Whole Life Costing for Sustainable Drainage

Report SR 627
March 2004

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HR Wallingford

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SR 622 An Assessment of the Social Impacts of Sustainable Drainage in the UK
SR 625 Maximising the Ecological Impacts of Sustainable Drainage Schemes
SR 626 The Operation and Maintenance of Sustainable Drainage Infrastructure (And Associated Costs)

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Summary

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Whole life costing involves estimating the total cost of a product, system or structure throughout its entire life. It is about identifying future costs and referring them back to present day costs using standard accounting techniques such as Present Value. It is recognised as an appropriate technique for use in valuing total costs of assets that have a regular operating and/or recurrent maintenance costs, based on formalised maintenance programmes.

All expenditure incurred by a sustainable drainage system owner / operator, whether it is termed operational or capital, results from the requirement to maintain the service of drainage of the surface water runoff. Adopting a long-term approach complements the fact that sustainable drainage assets will have a relatively long “useful” life, providing appropriate management and maintenance is financed.

This guide provides a brief background of sustainable drainage in England and Wales, and sets out a clear methodology for evaluating whole life costs for these systems. A case study is also presented.

Abbreviations

ABC	Activity based costing
CVM	Contingent Valuation Method
DEFRA	Department for Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions
DTLR	Department of Transport, Local Government and the Regions
DoE	Department of the Environment
EA	Environment Agency
FWR	Foundation for Water Research
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
SUDS	Sustainable Drainage Systems
UK	United Kingdom
WLC	Whole Life Costing

Glossary

Activity Based Costing (ABC) A process of individually listing and measuring the cost of each activity contributing to the production and delivery of a particular product or service.

Appraisal The process of defining objectives, examining options and weighing up the costs, benefits, risks and uncertainties of those options before a decision is made.

Assessment Either an appraisal or an evaluation (or both).

Capital Expenditure Money spent to acquire or upgrade physical assets.

Contingent Valuation This involves directly asking people how much they would be willing to pay for a good or service, or how much they are willing to accept to give it up.

Contingency An allowance of cash or resources to cover unforeseen circumstances.

Detention Basin A vegetated depression that is normally dry except following storm events, constructed to store water temporarily to attenuate flows (which may facilitate water treatment).

Direct Cost Costs that can be directly attributed to the development of a project.

Discounting A method used to convert future costs or benefits to present values using a discount rate.

Discount Rate The annual percentage rate at which the present value of a future pound, or other unit of account, is assumed to fall away through time.

Economic Analysis The comparison of those costs and benefits that can be reasonably quantified. Economic analysis takes into account the opportunity cost of labour and capital; it considers private and social costs and benefits including environmental and other intangible social effects. Economic costs try to measure the real, or resource, cost to the economy from undertaking a particular activity.

Externalities The non-market impacts of an intervention or activity which are not borne by those who generate them.

***Glossary** continued*

Filter Drain	A linear drain consisting of a trench filled with a permeable material, often with a perforated pipe in the base of the trench to assist drainage, to store and conduct water, but also may permit infiltration.
Filter Strip	A vegetated area of gently sloping ground designed to drain water evenly off impermeable areas and filter out silt and other particulates.
Financial Analysis	This deals with the cost and benefit flows from the point of view of a firm or individual; it traces the investment's monetary effects. Financial analysis is carried out to assess the financial effects of the project, including whether investment resources will be available at the required time. Financial analysis is also used for option appraisal and selection.
Fixed Cost	A cost that does not vary with size of system.
Indirect Cost	Costs that are not directly linked with the project, but will be linked in some way.
Infiltration Basin	A dry basin designed to promote infiltration of surface water to the ground.
Infiltration Trench	A trench, usually filled with granular material, designed to promote the passage of surface water to the ground.
Intangibles	Costs and benefits brought about by implementing a project, that cannot be quantified but are nevertheless significant. These can be ranked and weighted to reflect importance and priorities.
Life Cycle Assessment	Studies the environmental aspects and potential impacts throughout the product's life (i.e. from cradle to grave) from raw materials acquisition through production, use and disposal.
Monte Carlo analysis	A technique that allows assessment of the consequences of simultaneous uncertainty about key inputs, taking account of correlation between these inputs. The sampling of the input distribution is entirely random.

Glossary continued

Net Present Value — The discounted value of a stream of either future costs or benefits. The term Net Present Value (NPV) is used to describe the difference between the present value of a stream of costs and a stream of benefits.

Operational Expenditure — Expenditure incurred in the operating of the infrastructure assets.

Performance — Measure of the ability of the sustainable drainage system to fulfil its requirements.

Permeable Surface — A surface formed of material that is itself impervious to water but, by virtue of voids formed through the surface, allows infiltration through the pattern of voids, for example concrete block paving.

Pervious Surface — A surface that allows inflow of rainwater into the underlying construction or soil.

Porous Surface — A surface that infiltrates water across the entire surface of the material forming the surface, such as grass and gravel surfaces, porous concrete and porous asphalt.

Present Value — The future value expressed in present terms by means of discounting.

Private Costs — Costs directly carried by the operator of the sustainable drainage system. Private costs include direct, indirect, hidden, contingent and image costs.

Retention pond — A pond where runoff is detained for a sufficient time to allow settlement and biological treatment of some pollutants.

Risk — The product of probability (likelihood that a particular event will occur) and consequence.

Risk Register — A useful tool to identify, quantify and value the extent of risk and uncertainty relating to a proposal.

Sensitivity Analysis — Analysis of the effects on an appraisal of varying the projected values of important variables.

Glossary continued

Silt Trap	A protective feature to capture silt, for subsequent removal. Silt traps are sited upstream of drainage features the performance of which may be adversely affected by siltation.
Soakaway	A sub-surface structure to promote the infiltration of surface water to ground.
Social	Relating to human society and its modes of organisation.
Societal Costs	Costs that accrue to society as a result of an activity.
Swale	A shallow vegetated channel designed to conduct and retain water, but may also permit infiltration; the vegetation filters particulate matter.
Tangibles	The measurable and quantifiable costs and benefits brought about by implementing a project.
Uncertainty	The condition in which the number of possible outcomes is greater than the number of actual outcomes and it is impossible to attach probabilities to each possible outcome.
Useful Life	The length of time that a depreciable asset is expected to be usable.
Wetland	An area of land that is normally wet that has a high proportion of aquatic vegetation used to attenuate flows (which will usually facilitate water treatment).
Whole Life Costing (WLC)	Accounting system that considers all the costs (private and social) that accrue to its initiation, provision, operation, maintenance, servicing and decommissioning, over the useful life of an asset or a service.
Willingness to Pay	The amount that someone is willing to give up or pay to acquire a good or service.

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1. BACKGROUND AND USE OF THE GUIDE

1.1 Objectives of the Guide

The principal objectives of the guide are as follows:

1. To provide guidance to the UK construction industry (in particular - developers, house-builders, local authority and drainage engineers), on the assessment of whole life costs for sustainable drainage systems (SUDS).
2. To provide a practical framework for implementing whole life costing techniques.
3. To present a selection of capital and operation/maintenance costs collected for SUD schemes in the UK.
4. To present case studies of the application of whole life costing techniques for SUD schemes in the UK.
5. To compare and contrast whole life costs of SUDS and more conventional drainage alternatives.

1.2 Readership of the Guide

The guide is aimed at those individuals who are involved in the estimation of project implementation and ongoing maintenance costs associated with sustainable drainage schemes. It is designed to inform the needs of the developers, house-builders, local authorities, drainage designers and contractors when considering sustainable drainage systems as a method for the drainage of stormwater.

It is intended that the guide should be suitable for both the specialist and the non-specialist and, as such, a certain amount of general information is included.

Developers, adopting authorities and scheme owners will find useful information on:

- The benefits of adopting a whole life cost (WLC) approach to estimating scheme costs
- The data required to predict WLCs
- The benefits of considering WLC issues at feasibility stage
- Ways in which non-capital costs can be incorporated into costing analyses
- How to ensure that long-term operation and maintenance costs are considered at project inception stage.

Designers will find useful information on:

- How to undertake a WLC analysis.

Contractors will find useful information on:

- The data that they may need to provide designers / clients so that a WLC evaluation can be undertaken.

1.3 Structure and content of the Guide

Chapter 2 gives a background to SUDS and highlights the need for a WLC approach.
Chapter 3 gives an overview of WLC methods.
Chapter 4 discusses WLC data requirements.
Chapter 5 presents the proposed approach.
Chapter 6 presents the results of the capital cost collation exercise.
Chapter 7 presents the results of the operation and maintenance cost collation exercise.
Chapter 8 forms a case study example.
Chapter 9 draws conclusions from the report.

2. WHOLE LIFE COSTING AND SUSTAINABLE DRAINAGE

2.1 Sustainable drainage in England and Wales

There is increasing recognition in the UK that sustainable drainage systems (SUDS) can offer significant benefits over their conventional counterparts, in controlling and managing diffuse surface water drainage. The concepts behind SUDS are not new, however design approaches that aim to control runoff at source, and minimise the discharge of polluted material into the receiving watercourse have not, historically, been consistently implemented. Box 1 summarises the benefits of SUDS, as set out in the CIRIA SUDS Design Manual for England and Wales (2000):

Box 2.1 Benefits of Sustainable Drainage Systems (CIRIA (2000))

Drainage systems can be developed in line with the ideals of sustainable development, by balancing the different issues that should be influencing the design. Surface water drainage methods that take account of quantity, quality and amenity issues are collectively referred to as Sustainable Urban Drainage Systems (SUDS). These systems are more sustainable than conventional drainage methods because they:

- Manage runoff flow rates, reducing the impact of urbanisation on flooding
- Protect or enhance water quality
- Are sympathetic to the environmental setting and the needs of the local community
- Provide a habitat for wildlife
- Encourage natural groundwater recharge (where appropriate).

Unlike conventional systems, there are currently no statutory design standards or objectives for SUDS, and design guides are limited. Design guidance that is available to date is presented in Box 2.2, below.

Box 2.2 Existing SUDS design guidance

CIRIA R156	Infiltration drainage: manual for good practice, 1996
CIRIA R180	Review of the design and management of constructed wetlands, 1998
CIRIA 521	Design Manual for England and Wales, 2000
CIRIA 522	Design Manual for Scotland and Northern Ireland, 2000
CIRIA 523	SUDS Best Practice Manual, 2001
CIRIA 582	Source control using constructed pervious surfaces, 2001
CIRIA 663	SUDS techniques: hydraulic, structural and water quality issues, 2003

2.2 Roles of key stakeholders

The environmental regulator

The environmental regulator for England and Wales is the Environment Agency (EA). The principle aim of the EA (as defined by the 1995 Environment Act) is to protect, or enhance the environment so as to contribute to sustainable development. The EA is a non-departmental public body, with a Board appointed by, and responsible to, Government. Specific responsibilities of the EA include pollution control and management of water resources (including all ‘controlled waters’), as defined by the Water Resources Act, 1991. The EA exercises these responsibilities via a system of licenses and permits as well as through the setting of water quality objectives.

