Constructed Wetlands and Links with Sustainable Drainage Systems

R&D Technical Report P2-159/TR1

J. B. Ellis, R.B.E.Shutes and M.D.Revitt

Research Contractor:
Urban Pollution Research Centre
Middlesex University, London

Publishing Organisation
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, BRISTOL, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
Website: www.environment-agency.gov.uk

ISBN 1 8570 59182

Dissemination Status
Internal: Released to regions
External: Released to Public Domain

Statement of Use
This technical report contains a review of the design and use of constructed wetlands for the treatment of stormwater runoff from impervious surfaces in urban areas and the linkages between constructed wetlands and sustainable drainage systems. The information in this document is for use by Environment Agency staff and others involved in the control and management of surface water runoff from development.

Keywords
Constructed wetlands, urban stormwater runoff, urban runoff quality control, sustainable drainage systems (SuDS), urban catchment management, decision support systems, multicriteria assessment.

Research Contractor
This document was produced under R&D Project P2-159 by:
Urban Pollution Research Centre, Middlesex University, Bounds Green Road, London, N11 2NQ Tel: 02 08 411 5000 Fax: 02 08 411 6580 Website: www.mdx.ac.uk

Environment Agency's Project Managers
The Environment Agency's Project Managers for Project P2-159 were:
Dr Maxine Forshaw, National Centre for Ecotoxicology & Hazardous Substances
Barry Winter and Doug Mills, Thames Region

Further copies of this report are available from:
Environment Agency R&D Dissemination Centre, c/o
WRc, Frankland Road, Swindon, Wilts SN5 8YF

tel: 01793-865000 fax: 01793-514562 e-mail: publications@wrcplc.co.uk

CONTENTS Page

List of Tables

List of Figures

EXECUTIVE SUMMARY

The report provides a brief background to Environment Agency strategic policy development for sustainable drainage systems (SuDS) in urban catchments and defines the various types, nature and designs of wetland systems found in the UK. The information and data available from wetland systems used to treat domestic wastewater are, however, not directly applicable to stormwater wetlands due to the fundamental differences in inflow regimes and pollutant loading characteristics. A review of wetland processes includes application of plug-flow modelling to wetland pollutant removal rates. Basic performance and efficiency rate indicators are developed together with costing data and a full review is given of wetland design parameters and planting considerations together with examples of kinetic approaches for wetland sizing.

Wetland retrofitting, operation and maintenance are considered as well as the role of wetlands in amenity and wildlife provision. Issues of SuDS implementation and future catchment planning are reviewed in the context of future Agency approaches to the EU Water Framework Directive and partnerships with key stakeholders. Generic decision-support approaches for constructed wetland and SuDS design and selection procedure and for the design development of urban stormwater wetland treatment systems are also developed. A chapter on equivalent decision-support approaches for the design and selection of urban stormwater runoff systems in France is also included together with a final chapter identifying priority areas and themes for future research and development.

Pollutant removal efficiencies of constructed wetlands clearly perform better than natural systems and there is considerable evidence that toxic substances (metals, hydrocarbons, bacteria etc.) in both aqueous and sediment-associated phases are reduced in urban stormwater wetlands. However, negative efficiencies are not uncommon especially for organic and nutrient parameters and/or when inflow concentrations are low. Excessive outflow loadings are normally related to (re-)mobilisation of sediment-associated contaminants which can be flushed out during intense stormflow activity. Urban stormwater wetland design should be capable of treating storms with a minimum return period of 10 years and the system should be capable of treating the polluted first-flush of any storm event. A by-pass is recommended to direct higher storm flows away from the wetland to avoid disturbance of contaminated sediment. Hydraulic conductivity is one of the most important determinants in pollutant removal efficiency, and is especially important in sub-surface flow (SSF) constructed wetland systems where purification processes are largely confined to the root zone.

It is clear that regular and systematic wetland maintenance is critical in order to ensure the basic performance and longevity of urban wetlands, and over a 25 – 30 year lifetime the full maintenance and operational costs could well be roughly equivalent to initial construction costs. Adopting and managing authorities therefore need to fully and carefully evaluate how long-term, future maintenance costs can be covered. A simple diagnostic methodology is provided for predicting sediment removal maintenance requirement time.

It is important that the designer, developer and regulator establish what the general and/or specific objectives are before selecting a particular wetland or other alternative SuDS device. After establishing what the flood control, water quality and amenity objectives are, an analysis is then required of what is feasible on a particular site given the characteristic meteorological, physical, economic and institutional constraints.

A decision support approach to evaluate the relative sustainability of SuDS structures, as well as conventional pipe systems, has been developed utilising simple multicriteria analysis. The developed methodology identifies primary generic criteria based on technical/scientific performance, environmental impacts, social/urban community benefits and economic costings. A range of secondary sub-criteria and benchmark "standards" are also identified against which specific wetland or other SuDS structures and drainage options can be compared. A similar multicriteria decision support approach used by the Agence de L'Eau Seine-Normandie in France is also presented.

It is clear that substantial land value enhancement can be achieved through the provision of well designed and landscaped wetland facilities on urban development sites which can offer major community benefits as well as offsetting total investment costs. Waterfront sites can increase unit process/rentals by 3% to 13% on average with some ground rents on commercial "wetland park" developments increasing by two to three times. Urban social/community benefits will only accrue if they are considered early on in the design and planning process as they are frequently difficult and costly to retrofit into existing structures. Their success and long term community benefit is also essentially dependent on adoption agreements and continued, positive management either by public or private agencies. There have been widespread concerns expressed over the provision of open-water bodies such as wet retention (flood storage) ponds and wetlands in urban areas. However, given an extensive plant cover, restricted access to deep water and contaminated sediment areas can be safeguarded by barrier planting schemes and thus such concerns are much less appropriate in the case of constructed wetlands.

It is clear that constructed wetlands systems offer considerable potential as sustainable SuDS options for the control and treatment of urban stormwater runoff even given that their design and operational criteria is still an emerging engineering science. The review of current information has enabled a summary of the potential capabilities, performance and range of social/urban community benefits that can accrue from their implementation within integrated urban catchment planning, and provides generic end-user approaches for the quantification and evaluation of urban stormwater wetland sustainability.

Acknowledgement

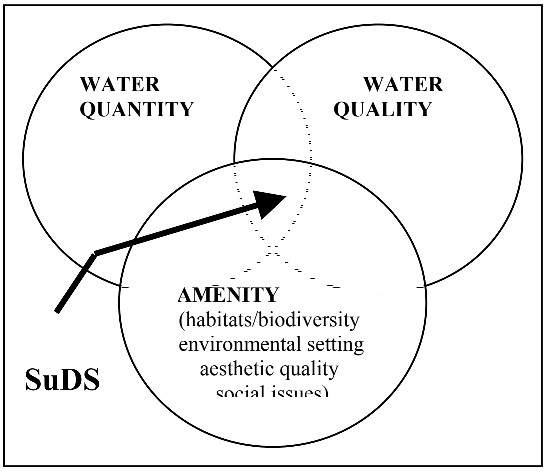
Thanks is given to all those Environment Agency staff who provided freely of their time and expertise during the completion of this report. However, the views expressed are entirely the responsibility of the authors and do not reflect future Environment Agency policy intentions. The work of Professor J-C Deutsch and Dr. J-M Mouchel of CEREVE, Ecole Nationale des Ponts et Chaussees, Paris in providing the draft material for the chapter relating to French stormwater systems and practices is gratefully acknowledged. The sections on French practice were considerably aided by the very helpful discussions with staff of the Agence de L'Eau Seine-Normandie (AESN), with the comments of Mme. Nadine Aires being of particular value and insight.

1. INTRODUCTION

1.1 Surface Water Runoff and SuDS

The concepts of Best Practical Environmental Options (BPEOs) are central to strategies for sustainable urban development and are intended to strike an appropriate balance between the costs and benefits of measures to protect the environment (DoE, 1996). Such practices are considered as reinforcing the water quality improvements achieved under various (Protection, Conservation and Enhancement) statutory duties such as Section 16 of the 1991 Water Resources Act, Section 12 of the 1991 Land Drainage Act and Section 4(3) of the 1995 Environment Act. However, control of surface water discharges is a discretionary power and the Environment Agency would seek to encourage a preventative approach so that at least the smaller discharges need not be subject to regulation.

A variety of structural control approaches are now available for local, on-site management of impermeable surface runoff in urban areas which collectively have become widely known as **Su**stainable **D**rainage **S**ystems (SuDS) and which include filter strips and swales, filter drains and permeable surfaces, infiltration systems as well as basins, ponds and wetlands. SuDS work by providing storage or flow attenuation and by exploiting the processes of sedimentation, filtration and biodegradation to remove pollutants. In addition, SuDS can be integrated into their environmental setting and offer the opportunity to improve ecological habitat and biodiversity as well as aesthetically enhancing the local urban environment (see diagram in box).



Early guidance notes issued by the former National Rivers Authority recognised the need for an integrated co-ordination of runoff quantity, quality and amenity considerations in the design of passive control structures for surface water runoff generated by urban development (NRA, 1994). The successor regulating agency (Environment Agency) continued this strategic objective of incorporating sustainable drainage systems into its Local Environment Agency Plans (LEAPs) and into the Town and Country planning system in general. Practical advice on planning approaches for sustainable urban drainage is, for example, contained in Regional Planning Guidance such as RPG 9 (Policy INF1, INF2) and RPG 23, in Pollution Prevention Guidelines such as PPG 1, 6, 11, 15 etc., and in the recent revised (2001) DETR Planning and Policy Guidelines (PPG) 25 "*Development and Flood Risk*" in which planning authorities are directly encouraged to invite SuDS applications. The March 1997 Environment Agency report "*Liaison with Local Planning Authorities*" identifies the various types of development applications which require formal Agency consultation and the range of guidance advice/circulars available to support planning decisions by local authorities. The document stresses the importance of promoting sustainable development and the Local Agenda 21 process, and in particular the need for adequate control of contaminated surface water runoff using more effective "soft-engineered" SuDS facilities such as grass swales, ponds and wetlands. The companion 1997 consultation report (Thames Environment 21) of the Environment Agency Thames Region set out the Agency strategic intention that planning policies and development proposals should "*require due consideration……of measures which prevent and control pollution from (both point) and diffuse sources through appropriate technologies and environmental management*". In particular, "*urban drainage systems are a key issue affecting water quality and the biology and ecology of urban watercourses*" (Environment Agency Thames Region, 1997).

The NRA Thames Region, within its Agenda 21 strategy, was an early advocate of sustainable approaches in schemes for new development in order to minimise the impacts of surface water runoff (NRA Thames Region, 1995). In July 1998, Thames Water issued a Policy Statement covering "*Surface Water Source Control*" which committed the utility to principles for sustainable infrastructure development which included reference to appropriate storage, attenuation and (bio)infiltration practices. A succession of CIRIA reports has also identified the potential benefits that can accrue to both developer and to the community from the adoption of sustainable drainage approaches (including wetlands and ponds) for the control and management of urban runoff (CIRIA, 1992; 1993; 1996; 1997; 2000a and b). The impetus provided by this work has resulted in an alliance of the England & Wales, Scottish and N Ireland regulatory authorities to produce a guidance booklet and accompanying video describing the range of available alternative sustainable drainage approaches (SEPA, EA and E & HS, 2000). There is therefore an increasing general presumption within the UK water industry in favour of SuDS approaches to surface drainage that has been embodied in guidance to local planning authorities and which is implicit in regulatory policy. This is likely to be reinforced by the terms of the EU Water Framework Directive (Article 11.3h) which contains a particular emphasis on the identification and control of diffuse pollution including that generated from urban sources.

Wetlands have long been used for the treatment of domestic wastewater, industrial (particularly acid mine drainage) and agricultural effluents (Hammer, 1989; Crites, 1988; Reed *et al*., 1995; Kadlec and Knight, 1996). The first UK wetland (reed bed) system for wastewater treatment was introduced in 1985 and there are now over 400 such systems in operation with Severn Trent Water having 130 of this total in 1998 (IWA, 2000). Reed bed treatment for domestic wastewater is now accepted within the revised Building Regulations (Part H2) for England & Wales and in the Scottish Building Standards Regulations (Part M, Technical Standards for Compliance) and detailed guidance for building regulation requirements is available (Grant and Griggs, 2001). More recently, increasing attention has been paid to the potential function of wetland treatment systems as attractive and cost-effective **Su**stainable **D**rainage **S**ystems (SuDS) for pollution control of urban stormwater surface runoff (Strecker *et al*., 1992; Moshiri, 1993; Olsen, 1993; Ellis *et al*., 1994a: Shutes *et al*., 1997; Shutes *et al*., 1999; CIRIA, 2000a and b).

In the Initial Report which preceded this Technical Report, over 100 wetland systems were identified in the UK and which are currently used in the control and management of urban surface runoff (UPRC/CEREVE, 2000). Table 1.1 shows the distribution of these wetlands in terms of urban land use type, flow system and SuDS categories. The numbers would be considerably larger if all combined retention/detention storage basins carrying self-seeded aquatic vegetation were to be included in the inventory. During the review of data for the CIRIA flood storage reservoir volume (Hall *et al*., 1993) for example, a total of 75 retention basins were identified in the Stort, Mole and Crane catchments. These varied in total storage capacity from 525m^3 up to 123,500m^3 and a large number contained marginal aquatic vegetation which had primarily self-seeded. Wetlands were also found to comprise some 30% of all SuDS types in a recent SEPA (1997) Scottish survey (Table 1.2). If vegetated systems incorporated into conventional wet retention/detention basins and other treatment train devices (shown in brackets in the table) are included in the database, then 42% of Scottish SuDS possess wetland technologies at some level of utilisation.

Table 1.1 Wetlands in UK Urban Surface Drainage Systems

Land Use Type	Total Wetland Numbers	Wetland Type				Wetland Flow Type		
		Constructed Wetlands	Wet Retention Basins	Combined Retention Detention	Extended Detention Basins	Surface Flow	Sub Surface Flow	Vertical Flow
Residential Housing	14	6	2	1	5	11	2	1
Commercial & Retail	17	2	10	1	1	13	1	
Industrial	12	6	1		5	11	1	
Highways & Roads	32	12	10	2	8	28	4	
Mixed Land Use	14	8	9			16	1	
Leisure & Amenity	7	2	4		1	7		
Airport	7	3	4			4	2	1
TOTALS	**103**	**39**	**40**	**4**	**20**	**90**	**11**	**2**

Table 1.2. Scottish SuDS Database

	Residential Housing	Leisure & Amenity	Industrial	Highways And Roads	Commercial & Retail
Flood Storage (Retention and/or Detention) Basins	5	4 (+1)	10 (+1)	-	2 (+2)
Wetlands	3 (+1)	1	4 (+1)	1	- (+1)
Infiltration Basins	1 (+1)	-	1	-	-
TOTALS	**9**	**5**	**15**	**1**	**2**

It is clear therefore, that wetlands are quite common components found in UK urban surface water drainage systems and that there is an increasing use of and interest in the application of artificial or constructed wetland technology for the treatment of potentially contaminated stormwater runoff within urban catchments.

1.2 Wetland Types and Definitions

1.2.1 Definitions.

Wetlands are a generic term covering a variety of water bodies supporting aquatic vegetation and providing a biofiltration capability. They include not only natural marsh and swamp environments but also artificially constructed storage basins or ponds. Wetlands are essentially transitional between terrestrial and aquatic systems, where the water table is normally at or near the soil surface or where there is a permanent shallow water cover (Mitsch and Gosselink, 1993). However, the presence of water by ponding, flooding or soil saturation is not always a good indicator of wetlands as they can often appear to be dry. Nevertheless, wetlands possess three basic characteristics:

- an area supporting (at least periodically) hydrophytic vegetation i.e. plants which grow in water
- substrates which are predominantly undrained hydric (continually wet) soils
- non-soil (rock/gravel) substrates which are either saturated with water or have a shallow, intermittent or seasonal water cover.

1.2.2 Natural and semi-natural wetlands.

Natural wetlands typically exhibit gradual hydroperiods (i.e. variation in water level), complex topographic structures, moderate to high wildlife habitat value, support few exotic species and are self-sustaining. They can be classified into three basic types:

- swamps which are dominated by water-tolerant woody plants and trees
- marshes dominated by soft-stemmed emergent plants such as rushes, reeds and sedges (but which can also contain submergent and floating plants)
- bogs which are characterised by acidic and low-nutrient water and acid-tolerant mosses.

> **Fir Wood Nature Reserve, Herts**
> A small natural wetland located near to Junction 24 on the M25 at Potters Bar receives soil-filtered runoff from the motorway. Although aqueous metal levels recorded in the wetland are well below statutory water quality standards, metal sediment levels show moderate to high levels of contamination (Sriyaraj and Shutes, 2001).

Although natural wetlands and their surrounding riparian area reduce diffuse pollution, they do so within a definite range of operational conditions. When either hydrologic or pollutant loadings exceed their natural assimilative capacity, they rapidly become stressed and degraded.

It is also possible to recognise a separate category of semi-natural wetlands which have developed in open water situations following colonisation by aquatic vegetation. Such semi-natural, self-seeded wetlands can be found in open waters initially designed as flood storage reservoirs (retention/detention basins) or ornamental ponds in urban areas. They also quite frequently occur in disused gravel pits, silt and ash (PFA) lagoons (Merritt, 1994). The Ruxley gravel pits adjacent to the River Cray in Kent and the

> **The Welsh Harp, N W London**
> The Welsh Harp basin, whilst originally constructed as an ornamental reservoir, now serves as a storm runoff attenuation facility for the highly urbanised 5.2 km^2 Silk Stream catchment, with some 60% of the annual flow volume being derived from impermeable surface runoff. The wet retention basin has an extensive *Typha* and *Phragmites* wetland marsh located at the inlet which has become an important wildfowl and bird reserve. Studies have shown that this semi-natural wetland functions as an effective pollution control facility for the treatment of urban runoff removing some 97% of Suspended Solids (SS) and between 50-80% of the hydrocarbons contained in both water and sediment passing through the basin (Jones, 1995). The Biological Monitoring Working Party (BMWP which assess the macroinvertebrate community status) scores improve from a very depressed value of 5 immediately upstream of the inlet to 50 below the wetland.

Great Linford pits on the upper Ouzel in Milton Keynes are also examples of self-seeded, wetland marshes. Both are important nature reserves and community assets and also have significant functions as stormwater balancing facilities.

1.2.3 Artificial or created wetlands.

Artificially constructed wetland storage basins or ponds which create "generic" wetland habitats, have the more limited objectives of flood and pollution control. Created stormwater wetlands which are dependent on surface water runoff are "semi-tidal" in nature, being continuously exposed to episodic inundation and subsequent drawdown. The extent of the changes in water level impose quite severe physiological constraints on the plant community. The resulting created wetland systems typically have a more clearly defined open water component than natural wetlands. The types of artificial constructed wetlands which can function as urban stormwater facilities include:

Shallow marsh systems requiring considerable space and which drain contributing areas often in excess of 10 hectares. They demand a reliable baseflow or groundwater supply to support emergent wetland plants. The 140 ha Potteric Carr Reserve at West Bessacarr near Doncaster receives surface runoff from a 1261 ha mixed urban catchment, is a very large marsh system. Whilst being a designated nature reserve dominated by carr marsh, it also retains its function as a major flood storage facility. The "water meadows" in the Chells district of Stevenage similarly operate as shallow marshes fed by overbank flows from the Aston End Brook generated by urban surface runoff during storm events.

> **Rye House Nature Reserve**
> The 5 ha Rye House nature reserve in the lower floodplain of the River Lea and operated jointly by the RSPB and Thames Water, is an example of a long established constructed shallow marsh. The wetland marsh was created in 1973 taking 90 Ml/day of treated sewage effluent from the adjacent tertiary treatment lagoons of Rye Mead sewage works. The wetland marsh is now managed as a series of compartments demonstrating a range of habitats from shallow pools and scrapes, through reed bed to carr.

Retention or wet (balancing) ponds/basins having a permanent water volume are amongst the most frequently encountered flood storage facilities in the UK for managing and controlling urban and highway runoff. Surface stormwater runoff displaces the water lying in the basin at the commencement of the storm event. Sedimentation within the basin will occur as well as biological uptake and other forms of treatment (volatilisation, complexation, photo-oxidation etc.). Retention ponds can have marginal rooted and submergent/floating aquatic vegetation with open water comprising typically some 50 - 75% of the total basin surface area.

> **The Ouzel Valley Lakes**
> The series of wet retention (balancing) lakes located in the Ouzel valley at Milton Keynes contain marginal aquatic vegetation which is partly semi-natural and partly artificially introduced. The largest lakes in this balancing system are Mount Farm Lake (95ha), Willen Lake (87ha) and Caldecotte Lake (44ha). All three are fringed by both emergent and submergent macrophytes which not only provide enhanced ecological and amenity functions, but also help to reduce the elevated nutrient, oil and heavy metal concentrations associated with wet weather urban surface discharges.

Small, semi-permanent (low-lying) marshes and pools have been frequently incorporated into dry detention basins to form an ***extended detention*** (***ED***) basin. Such wetlands (of between 10-25% of the total basin area) facilitate pollutant removal and mitigate

> **Extended Detention Basins in Essex and Herts**
> The 65ha Pinnacles Industrial Estate at Harlow, Essex discharging surface water to a 19,400 m^3 capacity storage basin and 10.93 ha of the M11 at Stansted Brook in Hertfordshire which discharges to a 4,900 m^3 capacity dry basin, now have low-level marsh located in the base of the storage facilities.

against short-circuiting, channelisation and sediment re-entrainement. A few ED basins are now being formally introduced under the SEPA SUDS initiative in Scotland on the Dunfermline (Eastern Expansion, DEX) site in Fife (McKissock *et al*., 2000). There is a modified ED basin with a semi-permanent pool as well as a low level wetland marsh in the off-line 38,000 m^3 detention basin located at North Weald, Essex and a number of industrial/commercial estates have extended dry detention basins to incorporate a wet marsh facility. A number of originally dry detention basins have shallow marsh/wetland vegetation occupying some part of the basin floor and now effectively function as extended detention facilities with the vegetation filtering out pollutants contained in the influent surface water flows.

M25, Barrow Court, Oxted, Surrey
7.29ha of the M25 (with AADT flows of 120,000 vehicles) drains to a dry detention basin of 3147m^3 maximum capacity. Pollutant levels retained in the basal marsh sediment varied between 162-55,892 mg/kg for total petroleum hydrocarbons and 15-14,762 µg/g for Cu, Zn and Pb (Ellis *et al*., 1997)

Combined pond/wetland (retention/detention) basins are storage facilities where part of the containing basin is given over to dead storage (permanent pools) and part to live (fill and drain) storage. Such combined retention/detention wetland designs have been adopted for the control and management of highway runoff as on the A34 Newbury bypass, the A4/A46 Bathford roundabout and at the M49 junction to the east of the southern Severn Bridge crossing. The designs frequently possess a front-end pool or chamber which traps sediment and associated pollutants providing treatment for the first flush and (the more frequent) small runoff events. The wetland cell (which can be separated by a filter strip or gabion wall from the permanent pond), provides for temporary storage, secondary biological treatment and attenuation of runoff from larger more infrequent storms. A final micropool or settlement pond might also be included to give a more limited tertiary treatment.

The A34 Newbury Bypass
A total of nine flood stroage basins have been built alongside the A34 Newbury Bypass to control and treat surface water design discharges varying between 20-120 l/s, from 13.5 km of dual, two-lane trunk road. Maximum design storage volumes vary between 121-676 m^3 with retention times of between 30-120 hours. One storage basin has been retrofitted with a SSF constructed wetland (*Phragmites*) and wet weather removal rates recorded for the wetland system has been high with SS and heavy metal removal efficiencies varying between 40-75% and 59-98% respectively (Scholes *et al*., 1999).

District Park (DEX), Dunfermline, Fife, Scotland
Combined dry/wet retention basins and SF wetlands treat surface water from a 600ha light industrial/commercial and highway catchment. Percentage metal removals from the wetlands are Cu 33%, Pb 25% and Zn 65%. Mean metal sediment levels are Cu 13, Pb 10.5 and Zn 30.2 mg/kg (Heal, 1999)

1.3 Constructed Wetlands and Flow Systems

1.3.1 Constructed wetlands

Constructed wetland basins normally have non-soil substrates and a permanent (but normally shallow) water volume which can be almost entirely covered in aquatic vegetation. Constructed wetlands may contain marsh, swamp and pond (lagoon) elements; the inlet zone for example, can resemble the latter form and be used as a sediment trap. The dominant feature of the system is the macrophyte zone containing emergent and/or floating vegetation that requires(or can withstand) wetting and drying cycles. . Constructed wetlands lack the full range of aquatic functions exhibited by natural wetlands and are not intended to provide species diversity. Whilst natural wetlands depend upon groundwater levels, constructed stormwater wetlands are dominated by surface runoff in a random "semi-tidal" hydroperiod characterised by cyclic patterns of inundation and drawdown.

Anton Crescent, Sutton, Surrey
The 1.3 ha Anton Crescent wetland in Sutton, Surrey has been built in a wet detention basin which serves a mixed residential and light commercial catchment. The basin has a maximum design storage capacity of 10,000 m^3 with a mean retention time of 10.8 days. The SF constructed wetland was planted with *Typha* to provide a wildlife conservation area and a local amenity/educational facility and now also provides a valuable water quality function with average removal rates for SS, Zn and Faecal Coliforms of 56%, 37% and 78% respectively (Cutbill, 1994). High metal levels are associated with the sediments filtered out by the macrophyte roots and stems (Cu 40, Pb 126.6 and Zn 120.7 mg/kg.

Such constructed wetlands typically experience much greater sediment inputs than natural wetlands. In addition to a more restricted aquatic flora, they are likely to provide an environment favourable to invasive terrestrial weed species especially during plant establishment. Open water would normally occupy up to 25 - 30% of the total basin surface area with remaining areas comprising shallows up to a maximum depth of 0.5m. Flood storage can also be added above the treatment wetland where the surrounding terrain permits.

Keytec 7 Pond, Pershore, Worcs.
The 10.9ha Keytec Industrial estate pond in Pershore, Worcs was designed as a flow balancing facility with a SF constructed wetland to provide 1500m^3 of stormwater storage with a retention time of 15-20 hours. The imposed pollution discharge consents for SS (100mg/l), BOD (20mg/l) and oils/hydrocarbons (5mg/l) have been successfully met throughout the operational lifetime of the basin.

1.3.2 Constructed Wetland Flow Systems

Although the design of artificially constructed wetlands varies making each system unique, the basic flow configurations can be divided into two categories:
Surface flow (SF) or ***free water surface*** (FWS) systems which are similar to natural marshes in that they are basins planted with emergent, submergent and/or floating wetland macrophyte plants. Such free surface water treatment wetlands mimic the hydrologic regime of natural wetlands. As indicated in Table 1.1, almost all constructed wetlands in the UK for the treatment of urban runoff comprise surface flow systems and resemble natural marshes, in that they can provide wildlife habitat and aesthetic benefits as well as water treatment. The influent passes as free-surface (overland) flow (and/or at shallow depths) and at low velocities above the supporting substrates. Figure 1.1a and b shows a (3 x 80m) linear SF design which has been

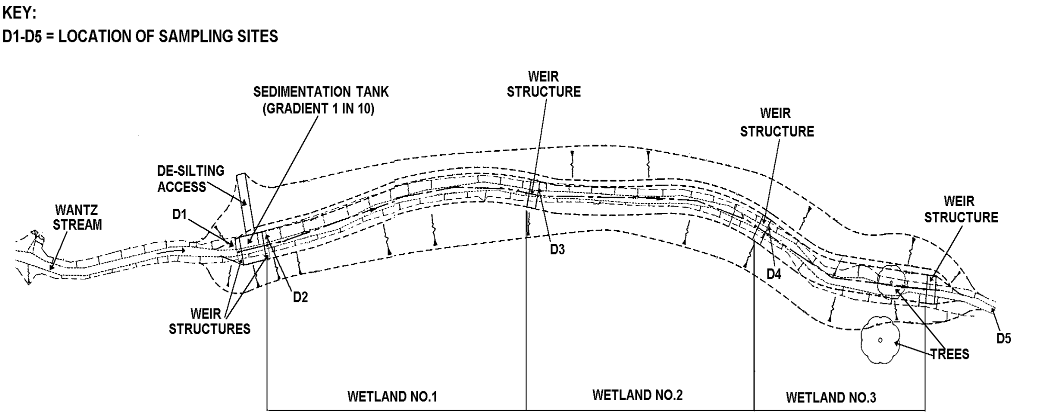


Figure 1.1a. SF Constructed Wetland Design (R Wantz, Dagenham, E London.)

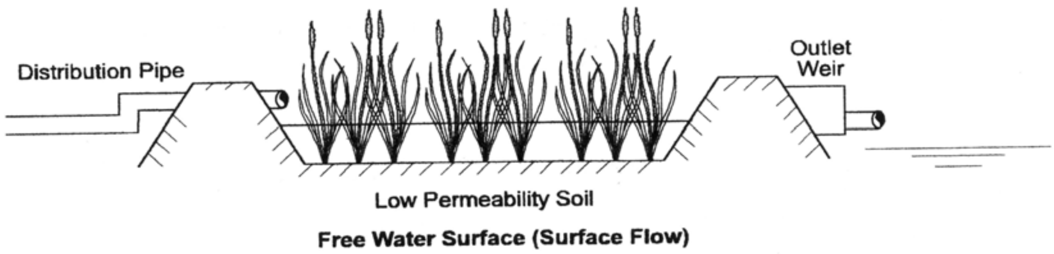


Figure 1.1b. SF Constructed Wetland Illustrative Cross-section

retrofitted into a widened stream channel in Dagenham, East London to treat surface runoff from a 440ha residential and commercial area (Scholes *et al*., 1999). The 1750m^2 modular wetland system is designed to meet 50% removal efficiencies for targeted pollutants (BOD, Pb, Zn and SS). SF/FWS systems with low flow rates are susceptible to winter ice-cover in temperate climates such as the UK, and have reduced efficiencies during such times since effective water depth and retention time are reduced (Kadlec and Knight, 1996).

Subsurface flow (SSF) systems operate with the influent flowing below the surface of the soil or gravel substrate. Purification occurs during contact with the plant roots and substrate surfaces, which are water-saturated and can therefore be considered to be oxygen-limited. The substrate in these systems is thermally insulated by the overlying vegetation and litter layer and so the wetland performance is not significantly reduced during the winter. Most of the earliest wetland treatment systems in Europe were SSF systems constructed to treat domestic wastewater. There are two basic flow configurations for SSF wetlands:

- horizontal flow (HF) systems where the effluent is fed in at the inlet but then flows slowly through the porous medium (normally gravel) under the surface of the bed in a more or less horizontal path to the outlet zone. These HF systems are also known in the UK as Reedbed Treatment Systems (RBTS) as the most frequently used plant is the common reed (*Phragmites australis*).

- vertical flow (VF) systems, which usually have a sand cap overlying the graded gravel/rock substrate, and are intermittently dosed from above to flood the surface of the bed. The effluent then drains vertically down through the bed to be collected at the base. Such VF systems are similar in design and operation to conventional percolating filters but are very rarely found on surface water drainage systems (Table 1.1).

Figure 1.2a and b illustrates a SSF constructed wetland system located at Brentwood, Essex to treat surface water discharges from a 400ha mixed urban catchment prior to entry into the River Ingrebourne. During high flows, untreated effluent also overflows into a natural *Typha* wetland in addition to passing through the SSF *Phragmites* wetland before final discharge to the river. The total wetland area is 204m^2 and the mean retention time is 50 minutes. Dry weather removals average 30 - 33% for Pb and Cu, 19% for Zn, 18% for SS, 26% for BOD and 50% for total ammonia with mean metal sediment removals varying between 17 - 33% (Revitt *et al.*, 1999).

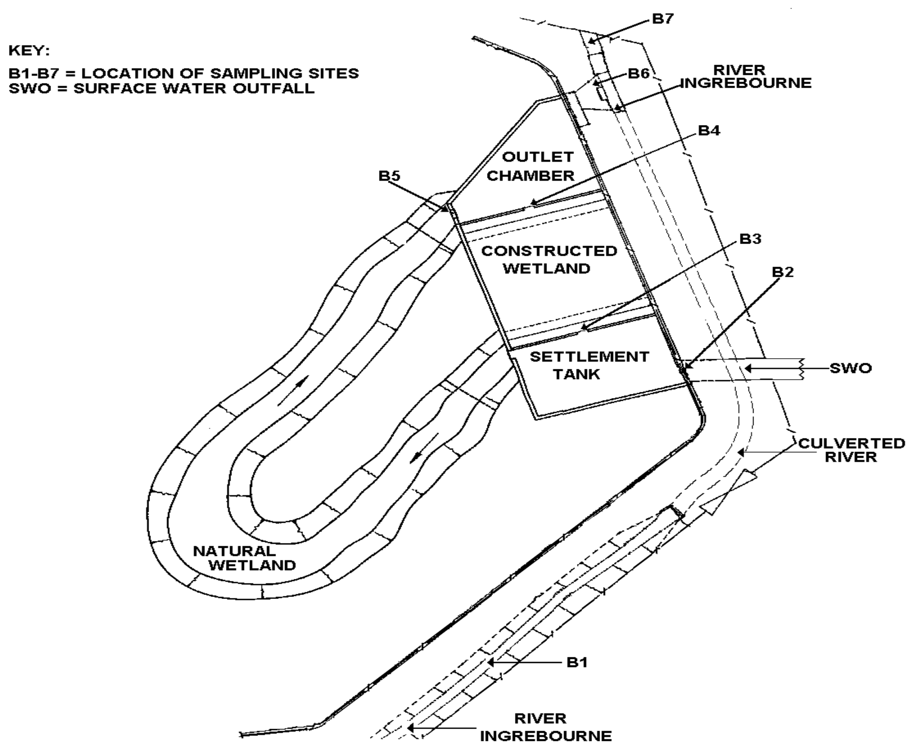


Figure 1.2a. A SSF Constructed Wetland (Brentwood, Essex)

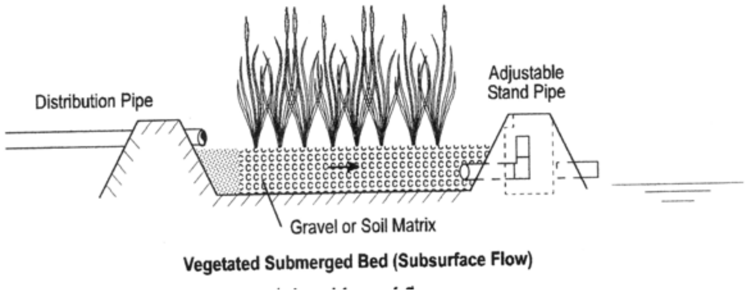


Figure 1.2b. A SSF Constructed Wetland Illustrative Cross-section

1.4 Pocket or Mini-Wetlands

A particular form of compact (or pocket) stormwater constructed wetland which has been developed in the eastern United States and which is suitable for small sites of 0.5 - 5.0 hectares. Such pocket wetlands may not have a reliable source of baseflow and thus are subject to large fluctuations in water level.

> **Welford Mini-Wetland, Leics**
> A pocket or mini-wetland can be found on the outskirts of the S Leicestershire village of Welford where surface water from the A50 has been drained to support a linear 0.25 ha marsh site immediately adjacent to the highway and which helps to alleviate flooding on a dip in the carriageway. The development was entirely the result of local community effort with technical advice from the Groundwork Trust and provides an aesthetic environmental focus for the village.

1.5 Modular or Treatment-Train Systems

In practice, there are no distinct boundaries between the various types of storage basin outlined in Section 1.2.3 above and all have similar basic design principles. They can be used in-series or as modular cells within a single overall structure and can be adapted to either on or off-line configurations. The module sequencing is important in order to ensure that the primary function of each is sustainable. One effective form of treatment-train might consist of an inlet sediment trap or forebay, followed by a wet retention or dry detention basin which is then discharged to a full wetland system. Islands in open water zones also provide important habitat and landscaping elements.

> **Wharrage Brook, Redditch, Worcs.**
> The Environment Agency Midlands Region has constructed a modular treatment train system downstream of the urbanised section on the Wharrage Brook near Redditch, Worcs. A primary silt trap is followed by wet retention for flow and quality balancing and a final SF reedbed for stabilisation and treatment (Tucker, 1999). The retrofitted design provides a maximum storage capacity of 3500 m^3 and serves a 4km^2 mixed urban catchment. Extensive surrounding landscaping has also provided valuable wildlife habitats and amenity features for the local urban community.

Series (or treatment-train) configurations can help to improve the treatment performance and can be particularly useful on steep sites, sites having several small separate "vacant" areas or in narrow, linear spaces along fields, road edges or river corridors. They can also be used as a basis for retrofitting SuDS components into cramped existing urban developments as evidenced by the restoration scheme in the floodplain of the River Skerne in Darlington (RRP, 1995). A linear series of small wetlands have also been successfully retrofitted into a ditch carrying the discharges

> **Webheath, Redditch, Worcs.**
> A 4 cell modular wetland system preceded by a small sedimentation basin has been recently retrofitted into a 270 housing development site at Webheath, Redditch. The linear reed bed cells (25m x 5m) have been retrofitted into a narrow pre-existing degraded channel on the site and provide a void storage of 50 m^3 per impervious hectare for the initial 5mm of effective rainfall-runoff.

from filter drains on the southern carriageways of the M25 just south of Junction 15 near Heathrow Airport.

The Environment Agency Midlands Region has developed an innovative modular treatment train approach for flood and quality control of urban stormwater runoff (Tucker, 1999). Their working design consists of four principal elements:

- a stilling basin and sediment trap ($10m^3$) to capture stormwater debris/litter, grit and oiled sediment. This front-end basin can also be used to retain oil and chemical spillages which may occur within the catchment
- a retention and attenuation of the first flush through mobilisation of void storage using simple orifice/notch weir controls
- a multi-cell linear reedbed construction, normally of HF configuration with a total surface area of $125m^2$ and $250m^2$ respectively for residential and industrial/commercial land
- a wet retention basin for storm flow balancing and final water quality treatment

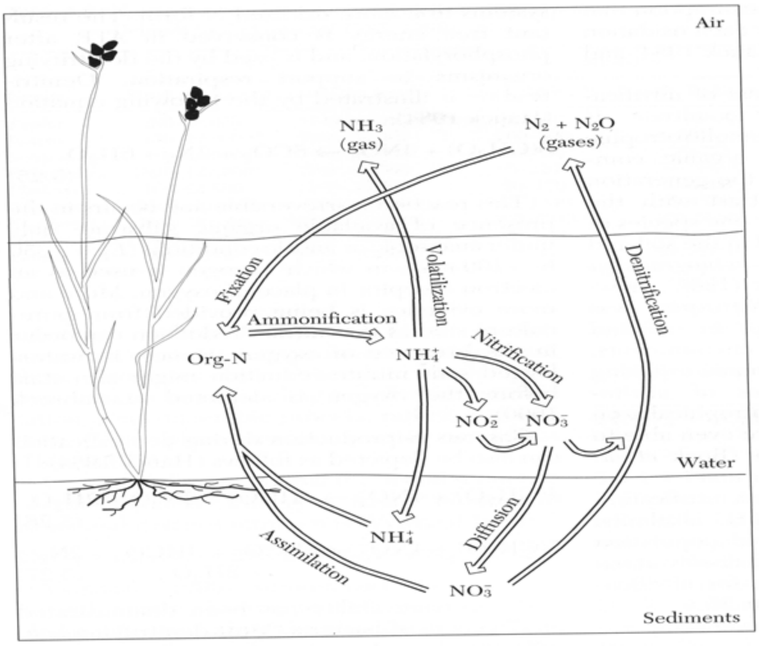
The Environment Agency Thames Region has supported the development of a similar modular sustainable drainage approach for the 6.5ha motorway service area at Junction 8 on the M40 near Oxford. The treatment-train design not only has first-flush (for the initial 10 mm of runoff) and spillage storage, SSF horizontal flow reedbeds and detention ponds (one being a combined detention/wetland system), but also has a range of additional source control structures including porous paving to vehicle parking surfaces, swales and infiltration trenches (Bray, 1999). The final treated stormwater is recycled for toilet flushing, irrigation and top-up water for ornamental ponds on the site. A similar modular SuDS complex but utilising a series of SF wetland systems has been introduced to control and treat the surface drainage for the M42 Junction 2, Hopwood Park motorway service area (Bray, 2001a). The design for the HGV parking area captures the 10mm first-flush volume and is treated by stone filtering followed by wetland treatment over a 48 hour period.

1.6 Wetland Processes

1.6.1 Introduction

A wetland system consists of biotic (plant, algae and associated fungi and bacteria) and abiotic (surface and interstitial water, sediment and detrital material) compartments. Each of the compartments can serve to differing degrees, as a storage location for pollutants entering the wetland. The vascular plants transfer nutrients, gas and other materials (including pollutants) from one part of the plant to another. The microbial compartment is extremely complex and is probably the least understood although it may be the most important wetland component. The micro-organisms are found in the water column, attached to living and dead organic material and within the detritus that builds up on the wetland substrate. Some (facultative) bacteria can grow in either aerobic or anaerobic environments whilst others (obligate bacteria) are specific to either aerobic or anaerobic conditions. Bacteria have a direct role in nutrient cycling and through their oxygen consumption can contribute to an increase in wetland BOD levels. Certain organic and inorganic material can accumulate in the wetland substrate and lead to predominantly oxygen-deficient sediments which generally tend to inhibit decomposition and oxidation reactions.

This means that associated metals, oils and nutrients can be tied-up in the sediment for long periods.



After: Kadlec and Knight,

Figure 1.3. Nitrogen Transformation in a Wetland System

When pollutants enter the wetland they are acted upon by biological, chemical and physical processes which interact in a complex fashion. Figure 1.3 illustrates in a simplified form the interactions which occur in a wetland system between the air-water-sediment phases during sequential nitrogen transformations. Plants will take up dissolved inorganic nutrients (ammonia, nitrate, phosphate etc.) and incorporate them into their tissue whilst bacteria and fungi attack the organic material, utilising both carbon compounds and nutrients. The wetland biota die and become detritus in the basal sediments or may be washed downstream. On an annual basis, pollutants may become buried in the sediments, transformed from one form to another, lost to the atmosphere or washed out of the wetland system either in the original or an altered form.

1.6.2 Pollutant removal processes

In order that the design and operational characteristics of wetland treatment systems are satisfactorily specified, it is necessary to have an understanding of the basic pollution removal mechanisms. Pollutants in urban surface runoff can be removed by wetlands as a result of sediment attachment, degradation, transformation and transfer. They can also be transferred to the atmosphere or groundwater although the latter pathway should be prevented by the use of an impermeable base or liner. The principal physical, chemical and biological removal mechanisms include sedimentation, adsorption, precipitation and dissolution, filtration, bacterial and biochemical interactions, volatilisation and infiltration. Due to the complex interactions between the physical and biochemical processes which occur in wetland systems, these removal mechanisms are not independent. The considerable variation in wetland characteristics e.g hydrology, biota, substrates etc., means that the dominant removal mechanisms will vary from one wetland to another as well as between differing storm events affecting the same wetland system. These inter- and intra-wetland variations help to explain why wetland pollutant removal efficiencies can vary with respect to both temporal and spatial resolution. Tables 1.3a and b summarise the principal mechanisms that capture, retain and transform various pollutant species found in urban runoff and the controlling factors that promote the various removal mechanisms and which lead to improved water quality.

As noted previously, the large majority of UK urban wetlands are free water surface systems containing emergent macrophytes in which the near-surface water layer is aerobic but with the deeper water and substrate being normally anaerobic. A constructed wetland has been traditionally thought to provide a combined aerobic-anaerobic environment. The anaerobic zone surrounds the root zone and at the same time provides a mini-aerobic zone surrounding the root hairs formed by the oxygen passed down from the stems and/or leaves of the aquatic vegetation and contributing to the degradation of oxygen-consuming substances and to nitrification. Ammonia is also oxidised into nitrate by nitrifying bacteria in aerobic zones (see Figure 1.3) with denitrification converting nitrate to free nitrogen (or nitrous oxide) in the anaerobic bottom layers and substrate by denitrifying bacteria. These processes will occur most rapidly during summer periods when high temperatures stimulate microbial activity. Solids, settleable organics and solid-associated pollutants such as bacteria, metals and oils are very effectively removed by the physical filtration offered by the vegetation which imposes a considerable hydraulic resistance to the incoming flow.

Soluble metals are typically transformed by microbial oxidation and precipitated in the wetland substrate in the form of oxides or sulphates with soluble BOD removed by both attached and suspended microbial growth in the aerobic surface water layers.

Table 1.3a. Wetland Pollutant Removal Mechanisms and their Major Controlling Factors

Pollutant Removal Mechanism	Pollutant	Major Controlling Factors
Sedimentation	Solids, BOD/COD, Bacteria/pathogens, Heavy metals, P, Synthetic organics	Low turbulence; Residence time; emergent plants
Adsorption	Heavy metals, Dissolved nutrients, Synthetic organics	Iron and Manganese Oxide particles; high organic carbon; neutral to alkaline pH
Biofiltration and microbial decomposition	BOD/COD, P, Hydrocarbons, Synthetic organics	Filter media; dense herbaceous plants; high plant surface area; organic carbon; dissolved oxygen; microbial populations
Plant uptake and metabolism	P, N, Heavy metals, Hydrocarbons	Large biomass with high plant activity and surface area; extensive root system
Chemical precipitation	Dissolved nutrients, heavy metals	High akalinity and pH
Ion exchange	Dissolved nutrients	High soil cation exchange capacity e.g clay
Oxidation	COD, Hydrocarbons, Synthetic organics	Aerobic conditions
Photolysis	As oxidation	Good light conditions
Volatilisation and aerosol formation	Volatile hydrocarbons, Synthetic organics	High temperatures and wind speeds
Natural die-off	Bacteria/pathogens	Plant excretion of phytotoxins
Nitrification	NH_3-N	DO > 2 mg/l; Low toxicants; Neutral pH; Temperature > 5-7 degrees C; relevant bacteria
Denitrification	NO_3-N, NO_2-N	Anaerobicity; Low toxicants; Temperature >15 degrees C; relevant bacteria
Reduction	Sulphate (resultant sulphide can precipitate metal sulphides)	Anaerobic (anoxic) zone in substrate; relevant bacteria
Infiltration	Dissolved species (nutrients, heavy metals, synthetic organics)	Permeable base and underlying soils

Table 1.3b. Relative Importance of Wetland Pollutant Removal Mechanisms

Pollutant Removal Mechanism	Pollutant								Description
	Settleable solids	Colloidal solids	BOD	N	P	Heavy metals	Organics	Bacteria, pathogens	
Physical									
Sedimentation	**P**	**S**	**I**	**I**	**I**	**I**	**I**	**I**	Gravitational settling of solids (and adsorbed pollutants).
Filtration	**S**	**S**			**I**	**I**		**I**	Particulate filtered mechanically as water passes through substrate and/or root mass.
Adsorption		**S**				**S**	**S**		Inter-particle attractive forces
Chemical									
Precipitation					**P**	**S**			Formation of co-precipitation with insoluble compounds.
Adsorption				**P**	**P**	**S**	**I**		Adsorption on substrate and plant surfaces.
Decomposition							**P**	**P**	Decomposition or alteration of less stable compounds by UV irradiation, oxidation, reduction etc
Biological									
Bacterial metabolism[a]		**P**	**P**	**P**	**I**		**P**		Removal of colloidal solids and soluble organics by suspended benthic and plant supported bacteria. Bacterial nitrification and denitrification.
Plant metabolism[a]				**S**	**S**	**I**	**S**	**S**	Metabolism of organics and other pollutants by plants. Root excretions may be toxic to certain micro-organisms.
Plant uptake				**S**	**S**	**S**	**S**		Significant quantities of these pollutants will be taken up by the roots.
Natural die-off								**P**	Natural decay of organisms in an unfavourable environment

KEY: **P** = Primary effect; **S** = Secondary effect
I = Incremental effect (an effect occurring incidental to removal of another pollutant)

[a] The term metabolism includes both biosynthesis and catabolic reactions

1.6.3 Hydraulic retention time and loading_rates

Perhaps the most important factor influencing the treatment mechanism function is hydraulic retention time i.e the average time that stormwater remains in the wetland. This can be expressed as the ratio of the mean wetland volume to mean outflow (or inflow) rate although it must be noted that if short-circuiting (or high summer evapotranspiration) occurs in the wetland, then the effective retention time can significantly differ from the calculated retention time. In addition, it incorrectly assumes that the entire wetland water volume is involved in the flow and that detention time response to variation in influent flow and pollutant characteristics is linear. Wetlands should have a minimum retention time of at least 10 - 15 hours for the design storm event or alternatively retain the average annual storm volume for a minimum of 5 - 10 hours to achieve a high level of removal efficiency (Revitt *et al*., 1999). When calculating the retention time for a SSF wetland system, the volume of the bed media must also be considered. The retention time of the bed is calculated from the porosity (or void fraction) of the substrate, which represents the fraction of the wetted volume that is occupied by free (drainable) water. The higher the porosity, the greater the retention volume of water per unit volume of media. However, excessive porosity can lead to scour in the bed causing breakdown of the substrate.

> **Hydraulic Retention Time (HRT)**
> The nominal HRT (days) is the volume (LWD) of free water in the wetland divided by the volumetric inflow rate (Q_{in}; m^3/day):
> $$HRT = LWD/Q_{in} \quad (\text{or } D/Q_{in})$$
> Where L and W are length and width (m); D is free water depth (expressed as: porosity x water depth). Mean retention time can also be determined by undertaking an accurate tracer study.

> **Porosity (Void Fraction)**
> Porosity (expressed as a decimal fraction) = Total Void Volume (m^3) / Total Wetland Volume (m^3)
> In an SSF wetland, free water volume fractions are typically 20-40% but can vary between 75-95% for a SF wetland system

The effectiveness of solids settling is directly related to the particle sedimentation time and time is also a crucial variable determining the efficiency of the biochemical processes. Chemically and biologically-mediated processes both have characteristic reaction rates that must be satisfied if optimum treatment is to be achieved. Thus hydraulic loading rates, water depths and duration of flooding become important criteria for the operation of wetland systems and these need to be considered on a site-specific basis in terms of design storm, substrate and vegetation conditions. Reed *et al* (1995) have suggested that a hydraulic loading rate of 0.2 m^3/m^2/day provides for maximum treatment efficiency whilst Ellis (1990) has recommended guidelines of up to $1m^3/m^2$.day (wetland surface area) and a void storage capacity of $50m^3$ and $100m^3$ per impervious hectare respectively for 5mm and 10mm effective runoff volume. These latter hydraulic design parameters have been successfully used in the modular wetland systems developed by the Environment Agency for urban runoff control and treatment within the Lower Severn area (Tucker, 1999).

> **Hydraulic Loading Rate (HLR)**
> HLR (m/d) is equal to the inflow rate (Q_{in}; m^3/d) divided by the wetland surface area (A_s; m^2):
> $$HLR = Q_i / A_s$$
> It does not imply that the inflow is uniformly distributed over the wetland surface.

1.6.4 Sedimentation

This is the (solid-liquid) separation process which uses gravitational settling to remove silt and suspended solids and is considered to be the predominant mechanism for the removal of many solid-associated pollutants from the water column. Assuming that complete mixing occurs during a storm event and that sedimentation is the dominant removal process, it is possible to derive for any given discharge a first-estimate of the required wetland volume and the percentage solids retention. Figure 1.4 shows that solids capture increases the smaller the event discharge (Q) is relative to the basin volume (V). Solids retention also increases as the inflow suspended solids concentration (C_{in}) increases relative to the background concentrations (C_{pr}). The individual curves refer to the ratio of inflow solids concentrations (C_{in}) to assumed background concentrations immediately preceding the storm event (C_{pr}).

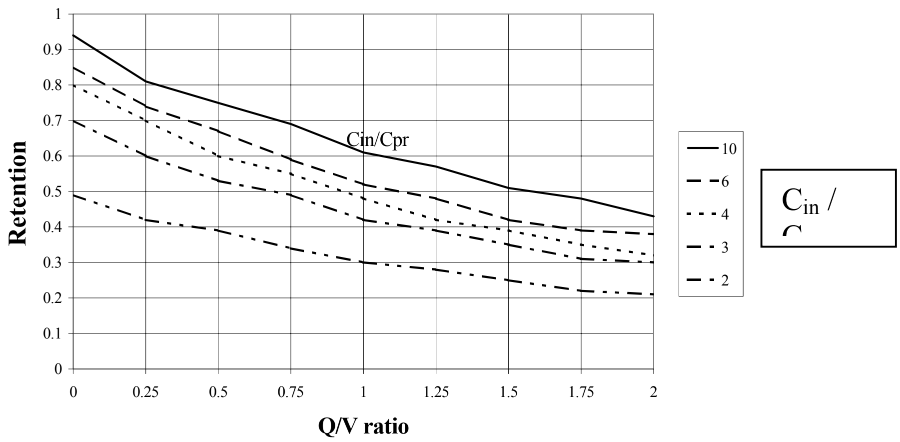


Figure 1.4. Solids Retention Under Differing Discharge and Volume Conditions.

Sedimentation rates in wetland systems following a storm event will be at least equivalent to those experienced in wet retention basins and first order settling rates can be determined from consideration of particle settling velocities using procedures such as outlined in Hall *et al* (1993) for flood storage detention basins. A procedure for calculating the settling velocity of coarse and fine particulates is given in Appendix A. Based on available data, it is possible to draw up a series of percentage solids v time retention curves for typical dry weather periods (or inter-storm intervals) as indicated in Figure 1.5 which illustrates typical capture curves for three wetland basin sites in S E England. It is evident that for all three sites, between 50 - 60% of the total suspended solids load can be expected to be removed within 5 days following most storm events with more than 70% of particles greater than 0.5mm being settled out. With the enhanced sedimentation enabled by vegetative biofiltration, it is evident that stormwater wetlands are fully capable of achieving satisfactory solids removal efficiencies.

Required Wetland Volume
The computations shown in Appendix A and the retention curves of Figure 5 can help to reach decisions on required wetland volumes (V) for a particular location by multiplying the retention time (HRT or t_{ret}) by the daily flow (Q_d ; m^3/d):

$$V = t_{ret} \times Q_d$$

to achieve a desired target level of solids reduction (and for any required sediment grading threshold)

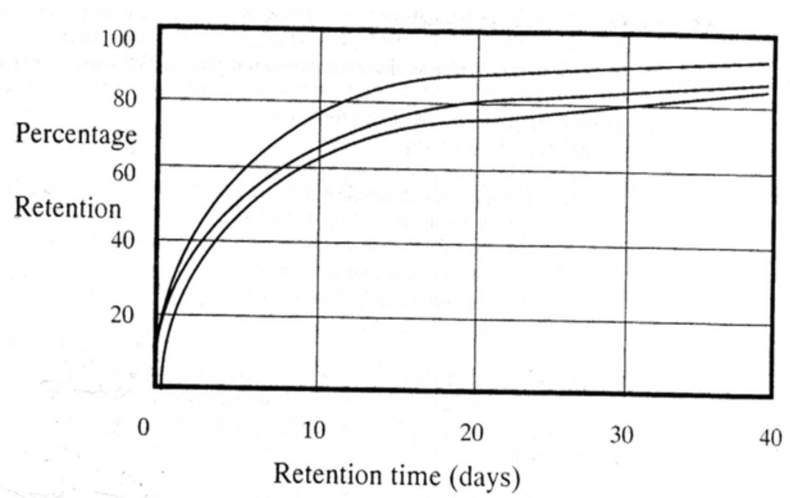


Figure 1.5. Solids Time Retention Curves for Three Wetland Sites

In wetlands having a significant biofilm mass, particles of less than 4-5 μm are unlikely to coagulate and may stay in stable suspension. Apart from retention time, the most significant factors affecting solids settling are emergent plant densities, turbulence, inlet-outlet conditions and water depth. Adverse flow conditions can be minimised by promoting sheet flow conditions into the wetland. The use of inlet distribution weirs or surface filter strips in SF wetlands or gabion blocks for SSF systems can provide efficient inlet flow distribution (Ellis, 1990). Uniform flows distributed evenly across the wetland macrophyte zone will reduce chanellisation and short-circuiting and enhance sedimentation rates as well as encourage the retention of the finer clay size particles (Lawrence and Breen, 1998).

