THE DEVELOPMENT OF A STRATEGIC APPROACH TO MANAGING DIFFUSE POLLUTION

BY

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I certify that this is the true and accurate version of the thesis approved by the examiners

Signed………………………………… **Date**…*11th March 2013*……

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PREFACE

Basis of Research

This thesis is based on papers published from a programme of work initiated in 1993, and first publications in 1995. Fifteen papers published over the subsequent period form the basis of the thesis and represent milestones in the development of a strategy to manage diffuse sources of pollution. The most recent paper was given in 2011. Twelve of those papers have been published in one or other of four internationally recognised, peer reviewed journals;

a) *Water Science and Technology*
b) *Science of The Total Environment*
c) *CIWEM Journal*
d) *Desalination*

The remaining three are also peer reviewed publications, but they are conference proceedings rather than peer reviewed mainstream journals. All are available as reference books, with ISBN numbers. They comprise two papers from the initial phase of the investigation, plus one on the regulatory regime developed as part of the strategy for managing diffuse sources. The conferences in which they were presented have or had a good reputation as influential opportunities to learn about new ideas and cutting edge projects or investigations and reviews. They are included because of the importance of their content especially at the outset of the period of research. Table 1.1 shows the journals and other publications on which this thesis is based.

Table 1 Journals and conference proceedings in which key papers have been published (see Appendix 1 for key and full references).

Journal	No. of papers published	Comments
Water Science & Technology	8	
Science of The Total Environment	1	
CIWEM Journal & predecessor	2	
Desalination	1	
Proceedings of biennial SAC/SEPA conferences, 1995-2006	2	Principal UK agricultural/environmental research conference
Proceedings of the Standing Conference on Stormwater Source Control	1	At outset of this research, the principal urban drainage forum in UK
Total number of papers	15	

Thirty eight co-authors were involved to varying extents in the selected published papers. Only by doing that was it possible to initiate and progress several projects and lines of investigation simultaneously and continue them in parallel, the aim being the development and implementation of a strategic approach to managing diffuse pollution. The variety of projects initiated was needed to gain a significant insight into the issues, identifying commonalities. Everything from storm event phenomena being important in both urban and rural catchments, to the similar regulatory approaches in both urban and rural contexts has been addressed. An introduction to diffuse pollution and how it can be controlled is given in Chapter 1.

Introduction to the Reviewed Papers: From Evidence to Solutions

The selected papers each represent key steps in the development of a coherent diffuse pollution management strategy that encompasses both rural and urban sources, and management techniques and technology. The papers are grouped in three Chapters (2, 3 and 4). The three themes overlapped in time as more knowledge identified more research needs in each category. The initial investigation and research effort was to present the problems and the technology developed for management of them (largely in USA) to the UK; quite how much research would be needed to take those ideas into UK practice was not appreciated at the outset. Consequently, at any one point in time, it was often appropriate to mention more than one of the specific main focus issues in any given paper. They have been grouped as follows to allow an appreciation of these major important research strands:

a) Problem definition (Chapter 2)

b) Abatement measures (Chapter 3)

c) Bringing measures into routine use (Chapter 4)

This thesis documents those investigations as above, with reference to the milestone papers published. It also provides a synthesis of knowledge and insights gained by that body of work, thereby contributing to research in this field, as well as being useful for policy makers and practitioners trying to reduce pollution.

In chapters 2, 3, 4, Figures, Tables and page numbers quoted from the key published papers in the thesis are underlined to identify important aspects of the original papers, and the full papers to which they refer are given in Appendix 1.

ACKNOWLEDGEMENTS

The contributions of many individuals to the outputs described in this thesis are gratefully acknowledged; co-authors, co-organisers of conferences and seminars, research funders, and colleagues in FRPB and then in SEPA, too numerous to specify all. All 38 co-authors from the selected publications are however listed in Appendix 2, and many key partners in projects and programmes are specified in Appendix 3.

The work undertaken for this thesis could not have been undertaken without the support and encouragement of the late Willie Halcrow, formerly Director of FRPB and then SEPA, and Andy Griffiths and Tricia Henton (also in SEPA) - organisational leaders who had the vision and management skills to recognise a business need and an environmental challenge, as well as the judgement to back a programme of necessary work to meet those needs. Similarly, the Scottish Executive (later the Scottish Government) has consistently provided far sighted leadership on diffuse pollution, notably Phil Gilmour on diffuse sources of FIOs, and Francis Brewis and Ian Speirs who supported this work across the spectrum of impacts from the outset, with funding and encouragement. Others amongst their colleagues were also at different times variously involved and always supportive, as well as a succession of excellent rural sector officials at national and local levels.

Sector engagement with agriculture and forestry was hugely helped by the SAC/SEPA biennial conference partnership, led initially by Tony Petchey and

Alan Frost for SAC, then Dave Merrilees, Karen Crighton and other colleagues.

For the urban aspects the research efforts would have been much more difficult without the interest and active initiative of academics in the Scottish Universities SUDS research partnerships in their various forms (usually led by Professor Chris Jefferies at the University of Abertay Dundee; putting in the time and effort to make things happen).

I wish to also acknowledge the importance for this work from the outset, of the inspirational leadership and encouragement of some key individuals nationally and internationally: Alan Frost, Phil Haygarth, Ralph Heath, Dave Kay, Chris Pratt, Larry Roesner, Tom Schueler, Peter Stahre, Dov Weitman and, most of all, Vladimir Novotny, the founder of the international diffuse pollution specialist group of IWA. This thesis is dedicated to the people who can recognise an issue and engage with it with enthusiasm, intelligence and drive to achieve good outcomes.

Finally, thanks are due to Professor Chris Jefferies at the University of Abertay for his unceasing encouragement, guidance and optimism in relation to this degree. The welcome and help of the UWTC team is also gratefully noted, not just during the period of registration for the PhD, but over the years of antecedent joint investigations. Leanne Gallagher has been wonderful helping with missing references, formatting issues, accessing university systems and keeping the administration issues under control.

ABSTRACT

This thesis explores how the concept of diffuse pollution, as developed by Novotny and Olem (1994), could usefully be applied in the UK and especially Scotland, to add insights and identify practical approaches to resolve chronic pollution problems. Investigations are reported that characterise the nature of the diffuse pollution problems facing the UK, in rural and urban contexts. Pollutants considered included suspended solids, nutrients, faecal indicator organisms, toxic metals and organic pollutants. Key characterisation aspects included the investigation of how concentration (not just load) varies with flow in diffuse pollution impacted watercourses. It was repeatedly found that higher concentrations occurred in high flows than in low flow conditions, in diffuse source impacted watercourses. Establishing evidence for that diffuse pollution characteristic led to innovative approaches to resolving aspects of the diffuse pollution problems. Key sectors investigated included arable and livestock systems in agriculture, urban development, industrial estates and transport. Physical measures to address the sources of diffuse pollutants were focused on best management practices (BMPs), following the concept developed in the USA. The consequent development of the SUDS concept for the built environment in the UK allowed for the incorporation of quantity and amenity considerations in stormwater management. Other developments beyond the initial (USEPA 1993) BMPs concept included looking at enhancing self-purification capacity for small watercourses. Finally, the strategy development is completed by examining means of bringing the control measures into routine practice.

LIST OF ABBREVIATIONS

BMPs Best Management Practices: Measures an agency may require to control diffuse pollution. They include structural and non-structural controls and procedures.

CAR (Controlled Activities) (Scotland) Regulations 2005. The CAR regulatory regime came into force on 1st April 2006, and included the first explicit diffuse pollution and SUDS requirements in the UK.

CIWEM Chartered Institution for Water and Environmental Management, headquarters and registered office 15 St John Street, London.

CFW Constructed Farm Wetland: artificial wetland constructed to provide sufficient retention time for biodegradation of pollutants in steading drainage, to approximate to river quality.

COPA Control of Pollution Act 1974.

CSO Combined sewer overflow: an overflow point on a combined sewer that releases excess flow in wet weather.

DoENI (Department of Environment, Northern Ireland). Duties include delivering environmental regulation in Northern Ireland.

EA The Environment Agency: the regulatory agency with responsibility for England and Wales, since 1st April 1996.

EU European Union

FIOs Faecal Indicator Organisms

FRPB Forth River Purification Board; one of the pre-SEPA catchment based regulators of the water environment in Scotland.

FWAG Farming and Wildlife Advisory Group

GBRs General Binding Rules.

IAWQ former International Association on Water Quality, a predecessor of IWA.

IWA International Water Association, Headquarters in Den Haag, registered office Alliance House, 12 Caxton Street, London.

LID Low Impact Development

NVZ Nitrate Vulnerable Zone

PAHs Polycyclic aromatic hydrocarbons

SAC Scottish Agricultural College. Combines agricultural research, teaching and training with agricultural advisory service provided through a series of offices across Scotland.

SAPG Scottish Agricultural Pollution Group: Forum comprising civil servants from Scottish government departments, representatives of the agriculture sector, and regulators (later SEPA).

SEARS Scotland's Environment and Rural Services, http://www.sears.scotland.gov.uk/

SEPA Scottish Environment Protection Agency

SfS2 Sewers for Scotland 2: Scottish Water guidance, under the provisions of the *WEWS Act* 2003, setting out non-statutory standards required by Scottish water for vesting SUDS features with the utility.

SUDS Sustainable Urban Drainage Systems.

SuDS Sustainable Drainage Systems.

SWO surface water Outfall: discharge outlet for a surface water sewer

UK United Kingdom

US United States: pertaining to the United States of America.

USDA United States Department of Agriculture

USEPA United States Environmental Protection Agency.

WEWS Act Water Environment and Water Services (Scotland) Act 2003

WFD Water Framework Directive of the European Union

GLOSSARY OF TERMS

Constructed wetland An artificial wetland designed to prevent pollution, and or to attenuate surface water during high flows.

Diffuse Pollution Pollution arising from land-use activities (urban and rural) that are dispersed across a catchment, and do not arise as a process effluent, municipal sewage effluent, deep mine or farm effluent discharge (Novotny 2003).

Effluent An aqueous waste stream from an industrial or farm process or a sewage treatment works or other designed sewage discharge.

Farm effluent Process *effluent* from a farm such as slurry, silage liquor, dairy wash waters, or pesticide sprayer wash water.

Point source: In pollution control terms for catchment management, most usefully refers to a continuous discharge of effluent to a water body, such as a municipal sewage *effluent*, or an industrial *effluent*.

Scottish Government Scottish civil service for administering Scotland (previously *Scottish Executive*).

Steading The built environment of a farm, including farm buildings, yards, storage areas and associated drainage features, plus effluent containment and management facilities.

Sustainable Drainage Systems. Term used in England and Wales, but nothing to do with sustainable drainage in any general sense, merely an alternative acronym for SUDS (still refers only to built environment).

Sustainable Urban Drainage Systems: Features and systems serving the built environment, which together seek to replicate the natural hydrological characteristics of green field land.

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“Diffuse pollution is not an issue – if there is a problem you simply ban the substance causing it” UK agricultural scientist, early 1990s. Suspended solids? Nutrients? Soil...?

CHAPTER 1 – Introduction to Diffuse Pollution: Problems & Solutions

1.1 Introduction to Diffuse Pollution

This thesis sets out the work undertaken to develop a strategic approach to managing diffuse pollution, a hitherto under-recognised major water quality issue. Investigations were required to identify and quantify sources of pollution, and also how to address them in Scotland. On that basis an appropriate regulatory regime for controlling diffuse sources was devised.

1.1.1 Aims and Key Questions

Several key questions needed to be posed and answered before progress could be made addressing the principal remaining water pollution challenge facing river purification boards in Scotland in the run up to the formation of the new Scottish Environment Protection Agency in 1996, and indeed all the UK agencies and others working on environmental issues. The questions are set out below, and have spanned the fourteen years of this research (1994-2008). In summary they are:

a) What is the nature of the diffuse pollution problem that has to be addressed: its scale and extent, significance, key pollutants, any trends, critical features as an environmental phenomenon, how to measure it, and the key sectors involved? (Chapter 2).

b) What sort of measures might be appropriate to manage diffuse sources in the UK? Specifically, how should existing techniques be adapted or reconciled with new ideas from elsewhere? Are there technical or local geographic issues about application of tried and tested approaches from the USA applied in Scotland and indeed the UK, and can the effectiveness of the measures be improved? Can the measures be retrofitted to achieve measurable improvements in environmental quality? (Chapter 3).

c) Can the BMPs concept developed in the USA be usefully applied here and if so, how should it be brought into routine application? Whether called BMPs or something else, how can appropriate measures to control diffuse pollution be routinely and effectively implemented, including regulation as appropriate? (Chapter 4).

The above questions were critical elements in the development of a strategic approach to address diffuse pollution in Scotland, and results of the work by this author and others, are set out in the following three chapters that link together the selected published papers. Chapter 2 introduces published papers addressing the first point (a) above, Chapter 3 the second (b), and Chapter 4 the third, (c). A resulting strategy is set out in Chapter 5. The outcomes and achievements from the published work are set out in Chapter 6, Achievements. This opening chapter introduces the subject of diffuse pollution and ways to manage it. It includes reference to preliminary work by the author that was not published in refereed journals but is an important part of the background context outlined in this Introduction.

1.1.2 Origins and Terminology

The phenomenon of unexplained limitations to the improvement in water quality achieved by investment in conventional effluent treatment plants, observed in the USA and Europe from 1970-80s onwards, indicated that there are additional pollution sources, and they can be significant, but often poorly understood. In the UK, one early definition quoted by The Environment Agency, referred to diffuse pollution as water pollution where the source is unknown. A clear rationale had in fact been developed in the USA some years earlier. The concept of diffuse pollution was established in the seminal work by Novotny and Olem (1994) that identified the following key characteristics of diffuse sources:

- Diffuse discharges enter the receiving surface waters in a diffuse manner at intermittent intervals that are related mostly to the occurrence of meteorological events.
- Waste generation (pollution) arises over an extensive area of land and is in transit overland before it reaches surface waters or infiltrates into shallow aquifers.
- Diffuse sources are difficult or impossible to be monitored at the point of origin.
- Unlike traditional point sources where treatment is the most effective method of pollution control, abatement of diffuse load is focused on land and runoff management practices.

- Compliance monitoring is carried out on land rather than in water.
- Water quality impacts are assessed on a catchment scale.
- Waste emissions and discharges cannot be measured in terms of effluent limitations.
- The extent of diffuse waste emissions (pollution) is related to certain uncontrollable climatic events, as well as geographic and geologic conditions and may differ greatly from place to place and from year to year.
- The most important pollutants from diffuse sources subject to management and control are suspended solids, nutrients, faecal pathogens and toxic compounds.

The use of the term 'waste' in the above description is confusing, in a UK context at least, since in many and possibly most situations the pollutant is an incidental contaminant rather than a waste material, and may even be a natural material that is only a pollutant when transported to the water environment in excessive quantities e.g. nutrients, faecal pathogens and suspended solids.

The term diffuse pollution is broadly synonymous with NPS pollution in the USA, where NPS means so called non-point source pollution. It has been preferred to the latter since it better describes the sources and distribution of this type of pollution, and does not lead to diversionary assumptions and misunderstandings. Everything has a source of one kind or another. Whether a pollutant input is from a pipe or can be identified as some other specific input to the water environment is irrelevant when considering diffuse sources. Thus a series of field drains discharging to a ditch are arguably point sources to that ditch, but such a pedantic view would miss the point that it is weather related processes that transport the pollutants from the drains, and from the land into the drains. Leaching of nitrates from intensively fertilised land to contaminate groundwater perhaps exemplifies diffuse pollution more unequivocally, but equally, each field of improved grassland on an area of hill farms on a sandstone aquifer, could be seen as nitrate point inputs to the aquifer. Therefore the key criteria for considering diffuse pollution are the dispersed nature of the sources and the weather related mobilisation and transport to water environment as indicated in Novotny and Olem (1994) above. That concept does not preclude aggregations rather than homogeneous distributions of sources, neither does it preclude occasional concentration of factors to make a particular source of greater significance than others, i.e. a diffuse pollution hotspot. Surface water drainage from a large industrial estate is typically a diffuse pollution hotspot (weather related mobilisation of pollutants having a locally significant impact) and placing a set of ring feeders for livestock on sloping ground by a stream typically produces a hotspot in a rural context.

In the USA, NPS pollution is defined by statute. Thus Novotny (2003) states that under the terms of the Clean Water Act, Section 502-14, US Congress, 1987: "*the term 'point source' means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal* *feeding operation, or vessel or other floating craft from which pollutants are discharged. The term does not include agricultural stormwater and return flows from irrigated agriculture.*"

The NPS term in its original use (in the USA) is therefore more about control and exclusions from its scope. Thus the point source definition excludes all agricultural runoff for example except for intensive feedlots, irrespective of whether inputs from "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel," etc. It is more about political lobbying than hydrological or water quality processes or risks. Novotny (2003, p. 35) argues that "traditional" point sources (municipal, industrial and agricultural) are different from diffuse sources, which, according to the statutory definition in the USA, may be both point and non-point.

Novotny (2003) concludes consideration of terms and definitions, by quoting the now generally accepted international definition of diffuse pollution, derived from the deliberations of a sixteen organisation working party in UK (D'Arcy *et al* 2000). Diffuse pollution is

"*Pollution arising from land-use activities (urban and rural) that are dispersed across a catchment, and do not arise as a process effluent, municipal sewage effluent, deep mine or farm effluent discharge*."

An effluent can usefully be defined as an aqueous waste stream. Examples include sewage effluent, process effluents from industrial activities (but not surface water drainage except where included in the effluent stream), and silage liquor (an aqueous waste derived from production of silage), wash waters of various kinds, and cattle or pig slurry.

1.2 Impacts on the Water Environment

1.2.1 Diffuse Pollution in International Context

Diffuse sources of pollution only became evident once major point sources associated with municipal sewage discharges or process effluents from industry, were eventually brought under more effective control. The 1970s for example saw great progress in restoration efforts for the Great Lakes of North America, after a history of water pollution that had led to the formation of the International Joint Commission (IJC), under the bilateral Boundary Water Treaty of 1909 between USA and Canada. In 1980 the Pollution from Land Use Activities Reference Group (PLUARG) set up by the IJC, reported two main problems: eutrophication associated with nutrient inputs and increasing contamination by toxic substances. Diffuse sources of nutrients are still an issue in some of the lakes, whilst studies on contamination by substances of emerging concern have shown that most of the chemicals identified are product based - pollution arising as a diffuse source problem, not at point of manufacture (Trepanier, 2010).

In the 1980s a National Urban Runoff Project (NURP) was undertaken in the USA over 4 years, at 28 sites throughout the United States. The findings (US Environmental Protection Agency 1983) established that there are high concentrations of toxic metals in urban runoff, and priority pollutants (toxic, mostly organic chemicals) were also detected in significant quantities, as well as high loadings of sediment and contamination by coliform and pathogenic bacteria and viruses. Data collected in the NURP study showed that uncontrolled discharges from surface water sewers taking runoff from residential, commercial and light industrial areas carried more than 10 times the annual loading of suspended solids than discharges from secondary treatment sewage plants (U.S. EPA, 1999). A Canadian study by Marsalek *et al* (1999) looked at urban runoff toxicity from 14 urban sites, and reported that only about two fifths of all data showed no toxic responses, one fifth indicated potential toxicity, one fifth confirmed toxicity, and one fifth showed severe toxicity. About 20% of samples from a multi-lane divided highway were severely toxic, contrasting with only about 1% of other urban stormwater samples. That study implicated traffic, and a much later study identified a traffic source for copper, one of the toxic substances often present in significant amounts in urban runoff (San Francisco Estuary Institute 2007). Other investigations highlighted the potential of industrial and commercial areas to contribute pollutants to the water environment in higher concentrations than from other land-uses (e.g. Whipple *et al*, 1974, Yu *et al* 1975).

The Chesapeake Bay Program of the EPA was established in 1976 to address pollution of the largest estuary on the east coast of the United States. Formerly a productive source of fish and shellfish, the fisheries declined and investigations implicated nutrients and toxic pollutants. It has been estimated that diffuse sources contribute about 82% of the nitrogen that reaches the Bay, and about 68% of the phosphorus (Cestti *et al* 2003). After decades of implementation of control measures, ‘legacy phosphorus’ has emerged as an important issue, still impacting water quality in many contributing catchments (Buda *et al* 2010, and Meals *et al* 2010).

In the early 1990s, the importance of diffuse sources was also reported in Europe (e.g. Behrendt 1993, Bendoricchio *et al* 1993, Verstappen GGC *et al*, 1993) and Japan (e.g. Yamada et al, 1993) and elsewhere. Novotny (2003, p.21) indicated that diffuse pollution problems had reached global proportions, with anoxia due to nitrate contamination being observed in the Black Sea, Adriatic Sea, Chesapeake Bay, and Gulf of Mexico. In each of those examples, the principal input of nitrate is major influent rivers, respectively: the Danube and Volga Rivers, the Po River, the Susquehanna and Potomac Rivers, and the Mississippi. The nitrate in those rivers has typically leached from farmland many kilometres upstream.

The above examples indicate the scale and severity of impacts on surface waters: rivers and lakes, estuaries, and even coastal waters. During the same period awareness of the importance of diffuse sources contaminating and damaging groundwater resources was also growing: Schock *et al* 1993 and Mostaghimi *et al* 1993 in USA, and Driescher and Gelbrecht (1993) and Fortina *et al* 1993 in Europe.

Land-use was recognised as a key indicator of the likely types of pollution. Land-use change was recognised as a key factor in generating increased diffuse pollutant loads and impacts, e.g. forest to agriculture or mining, agriculture to urban development.

The key sectors identified as important diffuse pollutant sources were: agriculture, forestry, urban and industrial development, and mining (especially springs arising from water table rebound in abandoned mines). Key processes for pollution were identified: overgrazing or stripping of vegetation and exposure of soil to wind and rain breaks up soil aggregations and allows it to be mobilised and carried into the water environment. Working the ground surface either in the course of arable farming, or construction activity in urban areas, exacerbates that process. The green revolution in agriculture in the 1960-70s, based on intensive use of pesticides and artificial fertilisers also had a negative impact, with increased losses of agrochemicals of all kinds to the water environment, and adverse effects of persistent pesticides in biota through concentration in food chains.

For mining activity, pumping out groundwater is a necessity which also has diffuse pollution consequences. It allows air to enter mineshafts and oxidise insoluble iron sulphides to soluble (ferrous) iron sulphate, which is then leached from the mine as water tables rebound on cessation of mining. The colourless ferrous sulphate is then itself oxidised in the watercourse, thereby stripping the water of sparingly soluble oxygen, and smothering the streambed in a precipitated insoluble ferric sulphate (characteristic orange ochre). In addition, overburden dumps at sand quarries as well as metals extraction and coal mines, led to chemical changes too, with consequent leachates often rich in toxic metals or very acidic depending on the local geology.

The impacts of urbanisation included hydrological consequences of increasing imperviousness: faster rates of runoff, scouring pollutants from urban surfaces and causing flooding, and reducing recharge of groundwater with less water consequently available for seeping into watercourses during dry weather periods (Horner *et al* 1994). Construction of combined sewers beneath impervious areas resulted in sewer surcharging or polluting storm sewer overflows to watercourses. Construction of separate sewers created opportunities for inadvertent direct discharges of polluting effluents direct to watercourse (Novotny 2003). Such wrong connections included foul drainage in housing areas and offices, as well as trade effluents, and *ad hoc* processes such as steam cleaning trucks or plant on industrial and commercial premises.

Catchment scale, integrated investigations to quantify significant inputs from all sectors have become a recognised first step prior to engaging with any one sector therein. Chesapeake Bay has already been noted and Moreton Bay in Queensland, Australia has also become a text book classic case study, involving partnership teams of scientists able to record all relevant phenomena, from source tracing using mineralogical analysis of sediments to the relationships between dugongs, sea grass and diffuse source turbidity (Dennison and Abal, 1999).

1.2.2 Diffuse Pollution in the UK

Diffuse sources of pollution were only just beginning to be recognised by regulatory agencies in the UK prior to the investigations set out in this research, and there was only limited academic work on the subject (mainly focused on groundwater e.g. Parker et al 1985, Harris and Skinner 1992). Other than for groundwater, academia was generally not engaged with regulatory or government organisations for this issue. Literature references to the term diffuse pollution in the UK are identified in table 1.1, and indicate the almost total focus on groundwater until 1995, especially in relation to agricultural inputs. That existing interest – in preparation for the EU Nitrates Directive – nonetheless also included a few urban investigations, again primarily concerned with groundwater contamination by chlorinated hydrocarbons associated with use of industrial solvents (e.g. Harris and Skinner 1992).

Table 1.1 UK literature references to diffuse pollution prior to 1995, which was the first diffuse pollution conference held in the UK, (in Edinburgh).
Y denotes focus of paper (from Aquiline abstracts, and Environmental Sciences and Pollution Management Abstracts, library search undertaken on 20th March 2008)

Reference	Rural	Urban	All issues	Groundwater	General Environment	BMPs
Parker et al, 1985	Y Nitrate	-	-	Y	-	-
Parker et al, 1987	Y Nitrate	-	-	Y	-	-
NRA, 1990	Y	Y	Y	Y	-	-
ENDS, 1991	Y	Y	Y	Y		
Harris and Skinner 1992		Y		Y		

Of The focus of investigations of drainage systems by regulators and water utilities was in relation to flooding aspects of urban drainage, or with pollution arising from combined sewers. Water pollution concerns and research interests were closely associated with major point sources: industrial and municipal sewage effluents. By contrast, often individually minor but collectively significant contamination associated with a myriad "normal business" activities, were frequently barely recognised in the UK as sources of pollution in rivers, lakes and coastal waters. Consequently relatively little attention had been focused on ways to mitigate those impacts here. In the UK there was not a recognised consensus definition of diffuse pollution until 2000 (see D'Arcy et al 2000).

Two important exceptions to that picture must be noted, although in neither instance was the term diffuse sources recognised at the time. The first was mining, with a high profile concern for pollution from abandoned mines (Royal Commission on Environmental Pollution 1992), based on earlier experiences in the pollution control agencies such as the Clyde and Forth River Purification Boards in Scotland, and in Cornwall (Johnson and Thornton 1987) and Wales (see Kelly 1988 for discussion of mining impacts on freshwaters).
The other important issue now recognised as a diffuse source problem, was urban drainage, in particular contaminated highway runoff (Ellis 1985, Ellis *et al* 1987, Hamilton and Harrison 1991).

The author led an investigation of the “unfinished business of water pollution control” in a small regional regulatory agency, the Forth River Purification Board (FRPB) from 1993 which identified diffuse pollution as an issue. Example aspects were the contamination of the water environment by oil and sediment from roads and from industrial and commercial developments, often conveyed by surface water sewer systems. In the rural sectors, examples included runoff from fields and forests, contaminated by sediment and nutrients, as well as oil from machinery and farm/forest vehicles.

The FRPB Water Quality Initiative (led by the author), and its publication *A Cleaner Future for Our Waters*, (FRPB 1994) was the first systematic examination of diffuse sources as well as impacts of major point sources, in a UK catchment (River Forth, including the Estuary and Firth). Figure 1.1 shows the causes of poor quality water identified for the freshwater rivers in the Forth catchment during that study. Diffuse sources, comprising urban runoff, agricultural drainage, forestry drainage, and water table rebound ferruginous springs from abandoned mines, accounted for more than half of the pollution identified.

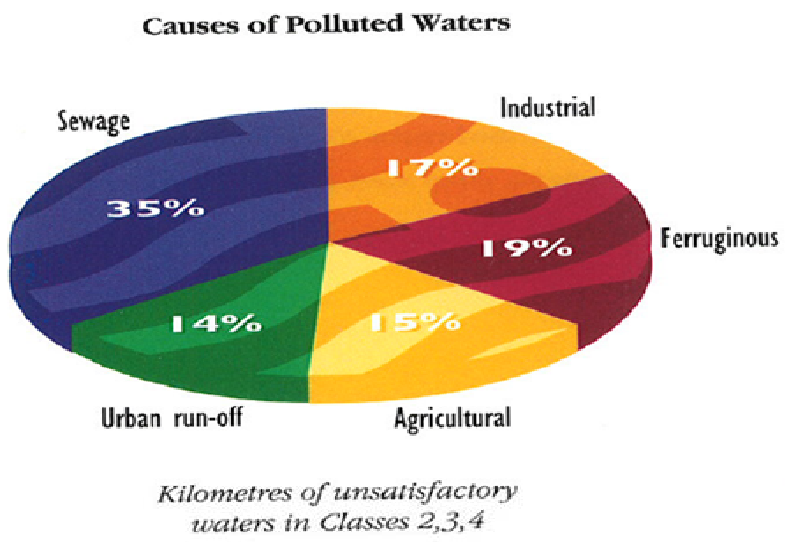


Figure 1.1 Causes of poor river water quality in the Forth Catchment, (FRPB, 1994).

The impacts and identification of associated sectors were estimated by a two stage process. The starting point was the identification of impacted reaches on the basis of chemical and biological data. The first step in the determination of causal sectors entailed examination of water chemistry data for breaches of Environmental Quality Standards (EQS). For example iron was a good indication of mining impacts, especially with associated elevated conductivity, or sometimes low pH (but many abandoned mines had well buffered water without a low pH in the Forth catchment). To some degree, nutrients, especially high nitrate, could indicate agriculture as a key causal sector. For other sectors, a chemical parameter that was a good predictor for a sector impact was not always as clear. In many instances all that could be determined was that there was poor biological quality with some indication of type of impact. The second stage of the process utilised catchment knowledge (of discharges especially, as well as land-use) in an expert judgement input, to determine the most likely causes of the observed impacts. The process was repeated in the Forth catchment the following year by different staff, without reference to the originator, but obtaining nonetheless similar results. It was then transferred to SEPA in 1996 where it was undertaken nationally with broadly consistent findings, giving some confidence to the repeatability of the process (see Table 1.2 below).

The formation of the Scottish Environment Protection Agency (SEPA) and The Environment Agency (EA) in April 1996, presented an opportunity to establish a national agenda for diffuse pollution. The *Nature's Way* video for IWA (then IAWQ) was led from Scotland, and launched in summer 1996, jointly by the two agencies (it featured both of the SEPA and EA Chief Executives), thereby signalling acceptance of diffuse pollution as a legitimate challenge facing both the EA and SEPA. The international illustration of diffuse pollution impacts in the *Nature's Way* video was followed by detailed impacts (and solutions) papers presented at the International Diffuse Pollution Specialist Group's third major conference in 1998, in Edinburgh (Novotny and D'Arcy 1999).

At the close of the 1998 conference there was unanimous agreement from the UK members of the steering group that a national report should be compiled that would set out available evidence as to the importance of diffuse pollution as an environmental issue for the UK. The project was again led from Scotland, but under the auspices of the Chartered Institution of Water and Environmental Management (CIWEM) who published the report (D'Arcy *et al*

2000) on completion, with a multi-agency launch in London. Sixteen organisations worked together on the project, representing major source sectors as well as leading specialist centres of expertise, plus the regulators. The report was structured by pollutant, with chapters on: oil and hydrocarbons, pesticides, suspended solids, organic wastes, faecal pathogens, nitrogen, phosphorus, trace metals, iron, acidifying pollutants, chemicals, and modelling and pathways.

The report quoted national diffuse pollution impacts data for Scotland. That was possible because the source apportionment process developed by the FRPB and noted above, had been taken into SEPA and refined and applied nationally, providing the evidence set out in the 1996 and more especially the 1999 State of environment reports (SEPA 1996, 1999), see Table 1.2. Such an approach had not however been developed for England, Wales or Northern Ireland at that time.

Table 1.2 Estimated diffuse pollution impacts in Scotland's rivers, with sewage and industrial effluent for comparison (SEPA 1999)

Cause of Pollution	Fair		Poor		Seriously Polluted		Total Polluted Water	
	Km	%	Km	%	Km	%	Km	%
Agriculture – diffuse sources	922	30.7	207	17.6	3	2.2	1,132	26.2
Agriculture – point sources (steadings)	154	5.1	113	9.6	5	3.6	272	6.3
Acidification	504	11.7	0.0	0.0	0.0	0.0	504	11.7
Urban drainage (contaminated surface drainage; all urban)	227	7.6	235	19.9	31	22.4	493	11.4
Mine drainage	219	7.3	149	12.6	15	10.9	383	8.9
Contaminated land	10	0.3	27	2.3	6	4.3	43	1.0
Forestry	18	0.6	0.0	0.0	0.0	0.0	18	0.4
Sewage effluent	870	28.9	523	44.4				
Industrial effluent	30	1.0	59	5.0	4	2.9	93	2.1

Consequences of the *Diffuse Pollution Impacts* report, (D'Arcy *et al* 2000) included a broad interest across the UK in diffuse pollution, with independent research on impacts (and solutions) by a range of organisations. The Scottish Government responded to all the actions leading up to and including the CIWEM *Diffuse Pollution Impacts* report, by allocating funds to SEPA for a national Scottish Diffuse Pollution Initiative (DPI), from 2001-2004.

1.2.3 Impacts Investigations by SEPA Diffuse Pollution Initiative

Initiated in 2001, the aims were threefold:

a) Initiate and steer research to better understand the causes of diffuse pollution and the probable effectiveness of possible remedial measures

b) Plan and manage a 4 year co-ordinated technical effort to promote higher levels of awareness and better understanding of diffuse pollution by target sectors involved in the problems and the solutions
c) Provide leadership, guidance and direction for SEPA, involving support from various functions within SEPA.

With regard to a) and b) above, some projects were undertaken in-house, others by short contracts, developing experience, expertise and operational capabilities for SEPA. Major research projects were undertaken in partnership with others, thereby doubling finds available and literally obtaining buy-in to the issues and solutions from sectors and researchers. Leadership, guidance and direction for SEPA were facilitated by a multi-department steering group set up, chaired by the SEPA CEO.

Over 20 technical reports were produced including several on impacts and characterisation of the problem, as a pre-requisite for action to address it. SEPA water quality and impacts data for the year 2000 was the basis for the project. All the diffuse sources data from that were summarised, by sector, at the outset to prioritise SEPA actions, and documented for the record on completion (MacCalman and D'Arcy, 2004). Sectors were summarised in a standardised way in the report: acidification, agriculture, contaminated land, urban drainage, mining and forestry, demonstrating an even-handed approach across the sectors, based upon available evidence of impacts or risks of impacts.

More detailed evidence of impacts and demonstrating the importance of particular urban pollutants was reported in SEPA report DPI no. 7, (published later as Wilson *et al* 2005) which highlighted the widespread presence of oil in stream sediments, as well as significant contamination by toxic metals and polyaromatic hydrocarbons (PAHs). That was consistent with international published evidence, e.g. Smullen et al (1999) which updated the NURP study (USEPA 1983) referred to in 1.3 ; Marsalek *et al* (1999) who reported toxicity of urban runoff; and subsequent evidence, e.g. Kominkova and Nabelkova (2006) who showed that sediment concentrations at “risky levels” were found especially below industrial estates and heavily trafficked areas.