The EA advises the Government on environmental improvements and programmes required to meet the needs of European Union Directives and national legislation. The implementation of the EU Water Framework Directive (WFD) will have major consequences for the protection of the aquatic environment, and the legislative context of the WFD may have a significant influence on the consideration and inclusion of SUDS approaches within future urban land-use planning programmes (Ellis *et al*, 2002). Both the EA and the Scottish Environmental Protection Agency (SEPA) are strongly advocating the implementation of SUD systems, wherever appropriate.

Developers

Developers are becoming increasingly aware of the opportunities that SUD systems offer to new development sites. They are likely to be positive about incorporating sustainable drainage, provided that they can make full provision for such systems and their land-take when negotiating the land purchase price.

The need for an integrated design solution incorporating both development and highway runoff often causes problems, due to the heavy burden of consultations required and the risks of disagreement between the different stakeholders as a result of the separation of responsibilities between highway and drainage authorities.

Two further barriers that may currently block SUDS implementation are the lack of design standards and consistent regulatory objectives to which developers can work, and the difficulties in securing agreement over system adoption. There is no one stakeholder who will agree to adopting SUDS in a particular situation, and property management companies may be unwilling to do so due to the uncertainty over future maintenance needs, liabilities, and costs.

The sewerage undertakers

The water utilities are the third set of key stakeholders, whose operations have a significant impact on the management of the water cycle in England and Wales. They are private utility companies working within a highly regulated regime. Economic and customer regulation comes from the Office of Water Services (Ofwat), and environmental regulation from the EA (see above). The water companies are supportive of the principles behind SUDS, but are currently reluctant to wholeheartedly embrace SUDS until design standards have been set, the uncertainties over their maintenance needs have been overcome, and a consistent national approach to ownership and adoption of the systems has been agreed.

As sewerage undertakers, they are often perceived to be the appropriate organisation to maintain SUDS in the long-term, as they do with conventional drainage infrastructure. However, the framework for maintenance is currently not in place, as they would need Ofwat to formally recognise SUD systems as drainage assets in order for them to be able to recoup revenue from such activities under the current regulatory pricing regime.

2.3 The planning process

It is standard regulatory policy not to seek formal consents for urban surface water discharges. However, both the EA and SEPA are committed to the promotion of source control and passive treatment as ‘best management practice’ in their response to strategic and local plans. Therefore, normal regulatory practice has to rely on planning conditions and building warrants as the means of delivering best practice. Both hard engineering or softer source control measures can be incorporated in the development design and covered by descriptive consent conditions and/or numeric standards (Ellis *et al*, 2002).

The Government’s guidance on Development and Flood Risk, PPG 25 (DTLR, 2001), recommends that local planning authorities work closely with the EA, sewerage undertakers and prospective developers to enable effective source control of surface water runoff through the encouragement of SUDS. The document also states that:

(a) All proposals for development should take account of potentially increased runoff
(b) Local planning authorities should consider the need for policies which encourage the use, in appropriate areas, of more sustainable drainage system to control runoff as near as possible to the source
(c) All new development should, as far as possible, incorporate sustainable drainage measures.

Increasingly, both Regional and Development Plans are recommending the consideration and implementation of sustainable drainage systems, as part of a more sustainable approach to water management for new development. Box 2.3 gives an example of a recent regional planning policy that strives to achieve these objectives.

Box 2.3 Regional planning guidance for the East Midlands, RPG8 (Policy 46)

Policy 46 :Water Use and Development

Development plans should include policies to promote the most efficient use of water and ensure large users of water will be located where abstraction will not put supplies to other users, or the environment, at risk. Development should proceed only if the necessary water supplies, drainage and sewerage are available and can be provided without significant environmental impact or economic costs within the development time-scale. Mitigating measures, funded by the developer, may be required in order to make development possible.

Development plan policies and the plans and programmes of the Environment Agency and water service providers should be co-ordinated to:

- protect or improve water quality and significantly reduce the risk of pollution, especially to vulnerable groundwater
- manage demand, conserve supply, reduce wastage and promote local recycling of water and the multiple use of water resources
- protect and enhance wetland species and habitats
- reduce unsustainable abstraction from watercourses and aquifers to sustainable levels
- reduce the effects of development on the water environment by incorporating sustainable drainage systems
- ensure that the timing and location of development takes account of potential economic and environmental constraints on water resources
- lessen the impacts of abstraction when river flows are low, especially by encouraging winter abstractions and storage reservoirs, particularly for agriculture.

Progress in Scotland is ahead of that in England and Wales in this arena, driven to a large extent by the need to improve the water quality status of small watercourses, which have been heavily influenced by urban runoff. All planning applications for new developments in Scotland must now incorporate SUDS in their drainage strategies and designs. However, in order to ensure that all stakeholders have bought in to this new approach, a great deal of public education and technical training has been required, and a considerable amount of research has been commissioned to investigate system performance, maintenance and associated costs.

2.4 Long term ownership issues and the need for whole life costing

In order for a developer to be able to incorporate a sustainable drainage strategy into the site plans at an early stage in the development proposals, there is a need for the following guidance to be made available:

1. Standard design guidance and design criteria for all SUDS components.
2. Standard maintenance schedules for all SUDS components.
3. Tools for understanding the likely capital costs of sustainable drainage systems.
4. Tools for understanding the likely total scheme cost over the lifetime of the systems.

This project does not attempt to cover the area of standard design guidance, as this is being covered in other projects. The main focus is on the development of tools to understand whole life costs of SUDS. Maintenance schedules have been proposed in HR Report SR 626 "The Operation and Maintenance of Sustainable Drainage Infrastructure (And Associated Costs), 2004" prepared as part of the same project.

Although capital costs of SUDS are likely to be lower than conventional drainage, maintenance requirements may be significant in comparison. An understanding of long-term costs is therefore an important consideration for any adopting authority. Property management companies, local authority service teams, or sewerage undertakers may therefore need help in understanding the potential financial implications of taking responsibility for these systems in the long-term.

Whole life costing tools will allow appropriate comparisons to be made between different design solutions, and between sustainable systems and more conventional alternatives. A tool that identifies the likely expenditure profile for the system over its design life will also allow future operators to enter into maintenance agreements with increased confidence, and with appropriate level of funding having been secured at the outset.

3. AN OVERVIEW OF WHOLE LIFE COSTING METHODOLOGIES

3.1 Introduction to Whole Life Costing

The concept of Whole Life Costing (WLC) within an engineering concept is nearly 20 years old, and first emerged in the field of buildings and structures. It grew out of a recognition that the initial cost of a structure was but one part of the total expenditure required over its lifetime, and that undue attention to minimising initial cost could, in fact, lead to greater overall cost. According to Bull (1993), approximately 60% of the total construction budget in most developed countries is spent on maintenance and repair. In the UK, an estimated 45% of the annual turnover in the construction industry is spent on maintenance and refurbishment. Unplanned or unexpected premature failure accounts for nearly half of this percentage (Clift and Bourke, 1999). Interest in WLC in the water sector first started in the mid 1990s, especially in its potential application to the rehabilitation of underground assets (Skipworth *et al*, 2002).

A widely accepted definition of Whole Life Costs, and the one currently adopted by the Construction Innovation and Strategy Panel (CRISP) Performance Theme Group, is as follows (Clift and Bourke, 1999):

" The systematic consideration of all relevant costs and revenues associated with the acquisition and ownership of an asset."

Whole Life Costing is about identifying future costs and referring them back to present day values using standard accounting techniques. It is recognised as an appropriate technique for use in valuing total costs of assets that have a regular operating and/or recurrent maintenance costs, based on formalised maintenance programmes.

3.2 Whole Life Costs

In considering the costs associated with SUDS, an economic or financial viewpoint can be taken. An economic appraisal seeks to evaluate all the costs and benefits to the community affected by a proposed development, while a financial appraisal is solely concerned with the tangible costs, earnings and revenues which accrue to the SUDS owner and operator.

The costs taken into account are those which specifically relate to the particular investment, project or asset under study. These costs fall into two categories – monetary and non-monetary; with non-monetary costs generally only applying to economic appraisal.

Monetary costs are those associated with cash payments to or from the SUDS owner and operator. There are two types of monetary costs – direct and indirect. Direct monetary costs are related directly to the asset itself, such as the capital, operating, maintenance and disposal costs. Indirect (or consequential) monetary costs arise as a 'consequence' of owning or operating an asset. The hire of standby equipment when an installation fails, or compensation payments are two examples.

Non-monetary costs are, for example, the economic cost to society caused by, say, flooding from a blocked sewer or a pollution event. Although techniques exist for estimating the equivalent monetary cost of such events, these costs do not have the same hard value as true monetary costs. Furthermore they are costs to society in general and not to one organisation (in this case the SUD owner and operator) in particular. They are also highly site-specific.

In an economic appraisal, the major difficulty is usually the assessment of the benefits and risks associated with the scheme, which may not be readily measurable in cash terms. These are variously referred to as social and environmental costs, societal costs, or externalities. For instance, it may be possible to quantify the environmental benefits of encouraging surface water runoff to recharge aquifers via infiltration through an assessment of the potential impacts of any rise in the water table. Determining the benefits accruing from enhanced recreational and amenity enhancement as a result of a sustainable drainage scheme would also be possible.

The different approaches are presented in Figure 3.1 below:

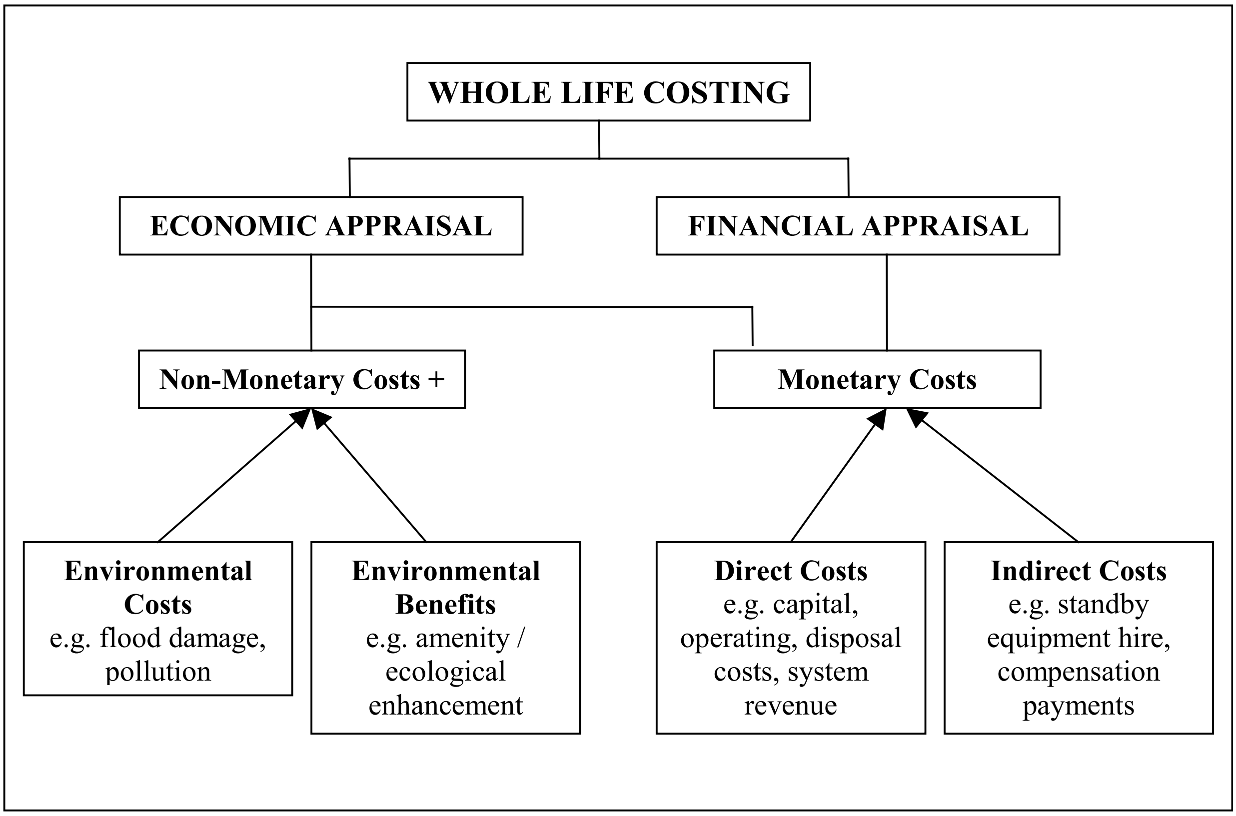

Figure 3.1 Economic and financial approaches to Whole Life Costing

A comprehensive literature review on WLC approaches is presented as Appendix A to this report.