Re-mobilisation of pollutants from oxygen-deficient benthal sediment may still occur as a result of the disturbance of bacterially decomposed organic matter deposited after storm events. Fine sediments either in suspension in the water column or re-suspended from the bed, may be flushed out when relatively clean stormwater enters the basin during a large storm event. The cleaner stormwater inflow displaces the more turbid wetland water, causing a net export of contaminated sediment. Microbial activity under reducing or anaerobic bed conditions can also release soluble pollutants (phosphate, nitrogen, heavy metals, ammonia) into the overlying water column and thus reduce the overall retention performance. In addition, bioturbation and benthic organism excretion can also release heavy metals into the overlying water column. Such re-mobilisation processes can be offset by increasing the wetland area or by cycling the wetland outflows through an open water zone (or further wetland cell) to take up the released nutrients and organic compounds. Whilst the underlying substrate may remain anoxic, the sediment-water interface layer is likely to be re-oxidised by both natural drawdown and recharge between and during rainfall events.

In gravel bed wetland systems, solids accumulation and associated biofilm development can impede influent contact with both the macrophyte roots and the underlying media especially adjacent to the inlet where most sedimentation occurs. Efficient inlet distribution (e.g using gabions) and carefully selected washed gravel media sizes can help to alleviate this problem. Where metal removal is a key water quality objective, mixing with coarse organic soil may be appropriate, although it should be noted that introduced weeds are likely to be present and can cause later problems.

1.6.5 Adsorption

Adsorption of pollutants onto the surface of suspended particulates, sediments, vegetation and organic matter is a principal mechanism for the removal of dissolved and colloidal pollutants such as nutrients, bacteria and the more soluble metal species as well as the more toxic polyaromatic hydrocarbons. As much as 70 - 90% of these pollutant groups can be associated with the fine particulate and colloids in stormwater runoff. Adsorption occurs as a result of electrostatic and physical forces as well as chemical reactions. Adsorption rates under sustained or attenuated loading conditions such as encountered with urban stormwater flows, are considered to be inversely related to the particle size and directly related to the organic matter content.

Adsorption Behaviour of a Pollutant
The balance or *equilibrium* between the solid-associated (C_s, sorbed) and dissolved (C_w) phases of a pollutant is commonly referred to as a *sorption isotherm*. The expression used to describe this pollutant *partitioning* or adsorption relationship is known as the *Freundlich isotherm*:

$$C_s = K. C_w^n$$

where K is the Freundlich constant (or pollutant adsorption coefficient) and n is a measure of deviation from linearity. A value of n = 1 reflects those situations in which the attractiveness of the solid for the sorbate remains the same for all levels of C_s. This linear isothermal relationship usually only applies over narrow ranges in C_w particularly at low pollutant concentrations. The distribution ratio (K_d) of total pollutant equilibrium concentrations in the sorbed and dissolved phases is expressed as:

$$K_d = C_s / C_w$$

$$\text{and hence; } K_d = K. C_w^{n-1}$$

Adsorption processes are therefore enhanced by increasing the contact of the surface runoff with the wetland mineral substrates and with the vegetative surfaces and plant detritus which provide large surface areas for adsorption. In addition, high retention times, shallow water depths and an even distribution of influent will further enhance the interactions of the stormwater with substrate and plant surfaces thereby increasing the adsorption potential. The macrophyte substrate and associated biofilm comprise essential treatment zones for colloidal and dissolved pollutants with organic carbon uptake rates being in the order of 0.2 - 1.2 g/m^2/day for a typical urban runoff wetland system (Cooper *et al*., 1996). This compares well with the uptake rates reported for trickling filters and maturation ponds which range between 0.14 - 0.96 g/m^2/day (Metcalf & Eddy Inc, 1991). The biofilm is particularly susceptible to scouring during storm events and thus the wetland should be designed to limit velocities within the macrophyte zone which ideally should be less than 0.3 - 0.5m/s.

Maximum Inflow Velocity
The expected maximum velocity (U_{max}; m/s) in the wetland can be calculated as a function of the peak flow rate (Q_{pkmax}; m^3/s) and wetland surface area (A_s; m^2) as: $U_{max} = Q_{pkmax} / A_s$

1.6.6 Precipitation and dissolution

Many ionic species such as heavy metals dissolve or precipitate in response to changes in the solution chemistry of the wetland environment. Microbial oxidation and precipitation in the wetland substrate fix metals such as cadmium, copper, lead, mercury and zinc as insoluble sulphides under the reducing conditions commonly found in wetlands. Fulvic and humic acids released by decaying organic matter can also form complexes with metal ions.

1.6.7 Filtration

Enhanced filtration occurs in most wetlands as a direct result of reduced velocities brought about by the hydraulic resistance of macrophyte roots, stems and plant tissue. Such biofiltration is most effective when inflow velocities are below 0.5 m/s and flows are distributed uniformly across the width of the bed. A dense vegetation cover can also be very effective at removing gross solids, litter and floatable material from the incoming stormwater flows. Further pollutant filtration will also occur within the soil matrix of the wetland substrate.

1.6.8 Biochemical interactions

Vegetative systems possess a variety of processes to remove nutrients and other pollutant material from the water column. In general, these processes include high plant productivity (a large biomass), decomposition of organic matter, adsorption and aerobic or anaerobic microbial mechanisms. Through interactions with the soil, water and air interfaces, plants can increase the assimilation of pollutants within a wetland system providing surfaces for bacterial growth and adsorption, filtration, nutrient association and the uptake of heavy metals, hydrocarbons etc. Various studies have demonstrated the efficiency of pollutant removal following contact with the macrophyte rhizosphere (Cooper *et al*., 1996).

Two principal biochemical processes operate to immobilise heavy metals in plant tissue following uptake; (i) complexation by free ions in root cell walls and, (ii) enzyme-mediated incorporation into shoot tissue. There is some evidence that aquatic macrophytes have genes providing a toxic tolerance which enables considerable plant metal accumulation to occur without interfering with vital metabolism processes. Plant uptake of these pollutants provides temporary removal of metals, nutrients and hydrocarbons from the sediments, allowing renewed adsorption sites within the sediment for the attraction of other ions. Heavy metals and low level (<1 mg/l) concentrations of soluble inorganic phosphorus are readily immobilised in neutral mineral soils by adsorption e.g on clay minerals and precipitation reactions e.g with aluminium and iron. As adsorption-precipitation phenomena are partially reversible, this process cannot be assumed to be a permanent sink for phosphorus or metals and incoming dilution water can for example, cause phosphorus release from the sediments into solution.

Pollutant Decay in Wetlands

The reduction achieved in pollutant concentrations across a constructed wetland can be related to a first-order kinetic relationship:

$$C_{out} = C_{in} \times \exp^{-kt}$$

where pollutant concentrations in the inflow and outflow are C_{in} and C_{out} respectively; k is the reaction rate constant and t is the Hydraulic Retention Time (HRT). For an unrestricted SF wetland flow system,

$$HRT = lwd / Q_{av}.$$

1.6.9 Volatilisation and aerosol formation

Evaporation and volatilisation can remove the most volatile pollutants such as ammonia, chlorinated hydrocarbons and some surface oils from wetlands. Air and water temperature, wind speed, subsurface agitation and particularly the existence of surface films can affect the rate of volatilisation. Aerosol formation may also play a minor role in removing wetland pollutants but only during periods of persistently strong winds.

1.6.10 Infiltration

For wetlands having underlying permeable soils, pollutants may be removed through direct infiltration to ground and may eventually reach the permanent groundwater level. Percolation through the underlying soil matrix will provide physical, chemical and biological attenuation depending on the matrix depth, particle size, organic content and degree of saturation. Whilst wetland recharge is unlikely to lead to groundwater contamination it should be avoided wherever possible by the use of an impermeable bed (clay or clay bentonite mixtures) or artificial (PVC or HDPE) liners.

1.7 Defining Wetland Pollutant Removal Rates

Constructed wetland process and design is still an emerging engineering technology possessing only a limited database in terms of pollutant removal performance. This is particularly true of stormwater wetland systems which have been largely built following empirical design criteria. The information available from the domestic wastewater treatment field regarding the effectiveness of constructed wetlands in pollutant removal may not be directly applicable to the use of wetland systems for non-point, stormwater runoff because of their fundamental differences. The two wastewater streams are very different in terms of hydrology, pollutant characteristics and loadings as well as in terms of operational and maintenance practices. Nevertheless, it is important that developers, regulatory agencies and other interested groups have the capability of at least a first-order estimate of the likely performance efficiency of any particular wetland design intended for stormwater treatment.

Plug Flow Reactor Model
Given plug flow conditions and with constant water volume, exponential pollutant profiles can be predicted as:

$$\ln [(C_{out} - C^*) / (C_{in} - C^*)] = -k_T y / HLR$$

$$[\text{or as: } (C_{out} / C_{in} = \exp(-k_T HLR) \text{ and } k = HLR(\ln C_{in} - \ln C_{out})]$$

where C_{in} and C_{out} are pollutant inflow and outflow concentrations (mg/l) respectively, C^* is the wetland pollutant background concentration (mg/l), y is the fractional distance (x) through the wetland length (L,m) i.e = x/L, k_T is the temperature dependent (area-based) first-order rate constant (m/yr) and HLR the Hydraulic Loading Rate (m/yr).
Rate constants can be corrected for temperature effects by:

$$k_T = k_{20}\, \theta^{(T - 20)}$$

where k_T and k_{20} are the reaction rate constants at T^O C and 20^O C respectively (m/yr) and θ is an empirically derived temperature correction factor (normally 1.09).

The treatment performance of wetland systems has been described by various mathematical models but given the reasonable assumption that constructed wetland systems operate as attached-growth biological reactors, their performance can be estimated from plug flow kinetics based on first-order decay (or assimilative) "k" rates for specific pollutants. First-order kinetics implies that the rate of change of pollutant concentration with time is proportional to the concentration and plug flow implies that stormwater entering the reactor flows as a coherent body along the length of the reactor. The change in concentration during the retention time in the reactor is therefore dependent solely on processes occurring within the plug flow. The basic equation under these conditions describing the first-order area-based wetland pollutant removal rate (J; g/m^2/yr) is of the form:

$$J = -k(C - C^*)$$

where k is the pollutant decay rate constant (m/yr) with C and C^* being the wetland and background pollutant concentrations (g/m^3) respectively. However, k is a lumped parameter representing a deposition rate in the case of solids and bacteria, a biodegradation rate for organics (BOD) and a reaction rate in the case of nutrients, metals and hydrocarbons. Thus the value of k really depends on the relevant operating "treatment" process and is normally expressed as a synthesised index value combining the differing removal processes. Any factor such as hydraulic retention time (HRT) which influences these processes can indirectly affect the final k value.

Although simple, this k - C^* area-based reduction model, adapted for treatment wetlands by Kadlec and Knight (1996), represents the highest level of complexity that can generally be calibrated with wetland data and provides a reasonable approximation of performance for a wide range of stormwater pollutants. Appendix B provides detail of the working method and illustrates how plug flow kinetic modelling approaches based on the first-order reaction rates can be applied to determine the size and residence time required to achieve target pollutant reduction in wetland systems. The approach has been widely used and was found for example, to best describe the performance of 21 stormwater constructed wetlands reviewed in a recent US Environmental Protection Agency (1998) BMP technology assessment.

However, despite the general utility of the k - C^* model it has not been universally accepted as it assumes spatially invariant time-averaged flow which is difficult to apply to urban wetlands under stormflow conditions. Rainfall will cause dilution and shorten retention times and such "augmentation" can lead to errors by as much as a factor of four in the determination of rate constants for a first-order reaction. Some guidance on deviation from the simple scheme can be obtained from Kadlec (1989) who argues that SF constructed wetlands have characteristics intermediate between plug flow and well mixed. The k - C^* two parameter model also does not account for adaptation trends in the wetland ecosystem as it matures or the effects of pH and dissolved oxygen as well as other factors which are known to affect the fate of pollutants in treatment systems. More complex models incorporating the effects of plant biomass, pulsed flows and varying residence times are available (Kadlec, 1996; Wong *et al*., 1998; Lawrence and Breen, 1998) but these require substantial calibration data and further field testing before they can be universally and simply applied to constructed urban stormwater wetlands.

Key Issues

- defining optimum hydraulic retention times (HRTs) and hydraulic loading rates (HLRs) for required (or target) pollutant removal efficiencies and varying wetland surface areas and volumes.
- assumed linear response of hydraulic retention time (HRT) to influent flow and wetland pollutant characteristics.
- the general utility of the k – C* model under non-steady, stormflow conditions and with wetland maturation.
- relative role of constructed wetlands within a SuDS treatment train.

2. URBAN WETLAND PERFORMANCE AND COSTS

2.1 Wetland Performance

2.1.1 Natural and semi-natural wetlands

Very few natural wetlands within the UK are used as deliberate treatment systems for contaminated discharges. However one study of such discharges is that of Richards, Moorehead & Laing Ltd (1992), on four natural wetlands in Wales which receive and treat metal-contaminated mine drainage waters. Table 2.1 shows the average and range (in brackets, with negative values denoting negative efficiencies) of metal removals recorded in these natural bog and marsh wetlands. Apart from one notable exception, removal efficiencies for most metals was generally poor and for some storm events, the wetlands themselves formed a significant source of metals to the downstream watercourse. This remobilisation of historically precipitated metal during stormflow conditions largely explains the poor performances recorded but the short hydraulic retention times may also be an important factor. The standing water volume in the wetlands and the active stormflow channels do not facilitate productive exchange and contact between the standing water, plants and substrate.

Table 2.1 Percentage Metal Removal Efficiencies from Acid Mine Drainage by Natural Wetlands in Wales

	Afon Goch, Parys, Anglesey	Hafna, Llanrwst	Esgair Ffraith, Machynlleth	Camdwrbach, Aberystwyth
Copper	10 (0 - 40)	- -	-19 -	- (78 - 96)
Zinc	-10 (-30 - 45)	-60 (-110 - 23)	-52 -	- (77 - 92)
Lead	-50 (-65 - 42)	82 (73 - 92)	31 -	-82 -
Cadmium	-15 (-22 - 41)	-38 (-99 - 50)	-26 -	- (79 - 98)

One specific study that has examined the impact of surface drainage on a natural wetland is that of Sriyaraj and Shutes (2001). Table 2.2 shows the range in both water and sediment metal concentrations recorded for this small natural wetland (*Typha latifolia* and *Glyceria maxima*) located in a Hertfordshire nature reserve at Potters Bar and which is subject to discharges from the M25. Whilst water concentrations do not exceed statutory water quality standards, the sediment metal concentrations clearly show moderate to high levels of contamination in comparison to unpolluted background sediment and with Swedish Environmental Protection Agency standards, with Cd and Zn being of particular concern. Biological diversity scores (BMWP and ASPT; see List of Acronyms) were found to be depressed downstream of the wetland site in comparison to those scores recorded by the Environment Agency at an upstream site above the wetland (Sriyaraj and Shutes, 2001).

Table 2.2 Metal Levels in a Natural Wetland Receiving Highway Runoff

	Water (μg/l)		**Water Quality Standard**[a] (μg/l)	**Sediment** (μg/g)		**Unpolluted Sediment**[*] (μg/g)	**Swedish EPA Sediment Metal Standard** (μg/g) (moderate/high)
	Inlet	Outlet		Inlet	Outlet		
Cd	0.5-0.6	0.5-1.7	5^S	5.8-8.7	12.2-44.4	0.1-2.0	0.7-2.0
Cu	1.4-2.4	0.1-0.9	10^O (AD)	14.1-41.5	5.8-17.0	4-20	25-50
Pb	3.3-5.7	3.7-4.9	10^O (AD)	29.7-73.4	24.5-95.5	4-40	30-100
Zn	1.7-8.5	1.2-1.9	75^O (AT)	70.8-239.8	59.5-104.2	23-50	175-300

[a] Standards for sensitive aquatic life at hardness 100 - 150 mg/l Ca CO_3
[S] Statutory EQS; [O] Operational EQS (A = annual average; D = dissolved and T = total)
[*] From Scholes *et al*., 1999

Semi-natural wetlands such as the Welsh Harp basin in NW London (see second box in Section 1.2.2 on page 4) provide a rather better performance efficiency especially if they are actively managed to improve the wetland productivity and pollution control efficiency. Shutes *et al.* (1993) reported for example, that as much as 54% - 61% of the total metal load in *Typha* can be stored and locked in the macrophyte rhizomes (subsurface stems) of such semi-natural wetlands. Jones (1995) also showed that the semi-natural Welsh Harp wetlands substantially reduced the aqueous poly-aromatic hydrocarbons (PAH) and alkane concentrations by 31% and 54% respectively. Table 2.3 shows the total mean hydrocarbon concentrations in water and sediment passing through the Welsh Harp basin and the total maximum PAH concentrations recorded in caged invertebrate water lice (*Asellus aquaticus*) exposed to stormwater flows during wet weather conditions (Jones, 1995). It is clear from the tabled data that reductions of between 50% to 70% in aquatic hydrocarbon levels are achieved in this semi-natural wetland environment thus providing a robust downstream protection function.

Table 2.3 Reductions in Hydrocarbon Concentrations within a Semi-natural Wetland; the Welsh Harp Basin, NW London.

	Alkane Concentrations	**PAH Concentrations**
INLET		
Water (μg/l)	665.4	128.8
Sediment (μg/g)	250.0	110.9
A.aquaticus tissue (μg/g)		32.42
OUTLET		
Water (μg/l)	322.7	36.8
Sediment (μg/g)	70.6	25.9
A.aquaticus tissue (μg/g)		12.31

2.1.2 Artificially constructed wetlands

Table 2.4 summarises the averages and ranges of removal percentages for various pollutants calculated from the data presented in the 1997 CIRIA report (Nuttall *et al*., 1997) for those constructed wetlands treating domestic wastewater (negative values denote negative efficiencies). The percentage removal efficiency is in most cases simply defined as: $(C_{in} - C_{out}) / C_{in} \times 100$, where C_{in} and C_{out} are the inflow and outflow pollutant concentrations respectively. The table also shows summary data that have been recorded in the UK for wetland systems receiving urban and highway runoff (Ellis, 1991 and 1999; Ellis and Revitt, 1991; Ellis *et al*., 1994b; Cooper *et al*., 1996; Cutbill, 1997). The data for extended detention basins is taken from US data (Urban Drainage & Flood Control District, 1992) as there are no comparable data recorded for UK sites.

Table 2.4. Percentage Pollutant Removals for Domestic Wastewater and Artificial Stormwater Wetland Systems in the UK

	SS	BOD	NH_4-N	NO_3-N	E.Coli
Domestic Wastewater					
Secondary treatment	83	82	18	45	68
	(69 - 94)	(70 -92)	(5 - 29)	(7 - 68)	(60 - 75)
Tertiary treatment	68	71	33	55	84
	(25 - 92)	(50 - 95)	(0 - 77)	(40 - 76)	(46 - 99)
Urban Runoff					
Wetlands	76	24	31	33	-
	(36 -95)	(-57 - 81)	(0 - 62)	(-17 - 68)	(52 - 88)
Combined					
Retention/Detention Basins	73			53	92
	(13 - 99)			(10 -99)	(86 - 99)
Wet (Retention) Ponds					
(with marginal vegetation)	55	40		29	
	(46 - 91)	(0 - 69)		(0 - 80)	
Extended Detention Basins[*]					
Highway Runoff	-	18		-	-
Wetlands (combined	(50 - 70)	-		(10 - 20)[#]	(50 - 90)
Retention/Detention)					
SF Wetlands					
	-	15		45[#]	82
SSF Wetlands	(13 - 75)	(5 - 32)		(10 - 60)[#]	(75 - 99)
	73			53[#]	92
	(13 - 99)			(10 - 96)[#]	(86 - 99)
	85			44[#]	88
	(62 - 97)			(25 - 98)[#]	(80 - 97)

[*]From US data (Urban Drainage & Flood Control District, 1992); [#]Data for Total Nitrogen

2.1.3 Metal removal efficiencies

Metal Removal from Motorway Runoff
A study of the performance of a 3900m^2 *Typha* wetland receiving runoff from a heavily-trafficked section (140,000 AADT) of the M25 near Junction 9 at Leatherhead, showed metal removal efficiencies varying between 88% - 94%.. The final 1000m^2 settlement pond was estimated to be responsible for about 35% of this total removal rate. Zn removal efficiencies were reduced as a result of solubilisation from anoxic wetland sediments (Hares and Ward, 1999).

A study on the A34 Newbury-Bypass yielded similar evidence of soluble Zn (and Cu) being remobilised across a stormwater wetland receiving runoff from 3.1ha of the highway carriageway. The 6995m^2 SF constructed wetland (*Phragmites*) is nested within a 11,189m^2 storage basin; some 25% of the basin area is occupied by permanent standing water. The study showed an effective settling of contaminated sediment in the front-end sedimentation trap which recorded metal sediment levels generally twice as high as that within the wetland sediment. However, the range of metals contained in association with the fine (<63µm) solids fraction, was frequently greater leaving the wetland than coming in (Pontier *et al*., 2000).

The equivalent data for metal removal efficiencies (with ranges shown in brackets and negative values denoting negative efficiencies) that have been noted for the various types of surface water wetland systems (Mungur *et al*., 1995; Ellis *et al*., 1994b; Cutbill, 1994; Mungur *et al*., 1998: Scholes *et al*., 1999; Ellis, 1999: Heal, 1999; Revitt *et al*., 1999: Revitt and Ellis, 2000; Halcrow/UPRC, 2000) are presented in Table 2.5. Although the data exhibit very large ranges, it is clear that artificially constructed wetlands perform better than natural systems and there is substantial evidence that water and suspended sediment metal concentrations are reduced in urban stormwater wetlands (Shutes *et al*., 1993; Cutbill, 1997; Hares and Ward, 1999). Some possible concern has been expressed over the ability of urban wetlands to sufficiently remove cadmium, with recorded storm outflow rates frequently exceeding the EU/Environment Agency water quality standard of 5µg/l (Revitt *et al*., 1999; Pontier *et al*., 2000). This concern is reinforced by the evidence of wetland flushing observed in the two highway studies noted in the above box.

There are about 30 constructed SF wetlands in the UK which provide a passive treatment for ferruginous discharges emanating from abandoned coal mines and spoil heaps which affect some 357 km of total stream length (Younger, 1997). Such gravity-flow wetland systems have been shown to remove up to 60% of the iron ochre at costs of between £25 - £54 per m^2 (Younger and Harbourne, 1995). The ochreous discharges from the Wheal Jane tin mine in Cornwall, the initial discharge from which contained more than 2500 mg Fe/l, have also been successfully tackled using wetland reedbed technology achieving 95% average iron removal. Two horizontal SF constructed (*Typha* and *Phragmites*) wetlands are used which are followed by a covered anaerobic cell and final open rock filter and collectively treat 129 m^3/day. Attempts are now being made to integrate metal contaminated mine drainage (MCMD) treatment wetlands into the surrounding landscape and to incorporate ecological function (including spontaneous ecological succession) as well as hydrochemical efficiency.

Table 2.5 Wetland Metal Removal Efficiencies for Natural and Artificial Wetlands in the UK

	Metals		Cadmium	Lead	Zinc	Copper
	Total	Dissolved				
Natural Wetlands			(-38 - 50)	(-50 - 82)	(-60 - 30)	(10 - 78)
Artificial Wetlands						
1. Urban Runoff						
Wetlands			- (5 - 73)	62 (6 - 70)	57 (-36 - 70)	51 (10 - 71)
Combined Retention/Detention Basins			- (10 - 30)	- (0 - 28)	- (3 - 22)	- (0 - 10)
2. Highway Runoff						
Wetlands	- (40 - 90)	- (-15 - 40)	- (20 - 72)	69 (-41 - 89)	42 (-36 - 71)	- (36 - 66)
Wet Retention Basins	- (45 - 85)	- (10 - 25)		52 (40 - 56)	38 (8 - 56)	
ED Basins	- (20 - 50)	- (0 - 5)				
Dry Detention Basins (with infiltration)	- (70 - 90)	- (10 - 20)				

2.1.4 Efficiency comparison

The reported performances of natural and constructed wetlands for suspended solids, nutrients and metals are compared in Figure 2.1 with the shaded boxes enclosing the 25^{th} to 75^{th} percentiles and the thick horizontal lines marking the median values. The arrows indicate the full range of reported values. As confirmed by Tables 2.4 and 2.5, removal efficiencies for solids range between 70 to 90% for constructed systems with comparable, but more variable removal efficiencies for metals. The performances of natural wetland systems by contrast are extremely variable and quite poor in many cases. The information available from the domestic wastewater treatment field regarding the effectiveness of constructed wetlands in pollutant removal may not be directly applicable to the use of wetland systems for non-point, stormwater runoff because of their fundamental differences. Wastewater treatment wetlands for example, are subject to constant (and fairly uniform) inflows whereas surface runoff generates pulsed stormwater loadings of varying physical and chemical composition.

Despite the variability recorded in pollutant removal efficiencies, some general observations can be made from the data:

- Figure 2.1 and Table 2.4 reveal a broad range of pollutant removal efficiencies although the median values are fairly consistent especially for suspended solids (SS), bacteria and nutrients. The variation is not unexpected given the range of hydraulic conditions, vegetation types and coverage as well as monitoring procedures.

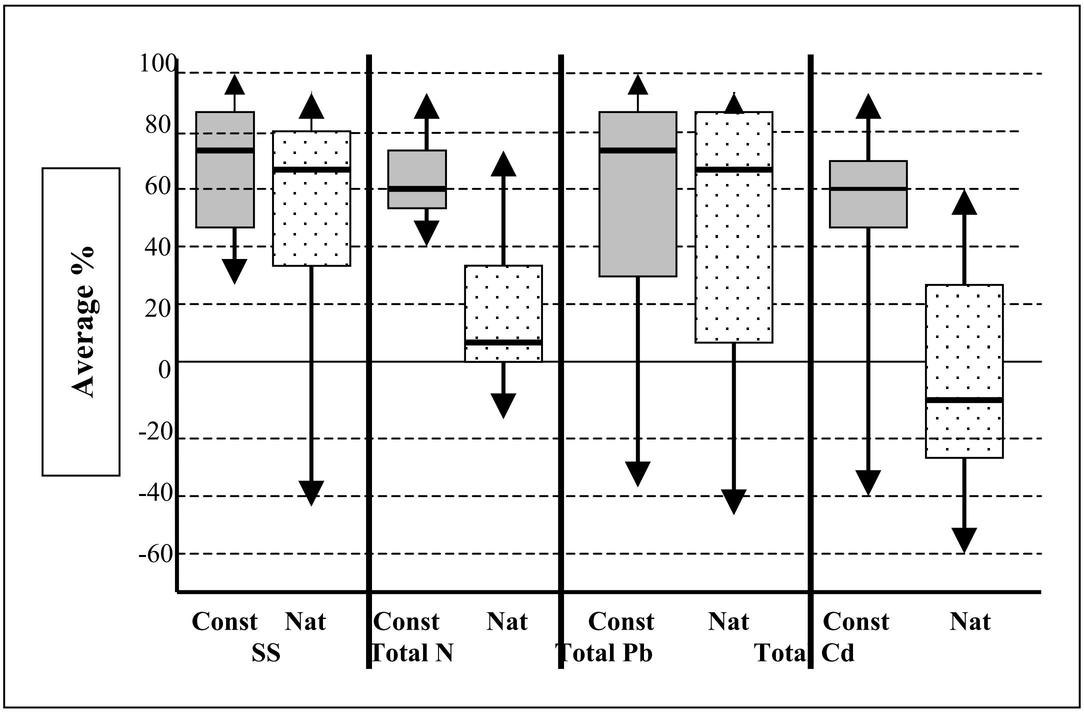


Figure 2.1 Performance Comparison of Constructed and Natural Wetlands

- suspended solids and BOD removal efficiencies tend to be more consistent in constructed wetlands intended for domestic wastewater treatment than in stormwater systems. This is most likely due to the design and management of the constructed systems as well as to the more uniform composition of inflow pollutant concentrations.
- nutrient removal efficiencies vary quite widely among all wetland types. The variations may be a function of the season, vegetation type and management of the wetland systems.
- metal removal efficiencies (Table 2.5) whilst generally variable, are better for artificially constructed systems than for natural wetlands. Under the right conditions, outflow loadings of dissolved zinc and copper can also be reduced, in comparison to inflow loadings.
- hydrocarbon removals in both semi-natural and artificial constructed wetlands is generally good.
- negative efficiencies especially for organic and metal determinands denote that wetlands can act as pollution sources. Excessive outflow loadings are normally associated with (re-)mobilisation of sediment-associated contaminants which are flushed out of the system during periods of intense stormflow activity or after prolonged dry periods. Hence, there is a need for a bypass to divert the higher stormflow volumes away from the wetland and/or for a pre-treatment settlement basin or trench.

The efficiency ratio approach and efficiency performance data reported above are based on the average difference between inflow and outflow storm event concentrations, but a number of workers have shown that there are defects in this methodology especially when inflow concentrations are low (Strecker *et al*., 2001). For example, a wet retention basin experiencing 500 mg/l TSS in the inflow and 100mg/l in the outflow would yield a higher pollutant removal efficiency than a wetland having 100 mg/l and 20 mg/l in the influent and effluent respectively. Yet the final water quality for the latter device is clearly superior and would provide more effective and efficient protection of the receiving water. This example points out the need to think carefully about whether pollutant removal efficiency, particularly when expressed only as percentage removal, is providing an accurate representation of how effective a performance is being provided by a SuDS facility. The percentage removal term is probably only really appropriate for sites and SuDS facilities subject to high pollutant input concentrations. In addition, given the dynamic nature of flow into and out of a wetland basin having a permanent mixing pool, the recorded inflow and outflow concentrations are not normally contemporaneous i.e not generated by the same storm event.

A better and certainly more rigorous approach to measuring efficiency and performance effectiveness, would be to derive a normal probability plot of the inflow and outflow pollutant event mean concentrations (EMCs) and match the latter distribution against set (or target) receiving water quality standards (or any discharge consent conditions). This would enable the determination of the exceedance probabilities of target standards for differing flow conditions and/or return periods. This is the basis on which the efficiency of various BMPs included within the US Environmental Protection Agency (EPA) National Stormwater Best Management Practices Database will be evaluated (Urban Water Resources Research Council and URS Greiner Woodward Clyde, 1999). This statistical methodology would also enable anomalous results to be identified a well as determining whether a small number of large storms are biasing the resulting overall efficiency value. Figure 2.2 illustrates the approach with inflow and outflow EMC values recorded either side of the central vertical line. The box plots indicate the inflow/outflow range, medians and quartile values. When measured against a receiving water quality target standard (or discharge consent) of 30 mg/l TSS, it is clear that the wetland system is providing an extremely satisfactory performance efficiency, with an overall outflow median value of 4.1 mg/l Total Suspended Solids (TSS). The probability of exceeding the target standard is less than 2%.

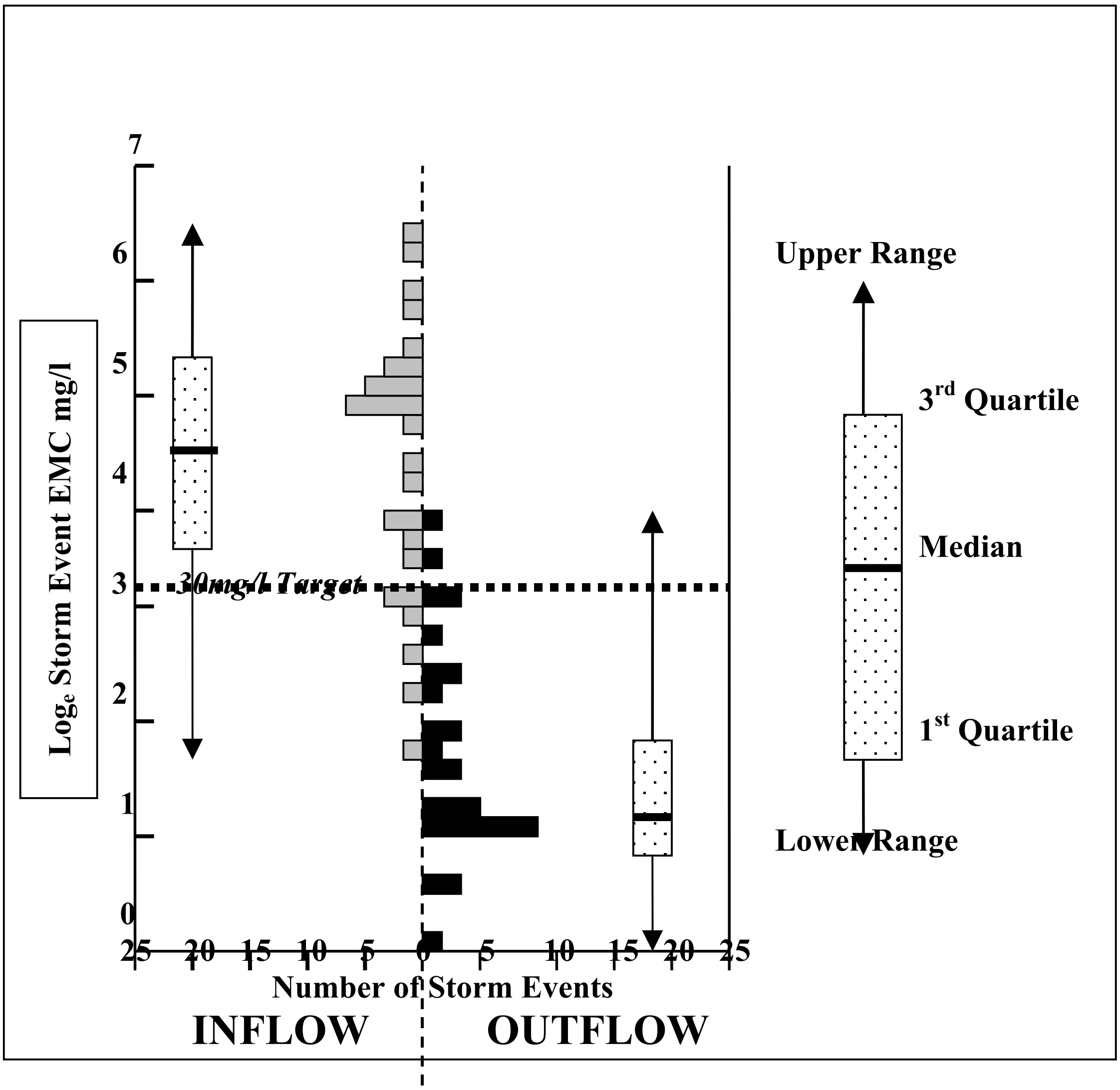


Figure 2.2 Log EMC Plots for Wetland TSS Data

It is clear that a comprehensive assessment of the performance of wetland SuDS is currently limited by a lack of data and the uncertainties are particularly evident in the use of wetland technologies for the management and treatment of urban surface runoff. The surface area and volume of a wetland system can greatly affect both the actual removal efficiency as well as the fundamental ability to accurately estimate the removal efficiencies in the first place. In large wetland systems where outflows are not contemporaneous with the storm inflow, the treatment cycle can span several storm events and therefore no single storm provides a complete picture of pollutant removal efficiency. The type of inlet structure and the flow patterns through the wetland will also significantly affect pollutant removal. This will be additionally influenced by seasonal changes which occur in vegetational productivity, hydraulic retention time and microbial activity. It is not yet feasible to provide definitive designs to meet specified and consistent performance requirements for given storm and catchment characteristics or to meet specific receiving water standards and storm return periods. In view of the diverse range of pollutant and stormflow loads and reduction requirements, as well as the local physical, social and economic constraints, the design, operation and maintenance requirements will also tend to be site specific.

Nevertheless, whilst accepting this qualification, it is still possible from the data and information currently available to broadly identify representative pollutant removal and flow attenuation capacities for various sustainable urban drainage options including wetland systems. Table 2.6 attempts to summarise these capabilities and provide an overview of the potential performances that each wetland option might be reasonably expected to achieve. The various SuDS designs undoubtedly vary in their ability to reduce the different types of pollution arising from urban development although each can also offer additional environmental benefits. It is therefore important that the designer, developer and regulator establish what the general and/or specific objectives are before selecting a particular SuDS type. After establishing what the flood control, water quality and amenity objectives are, an analysis is then required of what is feasible on a particular site given the characteristic physical, meteorological, economic and institutional constraints.

2.1.5 An international perspective

A review of data reported from overseas studies broadly confirms the findings arising from the UK wetland database. Strecker *et al*., (1992) have analysed the results from 26 studies conducted on constructed urban wetland systems in the US. Although good to high pollutant removal efficiencies were observed, the analysis identified the inherent random nature of the performance data with the absence of any meaningful direct relationships between performance and catchment parameters (Table 2.7) or with basin/runoff volumes. However, the WWAR and DAR values (see notes below Table 2.7), are very close to those recommended by European workers who have advocated for example, WWAR ratios of 2 - 3% and wetland basin volumes (V_b) equal to 4 to 6 times the mean storm runoff volume (V_r) (Hvitved-Jacobsen, 1990; Ellis, 1999).

Table 2.7 Reported Removal Rates for US Stormwater Constructed Wetlands

	Pollutant Removal Rates					**WWAR**	**DAR**
	SS	NH_3	TP	Pb	Zn		
Median	80.5%	44.5%	58.0%	83.0%	42.0%	3.65%	31.0
CV	27.7%	49.4%	48.5%	56.1%	38.8%	94.6%	156.2%
Average	77.1%	39.7%	57.2%	63.8%	48.7%	4.26%	131.0

WWAR = % ratio of wetland surface area to catchment area
DAR = Drainage Area Ratio
CV = Coefficient of Variation

Table 2.6 SuDS Pollutant Removal and Flow Attenuation Capacities

	Percentage Pollutant Removal Efficiency							Flow Attenuation Efficiency	
	Litter and Debris	Solids	BOD	P	N	Metals	Bacteria	Peak (allowable discharges)	Volume
Wetlands (Combined Ret/Det Basins)	NA	▒	⬚—⊞	⊞—▒	⬚—⊞	▒	⊞—■	⬚—⊞	□
Wet Retention Basins (With marginal vegetation)	NA	▒—■	⊞	⊞—▒	⬚	⊞—▒	⬚—⊞	⊞—▒	⬚
ED Basins (<10 hour detention; with marsh)	■	▒	⬚	⬚	⬚	⊞	?	▒	□
ED Basins (10-24 hour detention; with marsh)	■	■	⊞	⬚—▒	⬚	▒	? --- □	▒	⬚
Dry Detention Basin (First flush infiltration)	■	▒	▒	⊞	⬚—⊞	⊞	⬚	▒	⬚—⊞
Dry Detention Basin (Total infiltration)	■	■	▒	▒	⊞—▒	■	■	▒	▒—■

KEY: ■ 80-100%; ▒)-80%; 4(⊞%; 20-4⬚ 0-20% □

? Insufficient knowledge NA; Not applicable

- Level of pollutant removal will be subject to basin volume or surface areas relative to catchment runoff
- In silty clay/clay soils, high basin volumes or surface areas relative to catchment runoff will be required
- Flow attenuation in Retention and Detention Basins is a function of storm frequency, storage provision and outlet control

Table 2.8 Removal Rates for US Stormwater SSF and SF Wetlands

	SS	Total N	Total P	Faecal Coliforms
SSF systems				
Average	85.4%	44.6%	50.4%	88.5%
Range	67 - 97%	25 - 98%	20 - 97%	80 - 97%
SF systems				
Average	73.3%	63.3%	50.2%	92.5%
Range	13 - 99%	1.6 - 99%	7 - 98%	86 - 99%

Preliminary testing of the US EPA National Stormwater Standardised BMP Database confirms this variability that appears to characterise urban wetland performance (Urban Water Resources Research Council and URS Grenier Woodward Clyde, 1999). Table 2.8 which has been calculated from this 1999 US EPA Database suggests that this variability is independent of the wetland flow system used although for solids and solids-related pollutants, SSF systems tend to perform better than SF systems. However, retrofitted "packed bed" SF constructed wetlands in urban flood detention basins in Florida (City of Orlando Stormwater Utility Bureau, 1995) have given consistently good pollutant removal rates for SS (78 - 90%), total nitrogen (63 - 70%), total phosphorus (62 - 82%) and total metals (55 - 73%). Similar horizontal SF wetland retrofitting on 24 sites in the Melbourne urban area of Australia has been successful in reducing pollutant outflow concentrations from detention basins and in improving downstream habitat status whilst maintaining existing flood attenuation capabilities (Wong *et al*., 1998). Studies in the Sydney region (Shatwell and Cordery, 1999) have indicated average retention in urban SF wetlands of 80% and 60% for SS and Total P respectively during small to medium sized storm events but with very variable (and even negative) performance occurring during intense and/or large events.

2.2 Performance Indicators

Table 2.9 provides a qualitative summary of best practice guidance indicators in respect of wetland and dry/wet storage basin facilities. The table is intended to give first-screening evaluation of the robustness of the various wetland systems to achieve the stated functional objective. High design robustness gives a significant impact and probability of performing as intended. Low robustness and impact implies that there are many uncertainties with regard to how the design will perform for that function. The evaluation is both subjective and tentative being based on a review of the literature and by the working experience of the authors. Nevertheless it does indicate that wetland systems have a considerable potential to address all three elements of the SuDS triangle i.e water quantity, water quality and amenity/habitat.

Table 2.9 Wetland and Dry/Wet Storage Basin Indicators

	Pollutant Category				Flood Abatement		Amenity	
	Floating Debris	Sediment And Litter		Dissolved	Runoff Reduction	Peak Flow Reduction (with appropriate overflow control)	Open Space & Recreation	Landscape Quality, Habitat & Biodiversity
		Coarse	Fine					
Natural Wetlands	+	+ +	+ +	+	+	+ +		+ + +
Constructed Wetlands	+	+ + +	+ +	+		+ +	+	+ +
ED Basins	+	+ +	+			+ +	+ +	+
Dry Detention Basins	+	+ + +	+		+ + (Infiltration Basin)	+ + +	+ +	
Wet Retention Basins	+	+ +	+ +	+		+ +	++	+ +

Key: + minor impact; + + medium impact; + + + major impact.

Table 2.10 provides a semi-quantitative (but nevertheless still subjective) approach to the evaluation of wetland SuDS systems which considers various factors that influence selection, design and performance. The scoring system is based on the procedure developed by the US Environmental Protection Agency (Heaney *et al*., 1997) which scores all positive aspects of each system type from 1 (lowest) up to 5 (highest having the most desirable conditions) and negative aspects with increasingly negative values from -1 to -5. All parameters were weighted equally (weighting factor = 1) with the exception of those relating to the "applicability" to differing urban land uses. These three land use columns were allocated a weighting factor of one-third each. Thus constructed wetlands score extremely highly in terms of final water quality and flow control but have high O & M requirements and can influence downstream temperatures and therefore have low scores for these two parameters.

The scores and group rankings are again based (and therefore biased) on information and data gathered from the international literature and on personal experience. Despite their bias and subjectivity, the composite average rating scores reveal an overall group ranking that attempts to integrate most of the aspects that must be considered in stormwater runoff drainage design. However, they do not incorporate institutional issues such as the attitude of water companies to the adoption of non-pipe systems, the legal and administrative difficulties posed by multiple ownership or long term effectiveness.

Table 2.10 Evaluation of Wetland Effectiveness Potential

	Water Quality	Flow Rate Control	Runoff Volume Reduction	O & M Needs	Failure Potential	Applicability for Given Urban Land Use			Design Robustness		Potential for Groundwater Contamination	Potential for Temperature Increases to Discharges	Weighted Rating Average	Group Ranking
						Low-Medium residential	High Residential and Low/medium	Hiigh Denisty Commercial and industrial	Hydrologic and Hydraulic	Water quality				
Constructed Wetlands	5	5	2	-3	-1	4	5	2	4	3	-2	-3	**0.88**	**I**
ED Basins	4	5	1	-2	-2	4	4	3	4	4	-2	-2	**1.06**	**I**
Wet Retention Basins	5	5	1	-2	-1	4	4	3	4	4	-2	-4	**0.97**	**I**
Dry Detention Basins (With Infiltration)	4	5	5	-4	-4	5	5	2	3	4	-4	-1	**0.64**	**II**
Natural Wetlands	2	3	1	-2	-1	?	?	?	4	2	-1	-2	?	**III**

2.3 Treatment, Performance and Maintenance Costs

A variety of factors will affect the operational costs of treatment wetlands of which perhaps hydraulic retention time (HRT) is one of the most significant. Figure 2.3 is based on data for SSF wetland systems derived from the 1999 US EPA National Stormwater BMP Database which illustrates the cost of building such wetlands as a function of flow rate multiplied by retention time. Costs are presented in this way because wetland designs can have different treatment objectives e.g targeted suspended solids removals will require very different retention times than for nitrogen. Two similar flow rates having different treatment design objectives will therefore have very different costs. The figure is based on the assumption that longer retention times lead to improved water quality and although the linear fit has a relatively poor correlation, it does give a rough estimate of costs. Thus based on the "best-fit" equation, a 50m^3/day SSF wetland system with 24 hours of treatment would cost £31,786. Very similar cost-prediction relationships were defined for 18 wetlands and wet Extended Detention (ED) basins in the US Mid-Atlantic region (Brown and Schueler, 1997) where it was estimated that water quality storage comprised about one-third of the total cost of most stormwater basins and wetland systems. Therefore, a wetland facility costing a total of £21,074 on a 2ha commercial site and removing 52kg of phosphorus over its 25 year design life, would provide a cost-effectiveness of £139/kg removed. Brown *et al* (1999) have demonstrated for source control systems in the Sydney area, that wet detention basins would be the best management strategy given cost constraints but that wetlands become the best option if performance efficiency constraints are applied. Their optimisation techniques yield costings of £20-22/m^2 for urban stormwater constructed wetlands but note that there are steep increases in costs if more than 80 - 85% pollutant removal rates are required.

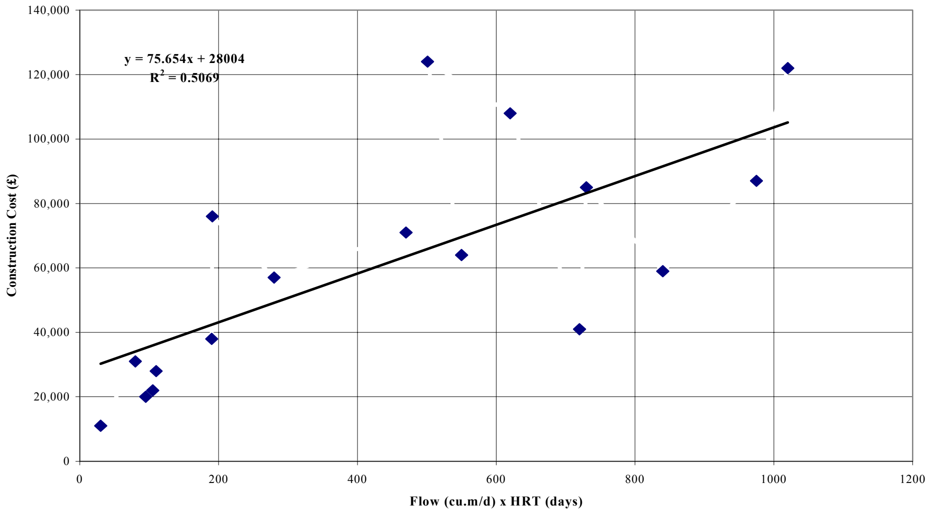


Figure 2.3 SSF Wetland Performance Costs

Very little data is available on cost criteria for UK wetland systems and what cost guidance is available is generally restricted to constructed wetlands intended for domestic or industrial wastewater treatment (CIRIA, 1997; IWA, 2000) although wetlands intended for the treatment of acid mine drainage have been quoted as between £25 - £54 per m^2 (Younger and Harbourne, 1995). The general distribution of capital costs between typical design, engineering and development elements for stormwater wetland systems can be estimated as shown in Table 2.11. This table clearly shows the additional costs over and above a conventional flood detention basin required for lining, providing a suitable substrate and planting in a wetland system. Suitable nursery stock of plants including planting for example, can cost around £3 - 5/m^2. For a typical stormwater flood detention basin, the sum of all costs related to design, consenting and legal fees, geotechnical testing and landscaping is equivalent to about 30% of the base construction cost (excavation, control structures and appurtenances e.g litter racks, rip-rap etc). If wetlands are incorporated (or retrofitted) into the detention basin, these costs increase by anything between 15 - 37% of the base construction cost. The IWA (2000) report suggests that the capital cost of a SSF wetland is 3 to 5 times that of a SF wetland to do the same job. Thus on the basis of performance to cost, it would seem difficult to justify SSF systems for stormwater treatment apart from any wish to keep the polluted water below the surface of the ground or media. Halcrow/UPRC (2000) have estimated the total cost of a 1750m^3 cellular highway wetland (with front-end 500m^3 sedimentation trench, 2000m^2 constructed wetland and 50m^3 final settlement pond), as being £144,500 based on the 1995 CESM3 Price Database. Some 30% of this total is taken up by the geotextile liner cost (£15-20/m^2). The inclusion of a Class I bypass oil interceptor would increase the cost by an additional £5000 for a 200 - 1300 l/s peak flow unit (Ellis and Chatfield, 2000). However, given that few stormwater wetlands are likely to be much larger than 0.5 - 0.75ha, land costs (especially on greenfield sites) represent only a minor proportion of total costs. It must also be borne in mind that the final "reclaim" value of the wetland site is unlikely to depreciate and thus the net present worth of the land following the nominal operational lifetime (say 20 - 25 years) should be considered as a credit in any economic evaluation.

Table 2.11 Distribution of Wetland Capital Costs

Item	SF Wetland	SSF Wetland
Geotechnical testing, excavation, compaction etc	16% - 20%	10% - 17%
Substrates (SF); Gravel (SSF)	3% - 5%	30% - 40%
Geotextile liner	20% - 25%	15%
Plants	10% - 12%	10% - 12%
Control structures	10% - 15%	5% - 10%
Formwork, pipework etc	10% - 12%	5% - 8%
Design and Landscaping	8% - 12%	6% - 13%
Others (incl. contingencies)	6% - 10%	6% - 10%

Some stormwater wetland systems in the UK have been constructed or retrofitted with minimal land and installation costs having been "rolled into" existing Environment Agency and/or local authority (re)development and flood relief schemes (Table 2.12). Wetland retrofitting into conventional wet retention basins for example, would normally only involve the costs of purchase and planting of aquatic vegetation. The various SF wetlands that have been introduced by the Environment Agency Midlands Region show a wide variation in total capital costs which reflects this.

Table 2.13 gives an indication of both capital and maintenance costs for a variety of source control systems (Revitt and Ellis, 2000) Wetland systems have low intrinsic Operational & Maintenance (O & M) costs which are also lower than conventional "hard engineered" drainage systems by a factor of 2 to 10. The costs indicated in Table 2.13 for operational maintenance suggest that they are insignificant compared to the initial capital investment although disposal of contaminated sediment as a hazardous waste (£50-60/m^3), replanting (about £3-5/m^2) and macrophyte harvesting could be expensive and labour-intensive items. The large range in costings shown in Table 2.13 for some treatment systems largely reflects local sizing requirements for particular devices which can especially influence for example, the final costs of retention basins and wetland systems. The 1999 US EPA National Stormwater BMP Database quotes a general average median annual O & M cost for SF constructed wetlands equivalent to £600/ha wetland surface area. Most O & M costs do not normally include monitoring costs despite the fact that for successful system control, wetlands should be regularly monitored (monthly to quarterly) for at least inflow and outflow water quality, water levels, sediment accumulation and indications of biological condition.

Table 2.12 Stormwater Wetlands in the Environment Agency Midlands Region

Location	Land Use	Total Catchment Area & Imp.ha	Wetland Surface Area	Maximum Storage Capacity	Other Storage & Treatment	Retention Time	Costs
Webheath, Redditch	Residential (270 houses)	?	$125m^2$ x 4 ($125m^2$/imp ha)	? ($50m^3$/imp ha)	Front-end sedimentation ($10m^3$/imp ha)	?	£22,000
Wheatpeaces, Tewkesbury	Residential (1500 houses)	?	$730m^2$	?	Front-end sedimentation	?	?
Keytec 7 Estate, Pershore	General industrial, commercial	10.9ha	?	$1500m^3$	? ?	15-20 hours	?
Tewkesbury Businesss Park	General industrial, commercial	28ha	$6300m^2$ ($250m^2$/imp ha)	?	Front-end sedimentation ($10m^3$/imp ha)	24 hours	?
Pershore School, Pershore	Industrial Estate	6ha	?	$165m^3$	? ?	?	?
Wharrage, Redditch	Mixed residential, industrial, commercial and highway (202 ha residential)	$4km^2$ (70 imp ha)	?	$3487m^3$	? ?	?	£125,000 (Construction)

A comparison of the annual maintenance costs (excluding monitoring) for conventional v SuDS drainage for the M42 Hopwood Park motorway service station indicated a saving of some £1220 pa (Bray, 2001b). A 6 month cleaning routine for a conventional gully chamber and oil interceptor is estimated at £1204 pa against an estimated cost for maintenance of an individual wetland component within the SuDS design of about £250 pa. The costings for annual maintenance of the SuDS scheme at the M40 Oxford motorway service station (see Section 4.2.1), was estimated at being £917 more than for an equivalent conventional drainage scheme (which would total £2800 pa) but with an annual maintenance saving of £7500 (CIRIA, 2001). The retrofitting of permeable paving and wetland drainage to the Lutra House, Preston site of the Environment Agency has proved to be no more expensive than using a conventional piped system. The limited cost comparisons available for operation and maintenance of wetland SuDS suggest that they may lie within ± 10 - 20% of conventional drainage systems. Cost-performance analysis using HydroWorks modelling for conventional drainage and the CIRIA (2000b) SuDS methodology, has suggested that SuDS are generally economically viable within those urban catchments (and especially greenfield sites) having large areas or numbers of opportunities for their implementation such as permeable soils and large open spaces (Walker, 2000).

Table 2.13 Capital and Maintenance Costs for Highway Treatment Systems

Treatment Device	Capital Cost (£'000s)	Maintenance Cost (£/per yr)	Comments
Gully/Carrier Pipe system	150 - 220	1000	No fin drainage allowed for in costs
Grass swale	15 - 40	350	Requires replacement after 10-12 years
Oil interceptors (with grit chamber)	5 - 30	300 - 400	
Sedimentation tank	30 - 80	300 - 350	Without sediment disposal
Sedimentation lagoon/basin	45 - 100	500 - 2000	Without sediment disposal
Retention (balancing) basin	15 - 300	250 - 1000	With no vegetation or off-site dewatering and disposal of sludge and cuttings
Wetland basin	15 - 160	200 - 250	Annual maintenance for first 5 years (declining to £80 - £100/yr after 3 years). Sediment disposal required after about 10-15 years.
Combined treatment train system	100 - 300	2000 - 3000	Assume grass swale, oil/grit interceptor, sediment forebay and wetland cells

There is undoubtedly a lack of general awareness of the need for and magnitude of maintenance associated with all SuDS devices including urban stormwater wetland and a general failure to regularly perform both routine and non-routine maintenance tasks. It is quite likely that both the performance and longevity of all SuDS urban wetlands will decline without adequate maintenance. In general terms, over an expected 25 - 30 years lifetime, the full maintenance cost of such SuDS facilities could well be equivalent to the initial construction costs. Given this, the adopting and managing authorities need to carefully and fully evaluate how such long-term, future maintenance costs are to be covered.