Sediment monitoring in the SEPA research (Wilson *et al* 2005) was a practical consequence of one of the defining characteristics of diffuse pollution identified by Novotny and Olem (1994), which is that the pollutants enter the receiving water in a diffuse manner at intermittent intervals associated with weather conditions. It was also in response to the difficulty of monitoring diffuse pollution inputs at source. Subsequently however, advances in monitoring techniques have allowed many studies to be undertaken to assess how pollutant concentrations vary over a series of storm events, for example Kim *et al* (2006), Fuji *et al* (2006) and Cho *et al* (2010).

Although involving a lot of samples and expense, with simultaneous flow measurement a requirement too, storm event sampling has proved to be vital in understanding diffuse pollution in a catchment. For example Fuji *et al* (2006) showed that 52-53% of the whole flow in the watercourse being investigated was caused by rainfall events, and conveyed 81-87% of COD loading, 68-73% DOC, 92-95% SS, 64-67% TN, and 76-81% TP. Clearly, any measures that sought only to address low flows would be inadequate, and this informed work in Scotland.

Work undertaken as part of the SEPA diffuse pollution initiative sought to establish a set of diffuse pollution monitoring stations, in example case study catchments for each major land-use in Scotland. Initial proposals were for an urban site, for a forestry site in the north, and for sites in one arable catchment and one livestock dominated catchment. The first catchments selected and provided with at least one storm event monitoring station were:

1) The Greens/PowBurn in Kinross (arable)
2) The Cessnock in Ayrshire (livestock)
3) The East Tullos burn, Aberdeen (industrial estate plus some housing)

The Central Belt sites numbered 1) and 2) above are indicated in Figure 1.2 below. The Greens/Pow Burn is a small tributary of Loch Leven. The Cessnock is a small river draining a livestock farming catchment in Ayrshire, in the West of Scotland.

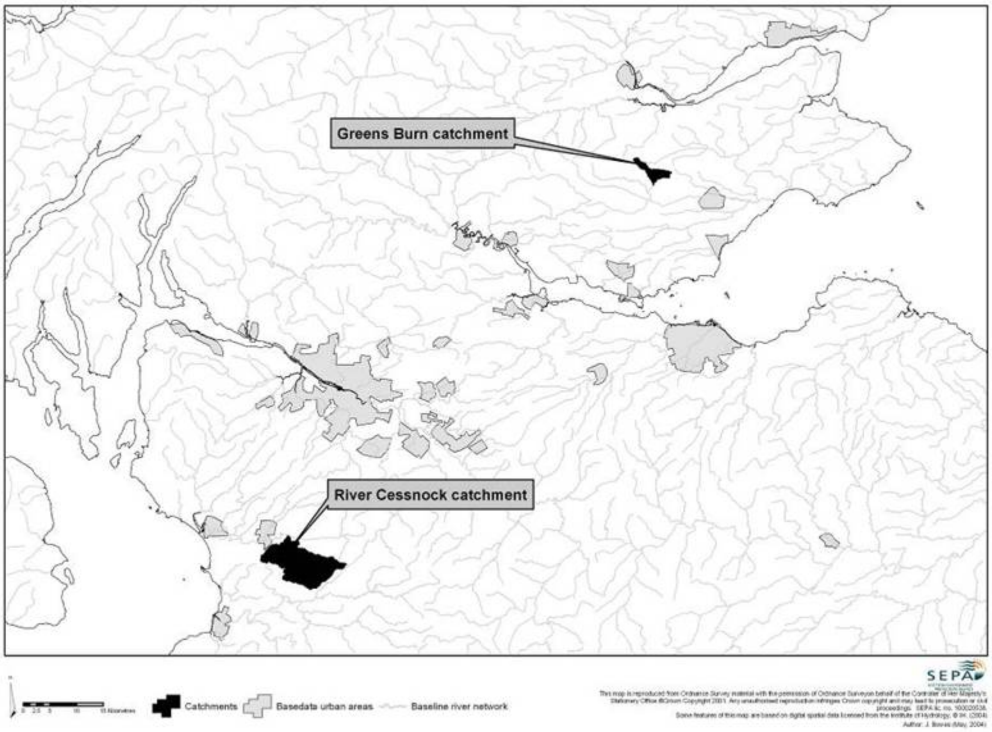


Figure 1.2 Map of 1st two catchment locations for storm event monitoring (from Greig, 2004, DPI No. 21, SEPA unpublished report).

Figure 1.3 (Jones *et al* 2003) shows how concentrations of two pollutants varied with flow in the Cessnock. It is important to note in the example in Figure 1.3, that at no time are pollutant concentrations at low flows greater than at high flows. This indicates that pollutant sources in the catchment are predominantly diffuse in nature. Importantly for understanding diffuse pollution impacts, the data show that there is no dilution at high flows, but the converse; high flows are when water quality is worst.

Relationship between river levels, ammonia and nitrate (30/6/02)

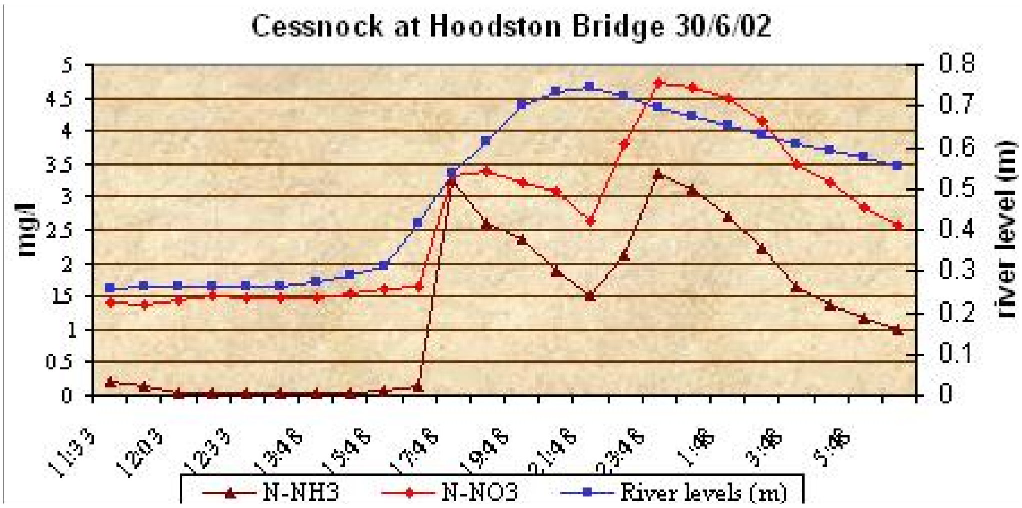


Figure 1.3 Example storm event (30/6/02) demonstrating weather-related mobilisation of diffuse source pollutants in the Cessnock, Ayrshire showing relationship between river levels, ammonia and nitrate (from Jones et al 2003).

The same pattern is clear in Figure 1.4, showing a storm event from a completely different watercourse, with an urban/industrial catchment, in Aberdeen (Cundill, 2010). Again, concentrations of pollutants rise with flow, following the hydrograph with generally no high flow concentrations being as low as those observed at low flows (Figure 1.4) – i.e. no dilution for pollution, for those parameters in that event.

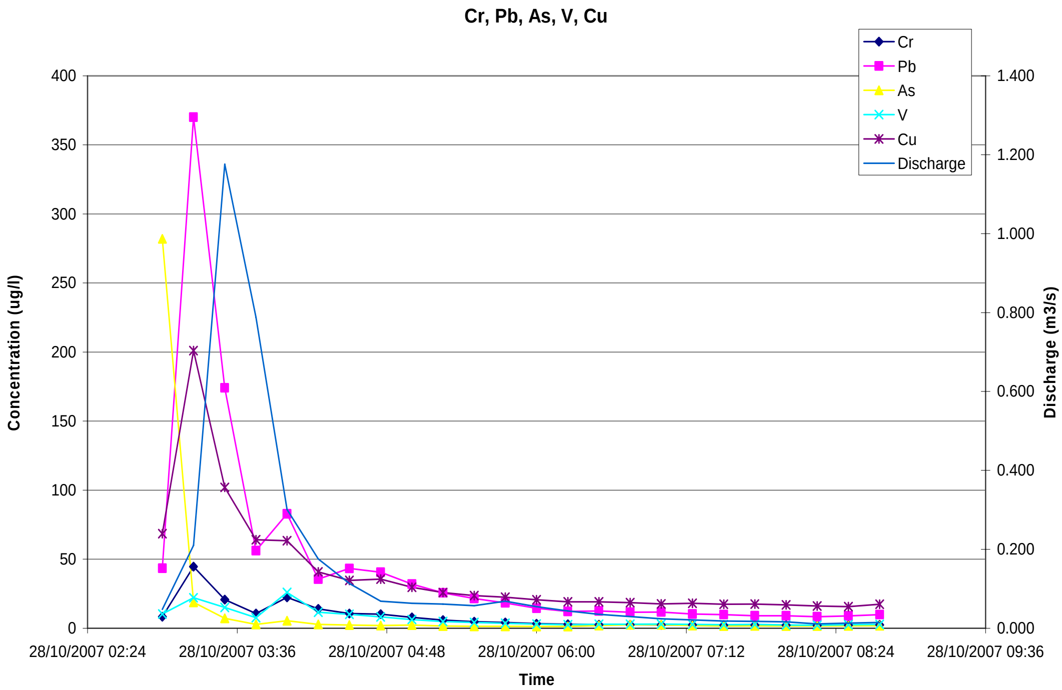


Figure 1.4 Examples of typical responses of metallic pollutants to discharge, in East Tullos Burn, storm event of 28.10.07 (from Cundill 2010).

The storm event driven nature of the pollution is a classic feature of diffuse source problems. Measured concentrations of pollutants, which showed such responses to storm events, included toxic metals (Figure 1.4), suspended solids, BOD and phosphate. The relationship of the concentration of a water quality parameter to flow in a watercourse will of course vary between parameters according to the nature of the catchment, as well as the details of the storm event. These two examples can be compared with other data that show differing patterns according to the storm event, and in some cases the impact of pollution incidents. In the Torry Burn for example, atypical responses were measured for TON, chloride and alkali metals (Cundill 2010).

A major driver for storm event monitoring in the UK was the risk of EU infraction proceedings for non-compliance with bathing water standards. Significant research was undertaken in Wales, parts of England and then in Scotland, to quantify the relative importance of wet weather loadings of faecal indicator organisms (e.g. Wyer et al, 2000). This is discussed further in section 1.5, below.

1.3 BMPS and Controlling Diffuse Pollution

1.3.1 International Context

The well-defined measures for managing diffuse sources developed in USA were known as best management practices, or BMPs (see for example Schueler *et al* 1992; Novotny and Olem 1994; USEPA 1993; Novotny 2003). The best management practice approach is of necessity a function of the nature of the problem and therefore BMPs seek to do one or more of the following:

- Reduce the quantities of potential pollutants applied to the land.
- Reduce exposure of potential pollutants to mobilisation by rain or other weather conditions (wind, snow melt etc).
- Make interventions to interrupt or divert pathways for pollution.
- Establish physical interventions to trap and remove entrained pollutants from drainage pathways.

BMPs highlighted the need for both good practices (behaviours) and good technology and infrastructure (Novotny 2003 and Campbell et al 2004).

Novotny and Olem (1994, p.18) defined best management practices (BMPs) as

"*Best management practices are methods, measures, or practices selected by an agency to meet its nonpoint (diffuse) source control needs. BMPs include but are not limited to, structural and non-structural controls and operations and maintenance procedures*."

The best management practices approach is to have a pollution prevention technique (ideally a choice of options) for every potentially polluting activity. Techniques vary from collection of debris rich in anti-fouling paint when cleaning and repainting boat hulls, to extensive, multiple module constructed wetlands treating runoff from motorways and industrial estates, with a treatment train of measures such as grass swales or gravel filter drains provided first stage treatment prior to the pond.

The size and scope of the US publication *Guidance Specifying Management Measures for Sources of Non-point Pollution in Coastal Waters* (USEPA 1993), gives a measure of the central importance of the BMPs approach to controlling diffuse pollution in the USA. Five sector based chapters are supported by chapters on wetlands, riparian areas and vegetative treatment systems, plus monitoring and tracking techniques. The guidance totals 846 pages and describes scores of specific BMPs for all sectors. An introduction to the guidance and explanation of associated aims and policy issues is given in Frederick and Dressing (1993).

The effectiveness of the BMPs approach was demonstrated in the USA by a series of studies, many of which are reported in USEPA publications, for example Success Stories vol. II (USEPA 1997). Guidance on techniques for investigating effectiveness were also published, for example the US Department of Agriculture (Forest Service), 1994. By the mid-1990s, a series of classic case studies were established, for example at Lake Champlain, where a paired rivers approach allowed for seasonal and year-on-year variability in weather conditions, (Meals and Hopkins, 2001) and Chesapeake Bay (Cestti *et al* 2003). Those studies were undertaken on a catchment scale; appropriate for diffuse pollution control as indicated in the characteristics identified by Novotny and Olem in 1994. The weight of evidence noted above on BMPs and their performance provided a basis for introducing the approach to the UK, for rural and for urban sectors.

1.3.2 Rural BMPs in the UK

Unsurprisingly, given the limited recognition of the problem in the UK in the mid-1990s, there was little awareness in the regulatory agencies of the sort of measures that might be effective in addressing diffuse sources of pollution. In the UK the rural sources of diffuse pollution needed a BMPs approach for the same reasons as in USA and everywhere else. Both of the terms (NPS and corresponding BMPs) first used in the USA, were used in the campaign video produced by the FRPB to support its Water Quality Initiative in 1994. In England, the Hampshire Avon (Huggins, 1998) was, independently and in parallel to the RFPB work, being evaluated for factors adversely influencing water quality. These researchers also discovered the USA experience and approach, anglicising and narrowing the scope to be Land Best Management Practices (LBMPs). This work was given national publicity and presented to add to awareness of diffuse pollution and the defined best practices approach to addressing it, by inviting a paper on the Hampshire Avon for the second Agriculture and Environment, diffuse pollution conference in Edinburgh in 1997 (Huggins, in Petchey et al 1998). At Middlesex University however, pollution associated with urban runoff was already a familiar subject for research (Ellis *et al* 1987), including possible treatment systems such as wetlands and swales (Ellis *et al* 1994, Zhang *et al* 1990). Focused on the environmental phenomena rather than jargon, those early papers did not seek to introduce the terms diffuse pollution or BMPs.

The BMPs approach was still relatively little known or poorly understood, so its importance was not sufficiently recognised. D'Arcy and Frost (2001) attempted to explain the difference between a BMPs approach and the sort of guidance that was still being published for farmers for example in the UK codes of good agricultural practice. That paper drew a distinction between "doing it right or wrong" as in the traditional farming codes of good practice, and diffuse pollution associated with land-use decisions, such as growing root crops or cereals, having sheep or cattle in a bathing water catchment, or winter vs. spring sowing in a phosphorus sensitive catchment. Subsequently a UK selection tool to aid use of rural BMPs was developed for English Nature (Hilton, 2003), but without reference to the USEPA manuals. In 2005 a web-based BMPs manual was developed for SEPA, in conjunction with a sector derived stakeholder group, (http://apps.sepa.org.uk/bmp/Guidance.aspx).

Although the extensive data sets on cost effectiveness, maintenance and performance in the original USEPA guidance (USEPA 1993) lends itself to a web-based application, it was still useful to be able to present a simpler summary of the rural BMPs options for farmers and others to consider. This was done using the Four Point Focus set out in Table 1.3 below, primarily to introduce the BMPs approach to farmers and farm advisors. Sinclair *et al* (2010) set out an introduction for farm advisors, farm regulators and interested farmers to the suite of BMPs in the above guidance, and how to use the web-based BMPs database.

Forestry pollution prevention guidance was generally well regarded by regulators across the UK as a consequence of efforts to prevent recurrence of widespread adverse impacts from the establishment of Britain's new forests by the Forestry Commission in earlier decades. Thus with the benefit of hindsight, the Forest and Water Guidelines (Forestry Commission, 1988), constituted good concise best practice advice for planting trees on a commercial scale. This included advice on slope, when not to plough, blocking drainage rills, constructing access roads, etc. By the time diffuse pollution became a recognised term in Scotland and elsewhere, forestry guidance had been further updated to recognise risks from harvesting, since much of the standing crop was mature by the 1990s. For those reasons forestry BMPs were not advocated as new techniques in the same way as BMPs were for farmland (Table 1.3 below) but were actually seen as possible useful soil stabilisation and shelter belt options for farmland (see river margins column in Table 1.3).

Table 1.3 Four Point Focus for BMPs in Scottish guidance (modified from Campbell et al 2004)

Steading	Field	River Margins	Planning Tools
Source control for yard runoff: grass filter strips, dispersed drainage onto land,	Min. Till techniques (many options)	Grass buffer/filter strips	Nutrient budgets
Collection of roof runoff for on-farm uses, or discharge to stream or ground	Conservation tillage	River bank restoration	Farm waste management plans
Slurry collection and storage for land application in accordance with farm waste plan	Under-sow crops with soil stabilising 2nd crop	Livestock exclusion fencing with alternative watering points	Targeted pesticide applications
Midden drainage collection in sealed tank	Check dams on seasonal rill risk areas, e.g. using field stones*	Riparian woodland	
Silage drainage collection in sealed tank	Permanent grass for at risk of erosion slopes of fields close to watercourses	Riparian habitat creation (buffer zone or feature)	
Biobeds for outdoor pesticide risk/ washdown areas (or grass)	On arable farms: permanent grass for fields that are at risk of flooding by rivers and streams.		
Constructed wetlands for the cleanest yard and track areas (to avoid overloading storage units).	Graze cattle rather than sheep on fields that drain to bathing waters (almost one tenth as many FIOs)**		
Reedbeds to treat septic tank drainage	Provide shelter belts for livestock away from watercourses on exposed fields		
Cut-off trenches for roads and tracks to take drainage into fields			

The effectiveness of rural BMPs was demonstrated in Scotland by studies undertaken by SEPA on the Greens/Pow Burn tributary of Loch Leven. Figure 1.6 presents evidence for the effectiveness of rural BMPs, specifically riparian buffer strips provided for several reasons in the catchment of a tributary of Loch Leven. The buffer strips were originally encouraged after fish mortalities implicated over-spraying during application of pesticides. Buffer strips were also thought to have potential benefits for stabilising erodible steep slopes and riparian margins on arable fields alongside the watercourse. Where topography would cause runoff to flow across riparian margins, it was anticipated that grass buffer strips might also act as filter strips for runoff from fields. In Figure 1.6, the effect of the buffer strips on inputs of suspended solids and phosphorus was demonstrated by a regression analysis of pre and post buffer strip relationships between pollutant concentration and flow. The results of this analysis highlighted a slope difference of -37% and -42% for suspended solids and phosphorous respectively, suggesting a consistent decline in inputs of these pollutants post buffer strip generation (Greig 2004).

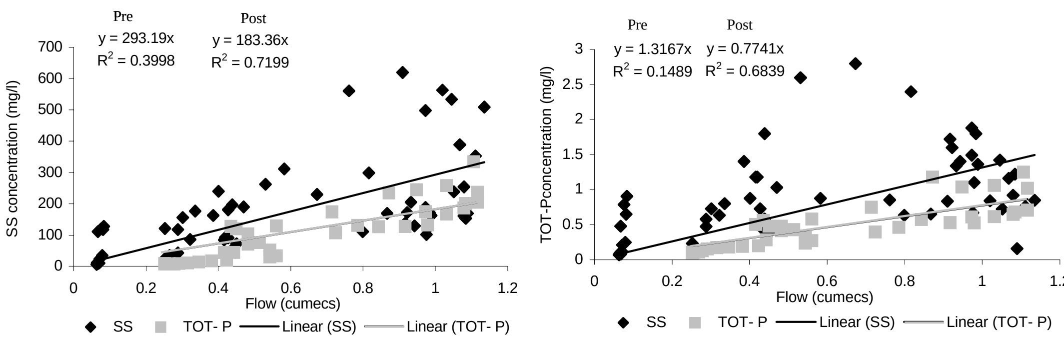


Figure 1.6 Pre and Post establishment of riparian buffer strip linear regression analysis pollutant concentration and flow,Greens Burn, Loch Leven tributary.
(a) Suspended Solids,
(b) TOT-P. Pre buffer strip ----- ◆ Post buffer strip ------ ■

Diffuse pollution sources in the Loch Leven catchment were targeted by a catchment management plan that brought the regulators together with farming sector to jointly identify and promote best practices. As part of that plan, free sampling and analysis of soils was offered to every farm in the catchment, supported by nutrient budget advice. A measure of the success of nutrient budgeting is perhaps the falling trend in nitrate concentrations in the Greens Burn tributary (Figure 1.7, SEPA unpublished data).

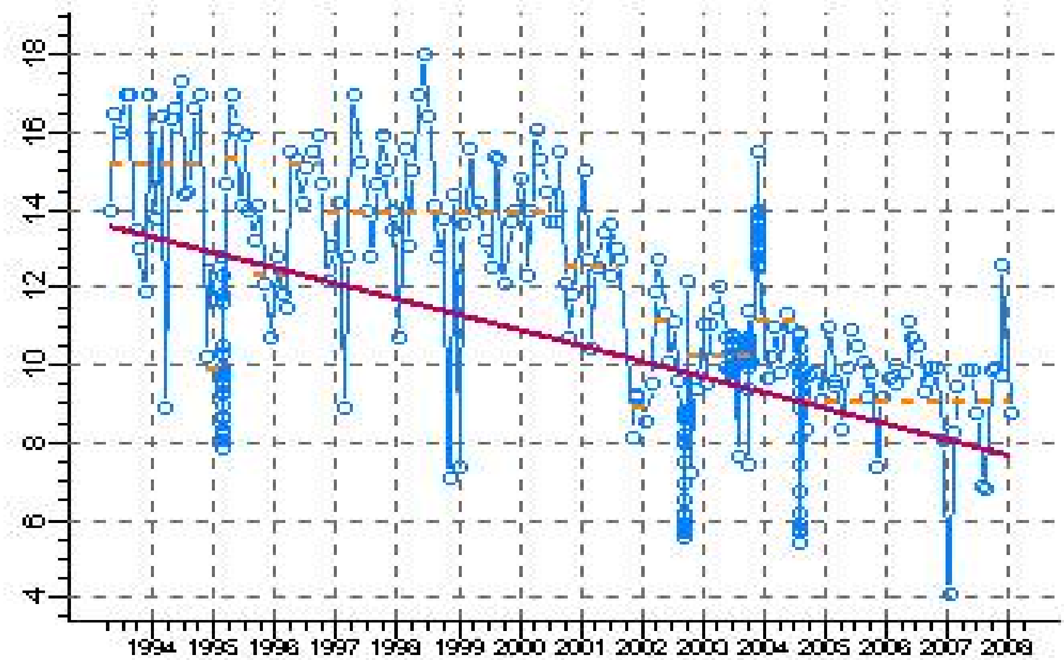


Figure 1.7 Decline in concentrations of nitrate in the Greens Burn, Loch Leven (SEPA unpublished data).

The loch catchment is also a Nitrate Vulnerable Zone (NVZ), and is unusual in recording a decline in nitrate concentrations in the surface waters of the area that gives rise to the elevated groundwater concentrations that risk non-compliance with the EU Nitrates Directive. The watercourse data for the stream draining the intensive farmland (Figure 1.7) perhaps gives confidence that the aquifer beneath those enriched soil horizons may also show a decline in nitrate contamination with time.

A diffuse pollution hotspot is where land-use activities and weather-related mobilisation of contaminants involves such high concentrations and or flows as to result in a locally significant impact on a water body. The Greens Burn also provided an example of a diffuse pollution hotspot and some approximate quantification of losses to the watercourse if action was not taken. Investigations at the head of the stream noticed that below one large field the runoff had concentrated in flow as well as pollutant load, and eroded a pathway to pollute the burn through a section of the riparian buffer strip. That 'diffuse pollution hotspot' was addressed by excavating a sump in the bottom corner of the field, where eroded soil typically smothered any crops before they could reach harvest time. As well as allowing peak runoff flows to dissipate in the sump, the side of the buffer strip along its length at the sump was protected by a reinforced embankment, see Figure 1.8a. After two years, the sump has been excavated twice, and approximately 200 tonnes of topsoil has been recovered and redistributed on the top of the field (D'Arcy 2012).

The concept of diffuse pollution hotspots is important, since impacts can be significant, yet resolution of the problem may be within the initiative and budget of the specific farmer. Addressing a hotspot might be preferable to making full scale changes across a field for example by switching to conservation tillage, under-sowing with grass, or other options often unfamiliar to Scottish farmers. The work in Scotland to identify the phenomenon of diffuse pollution hotspots and associated site specific technical solutions, suggests a research need to quantify hotspot loads by comparison with whole field losses.

Figure 1.8a Diffuse pollution “hotspot” BMP: flow dissipation and sedimentation sump in-field from buffer strip, Wester Gospetry farm, Greens burn, Loch Leven.

Figure 1.8b Farmer alongside part of excavated soil mound from sump.

Additional measures of the effectiveness of rural BMPs have been presented in the biennial SAC/SEPA Agriculture and Environment conferences, which became established following the success of the first two in 1995 and 1997. For example McKay and Nisbet (2006) outlined a pragmatic BMP for timber harvesting that set a limit to be the area felled within a catchment at any given period, so as to not exceed the pollutant absorption capacity of the water environment. The policy complements the Forest and Water Guidelines best practice advice from the Forestry Commission. Heal *et al* (2006) reported on constructed wetlands for treating surface runoff from farm steadings, which also led to new policy and guidance from SEPA.

1.3.3 Urban BMPs and SUDS in the UK

Monitoring urban BMPs, or SUDS as they became known after 1997, was undertaken in Scotland by a Scottish Universities SUDS Monitoring project, led by the University of Abertay Dundee (see Appendix 3). The SUDS concept advocated a three-fold approach to surface water management infrastructure that was symbolised by the SUDS triangle (D'Arcy 1998) (see Figure 1.9). The central idea was that for whatever primary reason a water feature was being created – flood risk management of runoff, or treatment of entrained pollutants for example, or simply an amenity feature – if carefully designed it should be possible to achieve some value for all three aspects, and thereby improve value for money.

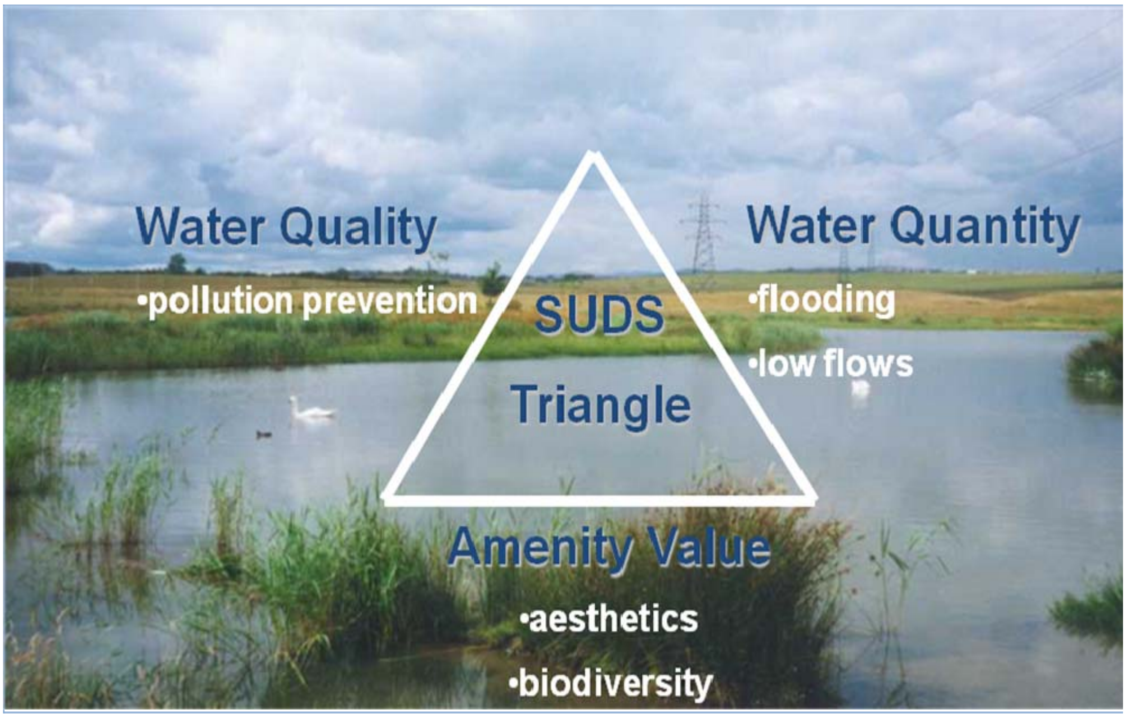


Figure 1.9 The sustainable drainage triangle concept (D'Arcy 1998).

The case for thinking in terms of the SUDS triangle is as follows. Whatever the principal driver for establishing a constructed pond, there is potential to achieve added value:

- Managing water quantity- e.g. a flood storage area could be a concrete box – but if it's a landscaped area of habitat that contributes to amenity interest as well and, if fitted with a multiple stage outlet, then it can achieve quality functions too.
- Managing water quality – large flood attenuation basins – built to store water during major flood events – often have a low-flow channel built through them to allow smaller relatively frequent storms to pass straight through them. A multi-stage outlet on such a facility that would detain the smaller stormwater flows too, allowing sedimentation and self-purification processes.

- Enhancing amenity – Attention to design details, especially at the margins and surrounding landscaping, can make a drainage feature into an attractive amenity.

Thus it is possible to design a surface water management system to optimise benefits for water quality, quantity, and amenity. Prior to formulation of the SUDS triangle concept, single purpose features in Scotland included for example, an amenity pond fed by mains water (e.g. Castle Business Park, Stirling), and an artificial lake constructed in Edinburgh Business Park, S Gyle, which was also fed by mains water, whilst surface runoff was piped to the local watercourse in a new culverted section. Examples of more sustainable developments in Scotland include the retention ponds at the DEX development, Dunfermline. Retention ponds are designed primarily to protect and improve water quality. But since they have large surface areas, only a small increase in depth can store sufficient water to achieve flood risk management requirements. Often protected by reed fringes for safety, at the DEX site these are home to a population of reed buntings, *Emberiza schoeniclus* **-** a LBAP species in Fife. The DEX development thus became an early exemplar of the SUDS concept, and the sustainable drainage triangle for multiple benefits. The Scottish SUDS Monitoring Group sought to assess performance for each of those SUDS triangle aspects. Flow attenuation, as a key performance consideration in relation to pluvial flooding risks, was investigated in relation to permeable surfaced car parks, grass swales, and ponds and basins. Figure 1.10 is from work done as part of that programme (Macdonald 2003).

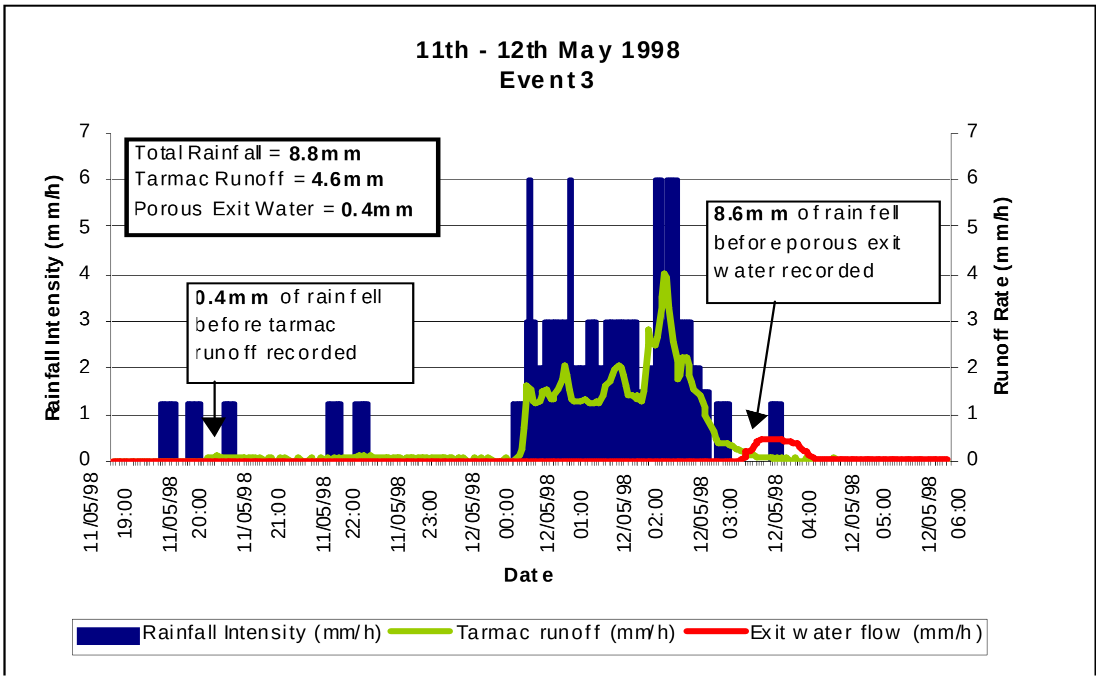


Figure 1.10 Comparative performance of a permeable pavement car park and a conventional blacktop surface, for flow attenuation for measured rainfall events (Macdonald, 2003).

The results clearly show very significant reductions in runoff rates where the permeable surface car park was used. Follow-up work at another permeable surface car park demonstrated the importance of following the supplier's specification for a half metre depth of stone fill to attenuate the runoff; at the second site that was not provided and benefits were far less significant (Macdonald 2003).

The effectiveness of permeable pavement technology for preventing pollution was investigated at Coventry University (Pratt *et al* 1999). The effectiveness of other SUDS for pollutant capture was assessed by the Scottish Universities SUDS Monitoring Group, e.g. retention ponds for motorways and also retail parks and mixed residential/commercial situations; filter drains serving roads and housing, detention basins serving highways, and roadside swales (Jefferies *et al* 1999, Jefferies *et al* 2001).

An important opportunity to evaluate the emerging SUDS technology (BMPs for water quality incorporated into flood risk management in drainage master planning) was provided by the Dunfermline East Expansion (DEX) development at Dunfermline. That development extended over 5.5 km2, and included housing, retail and commercial development, all provided for in a drainage master plan in which SUDS technology was a fundamental element (Campbell et al 2004), From the outset a strategic programme of investigations and evaluation was planned by the University of Abertay (McKissock et al 2001, Jefferies et al 2005, Spitzer 2007) and continued through the Scottish Universities SUDS Monitoring Group, for example sediment assessments by Heal and Drain, (2003), and Heal *et al* 2006, and investigations into the effectiveness of retention ponds at the DEX site in Dunfermline for pollutant capture (Spitzer and Jefferies 2005). The latter study assessed two retention ponds (Halbeath and Linburn), by collecting three sets of data: (i) continuously using sondes, (ii) sampling through storm events, and (iii) manual spot samples. Flow measurements were also recorded. The sonde data was very useful for detection of pollution events where low dissolved oxygen was an indicating parameter, and for the impact of salting roads and other surfaces in winter (evident in elevated conductivity). The continuous traces of flow and water quality provided evidence for the relationship between various pollutants and flow (Spitzer and Jefferies 2005). The peaks in pollutant concentrations generally followed the rise in flows. The balancing impact of the ponds, smoothing peaks in inlet quality and achieving relatively steady and acceptable water quality in the discharges, was evident in the outlet data from both ponds (Spitzer and Jefferies 2005).