3.3 Proposed approach

Whole Life Costing is therefore about identifying future costs and referring them back to present day costs using standard accounting techniques such as Present Value (PV). Different methodologies for discounting future costs do exist, but PV is the simplest and most commonly used discounting method available, and is also appropriate for application to sustainable drainage systems which may have a different time pattern of expenditure. It is therefore the only method that is discussed through this document. It should be noted that discounting costs to a PV has limitations and is sensitive to discount rates and assumptions of future costs and the timing of these costs.

Present Value (PV) is defined in MAFF (1999) as:

" the value of a stream of benefits or costs when discounted back to the present time"

It can be thought of as the sum of money that would be needed today to meet all future costs as they arise throughout the life cycle of a scheme or structure.

The formula for calculating the present value is given in equation (1).

$$PV = \sum_{t=0}^{t=N} \frac{C_t}{(1+\frac{r}{100})^t} \quad (1)$$

where N = Time horizon in years
C_t = Total monetary costs in year t
r = Discount rate

Discounting techniques are applied using an appropriate discount rate to adjust future costs. Figure 3.2 and Table 3.1 show the discounted cash flows for two schemes with differing capital and maintenance cost streams over a 25-year period. Scheme 1 has lower capital costs but assumes higher annual maintenance and full rehabilitation after 20 years. Scheme 2 has high initial capital costs and low recurrent costs.

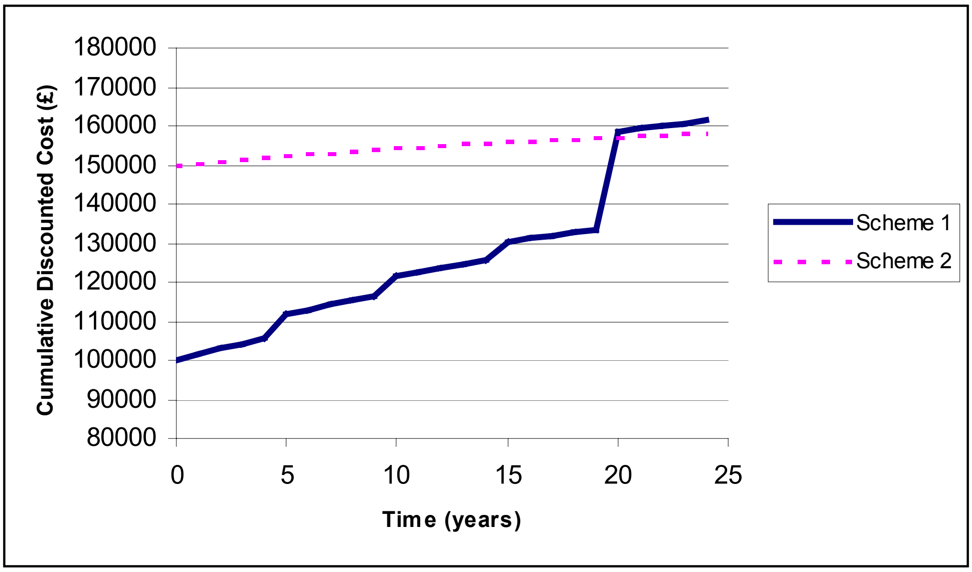

Figure 3.2 Cumulative discounted costs for two drainage schemes over 25 years, using a discount rate of 3.5%

Table 3.1 Present value of two drainage schemes over 25 years, using a discount rate of 3.5%

Year	Discount factor (@ 3.5% discount rate)	Scheme 1 (£)		Scheme 2 (£)	
		Annual costs	Discounted at 3.5%	Annual costs	Discounted at 3.5%
0	1	100,000	100,000	150,000	150,000
1	0.9662	1,500	1,449	500	483
2	0.9335	1,500	1,400	500	467
3	0.9019	1,500	1,353	500	451
4	0.8714	1,500	1,307	500	436
5	0.842	7,500	6,315	500	421
6	0.8135	1,500	1,220	500	407
7	0.786	1,500	1,179	500	393
8	0.7594	1,500	1,139	500	380
9	0.7337	1,500	1,101	500	367
10	0.7089	7,500	5,317	500	354
11	0.6849	1,500	1,027	500	342
12	0.6618	1,500	993	500	331
13	0.6394	1,500	959	500	320
14	0.6178	1,500	927	500	309
15	0.5969	7,500	4,477	500	298
16	0.5767	1,500	865	500	288
17	0.5572	1,500	836	500	279
18	0.5384	1,500	808	500	269
19	0.5202	1,500	780	500	260
20	0.5026	50,000	25,130	500	251
21	0.4856	1,500	728	500	243
22	0.4692	1,500	704	500	235
23	0.4533	1,500	680	500	227
24	0.438	1,500	657	500	219
PV			**161,351**		**158,029**

This shows that using a discount rate of 3.5 %, the total present value lifetime costs of the two schemes are very similar, despite the initial capital costs being significantly different.

3.4 The consideration of environmental costs and benefits

One of the requirements of the EU Water Framework Directive Article 5, recognises that “environmental and resource costs associated with damage or negative impact on the environment should be taken into account”. An economic appraisal of the impact of a development scheme may therefore be inclusive of such costs and the SUDS scheme may act as a ‘benefit’ in mitigating for such impacts. The DETR recognise (in their ‘Environmental Valuation Source List for the UK’ (DETR, 2000) that although there are techniques available to value externalities, environmental benefits have to be considered within a situation-specific context. The Treasury’s 2003 Green Book states that ‘wider social and environmental costs and benefits for which there is no market price need to be brought into any assessment. They will often be more difficult to assess but are often important and should not be ignored simply because they cannot be easily costed.’

The proposed WLC methodology must, therefore, have the flexibility to include such externalities within its framework so that appropriate weight can be given to the social and environmental benefits of SUDS in any economic analysis.

3.5 Barriers to the implementation of Whole Life Costing in drainage engineering

Traditionally, Whole Life Costing has not been extensively used for the development of options for the drainage of development sites. This is primarily due to the fact that conventional drainage components have automatically been adopted by the sewerage authority as an asset, as required under current legislation. There has therefore been a clear division of responsibility between capital outlay and long-term investment.

For sustainable drainage, the following issues are likely to influence uptake of the approach:

- High uncertainties associated with forecasting future maintenance costs
- Difficulties in defining realistic life expectancy of assets
- Lack of consistent historic data on which to base future cost forecasts
- Sensitivity of the results to discount rates.

As standardised maintenance schedules are developed and design lives are better understood, some uncertainties will be reduced. However, without a formalised procedure of recording construction out-turn costs for SUDS, a workable costing database will not be established.

3.6 The benefits of a Whole Life Costing approach

Whole Life Costing involves estimating the present day value of the total costs of a product, system or structure throughout its entire life. The objective is to enable informed decisions to be made regarding total lifetime expenditure. The benefits of undertaking such an appraisal are:

- Improved understanding of long-term scheme investment requirements, in addition to capital costs
- More cost-effective project choices at the project appraisal stage
- Explicit assessment and management of long term risk through the encouragement of a planned monitoring and maintenance regime
- Reduced uncertainties associated with development of appropriate adoption agreements / commuted sum contributions.

All expenditure incurred by the SUDS owner / operator, whether it is termed operational or capital, results from the requirement to maintain drainage of the surface water runoff. Adopting a long-term approach complements the fact that most sustainable drainage assets have a relatively long “useful” life, providing appropriate management and maintenance is undertaken.

4. DATA REQUIRED FOR A WHOLE LIFE COSTING APPROACH

In order to conduct a Whole Life Cost analysis, several parameters need to be assessed. These include the following:

- Design life
- Capital costs
- Operation and maintenance costs
- Monitoring costs
- Risk costs
- Environmental costs
- Disruption costs
- Disposal costs
- Residual costs
- Discount rate and discount period.

These are discussed in more detail in the following sections, with their applicability to the WLC of sustainable drainage schemes highlighted.

4.1 Design life

Design life is defined as the minimum length of time that a scheme or structure is required to perform its intended function. Design life can be divided into the following two categories:

- Service life — The period of time over which the owner expects the structure to perform
- Component life — A scheme or structure may contain components that run to a number of different life cycles. An understanding of the life of each component is crucial for conducting a whole life cost assessment and is necessary for ensuring that the structure will last for its intended service life.

There is various guidance available on the expected lifetime of conventional drainage components. However, there is high uncertainty over the design lives of sustainable drainage systems. In theory, with appropriate maintenance, their life should be unlimited as there is low risk of structural failure.

4.2 Capital costs

The capital costs of conventional drainage systems are well understood. However, as the construction of SUDS components has, to date, been a relatively infrequent activity, and as designs and construction methods are highly site specific, there is little information on SUDS capital costs.

SUDS capital costs should include the following:

- Planning and site investigation costs
- Design and project management/site supervision costs
- Clearance and land preparation work
- Material costs
- Construction (labour and equipment) costs
- Planting and post-construction landscaping costs (where specific to sustainable drainage works)
- Cost of land-take.

For a typical flood retention basin, the sum of all costs related relating 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.) (Ellis *et al*, 2003).

If a sustainable drainage system can be located on 'open space' land, and this land is a planning requirement, then logically there should be no cost allocation in land to the drainage system. In cases where land has to be sacrificed to accommodate a system, or where it becomes necessary to locate the SUD system outside the site thus requiring the purchase of additional land, then extra land costs will have to be included.

4.3 Operation and maintenance costs

Sustainable drainage schemes require ongoing maintenance in order to ensure short-term operation and minimise risks to long term performance. Maintenance activities are likely to comprise a major contribution to total life costs, and the lack of understanding and quantification of these to date is currently one of the barriers to facilitating adoption agreements.