The provision of attractive landscaping features which enhance the views from vantage points around a stormwater wetland facility can offer tangible landscape value and amenity benefits which can offset total costs. Some evidence for this value can be seen from increases in land values and house prices located adjacent to water features. Some estimates suggest that a stormwater wetland "waterfront" location on a business park/commercial estate can increase rentals by up to one-third and individual residential property prices by 3% to 13%. It is clear that landscaping and amenity upgrading of wetlands and urban lakes will stimulate the perceived attractiveness of the wider surrounding corridor and adjacent areas. Additionally, the more positive the local public attitude towards increases of development (or public) investments, the larger the sum they are willing to pay to use any amenity and recreational facilities provided on the site (Green and Tunstall, 1991). The surface drainage "water gardens" and surrounding grass "buffer" zones on the Aztec West Business Park close to the M4/M5 junction north of Bristol, were designed to integrate habitat and nature conservation with everyday working life. It has been suggested that this landscaping provision increased the ground rents on the business park by as much as two to three times (Holden, 1989).

Key Issues

- development of harmonised sampling and data collection procedures and protocols for reporting wetland performance and the establishment of a national SuDS database.
- the measurement of wetland performance in terms of percentage pollutant removal efficiencies rather than measured against water quality standards especially given that wetland treatment cycles can span several storm events.
- uncertain costings for varying wetland designs, operation and maintenance including identification of whole life-cycle costs. Identification of economic "added-value" afforded to urban development from wetland landscaping.

3. URBAN WETLAND DESIGN

3.1 Introduction

The successful design of constructed wetlands for urban surface runoff management requires the adoption of an integrated multi-disciplinary approach as performance criteria are difficult to set given the inherent random fluctuations in discharge and pollution loadings which characterise stormwater runoff. This temporal and spatial variability makes it difficult to define retention time and hydraulic loading and thus general design rules for urban stormwater wetlands have been developed from empirical performance data such as given in Section 2.1 and using "single-number" techniques such as drainage area ratio (see Table 2.7). Thus no UK urban stormwater constructed wetlands are alike in every design respect; a feature readily confirmed from site inspections.

Figure 3.1 illustrates a general integrated design approach showing the major linkages and interactions between the various wetland design elements. Consideration of water quality issues at the preliminary planning stage can help to mitigate or prevent stormwater management problems in urban catchments and reduce the magnitude and difficulty of surface water treatment. Hydrological effectiveness reflects the competing (and sometimes conflicting) factors of retention time, inflow characteristics and storage volume and defines the long term percentage of catchment runoff which enters the wetland basin. Hydraulic efficiency is strongly influenced by basin shape and depth; hydraulic structures such as inlets, outlets and berms; and by the type, extent and distribution of wetland vegetation. Wetland plants are adapted to specific wetting and drying cycles which also significantly influence the organic content and nutrient cycling in the basal sediments. A major factor in determining wetland hydro-cycling (and the overall treatment efficiency) is the interaction between catchment hydrology, basin bathymetry and the hydraulic behaviour (and location) of the outlet structure.

> **Hydrological effectiveness** describes the interaction between runoff capture, hydraulic retention time and wetland volume.
> **Hydraulic efficiency** describes the extent to which plug flow conditions are achieved and the proportion of wetland volume utilised during the passage of stormflow through the wetland system.
> **Treatment efficiency** defines the extent to which surface water runoff pollutants are removed within the wetland

3.2 Design Criteria

3.2.1 Return period and retention time

The treatment performance of a constructed wetland results from the combined effect of the hydrological effectiveness and the treatment efficiency. If design criteria were to be adopted for the treatment of maximum expected peak flows and/or loads, the wetland system would need to be extremely large and over-engineered or the outflow water quality standards considerably relaxed. The design criteria also need to make reference to existing or future water quality objectives (WQOs) and take into account the expected dilution capacities of the receiving water. Normally, performance criteria will be based

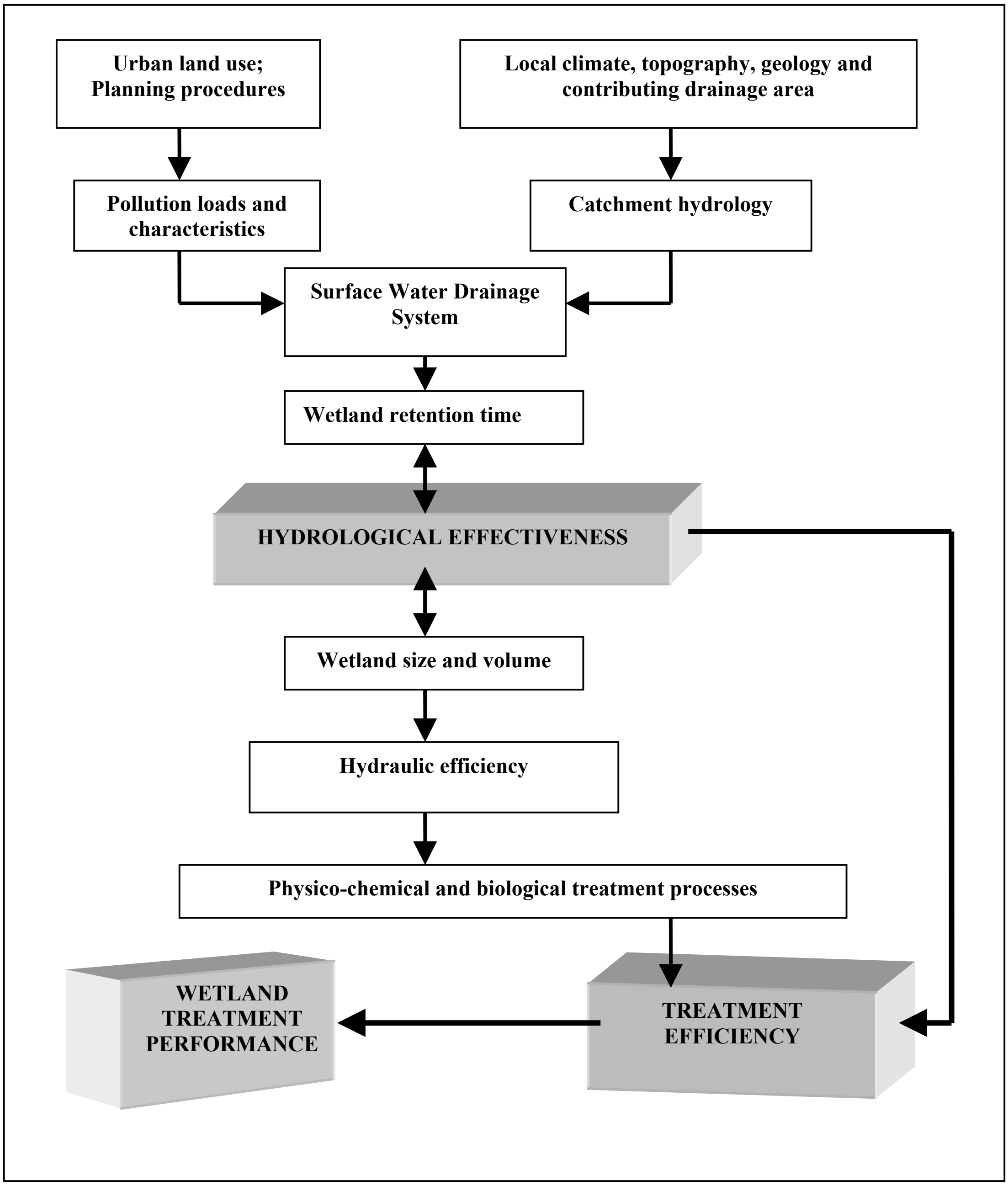


Figure 3.1 Linkages and Interactions between Wetland Design Elements

upon a selected design storm (1, 2…..10 years) to be retained (2, 4…….36 hours) and treated by the wetland and a specified critical flow quality level (e.g 5% flow rate, Q_5; 10% flow rate, Q_{10}……Q_{50}) in the receiving water to be protected. The worst pollution potential is likely to occur during summer with runoff from a short duration intense storm event following a dry period. In this case, a maximum pollution load will be mobilised, the highest inflow rates will be experienced and flows in the receiving watercourse will be at a minimum. The selection of the design storm return period and hydraulic retention time (HRT; see Section 1.6.3) determines the maximum flow intended for treatment in the wetland. Flows in excess of this design maximum should be diverted (or by-passed) directly to the receiving water following a preliminary treatment if possible (e.g oil and grit separation), otherwise such high flows are likely to disturb and mobilise the contaminated substrate as well as damaging the macrophyte vegetation. This is subject to any overall flow restrictions to the watercourse i.e. taking storage into account.

The most important criterion for the design of a constructed wetland is the selection of the design storm which in turn determines the wetland size and volume. The objective of the selection process is to determine the critical storm event which will cause the greatest pollution threat, with this storm event being described in terms of its duration, intensity and frequency of occurrence. In this analysis, it is assumed that the selection process will be based upon single rather than multiple event occurrences. Constructed wetlands can be designed to:

- retain short duration storms (e.g less than the 1:1 annual storm event) for the maximum retention time, ensuring that the high flows can be accommodated by the constructed wetland without overland flow in the case of SSF systems or short-circuiting in the case of SF systems. For example, a wetland basin sized to capture 90% of the average annual runoff with a 24 hour drawdown would be likely to overflow between 3 to 8 times per year. This would suggest that a feasible design storm for water quality control purposes might be in the order of a two to four month storm event.
- retain longer duration storms ensuring that the initial first flush volume (equivalent to 10 - 15 mm effective rainfall runoff) containing the heaviest pollution loads receives adequate treatment. It is important that the constructed wetland is large enough to capture the first flush of the larger storm events to achieve such partial treatment and to delay outflow discharges to the watercourse until natural dilution flows have risen.

Where the availability of land and finance is not problematic, the constructed wetland should be designed to treat storms with a return period of 10 years, although the design of attenuation could be up to the 100 year return period. If a compromise is necessary requiring a design based on a shorter return period, the system should be capable of treating the polluted first flush of any storm event. Retention time is an extremely important factor in the treatment performance of treatment by constructed wetlands and even a minimum retention time of only 30 minutes will help to remove the coarse sediment fractions. Considerations affecting the retention time include the aspect ratio (width : length), the vegetation, substrate porosity and hence hydraulic conductivity, depth of water, and the slope of the bed. Water level and flow control structures, for example flumes and weirs are also required to keep the hydraulic regime within desired parameters (Watson and Hobson, 1989). An "ideal" retention time is dependent on the pollutant removal processes operating in the wetland system. Solids sedimentation can be achieved relatively quickly and a 3 - 5 hour retention will remove a substantial proportion of the coarse solids. However, in order to achieve removal of degradable organics, bacteria and other toxic species associated with the finer solids fractions, much longer retention periods of at least 24 hours will be required (Halcrow/UPRC, 2000). When calculating the retention time in a SSF constructed wetland system, the volume of the bed media must also be taken into account (see Section 1.6.3)

The EA Midlands Region SF stormwater wetlands (Table 2.12) have all been designed to capture between 5mm - 10mm runoff volume for the 10 year event, with wetland bed void storages of 50 m^3 and 100 m^3 per impervious hectare of catchment for 5mm and 10mm effective runoff volume respectively based on recommendations proposed by Ellis (1990). Wetland surface areas of 125 m^2 and 250 m^2 per impervious hectare respectively for residential and commercial/industrial developments were also adopted with retention times varying between 15 - 20 hours but with an overall 24 hour drawdown period. A number of US agencies have suggested the use of the 6 months, 24 hour rainfall event as the appropriate "water quality design storm" (Horner *et al*., 1994), whilst others recommend retention of the first 15 - 20 mm of effective runoff for all storm events (up to the 10 year design event) to provide a first-flush treatment (Camp, Dresser and McKee, 1993).

3.2.2 Wetland sizing

Empirical Approaches

The principal problem of wetland design for the treatment of urban and highway runoff is that of optimum sizing given the episodic and random nature of discharge occurrence and the possibility of a rapid succession of inflow events. Sizing is crucial in controlling both the hydraulic loading and retention times needed to give maximum contact and biofiltration/uptake opportunities. The pollutant removal efficiency of an urban stormwater wetland will be directly affected by the frequency, spacing and duration of storm events, all of which are extremely difficult to pre-define. This explains why empirical approaches to the sizing of urban wetlands have been widely adopted. The utility and appeal of such approaches lies in their ability to provide a rapid and robust initial screening methodology for potential wetland alternatives at the early design stages but considerable caution must be exercised in extending them to final design (Kadlec, 2000).

One such approach is to consider the relative percentage of the contributing catchment area or connected impervious area and typically figures of between 1% to 5% have been suggested (Scheuler, 1992; Hvitved-Jacobsen, 1990; Ellis, 1999) for this wetland/watershed area ratio (WWAR). Assuming a 2% - 3% WWAR value, for a 10 hectare development site and with retention times equal to 4 - 6 times the mean storm runoff volume:

Surface area = 100,000m^2 x 2/100 = 2000m^2
Retention volume = 10 x 100 = 1000m^3
Average wetland depth = 1000 (m^3) / 2000 (m^2) = 0.5m

Such sizing criteria would pose considerable land-take difficulties and in any case does not account for any performance considerations.

Nevertheless, Kadlec and Knight (1996) have shown that such an approach derives hydraulic loading rates (HLR) which are equivalent to the range of HLR values quoted in the national US database (NADB) for point-source SF treatment wetlands (Knight *et al*., 1993). They state that as the average annual HLR is close to the mode of the distribution of point-source wetland HLRs, it is reasonable to expect that stormwater wetlands designed using WWAR criteria would perform somewhere near the average quoted for the emergent marsh

Wetland Sizing and HLR

As an illustrative example, given an average annual rainfall of 625mm and a runoff coefficient (Rc) of 65%:
average annual daily rainfall rate = 625 /365 = 1.71 mm/d
and total runoff = 1.71 x 0.65 = 1.11 mm/d (= Q_{av})
For a 4% contributing WWAR ratio (A_s = 1/25), the average annual wetland hydraulic loading rate (HLR = Q /A) will be:
1.11 x 25 = 27.75 mm/d
and sizing of the wetland basin can be based on this expected loading value. This calculation yields a high final HLR value but is based on a high Rc value and WWAR ratio.

database set in the NADB. In addition, comparison of the 50 point-source NADB wetland data set with that of 17 urban SF constructed wetlands included in the review by Strecker *et al* (1992) for the US Environment Protection Agency, showed very similar efficiency rates when examined on the basis of such empirical design criteria. The mean reduction of total phosphorus in the NADB marsh cells was 57% at an average HLR of 42 mm/d compared to a similar mean reduction of 57% for urban SF constructed stormwater marshes having a 4.3% wetland/watershed area ratio (WWAR) value. The equivalent reduction rates for total SS were 81% and 77.1% for the NADB and US EPA wetlands respectively.

Stormwater wetlands have also been sized to retain water volumes associated with storm events of a specified return period or probability of occurrence. Schueler (1992) has advocated that urban stormwater wetlands should be sized to contain effective runoff up to the 90th percentile value of the design storm event distribution. This particular "single-number" design approach has the advantage of allowing a variable percentage of contributing catchment, depending upon the annual rainfall pattern and annual rainfall total. As in the case of the WWAR ratio approach (see above), the derived loading and detention times for SF urban constructed wetlands correspond well with the mean values for point-source treatment wetlands. Schueler (1992) has implicitly acknowledged this in his listing of pollutant reductions which lie in the mid-range for other types of treatment wetlands e.g total phosphorous and total SS removals are quoted as 45% and 69% compared to the 57% and 81% mean cited for the NADB wetland marshes.

Wetland Sizing and Storm Event Design

Given a catchment area of 40ha and runoff coefficient (Rc) of 65% and average annual rainfall of 625mm, with a summer 90th percentile storm runoff value of 31.8mm:
Design storm volume = 0.65 x 0.0318 x 400,000 = 8268 m^3
For a 0.5 m depth, wetland surface area (A_s) = 8268 / 0.5 = 16,536 m^2 = 1.65 ha
Annual flow = 0.65 x 0.625 x 400,000 = 162,500 m^3/yr
Average annual detention time = 8268 m^3 /16,536 m^3/yr
= 0.05yr = 18.6d
Average annual wetland HLR = 162,500 m^3/yr / 16,536 m^2
= 9.83 m/yr
and wetland sizing can be based on the area, retention time and loading figures derived from the above calculations.

Rainfall Time-Series Analysis

Urbonas *et al* (1996) have demonstrated that the cumulative occurrence probability of daily rainfall data can be used to determine optimal sizing of urban runoff treatment control systems. In terms of percentage cumulative occurrence probability, long-term, hourly time series rainfall data for SE England shows that 90% of stormwater runoff could be treated if storms of 10 - 15mm effective runoff were to be captured. By comparison, the 1 year, 24 hours storm would generate over 20mm. Thus the most cost-effective operational range of stormwater runoff capture could be taken to be bounded by the annual 90th percentile value with relatively little treatment gains being secured for larger increases in control volumes. Clearly, required treatment volumes will increase with percentage impervious area, and Figure 3.2 provides a preliminary design guide to treatment storage volumes based on rainfall time series data for the Greater London region. Similar unit treatment relations can be derived from continuous simulation of the cumulative occurrence probability of local/regional long-term, daily rainfall data.

Where the wetland system is intended only to provide a sedimentation facility in terms of solids and solid-associated pollutant removal, the system can be designed to retain a volume equal to the catchment design treatment volume derived from Figure

3.2. However, where it is expected that the wetland will provide a secondary biological treatment to remove organics and other biodegradable pollutants or nutrients, the minimum permanent pool volume should be increased to 2 to 3 times the volumes noted in Figure 3.2 to allow for the increased amount of aquatic vegetation.

Inspection of Figure 3.2 might indicate that the most cost-effective stormwater storage volumes for water quality treatment could lie between 50 - 75 m^3/ha for most residential and commercial/industrial catchments in the SE England region. A wetland sized to capture such volumes will also retain the first-flush of larger storms. Oversizing the wetland basin will only result in the more frequent events (which carry most of the total annual pollution load), receiving less treatment and thus providing a poorer overall removal efficiency.

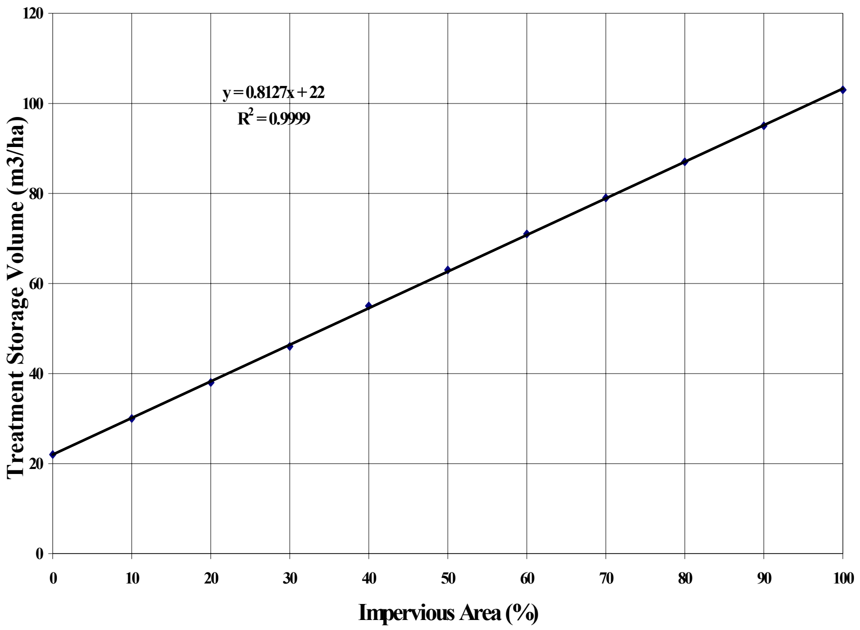


Figure 3.2 Wetland Treatment Storage Volumes

Kinetic Approaches

Kinetic design approaches based on first-order reaction rates (see Section 1.6.8), have been widely applied to determine the size and contact time required to achieve target pollutant reductions in wetlands intended for wastewater treatment (Reed *et al*., 1995). A general empirical approach to wetland sizing based on such kinetic design criteria has been suggested in Section 1.7 and based on the plug flow reactor model (see Appendix B), the size of a SF constructed wetland can be expressed in a generalised form as: $As = (L \times W) = (-k / Q)\ln[(C_{out} - C^*) / (C_{in} - C^*)]$ where As is wetland surface area (ha), Q is inflow rate (m^3/d), k is the pollutant decay rate constant (m/day), C_{in} and C_{out} are respectively the inflow and target outflow concentrations (mg/l) and

Kinetic Design of SSF Wetlands

A general empirical design equation has been suggested by Reed *et al* (1995):

$As = (L \times W) = Q_{in} [\ln(C_0 / C_t)] / k \times d \times \rho$

where As is surface area (m^2), L, W and d are length, width and depth (m), ρ is porosity (in decimal form), Q_{in} is discharge rate (m^3/s), k is the pollutant decay rate per second and C_0, C_t being initial and time-specific pollutant concentrations (mg/l).

C^* is the wetland background concentration (mg/l). Time series plots of pollutant decay through wetland systems have consistently shown organic carbon to be assimilated at very low rates and thus the use of BOD (or TOC) reaction rates for conservative sizing have been considered to be justified. BOD reaction rates for combined sewage effluent tend to be in the order of 1.1 - 2.0 per day (with BOD in the range of 150 - 300 mg/l and loading rates of 1 - 30g BOD m^2/d). The reaction rates for urban and highway stormwater runoff can be expected to be less given their much lower nutrient and organic mass loading rates e.g k values experimentally derived from 2 day retention data for a 1500 m^3, 0.6m deep and 1.3 ha SF constructed wetland were 0.8, 1.05, 3.05 and 4.04 for BOD, Total P, Total N and Total Coliforms respectively (Ellis, 1999). European design criteria suggest that a value of 0.1 is generally appropriate for k_{BOD} (Cooper, 1990). Preliminary model parameter values for both SF and SSF constructed wetlands have been given by Kadlec and Knight (1996) and are reproduced in Table 3.1 and worked examples are given in Appendix B.

Table 3.1 Kinetic Model Parameters for Wetland Design

	Pollutant Parameter Values				
	TSS	**BOD**	**TN**	**TP**	**F Coli**
SF Constructed Wetlands					
k_{20} (m/yr)	1000[a]	34	22	12	75
θ	1.09	1.09	1.05	1.01	1.09
C^* (mg/l)	$5.1 + 0.16C_{in}$	$3.5 + 0.053C_{in}$	1.5	0.02	300[b]
SSF Constructed Wetlands					
k_{20} (m/yr)	3000[a]	180	27	12	95
θ	1.09	1.09	1.05	1.01	1.09
C^* (mg/l)	$7.8 + 0.063C_{in}$	$3.5 + 0.053C_{in}$	1.5	0.02	10[c]

[a]Rough unsubstantiated estimate; should be determined from standard settling rate tests
[b]Central tendency of widely variable values; values in MPN/100ml
[c]Rough unsubstantiated estimate; values in MPN/100ml

Whilst a kinetic sizing approach therefore seems reasonable in terms of water quality performance, it would be unwise to place too much reliance in this simple modelling procedure. The inflows and pollution loadings associated with urban/highway runoff are highly variable and the use of average flow and pollutant concentrations can be misleading. First-order kinetics are probably not applicable beyond the initial rate period and hydraulic loading rates probably become much more dominant especially in smaller wetland systems. Additionally, as residence time increases, the value of k (pollutant decay rate per second) will change and the use of a single reaction rate based on organic carbon or BOD may well substantially oversize a wetland system primarily intended to treat solids, hydrocarbons and metals. Considerable variations in k values across wetland systems have also been noted (Cutbill, 1997; Ellis, 1999). Such variation reflects the variable sedimentation, filtration and uptake rates which occur within the wetland and which affect the overall assimilation rates. In addition, such variations may also reflect the synthesised nature of the process-based k lumped parameter (see Section 1.7.2). Nevertheless, the advantage of kinetic sizing is that the design procedure does allow a fairly rapid and robust first-order means of estimating removal performance at different hydraulic loading rates and utilises process-based water quality criteria in addition to hydraulic considerations.

In addition to the design storm and retention time, the following criteria are also recommended:

Aspect ratio (Width:Length)	:	1:4 to 1:5
Slope of Wetland Bed	:	1%
Minimum substrate bed depth	:	0.6m
Hydraulic conductivity of substrate	:	10^{-3} m/s to 10^{-2} m/s

Once the design storm and retention time choice has been made, the size of the conceptual constructed wetland can be calculated using Darcy's Law and the above criteria as: Average daily flow rate (Q_d; m^3/s) = Ac. k_h ($\partial H/\partial x$)
where Ac is the cross-sectional area of the bed, k_h is the hydraulic conductivity of the substrate (m/s) and ($\partial H/\partial x$) is the slope or hydraulic gradient of the bed (m/m). Darcy's Law assumes laminar uniform and constant flow in the media bed and clean water. In a SF wetland, flow will be channelled and short-circuited and the media will be covered with biological growths and therefore the equation only has limited usefulness in such wetland design. Nevertheless Darcy's Law does provide a reasonable approximation of flow conditions in SSF constructed wetland beds if moderate sized gravel (eg 10mm pea gravel) is used for the support medium. Figure 3.3 provides a schematic section through a SSF constructed wetland illustrating some of these design criteria.

> **Hydraulic Conductivity (k_h)**
>
> Is the coefficient of permeability representing the rate at which water moves through the porous media and can be determined directly from field tests or estimated for clean, un-rooted media as: $k_h = 12{,}600\ Dp^{1.9}$
> where Dp is the diameter of the substrate media. 8 - 12mm gravels typically have a k_h value of 270 m/d with silts (0.005 - 0.05mm) having a value about 0.08 mm/d.
> Siltation and algal/biomass accumulation will reduce the k_h value especially close to the wetland inlet by some 10% or so.

3.2.3 Optimal hydraulic loading

During storm events, high rates of stormwater runoff may discharge onto constructed wetlands, but optimal hydraulic loading rates (HLR; see Section 1.6.3) should not exceed $1m^3/m^2/d$ in order to achieve a satisfactory treatment (Ellis, 1990). Watson *et al* (1989) have suggested that an arbitrary HLR breakline appears to be about 2.7 ha catchment area/1000 m^3 storage volume/day, with wetlands having a large area per flow unit (a lower loading rate) being normally SF systems and smaller areas (with higher loadings) associated with SSF systems.

3.2.4 Flow velocity

Flow velocity should not exceed 0.3 to 0.5m/s at the inlet zone if effective sedimentation is to be achieved. At velocities greater than 0.7m/s, high flow may damage the plants physically and cause a decline in system efficiency. Section 1.6.5.2 shows how expected maximum inflow velocity can be determined from consideration of design peak flow rate (Q_{pkmax}) and wetland area (A).

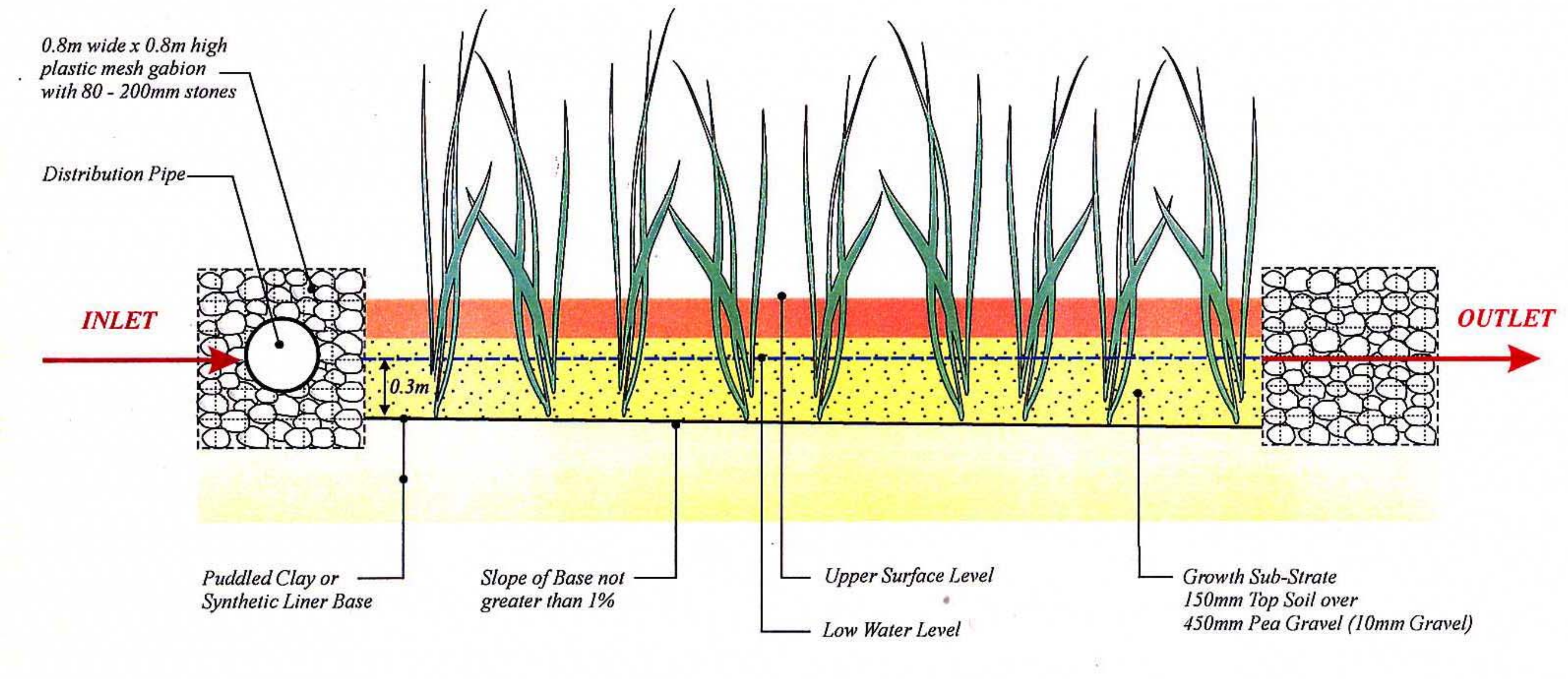


Figure 3.3 Section Through SubSurface Constructed Wetland

3.2.5 Inlet

The inlet pipe should be constructed in such a way that influent flow is evenly distributed across the width of the bed. This may be achieved using slotted inlet pipes or a notched gutter (slots should be large enough to prevent clogging by algae). The distribution system must be designed to allow maintenance in case of blockage. Riser pipe distributors have been adopted on many wastewater treatment systems (Cooper *et al*., 1996). A level spreader device (serrated weir plate, hard aprons etc.,) can give uniform gravity-fed distribution systems especially if they spread the influent flow across a fully-maintained grassed filter strip prior to entry into the wetland cell.

Some type of stilling structure under the inlet, usually a 1m wide stone trench (rip-rap or gabion zone), is necessary to either dissipate high water flows, or contain the inlet distributor pipe. Rip-rap and gabions are blankets of stones placed to protect erosion zones. The stones for rip-rap are laid directly on the bed, whereas they are packed in cages for gabions.

3.2.6 Substrate slope

The longitudinal slope of the substrate bed parallel to the flow path, should not be less than 1%. The surface of the substrate should be level (see Figure 3.3).

3.2.7 Outlet

The level at which the outlet is set is determined by the lowest water level required in the constructed wetland. Until further information is available, it is considered that the lowest level in the wetland should be 300mm below the substrate surface dependent on plant type (see Section 3.4). An additional source of water may be needed to supply the reedbeds during dry periods.

Ideally the outlet structure should incorporate control measures which allows the water level in the bed to be varied; a flexible plastic pipe linked to a chain is an appropriate low cost option (Cooper *et al*., 1996). The control should at least incorporate a measure to allow periodic raising of water level for weed control and bed oxidation. A recent 2001 HR Wallingford R&D project "*Guide for the Drainage of Development Sites*" Report SR574 on surface water runoff management commissioned by the DETR, has indicated that temporary storage may not be particularly effective in providing sufficient downstream flood protection for extreme events. One strong recommendation is for permanent storage with long release times, and this requirement can be satisfied by wetland basins fitted with adjustable outlet controls to maintain outflow rates and volumes compatible with a sustainable receiving water regime.

At the outlet zone it is recommended that an additional rip-rap (or gabion) zone be inserted to prevent weed growth and resuspension of reedbed substrates (Figure 3.3). Outlet structures are particularly prone to debris accumulation and a gabion zone (or debris screen/fence) will help to alleviate this problem. If high flood conditions at the site are anticipated, there should be appropriate provision such as emergency overflow spillways or by-passes, to facilitate through-flow and prevent disturbance and flushing of the wetland substrates.

3.2.8 Aspect ratio

An aspect ratio (length:width) of 4:1 to 5:1 for SSF wetlands and 10:1 or higher for SF wetlands has been recommended for domestic wastewater treatment wetlands. However, the IWA (2000) technical report considers that any aspect ratio with a good inlet distribution can be applied, as previous assumptions that wetlands with high aspect ratios would function more efficiently and be closer to plug flow have not been confirmed from tracer studies. Problems of short-circuiting can be minimised by careful construction, intermediate open-water zones for flow distribution and use of baffles and islands.

3.2.9 Aeration

A grid of slotted plastic pipes (say diameter of 100mm) should be installed vertically in the substrate (100mm protruding above the surface, and penetrating the full depth of the substrate) at 5m centres, to serve as static ventilation tubes and aid aeration of the root zone.

3.2.10 Bird deterrent

Plastic poles should be erected to support lines of bunting to discourage birds from feeding on young plants. The height of the bunting should be about 1.5m above the substrate surface.

3.2.11 Non-metallic items

Non-metallic items should be incorporated into the construction of the wetland so that metals in the wetland only come from stormwater runoff. Therefore gabions should be encased with geotextiles and the poles supporting bunting should be plastic.

3.3 Substrate Structure

Horizontal surface flow (SF) wetlands utilise a natural soil substrate to provide organics and nutrients to maintain plant growth, whereas subsurface flow (SSF) wetland substrates should primarily provide a good hydraulic conductivity. Nutrient supply can be supplemented to the subsurface flow if required. The following sections primarily address the subsurface structure of SSF wetlands.

A combination of organic and clay based soils, sand, gravels and stones are used in SSF constructed wetlands to provide support for plants, reactive surfaces for complexing of ions and other compounds and attachment surfaces for microbes which directly or indirectly utilise pollutants. The type of substrate used will have an effect on the hydraulic conductivity and efficiency of the constructed wetland and must allow for a sufficiently high hydraulic conductivity to enable wastewater to flow at a sufficient rate for treatment without backing up and causing overland flow.

Although wetland plants will grow optimally in deep rich soils which allow for extensive root and rhizome penetration, gravels are also needed to increase total hydraulic conductivity, provide a matrix for supporting plant roots and act as a silt trap during storm events. Nutrient-poor substrates should not be rejected as slow-release fertiliser pellets can be added. Studies conducted by Brodie *et al.* (1988) and Stillings *et al.* (1988) have suggested that substrate type is irrelevant to plant growth once the plants have become established.

Nutrient-poor peat based organic soils are best avoided due to their acidic nature and lack of support for emergent macrophytes, and hence the need for additional anchoring devices. Nutrient-poor clays and gravels on the other hand may be too compact for root penetration, or be impermeable to water required by roots (Emerson, 1961; Wein *et al.*, 1987). Clay soils may be more effective in adsorbing certain pollutants owing to their high cation exchange capacity, but should be used with care since changes in pH have been shown to release adsorbed pollutants. The texture of sandy soils allows for cost-effective planting by hand. Sands and gravels with low capillarity may require irrigation if drying out of roots is to be avoided during times of low influent discharge.

Gravel provides the most suitable substrate for SSF constructed wetland emergent plants, supporting adequate root growth, high conductivity and superior permeability. Ideally, prior to use, all components of a substrate mixture should be analysed for hydraulic conductivity, buffering capacity, pH, plant nutrient levels and microbial activity. Hydraulic conductivity is one of the most important determinants in pollutant removal efficiency, and is especially important in SSF constructed wetland systems where purification processes are largely confined to the root zone.

A sufficient rooting depth is also required to prevent physical damage of plants by high velocity stormflows and freezing. A 0.6m depth of washed pea gravel (10mm sized gravel) is appropriate and is similar to the 0.6m depth of root penetration possessed by the deep rooting *Phragmites*. Coarse organic top soil may be mixed with the gravel in a maximum ratio of 1:4 to provide a nutrient source and to enhance metal removal during the plant establishment phase. However, its addition will reduce the hydraulic conductivity of the substrate. Water depth and substrate depth are the most important determinants of retention time in SF systems and SSF systems, respectively. Factors determining the depth of substrate for a SSF system include cost of substrate, depth of root penetration, retention time and climate. Substrate temperatures in excess of 3-5°C must be maintained in order for sulphate-reduction processes to proceed. In colder climates substrate depth may be increased to maintain adequate temperatures.

Natural clay, bentonite, geotextile or plastic (high or low duty polyethylene) liners may be used as reedbed bases, in instances where prevention of leakage to groundwaters is imperative. An impermeable liner is also necessary to retain water in the wetland during dry periods. A required depth of at least 0.6m is required to contain the penetration of plant roots and rhizomes *(Typha latifolia:* 0.3m; *Phragmites:* 0.6m), and prevent leakage of pollutants to groundwater. The top surface of the substrate must be level. This allows flooding of the reedbed to occur for control of weed growth when the reeds are being established.

3.4 Planting Considerations

Constructed wetlands have traditionally utilised plant species commonly occurring in water bodies and watercourses, which were known to thrive in nutrient-rich situations and were generally pollutant tolerant. The main plant species utilised in sewage wastewater treatment has been the common reed (*Phragmites australis*), which led to the systems being known as reedbed treatment systems. Reedmace (*Typha latifolia* and *Typha angustifolia*) has been increasingly used, both in sewage-derived wastewater treatment and particularly in the treatment of surface runoff and industrial effluents. Other plant species have played a lesser role in wastewater treatment, such as flag iris (*Iris pseudacorus*), bulrush (*Schoenoplectus* spp.) and sedges (*Carex* spp.).

It is recommended that vegetation for stormwater wetland treatment systems should be selected using the following criteria:

- a rapid and relatively constant growth rate
- high biomass, root density and depth
- ease of propagation
- capacity to absorb or transform pollutants
- tolerance of eutrophic conditions
- ease of harvesting and potential of using harvested material
- growth form (visual appearance)
- ecological value
- local retail (or nursery) availability

A list of the most commonly utilised emergent/semi-aquatic and true aquatic plant species is given in Table 3.2. It is recommended that a horizontal SF or SSF constructed wetland is planted with one or both of two main species. Reedmace

Table 3.2 Plant Species Commonly Used in Constructed Wetlands

Scientific Name	Vernacular Name
Emergent Species	
Acorus calamus	Sweet-flag
Butomus umbellatus	Flowering rush
Carex spp.	Sedge species
Iris pseudacorus	Yellow iris
Juncus spp.	Rush species
Phalaris arundinacea	Reed canary grass
Phragmites australis	Common reed
Sagittarius spp.	Arrowhead species
Schoenoplectus spp.	Clubrush species
Typha latifolia	Common reedmace
Aquatic Species	
Lemna spp	Duckweed species
Myriophyllum spp.	Water milfoil species
Ranunculus flammula.	Lesser spearwort

(*Typha latifolia*) is shallow rooting and requires the water level to be maintained at or up to 100mm above the surface of the substrate; and also common reed (*Phragmites australis*) which is more tolerant of variation in the water level; and a fringe of other plants such as Iris, to soften the wetland appearance. The suitability of *Typha* for treating metal-contaminated waters is well known, but a recent study of *Phragmites* has shown that it accumulates zinc in its aerial sections more efficiently than *Typha* (Bateman *et al.,* in press). The use of a range of emergent and floating aquatic plants is recommended to enhance the ecological and visual interest and should be drawn from Table 3.2.

In constructed wetlands the required vegetation can, in theory, be established from either direct seeding into the growing media, seedling planting, root cuttings, leaf or shoot cuttings or whole plant translocation. However, experience from existing systems reveals that rhizome cuttings of *Phragmites* and *Typha* in particular have been most successful, along with pot grown seedlings. Plants can be obtained from existing wetlands with prior authorisation or from retailers. A retailer with experience of constructed wetland planting is recommended as pollution tolerant genotypes and a planting service may be available. Information on planting can be obtained from Merritt (1994) and Cooper *et al*., (1996).

Table 3.3 Summary of the Main Methods Used to Establish the Common Reed (*Phragmites australis*). (After Merritt, 1994)

Reed Source	Optimal Timing	Advantages	Disadvantages	Notes
Seeds	April- May	Easy to handle	1) Low seed viability 2) Very precise water levels required 3) Few commercial sources	Spread seed (20 - 125/m^2) on bare wet soil. 5 - 6 weeks after germination, flood to depth of 20mm, then gradually raise water as plants develop, to kill off terrestrial plants.
Pot grown plants	April-May (after frosts)	Easy to handle	1) High capital outlay 2) Intolerant of flooding 3) Few commercial sources	Plants in wet soil (4 plants/m^2) can produce fairly dense growth within first year. Gradually raise water levels as plants develop.
Stem cuttings	May-June	1) Easy to collect from managed reedbed 2) Easy to handle	1) Potential disturbance to source reedbed 2) Requires rapid transfer from donor site	Take 600mm apical cuttings from growing plants. Plant in shallow water. 10 - 15 stems/m^2 can give a good level of cover within first year.
Mature plants	Not known	1) Tolerant of fluctuating water levels 2) Timing more flexible	Requires heavy machinery for digging up and planting	Ensure roots are removed cleanly and planted to an appropriate depth.
Rhizome cuttings	Feb-April	Can be undertaken outside bird nesting season	1) Reasonable critical water level control 2) Difficult to collect	Cuttings should include 1 or 2 nodes. Plant in c. 40mm of damp soil with part of rhizome exposed. Flood gradually after shoots emerge.
Soil containing rhizomes	Feb-April	1) Can be undertaken outside bird nesting season 2) Soil may introduce associated invertebrate community 3) Collection is quick and does not require any specialist knowledge	1) May require extra excavation to accomodate added soil 2) Moving and planting require heavy machinery 3) Bulk results in high transport costs 4) Soil may introduce unwanted plants 5) Viability uncertain; only some rhizomes will be correctly aligned	Spread at least 0.25m depth of rhizome-containing soil across the required area. keep moist, but not flooded until shoots emerge. Then gradually raise water levels.

A summary of the main methods used to establish common reed is given in Table 3.3. Less information is available on establishing other species of emergent plants, but it is considered likely that most of the techniques developed for establishing reeds would be applicable to other rhizomatous species (Merritt, 1994).

Attention needs to be paid to water levels throughout the first growing season as young plants can be killed off by even shallow flooding. Nutrients may be a limiting factor of initial plant growth in urban and highway runoff treatment wetlands and a supplementary source of nutrients from slow release pellets may be required. Long term maintenance of water levels is also important to prevent stress on the plants, especially *Typha*. At sites which attract large numbers of waterfowl, netting should be used to protect the youngest shoots from grazing. Older reeds require at least the top one-third to be protruding above the water level (Merritt, 1994). Annual inspections of both the pre-settlement pond and the final settlement tank should be made to determine if sediment removal is required. If significant growths of algae are present, they should be removed and cylindrical bales of barley straw wrapped in hessian should be introduced to prevent further algal growths.

3.5 Pre and Post Treatment Structures

3.5.1 Oil separator, Silt trap/Infiltration trench and spillage containment

Traditional pollution control measures for urban and highway stormwater runoff in the UK have included grit and oil separators for the reduction of sediments and hydrocarbons. They are, however, inefficient in removing the majority of the pollution load and the finer and more mobile sediments and solid-associated pollutants including oil (which clog some designs of constructed wetland treating road runoff). Integrated pollution control systems including a combination of oil separators, silt traps/infiltration trenches, spillage containment facilities and wetland-forebays or lagoons, located prior to the constructed wetland cell(s), can provide for pre-treatment of raw stormwater runoff and help to prevent siltation in wetland inlet zones (Figure 3.4).

Oil and phytotoxic chemicals in urban and highway runoff can seriously affect the treatment efficiencies of constructed wetlands and the viability or performance of the plants. As constructed wetlands require 1-3 years to mature and become capable of efficient wastewater treatment, bypass oil separators, silt traps and/or infiltration trenches and spillage containment facilities must be installed prior to the discharge of runoff into the constructed wetland. All these structures must be tamper-proof and easily accessed. The spillage containment facility should have a minimum volume of 25 m^3. Whilst the provision of a front-end, pre-treatment sedimentation trap or lagoon may be an efficient engineering structure to take out litter, coarse grit and other solid-associated pollutants such as oil, such drop structures represent a trap for small amphibians, reptiles and other wildlife which may be funnelled through the sump during rainfall events (English Nature, 1995). In the M42 Hopwood Park motorway service area development, a 30 x 1.5 x 1.25m lined stone infiltration trench is used to intercept the initial 10mm firstflush from the HGV parking area to filter out the majority of surface-derived oil. When filled, the trench overflows across a 10m wide grass filter strip (facilitating silt removal) into a parallel swale channel which then delivers the excess flows into a vegetated balancing pond. Spillage is provided for by a separate vegetated pond linked to the trench by a perforated pipe at the base of the infiltration trench.

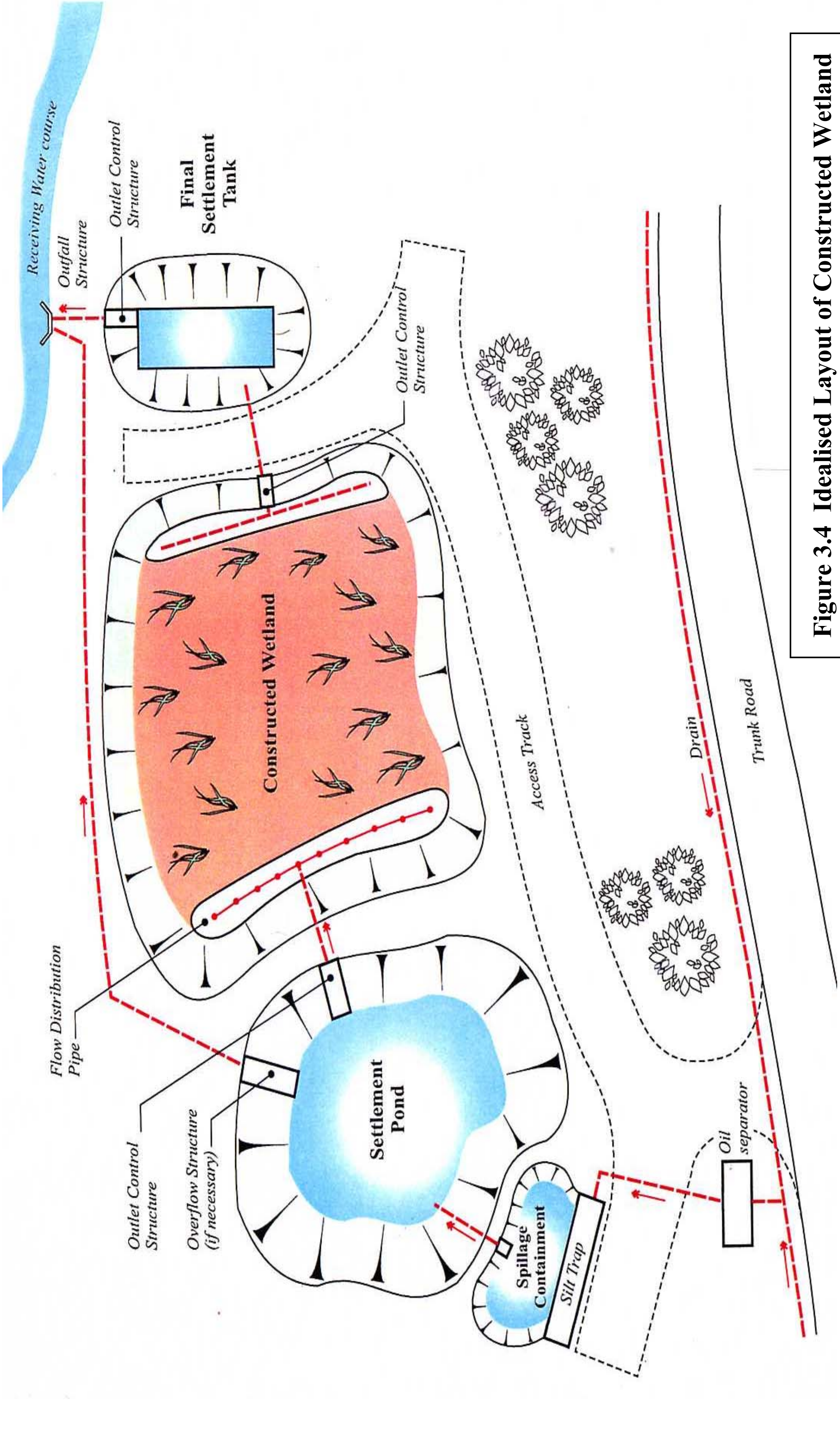


Figure 3.4 Idealised Layout of Constructed Wetland

The system is thus ecologically sustainable with no drop structures, but this gain must be offset against a more frequent O & M requirement and potentially reduced lifetime for the trench infill, particularly if coarse oiled grits clog the surface interstices and fissures. An alternative compromise might be to construct a standard front-end sedimentation trap/trench which can be covered by a steel grill mesh which in turn supports an overlying, shallow stone infill (less than 0.3m deep) or geoplastic block storage system such as Stormcell™ (Andoh *et al.*, 2000). This would have the advantage of providing a full surface filter and basal sedimentation facility which could be easily serviced but at less cost than a full stone infiltration trench, whilst at the same time being ecologically sustainable.

Where SuDS retrofitting is being considered to a conventional kerb-gutter-gulley system, it might be feasible to consider the use of a hydrodynamic separator with the flow-through supernatant effluent passing on to a lined stone infiltration trench or distributed over a grass filter strip and/or swale before discharging to a wetland system for final treatment. This form of pre-treatment has been adopted on part of the A5 Shrewsbury Bypass where road surface runoff passes from conventional fin drains to a separator, swale and wetland treatment-train system.. The basal contaminated sediments in the separator are discharged directly to the foul system.

Where land availability is not limited (ie. rural and semi-rural areas), forebays with additional oil booms on the water surface, have been advocated to serve as secondary sedimentation chambers to reduce the initial flush of pollutants into the main wetland (CIRIA, 1993). Such forebays can be readily constructed by inserting a submerged dam of crushed rock supported by rock gabions across the inlet zone or by constructing a diversion weir in the inflow channel (Hall *et al.*, 1993) to direct first-flush volumes to an off-line settlement pond. The incorporation of pre-settlement ponds if space is not limited is also recommended.

3.5.2 Pre-settlement pond

Ellis (1991) suggested from a review of a number of studies in the US and Europe, that maximum pollutant removal can be achieved in a pre-settlement pond which is equivalent to some 10 - 15% of the total wetland cell volume. The EA Midlands Region urban constructed wetlands utilise a stilling pond and sedimentation trap of 10 m^3 capacity to capture influent stormwater debris/litter, grit and oiled sediment. This front-end basin can also serve as a back-up spillage containment facility (Figure 3.4).

3.5.3 Final settlement tank

If sufficient land is available, a final settlement tank (concrete structure) with a minimum capacity of 50 m^3 extending across the width of the wetland can be installed (Figure 3.4). The tank will help prevent fine sediment from the wetland being transferred into the receiving water body. The final settlement tank is an idealised part of the overall system and only needs to be included in the overall design where greatest protection to sensitive receiving waters is required. Regular maintenance is recommended to prevent collected sediments being resuspended during high flows. The rate of sediment deposition will vary with each catchment so the frequency of sediment removal cannot be predicted. Annual inspections should be made to determine if sediment removal is required.

Key Issues

- selection of the critical storm event in terms of pollution retention and receiving water quality targets and standards.
- treatment of the "first-flush" of pollutants within a wetland system and the relation of individual pollutant removal rates to hydraulic retention time (HRT).
- development of UK regional treatment storage volume curves for time-series rainfall data.
- protocol for process-based, kinetic sizing of wetlands as a first-order screening methodology.
- over-colonisation and naturalisation of wetland vegetation.
- alternative "front-end" designs for more sustainable spillage and "first-flush" protection.

4. URBAN WETLAND RETROFITTING, OPERATION AND MAINTENANCE

4.1 Retro-fitting

Retro-fitting means the installation of a treatment system into a structure that already exists. The physical attenuation of storm runoff from urban developments and highways has been practised for many years and there are many such flood balancing facilities, for example, adjacent to highways and downstream of urban areas throughout the UK. Although these traditional facilities generally do not include vegetative systems, some have been naturally colonised by aquatic plants including reeds (see Section 1.2.2). To provide a quality treatment, in addition to their existing flood attenuation capabilities, it may be possible to retro-fit a constructed wetland into these structures. Such retrofitting can be done into either an existing wet detention (with permanent pool) or dry retention storage basin although in both cases prior consideration must be given to the potential loss of storage volume due to the introduction of the aquatic vegetation and substrate.

Given apparent changes in climate in the UK, with the increased risk of more frequent summer storms and prolonged periods of winter rainfall, it is now generally accepted that the introduction of SuDS structures into existing development is likely to have an important future role to play in the prevention of flooding and pollution of low lying urban areas. The revised (February 2001) DETR (now DEFRA) planning guidance for local authorities and developers, Planning & Policy Guideline (PPG) Note 25 "*Development and Flood Risk*", includes reference to the use of sustainable drainage measures. Nevertheless, the same weather conditions render the safe design of such SuDS even more problematical. Such wetland SuDS retrofitting into existing urban development should not therefore be undertaken lightly and requires careful design in collaboration with local residents, their elected representatives and planning authorities, the regulatory agencies, local land owners and the various private and public agencies having a vested interest. In particular, safety (whether real or perceived), post-project liability and maintenance are likely to be considerable constraints.

When considering whether to retro-fit subsurface flow (SSF) constructed wetlands into existing urban balancing ponds, the following issues need to be examined:

- does suitable access exist or can it be provided?
- can the storage for flood attenuation be safely reduced (at all or enough) so that the 0.6m deep substrate of a constructed wetland can be incorporated?
- is the outlet structure of the balancing pond offset from the inlet structure? If the outlet is offset (ie not directly opposite the inlet) then the flow could short-circuit. Short-circuiting could be reduced by inserting plastic baffles into the substrate to increase flow path length or introducing islands to direct water flows and reduce "dead" zones as well as helping oxygenation (Hall *et al.*, 1993).

- does the balancing pond have an impermeable liner? An impermeable lining is necessary to retain a minimum water depth to sustain the plants during periods of no rainfall.

It is anticipated that a constructed wetland retro-fitted into an urban stormwater balancing pond will operate as follows:

- initially, as storm flows arrive, the flow will pass through the substrate and therefore subsurface flow treatment will occur.
- if the storm flows continue until the water level in the pond rises above the surface of the substrate, then the constructed wetland will operate as a surface flow system.

An emergent vegetation/open water ratio of about 30:70 should be maintained as a minimum in order to sustain ecological utilisation. This ratio is the minimum threshold for a range of waterfowl and wetland bird species such as mallard, moorhen, coot etc (Hall *et al*., 1993). The wetland development close to the inlet and adjacent fringe will not only be ecologically valuable, but will also enhance metal, hydrocarbon and nutrient removal as well as help conceal unaesthetic changes in water level. A schematic example of a constructed wetland retrofitted into a balancing pond is given in Figures 4.1, 4.2 and 4.3.