The third part of the triangular concept for maximising public value from SUDS infrastructure was amenity. It was convenient to include biodiversity, since to local people seeing wildlife was an element of recreational activities around the ponds and wetlands, for example at Duloch Park, on the DEX site, Dunfermline.

Amenity aspects of SUDS were investigated by Apostolaki *et al* (2006), and more recently by Bastien *et al* (2012). Biodiversity information was collected, primarily by researchers at the Universities of Abertay, Edinburgh and Stirling. The evidence for the biodiversity value of the SUDS features, especially the retention ponds and stormwater wetlands was surprisingly good. For example a population of breeding reed buntings, a local biodiversity action plan (LBAP) species for Fife was discovered of in the extensive *Phragmites* margins of the retention ponds at the DEX site, Dunfermline (Wilby, University of Stirling, pers. com.). Equally notable was the intermittent presence of water voles at the several SUDS sites (see Table 1.4 below). A systematic assessment of the ecological quality of SUDS ponds was undertaken for SEPA by Pond Action (SEPA contract report, summary findings in McKissock *et al* 2001). Table 1.4 summarises the findings. The retention ponds typically supported a High to Very High (conservation value) invertebrate fauna, with Moderate to High Plant Conservation value.

Table 1.4 Measures of Biodiversity from example SUDS ponds (from McKissock et al, 2001, using data from Pond Action (2000) contract report for SEPA)

	Motorola Motorway	Motorola Lower	Freeport Upper	Houston Caw Burn	DEX Calais Wood Wetland
Invertebrates					
No. of spp.	40	37	58	24	40
No. of uncommon spp.	0	1	1	0	0
Conservation value	High	High	Very High	Moderate	High
Plants					
No. of native spp.	17	12	24	13	25
No. of uncommon spp.	3	2	1	0	4
Plant Conservation value	Moderate	Moderate	High	Moderate	High

The subsequent focus of BMP implementation in the UK has been on targeting measures, recognising the heterogeneous nature of landscapes in relation to pollution sources and risks. The diffuse pollution hotspot has already been discussed in a rural context, in the urban situation the publication of event mean concentration data for a variety of urban land uses (Mitchell 2001) has allowed priorities to be derived from published data, and efforts have been made to predict EQS failures on that basis (Ellis and Mitchell (2006). Research effort has also been focused on BMP selection, for example by considering effectiveness in capturing pollutants entrained in surface runoff in any given type of BMP (Scholes et al 2005). In view of the relatively low contamination levels compared to process effluents, for example hydrocarbons, it is not unreasonable to anticipate that conditions could be encouraged in BMP design to favour degradation, rather than merely capture of stormwater pollutants (Campbell et al 2004). This has been investigated by Napier *et al* (2009, 2011) who found that soil/vegetation BMPs/SUDS do indeed perform better than wet ponds for removal of hydrocarbons from sediments captured by the systems. That has important implications for BMP selection due to significant expense for disposal of oil contaminated sediment.

1.4 Bringing Measures into Practice

1.4.1 International Context

Definitive BMPs guidance was published in the early 1990s, after a pre-requisite period of investigation of effectiveness of the techniques, costs, maintenance needs, and other considerations (USEPA 1993). That guidance covered river management, farming, forestry, urban development, and harbours and recreational boating. Implementation of BMPs was achieved in USA by three inter-dependent mechanisms:

- Provision of technical guidance to introduce or encapsulate best practice, and to explain function and application of the range of techniques.
- Tax-payer funded aid to implement BMPs (e.g. for agricultural sector), or other economic instruments.
- Regulation of polluting sectors to prevent pollution, for example by requiring BMPs (especially for urban/industrial sectors).

These three mechanisms are sometimes seen as alternatives, but in practice businesses and administrations work in a climate where all three mechanisms exist, but the balance varies, and sometimes one mechanism can predominate (Campbell et al 2004).

1.4.1.1 Encouraging Implementation of Rural BMPs in North America and Europe

The same year as the USEPA coastal zone guidance was published (USEPA 1993), a major report on soil and water quality was published by a committee of the US National Academy of Sciences (Committee on Long-Range Soil and Water Conservation, 1993), setting out evidence of the diffuse source pollution problems and also of the effectiveness and limitations of various rural BMPs. That report was initiated in 1989 when the US Board of Agriculture of the National Research Council was asked to convene a committee to assess the science, technical tools, and policies needed to protect soil and water quality while providing for the production of food and fibre from US croplands. The report encapsulated a mass of technical detail on which the local and regional agricultural advisory services were able to base guidance to farmers and allocate funds for abatement programmes.

In the European Union (EU), food production subsidies under the EU Common Agricultural Policy were working against pollution prevention best practice. For example the numbers of sheep in the UK increased from 22 million in the 1940s to just below 44 million in 1993, whilst across the EU the number of sheep had more than doubled over 20 years (Sansom 1999).

Subsidised intensification was also a feature of the dairy, arable and other farming sectors engaged in food production. Novotny (2000) highlighted the lack of economic consequences for farmers for example, if their activities don't impact their own businesses, but cause impacts for the water resources of users downstream. In economic terms, Novotny argued that a mechanism is needed to make producers responsible for the cost of the damaged environment (Novotny 1988, 2000). It has been argued that pollution in general is an economic externality caused by the failure of the market to include in the economic value of the economic output the cost of damage caused by disposal of wastes into the environment (Jordan 1999).

The externality issue is classically addressed by regulation; conditions in a licence or some other statutory control to require pollution prevention and control. Novotny (2003) argues that the practical difficulties of regulating diffuse sources would require standard permits that would be unfair in some circumstances, but insufficient in others. On that basis, Novotny argued that voluntary adoption of BMPs by farmers, backed by taxpayer support for the measures, is justified. That argument however does not recognise that economic instruments are merely a different mechanism; a switch of emphasis does not necessarily mean that the problems of what measures on which farm in which catchment of a particular sensitivity suddenly disappear. The site specificity issue can only be resolved by site specific advice, which is expensive, whether in relation to a regulatory or a voluntary regime. Voluntary application of individual polluter effort to find solutions to problems of course should produce site specific solutions (see next section), if enough technical understanding is there within the sector. But that therefore requires site specific technical advice and expense, with no enforceable reward for outlay if merely a voluntary participation in a tax-payer funded scheme. Where projects have achieved measurable successes in USA, for example Lake Champlain (Meals and Hopkins 2002), targeted specialist advice has been coupled with funding for implementation of BMPs.

In Europe the EU Common Agricultural Policy (CAP) allocated tax-payer funded support to farmers on a production basis (e.g. per capita payments for livestock on a farm). In addition, some funds were available for farmers to try to mitigate the polluting consequences of intensive production of crops and livestock. Regulation of pollution from farms was inconsistent across the EU at that time, and the CAP funding would have required a draconian level of regulatory and very expensive educational effort to counter its environmental impacts. Campbell *et al* (2004) considered the various drivers for effecting a change in behaviour such as adoption of best management practices. The situation is illustrated diagrammatically in Figure 1.11 below;

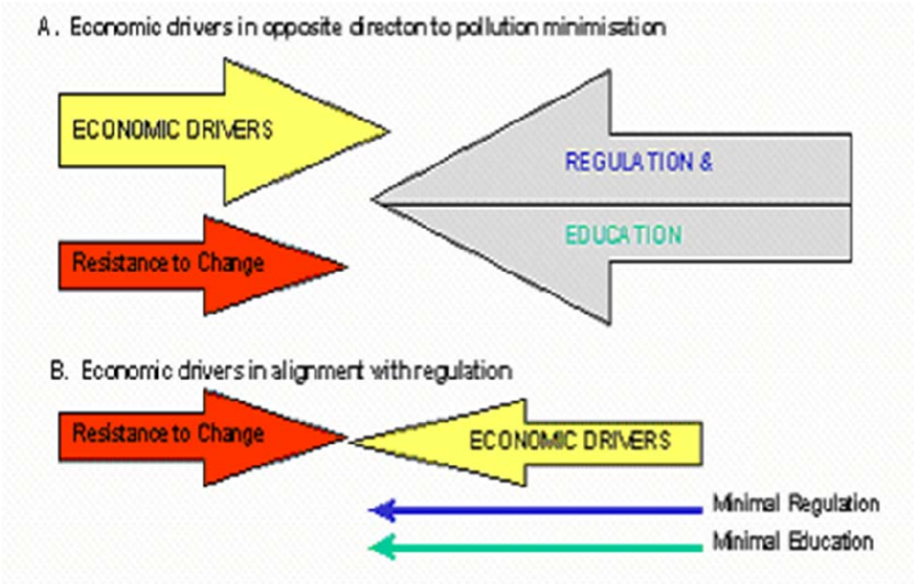


Figure 1.11 The case for alignment of all three drivers towards environmentally more sustainable practices (from Campbell et al 2004).

In 2000 at an international diffuse pollution conference in Bangkok, a group of European delegates proposed that the importance of the EU Common Agricultural Policy (CAP) be recognised by the Group, and an initiative be led over the next three IWA diffuse pollution specialist group conferences to address the need for CAP Reform, and identify and make the case for alternative support schemes that would have integral environmental support practices as conditions of payments. The first consequent CAP reform Workshop was held, led by Frost *et al* 2004 in Amsterdam in 2002; and the initiative was brought to a close at the IWA diffuse pollution conference in Dublin in 2003, from which a conference resolution for CAP reform was produced. The Dublin conference was attended by EU officials and Irish government representatives, including the Minister for Agriculture. The conference Resolution was taken up by the then President of IWA, Dr. Laszlo Somlyody, and advocated in Brussels (Somlyody 2005). The final shape of

CAP Reform did uncouple payments from production, but failed to require environmental practices. Thus it was simply payments. The overall size of payments was set on a gradually reducing scale, and some tax-payer savings were to be made available in agri-environmental support schemes including addressing diffuse pollution.

1.4.1.2 Driving Urban BMPs into Routine Use

The implementation of urban BMPs has been managed very differently in USA and Europe. Urban BMPs were included in the USEPA 1993 guidance, together with the other sectors. In addition, sector specific guidance manuals had been produced earlier for example Schueler 1987, Schueler *et al* 1992, as well as quickly following the USEPA (1993) guidance, e.g. Horner *et al* (1994). In North America, the role of regulation in implementing urban BMPs, has been much more direct and accepted than the equivalent need for BMPs in the rural sector. Stormwater (Separate Sewer) Permit Regulation is described in Novotny (2003), noting that stormwater is defined as storm water runoff, snow melt runoff, surface runoff, street wash water related to street cleaning or maintenance, infiltration and drainage. The USEPA rules seek to establish NPDES permit application requirements for:

- Stormwater discharges associated with industrial activity.
- Discharges from urban separate sewer systems.
- Discharges from construction sites.

Urban stormwater, which is considered by many to be nonpoint pollution, was declared a point source in order to achieve control (Novotny 2003). Originally, only industrial dischargers, large urban centres (greater than 10,000) and construction sites greater than 2 ha, were required to file for a permit. By 2003, most cities and urban areas with a population density greater than 385 people per square kilometre, were required to apply for a permit to discharge stormwater, and many cities use that requirement to prepare comprehensive drainage plans to address pollution as well as flood control.

In many cities in America and Europe, BMPs for urban stormwater are driven by flood risk issues. Seattle and Portland both have ambitious projects to disconnect rainwater from drainage systems, especially important on combined sewers. BMPs may be required as a means of allowing surface water to pass directly to the water environment, rather than into the sewer. That has also been done in Malmo, Sweden (Stahre 2006), and elsewhere. Planning is a key regulatory option to enable use of urban BMPs to be a requirement for new developments and redevelopments (see Stahre 2006), and in Australia too (FAWB 2009). Regulation, either through environmental agencies or planning authorities is the simplest way to overcome externality issues, which is not to say that economic aspects and education are not also important too (e.g. Chesapeake bay report on The Economics of Stormwater BMPs in the Mid-Atlantic Region (Brown and Schueler 1997).

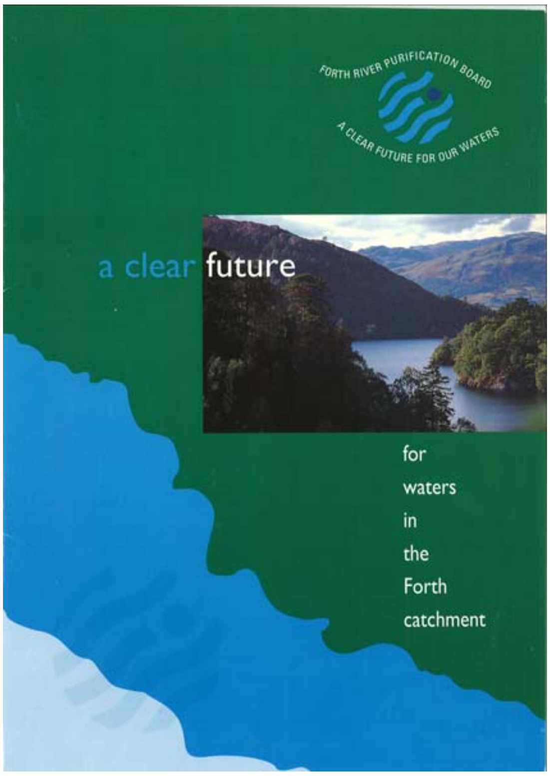
1.4.2 BMPS into Practice in the UK

Novotny (2003) set out a view of the three factors that contribute to diffuse pollution, and which need to be considered in trying to reduce pollution, and in section 1.4.1.2 above, the rationale for an integrated approach to implementing pollution prevention and control measures was set out. The work in the UK was part of that international debate (see chapter 7, Campbell *et al*, 2004). In view of the quantity a nd variety of activities in each aspect of the work to bring BMPs into routine use in the UK the following account is structured in three sections:

- Education and influencing
- Economic factors
- Regulation

1.4.2.1 Education and Influencing in the UK

The efforts of the FRPB were led by an awareness raising campaign (FRPB, 1994). That approach necessitated a pre-requisite effort on gathering factual material, as noted under UK Impacts above in section 1.2.2. That was then used to inform campaign material and be a basis for papers and presentations. Figure 1.12 shows the campaign document produced: A Cleaner Future for our Waters (FRPB, 1994).



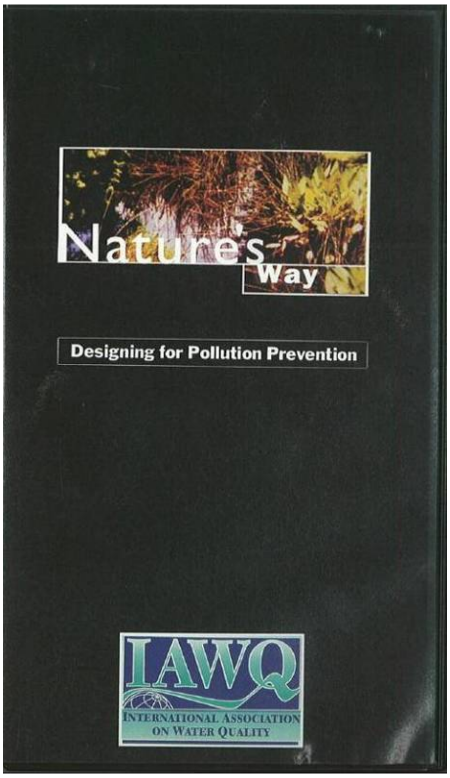


Figure 1.12 FRPB Campaign publication: A Clear Future for Our Waters (1994), and IAWQ video Nature's way (launched 1996 in UK, and included in the IWA book by Campbell et al in 2004).

The campaigning material and several conferences (see next sub-section) led directly to an invitation from the Diffuse Pollution Specialist Group of the IAWQ (subsequently merged to form the International Water Association, IWA) to produce an international diffuse pollution video, Nature's Way. That was completed in 1995 and launched at the inception of the new environment agencies in Scotland and England in 1996 (Pratt 1996) and subsequently internationally. A supporting text book did not get completed until much later (Campbell et al 2004). The Nature's Way video established diffuse pollution as a legitimate business issue for the two new UK agencies, since both of their CEOs featured in the film.

1.4.2.2 Sector Engagement and Conferences

The importance of sector engagement was recognised and a series of presentations at meetings of professional bodies associated with each key sector were organised. Often support was given to such an organisation, by suggesting a diffuse pollution theme for their annual meeting, or offering a theme for a special conference, and FRPB and later SEPA was able to bring in an international speaker with a decade or more of relevant experience (e.g. Scottish Hydraulics Study Group meeting of 22nd March 1996, just prior to launch of SEPA in April 1996).

For effective sector engagement, it was recognised that top level heads of organisations were necessary as indicators of organisational buy-into the issues. Issue champions and forward looking leaders cannot achieve the aims and purposes of the organisations within which they work, if top level managers and Directors are unaware of the issues and thus do not support pro-active action. Hence when the first Diffuse Pollution Conference in the UK was convened by staff in SAC and FRPB, the Principal and Chief Executive of SAC was invited to open the conference and thereby bring the agriculture sector on board with the issues (Thomas, 1996, Halcrow, 1996).

Similarly, the placement of key people as session chairs also became a tactical sector engagement issue, even though counter-intuitive to many conference planners who naturally sought to ask well known issue champions to be session chairs. The rationale developed over several conferences and seminars, especially for the urban sector when trying to introduce

BMPs/SUDS, was to invite a potential blockage figure from an essential stakeholder organisation to chair a session. The session chair role requires listening to the facts presented in at least 3 papers on the topic. It also should require some homework in preparation so as to be a bit up to speed on the issue and able to handle questions, promote discussion after papers, and not look foolish. In that way many indifferent or even hostile senior managers were able to become more positively engaged in diffuse pollution issues. Sometimes, of course, the figure head organisational management representatives were already on board and well briefed and aware of many of the aspects of the problems and solutions.

1.4.2.3 Sector Engagement and Publications in the UK

In parallel with conferences and seminars, a series of sector engagement and awareness raising articles were published in trade and technical press, initially working with a professional technical journalist e.g. Alexander and D'Arcy (1998). Later, direct publication was routine, e.g. D'Arcy 2005, 2006 and 2007. Co-authorship of technical publications was also recognised as a practical mechanism for engagement on both intra- and inter-organisational levels (see Appendix 2).

Two partnership publications are also important in understanding sector engagement, both published first by FRPB in partnership with the appropriate stakeholders, then subsequently by SEPA and stakeholders, and both publications were popular enough to be reprinted several times. The first was Buffer Strips, published by FRPB/SEPA, FWAG and SAC. The small booklet set out reasons why buffer strips could be desirable features on a farm, and an indication about means to fund them. As a practical measure to address diffuse pollution, the buffer strips idea was a simple flagship for carrying the diffuse pollution concept and issue to the agricultural sector. It was championed by both of the sector partners for several years, with events held at the farms of leading farmer businessmen “the farmers’ farmer”.

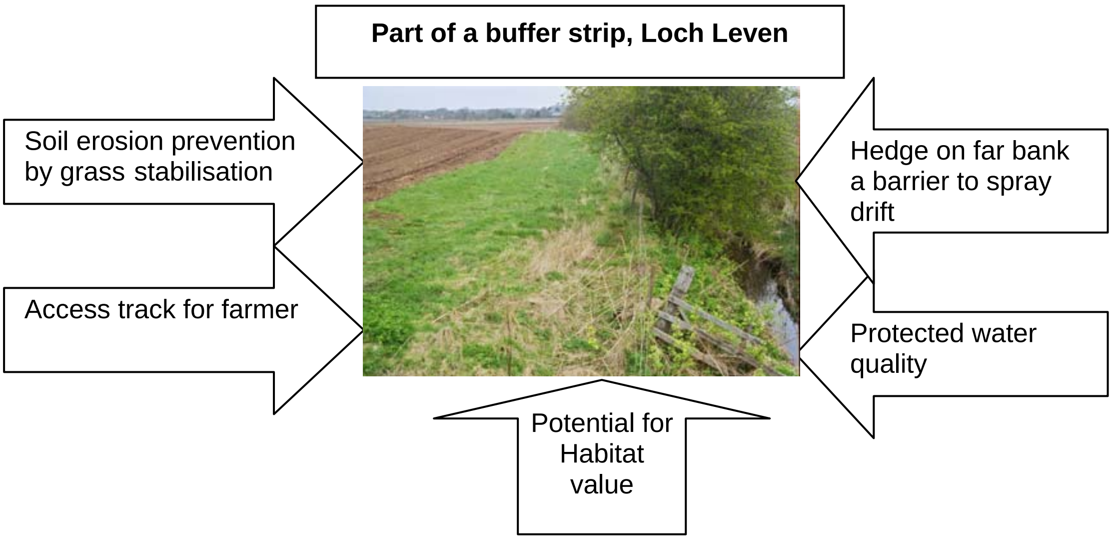


Figure 1.13 Linked benefits suggested by the buffer strips initiative of FWAG, SAC and FRPB (later SEPA). (See D’Arcy and Frost 2001).

An equivalent publication for urban BMPs was published at the same time (1995) by FRPB, after limited consultation with enthusiasts in the sectors, but then appeared as a *fait ccomplish* to sector leaders who had not been engaged in the process. It became a firmly regulator owned publication, under the banner of the UK “Environmental Alliance” of SEPA, Environment Agency and Environment and Heritage Service of Northern Ireland, (SEPA, 2000). It was not a partnership publication with stakeholders however, and when the Sustainable Urban Drainage Scottish Working Party (a stakeholder group) was convened in 1997, one of the first actions was to initiate a project to develop a stakeholder partnership led guidance manual, finally published three years later (CIRIA 2000). The need was established by evaluation of sector awareness of factors affecting use of the various BMP techniques (McKissock *et al* 1999).

The approach developed in the course of those two contrasting examples demonstrated not merely engagement as it can sometimes seem to be, when a regulator meets with sector representatives to tell them what to do, but genuine co-development of ideas and identification of barriers, testing the validity or otherwise of the latter, and co-developing ways forward. That model for a sector engagement process was published in Campbell et al, 2004, and is given below in Figure 1.14.

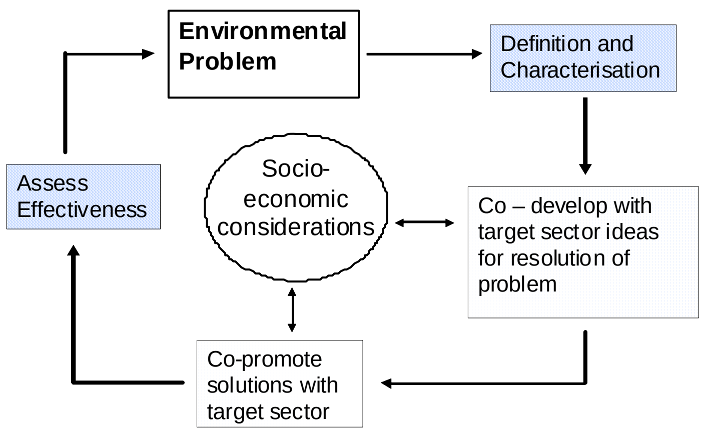


Figure 1.14 Stakeholder engagement (from Campbell 2004, p 233).

It was recognised that publication of technical guidance was not necessarily sufficient to achieve effective actions. The technical guidance manual for SUDS (CIRIA 2000) was therefore evaluated in another sector engagement process (McKissock et al (2003). Figure 1.15 shows the preferences of the sector for different forms of technical guidance.

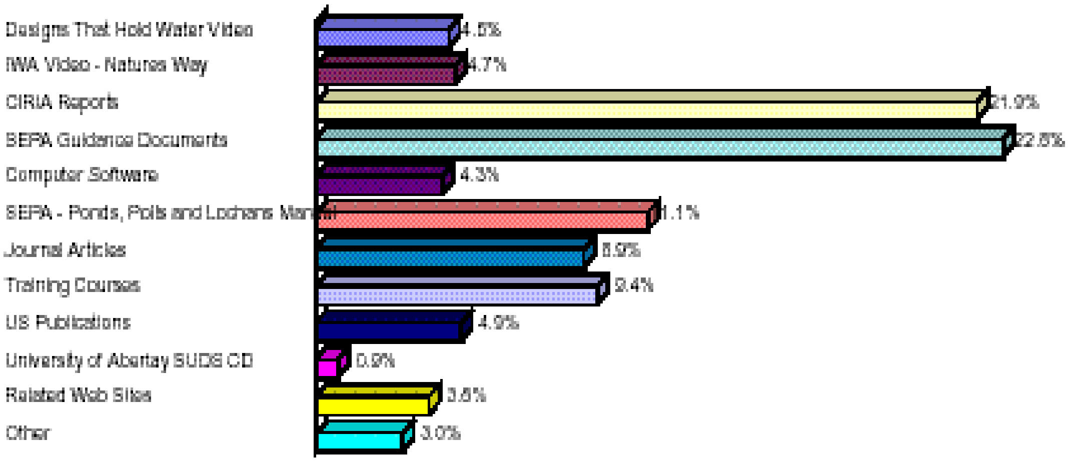


Figure 1.15 Preferences of urban sector for different forms of technical guidance (from Mckissock et al 2003) .

Although the environment agencies joint guidance publication was not a stakeholder developed publication, it was the most valued by stakeholders (developers) – reflecting the importance of regulatory drivers. The review influenced the preparation of replacement SUDS guidance by CIRIA (CIRIA 2008), and the planning of subsequent partnership publications such as SUDS for Roads (2010). A similar evaluation of guidance was also undertaken for rural sectors, as part of SEPA's diffuse pollution initiative.

1.4.2.4 Economic Factors in the UK

The importance of the economic environment in which farms, forestry, commercial and industrial businesses work, is often seen as a deterrent to pollution prevention activities. For rural sectors the importance of CAP reform has already been discussed in its European context; in particular the international IWA initiative. As part of the evidence for CAP reform, Frost *et al* (2004) showed that the most seriously polluting type of farming was also the least viable economically; dairy farming in Scotland.

Rural BMPs were also promoted in Scotland by a Scottish Government driven partnership initiative: the Four Point Plan (Audsley 2004). That effort sought to simplify presentation of the large range of potentially useful BMPs for farmers by presenting them in a four point plan for a farm. Economic drivers were highlighted, for example nutrient value of organic wastes from livestock farms, and seen as a positive, non-regulatory attractive way to encourage more environmentally safe practices with farmyard manure and slurry. Nutrient budgeting in NVZs provided another rural example of a cost saving option.

Most recently, a government driven partnership arrangement was established in Scotland, whereby the principal tax-payer funded organisations visiting farms would co-operate. The bulk of farm inspections each year are undertaken by the Scottish Government staff. Whilst the aim was "one stop shop" inspections to help the farmers, and better regulation (see below), an additional benefit was the scope to agree on financial deterrents to farmers for polluting activities, by government inspectors with holding a percentage of the farm payments.

For urban BMPs or SUDS, economic issues are addressed at least in part by a stakeholder partnership approach as in Figure 1.13 above. The key to making SUDS cost effective and at least cost neutral is to demonstrate implementation as an alternative technique, rather than an “add-on” measure with consequent added costs for developers.

There have been calls for economic drivers to be enhanced by discounting water charges for premises that have SUDS features serving them. Plans have been made to start with industrial premises, rather than households.

For both rural and urban sectors, a key part of persuasion to implement BMPs was linkage to additional benefits. Thus some rural landscape measures such as buffer strips were funded by set-aside payments, others by habitat creation payments, or forestry grants. In urban developments, it was hoped that SUDS features would be accommodated within the green space allocation already required by planning authorities, and not be an additional land-take. There is still scope for urban developers to make better use of landscaping opportunities to achieve cost-savings for SUDS.

1.4.2.5 UK Regulation

Regulation, especially in parallel with the associated drivers of education and economic environment, is essential to cost effectively change practices (see chapter 7 in Campbell et al 2004). It is less expensive than tax-payer funded subsidies - and such economic instruments have an equivocal record as drivers for environmental improvements (see Swedish case study in Campbell et al 2004, pp. 2005-6), unless underpinned with regulations and enforcement. Regulation is the least expensive approach for ensuring action across a sector to comply with best practices for environmental aspects of business activity. It can still fail if there is no enforcement.

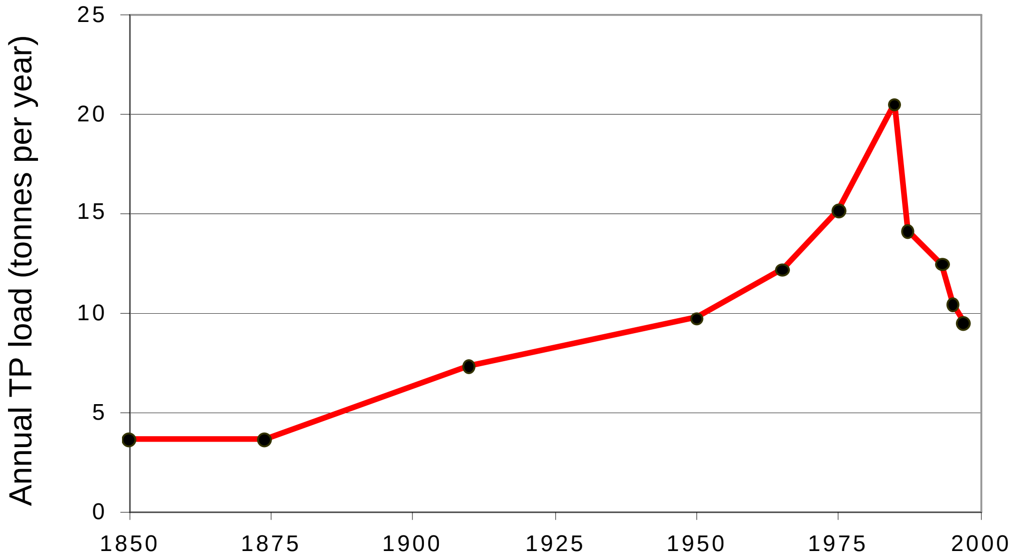


Figure 1.16 Regulation with no enforcement until 1987 (from D'Arcy et al 2006).

Figure 1.16 shows the impact of enforcement action to stop chronic and increasing levels of pollution in Loch Leven (D'Arcy et al 2006). As well as the evidence from environmental studies quoted in Campbell et al 2004, every day experience of everything from speeding fines and littering to smoking bans attests to the importance of regulation where behaviour change is believed by government to be important. Economic instruments and still less educational efforts do not have recourse to enforcement and ultimately action in the courts.

Nutrient management best practice in NVZs was reviewed by Goodlass (2006) who reported substantial reductions in nitrogen being applied for most crops except potatoes in NVZs, by comparison with adjoining non-NVZ designated farmland. D'Arcy *et al* (1998) found water quality improvements in one small rural stream where enforcement action taken, but not in a similar one where such action was not attempted.

As well as the EU Nitrates Directive already noted, the EU Bathing Waters Directive has been an important regulatory driver in the UK for action first to quantify diffuse sources, then to initiate appropriate actions. The threat of action by the EU against the UK government, stimulated the Scottish Government driven partnership initiative that has already been noted, involving thousands of farm visits by SEPA and implementation of a series of BMPs in livestock catchments (notably in the paired rivers study funded by Scottish Government, which successfully demonstrated the efficacy of stream fencing to exclude livestock, (Kay *et al* 2007). Although SEPA took very little direct regulatory enforcement action, despite the seriousness of pollution problems discovered from farms in the South West of Scotland, the threat EU enforcement action was always a key point made clear in sector engagement discussions.

The EU Water Framework Directive requires action to quantify and to address diffuse sources of water pollution. A novel regulatory regime was developed in Scotland through the CAR regulations (2006) enabled under the WEWS Act 2003, (see D'Arcy et al 2006). Those regulations established a category of statutory requirements that do not require registration or a licence from SEPA. They are simply legal requirements nonetheless, analogous to tyre tread depth requirements on a car, or the ban on smoking in public places. The very large number of diffuse sources precludes the application of conventional licensing approaches to statutory control of polluting discharges. The 2006 measures are known as General Binding Rules (GBRs). The next step, and a leap of imagination for conventionally minded regulators, is to recognise that although often individually minor, the collective impact of so many sources means they are important. That means there needs to be an inspection and enforcement regime. The large numbers mean a sampling approach is required, rather than visiting every source every year. Such an approach was first implemented in partnership with the Scottish Government and other agencies visiting farms, under the SEARS partnership. A regulatory regime for urban sources could be in partnership with local authorities, and benefit from use of statutory fixed penalties, which would in general be more appropriate for individually minor sources than recourse to court actions (D'Arcy *et al*, 2006).

Finally, the role of regulation to establish a market for specialist skills and products is often not recognised. Figure 1.17 represents the relationship between regulatory regime, technical guidance, and economic instruments in establishing best practice innovations against a background of existing guidelines and economic environment. By establishing the requirement to use best practice techniques, the regulatory regime creates a reliable market for technical expertise to be developed and new commercial products too.

For example after the CAR regulations established the requirement for all new development after 2006 to use SUDS technology for surface water drainage, the local authorities roads departments accepted the need to know about SUDS and to modify their long-existing roads and bridges guidance or rather to supplement it with a new SUDS for Roads guidance publication (SCOTS 2010). That opened a Scottish market for the sort of proprietary drainage BMPs developed in USA and elsewhere, for example the Hydro International Filterra unit was introduced at that time to the UK market. The new policies and guidance also clear the way for the technology to be an alternative rather than an add-on feature at extra cost.

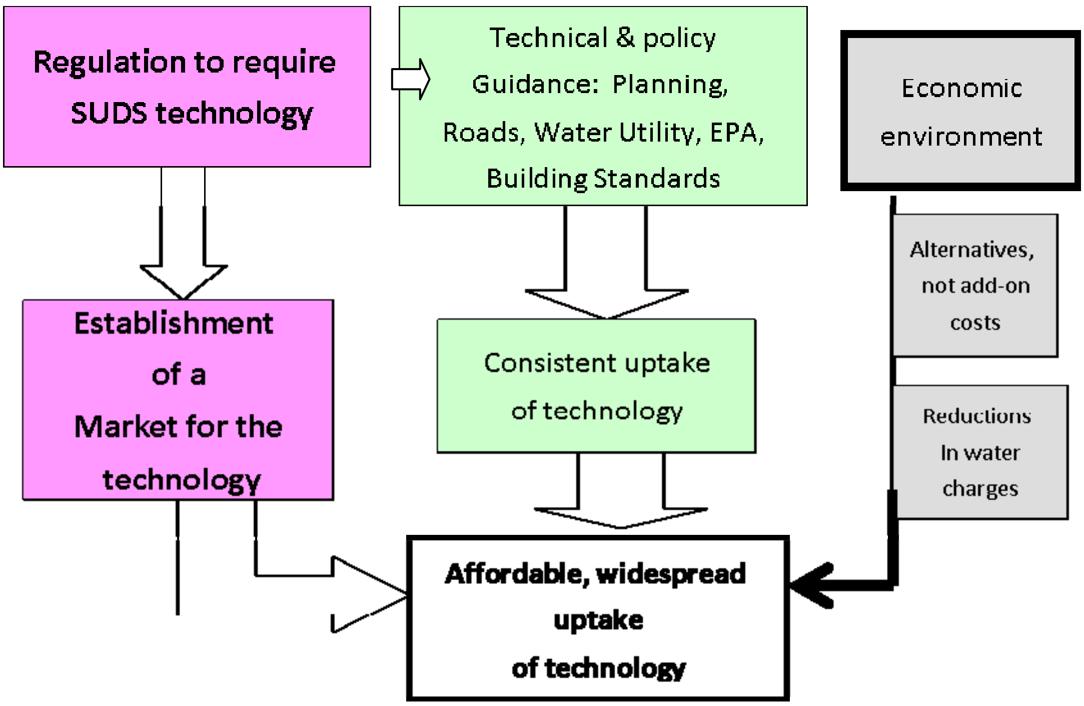


Figure 1.17 Showing role of regulations to establish the market (D'Arcy et al 2012).

