5-47.6)	29.6 (9.5-50.7)	110	1000[a]
Cu	39.5 (19.8-56.6)	14.1 (9.0-22.3)	16.1 (8.1-25.1)	14.2 (8.4-24.0)	16.8 (4.6-46.8)	110	130[b]
Fe (%)	**11.3** **(5.46-14.8)**	**4.27** (2.59-**6.08**)	**4.32** (2.30-**8.78**)	3.93 (1.18-**7.39**)	**7.62** (2.19-**20.2**)	4	---
Ni	44.1 (28.1-53.9)	24.6 (10.8-60.6)	38.2 (11.8-**71.1**)	29.8 (13.3-47.8)	31.7 (7.72-43.6)	75	70[b]
Pb	38.8 (12.6-68.9)	13.2 (6.6-26.5)	18.5 (9.90-30.2)	15.6 (8.61-28.4)	15.2 (0-53.5)	250	2000[a]
Zn	118 (62.9-182)	47.2 (15.8-115)	78.2 (50.2-203)	66.0 (38.2-119)	76.0 (42.2-152)	820	300[b]
Hydrocarbons	N/A	89.2 (22.3-288)	523 (38.1-**1510**)	515 (38.4-**2430**)	171 (28.8-541)	1500	---
Number of samples	8	14	16	19	28	---	---

[a] proposed land use = parks, playing areas and open spaces
[b] any uses where plants grow
Values for each SUDS are means with range in brackets
Values in bold exceed aquatic sediment and/or contaminated land standards

Multiple approaches for abatement

Evidence of contamination by persistent pollutants suggests that a four part approach to controlling diffuse pollution is needed, of which SUDS can only ever be the final component:

- Reduce persistent pollutants at source (e.g. use in manufacture of tyres, motor vehicle brake linings and urban engineering infrastructure).
- Contain pollution risks by best practice for storage and handling of potential pollutants (e.g. in Scotland implement the long-awaited oil storage regulations originally permitted by the Control of Pollution act 1974).
- Modify human behaviour (e.g. reduce litter and uncontrolled burning of waste, waste oil and solvents dumping, municipal and private use of pesticides, use of private cars).
- Use passive treatment best management practice technology (SUDS), employing the treatment train approach.

Public support and education are needed to achieve improvements, e.g. involvement in local developments presents education opportunities. Education challenges include: local community support for changes in behaviour to minimize pollution loads; local community support for SUDS features; public pressure on manufacturers to engage with the environmental issues resulting from persistent pollutants derived from their products.

CONCLUSIONS

Urban stream sediments are heavily contaminated and it is likely that most of the contamination is from diffuse sources. Hydrocarbons were the most ubiquitous serious contaminant detected in sediments in a survey of Scottish urban rivers. Four of the nine urban streams surveyed were sufficiently contaminated that if their sediments were dredged they would be classified as special waste in the UK. A range of degrees of contamination by toxic metals was measured; in every watercourse at least two metals were present in concentrations exceeding the likely adverse impact standard of the Ontario state government. The pattem of contamination, by PAHs especially, suggested that road traffic and other sources of combustion are very important sources of stream sediment contamination. Effective control of urban diffuse pollution is likely to require: SUDS retro-fits, enforceable housekeeping regulations, traffic reduction, public support and awareness raising to curtail polluting practices.

REFERENCES

Biological Monitoring Working Party (1978) Final Report of the Biological Monitoring Working Party: Assessment and presentation of the Biological quality of rivers in Great Britain. London: Department of the Environment Water Data Unit

D'Arcy BJ, Ellis JB, Ferrier R, Jenkins A and Dils R (2000) Diffuse Pollution Impacts: the environmental and economic impacts of diffuse Pollution in the UK. CIWEM, London. ISBN number 1 870752 46 5

Heal, K.V. (2002). Sedimentation in SUDS ponds in Scotland. In: Sustainable Urban Drainage Systems, Scottish Hydraulics Study Group 14th Annual Seminar, Glasgow, March 2002.

ICRCL (1987) Guidance on the Assessment and Redevelopment of Contaminated Land, Guidance Note 59-83. Department of the Environment, London.

Makepeace, D.K., Smith, D.W. and Stanley, S.J. (1995) Urban stormwater quality: summary of contaminant data. Critical Reviews in Environmental Sci. & Technol., 25, 93-139.

McLean, N. (1998) The effectiveness of two SUDS ponds serving highway runoff. Unpublished MSc thesis, University of Abertay, Dundee.

Mitchell, G., Lockyer, J. and McDonald, A. (2001) Pollution hazard from urban nonpoint sources: a GIS-model to support strategic environmental planning in the UK. Technical Report, School of Geography, University of Leeds.

Ontario Ministry of Environment (1993) Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario. Ontario Ministry of the Environment.

SEPA (2002) The future of Scotland's Waters – Guiding Principles on the Technical Requirements of the Water Framework Directive. Scottish Environment Protection Agency, Stirling.

Wilson and Clarke (2002). Persistent Pollutants in Freshwater Sediments. Unpublished SEPA report for SEPA Diffuse Pollution Initiative. December 2002. Edited version available as DPI Report No. 7, from SEPA Diffuse Pollution initiative, Edinburgh.