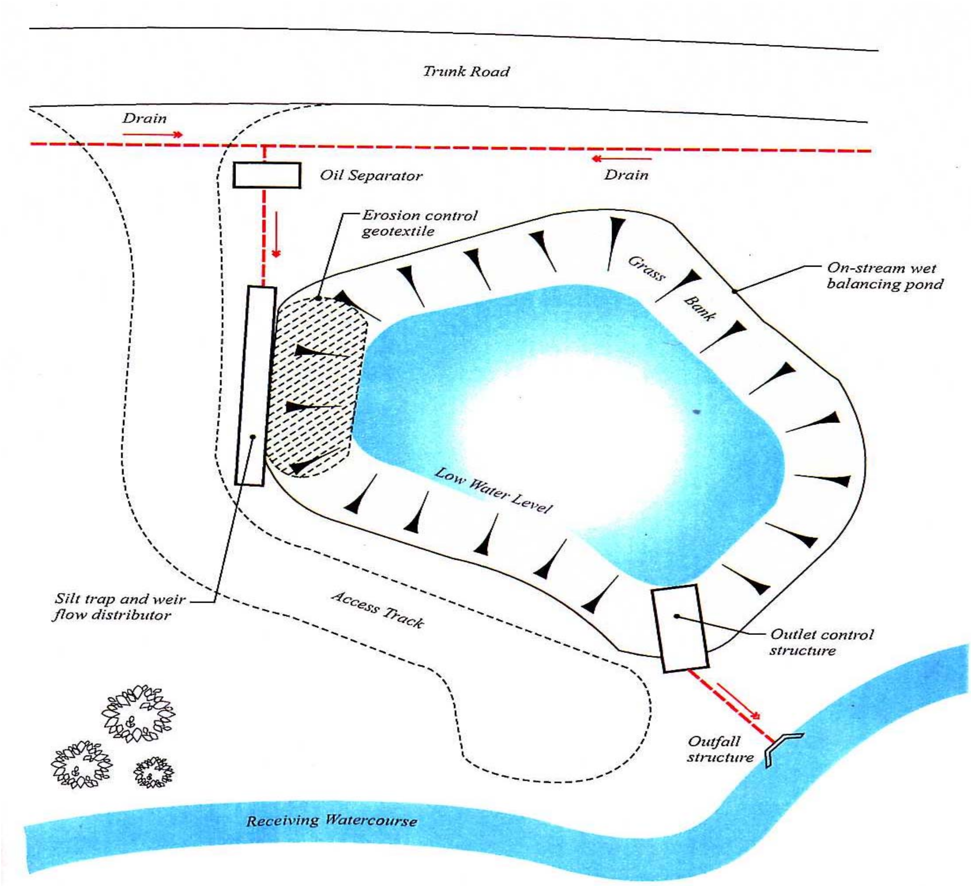


Figure 4.1 Original On-Stream Wet Retention Balancing Pond Before Retrofitting

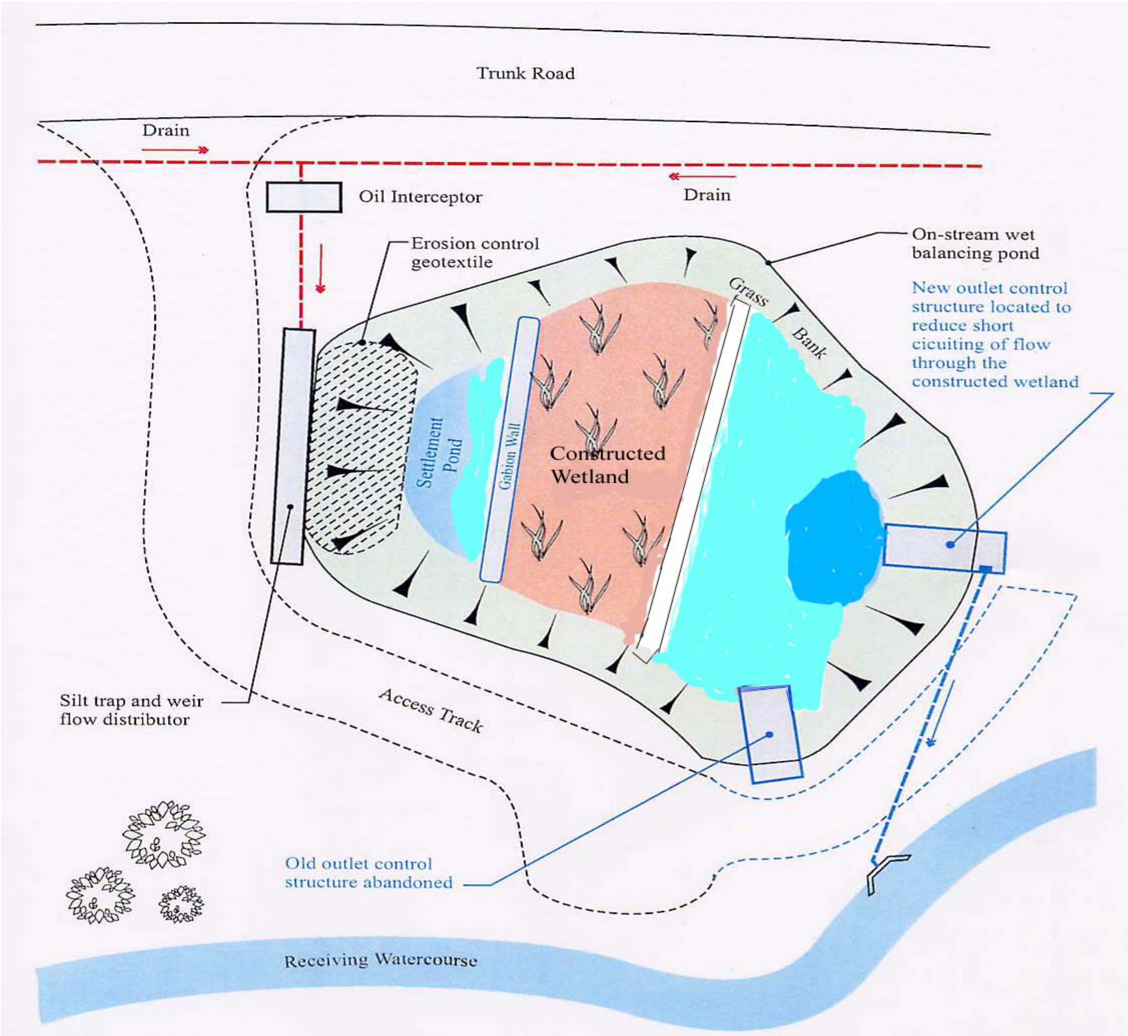


Figure 4.2 Flood Balancing Pond Following Retrofitting to Incorporate a Constructed Wetland

That retrofitting of wetlands into existing storage basins can provide opportunities for extending and integrating a range of environmental benefits into SuDS approaches can be illustrated by reference to the flood storage facility located at North Weald Bassett, Essex. An original off-line 38,000m^3 dry retention basin was constructed here in 1991/1992 to divert flood flows on the North Weald Brook up to the 1:50 storm event which were generated by upstream stormwater runoff from 350ha of agricultural and residential land use. A 0.5 km box culvert diverted wet weather flows to a 2ha dry storage basin which provided a drawdown time of 24 hours for the design storm event. The estimated total cost of the original scheme was £1.25M including cost of fees, land purchase and compensation payments. The consultant's report considered that the 1:50 year compensatory flood storage facility provided benefits of nearly £2.5M based on assessed damage to downstream commercial and residential property in North Weald Bassett (Dobbie & Partners Ltd., 1988).

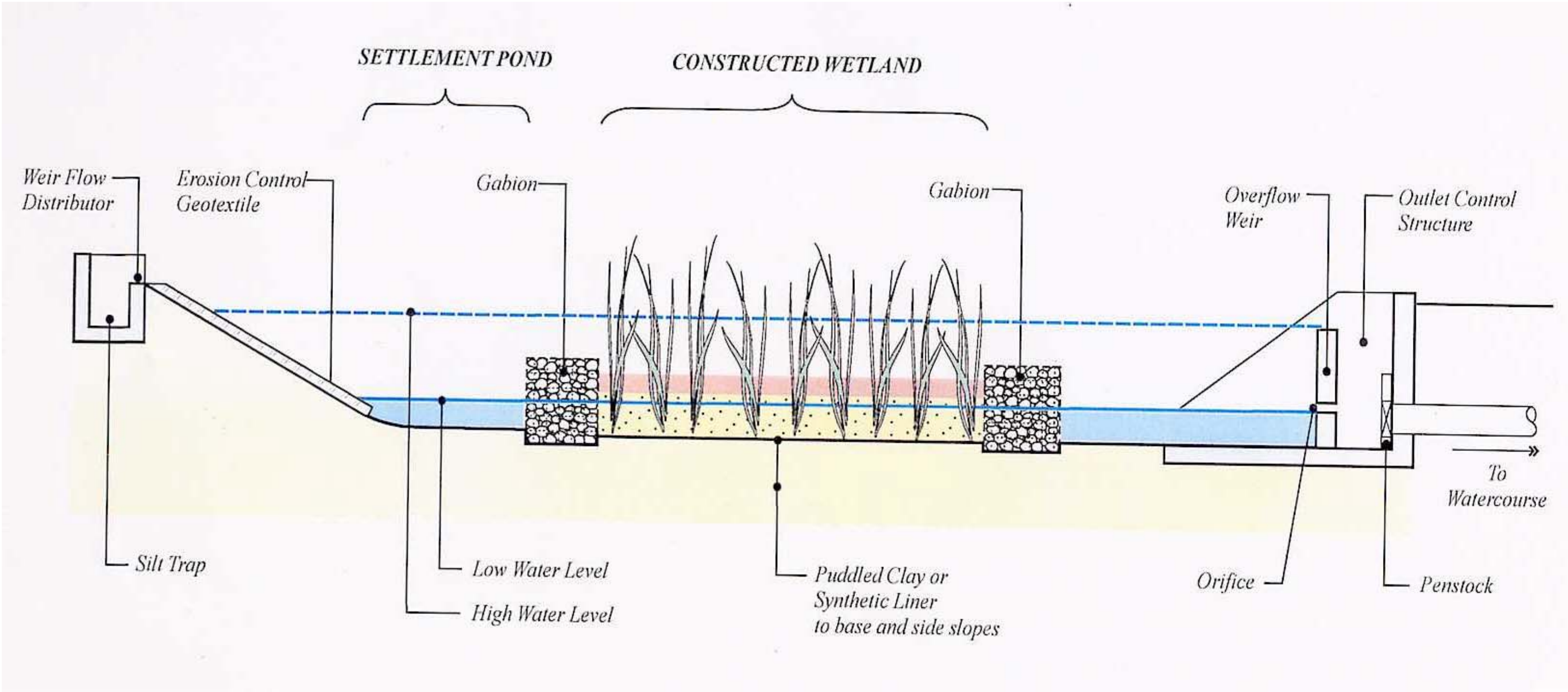


Figure 4.3 Section Through Retrofitted Constructed Wetland

The discounted protection benefits excluded consideration of traffic disruption, damage to roads, public utilities/services or costs of emergency services. Thus the total benefit figures (benefit-cost ratio of nearly 3:1), were well in excess of the capital costs of the flood diversion and storage scheme. The scheme was completed in 1991/1992 with the extended wetland facility being retrofitted by Epping Forest District Council into the dry flood storage basin during 1995/1996 essentially as a community amenity and educational feature. Spoil from the wetland excavation was used to build a small island as a wildlife refuge and to construct embayments on the southern margins of the basin with *Typha*, *Phragmites* and *Scirpus* species being planted to form the wetland vegetation. No consideration was given in this retrofit design to a water quality treatment function for the wetland although it may provide such a further secondary benefit. The original dry balancing basin was already fitted with a sediment trap at the inlet to contain coarse solids and debris prior to discharge into the open basin.

The Wharrage Wetlands, Redditch

A series of retrofitted facilities has been built by the Environment Agency Midlands Region into the existing flood plain of the Wixon Brook to store and treat contaminated storm runoff from a 4 km^2 urbanised catchment within which 65% is occupied by residential, industrial and highway surfaces. The retrofitted system utilises pools and cut-off meanders to construct storage ponds and reed beds. The wetland train consists of a 0.198ha upper silt and oil trap, a 0.369ha middle flow and quality balancing pond with marginal planting, and a final 0.214ha stabilisation and treatment (*Phragmites*) reed bed; a total 3,500 m^3 storage and treatment facility being provided. The excavated silt and spoil has been used to landscape the adjacent river corridor to provide valuable ecological micro-habitats for wildlife and amenity development including the construction of an artificial badger sett.

4.2 Wetland Operation and Maintenance Requirements

4.2.1 Introduction

Regular inspections of constructed wetlands must be undertaken to ensure their proper and continued function. If no maintenance regime is adopted, then experience has shown that early failure is likely to occur on many sites (Jefferies *et al.*, 1999). The problems that most frequently occur are blockages of inlets/outlets, flow regulating devices, siltation of storage areas, algal growth and plant dieback. This means that responsibilities and maintenance routines for maintenance and servicing schedules need to be clearly identified at an early stage and a distinction made between crisis (remedial) maintenance and regular "good practice" maintenance (Fenner, 2001). Bray (2001b) has developed a full maintenance inspection check list intended for the M42 Hopwood Park motorway service station area which for the wetland components in the SuDS design suggest maintenance intervals which vary between monthly (inlet, outlet, drop structures), annually (grass cutting) and bi-annually (valve checks, wetland sediment/plants etc). In practice, the maintenance frequency will be determined normally by site-specific needs. but maintenance operations should include:

- checking inlet and outlet structures
- checking weir settings
- cleaning-off surfaces where solids and floatable substances have accumulated to an extent that they may block flows
- removal of gross litter/solids
- checking sediment accumulation levels (wetlands, sediment traps, infiltration trenches etc..)
- bank erosion

- general maintenance of the appearance and status of the vegetation and any surrounding landscaped zones.

The operation and maintenance procedures connected with a constructed wetland are anticipated to include:

- jetting/cleaning sediment traps, removal of sediment;
- maintenance of the substrate and plants;
- harvesting;
- maintenance of water levels;
- maintenance of nutrient levels;
- general structure maintenance; and
- control of weed growth.

These are described in more detail below. To carry out the operation and maintenance requirements, "all-weather" vehicular access is required to all constructed wetlands.

4.2.2 Removal of sediment

Sediments will require removal from settlement trenches, ponds and final settlement tank, if present. The purpose of the constructed wetland is to isolate and contain the pollutants originating from urban and highway runoff, either as settled solids or within organic tissue, and prevent them from entering the water body. Some of the polluting agents will be degraded through biological processes, but many will persist in the settled sediment and will ultimately need to be removed and disposed off-site. An effective maintenance programme will need to be designed. Sediment is likely to be classified as hazardous waste and may require de-watering on site prior to disposal at a licensed waste facility. It is suggested that the routine maintenance programme includes a minimum frequency of annual inspections to assess whether sediment removal is necessary and inspection following major storm events to assess whether litter and gross solids have been introduced and need removing. This periodicity can be subsequently reviewed based on experience.

It has been suggested that sediment removal will not be required before 10 - 15 years although this operational lifespan will depend on local sedimentation rates and on whether the wetland basin was subject to solids accumulation during the constructional phases. The relationship between available storage volume and solids removal efficiency provides one basis for determining when sediment removal may be required. Field determination of accumulated sediment during regular inspection periods (Figure 4.4) can provide a useful diagnostic method for predicting when such sediment removal is likely to be necessary.

4.2.3 Maintenance of the substrate and plants

Maintenance requirements of constructed wetlands typically involve ensuring continued hydraulic conductivity of the substrate (by washing or replacement), removal of accumulated sludges in the settlement pond and inlet area of the wetland; removal of decaying algae and macrophytes in the settlement trenches, pre-treatment ponds and final settlement ponds and replacement of moribund areas of vegetation.

It is likely that constructed wetlands intended for urban and highway runoff treatment will only require significant maintenance between 15 and 25 years following commissioning. However, as more information is collected on systems for treating highly loaded sites such as those serving heavily-trafficked catchments, the figure for this maintenance period may change. Depending on the pollutant loadings it is expected that the maintenance will involve cleaning or removal of sections of contaminated substrate and the associated vegetation. To enable treatment to continue, only sections of the bed should be removed at any one time, or beds should be partitioned to allow one component to be restored.

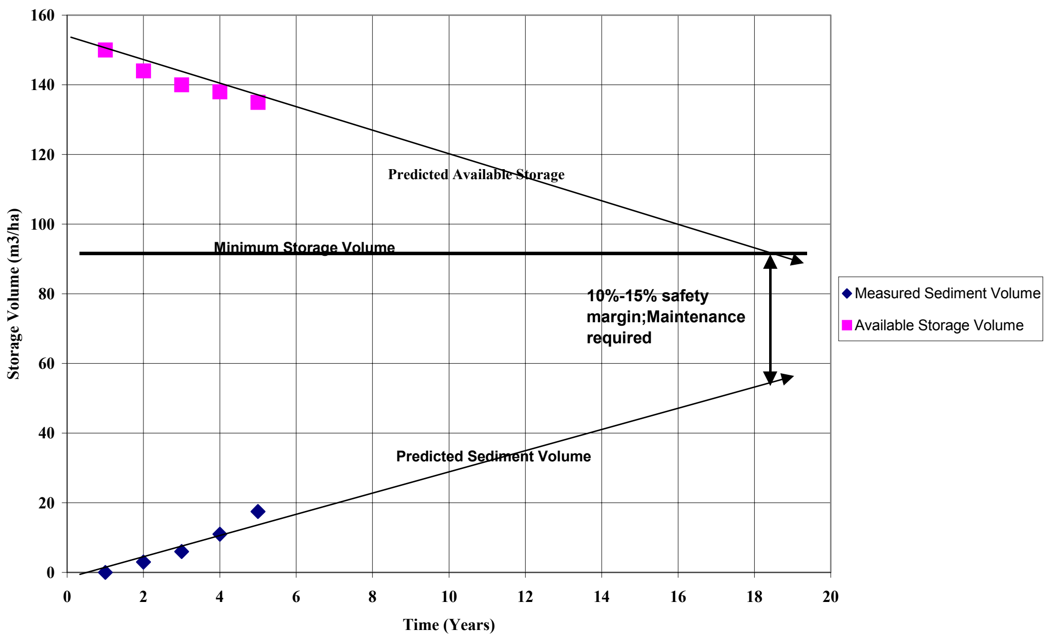


Figure 4.4 Predicting Sediment Removal Maintenance Requirement Time

Plant replacement may be required if the vegetation has been devastated by pests such as blackfly or greenfly. If the problem is noticed in time it may be possible to spray the plants. Biological control by ladybird beetles may prevent these infestations as the wetland matures. However, the occurrence is difficult to predict as the infestation will depend on factors such as location, alternative food sources in the area and winter severity.

It should be noted that any use of herbicide or pesticide in or near water courses (and this would include reedbeds) will require the prior approval of the Environment Agency.

4.2.4 Harvesting

The majority of constructed wetlands are not subjected to harvesting by removal of plant material as it is considered that the plant litter layer has a role to play in the treatment process by providing thermal insulation for the substrate and a large surface area of particles from decomposed leaves for the adsorption of metals. However, the harvesting of leaf material from constructed wetlands installed to treat road runoff, will remove metals that have bio-accumulated (Ellis, 1991), and thus help to prolong the wetland life span. However, there is not enough information available at present to decide whether or not harvesting is preferable.

4.2.5 Maintenance of water levels

A suitable outlet control should be installed to regulate the water level; a flexible plastic pipe linked to a chain is an appropriate low cost option (Cooper *et* al., 1996). Adjustment of water levels may be required during planting or periods of drought. The most expensive maintenance cost would be incurred for replanting if for example, during a prolonged dry period the wetland was allowed to dry out sufficiently to severely wilt or kill the plants. Again, there is little information available on the hardiness of plants to dry conditions and the critical length of such dry periods. It is known that *Typha latifolia* requires a water level to be maintained at or above the surface of the substrate (see Sections 3.3.2 and 3.3.5). Possible prevention measures include:

- tankering in water from a nearby water source when necessary;
- diverting water into the wetland from adjacent water courses by gravity, if the topography and water levels allow; or
- active pumping of water from a nearby water source such as a river or ground water aquifer via a borehole. If no electricity supply is available in the area solar powered pumps could be considered.

The problem of plants dying from lack of water is unlikely to occur every year in the UK (ie only during summer droughts). Therefore the cost of preventing the problem should be a key factor in deciding on the appropriate solution. Until more information is available on the frequency and severity of the problem, it is suggested that if water cannot be conveniently diverted from a nearby water source by gravity, then the maintenance programme should include tankering in water if necessary. At this stage, it does not appear to be economical to install a permanent pumping arrangement.

4.2.6 Maintaining nutrient levels

Constructed wetlands treating road runoff will receive few nutrients. However, nutrient concentrations in urban runoff will vary with the density of gardens and parks within the catchment . Therefore, it may be necessary to spread slow release fertiliser pellets periodically. There is not enough information available at present to determine the necessity or frequency of such fertiliser application.

4.2.7 Control of weed growth and algae

Periodic flooding of the constructed wetland may be necessary to control weed growth when the reeds and aquatic plants are initially growing to maturity. However, the density of reeds at maturity would considerably reduce or eliminate the possibility of weed growth. A flooding depth of 0.05m is sufficient, which is at the lower end of the recommended maximum range of water depths for *Phragmites australis* (IWA, 2000).

Filamentous algae and blooms of unicellular algae may develop in settlement trenches and ponds. Cylindrical bales of barley straw wrapped in hessian are being used successfully on selected treatment wetlands on the A34 Newbury Bypass to eliminate algal infestations.

4.2.8 Monitoring

Monitoring is extremely important to ensure a successful operational performance and early detection of changes in wetland performance requires adequate data collection and analysis. All urban stormwater wetlands should be systematically monitored for at least inflow and outflow water quality (concentrations and loadings), water levels and indicators of biological condition, preferably monthly and minimally on a quarterly seasonal basis. Nuisance species, weed growth and biological condition of the plants should also be noted such as reduced lengths of longest leaves, chlorosis or loss of green leaf coloration and curling of the plant leaf tips etc. Water quality parameters should include temperature, pH, conductivity, DO, BOD, TSS with metals, hydrocarbons and nutrients as required, together with information on sediment depth. One storm event during each season should also be sampled to provide information on short-term storm event performance.

Key Issues

- the impact of climatic change on wetland systems and their O&M requirements (including influence of prolonged low water levels).
- testing of O&M protocols for varying wetland designs and operation.
- long term disposal requirements of contaminated wetland sediments and predicting sediment maintenance and removal.

5. URBAN WETLANDS, WILDLIFE AND LANDSCAPE ENHANCEMENT

5.1 Multifunctional Use of Urban Wetlands

The 1991 Land Drainage Act, the 1995 Environment Act in addition to the Section 16 duties contained in the 1991 Water Resources Act, require that due consideration is given to environmental conservation and enhancement in improvement works and new development. In considering such environmental enhancement, it is essential to be mindful of local community interests including the need to make water bodies and wetlands both safe and visually acceptable whilst at the same time achieving semi-natural landscapes and habitats. Full amenity development may require the provision of special facilities which need to be landscaped into the overall wetland design (Adams and Dove, 1984).

The provision of attractive landscape features which enhance the views from vantage points around a wetland and from surrounding areas can offer tangible landscape value and amenity benefits. Some evidence for this value can be seen from increases in land values and house prices located adjacent to water features which are not vulnerable to flooding. The "urban wetland lake" concept also has a number of intangible benefits which include intrinsic, aesthetic, cultural and therapeutic values (Ellis, 1993). The intrinsic benefits of improved water quality are the sum of option and existence values (willingness-to-pay), and bequest values (Fisher and Raucher, 1984). For instance, many local people may never directly use any developed recreational or amenity benefits but may still value the maintenance of their quality because they know others can enjoy their use or because they value the preservation and enhancement of the environment they live in. There is considerable evidence that people living close to urban water and wetland bodies have a genuine interest in wildlife and amenity provision and in opportunities to view wildlife, local walking and exercising (ap Rheinallt *et al*., 1992). Public perception of the aesthetic and wildlife attributes of urban wetlands places considerable importance on the provision of a naturalistic and "undisturbed" open space possessing a diversity of flora and fauna and shoreline complexity (House and Sangster, 1991).

Wetland Amenity Benefits

People find water intrinsically attractive and wetlands create a natural focal point in any landscape. Opportunities that add to a wetland amenity include:

- creation of views over water
- designing in "reflection" pools
- creation of "visual surprises" through strategic siting of marginal/surrounding vegetation and gaps through marginal spoil mounds
- provision of wetland access, public open space, walks, jetties and boardwalks, picnic facilities etc
- use of soft engineering techniques e.g. wood, vegetation palettes, anchored willow branches etc

Improved water quality and landscaping of urban SUDS structures enhances aesthetic values for direct recreational and passive amenity use, community stewardship and bequest motives. The social, cultural and therapeutic values placed on clean water and nature conservation should also not be overlooked in any decision-making process. However, the intangible value of stormwater control and management, although considerable and consisting of several identifiable components, is difficult to measure. Nevertheless, it is clear that landscaping and amenity upgrading of wetlands and urban lakes will stimulate the perceived attractiveness of the wider surrounding corridor and adjacent areas. Additionally, the more positive the local public attitude towards increases of development (or public) investments, the larger the sum they are personally willing to pay to use the amenity and recreational facilities provided (Green and Tunstall, 1991). Scottish surveys have shown that public attitudes towards wetlands and wet retention basins is much more positive than for other SUDS types, particularly valuing their wildlife and amenity benefits (Apostolaki *et al*., 2001). However, 70% of those surveyed expressed concerns over safety when wetlands were located close to housing.

The landscape design for the area will provide a setting for the wetland such that it should appear to be a "natural" component of the overall setting. The developer and landscape architect should actively seek designs which tie the wetland into an open space network and the urban design of the local neighbourhood. Such landscaping then not only offers potential for local amenity use but also helps to gain the acceptance of people living nearby. Surrounding landscapes should however be low-maintenance features; gardened areas which require digging, weeding, application of fertilisers, pesticides etc., should be avoided especially close to the edge of the wetland.

There should be a clear human involvement in the wetland ecosystem. This can be engendered by paths/walkways, boardwalks, seats, jetties, attractive views, educational material (brochures, trail guides etc.) and display (including electronic) interpretation boards. A sense of ownership can be increased through involvement of the surrounding community in the design process, planting days, educational trails and so on. However, proper and continued development of the amenity and wildlife functions requires ongoing and active management (Payne, 1992; RSPB, 1996) which is not always achievable given limited personnel and finance as well as a lack of means of control e.g park ranger patrols, within the wetland systems. Bray (2001b) argues that long term SuDS management must include a landscape maintenance contract for continued effective performance and asserts that barriers to landscaping maintenance associated with SuDS schemes are more to do with reluctance to change administrative conventions rather than to any practical problems of site concern.

5.2 Landscape and Visual Issues

The use of vegetation is often considered to be a more aesthetically pleasing feature within the landscape than a concrete/brick treatment system with no vegetation. However, constructed wetlands for the treatment of urban and road runoff may well be located in places that are not their natural habitat. Their alien appearance may be accentuated by the design of regular shaped beds. Constructed wetlands can be designed to fit in with the natural environment and the following is a list of basic principles that should ideally be used at the design stage:

- the adoption of a straight-sided, square or rectangular-shaped constructed wetlands should be avoided. Curved-sides will assist in giving the constructed wetland a natural appearance and creation of bays will provide varying territories for aquatic birds.
- the lie of the land should be used to determine the appropriate site for the constructed wetland. Use should be made of natural dips and hollows, which will reflect the likely position for a reedbed.

- the use of additional plant species especially in the margins of a wetland would provide more visual appeal than a monoculture. It would also enhance the wildlife interest of the wetland.
- planting of appropriate herb and shrub species around the constructed wetland may visually enhance the area and provide an opportunity for screening and restricting public access. The planting of trees near the wetland should be avoided to prevent shading, invasion of roots and damage to any wetland liner.

Visual impacts that should be considered include those from the road and surrounding areas, particularly for local residents and from adjacent viewpoints. Visual impacts will occur, and will be different, both during construction and during operation of the constructed wetland and both will require consideration. Although the vegetated area can be made to appear "natural", associated infrastructure may introduce unnatural, man-made development. This may include access routes, parking areas, inlet and outlet structures and settlement ponds.

The significance of the visual impacts will depend upon the sensitivity of the landscape. For example, if it is in a designated area, such as an Area of Outstanding Natural Beauty (AONB), then the significance of any detrimental impacts may be high. Another consideration is the visibility of the site, including whether it is likely to be seen from a residential or other well-used area. A constructed stormwater wetland can enhance the visual appearance of the site, but this may not always be the case. In particular the removal of features of landscape importance to create constructed urban wetlands may be damaging to the local environment.

5.3 Landscape Development

Multifunctional development may also require the provision of special facilities which need to be landscaped into the overall wetland basin design (Ellis *et al*., 1990). For example, edge form may include the use of structures such as jetties, boardwalks, viewing platforms and the judicious but limited use of engineering materials such as stone or rip-rap. If cement or mortar is not used to lay the flags/stones, the intervening spaces can provide space for the colonisation of vegetation including wild flower species. The design should ensure that the wetland basin fits in with the surrounding landscape and that grassed areas with seating and viewing positions are provided. An example of a schematic landscaping design for a wetland retention basin is given in Figure 5.1 and which is based on a synthesis of landscaping features incorporated into the surface water balancing basins located within the Ouzel Valley around Milton Keynes . The areas should develop a strong and definite theme or character. This might be generated from particular views and topographic features around the wetland site or based on the cultural character and setting of the surrounding neighbourhood.

Many schools and particularly primary schools in urban areas, are attempting to utilise existing "natural" areas including local wetlands and flood storage basins as outdoor classrooms for environmental studies. The success

Designing Safe Wetlands

- carry out a risk assessment/safety audit
- provide warning signs and safety/rescue equipment where necessary and conduct regular inspections of all equipment and signage
- design wetlands with side slopes of no more than 1 in 4; good ecological design will normally give much gentler slopes than this anyway
- establish barrier planting schemes (hawthorn, scrub etc.,) to prevent access where necessary
- consider use of low fencing if necessary to prevent access to the water by young children

of the London Kings Cross Camley Street Local Nature Reserve (LNR) wetland attests to the intrinsic value of this educational function. This central city wetland fully involves the local community, schools and colleges as an integral element in the operation of the nature reserve thus entirely fulfilling the objectives of Local Agenda 21. The urban park reserve has made a considerable impact not only at the local level but also at the national and international level. It provides a model for further development and emphasises that the size of an urban lake park need not be a key factor in determining its role in conservation, recreation, education and landscape enhancement.

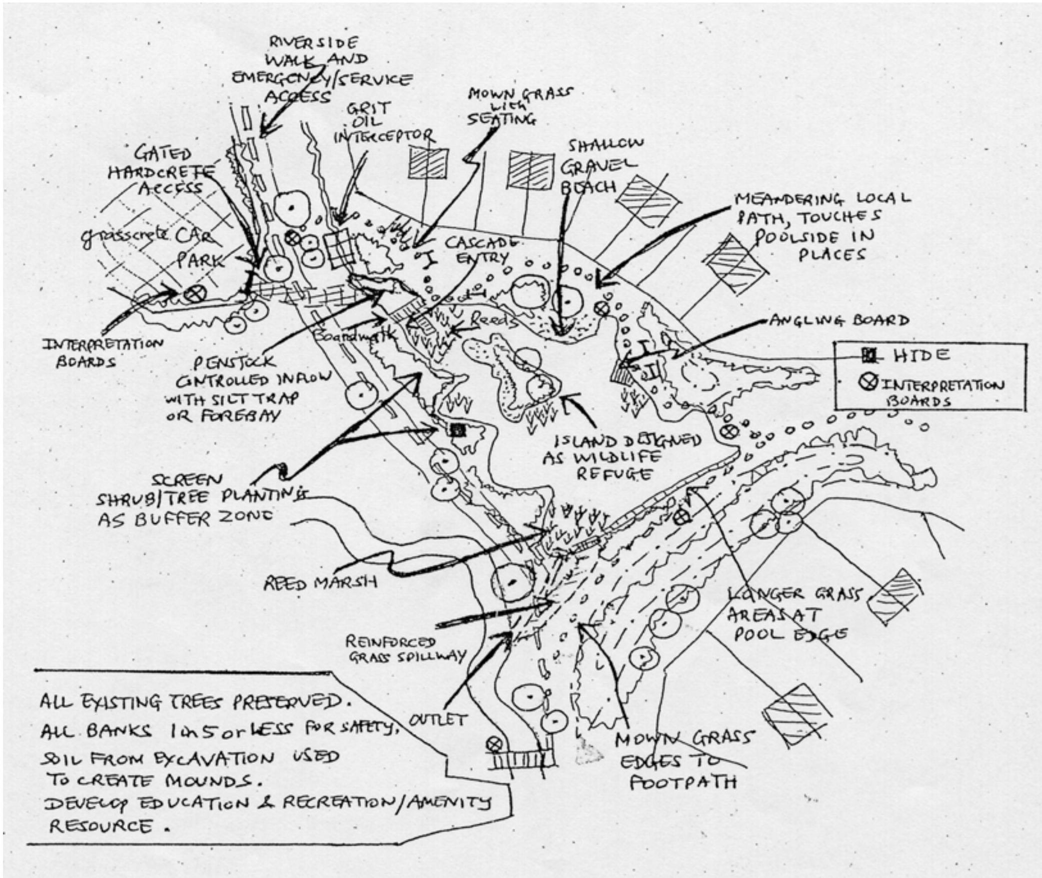


Figure 5.1 Schematic Landscaping for a Wet Retention and Wetland Basin.

The Great Notley Garden Village development near Braintree, Essex also illustrates an imaginative landscaping approach to new greenfield housing sites. The 188 ha housing development includes a country park with an ornamental pond together with wetland and surrounding landscaped pasture and woodland providing wildlife habitats and a central focus for community relaxation and recreation. The 7900m^2 constructed wetland (Figure 18) and adjacent 16,000m^2 recreational pond at the site have been designed not only to provide flood storage and stormwater treatment but also an integrated community facility. The wetland structures have been adopted by Anglian and Thames Water with the wetland itself and surrounding landscaping and park areas adopted by the local authority. In this respect, the site fulfils the objectives of Environment Agency environmental policy (DoE, 1996) for new urban developments which give sustainable added-value in terms of enhanced community landscape which is at the same time consonant with wildlife and conservation requirements as well as with flood storage and water quality needs. The country park style development with an ornamental pond and wetland setting within surrounding woodland and grassland, provides a naturalistic wildlife habitat and a central focus for community relaxation and amenity providing both flood water storage and aesthetic appeal (Oldham, 1995). Figure 5.2 illustrates the range of landscaping features that have been incorporated into the design of the stormwater constructed wetland.

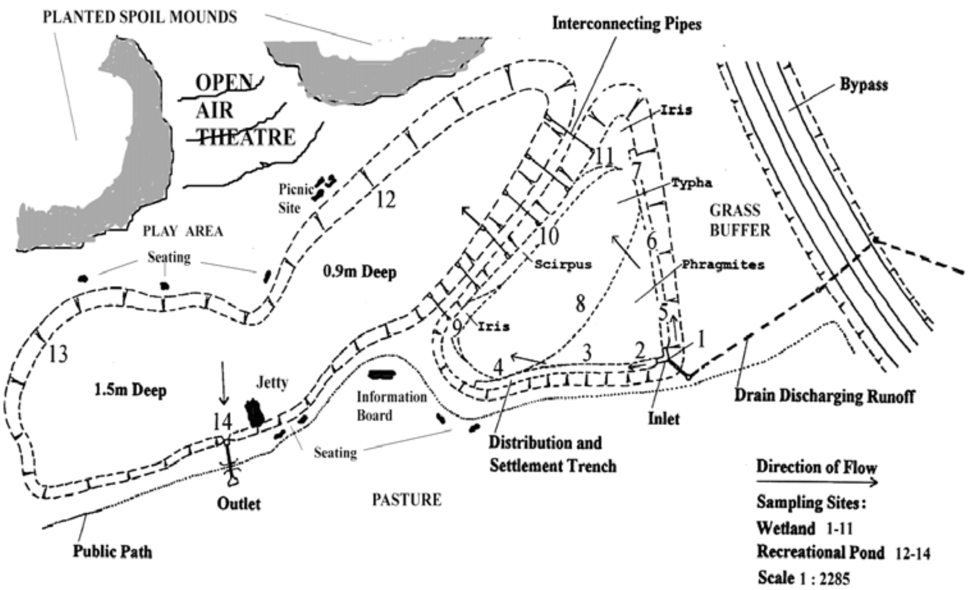


Figure 5.2 The Great Notley Garden Village Wetland

Many business parks and commercial estates have also provided surface runoff balancing basins with landscaped facilities to encourage wildlife and enhance the environmental quality of the working surroundings. The 68 ha Aztec West business park close to the M4/M5 junction north of Bristol (and the home of the Environment Agency HQ), has utilised marginal wetland and island refuges to strategically place nesting and roosting boxes to attract birds and wildlife. The four shallow (1.25m) "water gardens" with edge planting of local sedges, yellow flag (*Iris pseudoacorus*) and hard rush (*Juncus inflexus*), have surrounding fescue and bent grass "buffer" zones for passive recreation. Because of the shallowness of the surface water storage ponds, fountains have been installed for oxygenation as well as for ornamental effect. The lakes have been stocked with a variety of wildfowl including Chiloe widgeon, Laysan teal, mallard, Shoveler and Bar Head geese. Grass is left long on one side of the lake margin until July to provide cover for birds and this side of the lake is screened and protected from direct public access. Habitat and nature conservation are thus not seen as something special on the site but as part of everyday working life.

There is an increasing interest especially in Scandinavia, Germany and the United States, in the use of more formal ecological art and engineered flowforms in the design and landscaping of SUDS facilities for improving stormwater quality (Wenk, 1999). To date, there have been relatively few attempts to fully utilise the aesthetic and architectural potential of stormwater SUDS designs. Such designs attempt to combine art, water treatment and biology in a more formal sculptural manner. The approach emphasises the integration of stormwater and pollution control with ecological and civic functions. A unique example in the UK can be seen in the site-specific, hydroglyph sculptures integrated into and around tarns and ponds in the Grizedale Forest Sculpture Park in the Lake District (Hull, 1993). These stonework forms provide wildlife habitat enhancement and observation stations for the 300,000 annual visitors to the park. The award-winning "Strategic Framework" of MBM Arquitectes Ltd for the lower Lea Valley in E London includes a proposal for a 80 hectare "wetland square" to similarly integrate ecological and civic functions. Source control SUDS options will ensure that surface runoff to the sculptured wetland will be carefully managed as part of the overall urban regeneration scheme.

5.4 Wetland Wildlife Considerations

The use of vegetation, with the inevitable micro-organisms (whether introduced or naturally colonised), in effect constitutes a wetland habitat which is likely to prove attractive to a range of other wildlife species. Wildlife plays a subtle but important role in treatment wetlands since they are consumers that keep nutrients in circulation and regulate the populations of lower trophic levels in a manner that maximises system function (Worrall *et al.*, 1996) as well as enhancing aesthetic aspects. Perception surveys of urban wetlands strongly support the public appreciation of their wildlife potential with bird and wildlife watching being particularly highly valued (Mungur, 1997;Apostolaki *et al.*, 2001). A stormwater constructed wetland has the potential to improve the quality of the water reaching the local streams and rivers. This is likely to lead to ecological improvements in the aquatic habitats and a recent pilot survey of Scottish SuDS ponds and wetlands shows that they can support quite rich wildlife communities largely dominated by common species although most wetlands were found not to fulfil their ecological potential (SEPA, 2000). This may essentially be due to the problem of disturbance and the lack of a protective buffer-zone for most bird and other wildlife species in what are essentially public open spaces. In smaller wetlands, some form of screening or exclusion refuges may need to be provided if wildlife is to be encouraged.

Consideration must be given to the scope for implementing ecological principles into the design and management of urban wetland SUDS but it is essential to recognise that these schemes are part of the wider environment and as such should be integrated wherever possible with existing semi-natural habitats as well as with the needs of urban development. It is only through such an integrated approach that local biodiversity (biological diversity of habitats and species) can be preserved. As indicated in Table 5.1, urban wetlands can offer considerable potential wildlife benefits with high conservation value if designed and implemented carefully. Ponds that have been allowed to colonise naturally tend to have the highest ecological value and although dominated by common species, these wetlands may also support locally uncommon submerged plant species as well as mudwart (*Limosella aquatica*), newts and water voles. All this is an indication of the potential of urban wetland SuDS for providing new habitat for key species including UK Biodiversity Action Plan (BAP) species; a useful listing of ways to maximise the nature conservation value of SuDS ponds and wetlands is given in Powell *et al.*, 2001 and have been incorporated into the list of bullet points given below. In the Scottish SuDS surveys (Pond Action, 2000), the richest of the wetlands were those located in an area of extensive unimproved grassland and in close proximity to other aquatic habitats. Such locations facilitates colonisation of the SuDS wetlands by local native species. A range of common plants and animals which are quite tolerant of pollutants, particularly air breathing invertebrates such as water beetles, bugs and water snails, will quickly colonise ponds located in close proximity (within 1 km) of existing watercourses and wetlands.

Table 5.1 Conservation Value of Urban Wetlands

	M42 Hopwood Park MSA wetland	Milton Keynes Mount Farm Wetland	Welsh Harp (N London) wetland	Livingston Caw Burn (Industrial estate) wetland	Dunfermline (DEX Commercial Park) Wood Marsh
Invertebrates					
Number of species	37	58	40	24	38
Number of uncommon species	-	1	3	0	0
Conservation value	High	High	High	Moderate	High
Plants					
Number of native species	5 -13	24	17	13	25
Number of uncommon species	-	1	4	0	4
Conservation value	High	High	Moderate	Moderate	High

Sources: Welsh Harp Conservation Group, 1992; Milton Keynes Development Corporation, 1992; Pond Action, 2000; Bray, 2001b.

In designing a favourable system, various wetland ecological considerations need to be made to ensure the success of the scheme including:

- a small constructed wetland system based on a monoculture will have limited value, compared with an integrated treatment system containing a range of plant species and permanent open water.
- in order to realise the full potential of wetlands, careful consideration should be given to the incorporation of detention basins upstream and downstream of the wetland. In addition to sediment settlement provision, these water bodies can be expected to be attractive to aquatic invertebrates, amphibians and waterfowl.
- reedbeds should not be constructed in the shade of trees as this can lead to poor patchy growth.
- some plants will out-compete other species. Flooded conditions enable reeds to out-compete other species and this is a good method of weed control. Reeds (*Phragmites*) will displace bulrush (*Schoenoplectus*) and reedmace (*Typha*). However, reeds suffer competition from other species such as reed canary grass (*Phalaris*) and Iris in drained systems. The introduction of invasive exotic species such as *Crassula helmsii* will severely detract from the intrinsic conservation value of the wetland SuDS and their potential to contribute to local biodiversity planning. More seriously it creates a stepping stone from which invasive alien species can colonise local water bodies

Costs of Wetland Ecological Management

- creating 5 small 1 m^2 pools in the drawdown zone of a large wetland to provide additional habitat for water beetles: £1000 (or 5 person/days)
- herbicide spraying by professional contractors to control invasive alien plants: £5 per 10 m^2
- removing sediment (<20 m^3) manually to create local diversity: up to 50 volunteer personnel/days
- selective tree coppicing along 20 m of wetland margins: £500
- installation of dipping platform: £1000
- production and installation of laminated interpretation boards: £1000+
- dredging: £50 per m^3 plus £3 per m^3 for spoil taken off-site

that support a high quality native vegetation, which may be threatened by the competitive nature of these alien species.

- reedbeds should not be planted near willow trees (*Salix*) since seeds will be deposited into the wetland bed and the resulting willow trees, with deep roots, may damage any liner that is present (Cooper *et al*., 1996).
- the creation of undulating "hummocky margins" in shallow waters of retrofitted wetland designs; these mimic the natural physical diversity of semi-natural habitats. Smooth finished surfaces provide less physical habitat diversity for animals.
- shallow water and nutrient-rich wet mud provides ideal habitat for amphibians and invertebrates. This is a key habitat for many small annual wetland plant species that is often lost in the later stages of pond succession.
- spits and islands encourage invertebrates and wildfowl; grazing and trampling by wildfowl will also often diversify marginal wetland habitats.
- the encouragement of a mosaic development of marginal plants to maximise habitat structural diversity eg *Glyceria fluitans* (floating sweet-grass) which provides good habitat for newts and other invertebrates.
- the checking of planting schemes one and two years after establishment to ensure that specifications have been carried out and undertake immediate remedial action if invasive species are found.
- the land adjacent to the SUDS wetland can provide important terrestrial (foraging and hibernation) habitat for amphibians and nesting birds where managed sensitively. The vegetation should remain largely uncut to provide cover and should be planted only with native trees and shrubs such as willow (*Salix fragilis* or *Salix caprea*), alder, ash and hawthorn.
- including wherever possible, a short after-care programme about one year after creation. Use this to (a) undertake fine-tuning of the wetland design and (b) to capitalise on new opportunities that may have arisen e.g re-profiling margins, natural seepage to create new pools etc. Fine-tuning of this sort costs very little but will often greatly increase the biodiversity value.

The management of fish in wetlands should aim to promote a community which minimises the effect on algal and submerged water plant growth. Fish may influence lake ecology by selective predation of zooplankton which in turn reduces the grazing pressure on phytoplankton and increases the tendency for algal blooms to occur. One of the principal fish species responsible for these problems is the Bream . Fish may also be involved in nutrient recycling through feeding on the sediments and through digestion of particulate organic matter. Carp has been identified as a principal agent of such pathways. Carp and bream populations should be reduced and the wetland restocked with tench and crucian carp which have a less damaging effect. Pike can also be added as a predator when water clarity has improved (Mc Caskie and Lee, 1996).

Urban wetland habitats can be the basis for successful wildlife reserves and there are many examples of artificial wetlands which have acquired a wildlife value equivalent to that of natural wetlands and two examples are given here.

- The Sandwell Valley flood storage Forge Mill Pond at Great Barr, Birmingham was constructed in 1982 at a cost of approximately £1 Million. The central 8 ha lake is used for canoeing, windsurfing and dinghy sailing with the 2ha restricted-access eastern arm (0.5m deep) incorporating a 0.25 ha introduced wetland marsh with landscaped surroundings totalling some 10 ha. The constructed SF wetland is mostly planted with *Phragmites australis* interspersed with some *Typha*, lesser reed mace and pockets of *Phalaris*; all plants were introduced from a local reserve at Droitwich in the 1984-1985 period. The amenity and recreational facilities are administered by the Sandwell Metropolitan Borough Council with the wetland reserve and nature centre being operated by the RSPB. The wetland is now a designated wildlife reserve and despite the central urban location, over 130 species of birds are recorded annually with breeding grebes, whinchats, marsh harriers, wintering teal and snipe as well as waders such as migratory dunlin encouraged by the provision of a "scrape" in the drier area of the marsh. Over 35,000 people a year visit the wetland site where the RSPB operate an educational centre in the heart of the West Midlands conurbation. In order to maintain ecological diversity and encourage the breeding of new species, an active policy of habitat management has been devised with a warden overseeing the reserve and adjacent country park supported by a naturalist and part-time volunteers.

- A similar and highly successful wildlife habitat has been established in the semi-natural wetlands that have developed in the 96 ha Welsh Harp flood storage basin in N London which was designated as a Site of Special Scientific Interest (SSSI) in 1950. The wetland basin drains a 5 km^2 catchment area of which 65% is highly urbanised with some 60% of the annual flow volume being derived from impermeable urban surfaces (Hall, 1977). Oil booms have been installed at the stream inlets to the basin with trash screens and an automated "grab" litter and gross solids collector. The flood storage basin provides an efficient treatment removing between 50% - 80% of both water and sediment mean total hydrocarbons (see also Box in Section 1.2.2) and achieving up to 97% reduction in total suspended solids (Jones, 1995). The wetland is dominated by *Typha latifolia* and *Phragmites australis* with lesser areas occupied by *Phalaris* and *Salix* woodland. Studies have indicated that the plant rhizomes provide a matrix for contaminated sediment trapped by the biofiltration effect of the plant stems and roots. As much as 54% - 61% of the total metal uptake is stored in the rhizome (Shutes *et al*., 1993).

  24 floating vegetated rafts have been provided as nesting/roosting sites as a basis for a flourishing wildlife refuge. Over 100 bird species are regularly recorded annually with over 40 breeding species of Great Crested Grebes as well as kingfishers, cormorants, shags, grey herons and bitterns; the rafts also attract several pairs of common tern, *Sterna hirundo.* Marginal sedge marshland, 2m dykes and the planting of impenetrable shrubbery prevents general public access to sensitive breeding sites and observation hides. A wide 30 - 60m buffer zone surrounds the 2 km shoreline and provides a landscaped open space with viewing points, pathways, seating and nature walks as well as accompanying information/interpretation boards provided for aesthetic and general educational needs.

  The management of the wildlife habitats is the responsibility of a volunteer Conservation Group who sit on a Joint Committee with local authority and Environment Agency representatives. There is a fully staffed Field Centre on the site which offers day visits, short courses and other environmental educational training. Two countryside rangers lead guided walks, liaise with the local community and protect the conservation interests. However, conservation management of the wetland habitats is limited by local authority funds and is largely dependent on the goodwill of volunteers. The reeds create a valuable wildlife habitat for waterfowl and birds but require continual maintenance and long term control of succession to willow carr development. The wetland has recently been dredged in sections which involved the de-watering of contaminated sediment on-site and costly disposal to landfill (Batten, 1989). Silt removal does provide some opportunities however, and at the Welsh Harp was used to create irregularly shaped banks and islands to maximise water-land interface creating more suitable nesting sites.

Consideration must also be given to the potential for stormwater constructed wetlands to be harmful to the wildlife they attract as a result of direct poisoning or through pollutant bio-accumulation. The current understanding of the way pollutants affect organisms is far from comprehensive (Merritt, 1994), which makes it difficult to assess whether or not wildlife will be at risk from a constructed wetland treating contaminated urban and road runoff. Polluted wetlands are not universally good for wildlife, but they can provide valuable habitats for some forms of wildlife, providing high levels of toxic substances are not readily bio-available. Further monitoring of pollutant pathways through food chains in urban wetlands and of wildlife colonisation patterns is required to provide firmer evidence on the appropriateness of such SuDS habitats as wildlife refuges.

A number of further issues in relation to wetland ecology and wildlife may need to be considered as SuDS are introduced for urban stormwater treatment over the next 5 to 10 years:

- how will the frequency and practice of sediment removal impact upon rates of recovery and successional processes within these wetlands?
- how much do different aquatic plants differ in their value within wetland SuDS in terms of removing pollutants such as heavy metals, nutrients, hydrocarbons etc., and does this affect what vegetation should be encouraged at the outset?
- it is known that substantial die-back of common reed can occur under regimes of high toxic and nutrient loading and low oxygen availability. Whilst this is not a concern at the current stage of wetland SuDS implementation, it could be an issue in 10 years time and might then have a bearing on safety and amenity issues.
- urban wetland SuDS can become dominated by phytoplankton (perhaps also with the occurrence of blue-green algae). Whilst this may be eliminated by installing barley straw bales in pre-treatment settlement lagoons in a constructed wetland, it may prove more difficult to reverse in wetlands having significant areas of open water. In addition, illegal stocking of fish is common in retention ponds within suburban areas and is probably an inevitability in many wetland SuDS. Introduction of carp in particular can be a problem as these bottom-feeding fish can promote nutrient release from sediments. Whilst fish stocking will not impact on the primary function of the wetland SuDS, it could have major implications for amenity and conservation value. However, given that SuDS wetlands can be drained and fish removed, these might be fairly minor concerns, but an official

management response to fish introduction into a wetland SuDS is worth considering.

Key Issues

- influence of wetland landscaping on enhancement of development land values and construction unit prices.
- public attitudes to, and concerns regarding, wetland provision in urban areas.
- use of interpretive materials, educational facilities and formal amenity/wildlife management in developing local attitudes to urban wetlands.
- incompatibilities and inconsistencies between multifunctional uses of urban wetland systems especially in terms of long term flow and water quality control.
- conservation value of urban wetlands and "after-care" programmes for wetland landscaping.
- role of fish (especially carp) in urban wetlands and management control strategies.

6. SuDS IMPLEMENTATION AND CATCHMENT PLANNING

6.1 Introduction: The Need for Integrated Approaches

SuDS do not operate as a series of isolated drainage devices but should be designed and operated holistically. Each component adds to the performance of the whole of the drainage system. Such a policy perspective needs integrated participation of all stakeholders within a catchment-wide planning framework. The responsibilities and duties associated with urban surface water drainage in England & Wales are complex with the principal stakeholders including:

- The Environment Agency
- Local Councils
- Water companies
- Highway authorities
- Developers
- Non-Governmental Organisations (NGOs) and riparian owners

However, the duty for provision of drainage services for water companies as well as public and government bodies, is limited to that which is deemed to be affordable; there is no absolute duty to provide for expensive rare and extreme storm events. The statutory duty is confined to provide an effective service, and compensation for flooding and associated pollution is only a liability in the event of negligence. Flooding and pollution of any frequency, even when caused by inadequate provision, is still an insurable loss. Due to the strength of the regulation, and the conflict between individual customer service and responsibility for the community at large, Water Companies are in the "front-line" for criticism and are frequently called on to take action ahead of other responsible bodies. This pressure to act promptly has increased over the last five years, and it is felt that additional loading may be placed on sewer systems because the performance of other drainage systems has not kept pace with rising customer expectations and this has sharpened anxiety over innovative SuDS technology. Land drainage provisions and the right of riparian owners can also be complex, and there is a growing concern for the proliferation of dispersed, minor control systems for the general protection of urban watercourses and designated main rivers.

Improvements in urban drainage infrastructure need to keep pace with the communities which are served, but far too frequently conflicting agenda are evident. There is evidence for different standards of both design and operation in urban drainage systems even between Water Companies, and there is insufficient correlation and coordination between the standards used for highway and land drainage design. There are known limitations to the modelling of both overland flows and surface/sewered water quality as well as in the choice of appropriate rainfall intensity and frequency of occurrence for designing integrated systems. However, the successful implementation of SuDS technology relies on an integrated partnership approach and as such, the continued development and adoption of SuDS techniques offers an important vehicle for introducing improvements and benefits to urban community and catchment planning.

Urban wetland SuDS systems that function as flow and/or water quality control facilities for stormwater runoff normally discharge to controlled receiving waters within a defined catchment. It is therefore appropriate to review relevant catchment-based UK legislative and planning policy and practice together with perspectives on the implications of the EU Water Framework Directive for the management of diffuse urban surface water drainage and stormwater wetlands. Appendix C provides information on general discharge standards and consents for surface waters and details of the structure of existing receiving water quality classification within England & Wales. A brief outline is also given in Appendix C of sediment quality standards which might be appropriately applied as "limit" loadings for the contaminated sediment which accumulates within urban stormwater wetland systems.

Water pollution control in the UK has traditionally taken account of the dilution available within the receiving water. Environmental Quality Standards (EQS) have been defined for particular pollutants and discharges have been consented to ensure that these EQSs are not exceeded. The (as amended) 1974 Control of Pollution Act has been used to implement this approach and the interpretation of the Section 34 consenting powers have been strictly related to water quality considerations. However, the EQS approach is not applicable for controlling the discharge of contaminated urban surface water. The impact cannot be readily modelled; the toxic components are not defined; offenders are not easily traced; and EQSs are not available for the possible contaminants in sediment. In addition, a characteristic of urban diffuse pollution is that environmental impacts are often cumulative; by the time the case can be firmly proven, the damage may be irrevocable.

The only effective means of ensuring the protection of urban receiving waters is firstly to require best environmental practice (i.e reduce at source) and subsequently minimise the discharge of polluting material (through appropriate and effective mitigation measures to deal with unavoidable levels of contamination). Such an approach has been developed and applied in the forestry sector in the UK. The guidance as set out in "*Forest and Water Guidelines*" is enforced in effect, by the Forestry Authority who administer payments for forestry schemes. The question is can such similar best practice be encouraged, and where appropriate enforced, in the urban sector which is the source of many diffuse pollution problems? Some possibilities for the encouragement and dissemination of "best practice" are considered in the following sections.