Figure 1.17 also illustrates the impact of statutes on guidance and policy within an organisation. After the WEWS Act 2003 established a remit for Scottish Water for public SUDS, new guidance was commissioned by the utility that incorporated non-statutory guidance on the pre-conditions for vesting new SUDS with Scottish Water. The organisation also created a SUDS specialist post and began a programme of training for engineers, planning liaison staff and asset managers.

The statutory requirement for SUDS - if adequately enforced - should also lead to “fit for purpose” facilities being created in future, as the pre-requisite technical knowledge and experience amongst consulting engineers and developers has to be developed.

1.5 Introduction to the Reviewed Papers: From Evidence to Solutions

The international evidence about the nature of diffuse pollution and means to manage it as set out in this introductory chapter is drawn from the published literature, including guidance manuals and grey literature. For the UK aspects above, some unpublished material has been quoted too, where SEPA investigations for example produced important findings. Unfortunately in such cases, DPI reports, papers given at seminars and conferences but not published in peer reviewed journals typically are ephemeral, with limited effective life as records or arguments. Some of the outputs from such grey literature were published at least in summary in Campbell et al 2004 (and some here), but for most important data and findings, publication in academic papers has proven to be the safest means to provide an ongoing record. The selected published papers in the following three chapters document the investigations and findings, the approach as it developed on the basis of the evidence established, and application of experience and ideas to develop an appropriate control regime.

"A problem cannot be understood and managed until it can be measured" (anon.)

CHAPTER 2 – Characterising & Quantifying the Problem

Characterising and Quantifying the Problem *(papers presenting information to characterise the nature and significance of diffuse pollution as a problem).*

2.1 Introduction

Defining the nature and severity of a problem is a pre-requisite for the identification of solutions and means to implement them. It is therefore the first stage in the development of a strategy for resolving it. It was surmised at the outset that direct engagement with the sectors involved in the pollution problems would be essential, to harness their specialist knowledge and to gain sector understanding of the problem as a preliminary stage to buying-in to the solutions.

Eight papers are discussed in this Chapter (sections 2.2-2.9). Although they may appear at first comparison one with the next, to be unrelated, they are all key steps in changing awareness of diffuse pollution. Sometimes the investigations initiated had to be narrowly within a single sector. Thus, for example, the first paper quoted below, (D'Arcy *et al* 1999) is concerned with industrial pollution, whilst the second was part of an agriculture conference, the third was part of a built environment conference for drainage engineers. All three were necessary to target key sector researchers and regulators who themselves had very narrow research interests. But the commonality of the research needs and the technical approaches to prevention and control was evident to other environmental scientists, leading to an invitation to write the UK impacts and initiatives paper (D'Arcy *et al* 1998).

Figures, tables and page numbers quoted from those published papers in the text below are underlined to identify key aspects of the original papers, and the full papers to which they refer are given in Appendix 1.

The eight papers (2.2-2.9, below) cover a series of steps in the characterisation and quantification work needed as part of developing a strategy for managing diffuse sources:

(2.2) Making the shift from point source to diffuse source pollution for regulators; this industrial paper, (D'Arcy et al 1999), led directly from earlier work on industrial estates (D'Arcy and Bayes 1995).

(2.3) Rural diffuse pollution: a new UK issue was introduced for environmental scientists and managers, as well as rural sector advisors and other sector stakeholders.

(2.4) Urban diffuse pollution and best management practices was the urban equivalent for the UK of (2.3).

(2.5) An early assessment of diffuse pollution by UK regulators was achieved in this paper which brought together for the first time for this issue, policy leads from the largest UK environment agencies.

(2.6) Urban diffuse sources of faecal indicator organisms (FIOs) addressed a hitherto overlooked aspect of diffuse pollution in the UK

(2.7) A national urban stream sediments survey of toxic and persistent pollutants was a unique (for the UK) national assessment of the quality of urban waterbodies.

(2.8) Road traffic as a source of toxic and persistent pollutants was an initial investigation of a major source of those pollutants; a first attempt at a national assessment.

(2.9) A cross sector identification of issues, key pollutants, and pollution processes that comprise diffuse pollution was set out in this paper, summarising the types of impacts and characteristics of the problem.

2.2 Industrial Effluent Control and Waste Minimisation: Case Studies by UK Regulators

D'Arcy BJ, Todd RB, Wither AW (1999) Water Science and Technology, Volume 39, Number 10, 1999, pp. 281-287

This paper brought together staff from SEPA and the Environment Agency with the aim of demonstrating a new approach for engaging with industry, leading ultimately to a new approach to the control of pollution of the water environment by industrial premises. Although focused on point sources, it was one of the first papers in the UK at least, to highlight the importance of surface water drainage as a pathway for pollutants from industrial premises to reach the water environment. One of the secondary aims was to engage with staff from the UK environment agencies to try and raise interest in diffuse pollution. AW Wither subsequently became the leading figure for the EA to investigate and champion new technical measures to address diffuse source problems on bathing beaches. The paper was conceived by the author, based on an original idea from working with industry on Merseyside and written up as an unpublished report with AW Wither for North West Water. Additional Scottish examples were obtained from co-author, Bob Todd.

Key contributions of the paper to the development of a diffuse pollution strategy were:

a) Identification of surface water drainage as a pathway for pollution (p.286)
b) Highlighting that pollution load reductions should not simply be a matter of quantification followed by treatment plant, but instead focus first on source controls and pollution risk reduction actions (p.286).
c) Demonstrating that such actions can save a business money as well as reduce pollution (table 1, p.282).
d) The paper provided a factual basis to underpin a paper written by the author for SEPA management in 2006 to establish a Waste Minimisation Initiative as a national project (WaMI) that ran for several years. Reducing wastes stored out of doors on industrial estates is an important strategic approach to reduce contamination of surface water runoff.

2.3 Diffuse Pollution and Agriculture in the Forth Catchment

D'Arcy BJ, Ridgway IM, Marsden MW and Sargent RJ (1997). In Petchey A, D'Arcy BJ and Frost CA (eds): Diffuse Pollution and Agriculture. Scottish Agricultural College, Aberdeen. ISBN 1 85482 575 5

This was the first UK paper, by a regulator or researcher, specifically on diffuse pollution of the surface waters of a major catchment (the Forth). It was presented in the first UK conference on the subject (Petchey et al 1996), initiated and co-organised by the author (see table 1.2 for antecedent papers that were associated with groundwater issues).

It was an effort to get the sector based scientists to understand the environmental issues associated with routine agricultural practice. And, equally important, to help the environmental scientists appreciate the rural sector considerations (<u>p. 4 para.3</u>). The engagement of the sector with the environmental scientists was a major achievement and by popular demand from all sides of the rural scientific community the conference was repeated ("Diffuse Pollution 2") in 1997, with SEPA taking over the regulatory partnership from the former FRPB, and thereby endorsing the issue as a national priority. The SAC/SEPA conferences became institutionalised, on a biennial basis. The conference and its lead paper had a major impact on the workings of government/regulator/sector relationships and working groups, for example the stakeholder forum for the agriculture sector that brought together regulators, government and the publicly funded advisory organisations associated with agriculture (Scottish Agricultural Pollution Group, SAPG).

SAPG had hitherto principally met and reported the impacts of the agriculture sector by compiling annual statistics on the numbers of pollution incidents. After the two SAC joint conferences the focus of SAPG began to switch to a more rational, broader understanding of agricultural impacts on the water environment. The Scottish Government's code of good agricultural practice was re-written with a new section on diffuse pollution (contributed by the author). As a exercise in knowledge transfer this paper and the conference for which it was the flagship contribution from the environmental side, was therefore a significant success and a land mark in the development of diffuse pollution understanding in the UK.

Key contributions of the paper to the development of a diffuse pollution strategy were:

a) Identification of key classes of rural diffuse source pollutants: suspended solids, phosphate, nitrate, pesticides, and organic matter (e.g. in livestock contaminated drainage); (<u>p.3, "need for new ideas" paragraph and pp. 4-12</u>).
b) Initial indications of extent of the issue (<u>nutrients in rivers pp. 8-9; lochs and phosphorus pp. 10-11; tidal waters and nitrogen p.11</u>)
c) Initial indications of importance of the issue in a major catchment in Scotland (<u>pp. 1-3 and figures 2-3</u>).
d) Involvement of specialist (pesticides, nutrients, hydrology) colleagues as co-authors to ensure a breadth and depth of coverage of the issues in this first effort to establish diffuse pollution as an issue to be taken seriously.

e) Identification of potential routes to solutions (BMPs and how to implement such measures – pp. 13-15).

The paper was conceived and mapped out by the author who wrote pp 1-3, table 2 from the pesticides section (the rest of latter contributed by Ridgway), the silt and organic wastes sections (pp. 4-5, and 12-13 respectively (Marsden contributed the rivers and lochs nutrient sections) and the lead author (D'Arcy) wrote the rest of the paper.

Later papers in that conference considered nutrients, pesticides and organic wastes, but no other authors highlighted the importance of silt (or sediment, suspended matter) as a significant pollutant in its own right (see USEPA 1990), as well as a carrier for other contaminants such as nutrients and toxic substances. The observations written by the author on pp. 4-5 still stand, even now (except perhaps it would have been better to use sediment, or suspended solids as the term for the pollutant, rather than silt).

The paper was unusually long, reflecting the effort to present a persuasive amount of data, new terms, mindsets and insights to an initially sceptical audience (it was the first diffuse pollution conference for agriculture in the UK).

2.4 A New Scottish Approach to Urban Drainage in the Developments at Dunfermline

D'Arcy BJ (1998). Proceedings of the Standing Conference on Stormwater Source Control. Vol. XV. The School of the Built Environment, Coventry University, Coventry.

This paper was originally titled "Urban Best Management Practices" in order to introduce that concept to UK engineers and others to whom the paper was targeted. But it was published under the title "A new Scottish approach to urban drainage in developments at Dunfermline" as an action by the reviewing editor, since that was the title given to the author when inviting the presentation, and the term 'urban BMPs' was not welcomed by the editor. It was published in the series of proceedings of a conference series established by Professor Chris Pratt at The School of The Built Environment, University of Coventry: the Standing Conference on Stormwater Source Control. There were several strategic reasons for initiating this programme of research with this type of publication. The conferences had a good reputation for presenting new ideas and exchanging international experiences, and they attracted consultants and university researchers, so papers presented there had a good chance of influencing those two key target audiences. Initiated in 1990, by 1998 the standing conference was the main drainage event in the UK that sought to explore alternative technological approaches to stormwater management. Securing the mainstream support and interest of those urban drainage and environment enthusiasts was an essential starting point for moving academic research and innovation into mainstream practice in the UK.

This paper sought to add water quality considerations to the hydrological interests that had hitherto been the principal drivers for the Coventry meetings. Prior to this paper, most contributions to the Standing Conference meetings had been by civil engineers, typically with flooding or groundwater recharge as principal interest. The exceptions had been two papers in 1995 by the author that highlighted the problems of industrial estate drainage (D'Arcy and Bayes (1995) and very tentatively introduced ideas about BMPs (Bayes and D'Arcy, 1995), both written primarily by this author. The paper aimed to present the water quality drivers for using innovative surface water techniques and to introduce the techniques needed for attenuation within the drainage system for the unavoidable level of urban contamination. The structuring of the paper in two halves, the first half of the message highlighting the failures of conventional drainage philosophy to protect the water environment, was a key step in matching the rural paper quoted in 2.3, to establish the credibility of the case for a need to accept diffuse pollution (alongside the better recognised hydraulic impacts of urban drainage) as an important issue, prior to building a management strategy.

Key contributions of the paper to the development of a diffuse pollution strategy that were important or innovative in the UK at that time were:

a) Identification of pollutants and pollution pathways for urban drainage: highlighting diffuse pollution processes, such mobilisation of surface contamination in wet weather and discharge as contaminated runoff, rather than concerns about combined sewer overflows, or discharges from sewage treatment works that had hitherto dominated water quality considerations for drainage systems in the UK (section 1.2).

b) It was an early effort (first in the UK) to indicate potential significance of non-human urban diffuse sources of faecal indicator organisms, FIOs (section 1.2 last paragraph p. 2).

c) By drawing attention to the sources of pollution from roads and the ineffectiveness of conventional management regimes (section 1.3 of the paper) the paper was able to focus on perceived barriers for consideration of diffuse pollution management techniques in Scotland (and elsewhere in the UK).

d) The paper presented the BMPs concept developed in USA to UK engineers who were interested in source control, where source control referred to quantity management, not chemical and oil pollution in the equally accepted pollution control sense. The nature of the pollution problems required the BMPs approach in the UK too (section 2, including data on pollutant removal efficiencies and the necessary references from the technical literature from the USA, such as Schueler et al (1992) and USEPA(1993).

e) This paper originated, and is the first mention in the literature of the sustainable urban drainage triangle concept, and correct portrayal of it. That innovative idea was presented to stimulate the joining of the USA BMPs concept for water quality management, with the parallel but compatible interest in source control for stormwater management (section 4, figure 3), and to add as an indivisible part of the concept the idea that features could have an amenity value, perhaps including some biodiversity interest too.

The issue of urban diffuse sources of FIOs was revisited in more detail later as its importance and the need for focused research was recognised – see O'Keefe *et al* 2005 later in this section. The last three points are further considered in Chapter 4 in discussion of the introduction of management measures to control diffuse pollution.

2.5 Initiatives to Tackle Diffuse Pollution in the UK

D'Arcy BJ, Usman F, Griffiths D and Chatfield P (1998). Water Science & Technology. Vol. 38, No.10, pp 131-138.

This was an invited paper for a diffuse pollution session of a major international conference in Vancouver, Canada, held in June 1998. It was the first UK paper on diffuse pollution of the water environment in the literature; a modest attempt to look at familiar issues in that context. The invitation followed the success of the 1995 SAC/FRPB *Agriculture and Diffuse Pollution* conference in Edinburgh at which a USEPA speaker was present (Weitman, 1996) and the follow-up conference in 1997, at which another leading diffuse pollution authority had a paper (Novotny, 1998). It was also consequent upon the launch of the successful international diffuse pollution video *Nature's Way* (Pratt 1996).

Co-authors were invited from the Environment Agency, to strengthen the case for consideration of this issue across the UK. Although their contribution to writing the paper was minimal - they commented on the draft and added some references – their participation signalled interest by the largest environmental regulator in the UK and joint programmes of work and support for UK based campaigns and initiatives followed.

Key contributions of the paper to the development of a diffuse pollution strategy were:

a) 10 classes of diffuse source pollutants were identified together with example sources and an indication of associated environmental problems (table 1, p. 132) – a first in one paper for the UK.
b) The paper presented summary data for Scottish loadings of persistent pollutants with indications of the percentages that may derive largely from diffuse sources (p. 133, table 2).
c) Data was presented to suggest a link between restoration of water quality and enforcement action by the regulator in the UK (p. 137, figure 1).
d) Through interest in the paper, the EA co-authors subsequently found resources for major collaborative research projects and initiated dialogue with DoE too, to begin research on diffuse pollution in a serious way across the UK, not just in Scotland.
e) The consultations and discussions in planning this paper led to the participation by EA and several UK research organisations such as IGER, ADAS and CIRIA, as well as Scottish Executive and DoE (later

Defra) in a major diffuse pollution conference held later in 1998, in Edinburgh.

This paper consolidated the efforts of the two initial papers (2.3 and 2.4), bringing together urban, rural and other aspects into a single paper and engaging across the UK with the other regulatory agencies to establish a basis for recognition and basic initial level of understanding of the problem. Although more appropriate to Chapters 4 and 5 here, the paper also tabulated a suite of control options with indications of means of funding or enforcing actions (p. 134, Table 3). In addition, as discussed in Chapter 5, it began the process of partnership working between government agencies that was a key step in the developing strategic approach to manage diffuse pollution.

2.6 Urban Diffuse Sources of Faecal Indicators

O'Keefe B, D'Arcy B, Davidson J, Barbarito B and Clelland B (2005). Water Science & Technology. Vol. 51, No. 3-4, pp 183-190.

This paper was a joint effort between authors from SEPA and Scottish Water (the public water utility in Scotland). The author of this thesis was the initiator of the paper, and mapped out its aims and possible content in discussion with the first author (O'Keefe). The latter, as a leading SEPA microbiologist, was responsible for most of the field data and taking a scientific overview of the overall paper on completion, as well as presenting it at an international conference in Dublin in 2003. Davidson worked as a temporary technical assistant for the author (D'Arcy) at that time and undertook literature searches and some help with putting material together. Barbarito had undertaken work on one of the case study watercourses examined, and contributed that data and insights to the paper. Barbarito also provided technical information from Scottish Water, as a member of that organisation's water quality team, and helped raise awareness within Scottish Water. Clelland was a senior biologist in SEPA who provided an overview and objective comments, and helped develop interest within SEPA.

As noted in 2.4 above, this paper was planned and written to plug a gap in the span of research being undertaken across the UK at that time that was focused on the failure of bathing waters to meet EU standards for faecal indicator organisms (FIOs). Much of that work had focused on sewage discharges, but evidence (e.g. Wyer *et al* 2000) had been collected to show that diffuse sources were critical to compliance efforts, especially from livestock farming catchments draining to the coastal waters where standards where not being met. One of the leading researchers (Kay, pers. com) reported that he had obtained some anomalous values from urban catchments that were served by separate sewers, and suspected urban diffuse sources. Similarly work was being undertaken at Blackpool looking at the importance of bird roosts (Wither, pers com). This paper was consequently planned to quantify the risks presented by urban diffuse sources, including wrong connections in the drainage system.

The paper introduction in the paper explained the need and gave background details; written by D'Arcy, including quoting some literature information obtained by Davidson. The new evidence presented in the paper was drawn from two case studies. The first was Portobello Beach in Edinburgh, written by O'Keefe, with input from Barbarito and diffuse sources information from D'Arcy, e.g. dog estimates. Portobello was a failing beach; an urban bathing water influenced by a small freshwater tributary, the Figgate burn.

The second case study was the Lynne Burn in Dunfermline. This was not a bathing water site but an urban stream that had been studied by D'Arcy and O'Keefe (unpublished FRPB reports), to address local pollution concerns. In the course of those investigations a useful detailed knowledge of that town's drainage system and how it related to water quality in the burn had been obtained. That made it a useful case study to identify by example the sort of urban FIO sources that occur associated with the various urban drainage systems that are prevalent in the UK. That text was provided by D'Arcy. The discussion and conclusions were a consensus team effort, drafted by D'Arcy.

Key contributions of the paper to the development of a diffuse pollution strategy were:

a) This was the first SEPA paper to focus on urban diffuse sources of FIOs (p.183-184).
b) The paper drew attention to important work done elsewhere, for example in Melbourne Australia, and Seattle USA (p. 184) to support this otherwise isolated investigation.
c) The paper set out useful detailed explanation of the types of drainage system prevalent in UK towns and cities as they influence water quality

(e.g. p.183-4 urban sources of FIOs; and the Figgate and Lynne burn case studies pp. 185-187).

d) The paper estimated (from literature data) FIO load from dogs and other animal sources for a catchment with the population of the Figgate Burn, and hence what proportion that might be of actual FIO loads in the tributary of a bathing water (tables 1 & 2, and table 3, pp. 184-185), comparing the literature estimated potential load with actual measured loads to the bathing water.

e) The paper demonstrated that diffuse sources including bird roosts and pet faeces could be significant factors in bathing water compliance in urban areas (e.g. table 3, p.185).

f) It was shown that that urban stream quality can be adversely influenced by surcharging sewers as well as diffuse sources in high flows, and wrong connections and sewer chokes in low flows (figure 2, p.187).

The importance of this paper was demonstration, by quantification in specific watercourses, that diffuse sources could be significant. It built upon the earlier indication that this might be a problem (D'Arcy 1998, see section 2.4 above). As a result interest in management measures increased, as demonstrated by subsequent research by the Scottish Government on retrofitting SUDS in urban areas influencing bathing waters in Ayrshire. It supported the broader need for action for urban and diffuse sources of pollution, with FIOs being important diffuse source contaminants.

2.7 Persistent Pollutants Urban Rivers Sediment Survey: Implications for Pollution Control

Wilson C, Clarke R, D'Arcy BJ, Heal KV and Wright PW (2005). Water Science & Technology. Vol. 51, No. 3-4, pp 217-224.

This paper was part of the effort to further characterise and quantify urban diffuse pollutants, especially those involving persistent and or toxic pollutants. It therefore picked up those issues as raised in outline in the earlier papers described in sections 2.2. and 2.3, taking the investigations further.

The paper reports work undertaken by SEPA to characterise diffuse pollution as an influence on urban streams and identify probable causes of poor quality as measured by concentrations of pollutants in urban stream sediments. Nine urban streams were selected across Scotland, from Aberdeen in the NE, through the central belt from Dunfermline to Edinburgh and East Kilbride. The sample locations were identified to ensure there were no known major point sources such as sewage or trade effluents determining the quality of the samples. The research work was funded by the SEPA diffuse pollution initiative, led by the author. It was a major part of that initiative, with field and laboratory work led by two chemists, Wilson and Clarke. The additional authors were Heal at Edinburgh University who provided an academic steer for the field work as well as contributing material to the paper, and Wright, who was a temporary assistant to the author and provided help in collating material for the paper and presentation. The project was initiated by D'Arcy in conjunction with a SEPA organic chemist (IM Ridgway). D'Arcy co-wrote the abstract and wrote the introduction and the sections on implications for pollution control, and drafted the conclusions (p. 221-223).

Key contributions of the paper to the development of a diffuse pollution strategy were:

a) Evidence from a review of biological field scores of the selected urban streams demonstrated that urban stream quality is typically poor, and the selection of assessment sites indicated diffuse sources as a cause (table 1, p.218).
b) It was shown that stream sediment sampling provided a practical, cost-effective and informative means of assessing contamination by persistent pollutants (pp. 217-221).
c) Hydrocarbons were the most significant diffuse source urban pollutant, sediment samples being more frequently and typically close to or in excess of special or toxic waste threshold concentrations, than corresponding values for concentrations of toxic metals or PAHs (pp.218-9, fig.1).
d) Of the toxic metals, Pb, Cr, Ni, Zn and Cu most frequently exceeded sediment quality standards (p.218).
e) The pattern of PAH contamination suggested that pyrolytic sources were more ubiquitous and present in greater quantities than oil spill sources (pp.219-220).
f) PAHs data, oil and some toxic metals results indicated that traffic was a likely source of much of the urban sediment contamination (p.221).

g) Industrial estates probably accounted for a lot of the anomalous concentrations of pollutants that were not associated with roads and traffic (p.221).

The paper was important for the development of the diffuse pollution management strategy, since it showed that without the development of SUDS technology and other measures to address the sources of these pollutants, they will and do contaminate the aquatic environment to a significant extent. It was a pre-requisite investigation to really make the case for widespread application of measures such as SUDS, since an emerging barrier to SUDS had become concerns about accumulation of persistent pollutants in the SUDS facilities. The paper stimulated subsequent initiatives and research focused on reducing releases of persistent pollutants at source, by cleaner technology or by traffic management, establishing the need for that to be part of the management strategy (see 2.9).

2.8 A Review of Vehicle Related Metals and Polycyclic Aromatic Hydrocarbons in the UK Environment

Napier F, D'Arcy BJ and Jefferies C (2008). Desalination, vol. 226, Issues 1-3, pp 143-150.

This was a water pollution paper in the UK to focused on the automobile as a diffuse source of water pollution, for a variety of pollutants: toxic metals, oil, and PAHs. The paper was a desk exercise to quantify the importance of the automobile as a diffuse source of pollution. It was a logical extension of the sediment investigations undertaken earlier, and described in section 3.6 above. The project was devised by the second author. Napier carried out the desk investigations with guidance and input from D'Arcy and overview from Jefferies. The paper was presented by Napier, at the IWA international diffuse pollution conference in Istanbul in 2006. Some additional material from the original work was also presented by Napier at a workshop at that conference *Automobiles as sources of diffuse pollution*, which was initiated and chaired by D'Arcy. Both aspects are described subsequently, together with independent research undertaken in USA, in D'Arcy 2008.

Key contributions of the paper to the development of a diffuse pollution strategy were:

a) The paper focused attention on automobiles as a source of water pollution (figures 1-2)
b) The paper identified the main pollutants that would be likely to be associated with automobiles in relation to pollution of the water environment: oil, Pb, Zn, Cu, PAHs (figure 2).
c) It identified the main sources in an automobile of the problem contaminants, for example copper from brake pads (figure 2 and text).
d) The paper also highlighted management and control options and needs.

This was an important paper since it further investigated the issue highlighted in the previous work (section 2.7) and assessed sources, and also the needs and options to address them; essential to the development of a strategic approach to managing the diffuse sources of pollution. Many of the management options would not be considered as within the remit of environmental agency water pollution control business, for example traffic calming measures, air quality issues associated with vehicle engine exhausts. This paper, by characterising and documenting the problem, was essential to open minds to new perspectives on problems, and hence eventually on new approaches to resolving them. SEPA included the outputs from the work done for the paper in its 2006 State of the Environment Report, since it exemplified the complexity of some of the remaining environmental challenges facing the agency (SEPA 2006).

2.9 Diffuse Pollution – What is the Nature of the Problem?

Ferrier R, D'Arcy BJ, MacDonald J and Aitken M (2005). Journal of the Chartered Institution of Water and Environmental Management, WEJ I, pp 361-366.

This paper was a follow up to the publication of a major report to characterise and quantify diffuse pollution in the UK, a project initiated and led by the author, (D'Arcy *et al*, 2000). The report was published by the Chartered Institution for Water and Environmental Management (CIWEM), under whose auspices sixteen organisations collaborated to gather data on environmental and economic impacts of diffuse pollution. It was a successful national initiative (the report was reprinted three times) that was applauded even in USA, where it was quoted in Novotny 2003, adopting the definition of diffuse pollution from the report in the updating of the original Novotny and Olem

(1994) textbook. The paper is a summary of the impacts evidence gathered by D'Arcy *et al* (Ferrier was lead contractor working on compiling and editing the CIWEM report with D'Arcy and the other co-authors). The content was up-dated with some Scottish data from a SEPA initiative that began in 2000 (some inputs from MacDonald and Aitken). The second author led the drafting of this paper, but was unavailable to present it.

Key contributions of the paper to the development of a diffuse pollution strategy were:

a) The paper published a clear definition of diffuse pollution, developed by a consensus of 16 UK organisations involved in the original in the CIWEM report (D'Arcy et al 2000), where it was first published. This paper was the first refereed, mainstream journal publication to carry that definition in the UK (p.362).
b) That UK definition of diffuse pollution was taken up as the international definition, in the definitive text book (Novotny 2003) on diffuse pollution, published in America (p.361).
c) The paper gave a clear explanation of what diffuse pollution is, and why the concept is useful and important (pp.361-363).
d) As part of that, the paper stressed and illustrated the importance of high flows in measuring diffuse pollution and characterising impacts, and the need to quantify load rather than just focus on concentrations (p.363-4).
e) The paper demonstrated with SEPA catchment data that there is typically no dilution effect for rural situations at least; higher flows,

higher loadings, which was counter intuitive to many people (p.363 and Figure 1).

This was the definitive UK paper in a refereed journal that established an overview of the problem and characterised the key aspects.

2.10 Conclusions: Characterising and Quantifying the Problem

In summary, the above set of published papers achieved the general aim of characterising and quantifying diffuse pollution for rural and for urban sectors, across the UK. Detailed exemplification was undertaken for several of the issues as initial investigations were followed up with a series of narrower focus ones. For example for FIOs, after initial work in D'Arcy 1998, a focused paper by O'Keefe *et al* (2005) explored that aspect more thoroughly. Similarly for the other pollutants highlighted in the early papers, for example the toxic metals and hydrocarbons identified as important urban pollutants in D'Arcy (1998) and D'Arcy *et al* (1998) were more systematically investigated in a national survey of Scottish urban watercourse for contaminated sediments. For toxic metals and PAHs, the evidence produced in Wilson *et al* (2005) was further followed up by a desk study to review traffic as a diffuse source of water pollution (Napier *et al* 2008).

Novotny and Olem (1994) identified a set of diffuse pollution characteristics that established the nature of the concept of diffuse sources (see Chapter 1).

In the course of characterising and investigating diffuse pollution impacts in the UK, these papers also confirmed the validity of the Novotny and Olem (1994) concept as it applies to the UK. For example the importance of storm event monitoring demonstrated in Ferrier *et al* (2004) and in O'Keefe (2005) validated the mobilisation by rain and from the land attributes, and the sediment sampling in Wilson *et al* (2005) that highlighted the importance of combustion sources of PAHs exemplified the difficulty in measuring diffuse source pollutants at source as water pollution inputs. That validation of the basic diffuse pollution concept set out in Novotny and Olem (1994) enabled the far greater body of associated research done in the USA on diffuse pollution to be more readily appreciated in the UK.

The body of work included several *first time* achievements for UK investigations:

1. This set of papers introduced the term 'diffuse pollution' in a comprehensive way that had not been seen in the UK scientific literature prior to 1995, when the first of these papers was in presented (D'Arcy *et al* 1996).
2. The first UK diffuse pollution paper with that aim and title was published D'Arcy *et al* (1996) in the first rural diffuse pollution conference in the UK (Petchey et al 1996). The paper introduced all the classes of important rural pollutants that have subsequently been researched at length by others, with the exception of faecal pathogens. The paper presented some initial estimation and exemplification of impacts, in the Forth catchment.

3. The national survey of Scottish urban watercourse for contaminated sediments was the first for a country in the UK to assess systematically urban diffuse source impacts (Wilson *et al* 2005), assessing quality and contamination in 9 urban streams from Aberdeen to East Kilbride.
4. The first presentation of the sustainable drainage triangle concept was in D'Arcy (1998). That became an iconic symbol of what the SUDS concept was about (see CIRIA manuals). The idea has also been picked up in other countries as each sought to reproduce the concept in their own terms, for example Low Impact Development (LID) in USA (see D'Arcy 2009), and Water Sensitive Urban Design (WSUD) in Australia (FAWB 2009).
5. The CIWEM *Diffuse Pollution Impacts Report* was another UK first (D'Arcy *et al* 2000) and the basis of the last paper in this set, by Ferrier *et al* (2005). The latter paper was the first paper in the UK literature to demonstrate key aspects of diffuse pollution and why the concept mattered. For example explaining why concentrations increase with flow and thus loadings massively so. That knowledge is vital for understanding why bathing waters fail after wet weather, and why targeting nutrient management for inputs to lakes must examine high flow inputs from rivers, as well as point source sewage effluents (see also D'Arcy et al 2006).
6. The CIWEM report (D'Arcy et al 2000) as quoted in Ferrier et al (2005), also achieved the notable success of establishing a now internationally recognised (Novotny 2003) definition of diffuse pollution. Ferrier *et al*

(2005) brought that to the attention of the agencies and stakeholders in the UK.

In conclusion, the set of papers established a clear factual basis for the need to identify and assess measures to address these pollution problems in the UK, together with sufficient characterisation and understanding of the nature of the problem to sensibly select appropriate control options.

CHAPTER 3 – Abatement Measures

***Abatement Measures** (papers presenting information about possible mitigation and management measures, and their effectiveness. Such measures are known as BMPs: best management practices).*

3.1 Introduction

After first quantifying and understanding the pollution problem, as detailed in chapter 2, the identification of abatement measures and assessment of efficacy is the next logical step in a strategy to mitigate the impacts of diffuse sources of pollution. In this context, measures are the techniques and physical structures to prevent the release or mobilisation of pollutants into the water environment, including reducing amounts of pollutants applied where appropriate. In the USA and generally the technical literature such measures are known as Best Management Practices, or BMPs (USEPA 1993, and chapter 1 here). In a built environment context, urban BMPs such as ponds, swales, permeable surfaces etc., are better known in the UK as SUDS (Sustainable Urban Drainage Systems) or as some prefer, SuDS. The SUDS acronym generally refers to sustainable drainage systems, but meaning just urban BMPs, not sustainable farmland or forestry drainage systems. Several of the papers in Chapter 2 also mentioned control options: D'Arcy (1998), D'Arcy *et al* (1998), and Napier *et al* (2008). It is expected in a paper documenting problems that some mention of abatement options would be included, but more detailed investigations were needed. The latter included for example, D'Arcy and Roesner (1999), which set out the design criteria for the SUDS features at the Dunfermline DEX development, and D’Arcy and Harley (2003) that set out how the urban BMPs or SUDS techniques could be applied in the rural built environment. McKissock *et al* (2001) documented the DEX development as a case study, and Heal *et al* (2004) looked at the sustainability claim implicit in the *SUDS* term that was by then established in the UK in preference to *urban BMPS*. Heal *et al* (2006) investigated the effectiveness of constructed wetlands to treat steading runoff, assessing performance of specific individual units.

Four papers that considered control measures in principle and then in detail, including at a catchment scale, are introduced here. Chapter 2 in Campbell *et al* 2004 sets out the BMPs philosophy more comprehensively than can be attempted in a published paper. But that text book drew heavily nonetheless on the first of the four papers below. The second paper looked at implementation of BMPs in a rural context to assess their effectiveness on a catchment scale. The third paper does the same for urban BMPs, looking at several case studies and also reviewing contentious current issues at that time for urban BMPs technology. Finally, the fourth paper suggested an innovative development of the BMPs concept to feature enhancement of the self-purification capacity of watercourses to attenuate anthropogenic levels of background contamination, with examples for rural and for urban pollutants.

3.2 The Role of Best Management Practices in Alleviating Water Quality Problems Associated with Diffuse Pollution

D'Arcy BJ and Frost CA (2001). *Science of the Total Environment*, 265 (2001) 359-367. Elsevier Science B.V.