Operation and maintenance activities can be classified as follows:

- *Monitoring*
- *Regular, planned maintenance*
  (e.g. rodding culverts, clearing debris from manholes, grass-cutting, vegetation management, sediment removal, jetting of permeable surfaces and silt traps)
- *Unplanned maintenance / rehabilitation*
  (e.g. responding to problems e.g. blocked culverts/trash-racks, pollution incident, vegetation death etc)
- *Intermittent, planned maintenance*
  (e.g. for major mid-life refurbishment such as geotextile replacement, vegetation replacement, soakaway replacement etc).

Operation and maintenance costs will comprise:

- Labour and equipment costs
- Material costs
- Replacement and/or additional planting costs
- Disposal costs (of, for example, contaminated sediments, vegetation).

4.4 Monitoring costs

4.4.1 Visual monitoring

Regular monitoring of SUD schemes, undertaken as part of routine site maintenance visits, is vital to ensure that the performance of the system is not put at risk, as a result of:

- Blockages
- Reduction of storage volumes
- Deterioration of infiltration capacities
- Plant death
- Deterioration in visual appearance of the system.

Effective monitoring of:

- Litter build-up
- Inflow and outflow water quality, and indications of biological condition
- Sediment accumulation
- Plant growth
- Water levels and ponding
- Erosion damage and/or vandalism.

is therefore required to allow regular operation and maintenance, and irregular rehabilitation activities to be triggered at appropriate times.

4.4.2 Quantitative monitoring

The high level of uncertainty in the understanding of the performance of SUD schemes at present means that, in order to have confidence in the level of quantity and quality management, regular quantitative monitoring should be included as part of the scheme.

However, monitoring is an additional cost that is often perceived as unnecessary and expensive and such monitoring activities are therefore not commonplace. If the scheme is being handed over to an adopting authority, such activities will generally not be funded.

In certain circumstances, possibly where the receiving watercourse is particularly sensitive, the Environment Agency may, in the future, require monitoring as a planning condition for the development. This would be a site-specific requirement that would have to be included in the costs for the individual scheme.

4.5 Risk costs

There is great variation in the use of risk evaluation techniques across the water engineering industry. In sustainable drainage schemes, the residual risks can be managed to a certain extent through safe designs for exceedance, regular monitoring and appropriate maintenance. In most cases, the costs associated with the risks are likely to be ‘public’ or ‘societal’ costs and will not be borne by the SUDS owner or operator.

Risks associated with flooding from conventional sewerage systems during extreme events and/or the impacts on receiving water quality from CSO spills have historically been considered by sewerage undertakers (adopting authorities), rather than the scheme developers. However, the move towards explicit recognition of all relevant costs and benefits at project appraisal stage means that such considerations may be important for the future.

Table 4.1 presents an example of a register to account for the costs of likely risks associated with poor system performance.

Table 4.1 Example of a risk register management tool

Risk Item	Description (A)	Risk (B)	Probability of Occurrence (%) (C)	Consequence £ (D)	Risk Value £ (C) x (D)	Comment / Mitigation
1	Flood damage	None Marginal Severe	75 20 5	0 20,000 40,000	0 4,000 2,000	Probability will vary with maintenance
2	Infiltration reduction	None Marginal Severe	30 60 10	0 20,000 40,000	0 12,000 4,000	Probability will vary with maintenance
3	Reduced water quality performance	None Marginal Severe	60 30 10	0 5,000 15,000	0 1,500 1,500	Probability will vary with maintenance
3	Pollution incident	None Marginal Severe	60 30 10	0 5,000 15,000	0 1,500 1,500	Consequence may vary with management strategy
				Total	**28,000**	

It should be understood that all ‘consequence’ costs will be highly site specific and as a result cannot be ‘generalised’ or ‘standardised’ in any way.

4.6 Environmental costs

There are a range of environmental benefits that may accrue from implementing SUDS. These include amenity and recreation opportunities, biodiversity and ecological enhancement, aquifer and base flow augmentation, water quality improvements and net flood risk reductions.

The costing of such benefits is discussed here briefly. It is, however, unlikely that such approaches would be used in practice unless a detailed economic appraisal was being undertaken for a range of options, or for environmental impact assessment purposes. A practical problem is the need to be clear and rational about where to draw the boundaries around social and environmental issues, and the problem of the availability and usefulness of information required to undertake such an analysis.

Although it is possible to identify how and where environmental benefits (or ‘externalities’) may occur, it is less easy to estimate the economic values. Probably the most popular method of trying to estimate values for environmental characteristics is based on simulating a hypothetical market for environmental goods, and is known as Contingent Valuation Method (CVM). This estimates the willingness-to-pay for a change in the quality or quantity of an environmental good or service, using sample evidence drawn from questionnaires and surveys. The results are dependent upon the skill with which the questionnaires or surveys are drawn up, conducted and analysed as well as the attitude and characteristics of the population involved in the study.

To carry out a CVM study requires a significant investment in time and resources, however a growing number of CVM studies have now been carried out in the UK (e.g. to value water quality improvements, the benefits of reduced air pollution, and the value of ecologically important species). An alternative approach is to make use of the results of other CVM studies using a benefits transfer approach. This adjusts the values found from other studies by taking into account the characteristics of the study area, and could be a good indication of the range of possible values that might be expected from a full CVM study. The Environment Agency has produced a set of guidelines entitled ‘Assessment of Benefits for Water Quality and Water Resource Schemes in the PR04 Environment Programme’ (Risk & Policy Analysts, 1993), and this presents some relevant datasets.

There are a number of categories of environmental benefit that might be triggered by the development of a new landscape feature such as a SUDS scheme. These are discussed briefly in the following sections:

4.6.1 Recreation and landscape

Recreation and landscape benefits are generally too inter-linked to consider as separate impacts, due to the risk of double counting. In terms of recreation / landscape effects, the significance of the impact may depend upon the current scarcity of different land use types, e.g. in an area with a large number of reservoir and/or wetland features, an additional SUDS pond may have a low impact. However, in a highly urbanised setting, where existing access to water bodies and green open areas is low, the impact could be very significant.

The following series of questions can be used to determine whether the impacts on recreation / landscape are likely to be significant.

1. Is there access to the site?
2. Will recreation take place at the site?
3. Will the site be available to the public at all times of year?
4. What sort of facilities will be provided? (e.g. foot paths, disabled access, car parks, benches, toilets etc.)
5. Is the site is of high local or regional importance?

6. Are there expected to be noticeable impacts on the local landscape (i.e. are the site characteristics unique or common to the local area)?

There have been few comprehensive studies undertaken on evaluating a benefit for total recreation value. One study was carried out by Gaterell *et al* (1995) for Rutland Water. The results for this study indicated a total recreational value of £25.50 per visit, although the current guidelines recommend use of a lower bound figure of £9.40 per recreation day. A visit to a SUD pond would, however, be substantially shorter than a day, and together with the reduced access, facilities, and size of a SUD system – much lower values would be recommended. As a comparison, a study by Bishop (1992) valued landscape, wildlife and recreational amenities of two woodland sites as between £0.50 and £1.50 per visit. For users directly affected by the scheme, e.g. local householders, an annual household transfer value is required.

The per annum value of recreation benefits arising from the proposed scheme can be estimated using the following relationships:

Benefits = number of visits x transfer value (per visit per year)

Or

Benefits = number of visiting households x transfer value (per household per year)

The HR Report SR622, entitled "An Assessment of the Social Impacts of Sustainable Drainage Systems in the UK, 2003" (prepared as part of the same project), gives some guidance on the way people value ponds and this research could be used as part of potential future work to develop values for these benefits.

4.6.2 Amenity, property prices and regeneration

The quality of the local environment can affect property values, with both commercial and residential properties in close proximity to a high quality environment attracting high price premiums. These premiums may reflect, in part, the potential recreational benefits arising from the location, as well as some non-use values. The premiums also reflect the amenity gain accruing to properties in the form of an increase in the capitalised value of the properties from an improvement in environmental quality.

The following series of questions can be used to determine whether the impacts on amenity are likely to be significant.

1. Are there houses or office buildings close to (within 500 m) of the SUD system?
2. How many and what type of properties are located within 500 m of the SUD system?
3. To what extent will the SUD system be the focus of these properties (i.e. is it visible to/from the properties, is it a feature of the landscape surrounding the properties)?
4. What will the aesthetic quality be like (e.g. is litter being collected, will the water quality be poor or reasonable)?
5. Will the scheme significantly increase the attractiveness of the site?

Several studies have estimated the price premiums associated with nearness of premises to water-based environmental goods. The resulting values range between 2 % and 18.6 %. HR Wallingford (2003) suggests that land values and house prices located adjacent to SUDS water features may demand a 10 % differential. Other estimates suggest that a stormwater wetland "waterfront" location on a business part / commercial estate can increase rentals by 3 % - 13 % (Ellis *et al*, 2003). 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 or three times (Holden, 1989).

4.6.3 Receiving water quality improvements

It is not easy to derive economic values for water quality impacts. The complexity of the way in which pollutants entering the water environment affect chemical water quality and ecological status means that it is difficult to devise simple dose-response functions. Furthermore, the benefits of improving water quality are generally location-dependent.

Numerous studies have attempted to estimate the economic value of changes in water quality of flow rates/levels in water bodies, but establishing values that can be transferred is difficult. New research is planned by DEFRA, the EA and OFWAT to value the environmental benefits of changes in water quality.

4.6.4 Biodiversity and non-use values of SUD systems

Well-designed and maintained SUD systems are likely to support a variety of wildlife. The importance of such systems is highlighted by the fact that approximately one third of British flora is found in freshwater wetlands.

The benefits of biodiversity can be difficult to measure, define and value. There are two current approaches that could be adopted. The first is the use of generalised estimates of individual's willingness to pay to conserve/preserve freshwater dependant ecosystems, while the second is the use of replacement costs techniques to derive estimates of how much it would cost to create an area of similar conservation value elsewhere. The key issue will relate to whether a scheme is likely to deliver an ecological impact of such significance for it to be valued.

The HR Report SR625, "Maximising the Ecological Impacts of Sustainable Drainage Schemes, 2003" (prepared as part of the same project) gives some guidance on the ecological benefits that may accrue from sustainable drainage systems, and this research could be used as part of potential future work to develop values for these benefits.

4.7 Disposal costs

As discussed earlier, many SUD systems could be perceived as having infinite life expectancies, if the correct maintenance programme is implemented. However, there are some SUD components that are likely to require disposal of material as a result of operation and maintenance / rehabilitation activities.

Materials that are likely to require replacement at some point during the life of the system include:

- Vegetation (including aquatic planting and grass turfing)
- Granular fill
- Permeable surface blockwork
- Sediment
- Geotextiles.

Vegetation will require annual cutting as part of regular management. It may also die off, or become saturated with contaminants and require replacement (the process driver behind vegetation harvesting to retain optimum water quality performance). Sediment is likely to accumulate in ponds, in silt traps or across infiltration surfaces. Geotextiles and permeable blockwork may become clogged with fine silts and contaminants, reducing the infiltration potential. Granular fill should be washed and re-instated, when required, rather than replaced.

If the concentration of pollutants within sediments, geotextiles, vegetation etc. increases to high levels, then such materials may need to be disposed of to landfill, potentially classified as special waste. Costs for such operations would be significantly greater than the equivalent costs of disposal on site, or to land elsewhere. Toxicity tests would be required before any materials were extracted to determine disposal requirements.

