Restoration challenges for urban rivers


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Abstract Urban sources account for significant quantities of important diffuse pollutants, and urban watercourses are typically badly polluted. As well as toxic metals, hydrocarbons including PAHs, and suspended matter, priority urban pollutants include faecal pathogens and nutrients. Can urban watercourses be restored by sufficient reductions in pollution loads? Case studies in the UK and Sweden provide insights and some grounds for optimism. A major trans-Atlantic review of the performance of best management practices (BMPs) is informing BMP planning. New approaches such as the maximisation of self-purification capacity in the receiving waters may also need to be developed, alongside BMPs at source. Other initiatives in Europe, USA and China, including collaborative projects, are trying to address the intractable issues such as persistent pollutants from transport and urban infrastructure. The challenge is daunting, but there are clear ways forward and future research needs are evident.

Keywords Best management practice; pollutants; urban water recourses

Introduction

Best management practices (BMPs) have been widely deployed to minimise pollution in runoff from urban areas; practical experience in Sweden and parts of the USA goes back decades (Schueler, 1992; Campbell et al., 2004). But how effective have they been in practice at preventing deteriorations in quality as catchments urbanise? And can the technology be successfully retrofitted to restore degraded urban watercourses?

The River Annan in SW Scotland is an example of development threatening a good quality river, with runs of salmon and sea trout, as well as native brown trout populations (SEPA, 2002). The upgrading of a trunk road, making the route the principal flow for road traffic into and out of Scotland, caused major concerns for the Annan, together with the development of a large industrial estate based around a timber processing business. A two-stage BMPs treatment train has been put in place and has successfully protected the Annan. Initial attenuation of pollutants is via source control filter drains alongside the motorway, fed directly by road runoff. A series of ponds or detention basins receive the outflows from the filter drains, providing further treatment prior to discharge to the river (McNeil, 2000).

The challenge of applying that technology to restore urban watercourses is daunting. There are some 500 km of rivers polluted by contaminated runoff in Scotland alone. Capital spending programmes are being agreed with public utilities to provide retrofit solutions to urban water problems.

Halmstad case study

Halmstad city (ca. 85,000 inhabitants) on the west coast of Sweden is an area where excessive nutrient loadings to coastal waters have been identified as an issue and
addressed by various means, including de-nitrification in treatment wetlands (Fleischer et al., 1994, 2001). The stream of Knebildstorp in the west of Halmstad, has a catchment area of ca. 500 ha, comprising mainly small industrial areas and the regional airport. Surveys between 1984 and 1992 found no fish. Stormwater runoff entered the stream at about 10 locations, and during 1991–92 all these points were addressed by a variety of BMPs including pond and wetland retrofits, and extended detention in grass and woodland areas. Trout and salmon parr returned to the stream. The pond/wetland features varied in size from 100 m² to 500 m² and costs for these measures were about £30 k in 1991–92. In 1996, pollution from the airport caused a further loss of fish populations and other life in the stream. New ponds (three in series) were provided to control hazardous stormwater from the airport. Once again fish returned. Currently an additional 50 ha new industrial area is being developed (total area of 31,000 m² and an average depth of 1 m).

In a partnership approach between landscape architects and engineers, a drainage master plan provides for a three-stage treatment train:

- Slowing the release of stormwater flows on the individual industrial sites
- Slowing stormwater flow along roads by a system of trenches with flat grass-slopes
- Storing water in a system of ponds

**BMP and SUDS technology**

There are a range of BMP techniques available for developers and for retrofit programmers to consider (USEPA, 1993; Campbell et al., 2004). In the SUDS concept the water quality function of SUDS is considered in conjunction with flood management issues for developments (Campbell et al., 2004).