The purpose of this paper was to introduce and explain the Best Management Practices term and techniques to a UK audience as a useful and necessary concept. The invitation to write this paper came as a follow-up to the major international diffuse pollution conference held in Edinburgh in 1998 (Novotny and D'Arcy eds. 1999). At that conference there were many papers about diffuse source pollution problems and a lot of international visitors discussing BMPs, their effectiveness, costs, innovations etc. The invitation to write this paper was to meet a perceived need for an explanatory paper linking the pollution problems with the BMPs approach to managing them. The co-author, Frost, was rural issues theme summariser at the international conference in Edinburgh in 1998, but also with experience of studying and designing urban BMPs. Frost contributed overall comments on the daft by the main author, as well as providing the tables 1 and 2 to meet the needs identified in the draft text.

Key contributions of this paper to the development of a diffuse pollution strategy were:

a) The development of a rationale for a BMPs approach that differed from the prevalent EQS discharge standard setting that was used at the time for pollution abatement programmes (p.359-361)

b) The presentation of urban BMPs, including the sustainable drainage triangle concept originally advocated in D'Arcy 1998 (see section 2.4, Chapter 2), and the associated development of the SUDS concept (Figure 2, and p. 362).

c) Presentation of rural BMPs included the idea that each farming activity presents its own pollution risks and that there are or must be at least one, usually several, activity specific or appropriate measures that could mitigate those pollution risks.

d) Importantly for understanding diffuse pollution, it was explained that the choice of land-use activity may have more importance for determining water quality in the sub-catchment than simply farming in a 'right' or 'wrong' way. The consequence being that a BMPs manual was needed, rather than a simple code of good practice approach as developed previously (p. 363-366, Figure 3 and Table1). Thus potato growing is likely to result in 8 times the phosphorus loss that is associated with grass pasture, or oil seed rape may result in 6 times the N loss that might be associated with grass (Table1), but in a bathing water catchment the grassland would be a bigger pollution problem because it would be grazed, and sheep would be more of a problem than cattle (see FIOs chapter in D'Arcy *et al* 2000).

e) The implementation options described in the paper included economic incentives and support schemes, education, and regulation such as proscribing uses of certain chemicals.

f) A multiple benefits approach (e.g. some cost savings, wildlife habitat, access improvements, farming public relations) was identified as a necessity to overcome barriers to diffuse pollution measures (Figure 4, p. 366).

This was a key paper for the development of the diffuse pollution management strategy, establishing the BMPs and SUDS techniques within a rationale for their use.

3.3 The Restoration of Loch Leven, Scotland UK

D'Arcy BJ, May L, Long J, Fozzard IR, Greig S and Brachet A (2006). *Water Science & Technology* **53**(10), 183–191

BMPs had been evaluated in the USA and elsewhere and shown on a catchment scale to be able to deliver improvements in water quality (US EPA 1997). A catchment scale evaluation was needed to determine whether these measures could actually affect water quality on a catchment scale in the UK. BMPs had been identified as the mechanism to address diffuse sources of pollution in the earliest papers in the programme of investigations (D'Arcy *et al* 1996, and D'Arcy and Frost 2001). The paper was focused on a rural catchment, Loch Leven, and an intensively farmed tributary the Greens or Pow Burn. Diffuse sources were considered alongside major point sources, and the changes in their relative importance over 20 years were recorded. The paper sought to demonstrate the effectiveness or otherwise of diffuse pollution management measures (BMPs) for water quality protection and improvement.

The paper was conceived of and abstract written and submitted by D'Arcy. The leading academic with decades of research experience on the loch, May, was invited to be a co-author and contributed loch quality data and up-dated phosphorus loading figures for Loch Leven. Ecological monitoring data for tributary streams was sought from the third author Long, a SEPA ecologist, who also wrote that section with input from D'Arcy. Fozzard derived the original water quality targets in the LLAMAG (Loch Leven Area Management Advisory Group) report that sought to address pollution problems in Loch Leven (D'Arcy ed. 1993) and was consulted and included on that basis. Greig wrote the original unpublished SEPA report on the findings of the diffuse pollution monitoring stations (Greig 2004), from which the figure and text for the effectiveness of the Greens Burn buffer strips was taken in this paper. Greig had been working for the author at that time (2004), as part of the SEPA diffuse pollution initiative team. Brachet was a French post graduate student on a SEPA placement in the diffuse pollution team and provided help with data collation and literature research and presentation material.

Key contributions of this paper to the development of a diffuse pollution strategy were:

a) The benefits and disadvantages of alternative types of catchment management approach, were reported and discussed, including community alienation or engagement, (p. 185, and pp.189-10).

b) The identification of an improved measure of loch ecological status and associated water quality, which was less influenced by ephemeral events, set an example for water quality planning and target setting. The target selected by co-author L. May was the maximum depth to which rooted macrophytes occur (Figure 5, p.189).

c) Diffuse pollution loadings (as river borne phosphorus) were quantified and compared with the measured inputs to the loch from major point sources such as industrial effluent and municipal sewage discharges, showing the increasing importance of diffuse sources as point sources were controlled (Figure 3, p.188).

d) The paper published evidence of the effectiveness of buffer strips, as demonstrated by 'before and after' assessments, using storm event monitoring at a SEPA diffuse pollution monitoring site on the Greens Burn tributary of Loch Leven (Figure 4, p.189).

e) The tentative identification of pesticide use in the loch catchment as a possible continuing influence on the tributary streams and also the ecology of the loch (e.g. on algal-grazing zooplankton) was another driver for follow-up work in the catchment, and in similar catchments elsewhere with unexplained poor biological field scores (p.184 and p189).

This paper provided the documented rural case study analogous to the DEX site described for urban sectors in the other papers noted in 3.1 (D'Arcy and Roesner 1999, and McKissock et al 2001) , with documentation of quantified performance of the BMP measures. Of equal importance, it demonstrated at a catchment scale – where diffuse pollution impacts are usually evident – that measures can be effective. The restoration of Loch Leven has been a notable success story, although still incomplete, with diatom based hind-casting evidence suggesting further reductions are required for good ecological status.

3.4 Restoration Challenges for Urban Watercourses

D'Arcy BJ, Rosenqvist T, Mitchell G, Kellagher R and Billett S (2007). *Water Science & Technology* vol. 55, No. 3, pp 1-7.

The introduction of urban BMPs to new urban Scottish developments was described in D'Arcy 1998, and D'Arcy and Roesner 1999, and McKissock et al 2001). This paper sought to assess whether diffuse pollution from major new motorway and industrial and commercial developments could be effectively prevented by use of SUDS technology, and considered key issues facing application of the technology such as the fate of pollutants, the basis for established design criteria, and whether SUDS could be retrofitted to restore urban stream quality. The paper also sought to present an overview of research outputs from major trans-Atlantic collaborative investigations by UKWIR and ASCE in relation to BMP performance.

This was an invited key-note paper for an IWA international diffuse pollution conference. The subject and scope of paper needed was devised by D'Arcy, and co-authors were invited to contribute according to expertise and availability of data to achieve the planned content.

The paper identified continuing issues and possible solutions, and made reference to two case studies on a catchment scale:

1) Mitigation of the impacts of urbanisation exemplified by a major upgrade of the A74 trunk road, to become the principal only motorway link between Scotland and England (now the M74). The road follows the valley of the River Annan – still a top quality Salmonid river post M74 development.
2) Improving water quality in an urbanising stream by retrofitting BMPs.

The example used for the latter was Halmstad in Sweden, with data supplied by Rosenqvist. The key note was ambitious and also sought to examine the pollution risks in an urban environment, drawing on work done under contract with SEPA by Mitchell, using GIS land-use and storm runoff models, together with an EMCs database, to predict urban pollution hotspots, as well as indicate what degree of urbanisation in a catchment results in adverse impacts on local watercourses. Kellagher contributed to an assessment of the SUDS techniques available to regulators and developers, based on recent work with UKWIR and ASCE on a major trans-Atlantic review of the effectiveness of urban BMPs. Concern about the degradability of key urban pollutants found for example in stream sediments (Wilson *et al* 2005), required input from a SEPA contaminated land specialist, Billet. D'Arcy wrote most of the paper with inputs as above, and presented it at the IWA conference. Unfortunately the paper was too long and most of the tables and figures were cut by the conference editors for publication, so the final version (in *Water Science and Technology*) is mainly text with little of the direct supporting data, just references.

Key contributions of this paper to the development of a diffuse pollution strategy were:

a) The recognition that SUDS technology can adequately protect the quality of a salmonid river system crossed several times by a new motorway running the length of the valley (p.1).
b) The evidence from Halmstad in Sweden that SUDS can be retrofitted in a catchment and be sufficiently effective to allow the return of a trout fish population was important for developing strategic views on restoration possibilities for urban watercourses (pp. 1-2).
c) The evidence from Halmstad also showed that prior to the establishment of a treatment train of measures, the simple end of pipe features could not on their own guarantee persistent good quality in the Knebildstorp Stream in that case study (p.2).
d) Summary presentation of the findings of the UKWIR/ASCE research programme were made available by the publication of this paper (p.2).
e) Based on the dialogue with the co-author involved in the UKWIR project, it was possible in this paper (BMPs and SUDS technology section, pp.2-3, and Figure 1, p.3) to explain some of the misleading

conclusions indicated by the UKWIR report, that suggested larger size ponds produce poorer quality discharges. That conclusion was not based on a comparison of the quality of a series of different sized stormwater ponds, but on measurements of water quality in one very small, heavily contaminated pond, taken after different periods of antecedent dry weather and the corresponding quality data related to the residence time indicated by the antecedent dry weather period. Consequently a very misleading conclusion was reached, since in the small pond the high level of influent contamination resulted in anaerobic conditions developing during the dry periods when stagnant conditions occurred, and the researcher consequently used a typically irrelevant parameter for urban BMP discharge quality (ammonia) as the measure of performance. The paper was able to discretely counter the misleading conclusion promoted hitherto, by highlighting the importance of pollutant loading per unit area of pond surface, and including the data plot for the small pond (text p. 3 and Figure 1).

f) The importance of the key urban pollutants was highlighted, rather than simply focusing on a BMP feature's ability to trap sediment (text p. 3, and p.4).

g) The text supplied by Billett indicated that for some pollutants, such as higher molecular weight PAHs, even a long residence time pond such as a retention pond, would not hold pollutants long enough in suspension to allow degradation (p.5, degradation of pollutants).

h) The paper identified the need for and possibilities of enhancing self-purification capacity of watercourses, in addition to retrofitting

BMPs/SUDS in a catchment (p.5, last paragraph of 'Degradation of key urban pollutants' section).

i) The paper included a proposal for collaborative international projects to quantify the impact of road traffic so as to provide an evidence base for the need for cleaner technology (Non-BMP initiatives, pp 5-6).

The fate of pollutants issues raised in the paper led to a follow-up research project (Napier *et al* 2008). The penultimate point (h) was followed up in another paper for an IWA diffuse pollution conference, described in the next section, D'Arcy *et al* (2007). The last point led to the automobiles initiative of IWA's diffuse pollution group (D'Arcy 2008).

For the development of a strategic approach to manage diffuse pollution, this was an important paper that engaged very influential academics and leaders in the engineering and consulting field as co-authors, thereby allowing the demonstration of different and supportable view points and alternative explanations for data. Key stakeholder leaders needed to be in agreement as part of the development of any strategic approach that is dependent on sector buy-in and consensus.

The paper was also a land-mark reference in reporting for a catchment scale the impacts of SUDS technology to protect and indeed improve water quality in the local streams and river, in the same way that the Loch Leven paper demonstrated success at a catchment scale for rural issues (previous section, 3.3).

3.5 Riparian Wetlands for Enhancing the Self-purification Capacity of Streams

D'Arcy BJ, Mclean N, Heal K and Kay D (2007). *Water Science & Technology* 56 (1): 49-57.

The fate of pollutants such as oil and PAHs in SUDS highlighted in the previous paper, and especially the evidence for only limited removal by some systems, suggested a need to consider further options for restoration of water quality where land take problems precluded action at source. Could the self-purification capacity of watercourses be enhanced at the same time as creating more natural flow regimes and flood storage capacity?

A parallel piece of research to investigate the potential for SUDS retrofits to improve polluted urban streams was undertaken as a small contract for SEPA, by Edinburgh University at the instigation of the author and led to a useful publication by the research team and SEPA project manager (Heal et al 2005). That work showed a significant improvement in the quality of the Caw Burn below the constructed stormwater wetland established below Houston industrial estate, but indicated that further work would be needed to achieve good quality in the watercourse. The Caw Burn constructed wetland was designed to take the dry weather flow plus a small multiple thereof, but importantly, higher flows by-pass the system. The idea for this paper was to see how practical it might be to treat high flows, using the Caw Burn as one of two case studies for a desk exercise.

The EU Bathing Water Directive that had caused such concerns over failures due to diffuse sources, was to be revised with the imposition of even more demanding standards such that beaches that were good would become borderline, and existing borderline ones would fail. Was there an additional pollution management option that could be sought in addition to the BMPs approach for diffuse sources of FIOs? Again, a desk exercise was undertaken to see if high flows in the burn could be treated, rather than low flows. This second case study utilised data for a small rural watercourse, Brighouse Burn, in SW Scotland.

Those concerns suggested to the author the need for this paper and an abstract was written and submitted. Co-authors with experience of the two scenarios were invited to contribute: Heal because of the Caw Burn research, so that could be a case study for this project, and Kay for the Brighouse Burn case study in recognition of the data produced for that study (Kay *et al* 2007). The idea was explored with SEPA colleague and former hydrologist co-author Mclean and an approach agreed. The idea was explained to the two co-authors who had access to historical data from the two identified potential virtual retrofit case studies, and a pair of desk exercises were undertaken with them. Data for the Caw Burn was used for that case study as a desk exercise, and overseen by Heal. Such data was not available for the Brighouse burn, so a different approach was devised by Kay for that part of the paper.

Key contributions of this paper to the development of a diffuse pollution strategy were:

a) Highlight the need to consider the possibility of enhancing self-purification capacity of a watercourse to help address diffuse sources of contamination (Introduction, pp1-2).

b) Devise a theoretical means of sizing a potentially effective wetland for removing pollutants entrained in sediment at high flows (Possible design criteria pp 50-52).

c) Run two case studies as a desk exercise with high flow data for two real small burns, one with industrial estate pollutants, the other draining to a bathing beach, to determine probable sizes required and dimensions, so that the idea could be considered for further more detailed evaluation and development, or ruled out on grounds of land take (pp. 52-54).

d) Previous projects to consider in-river treatment processes had used on-line ponds, but had quickly been shown to be ineffective at anything other than low flows since residence time at high flows was too limited. Informed by the knowledge of diffuse pollution as a high flows phenomenon (see Ferrier et al 2005) this paper uniquely sought to provide a design approach that would be appropriate for high flows, when diffuse pollution loads are at a maximum (Introduction p. 49, and throughout the paper thereafter).

e) Flaws and questions needing further evaluation and methodology development were identified, alongside potential for application (Discussion, pp 54-55).

This concept is unlikely to be of widespread application, but where successful achievement of pollution load reductions are sufficiently imperative (e.g. to achieve compliance for the UK with EU standards) and local land-owner/stakeholder groups are willing to cooperate, it could be very useful. It may be most practical for large surface water discharges from industrial estates where land take requirements for retrofitting appropriate SUDS such as retention ponds are prohibitive and an alternative approach needs to be found. But as the paper was being prepared an independently conceived of but similar project was being developed for a small rural stream carrying nutrients from an intensive agricultural catchment into the Loch of Strathbeg in NE Scotland. The RSPB own the land around the watercourse and have created a series of pools and reedbeds for sedimentation of influxes of nutrient rich sediment, as well as to create more diverse freshwater habitats compatible with the Loch of Strathbeg nature reserve. That independent example plus the case studies in this paper suggest that the concept should have a place in a strategic approach to manage diffuse pollution.

3.6 Conclusions: Abatement Measures

The four selected papers together present important evidence for the value of BMPs in urban and rural contexts. The first paper remains a worthwhile explanation of the BMPs philosophy and how it differs from the control of effluent discharges by a major point source and EQS discharge permit approach. It was the principal if not the first such paper in the UK, focusing attention on landscapes and land-use and mitigating corresponding pollutant losses to the water environment. The need to switch from inspecting a farm and looking for a flow of slurry, or a haul of dead fish following a pesticide spillage, to reading the landscape and having knowledge of landscape losses of pollutants associated with land-use was and remains a radical change. The same challenge faces regulators of the urban environment: acceptance that a major oil or chemical spill is not the only influence on urban stream quality, but the anthropogenic background contamination associated with the urban land-use can be more chronic in impact and just as severe.

For the urban environment, D’Arcy and Frost (2001) was the first paper to take the sustainable drainage triangle concept that was first published in D’Arcy 1998, and develop it into a rationale that could begin to justify the new term SUDS, with its implied aspiration to be a more sustainable drainage approach.

Several important points were identified in the other papers that have a bearing on the development of a strategic approach to controlling diffuse pollution. Firstly, the significance of diffuse sources in a specific catchment, in comparison with quantified inputs from industry and municipal sewage discharges was an important achievement in D’Arcy *et al* (2006). That paper also published detailed evidence, based on storm event monitoring of water quality prior to and after establishment of buffer strips in an arable catchment that showed statistically significant improvement after the buffer strips were established.

The value of a treatment train of measures was demonstrated in the Knebildstorp Stream case study from Halmstad, Sweden, in D’Arcy et al (2007), and the efficacy of the M74 BMPs was also associated with a two-stage BMPs (SUDS) infrastructure. The latter comprised a roadside filter drain network, which in turn discharged via silt traps, to detention basis or constructed ponds. The M74 SUDS were assessed subsequently in Napier *et al* 2009 partly as a follow-up to the issues raised in D’Arcy *et al* 2007. Successive stages in controlling pollutant movement from the landscape into the water environment is a highly desirable feature of a control strategy; although not demonstrated in the equivalent rural assessment of catchment scale BMPs in D’Arcy *et al* (2006) it was subsequently implemented with dramatic effects in that watercourse, as noted in Chapter 1, in the discussion of diffuse pollution hotspots. One of the reasons for disappointing performance of farm constructed wetlands in the work by Heal *et al* 2006 was the end-of-pipe application of treatment practice rather than a treatment train of interventions. D’Arcy *et al* (2007) was also important for identifying and explaining away an anomalous conclusion in the major trans-Atlantic ASCE/UKWIR report on performance of BMPs, namely that larger ponds perform worse than small ones. There was in fact no evidence for that. The paper did however support the case for considering smaller retention ponds, by showing that even for periods of several weeks retention, many PAH compounds would not have broken down in the pond. Again for such pollutants, a treatment train approach was advocated, with probably soil-grass based units as first level measures.

The need for new management options for circumstances where conventional BMPs cannot be sufficiently effective to achieve environmental requirements emerged as an issue for two compelling reasons. The first was a lack of space in which to fit conventional ponds and basins in potential SUDS retrofit programmes to improve the quality of urban watercourses. The second was the shifting targets for bathing waters from EU that required a matching shift in control and discharge reduction performance from rural and urban diffuse sources. For both of those scenarios, an innovative new approach was developed as a desk exercise, but has been independently taken up in Scotland by RSPB, which suggests the ideas are practical.

Together, the four papers made valid contributions to the overall global body of knowledge and innovation in relation to the BMP approach and beyond, to addressing diffuse sources of pollution.

"The most important failure was one of imagination" Report of the National Commission on Terrorist Attacks on the United States.

CHAPTER 4 – Bringing Measures Into Routine Use

Bringing measures into routine use *(introducing papers addressing issues from education and guidance, catchment planning and partnerships, to economic instruments, and direct regulation).*

4.1 Introduction

Knowing that there is a pollution problem (Chapter 2), and knowing that there are technical measures that could effectively address that problem (Chapter 3), is not sufficient for resolution of the problem unless a third area of endeavour is successful – finding and applying means to bring the abatement and control measures into routine use, including targeting actions in priority areas. This chapter sets out the published papers that span a spectrum of actions that illustrate components of a strategic approach to getting measures taken up effectively.

Three papers are considered, but it should be noted that several of the initial papers already discussed (Chapters 2 and 3) included material intended to bring measures to the attention of the sectors and encourage application of the techniques for mitigation or control. These are considered in turn below. Initially, it was assumed that merely presenting the evidence and experience from other countries, where a great deal of money and effort had been invested over several years in characterising and addressing the pollution problem, would be sufficient to gain acceptance in the UK. A similar argument could be made for the acceptability of many of the management techniques – tried and tested technology, they could be adopted here. On that basis, all the early papers in Chapters 2 and 3 attempted an ‘everything in one paper’ approach – from problem to solution. The earliest of the papers was D’Arcy *et al* (1996) which introduced the concept of diffuse pollution to the UK, focused on rural aspects. A section on tackling diffuse pollution (pp. 13-15) discussed enforcement under the legislation prior to WFD, integrated catchment management, and partnerships for pollution prevention. Section 4 of D’Arcy (1998) was entitled “Towards sustainable urban drainage” and as well as introducing the *Sustainable Drainage Triangle* concept that embodied an integrated approach to drainage in all aspects with landscape and amenity, that part of the paper considered the need for different statutory bodies to work together, recognising that would be a requirement for effective storm water management. The final section of the paper introduced the new (founded in 1997) sustainable urban drainage Scottish working party (SUDSWP), a stakeholder group comprising SEPA , Scottish government departments (planning, roads), Scottish Water, Scottish Enterprise and representatives of local authorities and house builders.

Half of the paper on behalf of two UK environment agencies (D’Arcy *et al* 1998) was focused on controlling diffuse pollution, including statutory powers and their implementation, as well as economic drivers and education and best practice guidance (Table 3). It made a case for enforcement as part of an integrated approach to the agency business of persuasion (Figure 1).

The paper by D'Arcy and Frost (2000), which explained the concept of BMPs, also discussed in detail how they might be brought into routine use in the UK. A diagram (Figure 3, p.366) illustrated how land-use decisions were as important as compliance with pollution prevention requirements under a traditional code of practice, supporting discussion of the need for reform of the Common Agricultural Policy (CAP) of the EU to create an economic driver for managing diffuse pollution (pp. 363-365). Costs were estimated for various BMP options as part of the discussion (Table 2, pp. 365). Figure 4 indicated barriers to change that might be outweighed if water environment needs were just one part of the case to adopt prevention or control measures, off-setting barriers against amenity, biodiversity and benefits for the farmers (Figure 4, pp. 366). Examples of various possible multiple benefits were given, e.g. for encouraging buffer strips alongside farmland watercourses, allow the farmer to utilise his set-aside land requirement for that purpose, if habitat for game birds could be created there too, or if access for farm vehicles could be improved, or breeding areas for insect predators (beetle banks), the farmer would be more likely to create the necessary diffuse pollution features (Figure 4, pp. 366). On the same basis, D'Arcy and Frost (2001) also discussed the SUDS triangle concept, emphasising the need for multiple benefits to gain value for the cost of measures and hence persuade stakeholders to adopt the necessary techniques (pp. 362-363).

It was realised after the initial papers that more focus was needed on each aspect of the business of persuasion to bring measures into routine practice, and to address the barriers for uptake and acceptance of both the problem and the solutions. McKissock *et al* (2001) reported biological evidence for the wildlife value of SUDS, as part of efforts to investigate the amenity element of SUDS. Amenity was perceived as a means to encourage local authorities to allow SUDS features to be part of a green space requirement of developers in planning consents. A SUDS section was included in the SEPA publication *Ponds Pools and Lochans* (SEPA 2000). McKissock *et al* (2003) assessed the effectiveness of technical guidance for encouraging fit for purpose urban BMPs or SUDS, and an equivalent study by SEPA and SAC examined education and non-regulatory persuasion efforts for the rural sector (unpublished SEPA report).

Partnership working to address urban diffuse pollution, particularly implementation of SUDS technology, was addressed in Ellis et al (2002), the first of the three papers considered below. That left the other two aspects of persuasion to be considered: economic drivers and regulation. The two other papers below represent the selected published contribution to meeting that need, alongside the textbook Campbell *et al* (2004), which was the supporting publication in the strategy to bring diffuse pollution management into routine business in the UK.

4.2 Sustainable Urban Drainage Systems and Catchment Planning

Ellis JB, D'Arcy BJ and Chatfield PR (2002). J.CIWEM 2002, vol. 16, November, pp 286-291.

The opportunities of the EU Water Framework Directive for implementation of SUDS technology, and how that might be taken forward through catchment planning were considered in this paper. This paper was the product of several years of dialogue between the authors about the pollution sources in urban areas, and the implementation of effective measures to manage them. The senior author was a co-author of D'Arcy *et al* (2000), the CIWEM diffuse pollution impacts report. The aim of the latter project was to characterise and quantify the diffuse pollution problem in a report that could influence government; this paper was a follow-up to that report, to focus on some of the control measures to address urban diffuse sources. All three authors had been discussing and arguing about the issues involved for several years. For this paper, D'Arcy contributed the Scottish experience plus much of the philosophical overview of pollution management, subsequently published at length in Campbell *et al* (2004). Chatfield contributed the Environment Agency (England) perspectives. Ellis was the initiator and leader for the paper, and he did most of the writing, and editing to address feedback comments.

The main contributions of this paper to the development of a strategic approach to managing diffuse pollution were:

a) The paper indicated why conventional permitting processes of SEPA, EA and other agencies that involved setting discharge standards based on environmental quality standards, (EQS's) were not practical for most surface water discharges as a means of controlling diffuse source inputs (p. 286, last two paragraphs of Introduction), and consequently what alternative means of bringing appropriate control measures into effect are there? (p 286, Introduction, last sentence). Those considerations added weight to the original argument explained more fully in D'Arcy and Frost (2001).

b) The paper highlighted the statutory requirement under the Water Framework Directive to address diffuse sources of pollution (pp 286-287, Objectives and Key Elements).

c) The paper noted that the typical sampling programmes of the environment agencies and the environmental parameters monitored by them, were inadequate for the assessment of urban water quality (p. 287, paragraph 4, quoting percentage of rivers downgraded).

d) The paper highlighted that neither the Environment Agency nor SEPA have adequate powers on their own to address all that needs to be addressed to manage diffuse sources effectively. Therefore a spirit and reality of partnership working was a pre-requisite for managing diffuse pollution (p. 287, Table 1, also p. 288 table 2).

e) The paper noted the regulatory mechanisms in place at that time to bring the SUDS technology into use in the UK (most effectively used in Scotland) (p.289 Prohibition Notice Policy).

f) The importance of the formal planning process for bringing SUDS into practice (development control, as well as local and strategic plans) was identified and explained (p. 289-290).

g) Barriers and blockages to implementation of control measures such as SUDS technology were identified and discussed, with possible means of overcoming them considered (pp289-291, e.g. safety concerns about ponds, reluctance of local authorities to adopt SUDS, objections from conventional highways engineers, adoption standards).

h) The importance of stakeholder engagement was noted, with a description of the stakeholder group established since 1997 in Scotland (SUDSWP) (p. 290-291).

i) The need for policies and practices to focus on new developments for uptake of SUDS technology, to prevent the urban pollution problem getting larger with time, was recognised (p. 291, last paragraph of SUDS Implementation and Stakeholder partnerships).

j) The limitations of a focus solely on new development, if considering the needs to improve the water environment was recognised, noting the challenge for restoration of existing poor quality without a process for retrofitting too (p. 291, last paragraph of SUDS Implementation and Stakeholder partnerships).

Details of the regulatory regimes noted in (e) above, whilst correct at the time of publication, were superceded in Scotland at least, in 2006 (D'Arcy *et al* 2006), considered below.

4.3 Agricultural Environmental Management: Case Studies from Theory to Best Practice

Frost A, Stewart S, Kerr D, MacDonald J and D'Arcy B (2004). Water Science and Technology, vol. 49 No. 3, pp 71-79.

Economic instruments as drivers for using rural BMPs were the subject of a lot of interest during the discussions on reform of the Common Agricultural Policy (CAP) during the early years of the turn of the century, 2000-2005. The economic climate and scope for economic instruments to drive best practice into routine use are discussed in Campbell et al 2004, and this paper sought to exemplify the arguments set out in that text book. The work was initiated as a SEPA Diffuse Pollution Initiative (DPI) project: Frost, Stewart and Kerr were the contractors, and MacDonald within the DPI team was tasked with project management. The initial idea and project specification was developed by D'Arcy in dialogue with Frost (a logical follow-up paper to the earlier paper that sought to explain the need and uses for a BMPs approach in Scotland, (D'Arcy and Frost 2001). It was part of an initiative proposed by D'Arcy to the international specialist group of IAWQ/IWA diffuse pollution committee in 2000, that the group should encourage its European members to initiate research to build a case for CAP reform that could fund environmental improvements on farms. This paper was a direct output of that initiative and was presented by Frost at the IWA diffuse pollution specialist group conference in Amsterdam in 2002.

The main contributions of the paper to development of a strategy for managing diffuse pollution were:

a) The paper published examples of actual diffuse pollution problems likely to be found on a selection of different types of farms in Scotland (dairy, arable, mixed, upland, lowland) (pp.71-74, Fig. 1).

b) As an approach for the assessment of diffuse pollution risks that could be used for Scottish farms, 6 main areas of pollution risks were identified, with corresponding types of mitigation measures (pp. 72-4, Fig. 2).

c) For 6 case study farm types, the paper quantified and reported the economic status of the different types of farming activities in a diffuse pollution context (the most polluting were the least viable) (pp.75-75, Table 3).

d) A hypothetical support scheme for farmers was developed, based on their existing income from EU Common Agricultural Policy payments, but using those funds to establish appropriate BMP measures on the farms to mitigate diffuse pollution impacts (pp. 76-79, Tables 4 and 5).

As part of the IWA initiative to influence CAP reform, the paper was delivered as the key-note paper in a workshop in Dublin attended by several EU officials, politicians and agricultural sector representatives, as well as academics. It had considerable influence, leading to a presentation of a conference resolution to the EU by the then President of IWA, Laszlo Somlyody, in 2005.

In parallel, a great deal of effort was also initiated for urban sector, and reported by sector leads (e.g Wilson *et al* 2004) to also examine and encourage economic drivers to be more effective for encouraging that technology too; this is discussed in more detail in Campbell *et al* 2004, chapters 4 and 7.

4.4 Regulatory Options for the Management of Rural Diffuse Pollution

D'Arcy BJ, Schmulian K and Wade R (2006). In McTaggart I and Gairns L (eds), Managing Rural Diffuse Pollution. Selected papers from 6th SAC/SEPA biennial conference on Agriculture and Environment, Edinburgh 5-6 March 2006.

An appropriate regulatory regime is essential to underpin educational drivers such as policies, technical guidance, and design manuals, and also to complement or shape the economic regime within which it is hoped the technology will be able to be established (Campbell *et al* 2004, Chapter 7). This paper sets out the legislation implemented in Scotland, including the reasons for establishing the general binding rules approach for managing diffuse pollution, and for requiring the use of SUDS technology. The first author wrote the paper (and led the small team that drafted the General Binding Rules (GBRs) numbers 10-11, that deliver the above provisions in the Water Environment (Controlled activities) (Scotland) Regulations 2005. The second author (a member of the SEPA legal team at the time) provided a factual check on the statutes set out in the paper, and the third author provided a useful independent academic overview of the paper and challenged the observations therein constructively.

a) This paper was in many ways the conclusion of the programme of work to identify the problems, characterise them and identify and evaluate remedial measures then put in place an appropriate regulatory regime to require uptake of prevention practices and technology.

b) The paper described and explained the key provisions for managing diffuse pollution in the new Scottish legislation that came into force on 1st April 2006 (pp. 192, 193-195).

c) It explained why conventional regulatory approaches such as direct one to one licensing are generally inappropriate for thousands of often individually minor sources (typical of diffuse pollution) (p.199). That indirect means of regulation was a difficult departure from traditional direct regulation for many regulators; an almost impossible leap of imagination apparently.

d) The paper also described related provisions in the CAR regulations that also have some bearing on diffuse pollution, for example working in watercourses, powers to serve notices requiring remedial work and other provisions detailed in the paper (pp. 194).

e) An explanation of abatement enforcement provisions such as formal notices to undertake prevention actions (pp. 193), was followed by a forward vision of how an enforcement and inspection regime, with cost recovery by administrative penalties could be built around the new GBR provisions (pp.198-199).

The GBRs approach was subsequently set out for urban sources, in a series of papers and presentations to urban sectors, but have not yet been published in a journal. The importance of academic publications about the statutory regime and control options has been exemplified by presentations from academics who are new to the subject and yet are able to influence government (in England at least), and who state, without reference to papers or statutes, that diffuse sources cannot be regulated.

4.5 Bringing Measures into Routine Use: Conclusions

Campbell et al (2004) developed a philosophy of integrated controls, based partly on feedback from a paper described in Chapter 2 here (section 2.5). That paper, D'Arcy *et al* (1998), was much commented upon by North American delegates in Vancouver when presented, since they did not believe enforcement action was possible against farmers; a blockage that resulted in continuing pollution despite millions of dollars collected from taxpayers being spent on the participating farms. Such non-cooperation made predictive modelling difficult too. That reflects a common misconception, still prevalent in environmental management in the UK in 2012, that enforcement and regulation is only an alternative to other means of persuasion to change behaviour, such as education, and regulation is a somewhat unacceptable part of a management of change process. The reality of course, is that the two "alternatives" are indivisible, and also inseparably linked with the economic environment within which activities are undertaken. The real debate should be about the relative sizes of the roles for those three key elements, in various circumstances, in the business of persuasion:

- Regulation (including enforcement policy)
- Education and awareness raising, including technical advice and help
- Economic factors (including economic climate and economic instruments)

That philosophy is further considered in Campbell et al 2004, as noted in Chapter 1, and is also discussed in D'Arcy *et al* (2006). The establishment of a regulatory regime for diffuse sources of pollution as detailed in D'Arcy *et al* (2006) represents the culmination of the preceding years of investigations and gathering evidence. The general binding rules concept for regulating diffuse sources of pollution may not seem radical, since it is common sense when faced with a great many sources – several orders of magnitude greater than the numbers of effluent discharges regulated directly by the environment agencies. But even by 2012, a widespread adoption of such a simple approach across the UK has yet to be achieved, as regulators still seek to apply a point source mind-set that disregards anything less than an individually significant threshold. The scientists have accepted that the total impact of multiple minor inputs can be significant, but regulators have yet to accept the corresponding need to regulate such an impact, and hence to consider the several available opportunities to do that, including appropriate enforcement. That also applies to monitoring the causes of pollution: a sampling and inspection regime based on size and pollution load of a single individual discharge, is still usual, rather than for diffuse sources, a sample programme that would assess the importance of a sector by sampling parts of it on a strategic planned sub-sampling programme. Enforcement will only follow in a progressive, yet effective and fair way, once the aims and opportunities are more widely recognised. The perhaps surprising final conclusion of this body of work is that regulatory innovation is as difficult to see into practice as technical details of problem definition and details of abatement technology. But at least the statutes are in place in Scotland and now the opportunities are there to be taken.