6.2 SuDS and the EU Water Framework Directive

6.2.1 Objectives and key elements

The implementation of the EU Water Framework Directive (WFD) has major consequences for the protection of the aquatic environment including urban wetlands, which will require the UK to produce integrated catchment-based plans for dealing with diffuse pollution sources, including those generated within urban areas. It is within the legislative context of the WFD that perhaps the greatest opportunities will arise for the consideration and inclusion of SuDS approaches within future urban land use planning programmes. The WFD offers opportunities to review the adequacy of current regulatory measures for controlling and managing urban diffuse pollution and, in the light of such review, to either modify them or seek new powers. The key objectives which are of relevance to urban surface water drainage, and as set out in Article 1 of the Directive, include:

- the protection, restoration and enhancement of the status of aquatic ecosystems and associated wetlands
- protection and enhancement of artificial and heavily modified water bodies, with the aim of achieving "good ecological potential" and "good" surface water chemical status within 15 years.
- there will be prohibition on direct polluting discharges, such as urban runoff, to groundwaters.
- any anthropogenically induced significant and sustained upward trend in a pollutant, would have to be reversed.
- promotion of sustainable water use and consumption

Of particular relevance to the problem of urban surface water drainage, is the emphasis in the WFD placed on diffuse pollution. Whilst the Directive does not define diffuse pollution, it does specify the need to address the problems as follows:

- Article 11.3(h); "*for diffuse sources liable to cause diffuse pollution, measures to prevent or control the input of pollutants*" are required
- Article II requires the identification of "*significant sources*" of diffuse pollution
- Annex VII states that "*estimates of diffuse pollution*" are required in River Basin Management Plans (RBMPs)
- Annex IV requires operational monitoring for "*water bodies at risk from diffuse pollution*"

Whilst there is no statutory definition given in the WFD for diffuse pollution, a recent report (D'Arcy *et al*., 2000) has suggested that a practical and useful view for regulators is that it refers to multiple sources which would not be desirable to try and licence as point-source discharges. Such dispersed discharges are typical of impermeable surface water drainage and the same report indicates that urban runoff is responsible for over 11% of total polluted Scottish rivers (and 31% of seriously polluted rivers) and for the downgrading of at least 4% - 5% of rivers in England and Wales. The situation may be more serious than this given that existing regulatory authority monitoring systems for urban watercourses consistently fail to represent the true extent of diffuse pollution resulting from intermittent urban surface water drainage (Green and Faulkner, 2000; Ellis and Chatfield, 2001). Urban diffuse pollution is therefore, a significant issue and a largely unresolved problem of considerable relevance to the UK as a whole. This places particular importance on the development, introduction and testing of effective management strategies including SuDS approaches which will help to address the problem.

One of the underpinning principles of the WFD is the adoption of an holistic and integrated river basin management (IRBM) approach based on, *inter alia*, common objectives for water status, and common monitoring and assessment strategies. The Environment Agency already possesses functions and geographical boundaries compatible with many of the WFD requirements with River Basin Districts (RBDs) closely based on the Agency's existing regions. However, the Agency does not have jurisdiction over all of the areas covered by the Directive and coordination with a number of other bodies will therefore be vital to successful implementation, especially for the control and management of potentially contaminating urban runoff discharges. Table 6.1 identifies some areas where such cooperation will be important in achieving the key objectives of the WFD in respect to urban runoff and SuDS approaches.

Table 6.1 Other Bodies with Important Roles in the WFD

Areas of Interest	Competent Bodies Involved
Urban Land Use Planning/building regulations	Local Authorities/DEFRA
Conservation	English Nature/Countryside Agency/RSPB/Local Nature Trusts
Recreation	Countryside Agency/Local Authorities/British Waterways/Sports Council
Flood Defence	DEFRA/Local Authorities/Internal Drainage Boards
Navigation	British Waterways/Local Authorities
Water Resources (including wastewater and surface water drainage)	Water Companies

6.2.2 Urban diffuse pollution and river basin management planning

A key requirement within the WFD under Article 16 will be the production of River Basin Management Plans (RBMPs) which are viewed as the main mechanism of achieving the Directive's environmental objectives. A RBMP for a particular river basin should include:

- definition and characteristics of the river basin (by end of 2003)
- environmental monitoring data and consultation in preparation of RBMPs (to commence by end of 2006)
- details of the environmental impacts of human activity, including information on diffuse pollution sources, magnitudes and trends (by end of 2004)
- interim overview of significant RBD water management issues (end of 2007)
- strategic plan for the achievement of "good status" within RBDs to be specified within the Programme of Measures (by end of 2009)

The Environment Agency is familiar with water management strategies developed within the context of river basin planning and Table 6.2 identifies various types of recent and existing water management planning which impinge upon urban water bodies. However, one main difference between many of the recent and existing plans, and in particular Local Environment Agency Plans (LEAPs), is that RBMPs (and the associated programme of measures within them) will be statutory. Previously there have been few linkages between LEAPS (and their predecessors, catchment management plans) and local authority development plans despite circulars encouraging such cooperation (Slater *et al*., 1994). Therefore, it will be important to obtain as much agreement as possible amongst all parties on whom the Programme of Measures will have an impact. However, it is not fully clear how decisions on the 2005-10 AMP4 capital investment will be reached to lock in with operational requirements to meet the WFD initial timetable for improvements in water status by 2012.

Following RBD characterisation, the WFD planning cycle will need to carry out an analysis of the impact of human activities on the waterbodies within that catchment district, and in particular the identification of specific land use activities causing diffuse

Table 6.2 Types of Water Management Plans (England & Wales)

Type of Plan	Bodies Involved	Function	Level
Local Environment Agency Plans (LEAPs)	EA, Local Authorities and many others	Consultation on environmental improvements for a local area	District
Asset Management Plans (AMP)	Water Companies, OFWAT, EA	Setting out future Water Company infrastructure investment and price limits	Regional
Water Level Management Plans	EA, English Nature	Balancing/integrating the water level requirements for a particular inland area	District
Habitats Directive	English Nature, EA, others	Management(protection and improvement) of Habitats Directive sites	Regional
Biodiversity Action Plans (including Habitat & Species Action Plans)	Many	Implementing Rio Convention and subsequent UK Biodiversity Action Plan;	District
Local Agenda 21 Plans	Local Authorities, many others	Improving local biodiversity	District
Flood Defence Management Schemes	Local Authorities, EA, others	Maintain/improve coastal and inland flood protection	District
Catchment Abstraction Management Strategies (CAMS)	EA, Water Companies, stakeholders	Sustainable use of water resources within a catchment (129 across England & Wales)	Regional
Catchment Flood Management Plans (CFMPs; pilot studies started autumn 2001)	EA, DEFRA, Local/County Authorities, other flood defence operating authorities, stakeholders	Holistic view of flood risk at catchment scale	Regional

pollution problems. The Environment Agency is currently developing a series of models (including River Habitat Survey methodologies) to aid in the assessment of the impact of land use on water quality. A key issue of the modelling tools must be to investigate the impact and effectiveness of various management strategies including SuDS, on the ecological and chemical status of the watercourse. An outline of these actions is presented in Table 6.3 and shows the wide range of applications for the models. Risk-based analysis will be employed to identify waterbodies likely to fail (or be at risk of failing) environmental objectives.

The LEAP process provided a key opportunity for the Environment Agency to integrate its various functions. As noted by Woolhouse (1994), informal liason with key partners has become essential in the planning process and in addressing actions on issues highlighted by LEAPs. In addition, LEAPs were also specifically intended to complement and integrate with the publications and plans of local authorities and other organisations such as Local Agenda 21 plans (Environment Agency, 1999).

Table 6.3 Possible Management Strategies

Type	Strategy
SuDS	Source Control (including urban stormwater wetlands).
Flood Storage	Flood attenuation and water quality improvement.
Diffuse pollution from urban areas	Surface water drainage
Urban river corridors	Improved habitat
Habitat provision	Provision of refuges
Sewerage	CSO performance (e.g tanks, screens etc..)

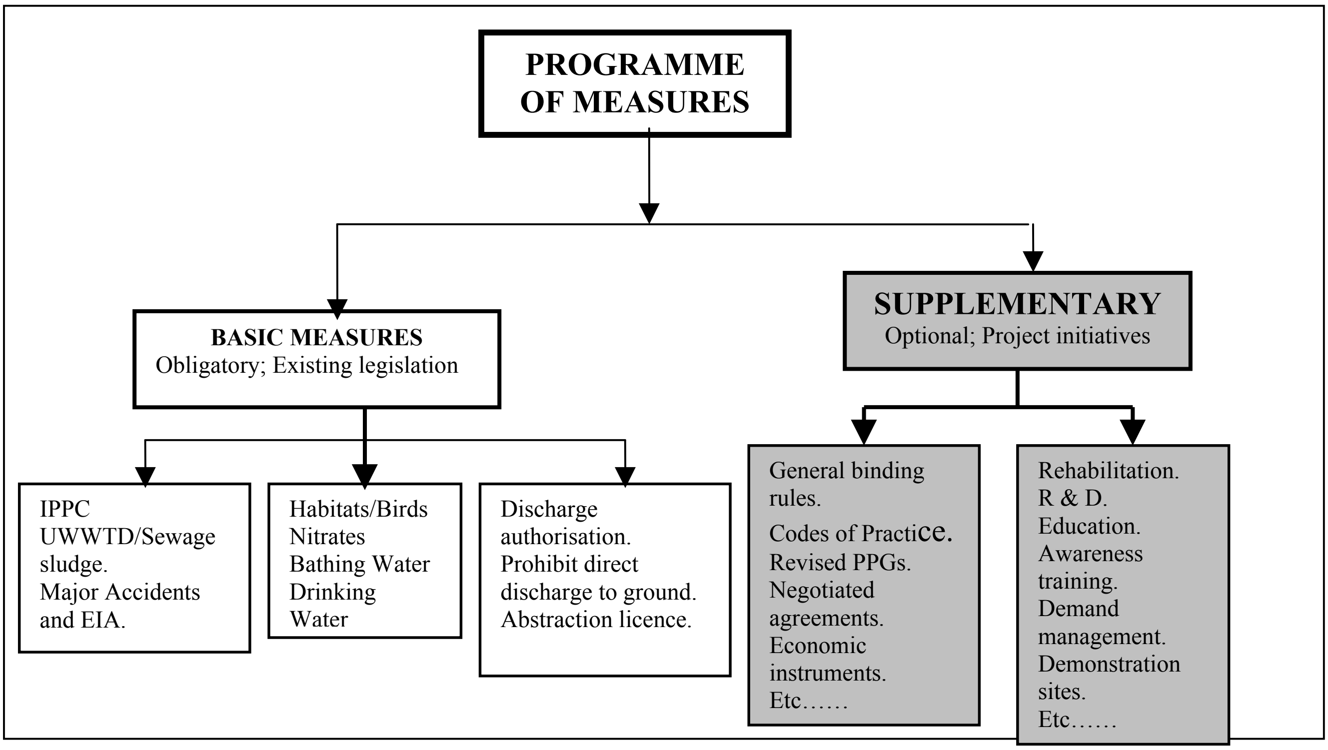


Figure 6.1 RBMP Programme of Measures

LEAPs have now evolved into "local contribution" plans but as pointed out by Williams (2001), the WFD will be only one (although major) pressure on the LEAP process which in effect already generate what is required in RBMPs. However, whilst "local contributions" can provide an integrated management plan for surface water management, the predecessor LEAPs did not always achieve their aims. In particular, there were concerns regarding the purpose and target audience of the LEAP process, especially in terms of involving the general public, and potential conflicts between local and regional planning aims.

The UK and Germany are jointly managing a pan-European R & D project looking at implications of the designation of water bodies as artificial or heavily modified and the Environment Agency has also already appointed an R & D manager with responsibility for diffuse pollution. For waters that will be subject to derogation (which may well include sections of urban watercourses), interim criteria, objectives and deadlines will need to be set, and which will be subject to review. Once monitoring has determined waterbody status within a RBD, the competent authorities must then use this information to develop an integrated Programme of Measures. Figure 6.1 illustrates the structural requirements for such a programme and it is possible that urban surface water discharges will be dealt with under Supplementary Measures utilising "General Binding Rules" with accompanying Codes of Practice (David Griffiths, Environment Agency, Bristol in Discussion Group Summary to Conference Launch, 16 October 2000, of the report on Diffuse Pollution Impacts, D'Arcy *et al*., 2000). Such Codes of Practice would need to be accompanied by revisions to existing Pollution Prevention Guidelines (PPGs), which could be extended to include specific reference and guidance to SuDS approaches for the mitigation and management of urban surface drainage. The application of such general SuDS "consenting prevention" conditions for surface water drainage for urban development might provide a necessary working lever to ensure that developers and local authorities adopt wherever possible and appropriate, SuDS techniques including urban stormwater wetlands.

6.3 Implementing SUDS within River Basin Management Planning

6.3.1 Prohibition notice policy

As stated in Section 6.2.3, it is standard UK regulatory policy (within the Agency, SEPA and the N Ireland E & HS) not to seek formal consents for urban surface water discharges. In the large majority of cases, seeking such a consent is a difficult and protracted process involving considerable administration, especially for a consent that will usually be just descriptive in nature i.e not much extra gain is achieved beyond a description in a planning consent. Risk-based assessments provide the main means of determining the appropriate level of regulatory control required. This allows control to be focused upon the specifications of the drainage system rather than numerical consent conditions.

Both the Agency and SEPA are committed to advocate source control and passive treatment such as urban wetlands as best management practice in their response to Strategic and Local Plans. Normal regulatory practice, therefore, is to rely on planning conditions and building warrants as the means of delivering best practice. Conditional Prohibition Notices can be served, for example, where source control, passive treatment or engineering measures such as oil interceptors are agreed with the discharger. Such SuDS structures can then be made a condition of the Notice. Absolute Prohibition Notices can be served for example, to cover required discharges from industrial estates, commercial developments, lorry parks etc., and as such would be subject to full consenting procedure. Either engineering and source control measures can be incorporated in the development design and be covered by descriptive consent conditions and/or numeric standards. The current Prohibition Notice policy provides a clear framework for guiding the Agency (and SEPA's) regulatory activity. Therefore, actions in respect of SuDS implementation should be seen as being supportive of this basic policy.

6.3.2 Planning and partnership approaches

SuDS Implementation and the Planning Process
Planners have a pivotal role in the regulation of urban development and it essential that they fully understand the problems faced by the regulatory agency with respect to

urban surface drainage. The planning system and local authorities are in a key position to bring about change and provide a major role in terms of controlling and influencing the decision-making process on urban land use activities. They can work within relevant development, structure and local plans as well as the AGENDA 21 process to encourage and introduce appropriate design guidance and community planning. However, planners can be faced with consultation responses on the one hand from the Agency promoting SuDS and on the other hand, resistance from other statutory consultees. This lack of co-ordination can cause serious difficulties for the planning process. Concerns have also been expressed over the lack of consideration for other local authority planning responsibilities. In addition, some existing "best practice" sites are regarded as examples of poor management practice which do not enhance the appearance of an area. Planning Authorities have specific reservations over safety and liability implications of SuDS ponds and wetlands where children can gain access. Some 300 SuDS devices are being currently monitored under a SEPA led project which aims to improve design, performance and maintenance criteria. This monitoring project is working closely with the SUDS Scottish Working Party (SUDSWP) which has produced, in conjunction with the Scottish Executive, a SuDS Planning Advice Note (PAN 61) to provide guidance for planners. Whilst the technical aspects relating to the appearance and safety of SuDS systems are a matter of promoting good design, the administrative and consultative difficulties encountered within the planning process are more difficult to address.

One approach for the Agency might be to positively seek to include within Strategic and Local Plans an explanation of the issues raised by impermeable surface water drainage together with recommendations for the use of best management practice including SuDS. The difficulties and challenges of achieving such a dialogue between the regulatory agency, local planning authorities and other interest groups such as water companies, is illustrated by the protracted six year negotiations regarding the introduction of SuDS into greenfield development within the Aylesbury Vale District Local Plan (CIRIA, 2001). Teamworking strategies might be reinforced through checking of planning uptake rates and the provision of Agency "presentations" to those Council Planning Departments where there is significant development pressure and where Local or Strategic Plans are under preparation. Such presentations would need to be well prepared to be effective and each Region of the Agency would require an appropriate in-house expertise and associated training programme. This should include skills and training in the technical aspects of the impact and control of urban surface water drainage as well as knowledge of the organisational and legislative framework for diffuse pollution. Access to suitable SuDS demonstration sites in addition to performance, maintenance and costing data would be extremely supportive to such in-house training. Coordination between the planning authorities and the regulatory agencies is crucial at the strategic catchment level in order to support decisions on, and to identify thresholds of, "carrying-capacity" and coping with changes in land use (Carroll and Howes, 1998). As part of such strategic scoping work, there needs to be integration between engineering, technical/ building services, planners and environment agencies in order to identify which SuDS options might be appropriate at county, district and regional levels. Without clear advice, local authorities will continue to be reluctant to adopt SuDS, even though their own Planning Policies indicate that their use may be preferred. Case studies (CIRIA, 2001) would suggest that SuDS take-up can be very dependent on the enthusiasm and persistence of informed individuals within the negotiating organisations, and who drive the planning process through initial apathy/reluctance, lack of information/experience and genuine concern over long term management issues. Irrespective of such reservations, progress is being made as evidenced by the local policy documents of South Gloucestershire District Council, Leicester City Council and Harrow Borough Council, all of which promote the use of SuDS in their local plans and who have produced guidelines for developers in association with the Environment Agency.

Partnership Agency/Planning Authority approaches would undoubtedly help in the promotion of SuDS best practice. This promotional policy approach to planners (and developers) has already being implemented to some extent with the issue of the joint UK regulatory authority booklet on sustainable urban drainage systems (SEPA, EA, and E & HS, 2000). However, this booklet only provides a rudimentary description of the various SuDS techniques and contains no design criteria or other technical specifications. A current Environment Agency national Working Group is looking at the issue of adoption, liability and maintenance of SuDS which may recommend relevant technical and administrative detail for their promotion. HR Wallingford have recently completed an R&D project commissioned by DETR on surface water runoff management and control which incorporates issues relating to development site storage and "allowable runoff" to receiving water bodies (“*Storage Requirements for Rainfall-Runoff from Greenfield Development Sites*”, Report SR580, May 2001). The design philosophy and procedure being advocated is that of permanent retention storage (over temporary detention) with slow release rates and/or source infiltration in order to achieve concepts of sustainability and downstream river protection during extreme events. This procedural advice is currently being reviewed by the Agency.

Discussion and consultation approaches have been successful in Scotland (see Section 6.3.2) with some Planning Authorities taking very positive attitudes towards SuDS e.g West Lothian highlighting surface water as an issue in their Bathgate Area Local Plan. The latest draft of the Stirling and Fife Council Planning Advice Note, "*Planning and Environmental Law*" states that the prevention of urban pollution by surface runoff requires the adoption of best practice and SuDS approaches. In Scotland, SUDSWP comprises a partnership of representatives from SEPA, local and water authorities, government and development interests and a model Framework Agreement for adoption and maintenance has been drawn up. Nevertheless, local authority responses are constrained to some extent because there is no obvious income stream associated with SuDS and their maintenance, and it is not apparent if flood defence spending for example, might be used (see Section 6.3.2). It may be possible for some local authorities to utilise approaches that have been used for other rather more familiar issues such as maintenance and management charges for flat blocks, open spaces etc.. In Bournemouth for example, Section 106 funding has been used to finance swale installations on retrofitted development.

DTLR PPG 25 (July 2001) "*Development and Flood Risk*" specifically refers to surface water drainage and SuDS which should be helpful in this dialogue between the Agency and Planning Authorities:

- "*all proposals for development should take account of potentially increased runoff*"

- "*local planning authorities should consider the need for policies which encourage the use in appropriate areas of more sustainable drainage systems to control runoff as near as possible to source*"
- "*guidance that all new developments should, as far as possible incorporate sustainable drainage measures*"
- "*surface water will need to be discussed with the Environment Agency and Sewerage Undertakers during the development and preparation of plans*"

PPG 25 emphasises the precautionary risk-based approach to ensure a stronger emphasis on planning in relation to river catchments at all stages in the plan-making process. In addition, DEFRA is now considering the possibility of following-up PPG25 with a consultative Flooding Direction which would ensure that the views of the Environment Agency on urban development flood risk and associated problems are properly considered. It is quite likely that such re-considerations of flood defence will include recommendations for retrofitting upstream source controls rather than focusing exclusively on downstream flood walls and embankments etc. The recent HR Wallingford report (SR 580) commissioned by DETR on "allowable runoff" from new development recommends the use of permanent or at least long term storage with slow rate of release and/or infiltration for protection from downstream receiving water flooding. Constructed wetlands linked in a series of cells and with adjustable outlet controls to provide an appropriate working range of water levels, could provide such long term, slow release. Where groundwater conditions are suitable, treated wetland discharges might also be directly infiltrated to ground. Such combined long term storage and treatment, slow release and infiltration could help to achieve more effective downstream flood and water quality protection providing a more sustainable receiving water regime.

SuDS Implementation and Developers

It is clear that developers are becoming more familiar with, and more willing to consider, SuDS construction. Developers will construct what is necessary, so long as the necessary design requirements can be taken account of when negotiating the land purchase price. However, they tend not to consult with the Agency until after land purchase and they are consequently under pressure to avoid any land-take which would be detrimental to the number of development units. Delays caused by disagreements between the Agency, the Water Companies and the Highways Agency (and/or County/District Highway Authorities) are also a frequent cause for complaint. Smaller developers commonly do not have the technical back-up to provide SuDS designs and complain that the Agency cannot provide clear design specifications or that suitably experienced consultants and landscape architects are not readily available. Closer liason and interaction between the regulatory authorities and the UK House Building Federation might help to facilitate a better understanding of the major issues.

The interpretation of the existing Building Regulations can be a source of problems for the construction of SuDS drainage systems which do not have clearly UK-defined construction standards. Most available design manuals principally relate to American conditions and the most recent UK regulatory authority SuDS publications (CIRIA, 2000a and b; SEPA, EA and E & HS, 2000), contain no construction guidance although some mainstream software products such as MicroDrainage and R-Win are now becoming available which address basic SuDS design (Ashley *et al*., 1998). The

April 2002 revisions to the Building Regulations (Part H2) and the proposed new Part M of the Technical Standards for compliance with the Building Standards (Scotland) Regulations 1990, as amended, both make reference to the need for a hierarchy of sustainable connections for surface water on new building developments. The suggested hierarchy recommends source control (infiltration), then passive treatment (swales, ponds, wetlands) followed by direct discharge to watercourse and failing this, recourse then made to sewered connection. Guidance on SuDS is included in the approved documents with specific reference to the use of reed beds for treating wastewater, greywater and surface runoff (Grant and Griggs, 2001).

SuDS Implementation and the Water Companies
Water Companies and especially those such as Thames, North West and Severn Trent who face particular problems with urban surface water drainage, represent another important target group and discussion Workshops/Seminars might provide an effective forum for airing Agency concerns. It is not clear however, to what extent such initiatives would be welcome by the Water Companies and it may be more effective to ensure good support and back-up for Agency staff involved with routine discussions about sites. Water Company PLCs are somewhat constrained because they need OFWAT to formally recognise SuDS as drainage assets. Recent OFWAT statements in this regard are very encouraging although it also raises the legal difficulty about the definition of sewers capable of adoption. Surface water drainage is already charged for by the water companies and there is resistance to provide treatment for discharges which have hitherto been discharged directly. Thus any additional charge for implementation of SuDS infrastructures could be viewed as an impediment as such discharges might then essentially be regarded as trade effluent. The water service companies are also becoming increasingly committed to such surface water source control approaches which seek to divert and control rainfall-runoff at source (see box). It might also be feasible for the Agency to discuss with the Water Companies and OFWAT the relative merits of setting baseline service-level targets for the introduction of SuDS such that for example, 5% - 10% of Water Company AMP4 capital investment should incorporate sustainable drainage approaches.

Surface Water Source Control: Policy Statement
July 1998. Thames Water
- seek to ensure that new connections to the public sewerage system do not pose an unacceptable threat of surcharge, flooding or pollution
- with advice from DETR, we will encourage ....sustainable infrastructure development which does not involve discharge to the public sewerage system.
- we recognise that it is preferable to use locally available watercourses, with attenuation or soakaways to drain the surface water runoff from sites.

The major concerns of many of the Water Companies are associated with adoption issues, SuDS design specification and their "unknown" maintenance requirements. It is not clear for example, whether the forthcoming 5th Edition of "*Sewers for Adoption*" will make any reference to the issue of SuDS adoption. On the other hand, indications are that both capital and maintenance costs for SuDS are less than would be incurred by traditional drainage and mechanical treatment systems. Water Companies in England & Wales might consider the East of Scotland Water Authority example of requiring developers to finance capital costs and provide a financial bond to cover future maintenance requirements. However, some Water Companies consider that the answer lies in more separation of contaminated sources of runoff rather than in novel pollution attenuation and treatment systems.

SuDS Implementation and Highway Drainage

The responsible highway authority for motorways and trunk roads in the UK was the former Department of Transport (DoT) but this has passed to the Secretary of State for the Environment, Transport & Regions who delegates responsibility to the Highways Agency. The operational management of trunk roads is distributed on a regional basis to appointed managing agents. For most other roads, the county council (or London Borough) is the designated authority although delegation often occurs to a district council to administer local residential roads. The specific powers vested in a county council in respect of highways are indicated in the box and the council will also be consulted for views on planning applications for development when flows to a watercourse from highway drains is substantial. There is provision under Section 21 of the 1936 Public Health Act and the 1991 Water Industry Act for the dual use of highway drains or public sewers for the combined drainage of surface waters from roads and domestic (non-commercial) properties. The joint-use procedure and cost-apportionment is covered by the 1981 National Water Council (NWC) "*Guideline Memorandum on Relationships between Water Authorities and Highway Authorities*". The ownership arrangements and continued use of such highway drains is covered by Section 264 of the 1980 Highways Act. However, Water Companies generally resist the connection of road drainage to public sewers particularly if any treatment is specified by the Environment Agency. Where road drains are used jointly for highway and property drainage, those lengths in joint use are normally adopted under Section 38 of the 1980 Highways Act by the sewerage undertaker. However, many developers favour the construction of highway drains in parallel with public sewers for domestic surface water drainage with each discharging separately to the same watercourse and even three pipe systems have been talked about for future development on difficult urban sites. In these circumstances, a highway drain is a private drain owned by the highway authority and may not be requisitioned. Undoubtedly, modification in the statutory regime controlling surface water drainage to clarify issues of ownership, adoption, joint use as well as other mainstream issues would appear to be overdue.

County Council Highway Powers. 1980 Highways Act.

- *s.38*: power to adopt a highway drain constructed by others
- *s.100*: power to prevent water flowing into a highway and power to drain water from a highway
- *s.101*: power to pipe or fill in roadside ditches, subject to drainage authority consent
- *s.110*: power to divert a watercourse after consulting the district council
- *s.339*: power to require developers to obtain consent for any works or the use of a watercourse for highway drainage.

The right to discharge surface water runoff from roads to receiving waters through highway drains (which include ditches, gutters, culverts, pipes and soakaways), is established in the 1980 Highways Act (Section 100). Under Section 89(5) of the 1991 Water Resources Act, the highways authority does not require the statutory defence of a discharge consent. However, under a liaison agreement, the measures (which could include SuDS) required to prevent or alleviate pollution will be agreed through consultation between the Agency and the highways authority or its agent prior to construction under the various provisions contained in the 1990 Town & Country Planning Act and the 1991 Town & Country Planning (Development Plan) Regulations.

Section 89(5), 1991 Water Resource s Act

"A highway authority or other person entitled to keep open a drain by virtue of Section 100 of the Highways Act 1980 shall not be guilty of a offence under Section 95 by reason of his causing or permitting any discharge to be made from a drain kept open by virtue of that section unless the discharge is made in contravention of a prohibition imposed under Section 86"

The planning legislation allows the Environment Agency to make representation opposing development projects (including new or improved highways), which are likely to have an unacceptable impact upon the aquatic environment, and Planning Policy Guidance (PPG) 12 provides background information on pollution prevention and surface runoff control. In addition, there is a policy implementation guidance note (SC/CC/014; September 1992) for highway discharge. For certain classes of development, the Agency will be a statutory consultee under the 1988 General Development Order and a local planning authority is bound (Article 18, GDO 1988) to take recommendations from such a consultee into consideration when making a determination on a specific development application. Additionally, local authority Unitary Development Plans (UDPs) are required to take into account the environmental implications of direct discharges to ground and specific requirements may be imposed by the Agency in relation to groundwater protection (under the 1998 Environment Agency "*Policy and Practice for the Protection of Groundwater*"). However, the Agency could choose to apply the provisions of Section 86 to serve a Conditional or an Absolute Prohibition Notice (see Section 6.3.1) to an existing or proposed highway drain if it saw fit to do so because of some particular pollution hazard. This could either require that a consent be obtained (under Schedule 10, para. 5(1), WRA 1991) or alternatively it may specify the conditions to be observed prior to the making of the discharge.

Whilst there may still be some misunderstandings between, and lack of knowledge about, the specific powers and roles of the various highway authorities due to the complex enveloping legal and administrative frameworks, it is quite evident that all the agencies are becoming increasingly aware of their responsibilities in respect of pollution control from highway discharges. The concern of the national regulatory bodies is reflected for example in the 1993 NRA guidance notes (SC/CC/014) on "*Drainage from Motorways, Highways and Other Roads*" intended to facilitate integration of specialist engineering, geomorphological and ecological knowledge into the design and implementation of highway drainage structures. The Environment Agency Thames Region has also recently published (1999) an interim guidance manual on the "*Treatment of Highway Runoff Using Constructed Wetlands*" intended to encourage alternative control and treatment approaches for highway drainage. Whilst the Highways Agency have been rather cautious in their approach to the use of vegetated treatment systems for the control and management of highway runoff, a new Advice Note covering this theme is now included within a new update to Section 2 (Drainage, HA 103/01), Volume 4 of the DMRB.

The Highways Agency have developed more specific guidance on pollution control for highway drainage through incorporation of a new section (Section 3, Part 10) on Water Quality and Drainage within Volume 11, "*Environmental Assessment*" in an update to the previous 1993 DoT/DoE "The Good Roads Guide" section of the "*Design Manual for Roads and Bridges*" (DMRB). SuDS structures are referred to in this DMRB update although no detailed design or construction guidance is provided and there is no agreement as to when they should be applied. A recent publication by the Institution of Highways & Transportation (2001) also recommends SuDS best practice structures for the control and management of road and highway runoff and provides more detail on their relative benefits over conventional gutter-kerb-sewer drainage systems. Whilst the adoption of such SuDS technology may well have resource implications for the highway authorities, coordinated approaches need to be adopted and maintained with the Environment Agency and other nature conservation bodies, to pursue the implementation and evaluation of such best practice. In addition, some modification in the statutory regime controlling surface water drainage, to clarify issues of ownership, adoption and joint use, would be beneficial.

SuDS Implementation and Stakeholder Partnerships
The evolution of water resource management under the Water Framework Directive towards an eco-centric, holistic approach to catchment management requires the sharing, coordination and integration of values and inputs from a broad range of agencies, public and other organisations when conceiving, designing and implementing policies, programmes or projects. Local community interest and general public support will be crucial in effectively achieving the goals of integrated urban catchment management under the Directive. Partnership approaches involving representatives of all stakeholder organisations (regulatory authority, water utilities, local authorities, housebuilders, developers and government) have been successful within a Scottish SuDS Working Party in implementing best practice technology for urban stormwater management. Such partnership approaches were considered essential because SuDS technology is not just about water quality, but also seeks to address quantity, amenity and habitat issues. The partnership approach has resulted in the production of a policy document (Policy No.15, 1997) covering the "*Regulation of Urban Drainage*" and SEPA is currently producing a discussion document to provide a view of the future development of surface water drainage policy. This will identify options for future policy covering urban development and its effects on the urban environment. Similar stakeholder partnerships might be encouraged within the Agency Regions in order to help overcome institutional inertia and hostility to "new" approaches and to help integrate SuDS into overall river basin management planning.

Such partnership efforts are likely to primarily focus on new greenfield development in order to prevent existing urban diffuse pollution problems from becoming bigger. To resolve the worst problems within existing urban developments, such as drainage from industrial/commercial estates, the Agency will need to work with the water utilities to identify the worst case impacts and to seek treatment measures where no alternatives are possible, in addition to conventional best "housekeeping" practice (such as bunding oil tanks). Potential approaches to the control and management of diffuse urban oil pollution from industrial and commercial premises, utilising a combination of SuDS and internal "housekeeping" containment measures, have already been identified (Ellis and Chatfield, 2001). Such control and treatment requirements should be sought by the Agency under existing statutes, in order to meet the requirements of the Water Framework Directive to have "*measures to prevent or mitigate the impact of diffuse pollutants*".

Whilst a pro-active approach to the implementation of SuDS technology is desirable, any imposition of Agency views or policy is likely to cause resentment amongst stakeholder groups. Concerns have been expressed in Scotland by most of the parties involved in urban development over a lack of consultation prior to SEPA's promotion of SuDS best practice. To some extent, this resentment will be inevitable, as many local and highway authorities in particular are not initially prepared to consider the issue. Thus it is necessary to raise the profile of urban surface water drainage and run education and training programmes on the potential of SuDS best practice. Where the issues of surface water become understood and appreciated, there is considerable potential for a more collaborative and partnership approach to future policy development. Inevitably there is a difficult balance to be sought between the regulatory lead role that the Environment Agency must take to promote a new philosophy, and the collaborative process which must subsequently develop if the process is to be successfully applied.

Key Issues

- application of sediment quality standards to urban wetlands.
- role of the Water Framework Directive (WFD) for future management of urban diffuse pollution and implications for SuDS (and wetland) provision.
- use of “General Binding Rules” for managing urban diffuse pollution and potential amendments/updating of PPGs to incorporate SuDS.
- formal development of integrated coordination of SuDS into the local authority development plan process and stakeholder partnership agreements.
- clarification of surface water sewer ownership, adoption and joint use issues.

7. DECISION SUPPORT APPROACHES FOR URBAN WETLANDS

7.1 Introduction: Towards a Multi-Criteria Approach

Whilst urban wetlands have been included as generic source control structures conforming to the principles of SuDS (SEPA, EA and E & HS, 2000; CIRIA, 2000a and b), there is no clear evidence of their self-sustainability in terms of long term pressure-response feedback loops. In the US, Scandinavia and Australia/New Zealand, the sustainability of such wetland systems is not invoked as a basic driver reason for their adoption. The national US manual for urban runoff quality control (WEF/ASCE, 1998) only refers to best management practice, whilst Australian/New Zealand urban drainage practice refers to environmentally-sensitive drainage systems. The evaluation of SuDS sustainability and self-purification to date has been mainly empirical and subjective in nature and lacking in the development and application of robust quantifiable sustainability criteria and indicators, particularly in respect of long-term performance, effects and costs.

At the same time, the UK government water regulator (OFWAT) currently has no statutory duty to incorporate sustainability or to anticipate future undefined regulations in respect of diffuse urban pollution. Hence, sustainability issues are not properly reflected in the way in which performance targets are set and the financial determinations only allow for the achievement of current performance standards within short 5 year time scales. OFWAT presumes that longer term considerations are dealt with by other partners in the regulatory process such as the Environment Agency and DEFRA. Yet it is becoming clear that traditional cost-benefit approaches to evaluating appropriate levels of service delivered at acceptable performance standards are being replaced by consideration of whole-life cycle costing. Given the increasing emphasis on service provision over and above asset ownership and operation, it is also becoming increasingly important to ensure that levels of service, serviceability targets and related performance measures provide adequate safeguards for whole life service provision. It is within this context that decisions need to be made regarding asset investment for wetland SuDS and which fully recognise contemporary decision-making processes as well as environmental, institutional, planning and regulatory constraints. Methodologies are needed to support decisions on preferred approaches which may reduce the cost of urban stormwater infrastructures whilst maintaining socially acceptable levels of service and minimising adverse environmental impacts. The biggest challenge to water service providers (WSPs) will be to convince stakeholders, particularly customers and financial regulators, that full cost water services include whole-life asset investments.

A number of workers have recently presented approaches for stormwater management which utilise universal or over-arching sustainability criteria or what might be termed sustainable system conditions. Such principles and conditions are taken to define the limiting constraints or aspirations by which sustainable urban drainage may be achieved (Crabtree, 2000; Everard and Street, 2001). Such approaches reference sustainable criteria against the release, pathways and transfer of pollutants; use of materials and energy; health, safety and maintenance issues; as well as institutional, regulatory and social factors. The approaches therefore acknowledge the complexity and uncertainty surrounding the decision-making processes associated with urban stormwater management and the proposed methodologies utilise formal multicriteria analysis techniques which can trade-off mandatory against more sustainable criteria.

Sustainability criteria for urban wetlands must be similarly referenced against those parameters related to all three elements of the SuDS triangle; water quantity, water quality and amenity. Thus, design and construction, environmental/ecological impact, operation and maintenance, health and safety, social/urban (community/amenity) and economic issues become prime potential sustainability criteria to facilitate comparisons and accreditation of drainage options with regard to capital cost, resource use, acceptability, performance, maintenance etc. However, the criteria which relate to the technical, environmental, biotic, social and economic dimensions of the SuDS triangle, have disparate and non-commensurate units of measurement (Ashley *et al*, 2001a) and are not readily amenable to deterministic approaches. It is therefore appropriate, if not necessary, to evaluate the sustainability of urban wetland systems against multi-criteria and multi-objectives placed within an overall subjective decision-support framework. The subjectivity of such a decision-making process is intrinsic in terms of the uncertainties associated with the various organisations and stakeholders involved in the decision-making process as well as the inherent variability observed in the controlling environmental processes.

7.2 Defining Primary Criteria, Indicators and Benchmarks

The primary components in the structure of any decision-support process must reference and define generic performance criteria together with appropriate supporting multi-criteria decision-making parameters. Any listing of primary (or secondary) criteria will inevitably be arbitrary to some degree, but such categorisations need to be generic, inclusive, flexible and dynamic if they are to support decision makers and stakeholders in selecting and comparing drainage system options intended to meet specified objectives.

Such multi-criteria approaches must be flexible and dynamic in order that they can be adapted and reviewed to meet changing circumstances and constraints within organisations, regulations and customers, and the same is true of technical and scientific knowledge of the operating systems. The application of multi-criteria analysis should also incorporate a risk and sensitivity assessment stage in terms of determining which options are more likely to be the more sustainable under uncertain and variable conditions.

It must also be recognised that such multi-criteria methodologies should, where appropriate, be capable of evaluating the "do-nothing" option as well as that offered by conventional drainage systems. In addition, it must be acknowledged that the final decision may well be driven or at least constrained by specific local considerations and hence result in a preferred option which may not be the most sustainable. Table 7.1 outlines a possible listing of primary generic criteria which might be universally acceptable as being basic sustainability indicators in the asset investment decision for urban wetland SuDS. The listing is compatible with existing methodologies which are being currently tested elsewhere within the UK water industry in conjunction with the EPSRC/UKWIR funded Sustainable Water Asset Resource Decisions (SWARD)

Table 7.1 Sustainability Criteria and Indicators for Urban Wetlands and SuDS

Category	Primary Criteria	Secondary Criteria	Possible Benchmarking Standards
Technical and Scientific Performance	• System performance (Quantity and Quality)	• (i) Storage and Flooding (ii) Receiving water quality	• (i) Design storm return interval (RI) storage volume; No. of floods per year and/or properties affected; Downstream protection value; Disruption time/costs (ii) Pollutant concentration probability exceedance; Firstflush capture potential (10/15mm effective runoff treatment for all storms); %age compliance with RQOs/consents etc.; No. of complaints; %age storm events captured for treatment; Pollutant degradation rates
	• System reliability	• Performance reliability, failure, health and safety	• %age pollutant removal; In-basin quality and health risk (eutrophication, odorous sediment, stagnant water , bacteriology etc..); Likelihood/risk of failure; Operational safety
	• System durability	• Design life	• Operational lifetime (storage volumes; sediment accumulation rates)
	• System flexibility and adaptability	• Capability for change over time including retrofitting	• Design freeboard (storage and water quality); Costs and ease of retrofitting and/or add-on structures and features
Environmental Impacts	• Water volume impact	• Flooding	• Drawdown times; Dilution ratios; Downstream erosion; Frequency of by-pass operation
	• Water quality impact	• Pollution control	• Treatment retention times; Litter/Gross solids; RW RE classification; Compliance with RQO and receiving water (RW) standards; Maintenance of lowflow status
	• Ecological impact	• Habitat and ecological diversity	• RW BMWP/ASPT scores; No. of key species and alien species introduced; SuDS ecological and conservation status (total flora/fauna); role in BAPs; PYSM eco-quality assessment
	• Resource use	• (i) Land use (ii) Material use (iii) Energy use (iv) Chemicals	• (i) Land take (area/cost); No. and value of development units lost (ii) Aggregates/concrete/top-soil/appurtenances use and costs (iii) Construction/O & M energy consumption (iv) On-site herbicide/pesticide applications
	• Maintenance, servicing provision and responsibilities	• O & M requirements	• Need and frequency for O & M servicing to maintain technical/environmental/amenity/habitat objectives • Need for monitoring (water quality, plant health etc)
Social and Urban Community Benefits	• Amenity; aesthetics, access and community benefits	• Social inclusion	• Community benefits (assessment of amenity--boating/fishing/recreation; access; aesthetics); No. of visits; Quality of life enhancement; Population and groups served
	• Public information, education and awareness	• Public awareness and understanding	• Information provided (Interpretation boards; visitor centres; signage); Knowledge in local community; Ranger service/Voluntary group participation; Demonstration site use
	• Stakeholder acceptability (perception and attitudes of risks and benefits)	• Perceived acceptability and impacts	• Willingness-to-adopt; Assessment of %age concerns (health/safety); Assessment of %age improvements gained; Awareness of risks
	• Health and safety risks	• Risk audits	• Probability of infection and safety risks; risk exposure audits; service/amenity outage times
Economic Costings	• Life cycle costs	• Investment and operational costs	• Design, capital, O & M and maintenance costs; Disposal and decommissioning costs; Other material and production costs
	• Financial risks	• Risk exposure	• C/B Analysis; Investment loss risk; Site reclaim value
	• Affordability	• Long term affordability	• Adoption and liability costs/risks; Amenity income streams (willingness-to-pay); Long term amenity costs • Economic add-on value (enhanced land/property values)

project (Ashley *et al*., 2001a) as well as with benchmarking criteria included in the government sustainability agenda (DETR, 2001). Table 7.1 also identifies a range of secondary indicators and benchmark "standards" against which a specific wetland or other SuDS structure or set of drainage options might be assessed. The methodology can also be applied to conventional kerb-gutter-gulley and pipe systems either as a stand-alone drainage option or in combination with a variety of SuDS structures in a treatment-train approach.

This multi-criteria approach has the advantage of being readily amenable to conventional spread sheet application which in turn facilitates the assessment of drainage options where one primary criterion e.g investment and/or O&M costing may be the predominant consideration or constraint. The multi-criteria matrix requires a mix of quantitative and qualitative measures some of which will have well defined numerical values (both dimensional and non-dimensional), whilst others will remain essentially descriptive (and frequently subjective) in nature, perhaps defined only by presence/absence notation. The listing could also provide a suitable basis for developing holistic accreditation criteria for assessing the relative sustainability of any existing urban wetland or other SuDS structures as well as providing a basis for post-project evaluation of sustainability gains achieved following the introduction of a SuDS initiative within an urban development.

7.3 Applying a Multi-Criteria Approach

Once the objectives of a specific scheme have been identified as a basis for a decision on the adoption of varying drainage options for an urban development (or re-development in the case of a retrofitting design), the multi-criteria approach can be implemented as illustrated in Figure 7.1. As indicated in the figure, the methodology can be single or multi-objective although the emphasis in the following detail and discussion is placed on stormwater treatment. The figure does not show the detail of the various phases involved during application, but these should include: risk and sensitivity assessment and detailed data collection and analysis covering both qualitative and quantitative elements in the key technical-environmental-social-economic components as needed.

If the multi-criteria methodology was being applied for the purpose of assessing the relative sustainability of an existing urban wetland or SuDS structure(s), then only Stages 3 to 5 need be worked through. Accreditation schemes for existing urban wetlands or SuDS structures would similarly only need to consider Stages 3 to 5. One deficiency in this sort of post-project approach for a stand-alone drainage option, would be that it is not clear how the outcome of the analysis might be interpreted given our present state of knowledge on the relative sustainability of differing urban drainage options. What is the absolute or target level of sustainability for a given set of criteria and benchmark standards against which the relative performance of differing drainage options might be matched and judged? The existing project has not been able (within the constraints of time and funding) to undertake any detailed case studies of the multi-criteria methodology in order to obtain a feel for the potential range of outcome values for differing combinations of urban wetland types or other

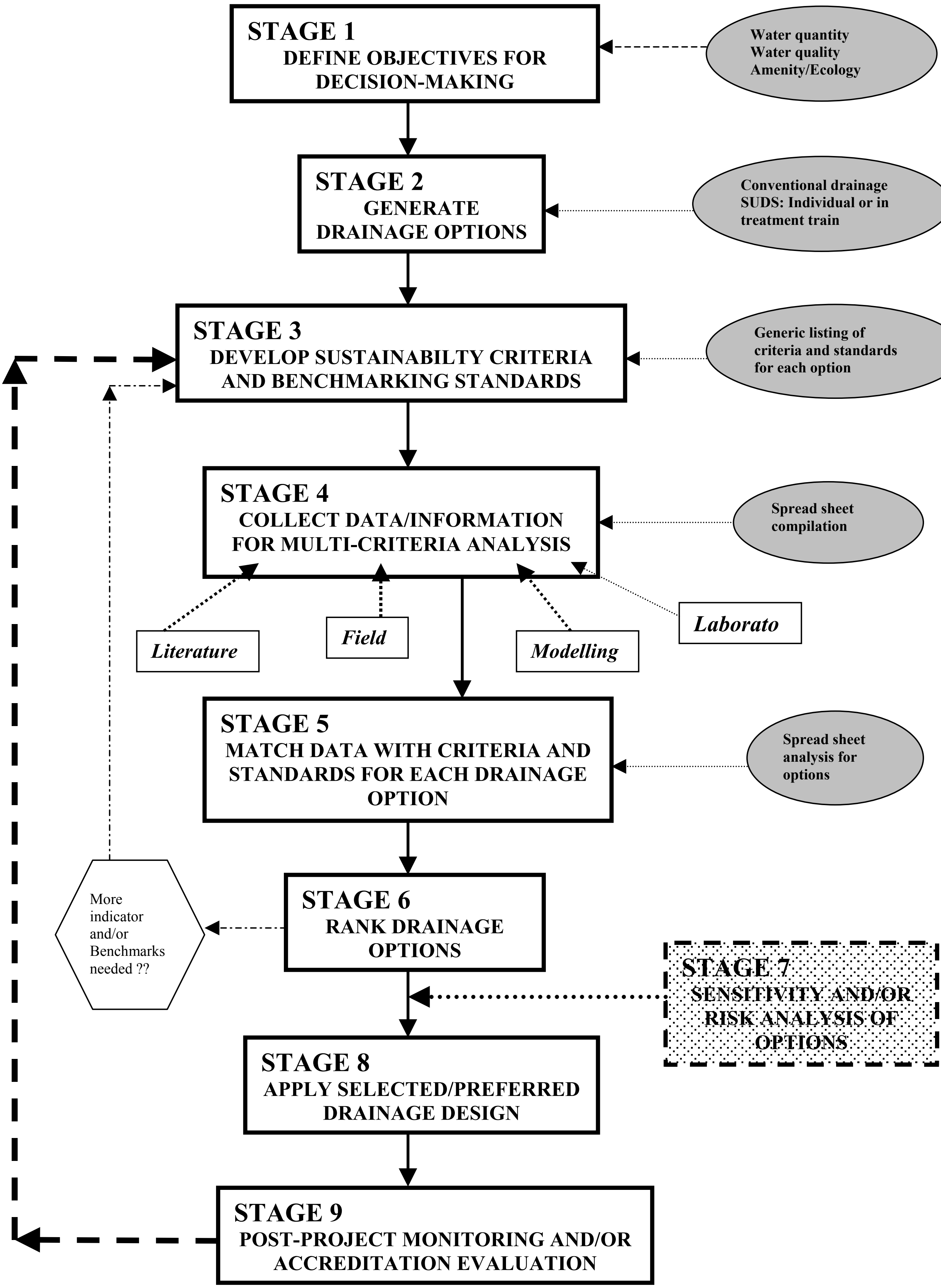


Figure 7.1 Multi-Criteria Analysis for the Evaluation of Urban Runoff Control and Treatment Options

SuDS structures. However, a simplified trial of the (lower level) methodology has been attempted in Section 7.5 for a relatively small constructed wetland intended to treat highway runoff. Irrespective of any reservations, multi-criteria analysis does offer a credible and standardised methodology of decision-support which is readily understandable from both regulatory and public awareness viewpoints, and which at the same time can provide a relatively simple framework within which the developer and local authority can work.

It is clear from examination of the nature and range of potential benchmarking standards that further consideration needs to be given to this set of indicator criteria. It would take considerable time, effort and cost to generate data and values for all the benchmark parameters listed in Table 7.1. In many cases, some of the listed data may be impossible to quantify or obtain on an individual basis e.g quite frequently resource costs (land take, design, material and energy consumption costs) in addition to life cycle costs are aggregated into a single lump sum. The costs of undertaking attitudinal and behavioural surveys to obtain information on community benefits and stakeholder acceptability or detailed Cost-Benefit Analysis, may well be prohibitive for first-time urban drainage or retrofitting schemes, although it may be possible even here to have recourse to literature evidence such as that provided by Apostolaki *et al.*, (2001) and Mungur (1997). Further research is certainly needed to test and refine the validity and robustness of various benchmarking standards and it might be appropriate and feasible to develop a two-tier multi-criteria approach. A lower level methodology would apply a minimum of readily derived benchmarking standards, but covering those which are considered as being essential and pivotal to deriving a meaningful yardstick overall measure of sustainability. The lower level benchmark parameters should essentially include:

- measures of hydraulic performance (e.g rate, volume, RI),
- pollution control (e.g retention time, prevention of adverse impacts--seasonal, chronic or accidental),
- ecological impact (e.g diversity, conservation etc),
- multifunctionality (e.g site constraints, social/urban uses, landscaping etc),
- costs (e.g capital, O&M)
- and operation/control indicators.

Further work is needed to prioritise these parameters and to verify their indicator values for general usage. In addition, this lower level approach could serve as a screening stage to narrow down to a small range of preferred options for more detailed consideration. A higher level methodology could be utilised for high-investment, high-impact schemes or for drainage options in locations where a full range and detail of information/data was known to be available.

7.4 Benchmark Indicator Standards

As previously noted, there are a multitude of potential benchmarking standards that can be used as criteria measures, index values or baseline information, but there is no clearly identifiable national forum that can readily arbitrate on which parameters should be prioritised. It is obvious that long term performance, health and safety together with O&M requirements are prime benchmark indicators which need to be much more fully determined before the sustainability of urban wetlands or other SuDS structures can be championed in an unqualified manner (Ellis, 2000; Crabtree,

Table 7.2a Technical & Scientific Benchmark Indicators

Primary Criteria	Secondary Criteria	Benchmark Standards Indicator Values/Indices/Baseline Information	Units
System Performance	(i)Storage and Flooding (ii)Receiving Water Quality	(i) - Design storm Return Interval (RI; 1,5,10, 25….yrs) storage volume - Runoff:Basin volume - Number of floods per year within catchment - Number of properties affected within catchment during flooding - Disruption time/costs - Downstream protection value (ii) - Pollutant concentration probability exceedance for given target levels - Firstflush capture potential (10/15mm effective runoff treatment for all storms) - %age storm events captured for treatment - %age compliance with consent/receiving water WQOs - Number of pollution (in-basin/receiving water) complaints	m^3/ha (**N**) Ratio (**N**) 1…..n (**N**) 1…..n (**N**) d/yr;£/yr (**N**); H/M/L (**D**) H/M/L (**D**) mg/l (**N**) mmrunoff/av. storm event (**N**) %/yr (**N**) %/yr (**N**) %/yr (**N**)
System Reliability	Performance Reliability, Failure, Health & Safety	- %age pollutant removal (for specified pollutants) - Hydraulic retention time - In-basin quality condition and health hazards - Uniform flow distribution - Likelihood of system failure; alarm/intervention procedures - Safety level/provision for accidental pollution etc - Plant health	Av. %/yr; %/storm event (**N**) Hours (**N**) Trophic state; smell; stagnant water condition, bacteriology etc (**D**) H/M/L (**D**) Probability (**D**) H/M/L (**D**) H/M/L (**D**)
System Durability	Design Life	- Operational lifetime - Sedimentation rates - Storage volume	Yrs (**D**) m^3/yr (**N**) % reduction per annum storage volume (**N**)
System Flexibility and adaptability	Capability for Change over Time	- Design freeboard for storage and water quality change - Ease of retrofitting and modification - Costs of retrofitting and add-on structures/features	%; m^3/lifetime (**N**) H/M/L (**D**) £ (av.cost) (**N**)

Table 7.2b Environmental Impacts Benchmark Indicators

Primary Criteria	Secondary Criteria	Benchmark Standards Indicator Values/Indices/Baseline Information	Units
Water Volume Impact	Flooding	- Drawdown times - Dilution ratios - Downstream erosion - Frequency of by-pass operation	Hrs (**N**) Ratio (**N**) H/M/L (**D**) %/yr (**N**)
Water quality Impact	Pollution Control	- Treatment retention times - Litter/gross solids; floating matter; surface oils - Receiving water classification (RE score) - Compliance with RQOs and receiving water standards - Low flow status	Hrs/av. storm event (**N**) H/M/L (**D**) RE1……..5 (**D**) %/yr (**N**) d/m^3 (**N**)
Ecological Impact	Habitat and Ecological Diversity	- Receiving water BMWP/ASTP hydrobiological scores - Number of wetland key species introduced - Number of wetland alien species introduced - Conservation status (plant/insect/invertebrate/mammal) - Role in local/regional/national BAPs - PYSM eco-quality wetland assessment	1….n (**N**) 1….n (**N**) 1….n (**N**) H/M/L (**D**) H/M/L (**D**) 1…..n (**N**)
Resource Use	(i) Land use (ii) Material use (iii) Energy use (iv)Chemicals	(i) - Land take (area/cost) - Number (and/or cost) of development units/space lost (ii) - Aggregate/concrete/top-soil/appurtenances use and costs (iii)- Construction and O & M energy consumption (iv)- On-site herbicide/pesticide applications	m^2; £ (**N**) 1……n; £ (**N**) H/M/L (**D**); £ (**N**) kW; kW/m^3 storage; £ (**N**) No./yr; litres/yr; £/yr (**N**)
Maintenance and Servicing Provision	O & M requirements	- Need and frequency for O & M servicing to maintain technical/ environmental/amenity/habitat objectives - Plant replacement - Sedimentation rate/sediment disposal	H/M/L (**D**) Freq/yr; £/yr (**N**) Freq/yr; £/yr;£ (**N**) m^3/yr; £ (**N**)

Table 7.2c Social and Urban Community Benefits Benchmark Indicators

Primary Criteria	Secondary Criteria	Benchmark Standards Indicator Values/Indices/Baseline Information	Units
Amenity; Aesthetics; Access and Community Benefits	Social Inclusion	- Level of amenity provision (fishing, boating, recreation etc) - Increased access provision - Community participation (Ranger service, volunteer groups etc); Numbers of visitors etc. - Formal community recognition, and/or designation (Visitor centre; Nature trails; birdwatching; environmental days etc) - Creation of new water features	H/M/L **(D)** H/M/L **(D)** H/M/L (**D**); Nos/year (**N**) H/M/L **(D)** H/M/L **(D)**
Public Information and Awareness	Public Awareness and Understanding	- Interpretation boards, signage, brochures/literature, visitors centre etc - Awareness in local/regional community - Use as educational site - Use as technical demonstration site	H/M/L **(D)** % awareness survey **(N)** Nos. of site visits **(N)** Site visits/Enquiries **(N)**
Stakeholder Acceptability	Perceived Acceptability and Impacts	- Local community willingness-to-pay - Perception of environmental benefits/risks - Assessment of improvements gained	£/visit **(N)** %user survey **(N)** % user survey **(N)**
Health and Safety Risks	Risk Audits	- Local community concerns (injury, infection, drowning etc) - Formal technical risk exposure audit (flood risk, health risk, safety risk, water quality, litter, habitat creation, maintenance/management etc)	% user survey **(N)** H/M/L **(D)**

Table 7.2d Economic Costings Benchmark Indicators

Primary Criteria	Secondary Criteria	Benchmark Standards Indicator Values/Indices/Baseline Information	Units
Life Cycle Costs	Investment and Operational Costs	- Design and capital costs - Operational & Maintenance costs - Plant replacement costs - Sediment monitoring and disposal costs - Site decommissioning costs	£ **(N)** £/yr; £ **(N)** £ **(N)** £ **(N)** £ **(N)**
Financial Risks	Risk Exposure	- Cost-Benefit analysis - Investment loss risk - Site reclaim value	C:B ratio **(N)** H/M/L (**D**); £ **(N)** H/M/L (**D**); £ **(N)**
Affordability	Long Term Affordability	- Adoption and liability coverage - Economic add-on value (enhanced land/property values) - Amenity income streams - Long term management provision and costs	H/M/L (**D**); £ **(N)** £ **(N)** £/year **(N)** H/M/L (**D**); £/yr; £ **(N)**

NOTES: **(N)** Numeric measurement unit
(D) Descriptive measurement unit
H High value/impact
M Medium value/impact
L Low value/impct

2000; Ashley *et al.*, 2001a). However, these indicators will require a substantial amount of good quality post-project monitoring which presently does not seem to be forthcoming, although the Scottish SuDS database being developed under the funding aegis of SEPA is beginning to yield useful short to medium term performance information (McKissock *et al.*, 1999). It is beyond the remit of the current project to undertake a comprehensive expert system (e.g DELPHI-type) benchmark survey of the various stakeholder groups involved, and having interest, in urban wetland SuDS. However, this should be included in the objectives of any further research on SuDS decision-support frameworks in order to calibrate the methodology and provide an approved standardised basis for acceptable evaluation and accreditation procedures.