4.8 Residual costs

In a full economic evaluation, the residual or 'reclaim' value of the land used for the drainage components should be included. It is unlikely that any land close to development areas would depreciate in value within a 20 – 50 year period, and thus the net present worth of the land following the nominal operational lifetime should be accounted for.

4.9 Discount rate and discount period

The discount rate is the rate used to convert all future costs and benefits to 'present values' so that they can be compared. It is the difference between the rate of return on the open market and inflation. The recommended discount rate has historically been set by financial institutions at between 5 and 10 %. In the public sector, the discount rate is set by the Treasury and they are currently recommending a rate of 3.5 %, a recent shift from a long-term value set at 6 %. The reduction in the discount rate effectively puts a higher weight on future costs, to encourage longer-term, more sustainable development. The Treasury are also recommending that for projects with long-term impacts, over thirty years, a declining schedule of discount rates should be used rather than the standard discount rate (see Table 4.2). The main rationale for declining long-term discount rates results from uncertainty about the future, which has been shown to cause declining discount rates over time.

Table 4.2 The treasury recommended declining long term discount rate

Period of years	0 - 30	31 - 75	76 - 125	126 - 200	201 - 300	300 +
Discount rate	3.5 %	3.0 %	2.5 %	2.0 %	1.5 %	1.0 %

Selection of the most appropriate discount rate is one of the most contentious issues in WLC analyses, as it can have a significant effect on the outcome of the analysis. Calculations using a high discount rate will make future costs less important, while a lower discount rate will reduce the impact of capital costs on the WLC.

Discount periods of 25-30 years are commonly used for analysis in the water industry. Commuted sums that can be paid by developers to local authorities for the adoption of SUDS are currently limited to 25 year periods. However, it is likely that the costlier rehabilitation works may be required from about this interval post-construction, so longer discount periods should be considered. The primary purpose of expenditure on sustainable drainage systems is to maintain the system performance, an implication of this being that there is an indefinite 'useful life' for the systems. The 'useful life' is in fact being constantly altered by the maintenance activities that are or are not undertaken. A period of analysis should be selected that ensures all significant future maintenance activities are accounted for.

The following graph shows the impact of time on the relative contribution of yearly costs to the total in a 100-year analysis, using both 3.5 (declining with time) % and 6 % discount rates.

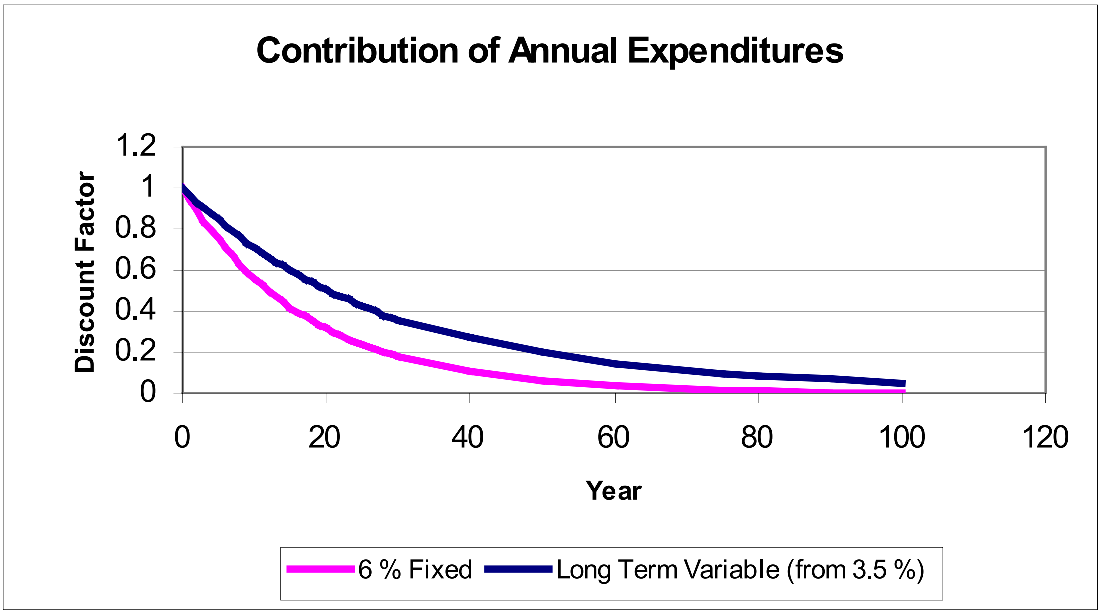

Figure 4.1 Contribution of annual costs using different discount rates

This shows that, at a 6 % discount rate, the relative contribution of annual expenditures becomes insignificant when compared to the WLC of the system for discount periods of greater than 50 years. Using a 3.5 % (declining with time) discount rate, greater weight is given to operation and maintenance costs, and thus expenditure between years 50 and 100 is more significant.

5. UNDERTAKING A WHOLE LIFE COST APPRAISAL FOR SUSTAINABLE DRAINAGE SYSTEMS

5.1 Adopted methodology

A simple Present Value (PV) Whole Life Costing approach is proposed for application to sustainable drainage systems, and this is summarised in Box 5.1:

Box 5.1 Whole Life Cost methodology proposed for SUDS

1. ***Identify all the capital cost elements***

2. ***Establish maintenance requirements***
   (including regular maintenance, non-regular activities, refurbishment needs, other operational requirements etc).

3. ***Estimate any disposal costs, monitoring costs, risk costs, and environmental costs / benefits that require consideration.***

4. ***Calculate Whole Life Cost***
   - Calculate all costs at current prices
   - Discount all costs to the base period
   - Sum discounted costs to establish the Net Present Value

Where WLC is being used as a tool to aid in option appraisal, then the following relationships will need to be considered:

a) The relationship between design options and corresponding maintenance requirements.
b) The relationship between design options and risk / environmental costs and benefits.
c) The relationship between maintenance options and risk / environmental costs and benefits.

These relationships are discussed further in the following section.

Once these have been established, then WLC can be used to aid selection of an appropriate solution that demands an investment profile that stakeholders are willing to buy into.

The approach is set out in Figure 5.1.

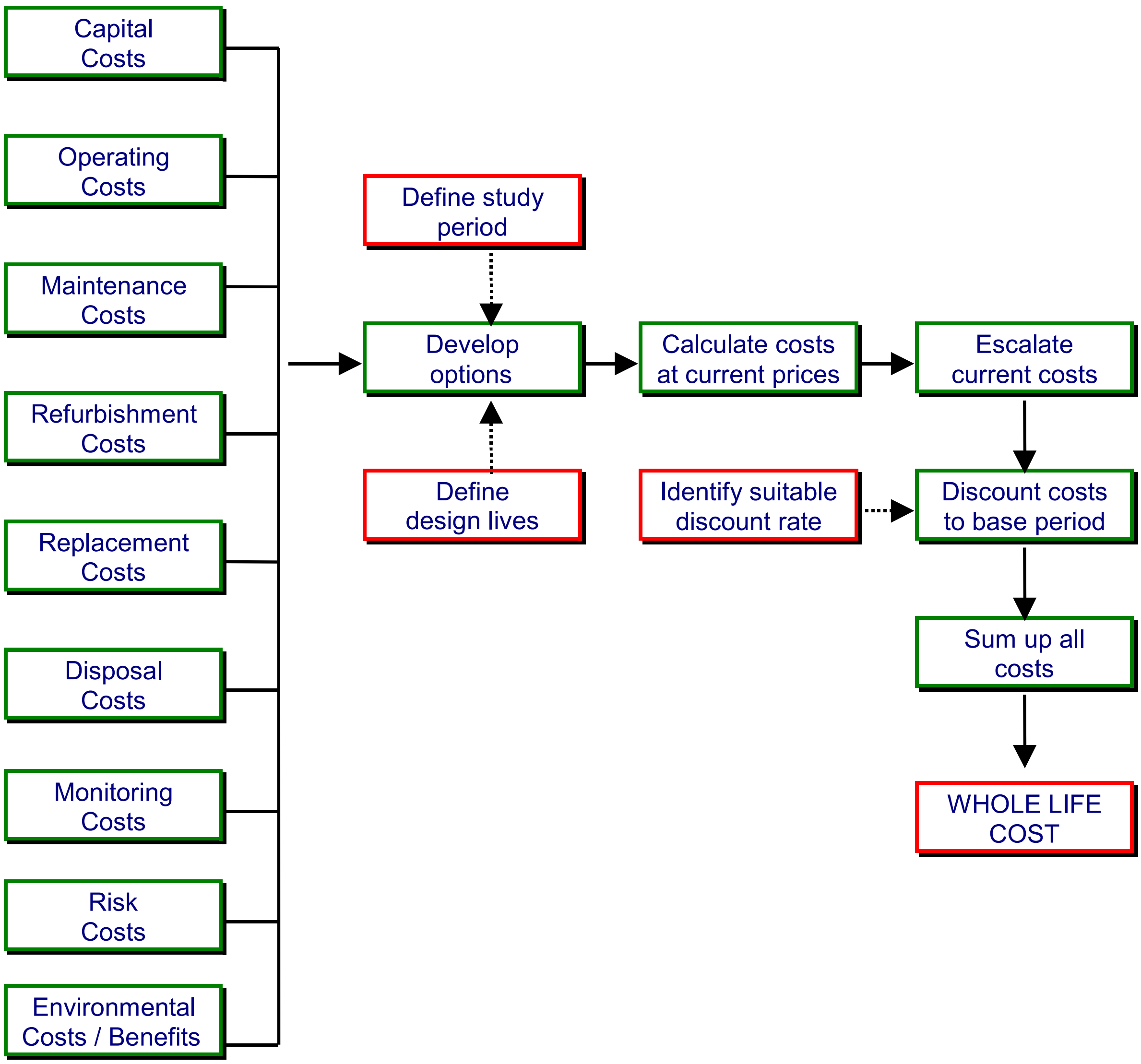

Figure 5.1 Flow diagram showing net present value Whole Life Costing methodology

5.2 Key relationships

5.2.1 Design and construction options and maintenance costs

The following sections provide examples of how decision-making at design and construction stages can influence both short and long-term maintenance needs of sustainable drainage schemes.

Sediment management

The extent to which the management of sediments is considered in the design, and through the construction process, may have a significant effect on both initial and long-term operation and maintenance costs.

Where best practice is adopted in the effective management of construction sediment loads, there will be a reduced risk of silt accumulation and/or system blockage in the early operational stages. This will remove or reduce the need for often costly early maintenance or rehabilitation activities.

With respect to the design of the SUD scheme, a sediment forebay or engineered silt trap structure upstream of the SUD system will facilitate the deposition (and subsequent collection) of silt in a localised area, where removal operations are relatively simple and low cost. Where such structures are not included, downstream filtration systems will be at higher risk of clogging, and open water systems e.g. ponds, wetlands will tend to accumulate sediment. As open water area increases, the methods involved in dredging out sediments will become increasingly complex and costly.

The disposal of sediment is also a key issue. There are potentially three available options for sediment disposal:

1. On-site to build up landscaped levels (may only be possible for SUDS within larger landscaped areas).
2. Off-site to land.
3. Off-site to land-fill (as special waste).