A recent review of the performance data contained in an international BMPs database is informing BMP planning in the USA and UK (see Urbonas, 2004 in Appendix 2 of Campbell et al., 2004). Included in the review is the retention time for design of stormwater ponds and wetlands. The results from the USA database showed that:

- Discharges from ponds had an irreducible minimum level of TSS of 5–20 mg/l
- Ponds were largely effective in the level of treatment that could be provided as long as the pond volume was at least equal to the average annual storm
- The variability of the outfall pollutants concentrations was minimised by sizing it to two to three times the average annual storm depth
- Further retention time was only effective in reducing phosphorous concentrations (as expected from the original NURP project findings; USEPA, 1993)
- Influent concentration did not have a significant influence on outfall concentrations
- Sediment concentration was a reasonable surrogate for metals concentrations
- Vegetation did not contribute significantly to the treatment process in terms of pollutant uptake in the macrophytes

There was still a range of uncertainties that remained unanswered in the USA/UK study, and warranted further investigation, including factors affecting bacterial removal and nutrients. A key issue was continuing uncertainty about the depth/volume/shape relationship effect on water quality. In addition it was noted that traditional measurements of BOD, TSS, and metals needed to be augmented by hydrocarbons, DO, NH₃, PAHs and temperature to understand the effluent impact on receiving waters. Furthermore the importance of load per unit surface area should be added.

Some of these issues have been or are being addressed elsewhere. BMP ponds are typically designed as multiple structures, with sedimentation forebays prior to the main body of the pond, or followed by a secondary wetland area and final polishing pool in a detention system (e.g. Schueler et al., 1992). But aside from those issues, there has been little discussion in the literature as to whether a pond should be a single or multiple structure for achieving
treatment objectives. An innovative development in the UK has been to distribute the modular elements of a pond system around a site where space and other considerations made that an attractive option (Bray, 2001). Figure 1 indicates the effect of retention time on ammonia concentrations at stages through the pond series. It is a sequence of very small ponds, serving part of a motorway services area at Hopwood, England. The first pond receives extremely contaminated drainage from a small area; a much higher loading per unit area of pond surface than would be the case for a conventional two-stage pond system or a flow balancing lake serving the entire estate. That allows for different conditions to develop in the ponds, as is normal for example in waste stabilisation pond technology. Hence high ammonia concentrations develop in the first pond, in between storm events, but the water quality in the final pond in the series (serving as a balancing pond for cleaner roof water as well as polishing the outflow from the two upstream ponds) is excellent under all flow conditions, and provides for attractive amenity use and some wildlife interest.

A multiple-stage treatment pond sequence would be appropriate for high levels of contamination, where the poor quality (anaerobic stage) pond would not be close to high amenity areas. Industrial and commercial sites, and probably some urban catchments in developing countries where higher levels of organic contamination occur than are characteristic in the UK, may benefit from such an approach. For high contamination hotspots in a catchment, where a foul sewer connection is unavailable or undesirable, it may be better however, to use dry passive treatment systems for urban runoff, such as grass filter strips or detention basins. That has also been done at Hopwood, a filter strip treating the runoff from a lorry park. In other circumstances it is perhaps a smart way of fitting treatment systems into restricted spaces within a development.

Analysis based on the assumption of plug flow for the Hopwood pond system indicated the fact that actual retention times vary from hours to weeks through the year, and that there is a need to consider the importance of the season in minimising receiving water impact.

Another consideration in sizing treatment ponds is the risk of pollution and the likely consequences. For an industrial estate, pollution incidents could wipe out a treatment pond. There is merit therefore, in selecting a retention pond design (rather than a detention pond) to provide greater dilution for inevitable incidents. Where the headwaters of

![Figure 1](https://iwaponline.com/wst/article-pdf/55/3/1/430868/1.pdf)

**Figure 1** Water quality performance of three ponds in series, Hopwood Park, UK. ≤0.6 mg/l is good quality in river classification scheme (from Woods Ballard et al., 2005)
a watercourse are urbanised, the BMPs have to be able to produce river water quality from the catchment they serve. Again, a treatment train is essential to deliver that, but it is good risk management to select retention pond size treatment lakes as the regional drainage facility to achieve quality objectives, at least until demonstrably effective and implementable alternative strategies are available.