Tables 7.2a to d provide, for each of the four main categories, a structured framework for some of the benchmark indicator standards and possible measurement "units" that might be used of both numeric (**N**) and descriptive (**D**) form e.g High, H; Medium, M or Low, L. The listings do not imply that all of the benchmarks need to be utilised in a multi-criteria analysis but simply give an indication of the range of benchmark standards that could be developed to cover the basic generic primary criteria. Whenever possible, the lower level methodology should adopt numerically measurable benchmarks in order to provide a quantitative basis for comparing the relative sustainability of urban drainage treatment options. It is also important that each of the criteria and benchmark indicators can be applied to all of the drainage and treatment options under consideration to provide a meaningful comparative evaluation.

Although most of the criteria and benchmark indicators are applicable to the assessment of the relative sustainability of generic SuDS, it is clear that certain criteria and standards will be more relevant or important in alternative locations or for specific types of drainage options. A greater weight might be placed for example, on social and urban community benefits criteria for drainage options to be installed in residential areas as compared to those to be introduced into commercial/industrial zones where performance criteria might be the principal drivers. Constructed wetlands have the opportunity to be scaled against all four sets of primary criteria identified in Tables 7.2a to d. Unfortunately, the social aspects of SuDS and stormwater management techniques have received little attention to date and are inherently difficult to quantify with many benchmarks not being easily converted to numerical data (Burkhard *et al*., 2000). However, social research methods, public behaviour and attitude surveys of urban water management systems are beginning to emerge (Mungur, 1997; Ashley *et al*., 2001b) and might be referenced against in the absence of specific local data/information.

7.5 Multi-Criteria Assessment of a Wetland System

As a basic trial of the multi-criteria analysis approach, the methodology has been applied to a horizontal sub-surface flow constructed wetland system known as Pond F/G on the A34 Newbury Bypass which was opened in November 1998 (see Figure 7.2). The pond has a total surface area of 850m^2 and receives drainage from 37,500m^2 of impervious and 33,100m^2 of pervious surface . It was retrofitted into a vegetated balancing pond (surface area 670m^2) and is preceded by an oil separator, silt trap, grass filter and settling pond. Thus, although Pond F/G is a sub-surface flow system having a treatment capacity of 120m^3 predicted for a storm with a 1in 1 year return interval (RI), the size and layout of the pond means that storm flows will over-top the substrate and therefore turn the system from sub-surface flow to surface flow (with a treatment capacity of 250m^3) part way through an intense storm event. The constructed wetland within Pond F/G was planted with an initial section of *Phragmites australis* followed by *Typha latifolia*. However, dieback of *Typha latifolia* occurred in the summer of 2000 because this plant species requires a higher water level and it was replaced by *Phragmites* in autumn 2000. The road surface of porous asphalt was replaced in both carriageways in the autumn of 1999.

The quantification and collation of benchmark indicators for the wetland Pond F/G on the A34 Newbury Bypass provides the basis for a broader perspective of its sustainability than given from an analysis of water quantity and quality data alone. The benchmarking data derive from the design, implementation and initial operational

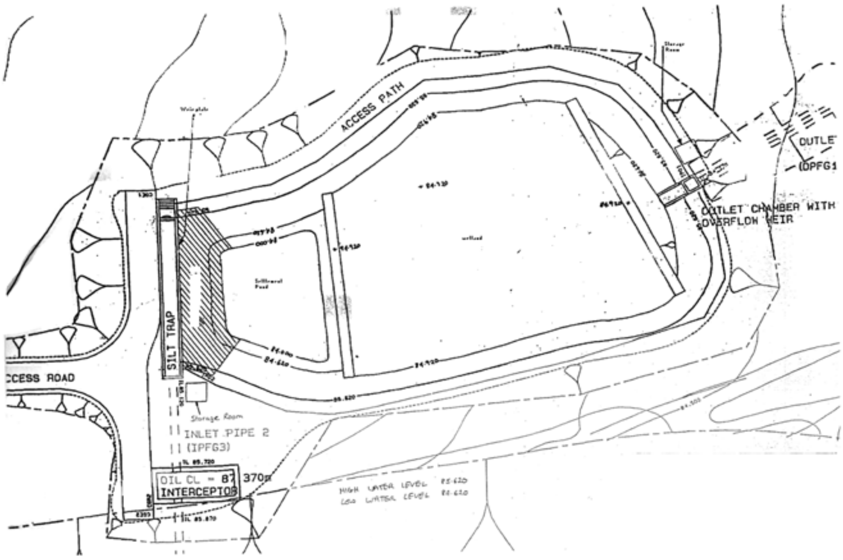


Figure 7.2 Design of Constructed Wetland Pond F/G adjacent to A34 Newbury Bypass

Table 7.3a Technical & Scientific Benchmark Indicators for the A34 Newbury Bypass Constructed Wetland (Pond F/G)

Primary Criteria	Secondary Criteria	Benchmark Standards Indicator Values/Indices/Baseline Information	Unit Value
System Performance	(i)Storage and Flooding (ii)Receiving Water Quality	(i) - Design storm Return Interval (RI) - Design storage volume - Downstream protection value (ii) - Firstflush capture potential - Number of pollution (in-basin/receiving water) complaints	1: 100 years 1100 m^3 **M** **H** (10mm captured for all storm events) 0 % / yr
System Reliability	Performance Reliability, Failure, Health & Safety	- %age pollutant removal TSS Cd Cr Cu Ni Pb Zn - Hydraulic retention time (of Subsurface system volume) - In-basin quality condition and health hazards - Uniform flow distribution - Likelihood of system failure - Safety level/provision - Plant health	%/storm event 40 - 75 90 - 99 24 - 49 -88 - (-97) 78 - 85 98 60 - 66 24 - 54 Hours/av. storm event Algal blooms in open water; weeds around basin **L** Low Probability **M** **H;** Phragmites **L;** Typha
System Durability	Design Life	- Operational lifetime	15 - 20 Yrs
System Flexibility and adaptability	Capability for Change over Time	- Ease of retrofitting and modification	**M**

NOTES: **H** High value/impact
M Medium value/impact
L Low value/impact

phases and Tables 7.3a and b provide a template for comparing the constructed wetland with other alternative SuDS treatment systems as well as serving to identify common design, operation and management problems. For example, the growth of algal blooms in the settlement ponds was not anticipated and the reference in Table 7.3a under "in-basin quality conditions", will provide an early warning for future system operation. In this regard, the benchmarking procedure provides a system of accreditation for the constructed wetland to assess its relative sustainability. The ranges of percentage pollutant removal for total suspended solids (TSS) and heavy metals are based on only two storm events recorded in 1999 and will be updated as more data becomes available, but they highlight the unexpected negative removal efficiencies of copper from the wetland which requires further investigation. Following saturation of the porous asphalt road surface in 5 - 7 years, the discharge of metals to the wetland pond may increase and influence the treatment performance of the system. It has not been possible to quantify a number of the full potential listing of technical and environmental benchmarking indicators given in Tables 7.2a and b for the Newbury wetland system but even the partial quantification provided in Tables 7.3a and b would suggest that it is an environmentally sustainable option.

Table 7.3b Environmental Impacts Benchmark Indicators for the A34 Newbury Bypass Constructed Wetland (Pond F/G)

Primary Criteria	Secondary Criteria	Benchmark Standards Indicator Values/Indices/Baseline Information	Unit Value
Water Volume Impact	Flooding	- Downstream flood potential - Downstream erosion potential	**L** **L**
Water quality Impact	Pollution Control	- Treatment retention times - Litter/gross solids	24 - 54 Hrs/av. storm event **H** (for plant only)
Ecological Impact	Habitat and Ecological Diversity	- Number of wetland key species introduced - Number of wetland alien species introduced - Conservation status (plant/insect/invertebrate/mammal) - Role in local/regional/national BAPs	2 plants 0 **M** **L**
Resource Use	(i) Land use (ii) Material use (iii) Energy use (iv)Chemicals	(i) - Land take (area/cost) (iv)- On-site herbicide/pesticide applications (during year 1)	2000 m^2; £20,000+ 1 application Glyphosate/ yr
Maintenance and Servicing Provision	O & M requirements	- Need and frequency for O & M servicing to maintain technical/ environmental/amenity/habitat objectives - Plant replacement	**H** 15 years

NOTES: **H** High value/impact
M Medium value/impact
L Low value/impact

The wetland pond is located on the margin of a rural field and is surrounded by metal fencing. There is no public access to its perimeter from the road or the field and the social/urban benefits indicator criteria are therefore not applicable although it can be argued that as a landscape feature, it provides an aesthetic value as a visual amenity. The outfall discharges to a small field ditch which is an ordinary watercourse (non-main river) and thus there are no receiving water RQOs or target consents. However, by analogy to other motorway wetland sites it might be expected that the ultimate intrinsic conservation value will be high (see Table 5.3 for referencing against the M42 Hopwood Park motorway service area (MSA) wetland sites where both plant and invertebrate colonisation has been high). The financial risk indicator criteria are also not critical for the design of this highway runoff treatment system and the long term affordability criteria will be evaluated when the system has matured.

7.6 Matrix Approaches

Chapter 2 (Sections 2.1 and 2.2) provides some examples of qualitative matrix-type approaches for the comparative evaluation of differing SuDS options based on a subjective analysis of their functional characteristics and performance. Table 2.6 utilises a matrix of SuDS pollutant removal and flow attenuation capabilities to provide a comparative evaluation, whilst Tables 2.9 and 2.10 provide more generalised indicator approaches based on effectiveness potential for the triad of water quantity, water quality and amenity functions. As indicated by Table 2.10, such approaches can be made semi-quantitative and all can be fairly readily and cheaply developed and applied. However, these examples are essentially technical performance applications and do not consider the full range of social or sustainability criteria or life time costing criteria. In addition, site-specific conditions and/or local operating experience can strongly influence the value and weighting placed against any particular category. Good working knowledge of reservoir porous paving structures for example, might well result in this SuDS being favoured over other source control options.

Table 7.4a SuDS Technology Evaluation Matrix

Criterion	Infiltration Systems	Porous Paving (with reservoir structure)	Grass Swales	Grass Filter Strip	Wet Retention Basins	Constructed Wetlands
Planning cost (Pre-planning and design)	+	o	+	o	+	-
Construction cost (Capital investment)	+	o	+	o	-	o
O & M cost (Including personnel, plant replacement and sediment disposal)	+	+	o	+	o	o
Technical implementation effort (excavation, lifetime O & M, decommissioning)	+	o	+	+	-	o
Water re-use (not including groundwater recharge)	-	-	-	-	+	+
Whole-life cost (Duration, affordability, flexibility for retrofitting etc)	+	-	+	+	+	o
Reliability against Failure (Forced and planned outage during lifetime)	-	o	+	+	+	o
Planning and Practical Experience (System performance knowledge)	o	+	o	-	+	-

KEY:

\+ more advantageous as compared to other technologies

o neither advantageous nor disadvantageous as compared to other technologies

\- less advantageous as compared to other technologies

A further supporting comparative matrix approach which includes sustainability referencing for various types of SuDS stormwater treatment systems is given in Tables 7.4a to c which can be used in conjunction with Tables 2.6, 2.9 and 2.10. This type of multi-matrix approach is primarily intended for general planning support in the pre-selection of integrated urban BMP systems and cannot be used for detailed design. Although wetlands may have the possibility of water re-use, there may be an overall water loss as a result of plant evapotranspiration during the summer period than occurs from an unvegetated open water system such as a wet retention pond.

Table 7.4b SuDS Stormwater Control Evaluation Matrix

SuDS	Peak Discharge Control			Volume Control	Groundwater Recharge	Potential Direct Water Re-use	Downstream Erosion and Flood Control
	RI 1:2	RI 1:10	RI 1:100				
Extended detention basin	●	●	◌	◌	○	?	◌
Wet retention basin	●	●	◌	◌	○	✓✓	●
Constructed wetland	●	●	○	◌	○	✓✓	◌
Infiltration basin	●	●	◌	●	●	✓	●
Porous paving (with reservoir structure)	●	○	○	●	●	✓	◌
Grass swale	◌	○	○	◌	●	✓	○
Grass filter strip	◌	○	○	◌	◌	✓	○

KEY: **RI** Return Interval (years)

- ○ Seldom or never provided
- ◌ Sometimes provided (but with careful design)
- ● Normally provided
- ✓✓ Direct re-use potential
- ✓ Groundwater recharge
- **?** Unknown

Inspection of Table 7.4a would suggest that wetlands generally seem to be neutral in terms of advantages and disadvantages over other SuDS systems. However, they gain in terms of overall operational efficiency of pollutant removal (Table 2.6) and have more advantage in terms of environmental and community amenity provision (Table 7.4c). Whilst the technical evaluation as identified in Table 7.4a would seem to place constructed wetlands at some disadvantage compared to other SuDS systems, the gains in performance and environmental capacity as well as in potential community benefits more than compensates for any technical shortfalls. Much of the neutrality recorded in technical requirement, effort and cost is due to the relatively limited experience of constructed wetlands for stormwater treatment as well as to the widespread (and generally unfounded) concerns associated with open water bodies in urban areas. Given an extensive plant cover and restricted access to deep water and contaminated sediment areas that can be safeguarded by barrier planting, such concerns are much less appropriate in the case of constructed wetlands.

Table 7.4c SuDS Environmental and Urban Community Amenities Evaluation Matrix

SuDS	Receiving Water Low Flow Status	Aquatic Habitat Creation	Wildlife Habitat Creation	Landscape Enhancement	Recreational Benefits	Hazard and Safety Reduction	Aesthetics	Community Acceptance
Extended detention basin	○	◌	◌	◌	◌	◌	◌	◌
Wet retention basin	○	●	●	●	●	◌	◌	●
Constructed wetland	◌	●	●	●	●	◌	●	●
Infiltration basin	●	○	○	◌	◌	●	○	◌
Porous paving	●	○	○	○	○	●	○	●
Grass swale	◌	○	◌	◌	○	●	◌	●
Grass filter strip	◌	○	◌	◌	○	●	◌	●

KEY

○ Seldom or never provided

◌ Sometimes provided (but with careful design modification)

● Normally provided

Constructed wetlands are also generally neutral in terms of comparative advantage/disadvantage to other SuDS technologies when considering storage volume, flow attenuation and groundwater recharge (Tables 2.6, 2.9 and 7.4b). However, whilst many other systems provide the latter benefit, they can also at the same time raise the possibility of groundwater contamination (see Table 2.10). The potential advantages offered by constructed wetlands become much clearer in Table 7.4c where they score highly as a result of a combination of integrated environmental and urban community benefits. However, it must be noted that these benefits will only accrue if they are considered early on in the design and planning process as they are frequently difficult and costly to retrofit into existing structures. Their success and long term community benefit is essentially dependent on adoption agreements and continued, positive management either by public or private agencies. In these terms "bigger is better", as large wetland facilities with wide surrounding buffer zones offer the greatest development opportunities for amenity/recreational provision and associated income streams. In addition, both constructed wetlands and wet retention basins can offer possibilities for water re-use such as park or garden irrigation.

Table 7.5 SuDS Restrictions Evaluation Matrix

SuDS	Gradient	High Water Table	Proximity to Bedrock	Proximity to Building Foundations	Land Take	Maximum Depth	Multifunctional Uses	High Sediment Input	Management and Liability
Extended detention basin	●	●	◌	●	○	●	●	◌	◌
Wet retention basin	●	●	◌	◌	○	○	●	◌	○
Constructed wetland	●	●	◌	◌	○	○	◌	○	○
Infiltration basin	◌	○	○	◌	◌	○	●	○	◌
Porous paving	○	○	○	○	○	○	○	○	◌
Grass swale	○	○	◌	◌	●	◌	○	○	●
Grass filter strip	◌	◌	◌	◌	●	●	○	○	●

KEY

○ May preclude the SuDS use

◌ Can be overcome with careful site design

● Generally not a restriction

The matrix criteria identified in Table 7.4c essentially relate to stormwater wetland systems that are intended for introduction within residential and /or commercial/industrial areas. The full range of criteria would not necessarily be applicable to wetlands intended for the control and treatment of highway runoff where recreational, amenity, aesthetics and community acceptance are generally not applicable considerations. The major difficulties indicated in the Table 7.4c matrix, are associated with health and safety and with downstream receiving water protection of low flow and thermal regimes where rapid changes in temperature due to incoming stormwater may present difficulties to fish and other aquatic species (see also Table 2.10). Nevertheless, with careful design, constructed wetlands can avoid (or at the very least minimise) all potential hazards.

Table 7.5 provides a general guidance matrix on a range of factors which can preclude or restrict the use of particular SuDS options. Wetlands together with other wet storage facilities such as retention and extended detention basins, have fewer overall restrictions although they can score badly against important factors such as space consumption and adoption/management liability.

7.7 Flow Chart SuDS Design Procedure

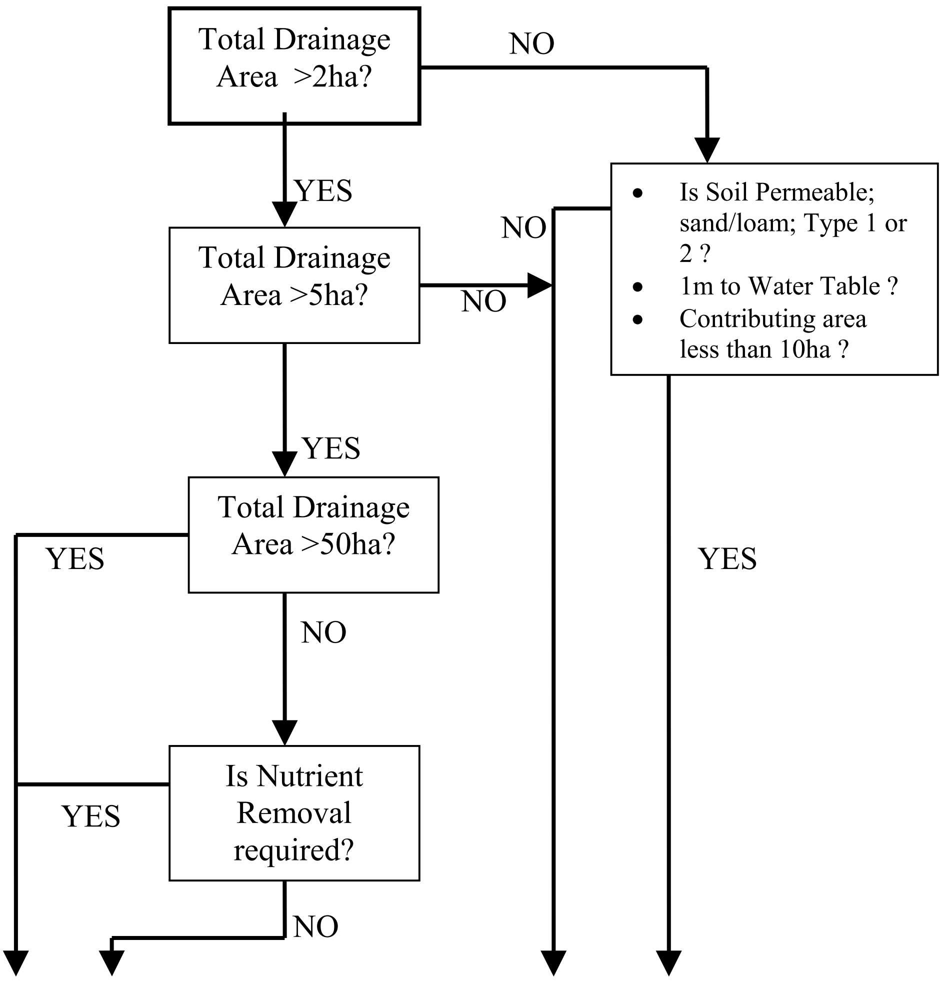
Figure 7.3 illustrates a further alternative approach to providing general guidance to the basic decisions and options available in the SuDS selection process for the treatment and management of urban stormwater runoff. This "decision-tree" approach has been developed for application to relatively small greenfield development sites and is included in the guidance notes provided to SEPA Pollution Prevention & Control (PPC) Divisional teams to accompany the Scottish CIRIA SuDS manual (CIRIA, 2000a).

Like evaluation matrices, such flow charts are intended to assist the designer, developer and planner with the initial screening for urban drainage SuDS that are likely to be most applicable for a given site; they are not in themselves a detailed design guide. However, before final selection is made, the initial screening outcomes must be examined against the specific site characteristics and planning specifications as well as evaluated in terms of cost effectiveness and institutional factors such as the liabilities for adoption. Such considerations might demote the initially screened SuDS candidate(s) and may in some cases rule them out altogether.

Note that the catchment areas indicated refer to the total drainage area served by the particular device. For smaller sub-catchments, the SuDS type denoted on the table layer may be used, in which case the size of the device serving the larger catchment can be reduced. A question mark (?) indicates that the particular SuDS application may be questionable because the catchment area is not large enough.

7.8 Wetland Design Procedure

The aim of this review has been to provide guidance on the design, operation and maintenance of urban stormwater constructed wetlands, including detail on their configuration, planting medium, water levels and type and extent of associated



		Infiltration Basins		✓
	✓	Extended Detention Basins	✓	
✓	✓	Retention Basins	?	
✓	✓	Wetland Basins	?	

Figure 7.3 SuDS Selection Process

vegetation in order to effectively treat contaminated urban surface runoff. In addition, the review has highlighted the mutual linkages between constructed wetlands and other sustainable drainage systems. Figure 7.4 presents a general process diagram for the design procedure and flow of required inputs and considerations at differing stages of design, implementation and operation. Each of the processing steps illustrated in the procedure have been considered in detail within the report to direct and support the user through this design process.

The inclusion of amenity/recreation as a separate sub-set within the process diagram reflects the fact that some wetland systems, such as those intended for highway runoff (and perhaps some developed within industrial zones), will not have need to recourse to such criteria. Whilst some landscaping of such wetlands may be necessary to maintain an acceptable aesthetic standard or to prevent weeds from drifting onto neighbouring agricultural land, this will not have any direct social amenity benefit.

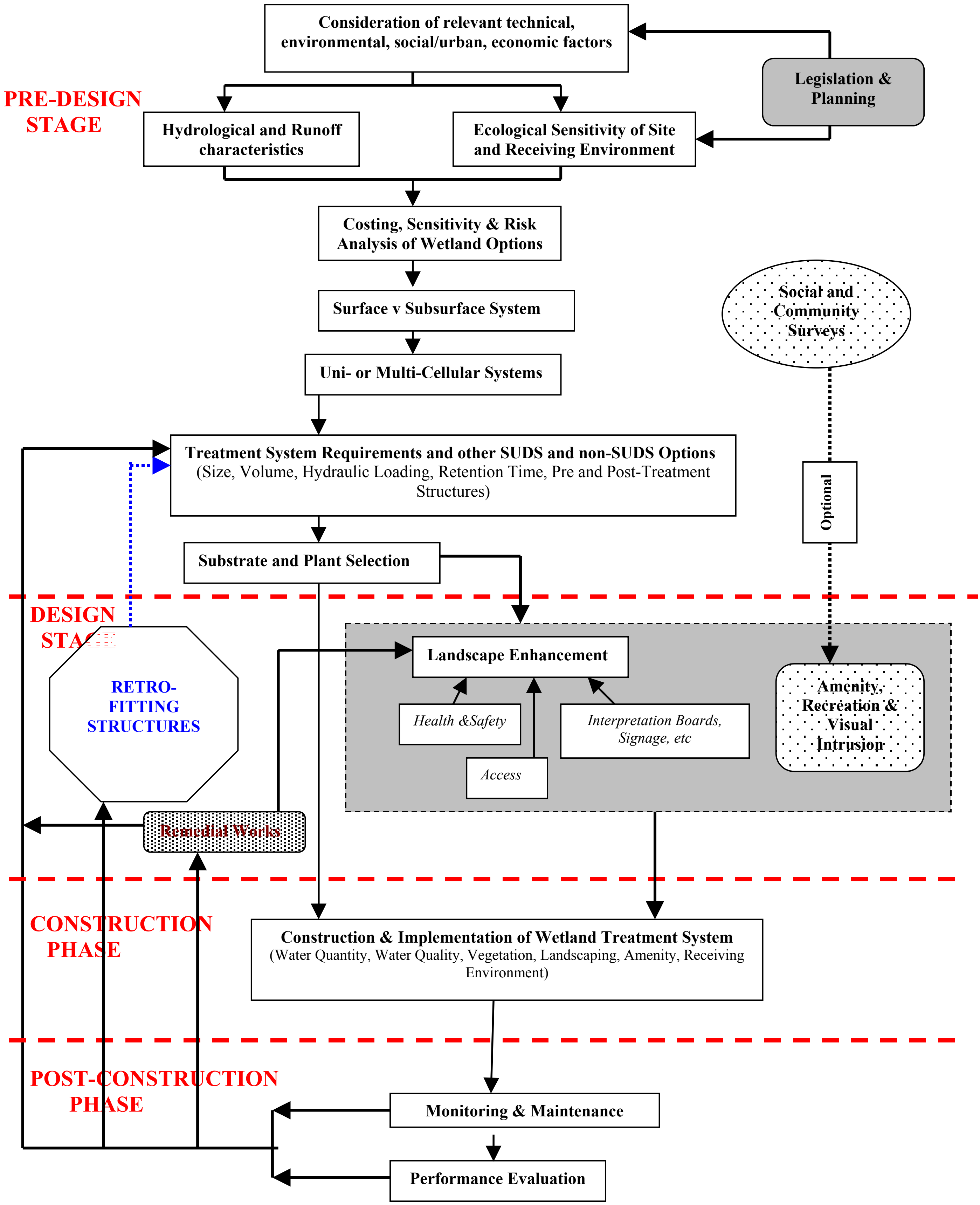


Figure 7.4 Process Diagram for the Design of Constructed Wetlands

Undoubtedly such wetland systems can offer conservation, habitat and aesthetic (quality-of-life) benefits irrespective of the exclusion of direct social/urban benefits, and these ecological criteria can be achieved through careful vegetation selection, planting considerations and control of water levels. The process design diagram thus has two routes from the design to construction phase, one of which by-passes amenity/recreational considerations when these are not required or are considered to be redundant to the particular location and/or design objectives. The sustainability of restricted-objective wetland systems must therefore be judged on their own merits, rather than with systems which can be referenced against the full range of technical, environmental and social/urban community benchmark indicators.

Key Issues

- evaluation of the degree and nature of wetland sustainability in terms of quantifiable generic criteria and indicators.
- role of SuDS devices as formal sewerage asset investments.
- development of accreditation protocols for evaluating the comparative sustainability of various SuDS devices.
- use of multi-criteria analysis (MCA) for the selection of SuDS drainage/treatment options

8. DECISION SUPPORT APPROACHES FOR URBAN STORM DRAINAGE SYSTEMS IN FRANCE

8.1 Introduction

Constructed urban wetlands have not been widely adopted in France because wetlands are traditionally associated with mosquitoes, and partly because of the rigid boundaries existing between disciplines. Ecologists have always been enthusiastic about wetlands but urban drainage engineers have been reluctant to adopt these natural water retention systems, mainly because they have not always been properly designed. For these and other reasons, many natural wetlands within France have disappeared during the past forty years. Within urban areas, creeks and small rivers have been gradually integrated into the underground sewer system.

Nevertheless, France has been one of the European states which became interested relatively early on in source control of urban stormwater run-off and BMP's with many wet retention basins being designed and introduced into french urban areas during the early sixties. The New Towns Construction policy, which was launched at the end of the fifties, allowed drastic changes in the design of sewer systems. A classical sewer system (i.e. with pipes) for stormwater runoff could not be designed for these towns, mainly for economic reasons. This led to the promotion of retention basins and to a new 1997 regulation on sewer systems, within which one chapter was devoted to the design of retention structures. It was followed by an important national research programme, led by the Ministry of Public Works, from 1978. Other techniques were soon investigated such as the use of porous pavements.

During the past twenty years, the concept of source control of urban storm runoff has become widely disseminated among drainage engineers in France. However, as the number of field experiments increased, it soon emerged that the difficulties of implementation were far from being solely technical in nature. Design engineers also had to face questions such as :

- how to convince people to infiltrate stormwater runoff directly to ground or to store rainfall-runoff on house roofs?
- how to convince elected officials to retain a section of developement land from urbanisation in order to build a retention basin or other source control device some years later?
- how to estimate the global life-time cost (initial investment and post-project maintenance) of innovative source control devices?

At the same time, the development of modelling and national measurement campaigns questioned the technical basis of traditional sewer system design using for example, the concept of a fixed design storm return period of 10 years, or the use of very simple models for the calculation of peak flows on very large urban catchments. New problems also appeared, such as the importance of the pollution impact associated with urban stormwater outfalls and combined sewer overflows, and the need to determine the impacts of such pollution sources on the environment which depends to some extent on quality objectives for groundwater, river or lake water. Appendix D provides an outline of the legislation relating to the planning, design and operation of surface water discharges and storage facilities in France, together with a brief description of prevailing water quality and sediment standards.

These legislative and technical developments have led to two outcomes. The first is the development of numerous research programmes to determine and specify the parameters which can give a good description of the state of the aquatic environment both now, and in the future, and particularly during wet weather conditions. The second is the idea that decisions in the field of urban sewerage are no longer taken exclusively by engineers or even following a dialogue between engineers and elected officials. Other stakeholders have to be involved in the decision process in order that the solution is acceptable to all interest and user groups. The variety of potential stakeholders include: drainage engineers in the state services, public health engineers at the county level, local government planners and technicians at different levels, urban designers, water agencies, private firms, local elected officials, local resident associations etc.

Thus urban decision-making is becoming increasingly complex. Faced with this situation, some important local communities have tried to make the process more objective, following two pathways :

- Organising the decision-making process by: identifying which stakeholder(s) should be involved, and at what stage, in order to facilitate communication between technicians and non-technicians, and providing methods to take into account the impact of new devices and associated equipment when they are in final operation.
- Involving all the potential stakeholders and taking into consideration the multiple objectives that might be contained in the decision-making process.

From the variety of decision-making methods available, multicriteria analysis (MCA) has become a commonly chosen tool. This method is now frequently used in the main cities within France as a decision support tool for urban sewer systems, and provides a method that could be equally applied to constructed wetlands. To illustrate how the method may be applied, the following section describes :

- the development and the implementation of a sewerage programme at the local community level
- the criteria for the choice of source control of urban runoff through a general methodology and a benchmarking inquiry conducted to resolve alternative solutions for source control.
- two case studies.

8.2 Sewerage Systems Procedures in Local Communities

Sewerage system development procedures have been defined by the 1992 French Water Law, and more explicitly by a decree dated June 3rd 1994 which gives directives to technicians, and makes sewerage programmes mandatory (see Appendix D). These programmes are the result of national studies that have analysed how the existing system functions, how final proposals are reached, and how long-term investment programmes are established. These sewer drainage programmes must be approved by the appropriate city council. The June 3rd decree sets out special directives concerning the way such urban sewerage programmes should be established, but a certain amount of freedom is left to stakeholders in terms of adapting these directives to the local context and in the final implementation and operation of the drainage programme. A one-year time scale for implementation is considered as being very important in the process as municipal budgets are approved annually.

Multicriteria analysis should be integrated into this global process and various research studies have tried to define a reference framework for the decision-making process itself. The methodology which has been proposed intends to describe the sequence of planning and design stages and to specify, for each one:

- the stakeholders involved
- the programme objectives
- the key-points on which a decision is required before moving on to the next stage.

Figure 8.1 shows a highly simplified diagram of the recommended decision-making process, identifying the two time-scales. In particular, this schedule allows for the integration and evaluation of new installations, with specific tools being proposed for various stages, as indicated in the following sections.

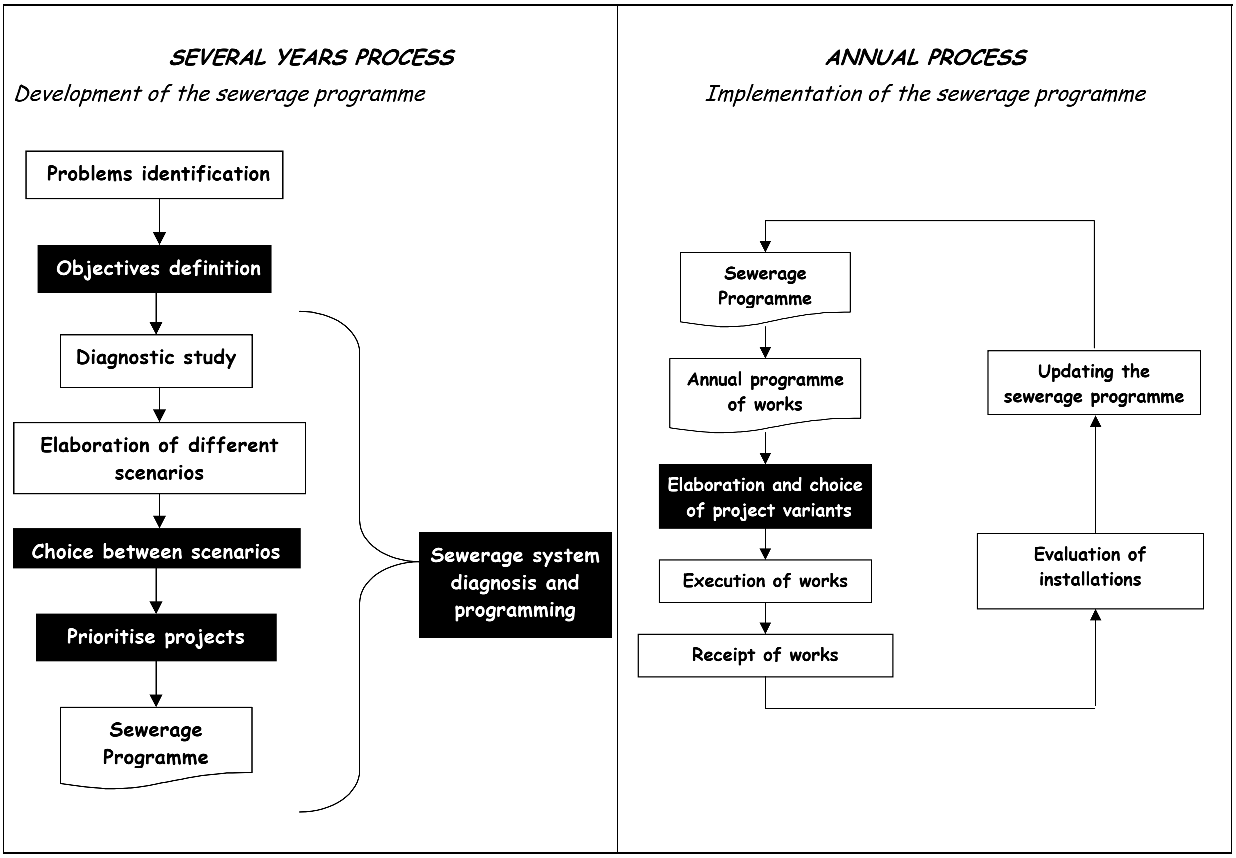


Figure 8.1 Simplified Diagram of the Decision-Making Process for Urban Drainage in France

8.2.1 Defining city sanitation objectives

This initial stage includes a checklist of potential objectives such as sanitary protection, flood control and participation in sustainable water management, the latter of which could be considered as being an external objective, since it refers to the direct and indirect operational effects of sewer systems on people's lives. Internal objectives also exist, e.g in considering the operational work undertaken by the employees within the sanitation services or the environmental image that elected representatives wish to give of their cities. Nevertheless, the main objectives of any urban sanitation programme are: economic efficiency, operational efficiency and positive socio-political impact, especially in terms of integration of facilities into city infrastructure and making them environmentally acceptable. These objectives also include the incorporation of indicators covering specific issues (e.g. legal or technical requirements) or indicators for converting political objectives into sanitation terms.

8.2.2 Sewerage project diagnosis and programming

The Book of Technical Specifications[1] for French public works projects is important for the municipal government level, not only in terms of selecting the private contractor who will eventually complete the work, but also for monitoring the diagnostic and design phases. Thus, a standard Book of Technical Specifications is provided which contains the elements necessary to adapt the specifications to each context.

8.2.3 Choosing between scenarios

Different strategies can be adopted for the sanitation of urban areas and there is frequently no obvious choice. The methodology advised here is that of multicriteria analysis (MCA). A standard list of criteria suited to a particular stage in the planning and design process is provided, together with recommendations on how the various criteria should be evaluated.

8.2.4 Prioritising projects

A checklist of typical constraints involved in the implementation of sewerage programmes is combined with a list of ratios that can be used within the remaining "room for manoeuvre".

8.2.5 Develop and choose project variants

At the end of a project design process, engineers often propose several variants to the decision-makers. This is often the case for stormwater retention devices, as they comprise surface drainage devices and, therefore, are of interest to inhabitants and their representatives. The recommended methodology for this stage in the planning process is again multicriteria analysis. A standard list of criteria for this type of source control device is provided, together with advice on how such retention facilities should be evaluated.

---

[1] In French : Cahier des Clauses Techniques Particulières (CCTP).

8.3 Criteria for Stormwater Source Control

This section is divided into two parts. In the first part, a design process is described to support the choice of particular stormwater source control devices, from the examination of the site specifications to the final design of the adopted solution. For defining technical and economic performance of these devices, it is necessary to collect data from existing operating systems. The second part of the criteria refers to the results of the exploitation of a national database concerning 167 French sites. The parameters used in the analysis are :

- updated investment and operation costs,
- site characteristics,
- drainage system characteristics,
- the level of satisfaction concerning hydraulic and environmental objectives,
- urban integration and population acceptance.

8.3.1 Design process for the selection of stormwater source control devices

The overall global design process is diagramatically represented in Figure 8.2. The four steps shown in this figure are described in the following sub-sections.

Feasibility study : Two types of criteria are used for the feasibility study: technical and socio-economic criteria. As infiltration systems are the main systems which are assessed for stormwater source control management in France, the chosen technical criteria are :

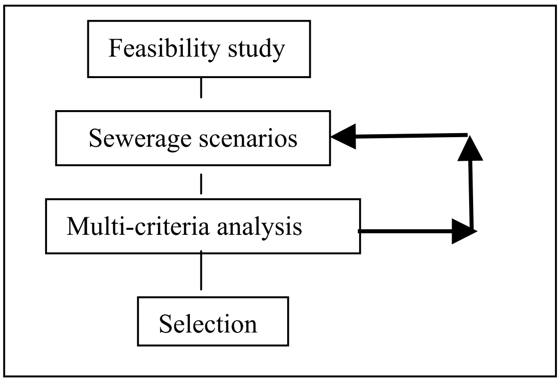


Figure 8.2 Design Process for the Selection of Stormwater Source Control Structures in France

- soil ability for water infiltration with the indicator being the mean hydraulic conductivity
- soil ability to receive stormwater run-off with the indicator being the pollution hazard to groundwater
- downstream system capacity with the indicator being the downstream flood potential

The socio-economic criteria are measured by two indicators: the need and frequency for Operation and Maintenance (O & M) servicing and total cost. The estimation of soil ability for water infiltration can be determined from existing maps, drill holes and field studies, and from an estimation of the hydraulic conductivity which depends on the soil type. If the value of the hydraulic conductivity is between 10^{-3} and 10^{-6} m/s, an infiltration system can be designed.

Table 8.1 Exclusion Criteria for Selecting Stormwater Control Structures in France

Criteria	Assessment (The restricting classes are in bold type)	Effect of the restricting class on possible solutions
Space availability	Yes **No**	Can use only the drained area
Susceptibility of the soil to water logging	Yes **No**	Infiltration techniques are not feasible
Groundwater vulnerability to rainwater	Yes **No**	Infiltration techniques not feasible
High water table level	**Near the surface (<1.5m)** Mean depth Deep or missing (>6m)	Infiltration techniques not feasible ; infiltration pits may be used
Water pollution risk	Low **Mean*** **High****	(*) Use of treatment devices (**) No use of infiltration techniques. Use of alternative treatment devices
Overburden capacity	**Low (P<2)** Standard (P>2)	No use of porous pavements for infiltration or linear techniques (e.g swales) for roads with heavy traffic
Soil surface permeability	**Low (<10^{-7}m/s)** Standard (>10^{-7}m/s)	Infiltration techniques not used
Deep soil permeability	**Low (<10^{-7}m/s)** Standard (>10^{-7}m/s)	Infiltration techniques not used
Permanent outlet	Existing **not existing**	Difficult to apply retention techniques
Risk of water loaded with fine suspended solids	No **Yes**	Use of a treatment device ; no use of porous pavement
Site slope	Low **Mean to high**	Installation of baffles
Traffic	Low (<T2) **High (>T2)**	Difficult to use porous structures
Important shear stress due to the traffic	No **Yes**	No use of porous pavement
Low water table level	Near the surface or mean depth **Deep or missing**	No use of wet retention basins with a pervious bottom
Permanent water flow	Existing **Not existing**	No use of wet retention basins
Altitude	Low (<900m) **High (>900m)**	No use of roof storage
Roof slope	Low **Mean*** **High****	(*) Installation of baffles on the roof (**) No storage on the roof
Possibility to store water on the building roof	Yes **No**	No storage on the roof

The pollution risk to soil and the groundwater is assessed from the stormwater run-off quality and the sensitivity of the receiving water body. The water table, for example, is a resource boundary for water consumption and must be adequately protected. The estimate of the pollution hazard, (either chronic or accidental), depends on the nature of the drained area (roofs, roads, car parks,etc) and on the type of land use (residential area, commercial area, industrial area, etc). The receiving water sensitivity must take into account both aspects and it is assessed by the pollution treatment ability of the unsaturated zone above the water table. The criteria for O & M servicing and cost do not need to be used at this stage, unless they lead to a rejection of the design of alternative techniques. The permanence of the water level of a wet retention basin is another feasibility criterion which depends on the hydrological functioning of the water table and on the evaporation limit.

Sewerage scenarios : The design of sewerage scenarios has two stages : the first is the elimination of solutions deemed unsuitable for the site, whilst the second is the choice of the combination of solutions which allows the design of a sewerage scenario. For the first stage, Table 8.1 outlines a list of criteria which lead to the possible exclusion of some solutions. The following approach is proposed for the second stage:

- choice of solutions taking into account their multifunctionality
- pre-designing these solutions from hydraulic and environmental points of view
- assessment of the measures and organisation which are needed in order to manage extreme events

The design parameters in Figure 8.3 can be considered to be similar for all source control techniques although for some techniques, specific parameters need to be

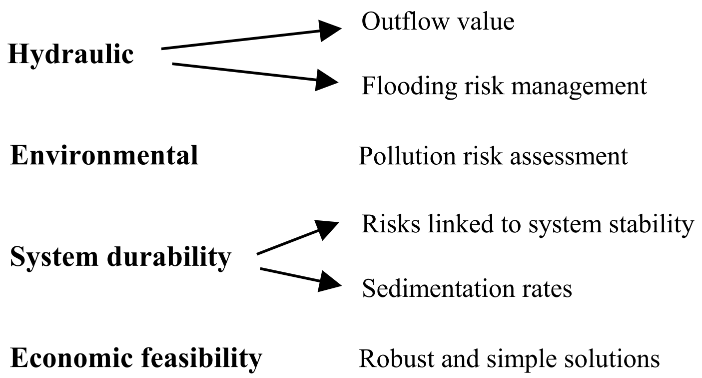


Figure 8.3 Design Parameters

added. The assessment of a sewerage system must take into account many points of view. As information on a particular site is normally incomplete, the assessment of some criteria can only be based upon wider field experience. The multicriteria assessment enables the alternative scenarios to be clarified and the choice of a satisfactory solution to be made. The main criteria are shown in Table 8.2.

Table 8.2 Stormwater Selection Criteria and Measurement Units

Field	Criteria	Units of Measureement
Urban Development	Landscape value	Numerical grade or descriptive assessment
	Site constraints	Numerical grade or descriptive assessment
	Multifunctionality	Binary (yes/no)
	Hydraulic performance	Numerical grade or descriptive assessment
Environmental Protection	Prevention of chronic pollution risks	Numerical grade or descriptive assessment
	Prevention of seasonal pollution risks	Numerical grade or descriptive assessment
	Prevention of accidential pollution risks	Numerical grade or descriptive assessment
Ecosystem Protection (during the life cycle of the sewerage system)	Criteria concerning effluent impacts on water, air, soil, solid waste production and raw material consumption	
Cost	Investment	Cost values
	O & M	Cost values
Maintenence	Ease	Numerical grade or descriptive assessment
	Control quality	Numerical grade or descriptive assessment

Criteria linked to urban development

These criteria must enable alternative techniques to be considered in terms of landscape design (water, plants and soil), the management of site constraints, and to offer other technical functions (e.g porous pavement) or recreational functions (e.g a sports ground within a dry retention basin). This last case must be viewed positively, because such multifunctionality can reduce the global cost of urban development.

Hydraulic performance

Sewerage systems are designed to protect an urban area against rainfall events of a given return period frequency. This design criterion is used to assess the impact of rain of a higher intensity than the design rainfall event. It takes into account the characteristics of the control structure and the site vulnerability. This criterion will be low when the overflooding of the structure leads only to light damage, such as the flooding of a car park. It is of median significance when the overflooding causes problems but does not have serious consequences. It will be high when the consequence is, for example, one of serious damage to buildings or a significant risk to life.

Environmental and ecosystem protection

The capacity of sewerage systems to protect the environment and associated ecosystems has to be assessed. At least two points of view exist here: consideration of the impact on the downstream aquatic environment and impact on the whole environment over both the short and long term. In the first case, models can be used, but they need numerous and specific data for validation and verification which are, most of the time, difficult to obtain. Thus, the approach is often 'expert-based'. In the second case where assessment of whole environmental impact is required, disposal of waste produced during the whole life of the design structure together with the energy and raw materials consumed, must be additionally considered. This criterion must be derived from life-cycle analysis. The aim here is to minimize the effluent discharges, the consumption of energy and raw materials and to reduce the quantity of waste.

Cost
Despite the numeric form of this criterion, there is considerable inherent uncertainty in its assessment, due to the following factors :

- the capital investment and O&M cost data are very heterogeneous in nature. They depend on the design of the structure (dimensioning, landscape provision and integration etc.), the location and cost of the site and the treatment process implemented by the local stakeholders.
- the type of answer given to the following question : who pays ? The answer to this question is variable and could be the local community or a private developer, but in most cases will depend upon the selected technique(s).
- the difficulty of comparing structures having two or more functions. The analysis of the costs corresponding to the different functions is very complex. How should one compare the costs of a dry landscaped basin with a wet retention basin or a grass swale ? How is it possible to separate the added costs of the hydraulic function and of the public green space function ?
- the difficulty of estimating the direct beneficial (or penal) cost of any limitation in flow for the downstream network or the non-increase of stormwater effluent at the overflow facilities, or resulting land values.

Operation and control
For the operation and control of alternative techniques, it is necessary to define which kind of operation is needed, and which stakeholders will be responsible for the management of each operation. This is of particular importance for a multifunctional structure as there may be several services having responsibility for the different levels and modes of operation. In this respect, the multifunctional mode can lead to the dilution (or abrogation) of individual responsibilities and inadequate long term maintenance of the structure and thus degrade the ability of the structure to perform its various design functions.

8.3.2 Economic database of French alternative techniques

This database covers different types of source control structure and different contexts of design. It contains 167 cases situated within three French areas : Lyon, Bordeaux and Seine Saint-Denis, Paris. For each case on a given site, the following information is given:

- Type of structure and materials used
- Storage volume
- Drained catchment area
- Year of implementation of the structure and the reference year for the costs
- Total investment costs, updated (and discounted) for the base year of 1999
- Mean annual O&M costs
- Quality mark for the information relating to investment and operating costs
- Qualitative assessment of the global perception of the structure by the stakeholders: technical operation, environmental impact and integration level (social, landscape etc).

Most of the cases in this national database are retention basins (143). The numbers of dry retention basins, of underground storage tanks and of storage systems in pre-fabricated elements (pipes with large dimensions) are sufficient to present some general statistics.

Dry retention basins: The range of storage volume is very large from 68 m^3 to 202,000 m^3 with a mean of 22 088 m^3 and a standard deviation of 610 m^3. The investment costs vary from 54 F/m^3 to 4479 F/m^3 with a mean of 895F/m^3 and a standard deviation of 1 143 F/m^3. The correlation between the storage volume parameter and the cost parameter is good (with a coefficient of determination, R^2 = 0.73 i.e 73% of the variance is explained by the two parameters). The basins which are integrated into the local urban framework have a mean cost of about 740 F/m^3 (standard deviation of 570 F/m^3) and non- integrated basins have a mean cost of 960 F/m^3 (standard deviation of 1333F/m^3). This means statistically, that for the sample in the data base, the additional costs due to multifunctionality are not very significant. The O&M costs vary from 0 to 83F/m^3 with an average of 10.6 F/m^3 and a standard deviation of 19.7 F/m^3. There is no correlation between these costs and the storage volume, between the investment costs and the O&M costs, or between the global costs and the operational quality.

Underground storage tanks: The range of storage volume is also very large varying between 10 to 39 000 m^3, with an average of 2 784 m^3 and a standard deviation of 7 370 m^3. The investment costs vary from 159F/m^3 to 9 946 F/m^3 with a mean of 2 369 F/m^3 and a standard deviation of 1 928 F/m^3. There is a good correlation with the storage volume (with R^2 = 0.79) but there is no statistical relation between the investment costs and the O&M costs, or between the global costs and the operational quality.

Prefabricated storage systems: These basins have a rather low storage volume with a mean of 150 m^3 and a standard deviation of 138 m^3. The investment costs vary from 1 062 F/m^3 to 7 276 F/m^3 with a mean of 2 854 F/m^3 and a standard deviation of 1 315 F/m^3. There is a good correlation with the storage volume (with R^2 = 0.86). Two classes can be distinguished in terms of O&M costs :

- 0 F/year for 32% of the cases, showing that there is no maintenance
- 3 F/year/m^3 for 2/3 of the cases, corresponding to annual cleansing.

8.4 Case Studies

Two case studies are presented here, one concerning choice between scenarios and the second concerning choice between projects; both studies are situated in the Paris area.

8.4.1 Choice between scenarios

The sewerage strategy for the Paris area presents a complex problem and a study began in 1997 to determine what might be the best strategy, according to the following points :

- the number and location of wastewater treatment plants, providing either centralised or decentralised treatment
- the management of surface stormwater: either through construction of storage tanks in order to direct stormflow to wastewater treatment plants, or

construction of specific treatment units on site at both/either local and regional level.

After several meetings, four scenarios were selected and compared using multicriteria analysis (MCA). This analysis was discussed during meetings where the following stakeholders were present: engineering consultants, local community planning and administrative officials, representatives of the Ministry of the Environment, the regulatory agency (Agence de l'Eau Seine-Normandie), other state services in charge of technical and legal regulations and various scientific experts. The final choice of strategic criteria and design parameters resulting from these meetings is presented in Table 8.3.

Table 8.3 Results of Multicriteria Analysis for the Paris Area

Criteria	Weight	Scenario			
		A	B	C	D
1 Environmental performance	25%	3	2	5	4
2 Flexibility	15%	2	3	4	5
3 Progressive construction	10%	5	4	3	2
4 Operation problems	15%	4	2	5	3
5 Construction constraints	10%	5	3	4	2
6 Construction problems	5%	5	4	3	2
7 Investment costs	10%	5	4	3	2
8 O&M costs	10%	5	3	4	2
Mark		78%	57%	83%	62%

Eight criteria were defined and were validated during extensive meetings. Each scenario was ranked with the highest rank being allocated a mark of 5, with the following ranks being given one point less than the previous. Relative importance was determined through a weighting procedure where 100 points was distributed between all of the criteria. This weighting reflected the desire of stakeholders to prioritise environmental performance. In fact, this weighting criterion includes several aspects (e.g impact during dry weather, wet weather etc), which could have been detailed as secondary indicators or sub-criteria. The ranking was extended to incorporate expected problems and issues, which were separated into operational and construction problems.

The use of multicriteria analysis has clarified the objectives attributed to the sewerage system and has facilitated the stakeholder debate. Nevertheless, with hindsight it would have been useful at the end of the evaluation and aggregation process, to have undertake an analysis of sensitivity (for instance, to measure the impact of a +/- 5% variation of the weight attributed to each criterion on the final result), in order to have an idea of the robustness of the selection procedure. It is significant that the methodology used for the weighting has been retrospectively questioned.

8.4.2 Choice between projects

The brief case study presented here involves the choice of a construction site for a county retention basin in Blanc-Mesnil (Seine Saint-Denis, Paris). Four sites were under consideration and were studied with a multicriteria analysis undertaken in order to compare them. The stakeholders and their interests in the choice of drainage facility were the following :

- the technical services from the county, in charge of real time control, new works and water quality. Some of these service groups, who will be responsible for the management of the future basin, look primarily for technical coherence in the project.
- the elected officials of the Seine Saint-Denis County and the Blanc-mesnil municipality who hold specific planning authority but who also have a general interest eg in amenity and/or recreational provision.
- the local inhabitants of Blanc-Mesnil who are preoccupied by specific problems such as ensuring an end to local flooding and the provision of neighbourhood environmental protection.

County services studied each aspect of the selection problem and established a list of criteria that were classed into four categories:

- hydraulic performance,
- environment of the project,
- feasibility
- and costs.