CHAPTER 5 – A Strategy for Managing Diffuse Pollution

5.1 Characterisation and monitoring

The EU Water Framework Directive requires that the proportion of a river's pollution load that is from diffuse sources should be identified and controlled. Characterisation of the pollution problem is essential for two reasons: (a) understanding as a pre-requisite for determining appropriate solutions, and (b) for effective sector engagement - persuading sectors that they are involved in the problem, and hence have a role in solving it. The importance of direct assessment of water quality by storm event monitoring has been demonstrated and showed that high river flows are characterised by high pollutant concentrations for several pollutants, (Ferrier *et al* 2005, D'Arcy *et al* 2006). Technical solutions that ignore that fact risk failure to achieve desired water quality objectives (D'Arcy *et al* 2007).

A hierarchy of environmental assessment intensity, from storm event sampling and continuous flow measurement at diffuse pollution monitoring stations, through routine monitoring across the country's waterbodies to modelling, with investigative work in addition, is set out in figure 5.1. Such an approach recognises the need for detailed evidence to secure a factual basis for policy and for understanding the natural processes driving diffuse pollution, and to underpin broader modelled information that it is cost effective to use for national characterisation. In terms of national coverage, and number of watercourses covered, the approaches in figure 5.1 could also be represented as a pyramid, with a handful of watercourses monitored at the apex (level 1) with additional and successively broader scale assessments down to the base (level 4). A similar rationale was advocated for BMPs and SUDS monitoring: from detailed in depth assessment of a few case study sites, to a programme of structured inspections of regional examples, a level of trouble-shooting/investigative monitoring, and finally a base-line of adoption standards and building control standards backed by pre-completion approval or vesting inspection or certification.

Storm event sampling for at least one example waterbody (catchment or sub-catchment) per land-use type demonstrates for sectors that model-based evidence is valid. Ideally, sets of paired rivers monitoring diffuse pollution loads from example catchments would be established, but practicalities may preclude that. Long term diffuse pollution monitoring stations are desirable to allow for greatly varying weather conditions from year to year. At least one long-term diffuse pollution monitoring station should be established for the following land-use categories, where storm event monitoring would be routine, together with flow recording:

- Intensive arable
- Intensive livestock
- Forestry
- Urban (general)
- Industrial estate with known significant adverse impact on the watercourse
- Major trunk road or motorway

- Upland moorland

An upland moorland site could also be part of a long term examination of changes in relation to climate change, with associated losses of soluble carbon and oxidation of soil organic carbon, especially on peat lands. As BMPs (including SUDS as appropriate) are retrofitted to the monitored catchments, long term measurement of water quality and land-use changes can demonstrate effectiveness or otherwise of the measures, for example buffer strips (D'Arcy *et al* 2006) and fencing off the watercourse to prevent access to livestock (Kay *et al* 2007). Data from such direct assessments underpins the abundant literature evidence to put to sectors regarding the effectiveness of particular BMPs involved in a roll-out of measures in a catchment or region.

Not all pollutant parameters are readily assessed by storm event monitoring – oil for example is very difficult to monitor quantitatively through a storm event. Therefore for urban water quality assessments sediment monitoring offers a cost-effective means of assessing pollution levels in a waterbody (Wilson et al 2005). Parallel biological assessments can provide evidence of any adverse impacts that may be associated with measured pollutant concentrations in sediments. A national programme of urban stream sediment monitoring following on from the baseline set by Wilson *et al* (2005) should be planned to provide quality evidence for one year in each of the WFD planning cycles.

As measures are rolled out in catchments across the country, it is only natural that local stakeholders would wish to know whether any improvement in water quality is being achieved. Strategically, there are at least two options:

1. Ecological assessment – good ecological quality is the fundamental aim of WFD, and such assessments in the reaches expected to show improvements can be undertaken relatively inexpensively.
2. In the longer term, a progressive switch to remote monitoring technology for water quality, integrating with hydrological monitoring locations to allow load as well as concentration to be monitored continually, could save a lot of expense when compared with sample collection for traditional laboratory based analysis of physical samples. The latter role would of course still be vital for toxic metals and organics, but could perhaps benefit from seeking partnerships with research laboratories for emerging pollutants, to separate costs of method development from unit costs per sample analysed, whilst retaining and enhancing the expert status of agency laboratories that is important for legal disputes in relation to evidence of pollution, as well as scientific validity.

In some catchments local anglers are being trained to undertake basic bankside surveys for ecological assessment of water quality (Jill Gillard, SEPA ecologist, pers. com.) – such initiatives could be encouraged elsewhere and for other interested local groups too. The application of remote water quality monitoring at hydrological stations is more of an organisational and institutional challenge than a technical one. These points are summarised in the monitoring and characterisation strategy set out in Figure 5.1.

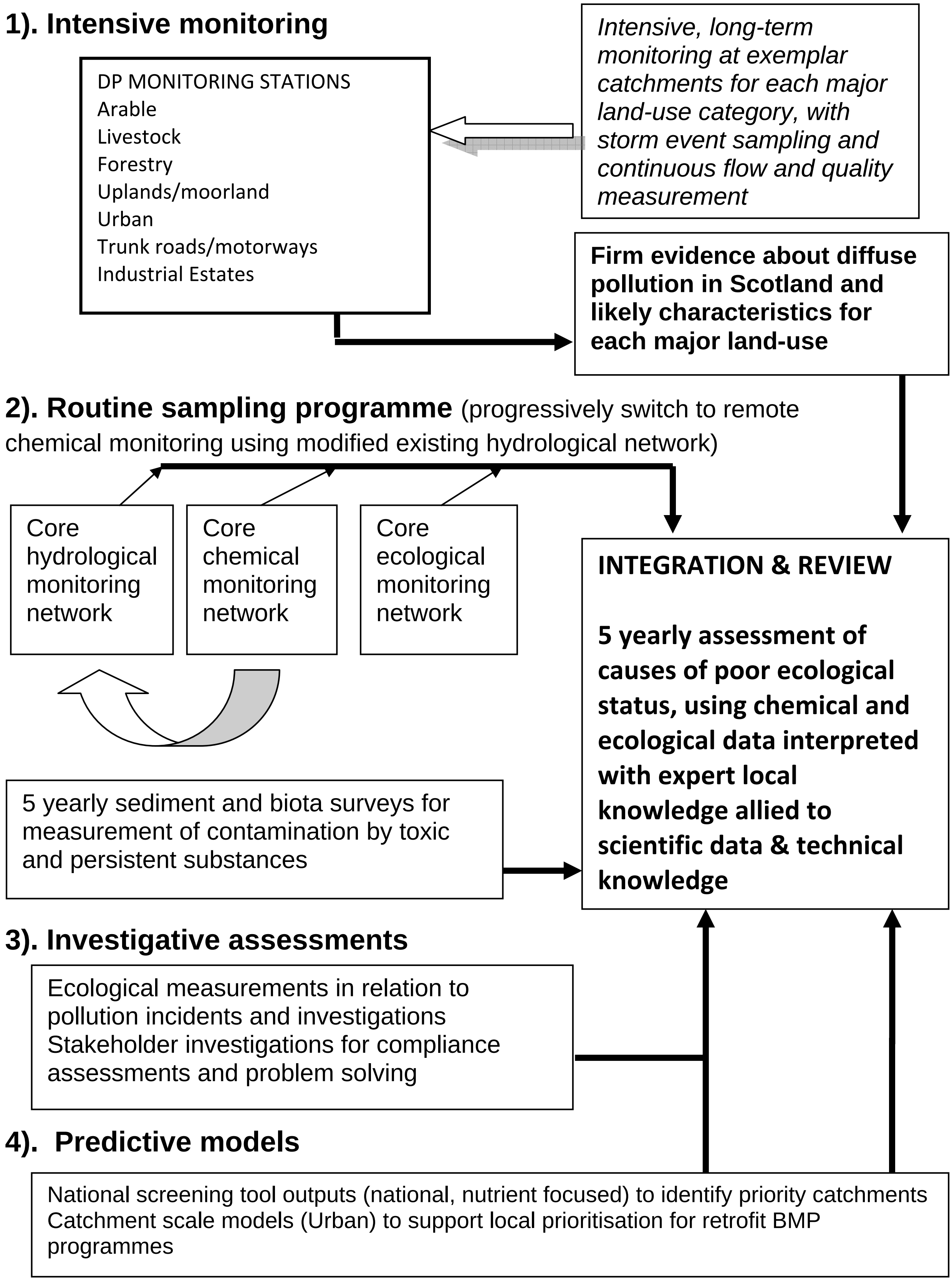


Figure 5.1 Hierarchy of approaches for monitoring the water environment for diffuse pollution impacts and understanding land-use changes.

5.2 Control Measures

Control measures need to be considered in two ways:

a) Which catchments are priorities for application of measures?

b) What measures from the suite of available options are most appropriate and likely to be taken up by the sectors involved?

The periodic assessment of water quality and causes of downgrading developed by FRPB and by SEPA that is based on measured water quality together with expert local knowledge, is being complemented by modelling programmes for rural catchments. Focused on phosphorus especially, the work aims to identify catchments that need to be priorities for remedial efforts, and at a more detailed scale to identify potential critical source areas within a catchment. An analogous approach has been developed for urban catchments (Ellis and Mitchell 2006), together with unpublished research to identify threshold values for the degree of urbanisation which, if unmitigated by SUDS, is likely to result in deterioration in waterbody quality.

For a capital spending programme to retrofit SUDS to improve the water quality of target urban waterbodies (D’Arcy *et al* 2011), a joint research project to evaluate the effectiveness of the retrofit measures would be a reasonable approach for such a ground-breaking process.

The desirability for a treatment train of measures in a SUDS scheme for developments has been indicated in a case study in Halmstad, Sweden (in D’Arcy *et al* 2007) and more detailed evidence of treatment train benefits was obtained by Napier *et al* (2009). A treatment train approach is equally pragmatic and desirable for rural situations, where combinations of measures are most likely to deliver water quality objectives, as demonstrated for example in the Loch Leven catchment with buffer strips (and hotspot actions) supported by nutrient budgeting and stabilising high risk slopes near watercourses by converting to grass (D'Arcy *et al* 2007). Less attention has been focused on treatment train BMPs at farm steadings. There is scope for example for more widespread application of inexpensive measures such as grass filter strips, diversion of minor flows close to source onto farmland, collection of roof water for use on the steading and reducing scour of pollutants from farmyards and hydraulic overload of slurry systems .

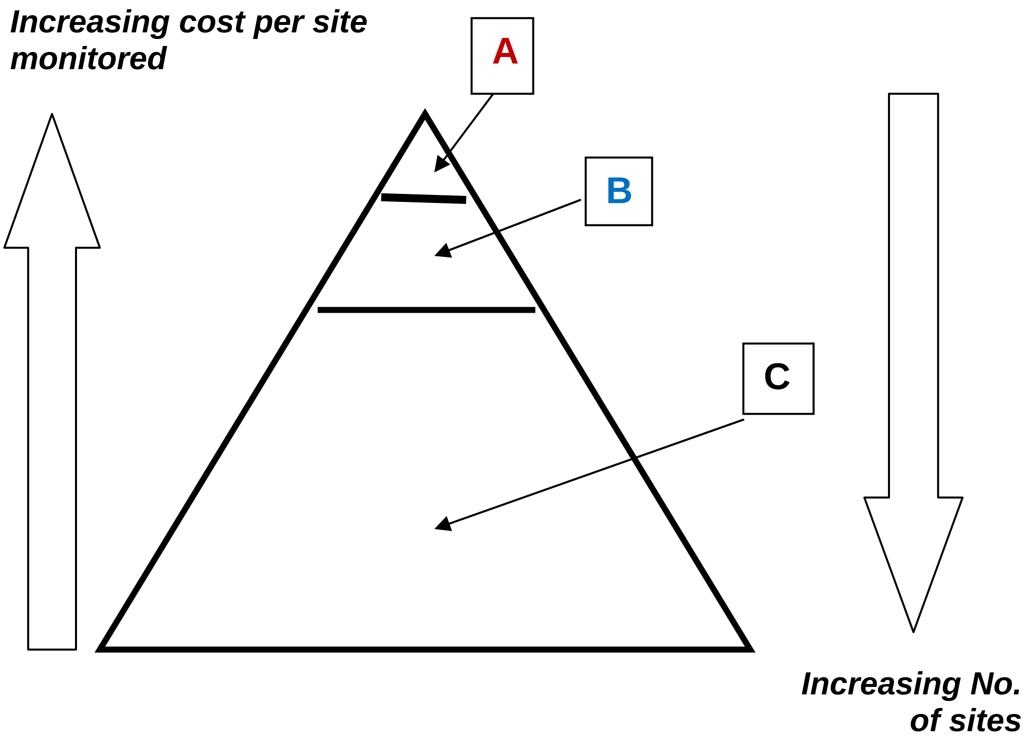
The appropriateness of particular SUDS can be considered from two different perspectives:

(a) effectiveness in capturing pollutants and hence prevention of pollution in the water environment,

(b) the fate of the captured pollutants within the SUDS features.

Evidence indicates that soil/vegetation systems that are periodically dry or at least drain down, (e.g. basins and swales, filter strips) are more likely to favour degradation of hydrocarbons for example than wet ponds or sediment traps (Napier *et al* 2009). A treatment train of measures that begins with soil/vegetation or perhaps permeable surfaces, and finishes with a constructed wetland, would address degradation of hydrocarbons close to source, and optimise the quality of the final stage measures such as ponds, for wildlife and amenity.

The treatment train approach refers primarily to BMPs or SUDS which intercept or trap pollutants, or prevent their release from soil and other surfaces. For manufactured polluting substances such as problem pesticides and PCBs, the most effective control approach can be to ban or restrict uses of the substances of concern. A similar approach to that outlined for environmental monitoring, and set out in Figure 5.1, can be adopted for assessment of the effectiveness of measures on an individual basis. That is essential to be able to inform sectors of the efficacy of the technology they are being asked to use, and secondly to allow innovation in pursuit of ever more cost-effective solutions. It is also essential if environmental monitoring shows catchment scale deterioration despite application of measures (investigational monitoring). Figure 5.2 sets out the approach for SUDS monitoring advocated by the Scottish Universities SUDS monitoring group at the early stage of the group's work (see Appendix III). An exactly analogous approach is appropriate for rural BMPs too.



Key: **A** denotes demonstration sites (intensively evaluated, data published, long term assessment).

B denotes SUDS sites inspected on a national rolling programme of monitoring by local agency teams as part of routine district work (a small number per team, across Scotland in urbanising areas). Includes retrofits in targeted urban stream recovery plans.

C denotes the great majority of SUDS sites for which expectations of fit for purpose design and construction are dependent upon adherence to published guidance, plus pre-adoption or completion certification or inspection.

Figure 5.2 Hierarchy of monitoring requirements for SUDS technology

With reference to Figure 5.2 it should be noted that no such agency led monitoring programme currently exists, there having been a prevailing dogma that only individually significant sources can ever be monitored. That view failed to recognise that collectively many minor sources comprise very significant causes of environmental pollution (e.g. urban drainage without SUDS). Equally important are the collectively essential anticipated benefits of many prevention measures such as SUDS features on new developments, which are the basis for preventing further deterioration. There has also been a failure to understand that even in a period of severe cutbacks and limited resources, it is possible to devise even a very limited programme. For example only a handful of sites could be selected for inspection per year in each SEPA team district, changing year on year. That would allow a level of activity as indicated by B in Figure 5.2, as well as have an important impact on sectors and regulatory activity (see section 5.3).

5.3 Sector Engagement and Regulation

Building on the evidence base established as suggested in Figure 5.1, and measures monitoring in Figure 5.2, Figure 5.3 indicates key aspects and actions in sector engagement. A web of inter-relations is indicated, since engagement has to occur in several ways, and not necessarily in a hierarchical pattern.

To address diffuse pollution requires engagement at three levels:

1. International
2. National
3. Local

International engagement is essential to influence issues that are beyond the scope of any one country, for example CAP reform for the EU countries (Mohaupt *et al*, 2006), influencing emerging legislation, such as the Water Framework Directive in Europe, and engaging with multi-national industries in relation to problem pollutants in specific products for example agricultural pesticides, anti-fouling paint, alkyl lead anti-knock in petrol, endocrine disrupting substances, or copper in brake pads (San Francisco Estuary Institute, 2007). Sector engagement is obviously essential if such discussions are to be productive.

At a national and local level, early engagement with sectors is essential for co-development of understanding of diffuse pollution problems, and then co-development of technical answers that are acceptable to regulators and sectors alike. A diffuse pollution management strategy must ensure engagement is not simply with enthusiasts in the sectors, but adequately engages with leadership figures too. Directors and CEOs can often be blockages in the uptake of new approaches and acceptance of measures; in any organisational hierarchy it is rare for the leaders and senior managers to attend training courses about new pollution issues such as diffuse pollution. The most effective means of briefing them and giving at least some insight into the issues is to give invitations to chair sessions at major conferences and seminars. This is a structural issue in any serious process for the dissemination of technical knowledge and awareness, and for engaging effectively with sectors. A conference also opens opportunities for two way dialogue, which is important in developing ideal solutions.

At a technical level, co-authorship of papers is an effective means of constructive engagement (for example D’Arcy and Frost (2001) for the agricultural sector, and D’Arcy *et al* (2007) for engagement with urban sectors). Planning joint conferences, seminars and training is an effective tool for two-way dialogue and effective engagement. Rural example outputs include Petchey *et al* (1996, 1998), and Gairns et al (2006), and for urban sectors a succession of seminars and conferences on diffuse pollution and sustainable drainage, staged with various partners including SUDSWP, SHSG, CIWEM and IWA (see Appendix 3).

Publishing news articles in trade press of target sectors is effective at reaching out to sectors nationally through their own media. A top down approach can be minimised if local sector champions are featured in such articles.

Local sector engagement is where environmental improvement actually happens. There is no substitute for well informed, technically trained, motivated, empowered and enthusiastic local officials in environment agencies, government advisory offices, local authorities, and water utilities, who can engage constructively with equivalent representatives of the sectors. It is therefore vital to ensure there are no conflicts, but instead a degree of common understanding of the BMP technology and its applications for pollution prevention in each sector, at local service delivery level.

Effectiveness or even limitations to the potential of such constructive dialogue can be a function of economic factors. One of the aims of national dialogue with government and sectors is to try and ensure there are minimal conflicts between environmental and other statutory requirements, or even contradictions between different environmental regulatory positions.

Incentivisation by economic drivers has been recognised as an important mechanism in any diffuse pollution strategy (Mohaupt *et al* 2006, Frost *et al* 2004). Environmental improvement is not always a cost, many examples of cost-neutral options or even cost savings have been documented for various sectors, e.g. industry (D'Arcy *et al* 1999), agriculture (Frost *et al* 2004), and urban development (Wilson *et al* 2004, Chris Pittner, WSP *pers. com*).

Unfortunately, no amount of constructive dialogue and enthusiasm will persuade every farmer, house-builder, site operator on an industrial estate or forestry contractor to have pollution prevention best practice as a priority concern. Legislation is enacted to allow regulatory activities and enforcement in such instances. The far more important strategic purpose of legislation however, is to establish rules and baselines for expected practices so that the compliant majority of a population can be clear about the requirements for good environmental practices.

For diffuse pollution the very large numbers of potential sources and activities involved requires a radical new approach to regulation and this is the reason that the unregistered general binding rules concept was introduced (D'Arcy *et al* 2006). It is not sufficient merely to have the legislation and regulations however, the sectors need to know about them in detail, and there has to be an effective enforcement strategy too. Both require publicity in local and national technical press, as well as through local meetings and dialogue at local scale, where delivery is most effective. A radical new approach to enforcement is also required for diffuse pollution control: a sampling plan for limited inspections of small numbers of premises, to be an unpublicised resource-driven management decision of the organisations involved. Sufficient resource should be allocated for follow-up actions to drive best practice forward at premises inspected. Even if the percentage of sites inspected per year is very small, the existence of an inspection and enforcement regime will have a significant impact. To date, the lack of inspections of urban diffuse sources of pollution is a serious failure in the UK. As part of the strategic approach outlined here, resource sharing between tax-payer funded organisations for inspections and enforcement is important. Currently achieved for agriculture, it remains to be negotiated and thought through for urban sectors.

SECTOR ENGAGEMENT: COMMUNICATION WEB

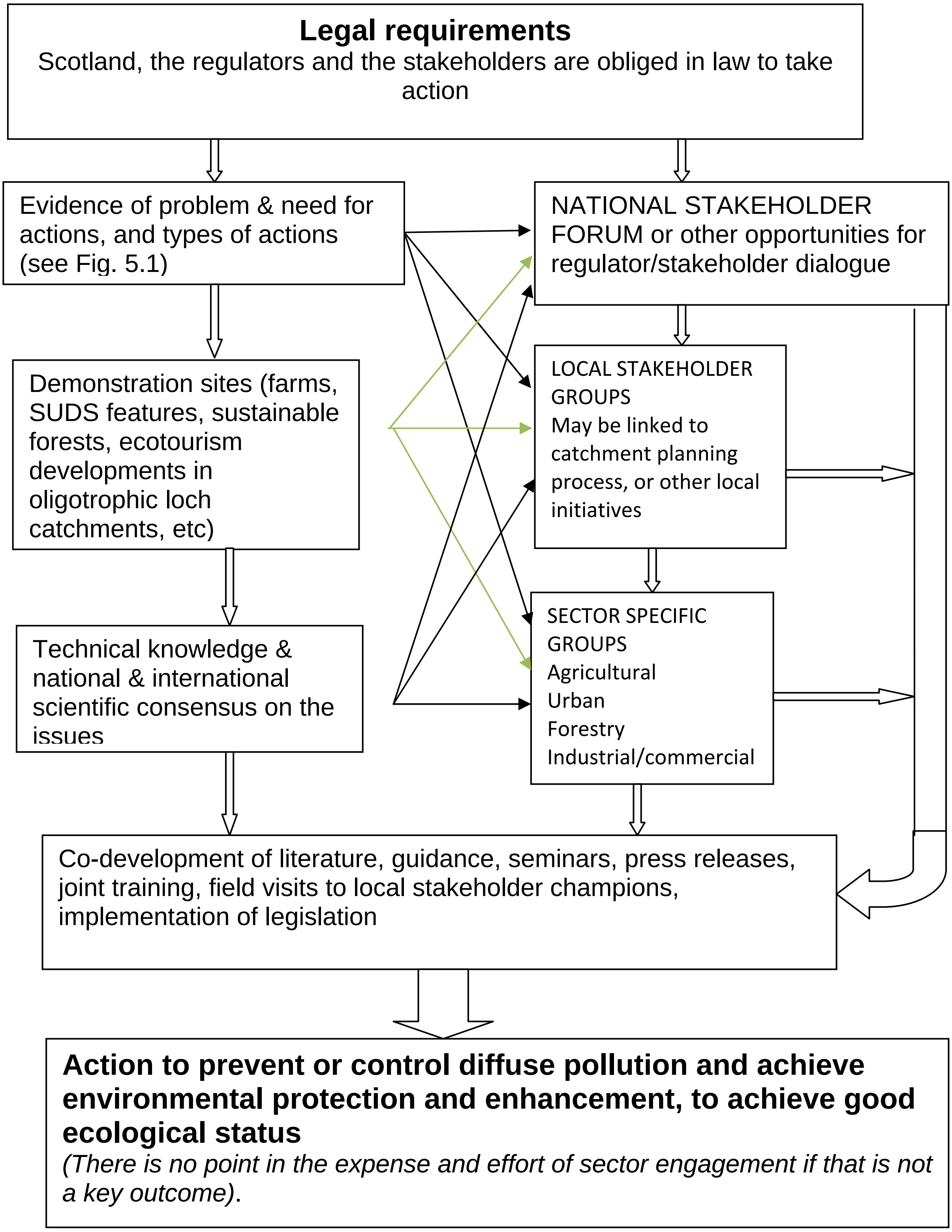


Figure 5.3 Schematic for stakeholder engagement for managing diffuse pollution at a national and local scale.

One possible approach for building an inspection and appropriate enforcement regime for urban diffuse sources in Scotland for example, might be a partnership approach between SEPA and local authorities. A shared responsibility for air quality already exists, with the local authorities taking actions to achieve clean air in their districts, with SEPA empowered to require review of effectiveness and improvements to such programmes. With encouragement from Scottish government, it should be possible to include in such a joint approach programmes to manage water pollution risks from traffic, alongside air quality issue which are currently the sole interest of SEPA in such dialogue. Local authorities often employ environment wardens, charged with a remit to combat littering, dog fouling, noisy and polluting individual motor vehicle exhausts, and more. Enforcement is built into their role too, using administrative penalties that are far more appropriate for such anti-social activities than recourse to court actions. That would be ideal for general urban areas.

For industrial estates, a different partnership would be more appropriate. SEPA policy has from the earliest SUDS policy development consistently required that surface water drainage from new industrial estates should be licensed, and similarly all major discharges that have an individually significant impact on receiving water quality should also be licensed. That includes many existing large industrial estates. Traditionally SEPA, water utility and sometimes local authority staff have worked together to address water pollution problems from industrial estates. But the new powers in the GBRs, together with the development of diffuse pollution management technology in the form of SUDS and proprietary BMPs, allows for a new iteration in the interests of improving chronic urban stream pollution, by serving notices to require pollution prevention actions, including retrofit SUDS where appropriate. In addition to such plot-by-plot (source control) actions, an enforcement regime should also allow for SEPA to serve a notice on Scottish Water to retrofit SUDS to treat the surface water drainage prior to discharge, should there be unreasonable slippage in an agreed capital programme for such infrastructure improvements to complete the treatment train of measures that has been shown to be effective for pollution prevention for industrial estates.

Thus the key components of an urban diffuse pollution control regime are almost already in existence and would take minimal changes to incorporate into a local strategy with each local council. It would of course require renewed recognition of the need acknowledged in 1996, and consequent political will and vision nationally to re-engage and drive progress now.

5.4 Conclusion

An integrated approach to sector engagement as set out above for Scotland, with a firm evidence base developed as suggested above, offers a means to meet the needs of the EU Water Framework Directive in relation to diffuse pollution, and may also be applicable in other EU countries and in principle at least, in some other regions of the world.

"Achieving a focus on the message, not the messenger, and thereby allowing facts to influence opinions"

CHAPTER 6 – Achievements and Future Prospects

As noted in Chapter 1, the processes that deliver pollutants from the landscape to the water environment have of course, been studied prior to the studies documented here, obvious examples being nutrients associated with agricultural activities, pollutants associated with traffic and road infrastructure, and atmospheric pollutants introduced to the water environment in precipitation. This thesis has explored how understanding of the environmental phenomena has been enhanced by recognition and investigation of the diffuse pollution concept, and in various small ways has sought to develop a little further that understanding.

The work of Novotny and Olem (1994) and others to develop a concept of diffuse pollution provided a rationale for better understanding of the processes of environmental contamination and delivery of pollutants to the water environment, with significant implications for appropriate pollution control regimes. It is important to accept that diffuse pollution is not simply a couple of words not necessarily adding anything new to understanding, otherwise progress will continue to be unnecessarily constrained. The following examples demonstrate views prevalent before diffuse pollution became a more widely understood phenomenon:

a) Simplistic assumptions by regulators and others that high flows were typically associated with dilution (and hence lower concentrations of pollutants), were widespread prior to understanding the nature of diffuse pollution and its key characteristics. Hitherto, it was often simply acknowledged that higher loads would often be carried in high flows merely because of vastly increased flow values.

b) Wet weather failures of bathing waters now associated with agricultural runoff were initially assumed to be due to CSOs (combined sewer overflows). That was a special case of a) above, and had to be repeatedly debunked by the quantification of river borne loads and point sources in a range of weather conditions (Kay and Wither 2000, Kay *et al* 2007).

Figure 6.1 shows part of a summary panel from a proposal for surface water best management from a 1984 write-up by the author of intensive studies at industrial estates in Merseyside. It illustrates how, although elements of key processes were clearly recognised even then, in the absence of a diffuse pollution rationale the necessary actions for effective pollution control (BMPs) were not recognised. There was clearly recognition of chronic impacts in watercourses, and that there were two categories of problems – chronic background contamination and irregular major incidents. But the need for pollutant attenuation drainage infrastructure (urban BMPs or SUDS) was unknown to UK regulators at that time. There was in effect, still a point source mentality to trying to restore water quality, despite the progressive, but incomplete (no storm event measurements) characterisation of the problem. The failure to recognise some of the key characteristics of the pollution problem (e.g. contamination at high flows) even now, has led at one of the worst estates in that study to the progressive implementation of the wrong solution: diversion of dry weather flows (assumed to capture a “first flush”) from the estate into the foul sewer – causing problems for the treatment works and ignoring the pollution at its worst in the surface water drainage (D’Arcy and Kim, in prep.).

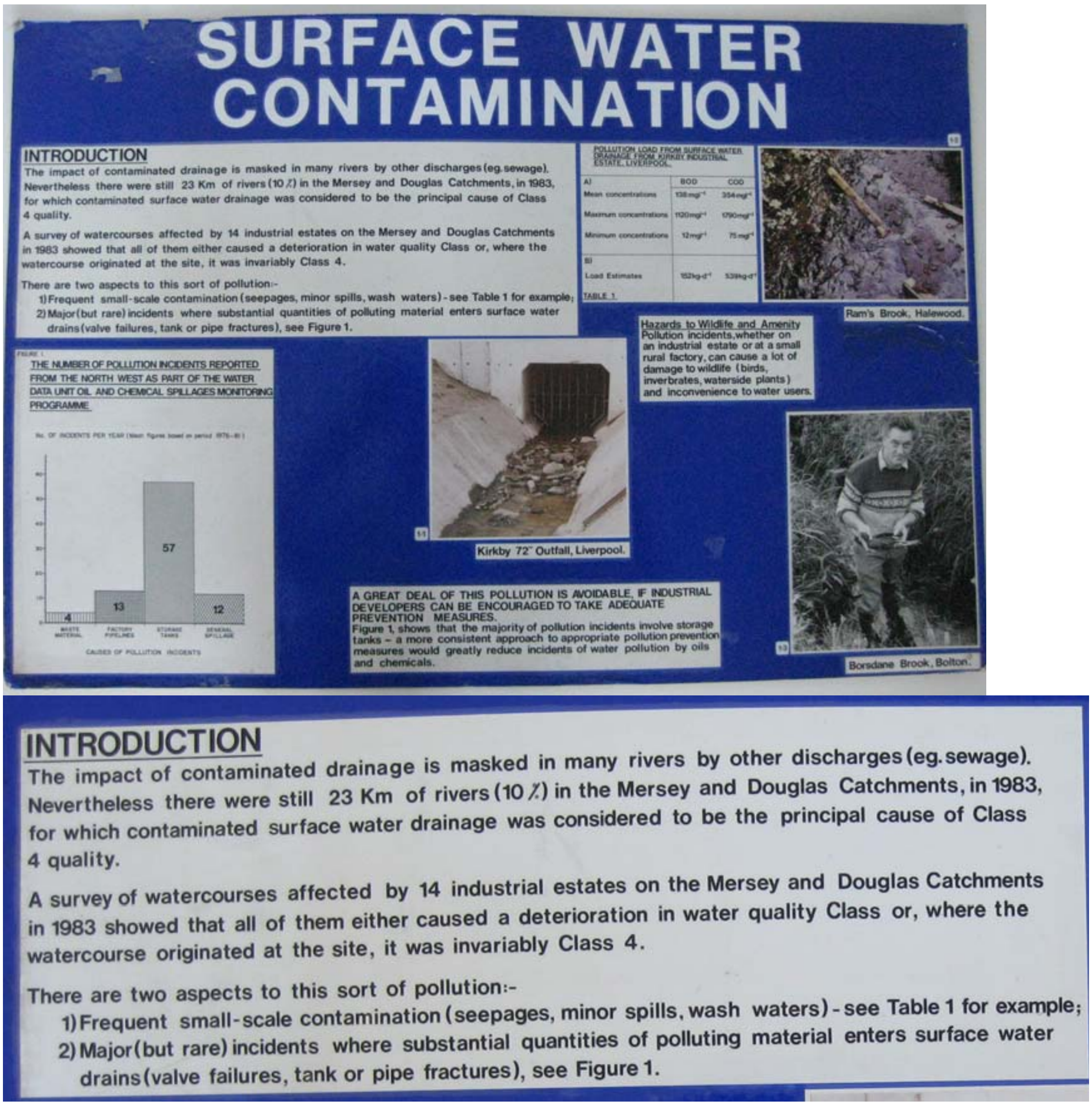


Figure 6.1 Best practice for industrial estate drainage as understood prior to diffuse pollution awareness, in the 1980s, highlighting recognition of the two aspects of the problem, chronic and episodic (D’Arcy, 1984), but no awareness of the need for BMP infrastructure, nor high flow aspects.

One of the over-arching achievements of this research was to put previous and continuing work into a diffuse pollution conceptual framework, following Novotny and Olem, and thereby encourage more productive research by others as well as the specific outputs for which the author had some direct responsibility in the published papers. One of the failings is that misunderstandings still occur; most regulators don't read academic text books or papers, and academics typically do not have the regulatory experience and insights to understand the perspectives of the regulators.

The development of a strategic approach to managing diffuse pollution here entailed three aspects:

- Problem definition, (Chapter 2)
- Identification and evaluation of technical measures to address the problem, (Chapter 3)
- Creating and encouraging an influencing regime to bring regulatory, economic and educational measures into practice: (Chapter 4).

By working with a technical team in SEPA and in partnership with others in a variety of stakeholder and academic organisations, it was possible to develop and steer a strategic approach to investigating problems and solutions. That series of investigations produced a number of significant outputs and some innovations, which are summarised as follows and detailed in the following sections:

1) Technical innovations and practices for quantifying and characterising diffuse pollution.

2) Conceptualisation of issues leading to new approaches for managing pollution.
3) Effective dissemination of findings and knowledge transfer from hitherto less widely known sources to regulators and stakeholders.
4) Regulatory innovation.

6.1 Technical Innovation and Practices for Quantifying and Characterising Diffuse Pollution

Technical innovation was a key part of the strategy to characterise and demonstrate the nature of the diffuse pollution problems. Whilst none of the techniques used to characterise diffuse pollution problems were new, the application by SEPA of the following techniques was novel for a regulatory agency in the UK.

The first national programme in Scotland, (sampling 27 sites on 9 urban watercourses from Aberdeen through Dundee, Edinburgh to SW Scotland) to assess urban stream sediment quality measured persistent pollutants and hydrocarbons (Wilson *et al* 2005). It effectively and quantitatively characterised the poor quality of urban watercourses in Scotland, and implicated combustion sources such as traffic as significant contributors to urban diffuse pollution impacts. It also demonstrated that sediment monitoring can be a useful technique for assessing contamination from diffuse source pollutants which are difficult to monitor by storm event sampling (oil and other hydrocarbons) and expensive (hydrocarbons and metals) if multiple sampling through a series of storm events.

Diffuse pollution monitoring stations for three example land-uses were established as part of the SEPA Diffuse Pollution Initiative led by the author from 2001-2005, building on earlier work led by the author in FRPB and SEPA from 1996. The storm event monitoring data from those stations provided the evidence which demonstrated that dilution is not an answer for diffuse sources (Ferrier *et al* 2005). It was also essential to allow analysis of water quality characteristics pre-and post-implementation of buffer zones (D'Arcy *et al* 2006).