If land is made available on site for de-watering of dredged or excavated sediments, then required disposal volumes could be significantly reduced. The opportunity to spread material to land (either on or off site) will depend on the level of toxicity of the sediments and this should be checked on-site in advance of disposal operations.

Inlet / outlet infrastructure

The design of headwalls, trash racks and flow control structures can all act to either obstruct or facilitate operation and maintenance activities. Headwall structures that extend above ground level can impede mowing and/or vegetation control operations, and poorly designed trash racks can be prone to blockage and difficult to clear. Easy access to these structures is important.

Inspection chambers / monitoring points

It is important that potential modes of failure of SUD components are identified at an early stage and that regular monitoring is undertaken at appropriate locations in order that risks of poor system performance are minimised. Effective monitoring will ensure that suitable maintenance can be defined, and will avert risk of failure. Monitoring points should be readily accessible, and where subsurface monitoring is required, then inspection chambers should be included within the design.

5.2.2 Design and construction options and risk / environmental values

The following sections provide examples of how decision-making at design and construction stages can influence the environmental benefits and perceived risks associated with sustainable drainage schemes.

Planting

Certain SUD components will rely on an appropriate level of both aquatic and bankside planting to fully realise their amenity and ecological benefit potential. It has been shown that aesthetic appeal is vital in forming positive public opinion of SUD systems, and that effective barrier planting can substantially reduce health and safety concerns. Aquatic planting is also likely to contribute to water quality treatment.

Geometry

Geometrical characteristics such as pond bank slopes, and the depth of water have also been shown to affect public opinion and environmental value of the site. If steeper slopes and/or greater water depths are chosen, then benefits may be reduced due to perceived health and safety risks.

Access area

Full environmental benefits may not be realised if the SUD system is not incorporated into a wider recreation / amenity area.

Area of open water

A very small area of open water is unlikely to present the amenity / recreational benefits of a pond/lake of a more significant size.

Construction programming

The integration of the evolution of the SUD scheme and the development during the early post-construction stages can be critical in forming public opinion and in ensuring ecological and technical performance. Where planting has to be delayed, public perception can be very poor unless education and awareness of the scheme are high. This can also lead to vandalism. The timing of planting is also crucial to ensure that the vegetation establishes well and that rates of die-off are low.

5.2.3 Maintenance options and risk / environmental values

The following sections provide examples of how decision-making with respect to operation and maintenance options can influence the environmental benefits and perceived risks associated with sustainable drainage schemes.

Vegetation maintenance

If aquatic and barrier planting is not maintained, then the environmental benefit associated with a scheme may deteriorate. There is also a risk that the volume available for detention storage may reduce with time. Lack of maintenance may also cause blockage, with associated increased risk of upstream flooding.

Sediment management

If sediment is not managed effectively, then the system could become unsightly, and the environmental benefit of the scheme may subsequently reduce.

Infrequent management may also lead to unacceptable levels of sediment toxicity, and reduced water quality treatment potential.

Litter removal

If litter is not collected and removed on a regular basis, the system can become unsightly, and the environmental benefit of the scheme may drop off with time.

Inspection of inlet / outlet infrastructure, together with removal of litter and debris from the SUD infrastructure is vital to ensure that risks to hydraulic performance are minimised as far as possible.

Maintenance of access

If the public access zone to the site is not maintained on a regular basis (e.g. grass cutting), then the opportunities for recreational benefits will reduce. It should be noted that maintenance of this zone may fall under local authority or estate management care, rather than the SUD owner.

5.3 Option appraisal and comparisons with conventional drainage solutions

Scenarios can be tested to assess the impact / risks of deviating from current best practice, in terms of either design and construction, and/or operation and maintenance requirements. Scenarios can also be developed to compare whole life costs associated with two alternative options. The relationships discussed above are not all-inclusive, and additional issues may need investigating for particular designs. The nature of the relationships will be design and site-specific, but some quantification of the impacts is required if options are to be appraised with confidence.

When comparing sustainable drainage solutions with more conventional alternatives, the following issues should be considered for the SUDS option:

- Absence of conventional kerbs and gullies
- Reduced need for pipes, manholes etc and absence of deep trench excavations
- Absence of storage tanks, leading to reduced excavations and construction costs
- Less need for wayleaves and easements to construct sewer outfalls
- Simpler construction.

It is fundamental to any analysis of costs and benefits, that the engineering alternatives, which are the subject of the appraisal, meet the same drainage objectives. Implementation of the Water Framework Directive will require consideration of the water quality of all surface water discharges, so the costs of providing additional treatment at outlets may need inclusion for more conventional solutions.

To make a real comparison between a conventional drainage system that discharges into the local sewerage network and a SUD solution which retains some or all of the flow on site, it is vital for any financial appraisal to consider the additional costs involved in providing enhanced downstream sewers and works as well as the capital cost of the site drainage. These are financial costs that may be met by others, such as the water authorities / adopting authorities rather than the developer (under Section 106 of the Water Industry Act 1991, a developer has a right of connection to the public sewerage system, subject to certain conditions, whether or not there is adequate capacity in the sewer), so may not be evident in an assessment that just looks at costs / benefits accruing to the site owner / operator.

If, however, the connection is to a private surface water sewer or highway drain, the cost of any necessary downstream improvement will usually be a requirement to achieve permission to connect. The cost of downstream improvement works would be funded from infrastructure charges, levied by the sewerage undertaker whether or not downstream improvements are necessary in a particular case. It is worth noting that in some regions, savings in infrastructure charges can be made if no connection is made to the surface water sewerage system.

6. CAPITAL COSTS OF SUSTAINABLE DRAINAGE SYSTEMS

6.1 Introduction

In attempting to determine reasonable cost estimates for sustainable drainage systems in the UK (that could be used for planning purposes), two approaches were followed. The first comprised a review and summary of cost estimates from literature. The second comprised a review and summary of real out-turn SUD construction costs, collated from industry.

6.2 Literature review

Although various manuals in the United States (US) report construction cost estimates for ponds, there are only three US studies that have systematically evaluated the construction costs associated with the full range of equivalent SUD components. In France, CERTU have published construction cost ranges (CERTU, 1999). However, there is very little cost information published for UK schemes, to date and where costs are available, there tends to be poor information to adequately characterise the system i.e. system size and/or contributing catchment area.

The three US studies used slightly different estimation procedures. Two of the studies were conducted in the Washington DC region and used a similar methodology (Wiegand *et al*, 1986; Brown and Schueler, 1997). In both studies, the costs were determined based on engineering estimates of construction costs from actual systems throughout the region. In the third study, conducted in South-eastern Wisconsin, costs were determined using standardised cost data for different elements of the system, and assumptions regarding system design (SWRPC, 1991).

Cost data found in literature is summarised in Table 6.1.

Table 6.1 Summary of SUD capital cost data from literature

SUD	Cost	Quantity	Reference
Wetland	**$C = 18.5V^{0.70}$** *C= construction, design and permitting cost ($)* *V = water quality volume (ft^3)*		Brown and Schueler (1997)
Retention pond	**$C = 7.75V^{0.75}$** *C= construction, design and permitting cost ($)* *V = water quality volume* (ft^3)		Wiegand *et al*, (1986)
	$363,827	340,350 ft^3	Texas Department of Transport (2000)
	$245,215	204,190 ft^3	Texas Department of Transport (2000)
	$108,310	69,000 ft^3	Texas Department of Transport (2000)
	$C = 24.5V^{0.705}$ *C= construction, design and permitting cost ($)* *V= volume in the pond to include the 10-year storm (ft^3)*		Brown and Schueler (1997)
	C = 1.06V **C = 0.43V** **C = 0.33V** **C = 0.31V** *C= construction, design and permitting cost ($)* *V = total basin volume (ft^3)*	23,300 ft^3 148,000 ft^3 547,000 ft^3 952,000 ft^3	SWRPC (1991)
	$17.50 - $35 m^3		CWP (1998)
	€ 9.1 to 61	m^3	CERTU (1998)
	€ 140 (standard deviation= €152)	m^3	Baptista *et al*. (2001)
Detention pond	**$C = 12.4V^{0.76}$** *C = construction, design and permitting cost ($)* *V = volume ($ft^3$)*		Brown and Schueler, (1997)
	$C = 7.47V^{0.78}$ *C = construction, design and permitting cost ($)* *V = volume ($ft^3$)*		Brown and Schueler (1997)
	$188,343	340,350 ft^3	Texas Department of Transport (2000)
	$133,202	204,190 ft^3	Texas Department of Transport (2000)
	$57,762	69,000 ft^3	Texas Department of Transport (2000)
	€ 9 to 91	m^3	CERTU (1998)
	€ 108 (standard deviation= €157)	m^3	Baptista *et al*. (2001)

Table 6.1 Summary of SUD capital cost data from literature (continued)

SUD	Cost	Quantity	Reference
Infiltration basin	**$C = 13.2\ V^{0.69}$** *C= construction, design and permitting cost ($)* *V = water quality volume* (ft^3)		Weigand *et al*, (1986)
	C = 1.3V *C= construction, design and permitting cost ($)* *V = water quality volume* (ft^3)	15,000 ft^3	SWRPC, (1991)
	C = 0.8V *C= construction, design and permitting cost ($)* *V = water quality volume* (ft^3)	76,300 ft^3	SWRPC, (1991)
	$92,877	340,350 ft^3	Texas Department of Transport (2000)
	$62,801	204,190 ft^3	Texas Department of Transport (2000)
	$26,336	6,900 ft^3	Texas Department of Transport (2000)
Infiltration / filter trench	**$4 per ft^3** of storm water treated.		SWRPC (1991)
	C = 3.9* V+2900 *C= construction, design and permitting cost ($)* *V = water quality volume (ft^3)*	3-foot deep, 100 foot long trench	SWRPC (1999)
	$C = 33.7V^{0.63}$ *C= construction, design and permitting cost ($)* *V = water quality volume (ft^3)*		Wiegand *et al*, (1986)
	C = 2V to 4V; average of 2.5V *C= construction, design and permitting cost ($)* *V = water quality volume (ft^3)*		Brown and Schueler (1997)
	$15,525	705 ft^3	Texas Department of Transport (2000)
	$9,255	423 ft^3	Texas Department of Transport (2000)
	$3,454	140 ft^3	Texas Department of Transport (2000)
	€ 30.5 to 38 (for filter trenches - includes excavation, filling and geosynthetic membrane)	m^3	CERTU (1998)
Permeable pavement	**C = 50,000*A** *C= construction, design and permitting cost ($)* *A = surface areas in acres*		SWRPC (1991)
	C = 80,000*A *C= construction, design and permitting cost ($)* *A = surface areas in acres*		Schueler (1987)
	$10,105	212 yd^2	Texas Department of Transport (2000)
	€ 152 to 228	m^3	CERTU (1998)

Table 6.1 Summary of SUD capital cost data from literature (continued)

SUD	Cost	Quantity	Reference
Filter strip	**Existing vegetation: $0**		SWRPC (1991)
	Seed: $13,800/acre		SWRPC (1991)
	Sod: $29,000/acre		SWRPC (1991)
Swale	**$0.25/ ft^2**		SWRPC (1991)
	$6,395	10,000ft^2	SWRPC (1991)
	$11,735	10,000ft^2	SWRPC (1991)
	$17,075	10,000ft^2	SWRPC (1991)
	$y=12,985x^{-0.9992}$ *x – water quality discharge ft^3/s* *y - unit costs $/acre-ft*		Not known
	€ 7.6 to 15 **€ 15 to 30.5**	m^3 stored volume linear metre	CERTU, 1998

6.3 Regional and transatlantic cost variations

Any capital costs reported in the literature need to be normalised both temporarily and spatially, based on inflation and regional differences. All the US costs quoted in this report have been adjusted to the 'twenty cities average' construction cost index, based on a methodology followed by the American Public Works Association. Regional adjustment factors for the UK are given in one of the standard UK civil engineering price databases (SPON'S, 2003), as follows:

Table 6.2 UK regional cost adjustment factors

Region	Adjustment factor
Outer London	1.00
Inner London	1.10
South East	0.96
South West	0.87
Midlands	0.82
East Anglia	0.87
Northern	0.78
North West	0.83
Scotland	0.82
Wales	0.78
Northern Ireland	0.60
Channel Islands	1.25

This demonstrates that cost of a SUDS scheme may vary depending on location.