The relative importance of each category was defined through a weighting procedure with 100 points being distributed firstly between these categories, and then between all of the specified criteria. The adopted weighting procedure demonstrates an aim to maintain an equilibrium between the four major categories, even if a lower priority was to be given to the hydraulic performance and the environmental impact of the project. The next step in the approach was to rank the drainage variants in terms of the identified criteria with the highest ranking being allocated a score of 5 with the following being given one point less than the previous. The results of the multicriteria analysis are presented in Table 8.4 and it is clear that the highest overall score is achieved by project A.

Two main objectives were reached through the application of this multicriteria analysis procedure. Firstly, the technical services group used it as a synthetic means of presenting the identified assets and weaknesses of each variant. Secondly, the social, technical, and economic aspects of each variant were made available for elected officials of the county who could then use the multicriteria analysis as a support tool to present and explain the four variants to the inhabitants of the city and other local interest groups.

The individual marks given to each variant for each criterion were at least as important as the final scores. Indeed, during the ensuing public debate, the drainage problem could be examined on the basis of each criterion with each stakeholder having the opportunity to explain their own point of view. The result of the debate was that one kind of criterion was revealed as being very important for inhabitants: that of local impacts. This led to the elimination of variant A despite it scoring highly on some criteria, particularly hydraulic performance. For the technical services group, the availability and constraints of the site were paramount factors, which led to the elimination of variant C in spite of its high performance in terms of local impacts. Finally, variant B was selected for implementation.

Table 8.4 Multicriteria Analysis for the Study of Four Sites for the Construction of a Retention Basin at Blanc-Mesnil, St Denis, Paris.

Criteria	Class	Weight	A	B	C	D
Response to hydraulic needs	Performance 30%	10%	5	2	3	4
Hydraulic performance		10%	5	2	4	3
Reliability		10%	5	3	2	4
Visual impact	Environment 30%	15%	2	4	5	3
Less needs for multifunctionality		10%	5	2	4	3
Operation impacts		5%	2	3	5	4
Immediate availabilty of the site	Feasibility 20%	15%	3	5	2	4
Realisation constraints		5%	3	4	2	5
Investment	Costs 20%	15%	4	5	2	3
O&M		5%	4	5	2	3
Mark			76%	72%	62%	70%

As a general conclusion, it is clear that although constructed wetlands are not in common use for the control and treatment of urban surface runoff in France, the multicriteria approaches which have been developed for general source control selection would enable the assesment of these structures and allow a comparison of them with other BMP's. However, there is no answer, at present, to the question as to why some particular types of drainage technology are used in one country and not in another.

Key Issues

- Stormwater selection criteria
- Selection procedures for urban drainage systems in France
- Use of multi-criteria analysis to evaluate sewerage strategies

9. RECOMMENDATIONS FOR FURTHER WORK

9.1 Introduction

It is clear that constructed wetlands, together with the full suite of SuDS devices, face considerable challenges before they are regarded by many drainage engineers as standard components in future urban drainage systems. These challenges include issues relating to technical and operational management, organisational and legal frameworks. The potential problems occur at various points in the four development phases (pre-design, design, construction and post-project phases) identified in Figure 7.4, but as pointed out in the CIRIA (2001) Best Practice Manual, many are issues which are essentially related to perception and lack of information/experience.

The suggestions for further work which are given below are not prioritised but are grouped into thematic issues related to wetland monitoring, technical and operational evaluation, design and management, life-cycle assessment and social/urban issues associated with wildlife/amenity provision. Many of the identified themes have been previously highlighted as key issues at the end of each chapter. The listed topics also vary from minor issues to major R&D projects many of which will require multi-disciplinary teams in order to be tackled successfully.

9.2 Database and Monitoring

- Development of national and standardised database for urban wetlands (as part of national SuDS monitoring) and consideration of the strategic role of SuDS for the control and management of surface runoff within urban catchments within future implementation of the Water Framework Directive. The US EPA sponsored "*National Stormwater Best Management Practices Database*" (NSBMPD) guide developed by Urban Water Resources Research Council/URS Greiner Woodward Clyde (1999), provides a base template from which a UK equivalent might be worked up. Figure 9.1 provides an outline of a possible database structure within which data might be categorised as:

  (a) "required"; mandatory data which would need to be completed in order for the SuDS device and associated data to be included as an accepted entry in the main database.
  (b) "essential"; primary data covering parameters which are considered essential in order that the SuDS device can be used as a demonstration site and which enables the performance of the device to be compared on a standardised basis with other SuDS and conventional drainage systems.
  (c) "useful to have"; a listing of data and descriptive information covering organisational, O&M, amenity and other issues of relevance.

- Development of national water quantity and water quality monitoring programme for differing types and locations (i.e residential, commercial, industrial, highway etc.) of urban wetlands (as part of national SuDS monitoring). This will need to identify a standard parameter base which is also compatible with requirements for monitoring of other SuDS structures.

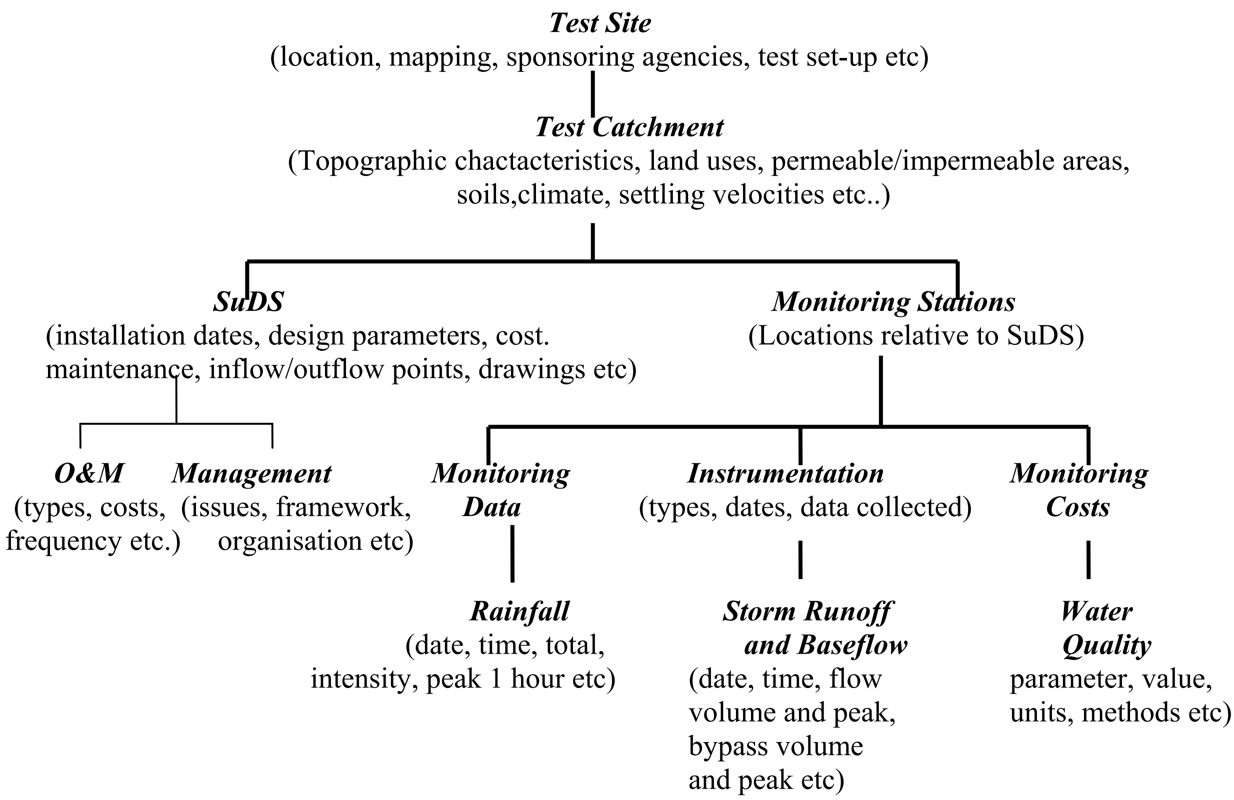


Figure 9.1 Possible National Database Structure

- Full scale field evaluation and revisions of decision-support approaches for urban wetland design and accreditation. Developing and testing of robust sustainability indicators, benchmark standards and accreditation procedures for urban wetlands (as part of national SuDS monitoring).

- Identification of selected national demonstration sites; to be developed in conjunction with developers, British House Building Federation etc.

9.3 Operational Evaluation

- The evaluation of long term performance and cost-effectiveness of differing urban wetland SuDS. Identification of pollutant retention efficiencies in terms of storm rainfall design and flow criteria.

- Evaluation of long term effects of below-surface pollutant infiltration from wetlands to groundwater and associated degradation mechanisms in the unsaturated zone

- The evaluation of urban wetland pollutant removal efficiencies; robust modelling procedures for the dynamic nature of wetland flows and mixing processes.

- Development of operational and maintenance handbooks and inspection routines for urban wetlands.

9.4 Pollutant Pathways

- Hydrocarbon chemical and microbial degradation; sediment and plant uptake.
- Metal uptake and food chain transfer.
- Pesticide degradation and plant uptake.
- Bacterial and pathogen pathways, exposure, degradation and resuscitation and uptake rates in sediment, plants, insects, invertebrates, birds and other wildlife.

9.5 Wetland Design and Management

- Significance of, and needs for, first-flush treatment; alternative techniques for first-flush treatment; role of wetlands in inner urban areas and in conjunction with conventional drainage systems.
- Issues of wetland adoption, liability including issues of long term wetland management and multi-party agreements particularly for secondary conjunctive uses where amenity provision, for example, is a prime subsidiary objective or problem of the SuDS development.
- Public attitudes and behavioural surveys of local/community uses of, and needs for, urban wetland systems. Such surveys are essential if robust social and urban community benchmarking and indicator standards are to be developed to fully quantify the sustainability of SuDS devices as indicated in Chapter 7.
- Wetland design for the removal of priority pollutants including methyl tertiary butyl ether (MTBE; which is now used as a petrol additive and which is soluble in water and not readily biodegraded), hydrocarbons, pesticides, bacteria/pathogens, oestrogens etc.

9.6 Life-cycle Assessment

- Whole life-cycle costing for urban wetlands, including MIPS (**M**aterials **I**ntensity **P**er **S**ervice Unit) analysis; (as part of national SuDS monitoring). MIPS enables the environmental impact costs of infrastructures and services to be determined and compared for varying service units (including sewers, SuDS etc), based on whole life-cycle consumption costs.
- Identification of separate land take, resource/energy use and O & M costs for differing urban wetland types.
- Identification and quantification of sedimentation rates for urban wetland environments; techniques for predicting sedimentation accumulation rates and associated pollutant contamination (uptake) rates; ultimate sediment disposal techniques, frequency and costs.
- Identification of plant replacement requirements, frequency and costs.

9.7 Wildlife/Amenity & Social/Urban Issues

- Issues related to over-successful wetland naturalisation and colonisation
- Issues of species colonisation including feeding, breeding etc.
- Food chain transfer and resultant effects of differing pollutants.
- Issues of fish management in urban wetlands.
- The identification and impact of pollutant pathways in urban wetlands.
- Health hazards posed to wildlife and the public from exposure to urban wetland pollutants such as bacteria/pathogens, hydrocarbons etc.
- Public attitudes to wildlife and ecological issues associated with urban wetlands and means of combating vandalism.

REFERENCES

Adams, L W and Dove, L E. 1984. *Urban wetlands for stormwater control and wildlife enhancement*. National Institute for Urban Wildlife, Columbia, Maryland, United States.

Apostolaki, S., Jefferies, C and Souter, N. 2001. Assessing the public perception of SUDS at two locations in Eastern Scotland. 28 - 37 in Pratt, C.J., Davies, H.W and Perry, J.L. (Edits): *Proc. 1st nat. Conf on Sustainable Dranage*. Coventry University, Coventry.

Ashley, R M., Morrison, R W., Fleming, R and Jefferies, C. 1998. Application of a computer model for BMP performance assessment and comparison between UK and German design practice. 513 - 520 in Butler, D and Maksimovic, C (Edits): *Proceedings IAWQ/IAHR 4th International Conference, Developments in Urban Drainage Modelling*. Imperial College of Science, Technology & Medicine, London.

Ashley, R.M., Smith, H., Jowitt, P.W., Butler, D., Blackwood, D.J., Davies, J.W., Gilmour, D and Foxon, T. 2001a. A multi-criteria analysis/risk management tool to assess the relative sustainability of water/wastewater systems; SWARD (Sustainable Water Industry Asset Resource Decisions). 221 - 231 in Pratt, C.J., Davies, J.W and Perry, J.L (Edits): *Proc. 1st Nat. Conf on Sustainable Drainage*, Coventry University, Coventry.

Ashley, R.M., Souter, N and Hendry, S. 2001b. The importance of public attitudes and behaviour for the management of urban water systems. *In Proc. UNESCO Conf. on Frontiers in Urban Water*, Marseilles, June 2001.

ap Rheinallt, T., House, M A., Hyde, V M and Sangster, E K. 1992. *Nature conservation in urban watercourses*. Report PRS 2482-M/1, Water Research Centre, Medmenham, Marlow, Bucks.

Bateman, M.J., Newman, A.P and Smith, S.J. 2001. A comparative study of the uptake and accumulation of zinc by *Typha latifolia* (L) and *Phragmites australis* (Cav.) Trin. Ex Steudel under hydroponic greenhouse conditions and the implications for wetland management. (Accepted for publication).

Batten, L A. 1989. Habitat management for bird species in urban wetlands. In: *Proceedings of Seminar on Urban Wetland Management*, Urban Pollution Research Centre, Middlesex University, 3 February 1989.

Bray, R.J. 1999. Design experience of source control on commercial development. In: *Vol XVII, Proceedings of 17th Meeting, Standing Conference on Stormwater Source Control*, Coventry University, Coventry.

Bray, R.J. 2001a. Environmental monitoring of sustainable drainage at Hopwood Park motorway service area M42 Junction 2. 58 – 70 in Pratt, C J., Davies, J W and Perry, J L (Edits); *Proceedings 1st National Conference on Sustainable Drainage*, June 2001, University of Coventry, Coventry.

Bray, R.J. 2001b. Maintenance of sustainable drainage: Experience on two EA demonstration sites in England. 93 – 104 in Pratt, C J., Davies, J W and Perry, J L (Edits); *Proceedings 1st National Conference on Sustainable Drainage*, June 2001, University of Coventry, Coventry.

Brodie, G A., Hammer, D A and Tomijanovich, D A. 1988. Constructed wetlands for wastewater treatment. 201 - 209 in *Proceedings 1st International Conference*, 13-17 June 1988, Tennessee Valley Authority, Chattanooga, Tennessee.

Brown. S., Shrestha, S and Riley, S J. 1999. The allocation of resources to stormwater pollution control. 381 - 389 in Ellis, J B (Edit); *Impacts of urban growth on surface water and groundwater quality*. Publ. No. 259., IAHS Press, Wallingford, Oxon.

Brown, W and Schueler, T. 1997. *The economics of stormwater BMPs in the Mid-Atlantic region*. Final Report, Centre for Watershed Protection, Silver spring, Maryland, USA.

Burkhard, R., Delectic, A and Craig, A. 2000. Techniques for water and wastewater management; A review of techniques and their integration in planning. *Urban Water*, 2, 197 - 221.

Camp, Dresser and McKee Inc. 1993. *California stormwater best management practice handbook*. State of California, Sacramento, California.

Carroll, B.A and Howes, H.R. 1998. Integrated environmental planning for sustainable development: The Environment Agency's role. *Journ. Chart. Inst. Water & Envir. Managt.,* 13 (1), 48 – 54.

CIRIA. (Maskell, A D; Ed) 1992. *Scope for control of urban runoff*. Report 123, Vols I-IV, Construction Industry Research & Information Association, London.

CIRIA. (Hall, M J., Hockin, D L and Ellis, J B) 1993. *Design of flood storage reservoirs*. Butterworth-Heinemann (also CIRIA), London.

CIRIA. 1996. *Sustainable urban runoff management*. Report 20. Construction Industry Research & Information Association, London.

CIRIA. (Nuttall, P M., Boon, A G and Rowell, M R) 1997. *Review of the design and management of constructed wetlands*. Report 180. Construction Industry Research & Information Association, London.

CIRIA. 2000a. *Sustainable urban drainage systems: A design manual for Scotland and N Ireland*. Report C521, Construction Industry Research & Information Association, London.

CIRIA. 2000b. *Sustainable urban drainage systems: A design manual for England & Wales.* Report C522, Construction Industry Research & Information Association, London.

CIRIA. 2001 *Sustainable urban drainage systems: Best Practice Manual*. Report C523, Construction Industry Research & Information Association, London.

City of Orlando Stormwater Utility Bureau. 1995. *Packed bed wetland stormwater treatment system*. Final Report, Florida Dept of Environmental Regulation, Tallahassee, Florida, USA

Cooper, P F. 1990. *European design and operation guidelines for reed bed treatment systems*. Report UI 17, WRc, Swindon.

Cooper, P F., Job, G D., Green, M B and Shutes, R B E. 1996. *Reed beds and constructed wetlands for wastewater treatment*. WRc, Swindon.

Crabtree, R.W. 2000. *A UK perspective on institutional constraints limiting advances in stormwater management*. Paper given at NATO Workshop, November 2000, St.Mariethal, Germany

Crites, R W. 1988. *Design manual: Constructed wetlands and aquatic plant systems for municipal wastewater treatment*. USEPA 625/1-88/022, US Govt. Printing Office, Washington DC, USA

Cutbill, L B. 1994. The potential for urban stormwater treatment by constructed wetlands. 677 - 686 in: *Proceedings IAWQ 4th International Conference on Wetland Systems for Water Pollution Control*, Guangzhou, China, 6-10 November 1994, IAWQ, London

Cutbill, L B. 1997. *Urban stormwater treatment by artificial wetlands*. Unpublished PhD thesis, University College, London.

D'Arcy, B J., Ellis, J B., Ferrier, R C., Jenkins, A and Dils, R. 2000. *Diffuse pollution impacts: The environmental and economic impacts of diffuse pollution in the UK*. Terence Dalton Publishers (CIWEM), Lavenham, Suffolk.

DETR. 2001. *Achieving a better quality of life: Review of progress towards sustainable development*. Department of the Environment, Transport and the Regions, HMSO, London.

Dobbie & Partners Ltd. 1988. *North Weald Brook Investigation*. Report to Epping Forest District Council, C H Dobbie & Partners Ltd, Croydon, Surrey

DoE. 1996. *The Environment Agency and sustainable development*. HMSO, London.

DTLR. 2001. Vegetative treatment systems for highway runoff. *Design manual for Roads and Bridges*. Advice Note, Volume 4, Section 2. Part 1, HA 103/01. HMSO, London.

Ellis, J B. 1990. Bioengineering design for water quality improvement of urban runoff. 34 - 47 in Balmforth, D J. (Edit): *Developments in storm drainage*. Proceedings of CIRIA/CIWEM Conference, Sheffield City University, Sheffield.

Ellis, J B. 1991. The design and operation of vegetative systems for urban runoff quality control. In: *Proc 3rd Standing Conf. Stormwater Source Control*, 1 - 12, Coventry University, Coventry.

Ellis, J B. 1993. Urban Lakes: Planning for amenity and leisure. In: *Proceedings of Seminar on Planning for Sustainable Development*. Churchill College, Cambridge, Smisson Foundation, Clevedon, Bristol.

Ellis, J B. 1999. Design considerations for the use of vegetative controls for the treatment of highway discharges. 357 - 364 in Ellis, J.B. (Edit); *Impacts of urban growth on surface water and groundwater quality*. Publ.No. 259, IAHS Press, Wallingford, Oxon

Ellis, J.B. 2000. Infiltration systems: A sustainable source control option for urban stormwater quality management?. *Journ. Chart. Inst. Water & Envir. Managt*., 14, 27 - 34.

Ellis, J B and Chatfield, P. 2000. Oils and Hydrocarbons. 9 - 20 in D'Arcy, B J., Ellis, J B., Ferrier, R C., Jenkins, A and Dils, R (Edits); *Diffuse Pollution Impacts*. Terence Dalton Publ., Lavenham, Suffolk.

Ellis, J B and Chatfield, P. 2001. Diffuse urban oil pollution in the UK. *Proceedings 5th IWA Conference on Diffuse Pollution*, June 2001, Milwaukee, Wisconsin, USA.

Ellis, J B and Revitt, D M. 1991. *Drainage for roads: Control and treatment of highway runoff*. Report NRA 43804/MID.012, National Rivers Authority, Reading.

Ellis, J B., Hall, M J and Hockin, D L. 1990. The design and operation of flood storage dams for recreational use. 133 - 136 in Tyler, N (Edit): *Proceedings 6th Conference on The Embankment Dam*, British Dam Society, Thomas Telford Ltd., London.

Ellis, J B., Revitt, D M and Llewellyn, N. 1997. Transport and the environment: Effects of organic pollution on water quality. *Journ.Chart.Inst.Water & Env. Managt*., 11 (3), 170 - 177.

Ellis, J B., Shutes, R B E., Revitt, D M and Zhang, T T. 1994a. Use of macrophytes for pollution treatment in urban wetlands. *Resources, Conservation & Recycling*, 11, 1-12.

Ellis, J B., Revitt, D M., Shutes, R B E and Langley, J M. 1994b. The performance of vegetated biofilters for highway runoff control. *Sci Total Env*., 146/147, 543 - 550.

Emerson, F B. 1961. Experimental establishment of food and cover plants in marshes created for wildlife in New York state. *New York Fish Game Journ*., 8(2), 130 - 144.

Environment Agency. 1997. *Liason with Local Planning Authorities.* Environment Agency, Bristol.

Environment Agency Thames Region. 1997. *Thames Environment 21: The Environment Agency strategy for land use planning in Thames region*. Environment Agency Thames Region, Reading.

Everard, M and Street, P. 2001. *Sustainable urban drainage systems; An evaluation using the Natural Step framework*. Draft Report, The Natural Step, London.

Fisher, A and Raucher, R. 1984. Intrinsic benefits of input water quality: Conceptual and empirical perspectives. *Advances in Applied Microeconomics*, 3, 37-66.

FWR. 1994. *Urban pollution management manual*. FR/CL0002. Foundation for Water Research, Medmenham, Bucks.

FWR. 1996. *Assessing the benefits of surface water quality impacts manual*. FR/CL0005. Foundation for Water Research, Medmenham, Bucks.

Grant, N and Griggs, J. 2001. *Reed beds: Applications, specification, design and maintenance*. Building Research Establishment, Garston, Watford, Herts.

Green, A and Faulkner, H. 2000. An assessment of the suitability of the Environment Agency's water quality classification system for use in urban catchments. *Journ.Chart.Inst.Water & Env.Managt*., 14 (2), 131 - 139.

Green, C H and Tunstall, S M. 1991. The evaluation of river water quality improvement by the contingent valuation method. *Applied Economics*, 23(7), 1135 - 1146.

Halcrow/UPRC. 1998. *Treatment of highway runoff using constructed wetlands: An interim manual*. Halcrow & Urban Pollution Research Centre, Middlesex University. Environment Agency Thames Region, Reading.

Halcrow/UPRC. 2000. *Protection of the water environment using balancing facilities.* Final Field Studies Report, Halcrow & Urban Pollution Research Centre, Middlesex University, Environment Agency Thames Region, Reading.

Hall, M J. 1977. The effects of urbanisation on storm runoff from two catchment areas in NW London. 144-152 in: *Effects of urbanisation on the hydrological regime*, Publ. 123, IAHS-UNESCO, Amsterdam.

Hall, M J., Hockin, D L and Ellis, J B. 1993. *Design of flood storage reservoirs*. Butterworth-Heinemann, London. (See also CIRIA, 1993)

Hammer, D A. (Edit). 1989. *Constructed wetlands for wastewater treatment: Municipal, industrial and Agricultural*. Lewis Publishers, Chelsea, Michigan, USA

Hares, R J and Ward, N I. 1999. Comparison of the heavy metal content of motorway stormwater following discharge into wet biofiltration and dry detention ponds along the London Orbital (M25) Motorway. *Science Total Env*., 235 (1/3), 169 - 178.

Heal, K. 1999. Metals in sediments of sustainable urban drainage structures in Scotland. 331 - 338 in Ellis, J.B. (Edit): *Impacts of Urban Growth on Surface Water and Groundwater Quality*. Publ. No. 259, IAHS Press, Wallingford, Oxon.

Heaney, J P., Wright, L., Sample, D., Urbonas, B., Mack, B W., Schmidt, M F., Solberg, M., Jones, J., Clary, J. and Brown, T. 1997. *Development of methodologies for the design of integrated wet weather flow collection/control/treatment systems for newly urbanised areas*. Vol.1, draft technical report, US Environmental Protection Agency, Edison, New Jersey, United States.

Holden, R. 1989. Wetland habitats in commercial estate development. In: *Proceedings of seminar on urban wetland management*. 3 February 1989. Urban Pollution Research Centre, Middlesex University, London.

Horner, R R., Skupien, J J., Livingston, E H and Shaver, H E. 1994. *Fundamentals of urban runoff management*. Terrene Institute, Washington DC.

House, M A and Sangster, E K. 1991. Public percepion of river corridor management. *Journ.Chart. Inst. Water & Env. Managt.*, 15 (3), 312-317.

Hull, L. 1993. Grizedale Forest Sculpture Park. *Sculpture Magazine Maquette*, May 1993.

Hvitved-Jacobsen, T. 1990. Design criteria for detention pond quality. 111 - 130 in Torno, H C (Edit): *Urban Storm Quality Enhancement*. American Society of Civil Engineers, New York.

Institution of Highways & Transportation. 2001. *Guidelines for the environmental management of highways*. Institution of Highways & Transportation, London.

IWA. 2000 *Constructed wetlands for pollution control: Processes, performance, design and operation*. (Eds; Kadlec, R H., Knight, R L., Vymazal, J., Brix, H., Cooper, P and Haberl, R). Scientific & Technical Report No.8., IWA Publishing, London.

Jones, R H. 1995. *Ecotoxicology of oil derived pollutants in urban receiving waters*. Unpublished PhD, Urban Pollution Research Centre, Middlesex University, London.

Kadlec, R H. 1996. An autobiotic wetland phosphorus model. *Ecological Engineering*, 8(2), 145 - 172.

Kadlec, R H. 2000. The inadequacy of first-order treatment wetland models. *Ecological Engineering*, 15, 105 - 119.

Kadlec, R H and Knight, R L. 1996. *Treatment wetlands*. CRC Press, Lewis Publishers, Boca Raton, Florida, USA.

Knight, R L., Ruble, R W., Kadlec, R H and Reed, S C. 1993. Wetlands for wastewater treatment performance database. 35 - 58 in Moshiri, G A (Edit):

Constructed wetlands for water quality improvement. Lewis Publishers Inc., Boca Raton, Florida.

Lawrence, I and Breen, P. 1998. *Design guidelines: Stormwater pollution control ponds and wetlands*. Cooperative Research Centre for Freshwater Ecology, University of Canberra, Canberra, Australia.

McCaskie, J and Lee, R. 1996. Restoring London's lakes. *Enact*., 4 (3), 4 - 7.

McKissock, G., Jeffries, C J and D'Arcy, B J. 1999 An assessment of drainage best practices in Scotland. *Journ Chart Inst Water & Env Managt*., 13(1), 47-54.

Merritt, A. 1994. *Wetlands, Industry and Wildlife: A manual of principles and practices*. The Wildfowl & Wetlands Trust, Slimbridge, Gloucs.

Metcalf and Eddy Inc. *Wastewater engineering: Treatment, disposal and reuse*. Third Edition, McGraw Hill, London.

Milton Keynes Development Corporation. 1992. *Monitoring studies of Milton Keynes balancing lakes*. Vols. 1-6. Urban Pollution Research Centre, Middlesex University. Milton Keynes Development Corporation, Milton Keynes.

Mitsch, W J and Gosselink, J G. 1993. *Wetlands*. Van Nostrand Reinhold, New York.

Moshiri, G A. (Ed). 1993. *Constructed wetlands for water quality improvement*. Lewis Publishers, Chelsea, Michigan, USA.

Mungur, A S. 1997. *The performance and perception of wetlands for the treatment of highway runoff*. Unpublished PhD thesis, Urban Pollution Research Centre, Middlesex University, London.

Mungur, A S., Shutes, R B E., Revitt, D M and House, M A. 1995. An assessment of metal removal from highway runoff by a natural wetland. *Water Sci Tech*., 32 (3), 169 - 175.

Mungur, A S., Shutes, R B E., Revitt, D M., House, M A and Fallon, C. 1998. A constructed wetland for the treatment of urban runoff. 329 - 341 in Wong, M.H., Wong, J.W.C and Baker, A.J.M. (Edits): *Remediation and Management of Degraded Lands*. Lewis Publishers Ltd., London.

NRA. 1993. *Guidelines for AMP2 periodic review* (Version 2). National Rivers Authority, Bristol.

NRA. 1994a. *Guidance notes for local planning authorities on the methods of protecting the water environment through development plans*. NRA, Bristol.

NRA Thames Region. 1995. *Thames 21: A planning perspective and a sustainable strategy for the Thames region*. NRA, Reading.

Nuttall, P M., Boon, A G and Rowell, M R. 1997. *Review of the design and management of constructed wetlands*. Report 180, Construction Industry Research and Information Association, London. (See also CIRIA, 1997)

Oldham, J. 1995. Sustainable development for large, mixed-use developments. In Volume IX, *Proceedings of Standing Conference on Stormwater Source Control*, Coventry University, Coventry.

Olsen, R K. 1993. *Created and natural wetlands for controlling non-point source pollution*. US Environmental Protection Agency., Cincinnati, Ohio, USA.

Payne, N. 1992. *Techniques for wildlife habitat management of wetlands*. McGraw Hill, London.

Pond Action. 2000. *An assessment of the ecological value of sustainable urban drainage systems in Scotland*. Report by Pond Action, Oxford Brookes University, Scottish Environment Protection Agency, Stirling.

Reed, S C., Crites, R W and Middlebrookes, E T. (Eds) 1995. *Natural systems for waste management and treatment*. McGraw Hill, New York, USA

Revitt, D M and Ellis, J B. 2000. Drainage, runoff and groundwater management. Chapter 4 in Mudge, G (Edit): *The environmental management of highways*. Institution of Highways and Transportation, London.

Revitt, D M., Shutes, R B E and Scholes, L. 1999. The use of constructed wetlands for reducing the impacts of urban surface runoff on receiving water quality. 349 -356 in Ellis, J.B. (Edit); *Impacts of urban growth on surface water and groundwater quality*. Publ. No. 259, IAHS Press, Wallingford, Oxon.

Richards, Moorehead & Laing Ltd. 1992. *Natural wetlands to ameliorate metal rich mine waters*. R & D Note 103, National Rivers Authority, Bristol.

RRP. 1995. *River restoration: Benefits for integrated catchment management*. Interim Report 1994, River Restoration Project Group, Huntingdon, Cambs.

RSPB. 1996. *Water management; Benefits for integrated catchment management*. Interim report 1994, River Restoration Project group, Huntingdon, Cambs.

Scheuler, T R. 1992. *Controlling urban runoff: A practical manual for planning and designing urban BMPs*. Washington Council of Governments, Washington DC.

Scholes, L N L., Shutes, R B E., Revitt, D M., Purchase, D and Forshaw, M. 1999. The removal of urban pollutants by constructed wetlands during wet weather. *Water Sci Tech*., 40(3), 333 - 340.

SEPA. 1997. *Urban best management practice database*. Tech. Report EQI, 17 December (G McKissock), Scottish Environment Protection Agency, East region, Edinburgh.

SEPA. 2000. *Ponds, pools and lochans*. Habitat Enhancement Initiative, Scottish Environment Protection Agency, Stirling.

SEPA, EA and E & HS. 2000. *An Introduction: Sustainable urban drainage systems*. Scottish Environment Protection Agency, Stirling, Environment Agency, Bristol and N Ireland Environment & Heritage Service, Belfast.

Shatwell, T and Cordery, I. 1999. Nutrient storage in urban wetlands. 339 - 348 in: Ellis, J B (Edit); *Impacts of urban growth on surface water and groundwater quality*. Publ. No.259, IAHS Press, Wallingford, Oxon.

Shutes, R B E., Ellis, J B., Revitt, D M and Zhang, T T. 1993. The use of *Typha latifolia* for heavy metal pollution control in urban wetlands. 407 - 414 in Moshiri, G.A. (Edit); *Constructed wetlands for water quality improvement*. Lewis Publishers, London.

Shutes, R B E., Revitt, D M., Mungur, A S and Scholes, L N L. 1997. The design of wetland systems for the treatment of urban runoff. *Water Sci Tech*., 35(5), 19 - 25.

Shutes, R B E., Revitt, D M., Lagerberg, I M and Barraud, V C E. 1999. The design of vegetative constructed wetlands for the treatment of highway runoff. *Sci Total Env*., 235, 189 - 197.

Sriyaraj, K and Shutes, R B E. 2001. An assessment of the impact of motorway runoff on a pond, wetland and stream. *Journ.Env.Geochem & Health*. (In press).

Stillings, L l., Gryta, J J and Ronnings, E A. 1988. Iron and manganese removal in a *Typha* dominated wetland during ten months following wetland construction in mine drainage and surface mine reclamation. 317 - 324 in *Information Circular 9183*, US Bureau of Mines, Pittsburgh, Pennsylvania.

Strecker, E W., Kersnor, J M, Driscoll, E D and Horner, R R. 1992. *The use of wetlands for controlling stormwater pollution*. Report EPA/600, The Terrane Institute, Washington DC, USA

Tucker, C. 1999. A modular approach to "end-of-pipe" stormwater treatment: Developments in the Lower Severn are of the Environment Agency. In*: Vol. XVII, Proceedings of 17th Meeting, Standing Conference on Stormwater Source Control*, Coventry University, Coventry.

Urban Drainage & Flood Control District. 1992. *Urban Storm Drainage Criteria Manual, Volume 3; Best Management Practices*. Urban Drainage & Flood Control District, Denver, Colorado, USA.

UPRC/CEREVE. 2000. *Review of best practices in the sue of constructed wetlands for pollution control*. Initial Report and Final Brief, UPRC, Middlesex University/CEREVE, Ecole des Ponts et Chaussees, Paris., Environment Agency Thames Region, R&D Project P-2-159, Reading, Berks.

Urban Water Resources Research Council and URS Greiner Woodward Clyde. 1999. *National Stormwater Best Management Practices (BMP) Database*. Environmental Protection Agency, Office of Water, Washington DC.

Urbonas, B R., Roesner, L A and Guo, C Y. 1996. Hydrology for optimal sizing of urban runoff treatment control systems. *Water Quality International*, February 1996, 30 - 33.

US Environmental Protection Agency. 1998. *Free water surface flow constructed wetlands for wastewater treatment and wildlife habitat: A technology assessment*. EPA/832-R-99-006. Office of Water, USEPA, Washington, DC.

Watson, J T and Hobson, T A. 1989. Hydraulic design considerations for control structures for constructed wetlands for wastewater treatment. 379 - 391 in Hammer, D A (Edit): *Constructed wetlands for wastewater treatment*. Lewis Publishers Inc., Chelsea, Michigan.

Watson, J T., Reed, S C., Kadlec, R H., Knight, R L and Whitehouse, A E. 1989. Performance expectations and loading rates for constructed wetlands. 319 - 352 in Hammer, D A (Edit): *Constructed wetlands for wastewater treatment*. Lewis Publishers Inc., Chelsea, Michigan.

WEF/ASCE. 1998. *Urban runoff quality management*. WEF Manual of Practice, No 23, Manual and Report on Engineering Practice, No 87., American Society of Civil Engineers, New York.

Wein, G R., Kroeger, S and Pierce, G J. 1987. Lacustrine vegetation establishment within a cooling reservoir. In *Proceedings 14th Annual Conference on Wetland Restoration and Creation*, Tampa, Florida.

Welsh Harp Conservation Group. 1992. *Annual Report*. London Borough of Barnet, Herts.

Wenk, W E. 1999. Stormwater as civic and ecological urban framework. 434 - 453 in Rowney, A C., Stahre, P and Roesner, L A (Edits): *Sustainable urban water resources in the 21st century*. American Society of Civil Engineers, Reston, Virginia, United States.

Wong, T H F., Breen, P F., Somes, N L G and Lloyd, S D. 1998. *Managing urban stormwater using constructed wetlands.* Cooperative Research Centre for catchment hydrology, Report 98/7, Monash University, Victoria, Australia.

Woolhouse, C. 1994. Catchment management plans: Current successes and future opportunities. 463 – 474 in Kirby, C and White, W.R (Edits); *Integrated River Basin Development*., J Wiley & Sons ltd., Chichester.

Worrall, P., Peberdy, K J and Millet, M C. 1996. Constructed wetlands and nature conservation. 1-1 to 1-9 in: *Proceedings 5th IAWQ International Conference on Wetland Systems for Water Pollution Control*, Vienna, Austria.

Younger, P L. (Edit). 1997. *Minewater treatment using wetlands*. Proceedings of CIWEM National Conference, 5 September 1997, University of Newcastle.

Younger, P L and Harbourne, K J. 1995. To pump or not to pump; Cost benefit analysis of future environmental management options for the abandoned Durham coalfield. *Journ Chart Inst Water & Env Managt*., 9 (4), 405 - 415.

APPENDIX A

WETLAND POLLUTANT EFFICIENCY RATES

1. Introduction

A full procedure for estimating the pollutant retention efficiency of a wetland basin as a function of particle size is given in Section 6.5 (pages 89 - 95) in the CIRIA manual "*Design of Flood Storage Reservoirs*" (Hall *et al*., 1993). A simplified modification of the procedure is presented here (in the form of a "look-up" table), with the emphasis being placed on solids retention.

2. Particle Settling Velocity

As a design guide, Table A1 provides values of fall velocity (Vs) for a typical range of particle diameters. The settling velocity (Vs) values in Column 3 assume a density (or specific weight) equivalent to common quartz (2.65) for all particle sizes. However, for particles less than 0.1mm (very fine sand), the density actually

Table A1. Solid Sizes and Settling Velocities

Solids Grade	Particle Diameter (d; mm)	Settling Velocity (Vs; mm/s at 10^o C) Density; 2650 kg/m^3	Density (kg/l)	Sedimentation Efficiency (%)
Pea Gravel	10.0	800.0	2.65	100
Coarse sand	1.0	200.0	2.65	95
Medium sand	0.5	70.0	2.5	90
Fine sand	0.2	22.0	2.5	90
Very fine sand	0.1	10.0	2.5	90
Coarse silt	0.05	6.7	2.3	80
Medium silt	0.01	0.18	2.0	70
Fine silt	0.005	0.016	1.7	60
Clay (and organics)	0.001	0.011	1.1	50

reduces quite sharply which reduces the sedimentation efficiency of such small relatively buoyant particles. In addition, even small eddies and currents induced by flow, wind or thermal gradients in the wetland will exacerbate this buoyancy as will short-circuiting. The sedimentation efficiency loss is therefore highest for the finest silt and clay gradings as can be seen from inspection of the final two columns in Table A1. It should be noted that Table A1 assumes an ambient temperature of 10^o C, but as temperature increases the kinematic viscosity and density decrease which in turn lead to an increase in the settling velocity. Thus the retention efficiency values quoted in Table A1 are on the conservative side for most UK weather conditions.

3. Solids Retention

The total solids retention of the wetland basin can be estimated as :

Retention (%) = Σ[Fraction (%) x {1 - e (-Vs.t / d)}]
where Vs is the fall velocity (m/s), t is time in seconds and d is the average wetland depth.

Solids retention for individual size ranges for any specific time period (say 0.2, 0.5, 0.8,1.2……n days) can be estimated as:

Retention = γ_n / γ_0 = $1 - 1/ [\{1 + (10n.Vs.As/Q)\}]$
where γ_n and γ_0 are the solids concentrations after 1 day, t_n and start time, t_0 respectively; Vs is the settling velocity (m/d); As is the wetland surface area, (ha x 10^4 m^2); Q is the (post-storm event) average dry weather flow rate (Ml/d x 10^3 m^3/d); and n is the sedimentation basin performance coefficient. Given the shallow depth and potential for significant inflow eddy currents within constructed wetlands, their sedimentation efficiency rating (especially for particle sizes below 80 μm), appear to be relatively poor (n = 🗁) to very poor (n = 1). The interception equations for these differing sedimentation conditions would thus be of the form:

Very Poor: $\gamma_n / \gamma_0 = 1 - 1/ (1 + \{10Vs. As/Q\})$
Poor: $\gamma_n / \gamma_0 = 1 - 1/ (1 + \{10Vs. As/Q\}^2)$
Excellent: $\gamma_n / \gamma_0 = 1 - e\ (10Vs. As/Q)$

The cumulative solids retention is then given by:

Cumulative Percentage Retention = $\Sigma[\text{Fraction (\%)} \times (1 - \gamma_n / \gamma_0)]$

4. Solids-Retention Curves

Based on particle size analysis of solids discharged to a wetland over specific time periods during and following a storm event, it is possible to compute a site-specific "solids-time" retention curve as illustrated by Figure 5 (Section 1.6.4.2, Chapter 1). The procedure can be shortened by taking a few key size groups from Table A1 e.g coarse sand, fine sand and clay. The procedure can also be improved by direct laboratory determination of the settling velocities rather than using the Vs values given in Table A1. A procedure for empirically determining Vs is given in Hall *et al* (1993) which utilises Camp's three-parameter function (Camp, 1946) for determining the trap efficiency. Vetter's formula is used to adjust for short-circuiting and basin turbulence (Vetter, 1940).

The use of estimated pollutant partition coefficients (and/or particle size weightings) derived from the literature for metals, hydrocarbons etc., can also be applied to derive an approximation of other toxic species removal rates. Table A2 provides estimates of

Table A2. Pollutant Load Fractions Attached to Stormwater Solids

Pollutant	Percentage Solids Partitioning
BOD	60 - 70
COD	75 - 85
Bacteria	80 - 90
Hydrocarbons	65 - 75
Zinc	30 - 45
Lead	75 - 85

of the range of observed pollutant loads attached to stormwater sediment, mainly associated with the finer particle size fractions below 0.05 mm. Adjustments can be made to the solids retention results obtained from the calculations in Section 3 above to derive an estimate of the retention efficiencies for the various toxic pollutant species noted in Table A2.

5. Empirical Approaches to Solids Removal

5.1 Solids removal is essentially a function of sedimentation i.e. (bio)infiltration and retention time, which is primarily affected by the relationships between size and settling velocity (Section 2 above). A number of empirically derived regression equations have been derived to predict solids removal efficiency for SSF wetlands in the absence of detailed data on influent particle size distribution and settling velocities (V_s). The two most widely used are those associated with the US NADB (Knight *et al*., 1993) and UK/Denmark wetland databases (Brix, 1994):

$C_{Sout} = 4.7 + 0.09\ C_{Sin}$ (Brix, 1994)
$C_{Sout} = 7.8 + 0.063\ C_{Sin}$ (Knight *et al*., 1993)
Reed (1994) has also suggested:
$C_{Sout} = C_{Sin}\ [(0.1058 + 0.0011)\ HLR\ (cm/day)]$

5.2 Taking the wetland design data from Section 2.2, Appendix B and the derived HLR value (0.043 m/d) of Section 2.3 in Appendix B, and assuming a TSS influent concentration (C_{Sin}) of 100 mg/l, the Reed equation derives an outflow (C_{Sout}) concentration of:

$$C_{Sout} = 100\ [\{(0.1058 + 0.0011)\ 4.3\}] = 46\ mg/l = 54\%\ \text{removal efficiency}$$

The UK/European and US NADB equations derive C_{Sout} values of 5.6 mg/l and 14.1 mg/l respectively i.e a 94% and 86% removal efficiency.

References

CAMP, T R. 1946. Sedimentation and the design of settling tanks. *Trans, Amer. Soc. Civil Eng*., 111, 895 - 952.

HALL, M J., HOCKIN, D L and ELLIS, J B. 1993. *Design of flood storage reservoirs*. Butterworth-Heinemann/CIRIA, London. ISBN 0 7506 1057 3

VETTER, C P. 1940. Technical aspects of the silt problem on the Colorado river. *Civ, Eng*., 10 (11), 698 - 701.

APPENDIX B

KINETIC DESIGN MODELLING OF WETLANDS
(See Section 1.7 and 3.2.2 in main text)

1. Introduction

1.1 Plug flow is generally considered to be the optimal flow condition for a wetland and is from a hydraulic viewpoint the preferred flow regime since all fluid elements reside around the normal residence time. Further, the removal rates of pollutants such as BOD, SS and nitrogen increase with the loading rate, which makes plug flow more desirable. Mathematically, plug flow can be defined as a residence time distribution (RTD) with a variance (σ^2) equal to zero i.e no dispersion other than the advection, and a quotient between mean time (t_{mn}) and nominal residence time (t_{nom}) which equals unity i.e no dead zones.

1.2 The generalised plug flow input/output reactor k - C^* model is given in the box in Section 1.7 as: (-k/HLR) = $\ln[(C_{out} - C^*) / (C_{in} - C^*)]$ and where the Hydraulic Loading Rate (HLR) = (Q_{in} / A_s); see third box in Section 1.6.3. Re-arrangement (with appropriate unit conversion) of this general model therefore provides a basis for determining the required surface area (A_s) of a SF wetland basin intended for the removal of a particular pollutant:

$$A_s = (Q/k) \ln[(C_{in} - C^*) / (C_{out} - C^*)]$$

1.3 Reed *et al* (1995) have also proposed a simplified kinetic design equation which places k into the numerator of the equation, and that can be used for preliminary estimation of SSF wetland sizing:

$$A_s = Q (\ln C_{out} - \ln C_{in}) / kD$$

where D is the free water depth (ρ x d); see boxes in Section 1.6.3.

2. Wetland Sizing

2.1 As an example, it is intended that a stormwater SF wetland should reduce the long-term inlet annual average Total Nitrogen (N_{tot}) concentration from 4.5 mg/l to a target outlet concentration of 1.6 mg/l for an average influent discharge (Q_{in}) of 25.8 m^3/d. What surface area (A_s) of wetland will be required? No values are given for the nitrogen decay rate constant (k_{Ntot}) or for the wetland background concentration (C^*) but reference to Table 3.1 gives values of 22 m/yr and 1.5 mg/l respectively for these two parameters.
Applying and re-arranging the general equation:

$$A_s = [(25.8 \times 365) \ln\{(4.5 - 1.5) / (1.6 - 1.5)\}] / 22$$
$$= 1,455.86 \text{ m}^2 = 0.15 \text{ ha}$$

It should be noted that the effect of ignoring the background C^* value would give a much smaller surface area (A_s) value of 0.046 ha. Reduced winter temperatures will also reduce the k value, thus leading to a requirement for larger surface areas. For example, with a mean winter temperature of 5^o C (see box in Section 1.7) and still ignoring the background C^* value:

$$k_{Ntot} = 20\,(1.09)^{(5-20)} = 10.6 \text{ m/yr}$$

which would yield a wetland surface (A_s) value of 0.095 ha (i.e twice as large).

2.2 A 0.6m deep SSF wetland with substrate porosity of 0.4 (40%) receives an average daily flow of 60.5 m^3/d with an influent BOD concentration of 140 mg/l and has an outflow target concentration of 10 mg/l. The prevailing winter temperature is 10^o C and the reaction rate constant (k) is 1.104 days at 20^o C. What surface area (A_s) is needed to meet the target concentration?

$$k_{BODt} = 1.104\,(1.09)^{(10-20)} = 0.47/\text{day}$$

$$\text{and } A_s = 60.5\,(\ln 140 - \ln 10) / (0.47 \times 0.6 \times 0.4) = (160 / 0.113)$$

$$= 1416 \text{ m}^2$$

2.3 An alternative non-kinetic approach to the sizing of SSF wetlands has been suggested by Reed (1993) which is based on the premise that in a "temperate" climate, the annual BOD removal rate approximates 2.5 kg/m^2/yr. Using the design information provided in Section 2.2 above, the annual BOD removal for the wetland would be: $[(C_{in} - C_{out})\,(Q/1000)]\,365$

$$= [(140 - 10)\,(60.5 / 1000)]\,365 = 2{,}871 \text{ kg/yr}$$

$$\text{and } A_s = (2871 / 2.5) = 1148 \text{ m}^2$$

which is within 20% of the 1416 m^2 figure derived from the kinetic procedure, and HLR = (Q / A_s) = (60.5 / 1416) = 0.043 m/d (= 4.3 cm/day)

3. Pollutant Decay Rates and Removal Efficiency

3.1 For the general pollution reduction rate (J) equation given in section 1.7:

$$J = -k\,(C_{in} - C^*)$$

and the pollutant mass balance equation, assuming plug flow conditions, for the wetland also can be expressed as:

$$HLR\,(\partial C_{in} / \partial x) = -k\,(C_{in} - C^*)$$

with the pollutant fraction remaining (F_R) in the wetland of the total possible change in pollutant (see box in Section 1.7) then being:

$$F_R = [(C_{out} - C^*) / (C_{in} - C^*) = e\,[(-k / HLR)]$$

3.2 The decay rate (k) for Total Nitrogen (N_{tot}) removal in a wetland is 31.7 m/yr at a determined HLR value of 28.65 m/yr. What is the pollutant fraction remaining (F_R) in the wetland?

$$F_R = [(C_{out} - C^*) / (C_{in} - C^*)] = e^{(-k / HLR)}$$

$$= e^{(-31.7 / 28.65)}$$

$$= 0.031$$

Therefore the percentage of total nitrogen retained within the wetland as a result of these conditions would be 33.1%.

Note that the combined dimensionless value (-k / HLR) is also known in many textbooks (e.g. Kadlec and Knight, 1995) as the Damkohler number (Da)

3.3 A SSF wetland is designed for a maximum stormwater discharge of 300 m^3/d with hydraulic retention time (HRT) of 4 days. The gravel (Diameter, Dp = 10mm) substrate has a porosity (ρ) of 40% and the average water depth (d) is 0.55m.

From the first box in Section 1.6.3, HRT = (LWD) / Q = ($A_s d\rho$ / Q)

$$4 = [(LW \times 0.55 \times 0.4) / 300] \text{ and as } LW = A_s$$

$$A_s = 5455 \text{ m}^2 \text{ and with } HLR = (Q / A_s)$$

$$HLR = 300 / 5455 = 0.055 \text{ m/d}$$

With a particle size of 10mm, the hydraulic conductivity (k_h) can be estimated as (see the last box in Section 3.2.2):

$$k_h = 12{,}600\ (0.01)^{1.9} = 2.0 \times 10^{-2} \text{ m/s}$$

3.4 The first-order kinetic plug flow reaction model can be used to predict the pollutant removal efficiency using the alternative form of the general model as shown in the box in Section 1.7:

$$C_{out} = C_{in}\, e\, [(-k / HLR)]$$

For the 1.3 ha Anton Crescent SF wetland in Sutton, Surrey, Cutbill (1997) calculated that the mean inlet concentration for Total Coliforms was 1990 MPN/100ml with an average annual HLR of 13.33 m/yr and decay rate k value of 19.89 m/yr. Therefore:

$$C_{out} = 1990\, e\, [(-19.89 / 13.33)] = 448 \text{ MPN/100ml}$$

$$= 77\% \text{ average annual removal rate}$$

Figure B1 illustrates the removal efficiency for varying hydraulic loading rates (HLR) values ranging from 1 up to 1,000 m/yr. The figure shows that the SF wetland is able to reduce bacterial concentrations effectively up to HLR rates of about 100 m/yr although 65% removal can be expected at rates of less than 12 m/yr.

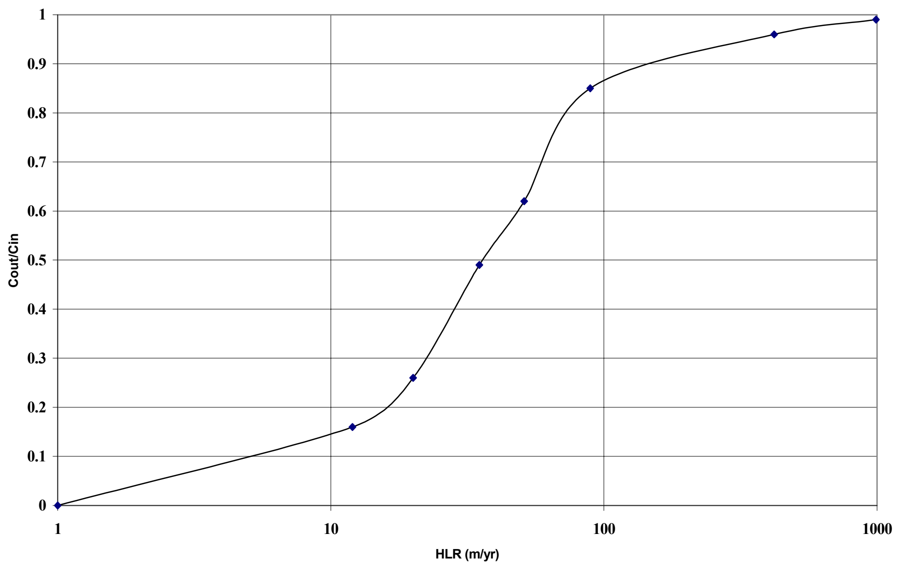


Figure B1. Bacterial Removal Efficiency and Hydraulic Loading Rate

References

BRIX, H. 1994. Constructed wetlands for municipal wastewater treatment in Europe. 325 - 333 in MITSCH, W J (Edit): *Global wetlands; Old world and new*. Elsevier Ltd., Amsterdam.

CUTBILL, L B. 1997. *Urban stormwater treatment by artificial wetlands*. Unpublished PhD thesis. University College, London.

KADLEC, R H and KNIGHT, R L. 1995. *Treatment wetlands*. CRC Press, Lewis Publishers, Boca Raton, Florida, USA

KNIGHT, R L., RUBLE, KADLEC, R H and REED, SC. 1993. Wetlands for wastewater treatment performance database. 35 - 58 in MOSHIRI, G A (Edit): *Constructed wetlands for waste quality improvement*. Lewis Publishers, Boca Raton, Florida, USA

REED, S C. 1993. *Subsurface flow constructed wetlands for wastewater treatment*. Report EPA832-R-93-008, Environment Protection Agency, Washington DC, USA.

REED, S C., CRITES, R W and MIDDLEBROOKES, E T (Edits). 1995. *Natural systems for waste management and treatment*. McGraw Hill, New York, USA

APPENDIX C

SURFACE WATER DISCHARGE, SEDIMENT QUALITY STANDARDS AND RECEVING WATER CLASSIFICATION IN ENGLAND & WALES

1. Discharge Standards and Consents for Surface Waters in England & Wales

1.1 Section 95 of the 1991 UK Water Industry Act states the general duty of sewerage undertakers is to "*provide, improve and extend…….a system of public sewers*"…. to achieve effectual drainage within urban areas. This duty includes the requirement to collect and dispose of surface water. Outfalls from separate (surface water) sewers are not subject to routine consent in the UK although under Section 85 of the 1991 Water Resources Act it is an offence to "*cause or knowingly permit any poisonous, noxious or polluting matter or any solid waste matter to enter any controlled waters*". Section 100 of the 1980 Highways Act gives the right to discharge road runoff to surface waters through highway drains (which include ditches, gutters, culverts and pipes).

1.2. However, under Section 89 (5) of the 1991 Water Resources Act (WRA), the highways authority does not require the statutory defence of a discharge consent although the 1998 Groundwater Regulations (which implement the EU Directive 80/68/EEC), does impose specific requirements. It should be noted that the exemption status for stormwater drainage does not apply in Scotland where they were taken out of direct control as a deregulation initiative at the time that the Scottish Environment Protection Agency (SEPA) was established. Measures required to prevent or alleviate pollution are usually agreed through consultation between the highways authority and the Environment Agency and a policy implementation guidance note (SC/CC/014) for highway discharges was issued in September 1992. The Environment Agency and Highways Agency have a Liaison Agreement in place which sets out their joint understanding of the relevant legislation and arrangements for early consultation on the effects of new and improvement schemes and maintenance works on the water environment. This is currently being updated and is intended to become a formal Memorandum of Understanding or Advice Note (see Section 6.3.2.4.4). The criminal defence against highway discharges embodied in Section 89 (5) WRA 1991 does not hold against liabilities arising under civil law where pollution can be shown and proven to be "*caused or knowingly permitted*".