Efforts to establish paired rivers studies – the usefulness of which had earlier been demonstrated in USA (for example Meals and Hopkins 2001) - were frustrated by a variety of circumstances even prior to cutbacks in budget, only being achieved for an at-risk bathing water quality location at Brighouse Bay in SW Scotland. Variable weather over successive monitoring seasons soon demonstrated the value of that monitoring innovation (Kay *et al* 2007).

The "high flows high concentrations" aspects of diffuse pollution were demonstrated for a range of pollutants in several watercourses draining a variety of land-use types (rural arable, rural livestock, and urban/industrial) (Ferrier *et al* 2005). That data provided evidence that it is a key diffuse pollution characteristic which offers a potential technique for appraisal of the relative importance of diffuse sources as compared with major effluents from industry and or municipal sewage sources. For example, if EQS exceedence is evident at low flows in a rural river, major point sources are implicated, if EQS compliant at lower flows, but not higher flows, then diffuse sources are the priority. Pollutograph/hydrograph comparisons were used successfully in staff training on diffuse pollution. One typical and recurring staff question relates to the possible importance of septic tanks in causing poor water quality at low flow. This is readily understood by trainees through pollutographs plotted alongside hydrographs for a water course impacted by diffuse pollution which showed higher concentrations of phosphorus (all forms) at higher flows than any observed at low flows. One watercourse which gave good illustrative evidence of this nature was the Greens Burn, the Loch Leven tributary that was evaluated for buffer strip efficacy (D'Arcy *et al* 2006).

Where no storm event data are available, an alternative method to allow low flow/high flow comparisons of water quality might be to express flow as percent exceedence flow, using the variation in flows likely over a series of months of spot sampling occasions to provide evidence of high flow low flow quality. This approach was piloted, when pollutant concentrations in a small urban stream, the Lyne Burn, Dunfermline, were plotted against exceedence flows. It was apparent that high flow quality was poor in the Tower Burn, a diffuse source/CSO impacted tributary. In contrast, the effects of wrong connections were more apparent during lower flows in the Calais Burn tributary, which was heavily impacted by wrong connections (O'Keefe *et al* 2005). The examination of quality against flow for a range of rivers expressed as percentile exceedence would be a useful technique to develop as an independent, data derived screening technique for targeting measures for catchment management under WFD. This relatively obvious and simple technique is not yet normal practice.

There are also important implications for the design and implementation of control techniques in the “high flows high concentrations” nature of diffuse pollution (e.g. D’Arcy *et al* 2007). The Brighouse Bay and Caw Burn studies demonstrated the poor prospects for stream improvement if a low flows treatment or enhancement approach were to be taken where diffuse sources predominate. A high flows treatment regime, involving the re-meandering of the stream channel to encourage high flows to flood a riparian wetland zone and deposit suspended pollutants, was developed and published as a desk exercise (D’Arcy *et al* 2007). This simple yet innovative idea has yet to be tested in reality, although river enhancement wetlands have been established independently by RSPB upstream of the Loch of Strathbeg, in NE Scotland working to different design principles (conventional sedimentation in widened-channel pools, with some riparian reedbeds).

Another characterisation investigation for understanding diffuse sources was the focus on motor vehicular traffic. In this research Wilson *et al* (2005) produced the initial SEPA evidence implicating traffic, by suggesting that combustion sources of PAHs predominated in several urban stream sediments, the main exceptions being where industrial estates were implicated as oil-derived PAH source areas. This study was followed up by a desk exercise to assess road traffic as a diffuse pollution source, including a suggestion that source control associated with traffic management and reduction would be useful (Napier *et al* 2008). That was in line with other papers considering management of diffuse urban sources, e.g. San Francisco Estuary Institute (2007), Ellis and Revitt, 2008. Traffic-derived pollutants were consequently the target pollutants measured in SUDS features subsequently evaluated by Napier *et al* (2009). Through the IWA Diffuse Pollution specialist group a key-note speaker from the California Brake pads partnership was invited to present a paper on research to quantify the importance of brake pad wear as a source of copper in San Francisco Bay. This supported the UK and other investigations that road traffic is a serious issue (examples already referenced above and in Chapter 1). The Napier *et al* (2008) work was also used in the State of the Environment report to mark 10 years of SEPA (SEPA 2006).

The above investigations also allowed the evaluation and validation of the ten key characteristics of diffuse pollution identified by Novotny and Olem (1994) in their seminal text. As set out in table 6.1, these have been demonstrated in Scottish example studies, and their importance as key features of diffuse pollution problems has been demonstrated (Ferrier *et al* 2005).

Table 6.1 Key Characteristics of diffuse source pollution (adapted from Novotny and Olem 1994), and their demonstration in Scottish studies

	Novotny & Olem 1994 characteristics of diffuse pollution	**Reference to demonstration as part of diffuse pollution strategy development**
1	Diffuse discharges enter the receiving surface waters in a diffuse manner at intermittent intervals that are related mostly to the occurrence of meteorological events.	Storm event monitoring: Ferrier *et al* 2005; D'Arcy *et al* 2006.
2	Waste generation (pollution) arises over an extensive area of land and is in transit overland before it reaches surface waters or infiltrates into shallow aquifers.	Agricultural assessments: D'Arcy *et al* 1996, D'Arcy and Frost 2001, Urban assessment: O'Keefe *et al* 2005.
3	Diffuse sources are difficult or impossible to be monitored at the point of origin.	Use of crop fertiliser applications & predicted losses, D'Arcy & Frost 2001; traffic paper, Napier *et al* 2008
4	Unlike traditional point sources where treatment is the most effective method of pollution control, abatement of diffuse load is focused on land and runoff management practices.	Agricultural examples in Frost *et al* 2004, and traffic controls advocated in Napier *et al* 2008.
5	Compliance monitoring is carried out on land rather than in water.	Assessment rationale in Frost *et al* 2004, GBR regulatory regime set out in D'Arcy *et al* 2006.
6	Water quality impacts are assessed on a catchment scale.	Examples for Loch Leven and Greens Burn tributary, in D'Arcy *et al* 2006, and for urban catchments in D'Arcy *et al* 2007, O'Keefe *et al* 2005.
7	Emissions and discharges cannot be measured in terms of effluent limitations.	Examples for traffic as water pollution source in Napier *et al* 2008, rationale set out in D'Arcy & Frost 2001, O'Keefe *et al* 2005
8	The extent of diffuse emissions (pollution) is related to certain uncontrollable climatic events, as well as geographic and geologic conditions and may differ greatly from place to place and from year to year.	Storm event monitoring in Ferrier *et al* 2005, D'Arcy *et al* 2006.
9	The most important pollutants from diffuse sources subject to management and control are suspended solids, nutrients, faecal pathogens and toxic compounds.	D'Arcy *et al* 1998, Wilson *et al* 2005, O'Keefe *et al* 2005.
10	Impacts can take time to become evident, as contamination can be cumulative*	Wilson *et al* 2005, D'Arcy *et al* 2006.

*added by author as published in CIWEM report in 2000, (D'Arcy *et al* 2000).

6.2 Conceptualisation of Issues Leading to New Approaches for Managing Pollution

Despite the characterisation and conceptualisation by Novotny and Olem (1994), a satisfactory definition of diffuse pollution was not devised until the CIWEM report (D'Arcy *et al* 2000). The subsequent second edition of the Novotny textbook (Novotny 2003) took up the CIWEM report definition as the definitive, consensus-based, rational definition (D'Arcy *et al* 2000, Ferrier *et al* 2005). Prior to that, there was confusion and uncertainty which was often compounded by simplistic literal interpretations of point source and non-point source as defining terms in ignorance of their original statutory meanings in legislation in USA (Novotny 1993). One EA early definition was something like "pollution that occurs when we don't know the source" – almost a statement of professional incompetence.

Probably the most well-known of the original concepts developed by the author in the course of the work was the *sustainable drainage triangle* (D'Arcy 1998) which has been widely used for its purpose of exemplifying the merit (and needs) of a multi-functional, and by implication, inter-disciplinary approach to stormwater management. The merits of a multi-functional approach to managing stormwater had been set out prior to then, e.g. Argue 1994, but not presented in a simple unified concept that might effectively influence developers, consultants and academics. The sustainable drainage triangle concept was first set out in a relatively obscure journal and this perhaps explains why the phrase was quickly and widely adopted but without reference to the source (e.g. CIRIA 2000, Wilson *et al* 2004). The concept was re-asserted, together with similar arguments for multi-purpose landscape features in the rural environment, in D'Arcy and Frost, 2001. The term SUDS undoubtedly followed, although the author had no part in deriving the acronym, merely the concept behind it.

BMPs are by definition (Novotny and Olem 1994) measures to address water quality issues, designed for rural, urban and other sectors. They do not have flood control as a primary purpose. Many urban BMP techniques however, have some stormwater flood risk management functions as the latter were easily incorporated into BMP features by provision of additional storage capacity with multiple stage flow controls on outlets. By coining the new term *Sustainable drainage systems*, it became possible to seek to embody the various different functions in the overall drainage design for a development, to try and mimic the natural hydrology of the area (D'Arcy 1998, Conlin 2000).

The "high flows high concentrations" aspects of diffuse pollution noted above have been identified and promoted as key to characterising diffuse pollution challenges and, as already noted, to determining appropriate technical solutions. The phrase has been useful as a quick summary conceptualisation of diffuse pollution and it is suggested that more use should be made of it. It is still not uncommon to hear people speak about dilution at higher flows for diffuse discharges. A full paper utilising the various catchments for which storm event data is available now, for a range of pollutants, as well as the suggested long-term plots of quality against flow as percentile exceedence values, would be a useful way of further exploring the nature of diffuse pollution with all the implications for control and catchment management. It is an important conceptual element of diffuse pollution management.

Finally, the linking of land-use to water quality for diffuse pollution (D'Arcy and Frost 2001) was achieved by a partnership venture with two rural organisations, first with FRPB, then with SEPA through the Buffer Strips initiative, from 1995-2000. The buffer zone concept was developed and used to highlight that water pollution risks were present on the land in everyday, routine farming practices. Whilst only one technique in a suite of BMP options for farmers and foresters, the simplicity of the idea of moving the potentially polluting activity back from the water's edge, was readily accepted by farmers and others. A buffer zone could be an unmanaged strip of riparian vegetation, a woodland belt, a grass filter strip, or a linear wetland margin. Each application of the idea exemplified another aspect of diffuse pollution and the landscape approach to mitigation. It was also an easily understandable example of a BMP type that could be a welcome land-use feature which could also attract wildlife, be attractive aesthetically, and attract government payments (D'Arcy and Frost 2001).

6.3 Effective Dissemination of Findings and Knowledge Transfer from Hitherto Less Widely Known (in UK) Sources to Regulators and Stakeholders.

Ferrier *et al* (2005) was the culmination of nearly ten years of engagement and partnership working. Partnership working to achieve stakeholder engagement has been a fundamental element in the strategy to manage diffuse pollution, from the outset. The early campaign videos by FRPB and then the IAWQ film *Nature's Way* launched diffuse pollution in the UK as a new issue for regulators, research organisations and sectors (Pratt *et al* 1996).

The international success of *Nature's Way*, led directly to the IWA (then IAWQ) Diffuse Pollution Specialist Group conference in Edinburgh in 1998 (Novotny and D'Arcy 1999) and international influence of the author as a committee member subsequently of the Specialist Group. That provided opportunities to engage directly with leadership players in all the UK agencies, as well as sector organisations and government officials. The international efforts with the Diffuse Pollution Specialist Group from 1995 led directly to invitations to write two papers: D'Arcy *et al* (1998), and D'Arcy *et al* (2007). That international profile opened doors for access to important co-authors in a UK context - in both of those papers at the time. The co-authors of the papers take the message to the sectors and influence agencies and government.

The Loch Leven restoration paper (D'Arcy et al 2006) could not have been written without the antecedent buffer strips initiative already noted, that had been co-developed with FWAG and SAC. The buffer strips initiative also led directly to the first UK diffuse pollution conferences (Petchey et al 1996, 1997), which were to become the biennial SAC/SEPA Agriculture & Environment conferences. Planning the conferences with SAC proved an excellent means of influencing the research agenda and programme of the rural sector, the two year lead in time being optimal. The conferences also provided opportunities to bring external and international speakers to add their insights and experience to the regulatory agenda in Scotland and the UK. By 2012 the biennial conferences have become an institution for agri-environmental dialogue in the UK, well attended by delegates from Defra, ADAS, IGER and other leading agricultural organisation from England, as well as their counterparts in Scotland. Those networking efforts provided co-authors and mutual understanding for several key papers: D'Arcy *et al* (1996), D'Arcy *et al* (1998), D'Arcy and Frost (2001), and Frost *et al* (2004).

Similar efforts were successful in progressing the urban agenda, as noted in Chapter 1, and example documents in Appendix 3, and the co-authors in Wilson *et al* 2005, O'Keefe *et al* 2005, D'Arcy *et al* 2007 and Napier *et al* 2009.

The total number of co-authors, 39 (Appendix 2) in the selected papers for this thesis is evidence of the partnership effort to encompass key organisations and develop consensus on issues, whether it be pollution impacts or remedial measures and programmes, across sectors.

6.4 Regulatory Innovation

D'Arcy *et al* (2006) described the general binding rules (GBRs) brought into force in Scotland in 2006. As non-registration statutory controls, they were thought by many regulators to mean that they would never need to be enforced and were only for trivial activities of little real interest, although their intent was well understood from the outset in the Scottish Government. The old regulators' thinking was a relic from a point source tradition and a stubborn inability to see or understand the challenges of managing diffuse sources, where so many activities have the potential to have significant collective impacts. By the time follow-up rules were agreed specifically for rural activities implicated in diffuse pollution, the necessity of non-registration statutory controls was more widely understood, although still some way short of ideal, with frustrations in relation to development of a proportionate and workable enforcement regime for rural and urban situations. In D'Arcy *et al* (2006) a case for an enforcement rational was set out, requiring partnership working to utilise the various tax-payer funded bodies with inspection staff to co-ordinate their use of resources in a monitoring strategy to cover target activities in a proportionate risk based way. The subsequent development of the SEARS partnership by Scottish Government provided an excellent opportunity for the rural sector which has been developed in a constructive partnership spirit. SEARS involves the public sector organisations with various regulatory responsibilities working together, to reduce duplication and make best use of resources to deliver their statutory functions. It involves the agricultural departments of the Scottish Government, SEPA, SNH and some others. An analogous partnership approach is still needed for the urban sectors.

Another regulatory innovation was achieved through discussions in the SUDS working Party (SUDSWP, see Appendix 2) where it was agreed that responsibility for public SUDS in Scotland should be given to Scottish Water, under the provisions of the WES Act, 2003. Reasons included the lack of drainage engineers in the regional councils following the setting up of the water utility and its predecessors, the single focus of the water utility on water (with the consequent freedom from budget debates about the need, for example, for schools or hospitals), and the opportunity for development of consistency and a broad level of understanding that could in theory be easier to achieve with a national organisation. The author argued that a Scottish Water remit would mean that a capital spending programme could be set up to achieve SUDS retrofits and thereby provide a much needed mechanism for improving urban watercourses (D'Arcy *et al* 2007).

6.5 Future Prospects for Urban Diffuse Pollution in the UK

6.5.1 The Water Framework Directive

The EU Water Framework Directive (WFD) establishes good ecological status at the heart of water environment requirements. What exactly might constitute good ecological status is beyond the scope of this thesis, since it did not feature in any of the published papers. But it is useful to note that the ecological base allows for recognition of both water quality impacts, and hydrological ones. For diffuse sources, the hydrological aspects of runoff from urban and rural land-uses are the characterising features of the pollution, so the two aspects are fundamentally linked for diffuse pollution management anyway. The interplay of those aspects are further considered below. The regulatory regime for diffuse pollution control in Scotland was brought in by the implementation of WFD. For urban diffuse sources, such an opportunity was not taken elsewhere in the UK, which has resulted in widespread misunderstandings across the UK as to the policies and actions in Scotland. In England it is a flooding agenda that is driving SUDS technology into use, under a totally different legislation, the Flood and Water Management Act 2010. That has implications in Scotland since most of the major consultants and house-builders in UK are based in England and naturally follow English policies and practices. As a consequence, the focus for SUDS in Scotland has already shifted, with a stronger emphasis on flood risk management. The continuing failure of government in England and Wales to include SUDS as mainstream means of managing diffuse source pollutants offers a depressing prospect of weakened drivers for one of the primary purposes in Scotland. Even the Water Framework Directive, which enabled SUDS to be established on an improved regulatory basis in Scotland, has had some disappointing impacts, for example on funding for pollution abatement research and innovations in Scotland including SUDS retrofits. That is because previously watercourses that were small but flowed through the parts of Scotland where millions of people live (the urban settlements) were accepted as priorities for abatement actions, but now face competition for resources from larger watercourses that more logically fit a WFD agenda. Although in theory departures from that position could be made, resources are already fully stretched on the larger waterbodies that fit the screening criteria. There is therefore a sense in which the implementation of WFD in the UK has been bad for urban water quality prospects. The WFD has come to dominate government policy on diffuse pollution, limiting water environment interest in vital pollution sources that are for example controlled by air quality or traffic management policies (e.g. persistent and toxic pollutants from motor vehicles) and which need an integrated approach and possible joined-up investigations of traffic as a water quality as well as air quality and human health issue. Another threat to development of effective means to control diffuse pollution in the UK is the continuing failure of the Environment Agency in England and Wales, and the Environment and Heritage Service in Northern Ireland, to adopt a technique for apportioning causes of poor quality water to particular sectors, as has been done in SEPA since its inception (SEPA 1996). The CIWEM report on Diffuse Pollution Impacts (D'Arcy *et al* 2000) stimulated government interest in the issue, prior to implementation of WFD, but the lack of source apportionment for urban diffuse sources in relation to municipal sewage effluent, industrial effluent and agriculture for example, at that time and subsequently, has undermined the case for urban control measures in England, Wales and Northern Ireland.

The WFD requirements for good ecological status encourage the physical restoration of urban and rural watercourses; Figure 6.2 shows an example urban watercourse in need of restoration.

Figure 6.2 The Salmon Brook, London, illustrating poor ecological status (photograph from The Environment Agency).

This potentially provides opportunities for managing diffuse pollution if the considerations set out in D'Arcy *et al* 2007could be followed; using river restoration to enhance self-purification capacity. A pre-requisite will be the acceptance of the high flows high concentrations (and massive loads) characteristic of diffuse pollution dominated watercourses. Bathing waters impacted by livestock derived faecal pathogens will be key priority watercourses for such measures to achieve multiple benefits for restoration of good ecological quality, since the above criterion of high flow relationships is already very well established (e.g. Kay *et al* 2007), and opportunities should be sought in rural and urban situations, although the latter may be too severely constrained by the existing built environment. In Scotland funds have been made available from Scottish Government, and SEPA has certainly been enthusiastic about the use of such funds even for small watercourses, but the scheme is dependent on local land-owner/stakeholder partnerships being established and coming forward with proposals to bid for the funds.

In the urban environment however, the good ecological status aspirations of many urban stream proposals will be equally constrained by the facts of urban hydrology, unless mitigated by retrofit SUDS. The hydrology of impervious surfaces in urban areas is of course why so many urban watercourses are lined with brick or concrete. Merely re-establishing meanders and removing the concrete will be pointless unless the imperviousness of the urban catchment is also addressed. Far greater dialogue in the UK between river restoration leaders and their SUDS counterparts is needed. Realistically the enormous size of the challenge probably precludes more than a handful of demonstration projects in relation to the number of potential candidate watercourses. An additional priority, such as bathing water quality downstream, or urban recreation or nature conservation interests will probably be a pre-requisite for integrated projects.

For water quality, the need for cleaner technology to reduce the contamination of the water environment by persistent and toxic substances remains an important priority, and sediment standards in support of good ecological status objectives may help drive such opportunities, The current economic climate may result in delays however, if additional costs for industry as well as the responsible bodies for monitoring are considered. In the interim, pollutant capture systems, including SUDS, will continue to be the principal defence against environmental contamination, underpinning best practice housekeeping techniques, e.g. for storage and handling of oil and chemicals and use of agricultural chemicals including pesticides.

6.5.2 The Green Agenda

The emergence of green infrastructure strategies in recent years could be a useful development to enhance the provision of landscape measures to address diffuse pollution, whether as buffer strips in rural landscapes or green infrastructure in cities and towns; e.g. the Defra 'blue corridors' scoping study (Defra 2011). Ever since the Rio Summit and the emergence of biodiversity as a key policy element for national and local government, the potential for habitat benefits associated with landscape diffuse pollution control features has been recognised. In the UK, the sustainable drainage triangle promoted the idea of biodiversity benefits, as did the rural buffer strips initiative in Scotland. Subsequently, the emergence of green roof technology for similar multiple benefits has added another green infrastructure option to the built environment and is now a recognised SUDS option for water quality, if not for flood risk management in the UK. Deeper green roof soil and sub-base structures with greater potential for biodiversity have also been developed, for example the innovations marketed as Living roofs. SEPA funded biodiversity surveys by Pond Action (reported in McKissock *et al* 2001) and also published guidance on optimising wildlife interest of SUDS ponds: *Ponds, Pools and Lochans*. The Nature Conservation Act, 2004, in Scotland imposed a duty on organisations spending public money to protect and promote biodiversity in the course of their business. Consequently, Scottish Water and local authorities might reasonably be expected to be mindful of that statutory duty in relation to their respective SUDS and flood risk management and urban renewal duties. It has nevertheless remained very much the poor relation of flood risk issues and water quality in relation to SUDS designs and in particular routine practices, even in Scotland, although there are nonetheless some good example developments (see figure 6.3, and 6.4). The *Phragmites* borders at the SUDS ponds in Duloch Park for example (figure 6.3) support a population of reed buntings, an LBAP species for Fife.

Figure 6.3 Frog spawn and tadpoles in conveyance swale J4M8 business park, Livingston, and *Phragmites* reed fringe at retention pond at Duloch Park.

Where a treatment train of measures can be achieved, biodiversity interest in the final feature (a pond or detention basin for example) will be enhanced by the flow control and pollutant attenuation in upstream features such as permeable surfaces, filter drains, filter strips and swales. That driver for source control techniques and a requirement for the application of the treatment train approach needs to be more strongly advocated if biodiversity and wildlife interests are to be fully realised. In England and Wales it could become a significant driver for SUDS technology with the launch of the new publication from RSPB/WWT "*Sustainable Drainage Systems (SuDS): maximising the potential for people and wildlife*" planned for January 2013.

Figure 6.4 shows the stormwater wetlands serving the timber industries industrial estate near Lockerbie, Steven’s Croft, which exemplifies multiple benefit opportunities even at industrial developments.

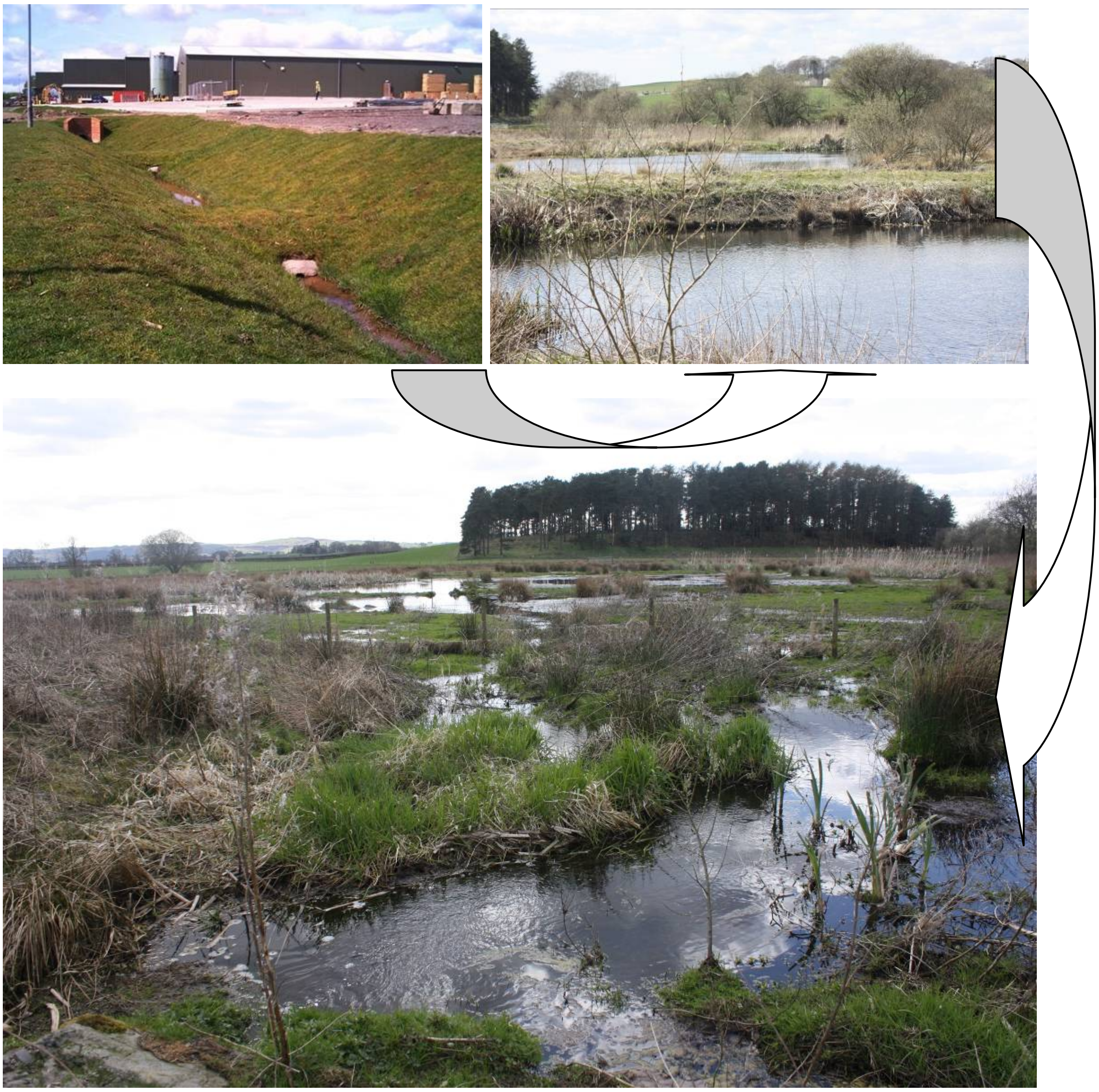


Figure 6.4 The SUDS treatment train at Steven’s Croft industrial estate, Lockerbie, showing one of the swales serving units close to source, followed by the two ponds and then the final series of stormwater wetland pools prior to discharge to the watercourse.

The wetlands are the final stage in polishing stormwater drainage from the industries on the estate that have provided initial attenuation features close to source such as grass swales (example shown), gravel filter drains and a small preliminary pond. Flows then combine to discharge into a pair of sedimentation ponds in series, with a penstock valve at the outlet from the first one into the second, to allow isolation of any spilled material in the event of a major accident. The discharge from the second of those ponds then passes to a series of shallow wetland pools prior to discharge to the small receiving water (a tributary of the River Annan). The development received a Habitat Enhancement Initiative award from SEPA.

Another driver for biodiversity that might become more widely recognised is the potential for cost savings if habitat enhancement is given greater priority. Mowing grass around pond margins and in detention basins less frequently can enhance habitat by allowing vegetation other than short grass lawn to become established, greatly increasing cover for wildlife and adding biodiversity value (Figure 6.5).

Figure 6.5 Uncut vegetation at a detention basin and a retention pond, Dunfermline.

Recognition of these positive attributes of SUDS technology should be increased by the relatively recent emergence of the ecosystem services concept in the UK (UK NEA, 2011; Lundy and Wade, 2011) as a high profile value system. It offers a means of adding value to the green landscape assets represented by SUDS, as amenity features for informal recreation as well as the habitat and wildlife value, flood risk management and pollution control functions.

Planning processes have always been recognised as an early formal opportunity to engage with developers in relation to the achievement of environmental improvements. Local planning control authorities in Scotland were initially encouraged to put paragraphs into local and regional strategic plans advising of policy to see sustainable drainage technology used for draining new developments. Subsequent detailed comments were then made on a case by case basis through the development control process. Nevertheless, the need for informal dialogue even before the planning process commenced was recognised and embodied in early government planning guidance for SUDS in Scotland, PAN 61. The planning process perhaps offers the best opportunity for achievement of a green landscape agenda, since green space requirements and landscaping aesthetics are core business for local planning authorities. In contrast the planning process has limited scope where statutory positions on environmental matters such as water pollution are clearly established within the remit of consultees such as SEPA and Scottish Water.

The green agenda for the rural environment also has considerable potential to be a positive driver for BMPs on farmland and in forestry and upland management. It has the great advantage of being historically at least, a funded opportunity for farmers, through habitat creation schemes under the Common Agricultural Policy (CAP) as well as earlier opportunities provided by set-aside land. Other income streams have been used by farmers, for example for buffer strips at Loch Leven, and the ecosystem services approach may identify new sources of funding in future as CAP reform reduces farmer payments. Ecotourism may become a more important opportunity for habitat enhancement alongside watercourses linked with informal recreation, for example. Fishery interests might also be increasingly important economic drivers for diffuse pollution land-use measures such as riparian woodland strips (the benefits of woody debris for stream ecology for example are increasingly well recognised by land-owners). Finally, the de-intensification of land-use in catchments draining to water supply reservoirs or lakes as an economic option for funding by water utilities is beginning to emerge as a driver for diffuse pollution management in parts of the UK.

6.5.3. Bathing Water Quality

The EU Bathing Water Framework Directive impacts usefully on diffuse pollution management, and was the prime driver behind the review by Kay and Wither (2000). The anticipated revised requirements were the driver behind the preliminary assessment of potential additional measures to address diffuse sources of FIOs in high flow conditions (D'Arcy *et al* 2007). A renewed focus on improved BMP options for diffuse sources of FIOs will continue to be an important driver for further improvements to the water environment. In urban contexts it could be aligned with river restoration schemes, as well as landscape enhancement for amenity and wildlife. A recent government consultation stated: “Last year diffuse urban pollution also accounted for the major reason behind 23 bathing water failures” (Defra, 2012), so the problem has certainly not been resolved.

6.5.4. SuDS and Floods – Sustainable Drainage for Flood Risk Management

The Flood and Water Management Act (2010) has become the principal driver for SUDS/SuDS in England and Wales. Since in those countries no other statutory driver has been established, it is rightly welcomed there. It might also have some benefits in Scotland, where SUDS technology has already been established under pollution control legislation. If Scotland blindly follows England however, it could be disastrous by undermining all that has been achieved to date, for example by impacting on the remit of Scottish Water to manage public SUDS, including establishment of a capital programme for retrofits to address chronic pollution. Scottish Water will increasingly be seen to be out-of-step with the water utilities in England and Wales, in relation to remit and capital programmes to address chronic pollution associated with urban diffuse pollution. The public consultation by Defra on addressing urban diffuse pollution of the water environment (Defra 2012) mentions that SuDS are recognised means of reducing pollution in urban runoff and are to be encouraged, but in considering mechanisms to do that it seems to limit the scope for SuDS. Thus it states in the section “Spatial planning - National Planning Policy Framework” that local planning authorities should:

“develop policies that take account of and manage flood risk from all sources and where development is necessary in areas where there is a flood risk, ensure it gives priority to the use of sustainable drainage systems, so that flood risk is not increased”.

Leaving aside the questionable value of applying SuDS in a landscape that has been identified as a flood risk area (beyond the scope of this thesis), it appears to only advocate SuDs as a necessity in relation to an identified flood risk.

There are some potential benefits however. Where the case for a water quality driven treatment train of SUDS measures is weakest, for example in housing areas, the case for flow attenuation at source is strongest – since housing areas far exceed the areas of other urban land-uses in the catchments of most urban watercourses. The desirability of attenuating storm flows at source (e.g. roof runoff and driveways) is likely to become an important driver for source control in housing and other lower pollution risk situations. It could therefore reinforce the effectiveness of treatment at a regional scale, since most source control techniques do not have high flow by-pass routes, (instead allowing very local flooding in major storms but without presenting risks of damage to life or property). That contrasts with an end-of-system SUDS approach, whereby un-attenuated flows pass forward in a conventional pipe system that usually requires an overflow and potential for by-pass of pollutant load at the SUDS feature, as well as less effective flood risk management if inlets are blocked and not noticed until a flood event.

If a unit plot SUDS approach can be developed, whereby each plot has self-contained SUDS features to attenuate flow and first level of water quality treatment too, the costs for the public sector in maintaining downstream features will be reduced, and the cost for developers reduced too since the resulting feature would be smaller if accepting flows already benefitting from attenuation at source. The possibility of such an approach would therefore provide an economic driver for source control. Therefore the flood risks focus across the UK can have a major role in shaping the types of SUDS features and the scales of application of the technology in future, if the unit plot approach to roll out of the technology is adopted by the regulatory and planning authorities.

Similar joined-up management approaches to the rural environment could also accrue; for example restoration of peat-lands and other upland habitats by restoring natural water regimes (sustainable drainage?) and blocking the man-made rapid drainage pathways created in headwaters of river systems such as the Tay in Scotland and especially the Severn in Wales/England when upland areas were afforested. Carbon management drivers should also push in the same direction. Such land-use changes are also a good fit with the ecosystem services concept that is seeking to quantify benefits of such landscape management opportunities.

6.6 Overall Conclusions

The work in this thesis has shown that the diffuse pollution concept developed by Novotny and Olem (1994) is valid for explaining observed pollution characteristics in UK waterbodies, and is a useful basis for determining a strategic approach to managing the pollution problems.

A management strategy has been identified that encompasses characterisation and quantification together with identification of best practice means to address the pollution. An appropriate regulatory and engagement regime has been developed and implemented.

Some modest advances in understanding diffuse pollution have been achieved, at least in a UK context, and should provide a firm basis for further work and application of the lessons learned. Additional research is still needed to further test the prediction based on observations reported herein that high flows are associated with high concentrations (not just loads) in watercourses primarily impacted by diffuse sources. If validated, a useful technique for source apportionment and prioritisation for pollution control action could result, linking risk of EQS failure with diffuse sources.

Other research needs relate to sediment and environmental quality standards. This in part relates to the pressure (in some areas) to move towards further and more stringent EQS and sediment standards. How those standards may develop will be dependent on a case being made for effective environmental management benefits without adverse impact on costs.

The innovations in regulation need to be followed up by an equally fresh partnership approach to enforcement. That might result from cutbacks in public spending that could force an examination of remits of national (UK) environmental agencies and local authorities, including local authority field staff deployed on enforcement of littering, dog fouling and dumping oil and other wastes.

The requirements of the Water Framework Directive for good ecological status bring together the key elements of diffuse pollution processes: pollutants are washed off the landscape in wet weather, and the wet weather erosion of the landscape and watercourses also impacts on the ecological status of the waterbody. Reinforced by the requirements of the flood and water management legislation across the UK, cost savings can be important drivers for the treatment train application of SUDS technology, especially in housing areas, and flood risk management also can combine well with WFD drivers for upland management in rural headwaters of UK rivers.