**What are the most important urban pollutants?**

A lot of evidence indicates that pollutants such as oil, PAHs, toxic metals, nutrients, and faecal indicator organisms, as well as suspended matter, are the most important urban pollutants (D’Arcy *et al.*, 2000; Choe *et al.*, 2002; Mitchell, 2005; O’Keefe *et al.*, 2005; Wilson *et al.*, 2005). Pesticides are another major pollutant class and Jongbloed *et al.* (2004) showed the pre-eminence of municipalities (in the weed-obsessed western world at least), rather than agriculture, as sources of herbicides.

In China research by Yin (personal communication) in combined sewer catchments found that diffuse surface sources predominated for N and P. These findings were probably explained by the extent and frequency of streetside cooking and vegetable/fruit vending in Chinese culture. Dust and roadside litter contributed to the high suspended solids values found for surface sources, as well as probably contributing to the nutrient loads. Any moves to separate sewers or use SUDS technology for countries with similar urban ways of life will have to take these factors into consideration. Yin reports event mean concentration (EMC) values for TP ranging from 0.77 mg/l to 1.01 mg/l – which compares with an average of 1.96 reported by Choe *et al.* (2002) from Korea.

Even in Europe, urban areas contribute significant nutrient loadings: 8.18 kg/ha/yr TN and 1.24 kg/ha/yr TP reported by Mitchell (2005), probably related to a variety of factors including use of phosphate detergents, fertilisation of gardens and parkland, topsoil disturbance during construction, foul drainage, wrong connections into surface water systems, and perhaps bird roosts and pets/feral animals. There is far less scope for locking up nutrients in soil and vegetation in urban environments. For two study catchments in Yorkshire, UK, higher N and P losses per unit area were measured from the urban areas (residential) than from the nearby rural catchment. Neil *et al.* (2000) reported annual N and P loss estimates respectively of 36.73 kg/ha/yr and 3.80 kg/ha/yr for the Aire basin (very urban), which can be compared with 12.94 and 0.59 kg/ha/yr for the nearby rural Wharfe basin.

For a toxic and ubiquitous urban pollutant such as oil, the estimates of oil contamination in runoff from urban areas (13.22 kg/ha/yr in Mitchell, 2005) allow a comparison with more familiar sources: for the West Yorkshire region in England alone, the equivalent of 17 full road tankers of oil per year is lost to the urban surface water drainage system. PAHs are also toxic and ubiquitous in the urban environment. Wilson *et al.* (2005) showed that combustion sources were pre-eminent in sediments from several urban streams in Scotland, and in the Netherlands diesel vehicles are subject to ever tighter controls (driven by air quality public health concerns) including subsidies for PAH catalytic converters (Hellings, personal communication).

**Land-use and issues of scale for pollution risks**

Working with a diffuse pollution database comprising 160 studies, reporting data from 672 urban catchments, flow weighted concentrations for 18 pollutants were published by Mitchell (2005). Information from that database is predominantly based on Northern European studies, for which sufficient data was available to allow statistically defensible resolution by land-use class. Roads are a major source of pollutants, but for nutrients, residential areas produce higher concentrations.
Are there step changes in environmental risk between a village and a town as local air quality, and rain (scavenging pollutants such as PAHs from roofs as well as roads and other surfaces), becomes a significant contributing factor? Analysis of the urban EMC database suggests not, but further work is currently progressing using ecological data, for which it appears there is a gradation in quality from pristine through to heavily urbanised, with a parallel decline in ecological scores.