1.3 The Environment Agency can choose to apply the provisions of Section 86 of the WRA 1991 to serve a Conditional or Absolute Prohibition Notice to an existing surface water outfall (SWO), if it saw fit to do so because of some particular pollution hazard. This could either require that a consent be obtained (under Schedule 10, para 5 (1), WRA 1991) or alternatively the Agency may specify the conditions to be observed prior to the approval of a discharge. SEPA has a similar fall-back power of serving a prohibitive Notice requiring pollution prevention measures; the only defence against an Absolute Prohibition Notice being a discharge consent. On the basis of the limited information available at the time of writing this report, there are about 50,000 SWOs in the UK of which some 7% (about 3540) are consented. Where surface water discharges are highlighted as a cause of receiving water quality problems, a similar approach to that applied to combined sewer overflows (CSOs) is likely to be adopted based on discharge frequency-duration-magnitude relationships.

1.4 The consenting approach includes the assessment of the effects of short duration pollution pulses on the aquatic biota together with consideration of aesthetic requirements (e.g no visible oil, gross solids limitation etc..). The nature and form of surface water outfall (SWO) consents is therefore likely to be similar to those set for combined sewer overflows (CSOs) and the Environment Agency may also set conditions for treatment in a consent. The conceptual regulatory approach to such intermittent, wet weather storm discharges that has been adopted in the UK Urban Pollution Management (UPM) Manual, is one of environmental quality standards linked to use-related objectives (FWR, 1994). Three major water-related uses have been identified as being potentially affected by CSOs and SWOs:

- River Aquatic Life; where short periods of low DO and/or high un-ionised ammonia can hinder the development of a sustainable fishery in inland waters
- Bathing; where frequent and persistent high bacterial concentrations can cause non-compliance with the EU Bathing Directive standards
- General Amenity; where gross solids and litter can lower the perceived quality of the receiving water body resulting in public complaints

1.5 Environmental quality standards for intermittent discharges have been developed (FWR, 1994) for River Aquatic Life based on intensity/duration/frequency relationships for DO and un-ionised ammonia and are illustrated in Table C1. The intermittent standards in the table give allowable return periods for specified DO and ammonia thresholds. For example, the minimum return period for DO falling below 4 mg/l for a 1 hour spillage period is one month i.e such an event should not happen more frequently than 12 times a year on average. The UPM Manual standards are based on literature information and the results of ecotoxicological investigations based on viability of fish and invertebrate communities.

Table C1. Standards for Intermittent Discharges

Flow Return Period	**Dissolved Oxygen (DO) Concentration** (mg/l)				**Ammonical Nitrogen (NH_3-N)** (mg/l)		
	Exposure Period				1 Hour	6 Hours	24 Hours
	0.25 hours	1 Hour	6 Hours	24 Hours			
1 Week	4.0	6.0	7.0	7.5	-	-	-
1 Month	3.5	4.0	5.0	5.5	0.175	0.100	0.040
3 Months	3.0	3.5	4.5	5.0	0.250	0.150	0.060
1 Year	2.7	3.0	4.0	4.5	0.275	0.175	0.075

1.6 The environmental standards for protection of Bathing Waters are well known from the EU Directive which is being currently reviewed. As yet no inland waters within the UK have been designated under the terms of the Directive and as such surface water outfalls discharging to recreational receiving waters are not strictly subject to the Directive. However, the acceptable duration of non-compliance due to storm discharges would be about 1.8% of the "bathing or recreational season". An alternative emission-based approach has been developed for CSOs in the form of a simple spill frequency criterion, expressed as not more than three spills on average per "bathing season" (NRA, 1993).

1.7 The Environment Agency Regions Complaints Registers indicate that urban runoff is the source of some 2 - 10% of public complaints compared to 5 - 20% in the case of sewage-related pollution associated with CSOs (FWR,1996). Aesthetic pollution caused by intermittent urban discharges can be judged on the basis of litter, refuse, colour, odour, visible oil, foaming and excessive fungal growth in the receiving water below a combined sewer overflow or surface water outfall discharge point.

1.8 It should be noted that fundamental change to the current UK water quality legislation will take place with the rolling implementation of the EU Water Framework Directive over the next five years or so. It is not as yet at all clear what the implications or effects of the new legislation will have on procedures for approving and/or consenting surface water discharges although it may be that the Environment Agency will wish to adopt a Supplementary Measures approach under the Directive using "general binding rules" to tackle diffuse pollution accompanied by more extensive and targeted Codes of Practice embodied in revised Pollution Prevention Guidelines (PPGs); see Section 6.2.2.

2 Receiving Water Quality Classification in England & Wales

2.1 Under the provisions of the 1991 Water Resources Act, the National Water Council (NWC) classification scheme of absolute measures of receiving water quality has been replaced with a General Quality Assessment (GQA) to be applied to a given river reach and a Rivers Ecosystem (RE) classification for the statutory Water Quality Objectives (WQOs) required to meet specified local use-related needs. The former GQA addresses four main categories (or Windows) covering General Chemical, Nutrients, Biological and Aesthetic Quality whilst the RE classification establishes clear quality targets (and specified compliance dates) for all controlled waters on a statutory basis.

2.2 Only the general Chemical Window is currently in place and only for a limited number of determinands although the structure of the Biological Window has recently been issued in draft form and is based on a comparison of the observed freshwater invertebrate fauna at a site with that which would be expected if no pollution was present. Appendix C shows the structure of and relationships between these new water quality assessment approaches and the previous NWC system. In the event that both a WQO and a GQA exists for a particular water, then the Environment Agency will be legally obliged within a specified period, to improve the water quality such that the GQA is similar or better than the WQO equivalent parameters. As such therefore, the statutory WQO of the receiving water will dictate the treatment level required for surface water discharges (including urban and highway runoff).

2.3 Where statutory WQOs do not exist, either the GQA or interim, non-statutory WQOs will be used. Where a stream reach supports more than one use-function, and where both statutory and non-statutory water quality requirements pertain, the most stringent of the combined specifications will apply. Therefore the assessment of new roads or road improvements must include consideration of all the uses (both upstream and downstream) to which the watercourse is put.

3 Sediment Quality Standards

3.1 Wetland SuDS structures will accumulate contaminated sediment including toxic metals which will ultimately require disposal and thus become subject to prevailing regulatory limits for contaminated soil and biosolids. Table C2 gives "trigger" or threshold loading limits as defined under EU legislation for biosolids and soil expressed in either annual or total cumulative loadings. As a basis for comparison with the standard EU limits, the table also shows regulatory limits that have been established elsewhere and which are often referred to in the literature.

3.2 The UK Inter-Departmental Committee on the Redevelopment of Contaminated Land (ICRCL) values are those quoted for parks and open spaces whilst the Dutch values are those defining clearly contaminated land. Even adopting the maximum loading rates shown in the table would suggest that the operational lives of most wetlands would be at least 20 - 50 years especially if given regular and proper maintenance. However, the relatively low loading limits specified for cadmium might provide a more critical restriction.

Table C2. Sediment Quality Standards

Pollutant	**UK ICRCL** (mg/kg)	**EU 1986 Directive**				**Dutch Ministry of Public Housing** (mg/kg)	**Swedish EPA** "Moderate pollution" (mg/kg)	**US EPA** 503 Regulations (kg/ha/yr)	**Canada** Ontario Ministry of Env. (Lowest Effect Level) (mg/kg)
		Biosolids (mg/kg)	UK 90% (1996/97) Biosolids Limit	Soil (mg/kg)	Application Loading 10 yr average (kg/ha/yr)				
Zinc	300	2500 - 4000	1076	150 - 300	30	720	175 - 300	140	110.0
Lead	2000	750 - 1200	288	50 - 300	15	530	30 - 100	15	31.0
Cadmium	15	20 - 40	3.4	1.3	0.15	12	1.7 - 2.0	1.9	1.0
Copper		1000 - 1750	758	50 - 140	12		25 - 50		25

References

FWR. 1994. *Urban pollution management manual*. FR/CL0002, Foundation for Water Research, Medmenham, Bucks.

WATER QUALITY ASSESSMENT SCHEMES
(Formerly consolidated within the NWC scheme)

GENERAL QUALITY ASSESSMENTS (GQA)
(For survey assessment purposes)
Will consist of **FOUR** separate **WINDOWS** as given below

WATER QUALITY OBJECTIVES (WQOs)

(On pass/fail basis for management purposes)

2. NUTRIENTS

4. AESTHETIC QUALITY

3. BIOLOGICAL QUALITY	**1. CHEMICAL** Water Quality	GRADE	DO % Sat 10%ile	BOD mg/l 90%ile	Total Ammonia mg/l 90%ile	Total Zinc µg/l 95%ile	Dissolved Copper µg/l 95%ile	Hardness mg/l CaCo$_3$	RIVER ECO-SYSTEM (RE) WQOs	Former NWC System
A Better than expected; high diversity; several species in each taxa	Very Good	A	80	2.5	0.25	30 200	5 22	≤10 10 - 50	**RE1**	**1a**
B Short of expected; small reduction in pollution tolerant taxa	Good	B	70	4	0.60	300 500	40 112	50 - 100 >100	**RE2**	**1b**
C Worse than expected; many sensitive species absent; rise in pollution tolerant taxa	Fairly Good	C	60	6	1.3	300 700	5 22	≤10 10 - 50	**RE3**	**2**
D Worse than expected; sensitive taxa scarce; some pollution tolerant species in large numbers	Fair	D	50	8	2.5	1000	40	50 - 100	**RE4**	
E Restricted to pollution tolerant species; a few taxa dominant; sensitive taxa rare or absent	Poor	E	20	15	9.0	-	-	-	**RE5**	**3**
F Limited to few pollution tolerant taxa; or no life present	Bad	F	-	-	-	-	-	-		**4**

Figure C1 Water Quality Assessment Schemes

APPENDIX D

LEGAL REGULATIONS, WATER QUALITY AND SEDIMENT STANDARDS IN FRANCE FOR SURFACE WATER DISCHARGES AND THE ENVIRONMENT

D1. Stormwater Control

1.1 Law 92-3 of 3 January 1992, article 35.III requires urban communities to delimit after a public investigation:

- zones within which measures should be taken to limit the impermeabilisation of land and to ensure stormwater control
- zones within which it is necessary to provide devices for collection, storage and when needed, treatment of stormwater if the pollutant load discharged to the receiving waters is likely to seriously damage the efficiency of the sewerage system

1.2 The above two paragraphs of article 35.III invoke directly or indirectly the need for retention (permanent wet) basins which may form part of the array of devices recommended for good management of the urban water cycle

D2. Discharge Permit

2.1 The byelaw of 20 November 1979, framed for application of decree number 73-218, lays down provisos applicable to the stormwater discharged from channels, pipes etc. (decree no. 73-218 was later abrogated)

2.2 Law 92-3 of 3 January 1992 prescribes in article 10 the procedures for declaration or permit for works involving pairing out, flow, discharge or storage which may be directly or indirectly, chronic or occasionally, polluting or non-polluting.

2.3 Decree no.93-743 of 29 March 1993 gives the list of these works in its annexure, notably:

- Clause 2.7.0; Creation of ponds or water bodies with a surface area
  - larger than 3ha would need a Permit
  - larger than 2000 m^2 but smaller than 3ha would need a Declaration
- Clause 5.3.0; Regarding discharge of stormwater into surface waters or into an infiltration pond, if the total water catchment area is-
  - larger than or equal to 20ha, a Permit is required
  - large than 1ha but smaller than 20ha, a Declaration is required

D3. Environmental Impact Study/Statement

Under article 2 of law 76-629 of 10 July 1976, open basins, irrespective of their size, are subject to an impact study under current french law where "the preliminary study before planning or installation of works which, by virtue of their size or their influence on the natural environment, could undermine the latter, should include an impact study….to assess the consequences".

D4. Public Safety and Health

4.1 Retention (wetland) basins are governed by the municipal police as specified in the Code of Communes and Departmental Sanitary Regulations.

- Article L.131-2 stipulates:
  - the mayor is responsible….for taking suitable precautions to put a stop to pollution of all types
- Article L.131-11 stipulates:
  - the mayor can require the owners, beneficiaries and users to enclose by proper fencing, all holes, wells, shafts and excavations likely to endanger public safety

4.2 Article 36 of the Standard Departmental Sanitary Regulations concerning storage of non-potable water stipulates:

- "water storages have to be emptied as often as necessary, in particular to prevent proliferation of insects. They have to be cleaned and disinfected as often as necessary, but at least once a year".

However, these provisos may not be strictly applicable to stormwater retention (wetland) basins.

D5. Urban Planning

5.1 Retention (wetland) basins are not explicitly mentioned in the Code for Town Planning. They may however, be considered a part of lowering or raising the level of land operations, which are frequently mentioned in the Code.

5.2 Article L121-10 states:

- the town planning documents specify conditions that assist in prevention of natural as well as technological risks. The provisos of this article have to be considered as law for Town and Country Planning in the sense of article L111-11 of the French Code of Urbanisation. This article confers a special articulation between elaboration of town planning documents and studies of stormwater networks and retention (wetland) basins. It refers to the obligations of the communities regarding division of their territory into zones (cf with D1 above) and the measures limiting the impermeabilisation of land conforming to law 92-3 of 3 January 1992
- Article L123-1 reads: "the Plan d'Occupation des Sols (POS; land use plan) should fix the sites reserved for public roads and works" and clearly, retention basins should figure among the sites reserved by POS. In this context, attention is drawn to the consequences of article L.123-9 which specifies the rights of owners and the obligations of the community with respect to reserved sites.

5.2 Under POS, retention basins are governed by articles R.123-18 (Graphic Documents) and R.123-21 (Regulation) which relate to identified zones which are either subject to special conditions (e.g prescribed land uses and operations) or prohibiting buildings and facilities, lowering or raising land etc.

5.3 According to the Code of Urbanisation (article L.421-1), a request for a building permit must be made in most cases of retention (wetland) basins although article R.422-2 allows exemption for technical structures whose floor area is smaller than 20 m^2 and height less than 3m. It should be noted that French Circular DAU of 25 July 1986 (Direction de l'Architecture et de l'Urbanisme, Ministry of Public Works and Transport), contains information that does not coincide with the contents of the above articles of the Code of Urbanisation. The revised article R.421-1 gives a special list of works or structures exempted from the application of building permits which includes "basins, irrespective of their usage; pleasure, agricultural, pisiculture, aquaculture and uncovered swimming pools"

5.4 Article L.422-2 stipulates that works exempted from the building permit should nevertheless be subject to a preliminary Declaration in which full detail (article R.422-3) of the proposed works be given.

5.5 According to the French Code of Urbanisation under article R.422-2, retention (wetland) basins belong to a group of installations and works for which a request for Authorisation must also be made.

5.6 The Code of Urbanisation provides (under L.332-9; Plan d'Amenagement d'Ensemble, PAE) that private operators/developers may be required to meet all or at least part of the cost of public facilities needed or associated with retention basins in accordance with the town and country plans

5.7 Article R.123-18, Sections c and d of the Code of Urbanisation define NC and ND zones which are protected zones by virtue of their agricultural, groundwater (NC) or aesthetic, historical, ecological (ND) value. Within such zones, the construction of retention (wetland) basins would be subject to particular attention and questioning.

D6. Accidental Pollution

6.1 Law no.84-512 of 29 June 1984 (Fishing) and Law no.92-3 of 3 January 1992 (Water) include essential legal means of initiating judicial action in the case of accidental pollution and where harm or damage is caused in receiving waters to either fish (article L.231-3 of the Rural Code) or to flora/fauna as well modifications to the normal food chain regime (article 22 of the Water Law).

6.2 The civil legal process is independent of any penal action taken by the water police and may be pursued even in the absence of police action; its objective is to obtain appropriate compensation as based on articles 1382, 1383, 1384 *et seq* of the Civil Code.

D7. French Water Quality Standards

7.1 The water quality standards currently in use in France are rather embryonic in nature and mix various physical, chemical and biological data to produce a unique five category classification namely, 1A, 1B, 2, 3 and HC. This system is in the process of being changed and a new approach, termed SEQ (Water Quality Evaluation System) has been constructed and recently proposed for use (Etudes Agence de l'Eau, n°72, 1999; n° 64, 2000). The SEQ is based on three main components : water (SEQ-Eau), hydrology and morphology (SEQ-Physique) and aquatic life (SEQ-Bio). For each of these components, a number of parameters have been chosen defining quality alterations, and a set of thresholds is given for each of them, and for selected water uses. For example regarding the SEQ-Eau, thresholds are different for biological potential, drinking water production, bathing, irrigation, livestock and fish farming. Alterations include organic matter, eutrophication (N, P, phytoplankton), suspended solids, micro-pollutants (in water, sediments, bryophytes…), and pathogenic organisms. A significant effort has been made to relate the thresholds to real constraints on uses. Data bases have been compiled including for example : acute or chronic No Observable Effect Concentration (NOEC) levels as well as LC50 for micro-pollutants (alteration) and life support (water use), treatment cost and toxicity on man for micro-pollutants (alteration) and drinking water production (water use). A rigorous strategy has been established to derive thresholds from such data, including expert comments, thus enabling the SEQ system to evolve with increasing knowledge.

7.2 The following table D1 gathers the currently proposed thresholds for lead in water (µg/l) which would be introduced under the above legislation.

Table D1. Proposed SEQ Standards

	1 (green)	2 (blue)	3 (yellow)	4 (orange)	5 (red)
Life support*	2.1/5.2/10	21/52/100	100/250/500	370/930/1900	
Drinking water production	5	10	50	50	
Irrigation	200	200	2000	2000	
Livestock		50	100		
Fish farming		30	30		

* three thresholds depending on water hardness.

The SEQ-eau, whilst not yet official, does seem much more advanced than the other proposed SEQ's (hydrology and morphology, aquatic life). There is no proposed SEQ for wetlands, although a recent review has been written trying to sketch out a first set of parameters to define wetland quality (Fustec and Frochot, 1998).

7.3 Highway runoff discharges have to be authorised by government representatives, because of the expected negative consequences of de-icing salts released into the environment. However, information brought forward by highway companies to obtain this official agreement is expected to include information about the impact of metals, hydrocarbons and suspended solids. However this is not legally required (although a freshwater fishery owner recently won his case in the courts and obtained such information from a highway society). The discharges also have to be legally authorised as soon as the impervious catchment is greater than 20 ha, as soon as the expected flow is higher than 10000 m^3 per day, or higher than 25% of the reference flow of the receiving river. There also exist legal constraints regarding flooding, but mainly to prevent embanking of natural flows by civil engineering works. The constraints do not seem to be active for runoff problems.

D8.

Table D2. Pollution Standards for Retention and Wetland Basin Sediments
(L'eau et la Route, Vol 7; ASFA, 1998; ROBIN, 1996)

	Pb	Cd	Zn	HC	Total-P	Total-N
Grassy ditches	187	0.87	186	523	0.8	2
Basins	167-375	0.95-1.40	365-116	187-9499		
Norm NF U44 041 (reference value for sewage sludge)	800	20	3000			
Norm NF U44 041 (reference value for soil which can accept sewage sludge)	100	2	300			
European Directive 86-278 (12/06/1986) (reference value for sewage sludge)	750-1200	20-40	2500-4000			
European Directive 86-278 (12/06/1986) (reference value for soils)	50-300	1-3	150-300			

(All data mg/g)

D9 Bibliography

AGENCE DE L'EAU, STU. 1994. Guide technique des bassins de retenues d'eaux pluviales. Lavoisier, Paris 273 p.

ASFA 1998, Synthèse de l'efficacité des ouvrages de traitement des eaux pluviales routières. Programme recherche et développement environnement Étude N°98-7-2-2, 45 p

FUSTEC, E and FROCHOT, B. 1995. Fonctions des zones humides; Synthese bibliographique. Publ. Agence de l'Eau Seine-Normandie.

ROBIN E, 1996, Fonctionnement et efficacité des ouvrages de traitement des eux pluviales d'origine routière. Rapport de stage DEA « Systèmes Spatiaux et Aménagements Régionaux »64 p.
SETRA, 1993 L'eau et la Route, 7 vol.

SEQ. 1999. Les outils d'évaluation de la qualité des cours d'eau. Les études des Agences de l'Eau. No.72. 11 pages.

SEQ. 2000. Les outils d'evalution de la qualite des cours d'eau. Les etudes des Agences de l'Eau. No. 64. 9 pages.

SEQ-EAU. 1999. Système d'évaluation de la qualité de l'eau des cours d'eau. SEQ-Eau, version 1, Annexe A. Grilles des seuils par altération avec justifications; pp 28.

APPENDIX E

WETLAND LOCATIONS AND DETAIL

E1. Residential (and mixed) Catchment Runoff

Anton Crescent, Sutton, Surrey				
Residential and light commercial	Surface stormwater runoff ; 1:50 design; 165.5 m^3/d.	Flood storage, 1.3 ha; wet retention basin; SF wetland with excavated pond at outlet; *Typha*	Maximum design storage capacity; 10,000 m^3 Wetland area; 13, 125 m^2 Mean retention time; 10.8 days	Wildlife conservation area; local amenity; educational facility Average removal %: N -19%; SS 56%; Pb 7%; Zn 37%; Faecal Coli 78% High levels of metals reported in sediment (Cd, 1.5; Cu 40.0; Pb 126.6; Zn 120.7 mg/kg) Plant tissue (leaf) metal levels also recorded

Great Notley Garden Village, Braintree, Essex				
Residential (2000 houses); low density retail and business; Highway. 188.18 ha	Surface stormwater ruunoff; 1:100 design Maximum discharge; 272.4 l/s	Flood storage; wet retention basin; SF wetland with sediment trench followed by 16,000 m^2 pond. *Typha, Phragmites* (also *Iris , Scirpus)*	Maximum design storage capacity; 30,000 m^3 Wetland area; 7, 900 m^2	Final open water recreational pond. % removal range: Cd 10-99; Cu 94-97; Pb 89-97; Zn 10-99. Sediment metal levels: Cd 2±1.9; Cu 24±19.4; Pb 31±10.3; Zn 65±49.7 Plant tissue and rhizome metal levels also recorded

Thorley Pond, Bishops Stortford, Herts				
Residential (2500 houses) 172 ha	Surface stormwater runoff; 1:30 design; Consent discharge; 1.89 m^3/s	Flood storage; Dry detention basin Low wet marsh in base of pond	Maximum design storage capacity; 8,000 m^3	

Newton Park East, Harrow, Middlesex				
Residential 2.5 km^2	Surface stormwater runoff; 1:2 design	Flood strorage; Extended detention (ED) basin; Low marsh to base	Maximum design storage capacity: 1,075 m^3	To provide local flood relief on the Yeading brook

Redhill Brook, Holmethorpe, Redhill, Surrey				
Residential	Surface stormwater runoff;	Flood storage; Wet retention pond with large self-seeded reed bed (*Typha*)	Maximum design storage capacity; 2,400 m^3	

Broadfield, Crawley, Hants				
Residential 236 ha	Surface stormwater runoff; 1:10 design 1.25 m^3/s	Flood storage; Extended detention (ED) basin; Low wet marsh to base with macrophyte vegetation	Maximum design storage capacity; 30, 800 m^3	Considered to be the most "sensitive" of all the flood storage basins in Crawley

Langshott, Horley, Surrey				
Residential 12 ha	Surface stormwater runoff; 1:50 design Maximum flow; 70 l/s	Flood storage; Dry detention basin; Low marsh and reeds to base of pond and at outlet	Maximum design storage capacity; 2,303 m^3	

Brentwood, Essex				
Residential and mixed land use 400 ha	Surface stormwater runoff	Flood storage; SSF constructed wetland (*Phragmites*) followed by a SF natural wetland (*Typha*)	Wetland area; 204 m^2 Mean retention time; 50 mins	Front-end settlement basin. Elevated inflows of Pb (195 µg/l), Zn (132 µg/l) and high BOD (75 mg/l). Mean % removals (Water): *Dry weather*; Zn 19; Cd 33; Pb 30; Cu -15; BOD 17; SS 18; Total Amm 50. *Wet weather*; Zn 22; Cd -4; Pb 16; Cu 8; BOD 15; SS 4; Total Amm 59. Mean % removals (Sediment): Zn -35; Cd 17; Pb 32; Cu 33. Plant tissue metal levels also recorded.

St Johns Wood, Tamar, Cornwall				
Mixed urban land use	Surface stormwater runoff	Diversion pond; SF RBTS constructed wetland		To mitigate the effects of urban runoff into a saltmarsh reserve

North Weald, Essex				
Residential and agricultural runoff.	Surface stormwater runoff	Diversion pond; ED Basin with wet retention pond to base and SF constructed wetland; *Typha/Phragmites*		Wildlife enhancement and local educational facility

Claver House East, Dundee, Fife, Scotland				
Residential	Surface stormwater runoff	Flood storage. Wet retention basin with SF constructed wetland		Wetlands within woodland area; to overcome cost of 2m outfall pipe.

Webheath, Redditch, Worcs.				
Residential 270 houses	Surface stormwater runoff	Flood storage and pollution control; Stilling and sedimentation basin to wet retention balancing pond followed by 4 25m x 5m linear constructed reedbeds	Wetland 125 m^2 per impervious hectare of catchment; Void storage in reedbed--50 m^3 per impervious hectare of catchment--5 mm runoff volume	Retrofitted into previous degraded channel; Front-end stilling basin and pollution trap--10 m^3 per impervious hectare of catchment

Tewkesbury, Gloucs.				
Residential 1500 houses (drained by 6 outfalls)	Surface stormwater runoff	Flood storage and pollution control; Stilling and sedimentation basin into 146m x 5m linear SF constructed reedbed wetland		Retrofitted into existing ditched floodplain of watercourse

Arbroath Road, Dundee, Fife, Scotland				
Residential 400 homes	Surface stormwater runoff	Flood storage and pollution control. Wet retention basins with SF constructed wetland(s)		

Menstrie Mains, Clackmannan, Scotland				
Residential	Surface stormwater runoff	Flood storage. SF constructed wetlands		Filter drains to housing areas followed by wetlands

Newcastle Great Park, Newcastle-upon-Tyne				
Residential Greenfield site. 172ha residential, 2.9ha park & ride, 139ha commercial. Plus 144ha service centre and roads etc	Surface Stormwater runoff	Flood storage and pollution Control. Constructed wetland reed beds	7 wetland cells. 300 - 5400 m^3 permanent water volumes; 1130 - 20000 m^3 design storage volumes	Wetland surrounds to be fully landscaped

Welfield Park, Stevenage				
Residential and access/service roads	Surface stormwater runoff	Flood storage; Wet retention pond with marginal vegetation		

E2. Commercial/Industrial and Business Estate Runoff

Pinnacles Estate, Harlow, Essex				
Light Industrial and commercial; 65 ha	Surface stormwater runoff; 1:10 design; Consent discharge; 0.163 m^3/s	Flood storage; Dry detention basin; Low wet pond marsh in base of pond	Maximum design storage capacity; 19,400 m^3	

Rowley Wood, Northgate, Crawley, Hants				
Industrial; 201 ha	Surface stormwater runoff; 1:1 design;	Flood strorage; Dry detention basin; Low marsh at outlet	Maximum design storage capacity; 5,432 m^3	

Stockley Park, Southall, Hillingdon.				
Business and commercial estate; 26.92 ha	Surface stormwater runoff; 1:30 design; Consent discharge; 0.065 m^3/s	Flood storage; 6 Wet retention basins; Self-seeded marginal marsh and macrophytes to 4 of the ponds	Maximum design storage capacity; 11,950 m^3	Ponds used by London Borough of Hillingdon for passive amenity and recreation

Hookwood, Reigate, Surrey				
Retail and commercial; car parking	Surface stormwater runoff; 1:10 design	Flood storage; Dry/wet detention and retention basin; Self-seeded reeds and marsh in wet pond area.		

Aztec West, Junction 16 M5, N Bristol				
Business and commercial; 68 ha	Surface stormwater runoff; (roofs, car parks, roads)	Flood storage; 2 Dry detention basins; 2 Wet retention basins with *Juncus/Iris* vegetation		Front-end oil interceptors. Ornamental ponds; landscaped surroundings; Wildlife and birds; Landscaped surroundings

Furzen Farm Industrial Estate, Pershore, Worcs.				
General industrial; 4 ha	Surface stormwater runoff.	Flood balancing and pollution control; Dry detention basin; SF constructed wetland to base		Landscaped to provide amenity feature.

Solent Business Park, Whiteley, Hamps.				
Business and commercial; 47 ha	Surface stormwater runoff; (roofs, car parks, roads); 1:50 design	Flood storage; Wet retention balancing lake with marginal vegetation		To protect downstream woodland SSSI. Provision of landscaped amenity and recreation area.

Norbord, Inveren, Scotland				
Industrial	Surface stormwater runoff; (yards/paved surfaces)	Pollution control; SS HF constructed vegetated lagoon		Intended to treat contaminated surface runoff (HCs, solvents, metals). Average treated wetland effluent against consent limits mg/l ; BOD 11/25; SS 19/35; phenol 0/1; Zn 0.195/0.75.

Service Area, Junction 8 M40, Oxford				
Commercial, retail, car and HGV parking; 6.5 ha	Surface stormwater runoff; 1:1 design 19.2 l/s	Flood balancing and pollution control: Sedimentation pond followed by SS HF constructed wetland and final wet retention balancing pond(s).		Porous block paving to vehicle parking surfaces, filter strips and collector (stone) trenches; First flush of 10mm runoff (1 l/s) to sedimentation pond; Bypass swale-flow direct to balancing ponds; Separate wastewater flows to four linear SS HF constructed wetlands then discharge to balancing ponds; Landscaped surrounding areas.

Tewkesbury Business Park, Gloucs.				
General industrial 28 ha.	Surface stormwater runoff	Flood balancing and compensation basin; Dry detention basin; SF constructed wetland to base.	Wetland area; 6,300 m^2. (250 m^2 per impervious hectare catchment); Void storage in reedbed--10 mm runoff volume; 24 hour drawdown	Front-end stilling basin and pollution trap--10 m^3 per impervious hectare of catchment

Keytec 7 Business Park, Pershore, Worcs.				
Genreal industrial. 10.9 ha	Surface stormwater runoff; 1:5 year design	Flood balancing and pollution control; Wet retention basin with SF marginal constructed wetland; *Typha*	Maximum design storage volume; 1500 m^3. Retention time; 15-20 hours	Consents; SS 100 mg/l, BOD 20 mg/l and Oils/HCs 5 mg/l; all have been successfully met over past 5 years. One major oil spillage but reedbed recovered within a few months. Landscaped to provide amenity feature; stable wildlife habitat.

Pershore High School, Pershore, Worcs.				
Industrial estate; 6 ha	Surface stormwater runoff.	Flood balancing and pollution control; Wet retention basin; 2 x SF constructed wetlands followed by balancing pond		Retrofitted into previous ditch watercourse; Front-end sedimentation basin and pollution trap; Educational facility for local school

District Park, Dunfermline (DEX), Fife, Scotland				
Light industrial, Commercial and highway (M90). 600 ha	Surface stormwater runoff; 1:100 design	Flood balancing, pollution control and amenity. Dry and Wet retention basins; SF constructed wetlands and marginal vegetation to wet basins		Landscaped wetland treatment area with swales, filter drainage for road/car parking runoff and flood storage basin % metal removals recorded in wetland: Cd 0; Cu Cu 33; Pb 25; Zn 65. Mean metal sediment levels (mg/kg): Cd 0.09; Cu 13; Pb 10.5; Zn 30.2

Linburn Road, Dunfermline (DEX), Fife, Scotland				
Residential, commercial and retail. 4500 homes	Surface stormwater runoff	Flood balancing, pollution control and amenity. Wet retention basin with marginal vegetation		Landscaped wetland area; leisure park facility.

Cambuslang Investment Park, Glasgow				
Commercial and light industrial	Surface stormwater runoff	Flood balancing. Wet retention basins with marginal vegetation.		Attenuation storage when the River Clyde is high.

Deer Park Business Campus, Livingston, W Lothian, Scotland				
Commercial	Surface stormwater runoff	Flood balancing. Wet retention basins with SF constructed wetlands		Landscaping and possible amenity.

Deans Industrial Estate, Livingston, W Lothian, Scotland				
Light industrial and commercial	Surface stormwater runoff	Flood strorage. Wet retention basins with SF constructed wetlands		Swale inflows to basin; drainage to Lochshot Burn.

Forrestburn International Racing Circuit, Shotts, N Lanark, Scotland				
Impermeable runoff from car parking, hard standing and race circuit	Surface stormwater runoff	Flood storage. SF constructed wetlands		Wetlands will be followed by infiltration trenches.

Houston Industrial Estate, Livingston, W Lothian, Scotland				
Light industrial and commercial	Surface stormwater runoff	Flood storage. Wet retention basins with SF constructed wetlands		Swale inflow channels to wetlands.

Drumshoreland Road, Pumpherston, Livingston, W Lothian, Scotland				
Industrial	Surface stormwater runoff	Pollution control. SF constructed wetlands		To trap and treat oil/HC runoff from mineral oil/paraffin depot

Century Park Business Centre, Luton, Beds				
Commercial and light industrial. 43 ha (15,000 pop)	Surface stormwater runoff; 1:10 design	Flood storage and pollution control. Overflows from grassed swale into 3 wet retention (attenuation) lakes with macrophyte marginal vegetation.	Total (maximum) storage capacity; 20,000 m^3	Front-end oil/sediment interceptor. Overflow from lakes via boreholes and soakaways to ground

Blythe Valley Business Park, Solihull, W Midlands				
Business and commercial. 80 ha	Surface stormwater runoff. 1:1 design	Floodstorage, pollution control and amenity 2 Wet retention (balancing) ponds with marginal vegetation		Front-end oil interceptors and forebay sedimentation basins. Protect downstream SSSI. Landscaped surroundings.

E3. Highway Catchment Runoff

M11, Stansted Brook, Herts				
M11 10.93 ha	Motorway runoff; 1:10 design; Consent discharge; 5 m^3/s	Flood balancing; Dry detention basin Low marsh at inlet and outlet	Maximum design storage capacity; 4,900 m^3 (Plus additional 20,000 m^3 storage planned	At junction of M11 with Stansted rail link

M25, Junction 9, Leatherhead Interchange, Surrey				
M25 4 ha AADT; 140,000	Motorway runoff; 1:25 design; Maximum discharge; 170 l/s	Flood balancing; 2 basins; wet biofiltration pond with *Typha* and a smaller wet sedimentation pond	Maximum design storage capacity: 2730 m^3 + 500 m^3 = 3230 m^3	Front-end silt trap. Connection between two basins through outfall headwall which acts as flow control device.

M25, Reigate Hill (Pond No.3, Surrey				
M25	Motorway runoff;	Flood balancing; Dry detention basin with wet base fully occupied by *Typha* reed		

M25, Barrow Court, Oxted, Surrey				
M25 7.29 ha AADT; 120,000	Motorway runoff; 1:30 design Maximum discharge; 687 l/s	Flow balancing; Dry detention basin with wet base and margins occupied by marsh vegetation and scrub	Maximum design storage capacity; 3,147 m^3	Clear build-up of metals in basal pond sediments (Cu 15-310; Zn 85-1110; Cd 0.5-74; Pb 60-14762 μg/g) Total Petroleum Hydrocarbons in basal sediment: 12,162-55,892 mg/kg

M23, Burstow, Surrey				
M23	Motorway runoff	Flood balancing; Combined detention/retention basin. Retention basin occupied with marsh vegetation	Maximum design storage capacity; 2,125 m^3	

M23, Smallfield (North), Surrey				
M23 1.8 ha	Motorway runoff; 1:60 design	Flood balancing; Dry detention basin with stream channel in base occupied by wetland vegetation	Maximum design storage capacity; 3,711 m^3 Drawdown time: 125 hours	

M23, Smallfield (South), Surrey				
M23 2.9 ha	Motorway runoff	Flood storage; Dry detention basin with wetland pond to base with reeds, marsh and scrub vegetation	Wetland area about 1,200 m^2	

M23, South Nutfield, Surrey				
M23 5.5 ha	Motorway runoff; 1:5 design	Flood storage; Extended detention (ED) basin; Wetland marsh/reed to excavated base of pond	Wetland area about 2,400 m^2	

M23, Tilgate, Surrey				
M23	Motorway runoff;	Flood storage; Wet detention basin; Self-seeded aquatic vegetation including *Typha, salix* and marsh species	Maximum design storage capacity; 13, 031 m^3	Motorway drainage via interceptor ponds

M23, Weatherhill, Surrey				
M23 6.1 ha	Motorway runoff;	Flood storage Dry detention basin with wet pond/channel to base containing reeds and marsh	Maximum design storage capacity; 5,184 m^3 Drawdown time; 59 hours	

A34, Newbury Bypass				
A34 bypass. 13.5 km dual two lane trunk road; Discharges; 20-120 l/s for 1:50 and 1:25 design	Highway runoff;	Flood storage and balancing; 9 x wet detention basins with SF and SSF constructed wetlands. Front-end bypass interceptors(oil/silt) followed by grass filters and reedbeds *Phragmites/Typha*.	Maximum design storage volumes; 121-676 m^3 Retention times; 30-120 hours	% metal removals recorded: BOD -63-64; Cu -58-83; Cd -89-83; Zn -56-76. Wet weather % removals recorded: SS 40-75; Cd 90-99; Cu -88-97; Pb 98; Zn 59-66. Metal sediment levels (μg/g); Zn, 20-28; Cd, 3-7; Pb 17-18; Cu, 4-12. Metal levels in plant tissue also recorded

A49, Hereford Bypass, Lugg Meadows				
A49	Trunk road runoff	Flood storage; SF Constructed wetland		Retrofitted into drainage ditch

A4/A46 Batheaston Bypass,				
A4/A46 junction; 3.8 ha	Trunk road runoff; 1:1 design; 76 l/s (up to 106 l/s for 1:100 storm)	Flood storage; Wet retention with constructed SF wetland *Phragmites/Typha* with *Scirpus.*	Maximum design storage capacity; 320 m^3 9 ha wetland area 8 hour retention time	Front-end oil bypass interceptor. Special designed oxbow lake. Wetland nature conservation area

Austin Drive, Coventry, Warcs.				
New road area.	Residential inner city road runoff	Pollution control; Swale with wetland to base near outlet of channel. *Phragmites*, *Burr Reed*, *Rumex* etc.	Wetland area: 300 m^2	To prevent pollution to the Coventry Canal and to avoid £2M capital expenditure on conventional drainage. Front-end oil/silt interceptor then into grassed swale before entering wetland and final discharge into the Coventry Canal.

A1(M)/A59 Junction, Dishforth, Yorks.				
Walshford-Dishforth motorway Section.	Motorway runoff;	Balancing pond and pollution control; Constructed wetland with *Typha*		Surrounding landscaping

M5, Junctions 22 and 24, Bridgewater, Somerset.				
	Motorway runoff			

M6, Tebay, Cumbria.				
	Motorway runoff	Balancing pond Constructed wetland		

M1, Junction 9, Harpenden, Herts.				
	Motorway runoff	Balancing pond		

M40, Junction 9, Wendlebury, Oxford.				
	Motorway runoff	Balancing pond		

A36, Warminster Bypass, Somerset.				
	Highway runoff	2 x balancing ponds		

A303/A36, Wylye Junction, Wilts.				
	Highway runoff			

A5, Fazeley (Two Gates Wilnecote Bypass), Staffs.				
	Highway runoff			

A1079, Market Weighton, Yorks.				
	Highway runoff			

M42, Junction 2, Hopwood Park Service Station				
Surface drainage for car/HGV parking and fuelling areas. 9 ha drainage area. 5l/s/ha design runoff rate	Hard standing surface runoff	Series of small in-series wetland cells following either filtration trench or hydrodynamic separators. *Typha/Phragmites* with other plants	10mm first-flush capture. 48 hour "filtering" period	95 - 99% retention for heavy metals, TSS and BOD for HGV parking area. 79 - 83% retention for heavy metals for fuelling/car park areas with 89% BOD and 97% TSS. High nature conservation value.

M40, Junction 8, Oxford Service Station				
Surface drainage for car/HGV parking and fuelling areas	Hard standing surface runoff	Surface runoff from car park to 4 in-series wetland cells discharging to final balancing pond. Surface runoff from HGV park to a settlement pond and wetland		

E4. Airport Runoff

Stansted Airport (BAA), Herts				
Pond (B), Start Hill 122 ha	Airport runoff; 1:100 design; 1.02 m^3/s design flow	Flow balancing; Wet retention basin; Marginal macrophyte vegetation	Maximum design storage capacity; 44,580 m^3	Front-end oil separator
Pond (C), Takeley Street 488 ha	Airport runoff; 1:100 design; 1.36 m^3/s design flow	Flow balancing and de-cing separation; Wet retention basins; Marginal vegetation	Maximum design storage capacity; 123, 500 m^3	Retention basin in 3 compartments for de-icant separation; 10 year design flow for diversion is 1.723 m^3/s

Heathrow Airport (BAA), Eastern Balancing Reservoir, Hatton				
369 ha	Airport runoff;	Flow balancing and fire-fighting aeration; Wet retention basin; Self-seeded marginal macrophytes	Surface area; 227,100 m^2	Old gravel pits

Heathrow Airport (BAA), Southern Balancing Reservoir, Hatton				
354 ha	Airport runoff	Flow balancing and fire-fighting aeration; Wet retention basin; Self-seeded marginal macrophytes	Maximum design storage capacity; 962,000 m^3 Surface area; 370,000 m^2	Old gravel pits

Heathrow Airport (BAA), Experimental Reedbeds				
245 ha 8.6 m^3/day	Airport runoff	Pollution control (de-icing removal); SF constructed wetland SSF constructed wetland (*Typha/Phragmites*) Rafted lagoon	Retention time: 16 hours	Experimental reedbed systems. Elevated BOD inflows: 270 mg/. Glycol inflows: 1180-6326 mg/l. % Removals recorded: Glycol (SF system), 40-60%; (SSF system), 26-99%; BOD (SF system), 18%; (SSF system) 22%; Faecal Coli (SF system), 97%; (SSF system), 98%.

Teeside Airport, Stockton, Cleveland				
	Airport runoff	Flow balancing, de-icing removal and foam/detergent removal. VF constructed wetland		

E5. Other Surface Runoff

Spellbrook, Stort Navigation Channel, Herts				
	River overbank discharge. 1:10 design	Flood storage; Dry detention basin with low marsh. *Typha*	Maximum design storage capacity; 69,000 m^3	Pond designated as SSSI

Syon Park Lake, Brentford, Hounslow				
	Ornamental lake with provision for flood storage;	Flood storage; Wet retention basin; Macrophyte vegetation		Flows from Duke of Northumberland's River above 215 l/s are passed to the lake for storage. Runoff from West Middx Hospital also passed to lake

Dagenham, Wantz River, Essex				
Residential and industrial/ Commercial. 440 ha	River overbank discharges	Flood storage and pollution control; 3 x 250m SF linear constructed wetland cells with first in *Typha* and last two in *Phragnites*	Wetland area: 1750 m^2	Front-end sedimentation basin. Elevated inflow levels of metals (Pb 285 µg/l; Zn 550 µg/l), THMs and high BOD (69.4 mg/l) ; wetlands are targeted for 50% removals. Mean % removals (Water): *Dry Weather*; Zn 31; Cd 48; Pb 37; Cu 23; BOD -23; SS 35; Total Amm 6; TMHs 32. *Wet weather*; Zn 71; Cd 72; Pb 69; Cu 7;BOD 24; SS -16; Total Amm 38 Mean % removals (Sediment): Zn -12; Cd 25; Pb 20; Cu 12. Plant tissue mertal levels also recorded

Wharrage, Redditch, Worcs.				
Residential, Highway and industrial; 4 km^2; 70 ha impervious.	Urban runoff and overbank discharge in the Wharrage Brook.	Flood storage and pollution control; Primary silt/pollution trap followed by wet retention balancing pond and final SF constructed reedbed	Maximum design storage capacity; About 3500 m^3	Retrofitted into existing river floodplain and meanders; Extensive surrounding landscaping; Wildlife habitats and amenity features.

Martin Mere, Lancashire				
Agricultural runoff	Surface stormwater runoff	Flood storage; Wet retention lagoon (SF) with semi-natural marsh rafted vegetation; *Typha/Phragmites*		Wildlife reserve; habitat protection/creation.

South Finger Lake, Slimbridge, Gloucs.				
Agricultural and residential runoff; 2000 m^3/day	Surface stormwater runoff	Flood storage; Wet retention lagoon with SF constructed wetlands	Wetland area; 11,900 m^2	Wildlife reserve; habitat protection

Great Linford Pit, Milton Keynes				
Residential, commercial and industrial.	Urban runoff	Flood storage; Wet retention pond; Marginal macrophyte vegetation.		Disused quarry on flood plain of upper Ouzel.

Welsh Harp Basin, Brent, N London				
Residential, commercial, industrial and highways. 5.2 km^2	Urban runoff and storm overflows; 60% of annual river flow volume from impervious surfaces.	Flood storage; Wet retention basin; Semi-natural macrophyte vegetation at inlet; *Typha/Phragmites* and *Phalaris*		Designated SSSI and RSPB nature reserve; Recreation and amenity including sailing, canoeing, fishing; Mean % Removals in total concentrations: SS 97%; SOD 61%; Alkanes 46% (water) 68% (sediment); PAH 69% (water) 73% (sediment); Faecal coliforms 85% 59% reduction in PAH in *A.aquaticus* tissue; Improvement in BMWP score from 5 to 50; Mean metal levels (mg/kg) at inlet in water and sediment: Cu 59.6, 219.8; Pb 36.2, 841; Zn 136.6, 778.9; Cd 8.9, 12.5. Metal levels also recorded in plant tissue.

Stoneyfield Park, W Hendon, N London				
Residential, motorway and general urban	Urban stormwater runoff	Ornamental flood storage; Marginal macrophyte vegetation; *Typha*		Mean metal levels (mg/kg) recorded in water and sediment: Cu 39.4, 119.9; Pb27.4, 696.2; Zn 77.5, 506.0; Cd 6.0, 9.7. Metal levels also recorded in plant tissues.

Willen Lake, Milton Keynes				
Residential and Highway; 1:200 design	Urban surface runoff	Flood balancing; Marginal macrophyte vegetation. *Phragmites/Typha*	Surface area; 87 ha 3 ha marginal macrophytes	Measured inflow concentrations(mg/l) : Cl 80-159; Po_4 0.004-0.257; Zn 0.01-0.02; Pb 0.12-0.26; Cu 0.01. Faecal Colifoms; >200 MPN/100ml Extensive surrounding landscaping

River Skerne, Haughton, Darlington, Co Durham				
Urban and agricultural runoff; River restoration in urban flood plain; Suburban housing and old industrial estate; 250 km^2 4700 pop in local flood plain	Surface runoff; urban and agricultural. Annual mean flow; 1.61 m^3/s	Inclusion of 3 wetlands in "cut-off" meanders within upgraded flood plain; Use as overbank treatment for flood runoff and for treatment of inflow urban runoff into restored 2 km section.	2 km river reach in degraded urban fringe open space	Pollutant inflow values (range) to reach: SS 1-92; BOD 1-10; Total N 4-20; Phenol 0.02-0.26 mg/l. BMWP score; 41-68

Tooting Common Lake, Wandsworth, S London.				
Urban residential; 89 ha; 200 m^3/day	Surface runoff from surrounding urban common land	2 SSF constructed wetland reedbeds; *Phragmites* and *Carex/Iris/Juncus* and *Typha* wetlands. Introduced as "buffer zone" between shore and open water.	Surface area; 7608 m^2	Ornamental lake in disused gravel pit; Eutrophication; Total P 330 µg/l; with toxic blooms; Target P levels; 35-100 µg/l and Oxygen > 4 mg/l Mean % Removals: Chlorophyll a 16; Ammonia -9; Nitrate 27; Orthophosphate 18; Bacteria 70-90.

Maghull Brook, Lydiate, S Lancs.				
Residential and urban runoff; 3 km^2 65% urbanised; 1:50 design	Surface stormwater runoff	Overbank and marginal discharges; Marginal aquatic vegetation to restored bermed edges of channel; Treat overbank and inflowing urban discharges	Retrofitting of widened channel and marginal reedbeds	Illegal connections from local housing causing water quality problems. Marginal landscaping to edge of wetlands to provide a wildlife corridor

Mount Farm Lake, Milton Keynes				
Residential, highway and industrial;	Urban surface runoff	Flood balancing; Marginal and submerged macrophyte vegetation. *Phragmites, Typha, Juncus* with *Nymphea*	Surface area; 95 ha	Front-end oil interceptor. Measured inflow concentrations (mg/l): Cl 300-3000; Po_4 0.07-0.12; Zn 0.01-0.06; Pb 0.03-0.02. Faecal Coliforms; >10,000MPN/100ml Fish kills recorded

Caldecotte Lake, Milton Keynes				
Residential and highway; 1:50 design	Urban surface runoff	Flood balancing; Marginal macrophyte vegetation. *Typha, Juncus* with *Elodea*	Surface area; 44 ha	Front-end oil interceptor. Measured inflow concentration (mg/l): Cl 56 mg/l; Po_4 0.001-0.42; Pb 0.01-0.2. Island refuges.

Rye House Marsh, Rye Meads, Roydon, Herts.				
Overbank river discharges and treated sewage. 5 ha	Surface runoff; urban and agricultural; Treated sewage effluent; 90Ml/day	Wildlife habitat Compartmentalised wetland cells. *Typha/Phrgamites* and *Glyceria* marsh		RSPB nature reserve; About 15,000 visitors per annum. Measured inflow concentrations: BOD 2-6; Po_4 3.5-11.0 mg/l; Zn 14-21; Cu 5-11 µg/l.

Potteric Carr Reserve, West Bessacarr, Doncaster				
Surface runoff. 1261 ha; 1:50 design	Surface runoff; urban, agricultural and treated effluent; derelict industrial site.	Flood storage. *Typha/Phragmites* wetland with carr marsh	Wetland/carr area; 140 ha Maximum design storage capacity; 230,000 m^3	Wildlife habitat; designated nature reserve.

Camley Street Nature Park, Kings Cross, N London				
Urban, old industrial site	Canal (Regents Canal) feed water. Marginal macrophyte reedbed grading into marsh	Canal overspill water		Local Nature Reserve; Wildlife habitat; conservation and amenity; Educational facility.

Newhall Valley, Walmley, W Midlands				
Residential and road runoff. 600 houses	Surface runoff to Plants Brook	Stormwater attenuation schemes. Rough wet meadows and wetlands within floodplain. Alder/willow carr		SLINC designation. SUDS options selected for front-end structures include infiltration trenches and swales to recharge wetland during high flows.

List of Acronyms

AMP	Asset Management Plan
ASPT	Average Score Per Taxon
AONB	Area of Outstanding Natural Beauty
BAP	Biodiversity Action Plan
BMWP	Biological Monitoring Working Party
BOD	Biochemical Oxygen Demand
BMP	Best Management Practice
BPEO	Best Practicable Environmental Option
CESM3	Civil Engineering Standard Method of Measurement
CIRIA	Construction Industry Research & Information Association
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
CW	Constructed Wetland
DEFRA	Department of Environment, Food and Rural Affairs
DETR	Department of Environment, Transport and the Regions
DO	Dissolved Oxygen
DTLR	Department of Transport, Local Government and Regions
ED	Extended Detention Basin
EMC	Event Mean Concentration
EIA	Environmental Impact Analysis
EPSRC	Engineering and Physical Sciences Research Council
EQI	Environmental Quality Index
EQS	Environmental Quality Standard
FWR	Foundation for Water Research

GQA	General Quality Assessment
HLR	Hydraulic Loading Rate
HRT	Hydraulic Retention Time
IPPC	Integrated Pollution Prevention and Control
IRBM	Integrated River Basin Management
LCP	Local Contribution Plans
LEAP	Local Environment Agency Plan
LNR	Local Nature Reserve
MIPS	Material Intensity per Service Unit
MTBE	Methyl Tertiary Butyl Ether
NGO	Non-Government Organisation
NNR	National Nature Reserve
NOEC	No Observable Effect Concentration
NWC	National Water Council
O&M	Operation & Maintenance
OFWAT	Office of Water Services
PAH	Poly-Aromatic Hydrocarbons
PAN	Planning Advice Note
PPGs	Pollution Prevention Guidelines
PPG 25	Planning Policy Guidance Note 25 (DTLR)
RBD	River Basin District
RBMP	River Basin Management Plan
RE	River Ecosystem
RHS	River Habitat Survey
RIVPACS	River Invertebrate Prediction and Classification System

RSPB	Royal Society for the Protection of Birds
RQO	River Quality Objective
SEPA	Scottish Environment Protection Agency
SS	Suspended Solids
SF	Surface Flow Constructed Wetland System
SSF	Sub-surface Flow Constructed Wetland System
SLINC	Site of Local Importance for Nature Conservation
SPA	Special Protected Area
SSSI	Site of Special Scientific Interest
SuDS	Sustainable Drainage Systems
SUDS	Sustainable Urban Drainage Systems (as used in Scotland)
SWO	Surface Water Outfall
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TSS	Total Suspended Solids
UDP	Unitary Development Plan
USEPA	United States Environmental Protection Agency
UKWIR	United Kingdom Water Industry Research
VF	Vertical Flow Constructed Wetland System
WFD	Water Framework Directive
WQO	Water Quality Objectives
WWAR	Wetland Area to Watershed Area Ratio

Glossary

Aspect Ratio	Length to width ratio of a Constructed Wetland
Biochemical oxygen Demand (BOD)	The amount of oxygen consumed by the degradation of organic materials
Bioaccumulation	The uptake or accumulation of a compound by a living organisms as a result of exposure to the compound
Bioavailability	The extent by which an ion or compound is freely available for uptake by living organisms
Biomass	The mass of animals and plants within a habitat measured at a given time
Chemical oxygen demand (COD)	The amount of oxygen consumed by chemical oxidation of organic material
Chlorosis	Pale coloration in plants leaves caused by a failure of chlorophyll synthesis
Consent standard	Licence to discharge wastewater at or better than a standard set by a regulatory authority. UK Water Companies usually have to comply with BOD/TSS/amm-N standards, and possibly with additional nitrate and bacteria standards
Constructed wetland	Artificial wetland engineered to achieve biological and physiochemical improvement in the environment
Derogation	Temporarily deferred designation
Emergent macrophytes	Aquatic plants rooted in the support medium with much of their green parts above the surface of the water
Heavy metal	Metalliferous elements and their derivatives including zinc, lead, copper, iron, mercury, cadmium, cobalt, lead nickel and aluminium
Hydraulic conductivity	The ability of support medium to conduct fluid through the interstices between particles which make up the medium
Hydrophyte	Plant which grows in areas with periodic or continuous flooding

Micro-organism	An organism that is not visible with the naked eye
Nitrification	A two-stage process. Ammonia is first converted to nitrite and then from nitrite to nitrate
Denitrification	A microbial process that reduces nitrate to nitrite and nitrite to nitrogen gas
pH	Scale based on hydrogen ion concentration and ranging from highly acid (1) to highly alkaline (14)
Productivity	The rate of production of biomass
Rhizosphere	Zone of soil immediately around roots and rhizomes and modified by them
Rhizomes	Below ground stem of macrophytes
Rip-rap zone	Area of stones placed directly on the ground to protect locations prone to soil erosion, the stones can vary in size but are usually larger than 100mm
Root zone	The area around the growing tips of the roots of a plant
Support medium	Gravel, soil or other material used as the matrix within the constructed wetland
Suspended solids (SS)	Dry weight per volume of matter retained by a filter
Total suspended solids (TSS)	Material remaining in a sample when all the water has been evaporated