It was thought that there may be significant differences in unit costs between the UK and the US, as a result of different tax regimes and costs of materials and labour. Fixed items were selected from SPON'S (2003) and an equivalent US costing manual. As shown in Figure 6.1, there is some evidence that materials may be slightly more expensive in the UK, however labour costs appeared to be similar.

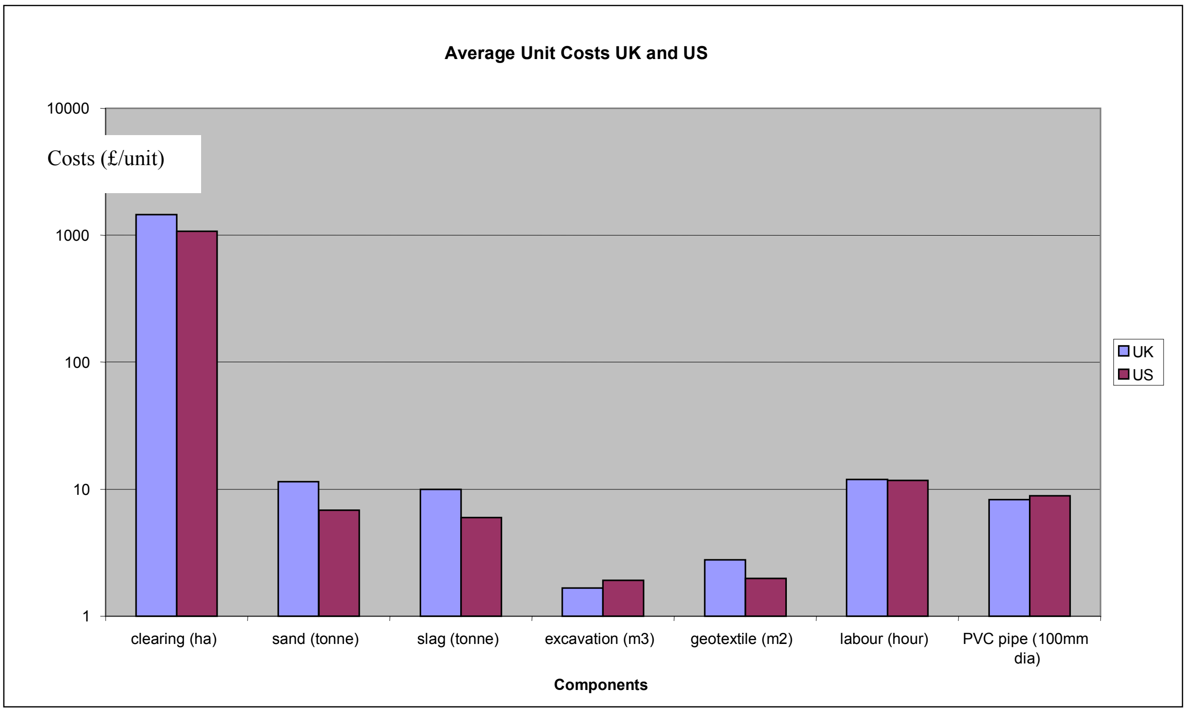

Figure 6.1 UK / US unit rate cost comparison from standard civil engineering costing databases

6.4 UK SUD scheme construction costs

An ideal dataset would have included actual out-turn construction costs for the full suite of sustainable drainage systems, for a range of sizes, covering a range of conditions / criteria. This would have provided both the mean and the bounds for cost estimates to be included in the study and would have contributed towards robust whole life cost estimates. An alternative would have been that full cost breakdowns be available, so that an assessment could have been made of the variability in contribution of different cost components, and their impact on overall construction costs.

An extensive consultation exercise was undertaken in an attempt to secure actual construction costs for sustainable drainage schemes across the UK. Significant difficulties in collating such information were encountered. These could mainly be attributed to the following issues:

1. Construction of sustainable drainage components providing open, surface storage tends to be undertaken as part of the post-construction, landscaping activities. Thus the costs specifically associated with the drainage are hidden within large, lump-sum, landscaping fees and cannot be extracted as a separate item.

2. Construction of sustainable drainage components providing covered, subsurface storage (e.g. pervious pavements) tends to be undertaken as part of the highway infrastructure development and again, costs tend to be hidden within larger bill items.

3. There is currently no system through which capital costs are recorded or presented in a consistent way.

4. Projects, of which sustainable drainage infrastructure form a part, are generally costed by building contractors and then bid for using a lump-sum, fixed price. A full breakdown of costs for drainage components is unlikely to be included as part of a tender. Final costs may exceed or fall below initial estimates.

5. The final costs of the sustainable drainage infrastructure are likely to be very dependent on whether appropriate equipment and labour is available on the site at the time. If specialist teams have to be engaged, then costs could rise rapidly.

6. Confidentiality / competitive pricing issues.

It was anticipated at project definition stage, that the Project Steering Group would be responsible for supplying the main bulk of this data, however little information was forthcoming (primarily for the reasons given above). An external consultation exercise was, therefore, also undertaken.

The schemes from which costs were collated are summarised in Table 6.3.

Table 6.3 Summary of SUD scheme construction costs

SUD	ID	Region	Treatment Volume	£	£/m^3	Description
Wetland	1	SE England	2,022m^3	32,000	16	Residential site. A series of 3 reed beds. Submerged pipes and grass spillways connect the reed-beds. Price includes reeds and inlet and outlet structures.
	2	Midlands	3,487m^3	125,000	36	Mixed residential, industrial, commercial and highway. Total construction cost.
	3	SE England	1,680 m^3	45,000	27	Residential site. A series of 3 reed beds. Weir overflows connect the reed beds.
Retention Pond	1	SE England	5,625 m^3	96,567	17	Residential site. The site is served by a series of interconnected swales and ponds. This is the largest pond and maintained as formal landscape feature. There is a large concrete weir control structure on the outlet. The pond has amenity and attenuation functions.
	2	SE England	3,000 m^3	24,719	8	Residential site. The site is served by a series of interconnected swales and 8 natural ponds. The ponds' main function is attenuation but they also have emergent wetland vegetation.
	3	SE England	5,362 m^3	67,979	13	
	4	SE England	393 m^3	7,209	18	
	5	SE England	1,162 m^3	19,157	16	
	6	SE England	1,320 m^3	36,255	27	
	7	SE England	1,725 m^3	15,820	9	
	8	SE England	925 m^3	6,633	7	
	9	SE England	2,595 m^3	14,406	6	
	10	NW England	4,531 m^3	256,331	57	Public site. There is a reed bed and stream as well as an open pond. The pond has formal landscape features including a fountain and timber edging. The pond has attenuation, amenity and water quality functions.
	11	SE England	13,000 m^3	71,000	6	Residential site. The storm water is pre-treated by a series of reed-beds. The main function of the pond is attenuation.

Table 6.3 Summary of SUD scheme construction costs (continued)

SUD	ID	Region	Size	£	£/unit	Description
Infiltration Basin	1	SE England	40,540 m^3	578,387	14	Residential site: The storm water is conveyed through a series of filter drains, a petrol interceptor and a hydro-brake before discharging to the basin. The basin is drained by infiltration with imported gravels to improve soil permeability.
Permeable Pavement	1	SW England	1,500 m^2	52,215	35	Retail carpark. The ground works mentioned in the costing would only cover the installation of the Sub-base material including rolling but it does not cover the cost of excavation and preparation.
	2	Midlands	5,188 m^2	75,890	15	Public site. The price includes excavation and installation. The system is in a Park and Ride car park and is just compacted gravel, not permeable blocks. The system is drained by infiltration.
	3	Midlands	6,572 m^2	233,700	36	Retail carpark. The roads are asphalt, and drain the permeable carpark spaces. The system is lined and discharges to a river by a 225mm pipe. The cost includes the total carpark costs.
	4	SW England	20,495 m^2	718,036	35	Retail carpark. Some areas are asphalt, and drain via a bypass interceptor to the permeable areas. The system is lined and discharges to a river by a 110mm pipe. The cost includes all the drainage costs.
Infiltration Trench	1	Midlands	115 m^3	6700	58	Public carpark. A council park and ride served by soakaways, infiltration trenches and a permeable carpark.
	2	Midlands	216 m^3	12,594	58	
	3	Midlands	60 m^3	3412	58	
Soakaways	1	Midlands	5.9 m^3	544	92	
	2	Midlands	1.15 m^3	144	125	
Filter Drain	1	Midlands	170 m^3	14,895	88	Residential site: The storm water is conveyed through a series of filter drains, a petrol interceptor and a hydro-brake before discharging to an infiltration basin.
	2	Midlands	33 m^3	3,840	116	
	3	Midlands	55 m^3	8,685	158	

Table 6.3 Summary of SUD scheme construction costs (continued)

SUD	ID	Region	Surface Area	£	£/m²	Description
Swale	1	SE England	1,120 m^2	13,440	12	Residential site: The site is served by a series of interconnected swales and ponds. The swales are not typical. They are relatively deep and wide with a constant base flow. The main function is attenuation and conveyance. The channels are filled with emergent wetland vegetation.
	2	SE England	975 m^2	11,700	12	
	3	SE England	1,020 m^2	12,240	12	

6.5 Comparison of UK scheme costs with costs extracted from literature review

The UK scheme costs collated in the previous section are presented, together with the relationships extracted from literature, in the following figures. Brief commentary is also given.