The continuing interest in green infrastructure and features in both rural and urban situations also has considerable potential to drive SUDS technology forward and to ensure features are optimised for multiple benefits. Awakening awareness and interest by wildlife focused non-governmental organisations such as RSPB and WWT should help this.

Economic conditions that require efficient use of resources, especially when considered from the perspective of ecosystem services, should continue to support public and business interest in the application of measures to manage diffuse pollution of rural and urban environments.

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APPENDIX I – List of the Selected Published Papers

The 15 core published refereed papers that are the basis for this thesis, and which are each described (aims, significance and achievements) in Chapters 3, 4 and 5, are as follows:

1. D'Arcy BJ, Todd RB and Wither AW (1999). Industrial Effluent Control and Waste Minimisation: Case Studies by UK regulators. *Water Science and Technology*. Vol. 39, Number 10, pp. 281-287.

2*. D'Arcy BJ, Ridgway IM, Marsden MW and Sargent RJ (1996). Diffuse Pollution and Agriculture in the Forth Catchment. In Petchey A, D'Arcy BJ and Frost CA (eds): *Diffuse Pollution and Agriculture*. Scottish Agricultural College, Aberdeen. ISBN 1 85482 575 5

3*. D'Arcy BJ (1998). A New Scottish Approach to Urban Drainage in the Developments at Dunfermline. *Proceedings of the Standing Conference on Stormwater Source Control*. Vol. XV. The School of the Built Environment, Coventry University, Coventry.

4. D'Arcy BJ, **Usman F, Griffiths D and Chatfield P** (**1998**). Initiatives to Tackle Diffuse Pollution in the UK. *Water Science & Technology.* Vol. 38, No.10, pp 131-138.

5. **O'Keefe B, D'Arcy B, Davidson J, Barbarito B and Clelland B (2005)**. Urban Diffuse Sources of Faecal Indicators. *Water Science & Technology*. Vol. 51, No. 3-4, pp 183-190.

6. **Wilson C, Clarke R, D'Arcy BJ, Heal KV and Wright PW (2005)**. Persistent Pollutants Urban Rivers Sediment Survey: Implications for Pollution Control. *Water Science & Technology*. Vol. 51, No. 3-4, pp217-224.

7. **Napier F, D'Arcy BJ and Jefferies C (2008).** A Review of Vehicle Related Metals and Polycyclic Aromatic Hydrocarbons in the UK Environment. *Desalination*, vol 226 Issues 1-3, pp 143-150.

8. **Ferrier R, D'Arcy BJ, MacDonald J and Aitken M (2005)** Diffuse Pollution – What is the Nature of the Problem? Journal of the Chartered Institution of Water and Environmental Management WEJ I, pp 361-366.

9. **D'Arcy B and Frost A (2001)**. The Role of Best Management Practices in Alleviating Water Quality Problems Associated with Diffuse Pollution. *The Science of The Total Environment*, 265 (2001) 359-367. Elsevier.

10. **D'Arcy BJ, May L, Long J, Fozzard IR, Greig S and Brachet A (2006)**. The Restoration of Loch Leven, Scotland UK. *Water Science & Technology* **53**(10), 183–191

11. D'Arcy BJ, Rosenqvist T, Mitchell G, Kellagher R and Billett S (2007). Restoration Challenges for Urban Watercourses. *Water Science & Technology* vol. 55, No. 3, pp 1-7.

12. D'Arcy BJ, Mclean N, Heal K and Kay D (2007) Riparian Wetlands for Enhancing the Self Purification Capacity of Streams. *Water Science & Technology* **56** (1): 49-57.

13. Ellis JB, D'Arcy BJ and Chatfield PR (2002). Sustainable Urban Drainage Systems and Catchment Planning. *J.CIWEM* 2002, vol. 16, November, pp 286-291.

14. Frost A, Stewart S, Kerr D, MacDonald J and D'Arcy B (2004). Agricultural Environmental Management: Case Studies from Theory to Practice. *Water Science & Technology*. Vol. 49, No. 3, pp71-79.

15*. D'Arcy BJ, Schmulian K and Wade R (2006) Regulatory Options for the Management of Rural Diffuse Pollution. In McTaggart I and Gairns L (eds), *Managing Rural Diffuse Pollution.* Selected papers from 6th SAC/SEPA Biennial Conference on Agriculture and Environment. Edinburgh 5-6 March 2006.

*****These 3 papers were published in edited and peer reviewed conference proceedings, not mainstream peer reviewed journals; they are included because they were the first UK papers to be published on the subjects indicated. The last one (D'Arcy *et al,* 2006) remains the principal published paper that explains the General Binding Rules (GBRs) approach developed for controlling diffused sources, and describes the GBRs that apply to the built environment in Scotland. It therefore remains an essential reference paper.

The content of Appendix I, pages 193-322, have been removed for copyright reasons. The content comprises 12 peer reviewed journal articles and 3 published conference papers. The citations to the paers are listed below.

D'Arcy, B. J., Todd, R. B., & Wither, A. W. (1999). Industrial effluent control and waste minimisation: Case studies by UK regulators. *Water Science and Technology.* 39(10-11): pp.281-287. doi:10.1016/S0273-1223(99)00306-6

D’Arcy, B. J., Ridgway, I. M., Marsden, M. W., & Sargent R. J. (1996). Diffuse pollution and agriculture in the Forth catchment. In: Petchey, A., D’Arcy, B. J., and Frost, C. A. (eds). *Diffuse Pollution and Agriculture.* Scottish Agricultural College, Aberdeen.

D’Arcy, B. J. (1998). A new Scottish approach to urban drainage in the developments at Dunfermline. In: *Proceedings of the Standing Conference on Stormwater Source Control*. Vol. XV. The school of the built environment, Coventry University, Coventry.

D'Arcy, B. J., Usman, F., Griffiths, D., & Chatfield, P. (1998). Initiatives to tackle diffuse pollution in the UK. *Water Science and Technology,* 38(10): pp.131-138. doi:10.1016/S0273-1223(98)00742-2

O'Keefe, B., D'Arcy, B. J., Davidson, J., Barbarito, B., & Clelland, B. (2005). Urban diffuse sources of faecal indicators. *Water Science and Technology.* 51(3-4): pp.183-190.

Wilson, C., Clarke, R., D'Arcy, B. J., Heal, K. V., & Wright, P. W. (2005). Persistent pollutants urban rivers sediment survey: Implications for pollution control. *Water Science and Technology.* 51(3-4): pp.217-224.

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): pp.143-150. doi:10.1016/j.desal.2007.02.104

Ferrier, R. C., D’Arcy, B. J., MacDonald, J., & Aitken, M. (2005). Diffuse pollution - what is the nature of the problem? *Water and Environment Journal. 19*(4): pp.361-366. doi:10.1111/j.1747-6593.2005.tb00574.x

D'Arcy, B., & Frost, A. (2001). The role of best management practices in alleviating water quality problems associated with diffuse pollution. *Science of the Total Environment.* 265(1–3): pp.359-367. doi:10.1016/S0048-9697(00)00676-8

D'Arcy, B. J., May, L., Long, J., Fozzard, I. R., Greig, S., & Brachet, A. (2006). The restoration of loch leven, scotland, UK. *Water Science and Technology.* 53(10): pp.183-191. doi:10.2166/wst.2006.311

D'Arcy, B. J., Rosenqvist, T., Mitchell, G., Kellagher, R., & Billett, S. (2007). Restoration challenges for urban rivers. *Water Science and Technology.* 55(3): pp.1-7. doi: 10.2166/wst.2007.065

D'Arcy, B. J., McLean, N., Heal, K. V., & Kay, D. (2007). Riparian wetlands for enhancing the self-purification capacity of streams. *Water Science and Technology.* 56(1): pp.49-57. doi:10.2166/wst.2007.435

Ellis, J. B., D'Arcy, B. J., & Chatfield, P. R. (2002). Sustainable urban-drainage systems and catchment planning. *Water and Environment Journal.* 16(4): pp.286-291. doi:10.1111/j.1747-6593.2002.tb00418.x

Frost, A., Stewart, S., Kerr, D., MacDonald, J., & D'Arcy, B. (2004). Agricultural environmental management; case studies from theory to practice. *Water Science and Technology.* 49(3): pp.71-79.

D'Arcy, B. J., Schmulian, K., and Wade, R. (2006). Regulatory options for the management of rural diffuse pollution. In: McTaggart, I., and Gairns, L. (eds). *Managing Rural Diffuse Pollution.* Selected papers from 6th SAC/SEPA Biennial Conference on Agriculture and Environment. Edinburgh.

APPENDIX II – Co-Authors

This table lists the co-authors in the sequence in which they appear in the papers submitted for this thesis.

No.	Co-author	Organisation at time of writing paper	Role in paper	Paper & chapter reference
1.	Todd, B.	Scottish Environment Prote3ction Agency (SEPA)	Input on industrial pollution case studies from Scotland	*Industrial effluent control and waste minimisation* etc. Paper no. 2.2
2.	Wither, A.W.	Environment Agency, (EA)	Input on industrial pollution case studies from England	Paper no. 2.2
3.	Ridgway, I.M.	FRPB	Organic chemist: pesticides evidence	Paper no. 2.3
4	Marsden, M.W.	FRPB	Ecologist: nutrients and eutrophication impacts	Paper no. 2.3
5	Sargent, R.J.	FRPB	Hydrologist: overview & some figures	Paper no. 2.3
6.	Usman, F.	SEPA	Evaluation of pollution prevention campaigns	*Initiatives to tackle diffuse pollution in the UK*. Paper no. 2.5
7.	Griffiths, D.	EA	Comments and buy-in; national perspective for England & Wales	Paper no. 2.5
8.	Chatfield, P	EA	Comments and buy-in, especially re Pollution Prevention Campaigns	Paper no. 2.5

9.	O'Keefe, B.	SEPA	Microbiologist: principal SEPA data input and specialist microbiology overview	*Urban diffuse sources of faecal indicators* Paper no. 2.6
10.	Davidson J.	SEPA	Lit. searches and assistance in presentation	Paper no. 2.6
11.	Barbarito B.	Scottish Water	Water quality loadings data from university of Edinburgh study prior to joining Scottish Water, plus Water utility buy-in & perspectives	Paper no. 2.6
12.	Clelland, B.	SEPA	Overview as senior ecologist	Paper no. 2.6
13.	Wilson C.	SEPA (contract chemist)	Co-lead for lab. Analysis and field work	*Persistent pollutants urban rivers sediment survey: implications for pollution control*. Paper no. 2.7
14.	Clarke, R	SEPA Chemistry	Lead for lab. Analysis & field work	Paper no. 2.7
15.	Wright, P.	SEPA (tech. Asst. In diffuse pollution team)	Assistance with figures and presentation	Paper no. 2.7
16.	Napier, F.	Abertay university contract researcher in SEPA	Lit. search and compiling figures, tables and draft text, in SEPA, under direction of BJ D'Arcy.	*A review of vehicle related metals and polycyclic aromatic hydrocarbons in the UK environment*. Paper no. 2.8
17.	Jefferies, C	University of Abertay Dundee	Prof. at UWWTC, providing academic advice and overseeing paper.	Paper no. 2.8

18.	Ferrier, R.	Macaulay Land Use Research Institute (MLURI)	Lead contractor for SEPA led project to quantify diffuse pollution in UK. Paper presenter in absence of project leader, who became 2nd author.	*Diffuse Pollution – what is the nature of the problem?* Paper no. 2.9
19.	MacDonald, J.	SEPA (diffuse pollution team)	Research lead within diffuse pollution team	Paper no. 2.9
20.	Aitken, M.	SAC	Soil scientist and diffuse pollution specialist	Paper no. 2.9
21.	Frost, C.A.	Soil & Water (Independent consultant; diffuse pollution & constructed wetland specialist)	Dialogue and foil against which to test ideas, and begin consensus building between agricultural and water pollution views on BMPs.	*The role of best management practices in alleviating water quality problems associated with diffuse pollution*. Paper no. 3.2
22.	May, L.	Centre for Ecology and Hydrology (CEH)	Provided Loch Leven datasets and especially figure on improving trend in water quality, and overview editing	*The Restoration of Loch Leven, Scotland UK*. Paper no. 3.3
23.	Long, J.	SEPA senior ecologist	Provided data and interpretation for quality of tribs.	Paper no. 3.3
24.	Fozzard, I.R.	SEPA lakes specialist	Provided evidence for the original water quality targets derived by IRF for L. Leven.	Paper no. 3.3
25.	Greig, S.	SEPA Diffuse Pollution team tech. Asst.	Evaluated storm event data prior to and after provision of buffer strips on a trib burn.	Paper no. 3.3
26.	Brachet, A.	Post-grad. student placement in SEPA	Undertook miscellaneous delegated research tasks under direction & supervision of lead author	Paper no. 3.3

27.	Rosenqvist, T.	Local authority Technical Chief, Halmstad, Sweden	Provided data and facts about the recovery of the Knebildstorp stream.	*Restoration challenges for urban watercourses*. Paper no. 3.4
28.	Mitchell, G.	Leeds University (Geography Dept.).	Modelled and measured urban quality data and interpretation	Paper no. 3.4
29.	Kellagher, R.	HR Wallingford	Results from UKWIR study on performance of SUDS	Paper no. 3.4
30.	Billet, S.	SEPA	Lit. data on degradation or otherwise of PAHs and oil.	Paper no. 3.4
31.	Mclean, N.	SEPA (SUDS Specialist)	Co-developed concept for the paper with lead author.	*Riparian wetlands for enhancing the self purification capacity of streams*. Paper no. 3.5
32.	Heal, K.	University of Edinburgh	Applied concept of the paper to Caw Burn to provide first case study desk exercise for the concept.	Paper no. 3.5
33.	Kay, D.	Centre for Research in Environmental Health, University of Aberystwyth.	Provided 2nd case study for the paper.	Paper no. 3.5
34.	Ellis, J.B.	Middlesex University	Initiated the paper and did most of the writing for it, including editing to incorporate co-author input and feedback.	*Sustainable Urban Drainage Systems and catchment Planning.* Paper no. 4.2
8.	Chatfield, P.	EA	Contributed EA perspectives	Paper no. 4.2

21.	Frost, C.A.	Soil & Water, consultant	Lead contractor for the project, contributed the case studies, led development of a potential model payment scheme for farm support for environmental benefits.	*Agricultural environmental management: case studies from theory to practice.* Paper no. 4.3
35.	Stewart, S.	SAC	Environmental (habitats and spp.) expertise	Paper no. 4.3
36.	Kerr, D.	SAC	Input on basis of knowledge of existing agric. Support schemes	Paper no. 4.3
19. (ii)	MacDonald J.	SEPA (diffuse pollution team)	Led project for DP team, under direction of last author who initiated project.	Paper no. 4.3
37.	Schmulian, K.	SEPA (diffuse pollution specialist in legal team)	Checked accuracy of statutory references and assertions.	*Regulatory options for the management of rural diffuse pollution*. Paper no. 4.4
38.	Wade, R.	University of Abertay Dundee	Provided academic rigour and overview, as well as some non-agency, non-govt. viewpoints	Paper no. 4.4

APPENDIX III – Partnerships, Seminars & Conferences

The 6 documents comprising the examples in this Appendix are described below, indicating their importance and reason for inclusion.

1) An academic/regulator partnership was established to investigate the performance of SUDS as they were brought into practice from the outset in Scotland: The **Scottish Universities SUDS Monitoring Group**. The group as constituted in the document arose from an earlier more informal urban BMPs group set up in 1994 in the Forth catchment, as part of the FRPB's Clear Future for Our Waters, Water Quality Initiative.
2) The composition of the stakeholder group for implementation of SUDS technology in Scotland identifies the key organisations that were brought together to oversee the implementation of the technology and resolve any disputes and address needs for successful implementation, including ongoing maintenance and statutory constraints or uncertainties: the **Sustainable Urban Drainage Scottish Working Party**, SUDSWP. SUDSWP was established in October 1997.
3) The contents page from the first diffuse pollution conference held in the UK in 1995, by a partnership initiative of FRPB and SAC: **Diffuse Pollution and Agriculture**. The contents page illustrates the engagement with the polluting sector and the regulator, at the highest levels, as chairs or key-notes, as well as seeking input and acceptance of the issue from across the UK through selection of the papers.

4) There is an active and influential drainage research network in Scotland: the **Scottish Hydraulics Study Group** (SHSG). The example seminar shows how the existing network was used to disseminate information as well as to encourage Scottish academics and others to speak about aspects of the issues. The SHSG was encouraged to stage the seminar, by the offer of a key-note presentation from SEPA, together with an international expert speaker (Larry Roesner).
5) The **CIWEM** *Diffuse Pollution Impacts* report was an important sector engagement exercise as well as setting out an issue for government and agency attention; the appended page vii from the report shows the organisations and representatives involved.
6) The last document is an example of how the national (UK) environmental professional body, the Chartered Institute for Water and Environmental Management, **CIWEM**, was also used to disseminate diffused pollution and SUDS information and engage with influential figures and organisations (bringing in the Environment Agency for example).

1)

Scottish Universities SUDS Monitoring Programme

Phase 1 1997-2001

Principal funders:

- SNIFFER
- Scottish Water Authorities
- Carnegie Trust
- Environment Agency

Other funders:

- City of Dundee Council
- Yorkshire Water
- Meedhurst Project Management
- Wilcon Homes
- Formpave

Managed by:

- Chris Jefferies (Abertay University)
- Brian D'Arcy (SEPA)

Aim:

- to accumulate data and knowledge on Scottish SUDS
- to bridge gap between SUDS design and performance
- to inform on good practice

Mechanisms:

- database of SUDS in Scotland
- performance monitoring
- reports

Contributing Universities:

- Aberdeen, Abertay, Edinburgh, Heriot-Watt

Further details, including information on Phase 2 (2001-2004) from:
Brian D'Arcy (tel 01738 627989, fax 01738 630997, email brian.darcy@sepa.org.uk)
Chris Jefferies (tel 01382 308170, fax 01382 308117, email cetcj@tay.ac.uk)

2)

SUSTAINABLE URBAN DRAINAGE SCOTTISH WORKING PARTY

MEMBERSHIP

East of Scotland Water
West of Scotland Water
North of Scotland Water Authority
Scottish Executive
COSLA
Scottish Environment Protection Agency
Scottish Housebuilders Association
Scottish Enterprise Lanarkshire
Society of Chief Officers of Transportation in Scotland (SCOTS)
Scottish Society of Directors of Planning (SSDP)
CIRIA (corresponding members)

East of Scotland Water
COSLA Promoting Scottish Local Government
CIRIA sharing knowledge building best practice
North of Scotland Water Authority
SCOTTISH BUILDING EMPLOYERS' FEDERATION
WEST OF SCOTLAND water
Scottish Enterprise Lanarkshire
SEPA SCOTTISH ENVIRONMENT PROTECTION AGENCY
THE SCOTTISH OFFICE

WORKING PARTY suds

STATEMENT OF PURPOSE

The aim of the Sustainable Urban Drainage Scottish Working Party is to encourage development that does not adversely affect the aquatic environment. This will be done by developing and promoting policies and solutions for sustainable surface water drainage at new developments in Scotland.

The Working Party believes that the aim of sustainable urban drainage will only be achieved through the co-operation of all the organisations involved in urban development. To this end the Working Party will promote a partnership approach, through communication and education, to sharing the responsibility for protecting the aquatic environment.

THIS WILL BE ACHIEVED BY

1. Co-ordinating research into Sustainable Urban Drainage Systems already in use in Scotland;
2. Developing a framework in which Sustainable Urban Drainage Systems can be applied;
3. Producing a set of policies and a design manual for Sustainable Urban Drainage in Scotland;
4. Promoting a better understanding of Sustainable Urban Drainage Systems including their economic, social and environmental effects.

ACHIEVEMENTS TO DATE

SUDSWP has achieved a number of its aims since its initial meeting in October 1997, these include:

- research projects into SUDS are on-going in a number of Scottish Universities; and
- a technical design manual for SUDS is now available from CIRIA (see address over leaf); and
- a national framework for an agreement for the maintenance of shared public SUDS, has been made between Unitary Authorities and the Water Authorities. This will be reviewed in March 2002.

Work by SUDSWP is on-going.

MEMBERSHIP OF
SUSTAINABLE URBAN DRAINAGE SCOTTISH WORKING PARTY

Colin Bayes (Chairman)
SEPA
Head Office
Erskine Court
The Castle Business Park
STIRLING
FK9 4TR

John Toole (Deputy Chair)
West Lothian Council
Highways
Peel House
Ladywell East
Livingston
WEST LOTHIAN
EH54 6AG

Martin Squibbs
North of Scotland Water Authority
Bullion House
Invergowrie
DUNDEE
DD2 5BB

Jim Conlin
East of Scotland Water Authority
Pentland Gait
597 Calder Road
EDINBURGH
EH11 4HJ

Ian Stewart
West of Scotland Water Authority
Operations Services
419 Balmore Road
GLASGOW
G22 6NU

Brian D'Arcy
SEPA
Clearwater House
Heriot Watt Research Park
Avenue North
Riccarton
EDINBURGH
EH14 4AP

John Greaves
Highland Council
Glen Urquhart
INVERNESS
IV3 5NX

Tom Williamson
Scottish Executive
Planning Services
Room 2-H77
Victoria Quay
EDINBURGH
EH6 6QQ

Forbes Macgregor
Scottish Executive
Development Department
Project Construction Division
Victoria Quay
EDINBURGH
EH6 6QQ

Frank Guz
Dundee City Council
Tayside House
Crichton Street
DUNDEE
DD1 3RB

Tom Docherty
T Docherty Ltd & Interbuild
Milton Mill
Monifieth
DUNDEE
DD5 4NZ

Jock Maxwell
Meedhurst Project Management
Sterling House
35 High Street
ASCOT
Berkshire

Ian Corner
SEPA West
5 Redwood Crescent
Peel Park
EAST KILBRIDE
Glasgow
G74 5PP

John Watson
Scottish Enterprise Lanarkshire
New Lanark House
Strathclyde Business Park
BELLSHILL
ML4 3AD

Graeme Rose
SEPA
Greyhope House
Greyhope Road
Torry
ABERDEEN
AB11 9RD

CIRIA
(corresponding members)
3rd Floor
1-2 Castle Lane
Westminster
LONDON
SW1E 6DR

Sarah Gillman
(Technical Secretary)
SEPA
Head Office
Erskine Court
The Castle Business Park
STIRLING
FK9 4TR

Copies of the
SUDS Design Manual for Scotland and Northern Ireland
can be ordered from

CIRIA
Publications
6 Storey's Gate
Westminster
London
SW1P 3AU

Tel: 020 7222 8891

SUDSWP 5/2000 2K

3)

Diffuse Pollution and Agriculture

Published by: The Scottish Agricultural College
Craibstone, Bucksburn,
Aberdeen AB21 9YA

Editors: A M Petchey, B J D'Arcy and C A Frost
Layout and typesetting: Heather Burgess
Conference Administrator: Fiona Grant

Printed in Scotland by: Nevisprint Ltd
Unit 3, Caol Industrial Estate
Fort William
Inverness-shire
PH33 7PQ

ISBN 1 85482 575 5

CONTENTS

POSTER PRESENTATIONS

FIELD TRIP

Visits were made to the RSPB's Vane Farm Visitor Centre and Field Station overlooking Loch Leven and Channel Farm (Mr Sandy Braid) which is an intensive arable and vegetable growin, farm. The Kinnesswood public water supply boreholes (3) were noted; they were a candidate nitrate vulnerable zone which on investigation proved unlikely to exceed 50 mg/l NO_3. Lastly a visit was made to Balmalcolm (Mr Alec Sampson), an intensive vegetable farm, the largest lettuce producer in the north of Britain and site of the only nitrate vulnerable zone in Scotland.

PREFACE

This Conference was a significant landmark in the development of collaboration between land users and those responsible for water quality in the East of Scotland. The Conference broke new ground in that it brought together agriculturalists, their scientific advisors, water pollution scientists and regulators to consider the growing body of evidence on the environmental impact of modern land use practices and possible ways of mitigating that impact. Much has been said and written about the risks perceived from the intensification of agriculture and the growth of forestry in respect of loss of natural habitat and effects upon water quality. This has served to raise awareness of the general issue but there has been little in the way of practical advice to assist land users in reducing these impacts or to focus upon actual effects and means of reducing these in the future.

The Conference was marked by its practical focus upon central issues relating to diffuse pollution from agriculture, in particular nitrates, phosphorous, pesticides and the nature of the regulatory regime and its effectiveness. The presentation of up-to-date papers on these central issues led to lively debate and established a remarkable rapport amongst delegates to the Conference. The most important debate was on the way ahead and Conference agreed that research into practical solutions, co-operation at all levels between regulators and land users and the formation of partnerships were the only way forward if lasting change and improvement is to be brought about.

The determination of delegates to succeed in this has been evidenced by follow-up research on nitrates and the formation of further partnerships to apply new methods to farming within the region. Publication of these proceedings and the organisation of the second regional conference on diffuse pollution and agriculture for 1997 will also ensure that the initiative shown by the organisers of the first conference is not lost.

On 1 April 1996 the powers, duties and staff of the former River Purification Boards transferred to the Scottish Environment Protection Agency. The Agency is a powerful new body charged with creating an integrated system for environmental protection in Scotland and also with contributing to the Government's aim of achieving sustainable development. The Agency will be an effective regulator fully discharging its statutory obligations but this of itself will not bring about the changes in the quality of Scotland's environment that are required. The Agency sees collaboration and co-operation with those that it regulates and other users of the environment as the principal means of making progress towards its objectives. The proceedings of this Conference and the agenda that it set for the future are excellent examples for the Agency to build upon.

W Halcrow
Director
Scottish Environment Protection Agency

4)

The **Scottish Hydraulics Study Group** is an inter-disciplinary gathering of researchers and engineers in the field of hydraulics in Scotland. It held its first meeting in 1988 and its aim is to promote discussion and disseminate information on all aspects of hydraulics.

In addition to the annual one-day seminar such as the one advertised in this leaflet, the group holds four evening meetings each year and an annual prestige lecture named in honour of Peter McCrae, one of the founder members.

The group is affiliated to the Institution of Civil Engineers through both the Glasgow and West of Scotland and the East of Scotland Local Associations.

o - O - o

The principles of Sustainable Urban Drainage Schemes (SUDS) are now quite well established. The concept is to introduce natural hydrological processes such as attenuation and infiltration into urban drainage schemes instead of traditional non-porous surfaces and pipes. This can have substantial benefits in terms of reducing the risk of flooding or allowing areas to be developed without overloading existing drainage systems while providing environmental and amenity benefits. This seminar will look at these benefits as well as the practical problems of maintenance and dealing with difficult soil and climate conditions.

The seminar will be supported by a technical exhibition featuring some of the latest developments and products in this area.

Scottish Hydraulics Study Group

THE INSTITUTION OF CIVIL ENGINEERS

Present

A ONE-DAY SEMINAR

On

SUSTAINABLE URBAN DRAINAGE

Recent Developments and Best Practice

Friday 22nd March 2002

at the

The Scottish Engineering Centre
(Teachers Building)

St Enoch Square **Glasgow**

The Scottish Hydraulics Study Group is affiliated to the Institution of Civil Engineers

PROVISIONAL PROGRAMME

9.30	**Registration and Coffee**	
10.00	**Introduction and Welcome**	Dr Steve Wallis, *Chairman, SHSG*
10.05	**Keynote Address**	Brian Darcy, *SEPA*
10.25	**Climate Change Issues**	David Balmforth, *Montgomery Watson Harza*
10.50	*Tea/Coffee*	
11.20	**Engineering Experiences of SUDS**	Larry Roesner
11.45	**Highway Drainage**	Lynton Barstow, *Wavin Plastics* Derek Fordyce, *Heriot-Watt Univ.*
12.10	**Maintenance Issues**	Robert Bray, *Robert Bray Associates*
12.35	*Lunch and Technical Exhibition*	
13.55	**SUDS Research in Scotland**	
14.00	**Sedimentation in Ponds**	Dr Kate Heal *Univ. of Edinburgh* Dr Steve Wallis, *Heriot-Watt Univ.*
14.20	**Grass Buffer Strips**	Dr Ana Deletic, *University of Aberdeen*
14.40	**Swales**	Kirsteen MacDonald, *Ewan Associates*
15.00	*Tea/Coffee*	
15.30	**Porous Surfaces**	Peter Hart, *Formpave*
15.55	**Implementation Case Study**	Tim Darlow, *SISTECH*
16.20	**Closure**	

Registration Fees (includes lunch, teas/coffees and a bound volume of the papers)

Normal rate	£80.00 + VAT	=	**£94.00**
Full time students / retired	£40.00 + VAT	=	**£47.00**

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e-mail: martin.mansell@paisley.ac.uk

Space will be available for exhibitors. Please indicate if required

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Names of Delegates
(1) ………………………………………………………………
(2) ………………………………………………………………
(3) ………………………………………………………………

Organisation (if applicable)
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Address
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………………………………… Post Code …………………

e-mail …………………………………………………

Fee enclosed ….@ £94.00 ….. @ £47.00 Total £……………

Do you require exhibition space? Yes/No

5)

DIFFUSE POLLUTION IMPACTS

The Environmental and Economic Impacts of Diffuse Pollution in the U.K.

Edited by,

B. J. D'Arcy, J. B. Ellis, R. C. Ferrier,
A. Jenkins and R. Dils

STEERING GROUP

This book is produced under the auspices of the Chartered Institution of Water and Environmental Management (CIWEM) and the UK Branch Committee of the International Water Association (IWA) with the guidance of a national steering group comprising:

• **British Geological Survey**	Barry Rawlins Louise Ander Fiona Fordyce
• **Centre for Ecology and Hydrology (Wallingford)**	Alan Jenkins (IWA UK Branch Committee)
• **CIWEM**	John Hawkins
• **East of Scotland Water**	Morag Garden Drew Jamieson
• **English Nature**	Chris Mainstone
• **Environment Agency**	Phil Chatfield Rachael Dils Dave Griffiths Jackie Vale Andrew Wither
• **Environment and Heritage Service, DOE Northern Ireland**	Ray Bennett
• **Institute of Grassland and Environmental Research**	Phil Haygarth
• **Macaulay Land Use Research Institute**	Bob Ferrier
• **Middlesex University**	Bryan Ellis
• **North West Water**	Peter Head
• **Scottish Agricultural College**	Alan Frost Tony Petchey
• **Scottish Environment Protection Agency**	Brian D'Arcy (IWA UK Branch Committee) Bob Sargent
• **Severn Trent Water**	Alison Court Andrew Heather
• **University of Wales, Aberystwyth**	David Kay

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THE CHARTERED INSTITUTION OF WATER AND ENVIRONMENTAL MANAGEMENT

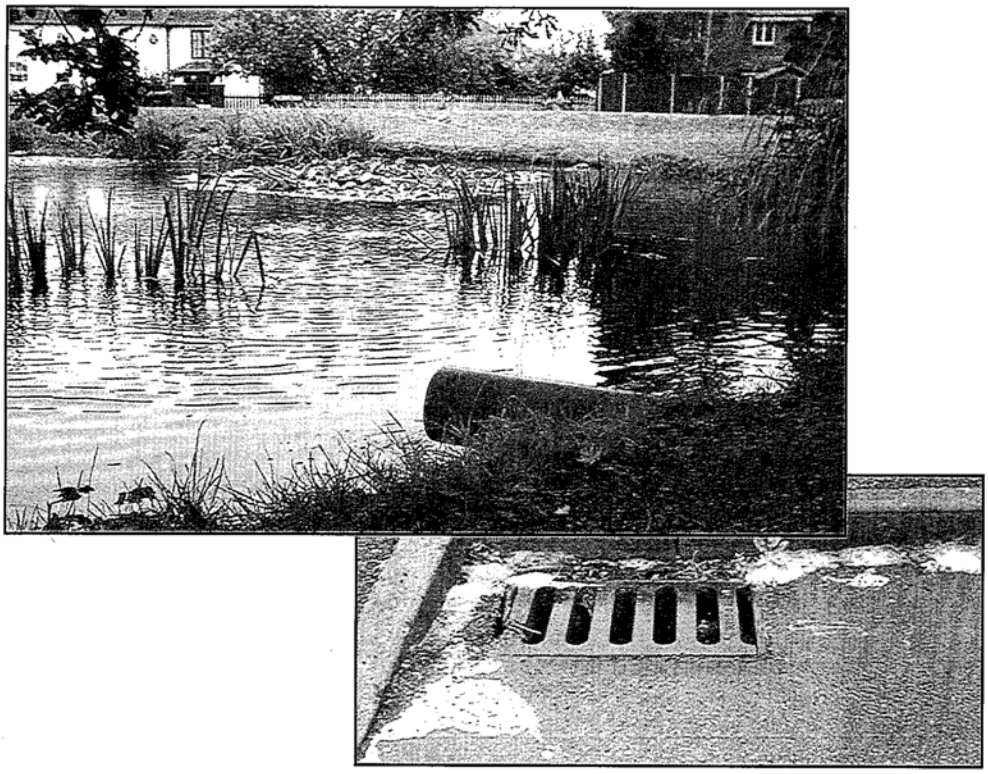
Midlands

Sustainable Urban Drainage Systems

Symposium

Part I

"Developments in the Management of Urban Run off."



22 November 2000

Loughborough University

CIWEM TRAINING AND DEVELOPMENT DAY

Sustainable Urban Drainage (SUDS)

Wednesday 22nd November,
Loughborough University, Hazlerigg Hall

Chairman – Prof. Andrew Wheatley

PROGRAMME

08.45 to 09.35	Registration and Coffee
09.35 to 09.40	Welcome to Delegates
09.40 to 09.45	Conference Chairman's Introduction
09.45 to 10.00	Keynote Speech
10.00 to 10.30	PAPER 1. Storm water and catchment management. Philip Chatfield, The Environment Agency
10.30 to 11.00	PAPER 2. Water Quality Objectives and Regulation. David Griffiths, The Environment Agency
11.00 to 11.30	*Coffee*
11.30 to 12.00	PAPER 3. Balancing the Impact of Urban drainage on the environment. Prof. Chris Pratt, Coventry University
12.00 to 12.30	PAPER 4. Design and Performance of oil/water separators. Nur Muhammad & Prof. Andrew Wheatley, Loughborough University
12.30 to 14.00	*Lunch*

14.00 to 14.30	PAPER 5. Constructed Wetlands for Urban and Highway Runoff Treatment. Prof. Brian Shutes, Middlesex University
14.30 to 15.00	Paper 6. Landfill leachate treatment at Pride Park, Derby. Ian MacBeth & Richard Harpham, Alphaeus
15.00 to 15.30	*Coffee*
15.30 to 16.00	PAPER 7. Rainwater recycling and reuse. Michael Farnsworth, Monsoon
16.00 to 16.30	PAPER 8. Storm water attenuation with organic green roofs. Dr. Adam O'Rourke, Nottingham Trent University
16.30 to 16.40	Chairman's concluding remarks
16.40	*Close*