**Degradation of key urban pollutants**

Even if cleaner technology and practices can be developed in parallel with such efforts it is rational to try and optimise the choice of BMP facilities for degradation of the key pollutants if possible. Wischmann and Steinhart (1997), indicated that for the degradation of PAHs over time there was little degradation over the initial 40 days, with loss of PAHs occurring significantly between 60–180 days. It seems clear therefore that simply extending the residence time in a deep pond from one week (a detention pond) to three to four weeks (a retention pond as designed for nutrient management), is not going to have any benefit for degradation of PAHs. And those results are from microcosms amended with compost (soil/compost mixture); degradation rates *in situ* are likely to be even slower, especially for the higher molecular weight more toxic compounds. Therefore, the introduction of oil and PAHs to treatment ponds in significant quantities does not seem sensible. They will settle out, adsorbed on silt, but are unlikely to break down. Treatment train measures that expose pollutants in runoff to sunlight (UV and also temperature effects) and aerobic soil conditions seem most appropriate for urban runoff. This means grass filter strips especially, and other source control systems such as swales and filter drains are important. There is evidence that specialised microbes develop in response to regular contamination, increasing the efficacy of the treatment system, but more research on the fate of key pollutants is needed, especially in soil systems, and in relation to groundwater risks associated with some BMP types in free draining soils. Clearly there are implications for selection of SUDS/BMPs; underpinning the importance of matching the type of technology with the risks, and of the treatment train approach (Bray (2001), and treatment train discussion in Campbell et al., 2004). These ideas have been developed further by Scholes et al. (2005), who are developing a scoring system for selecting BMPs.

With regard to treatment options for diffuse pollution, it makes sense to conserve the self-purification capacity of the natural drainage system: the rivers, lakes and streams and especially associated flood plains and wetlands. For urbanising headwaters and small urban streams, new technology needs to be developed to enhance the self-purification capacity of the watercourse, to address the levels of diffuse pollution that BMP retrofits are unlikely to control. Spilling high flows onto marginal riparian land (recreating marshes) where suspended pollutants can be left to degrade as storm flows drop, is likely to be much more practical than in-river treatment lakes or ponds.

**Non-BMP initiatives**

Initiatives to try and reduce the pollution load at source, especially for persistent pollutants such as toxic metals and high molecular weight PAHs, are essential. Significant work has been done over the past decade looking at roads as a source of these pollutants. Investigations in the Netherlands have highlighted the importance of the construction industry, and latterly in the UK the Environmental Agency has identified street structures such as galvanised hand rails, crash barriers, lampposts and manhole covers as significant sources. But what about the motor vehicles using the roads? There is evidence (e.g. Davis et al., 2001), but as yet inadequately collated and related to major exemplar water bodies, to build a safe case to present to the various contributing sectors to then press for prevention
actions. A joint UK/China/USA assessment of the importance of motor vehicles as sources of persistent pollutants began in 2005. Interim measures for traffic sources might include reductions in traffic volume; how to estimate by what amount local authorities need to reduce traffic volume in order to protect water quality? This is a research need, but obviously should be addressed as part of a project looking in an integrated way at all environmental impacts of the motor car. Non-BMP solutions such as banning lead in petrol and reducing PAH pollution from road surfacing materials exemplify important options; regulation in one form or another is important (D’Arcy and Wright, 2004).

Conclusions
BMPs are rightly recognised as essential. Even widespread application of the newer SUDS concept is not on its own going to restore urban river quality. Still more radical initiatives are required, as outlined in this paper, including engagement with the construction and motor vehicle manufacturing industries, as well as taking a more integrated environmental approach to urban planning. The latter should include contaminated land risks, and water aspects too, of traffic volume reduction, as well as the more obvious congestion and air quality considerations. But new modelling tools are required. Research needs, also include better understanding of the fate of key pollutants in BMP facilities, and the urban environment generally. The importance of soil and sunlight has a bearing on BMP selection and the case for a treatment train approach. The efficacy and cost of public and industrial sector education also needs to be quantified and compared with simple regulatory approaches and economic drivers. Nevertheless, there are already some good case studies that do give cause for optimism, and a lot of good work is underway, in research terms and in establishing additional demonstration sites.

Acknowledgements
The assistance of Alison Dick, Neil Mclean, Fiona Napier, Chris Jefferies and Chongqing Yin is gratefully acknowledged.

References