6.5.1 Wetlands

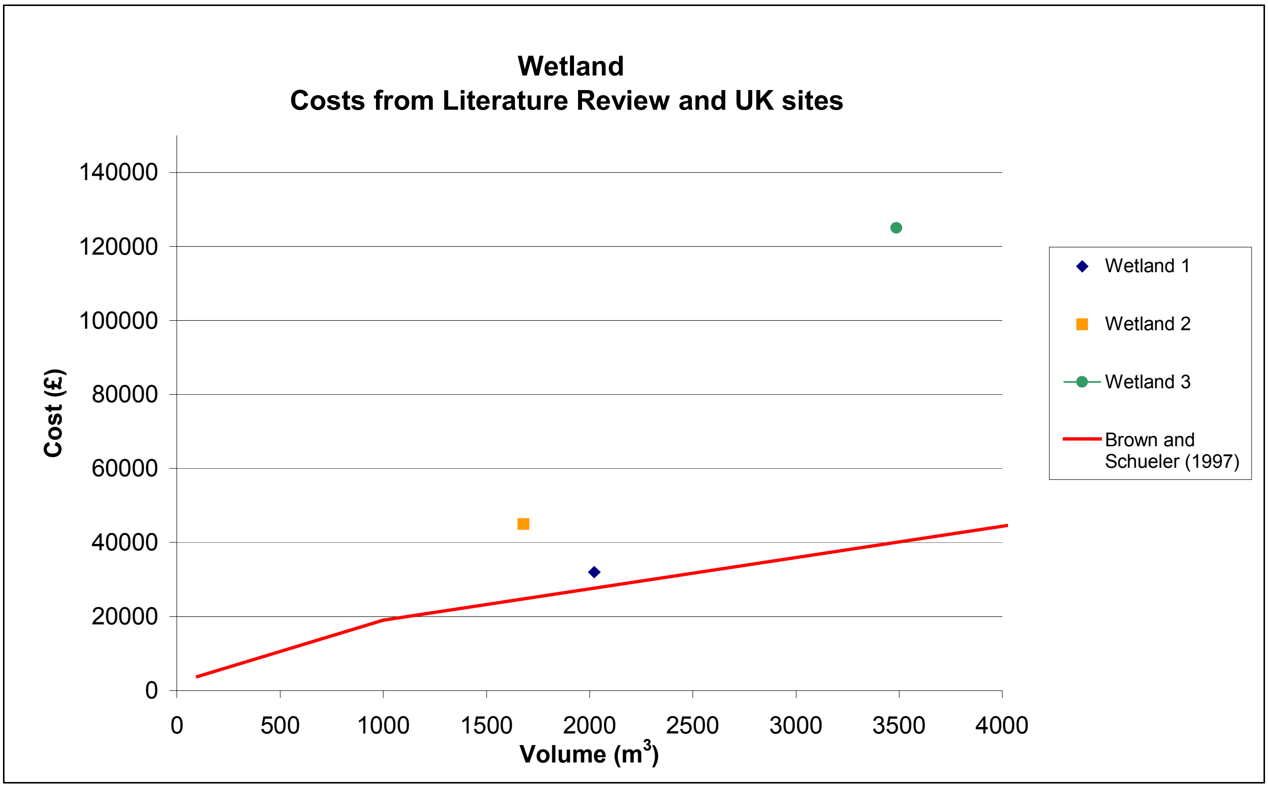

Figure 6.2 Wetland costs from literature and UK schemes

Notes:

1. 'Volume' represents the water quality treatment volume
2. Few data points
3. Costs can be highly dependent on:
    - Level of amenity function provided by the wetland

- Inlet and outlet infrastructure (also conveyance infrastructure between reed beds)
- Density and diversity of planting

4. The general distribution of capital costs between design, materials and construction for stormwater wetland systems can be estimated as shown in the following table (Ellis *et al*, 2003).

Table 6.4 Distribution of wetland capital costs

Item	Proportion of Wetland Cost (%)
Geotechnical testing, excavation, compaction etc	16 – 20
Substrates, gravel	3 – 5
Geotextile liner	20 – 25
Plants	10 –12
Control structures	10 – 15
Formwork, pipework etc	10 – 12
Design and Landscaping	8 – 12
Others (incl. Contingencies)	6 - 10

5. Suitable stocks of nursery plants for wetland planting can cost around £3-£5 / m^2.
6. From the limited data available to this study, wetlands may cost in the region of £25 - £30 / m^3 of treatment volume provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.5.2 Retention ponds

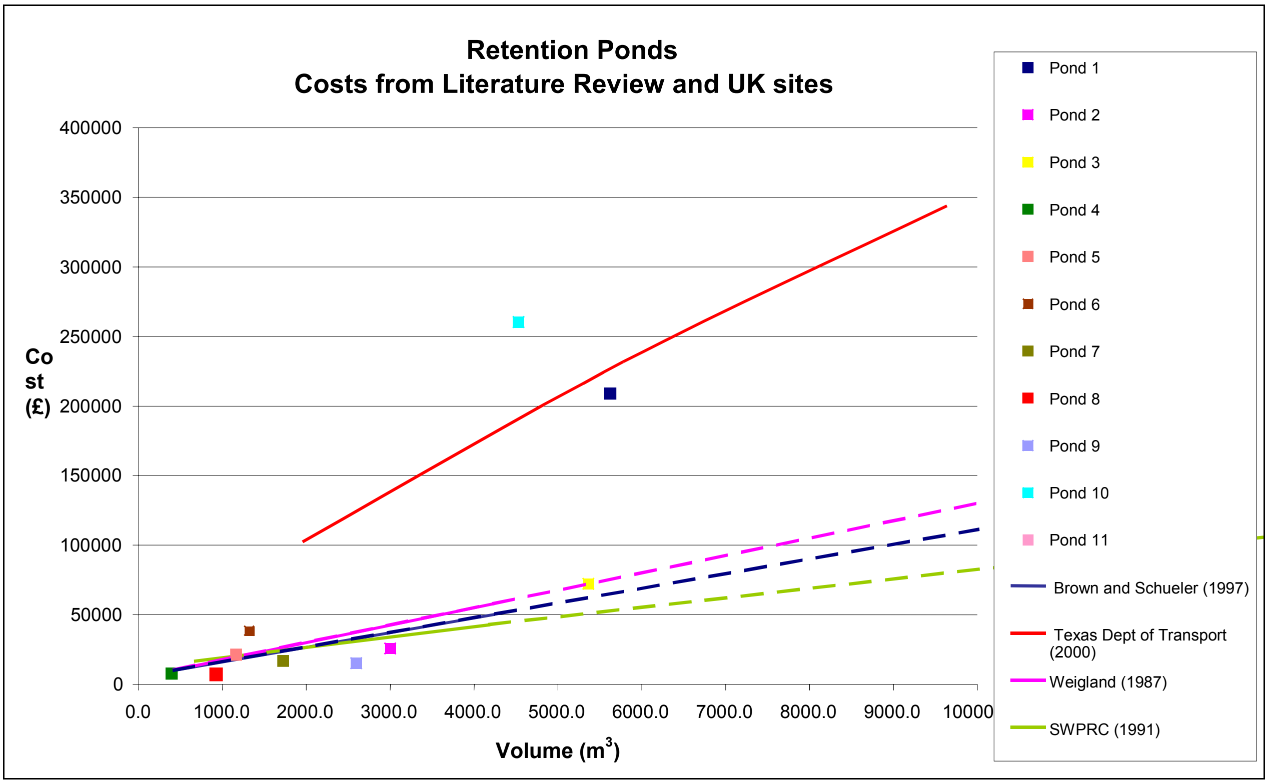

Figure 6.3 Retention pond costs from literature and UK schemes

Notes:

1. 'Volume' represents 'Water Quality Volume'.
2. Costs emanating from Texas Department of Transport (the highest line on the graph) are likely to be primarily associated with schemes directly adjacent to major highways. Traffic management costs, together with costs associated with working in difficult / hazardous locations may contribute to this line being high.
3. Ponds 1 and 10 are located in public areas, and have a high level of 'amenity' characteristics, being formal landscape features (e.g. fountains, timber edgings, substantial flow control structures etc). However, it is likely that larger ponds may fall into this category, and therefore costs / m^3 may rise accordingly.
4. From the limited data available to this study, retention ponds may cost in the region of £15 - £20 / m^3 of treatment volume provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances. Site-specific design criteria will influence attenuation volume and this will have a direct impact on cost.

6.5.3 Detention basins

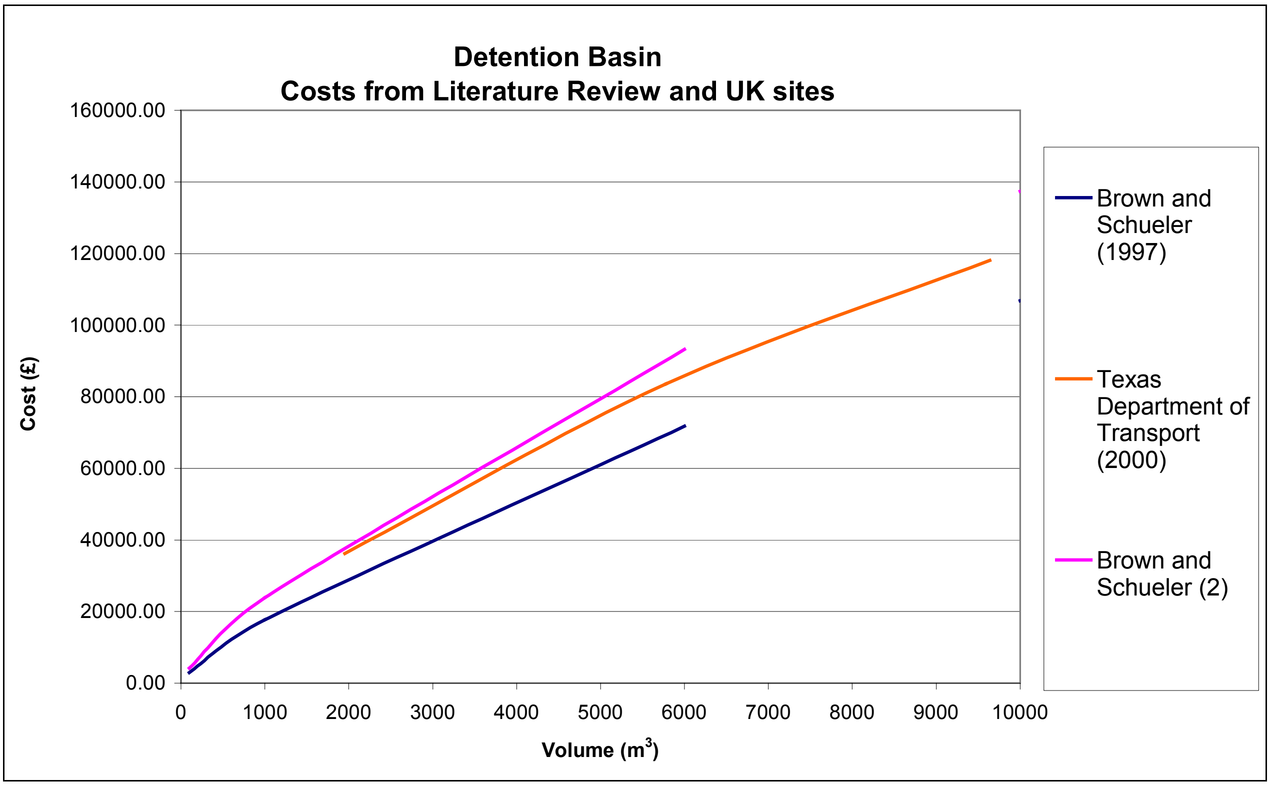

Figure 6.4 Detention basin costs from literature and UK schemes

Notes:

1. No UK costs available for comparison.
2. From the limited data available to this study, detention basins may cost in the region of £15 - £20 / m^3 of detention volume provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.5.4 Infiltration basins

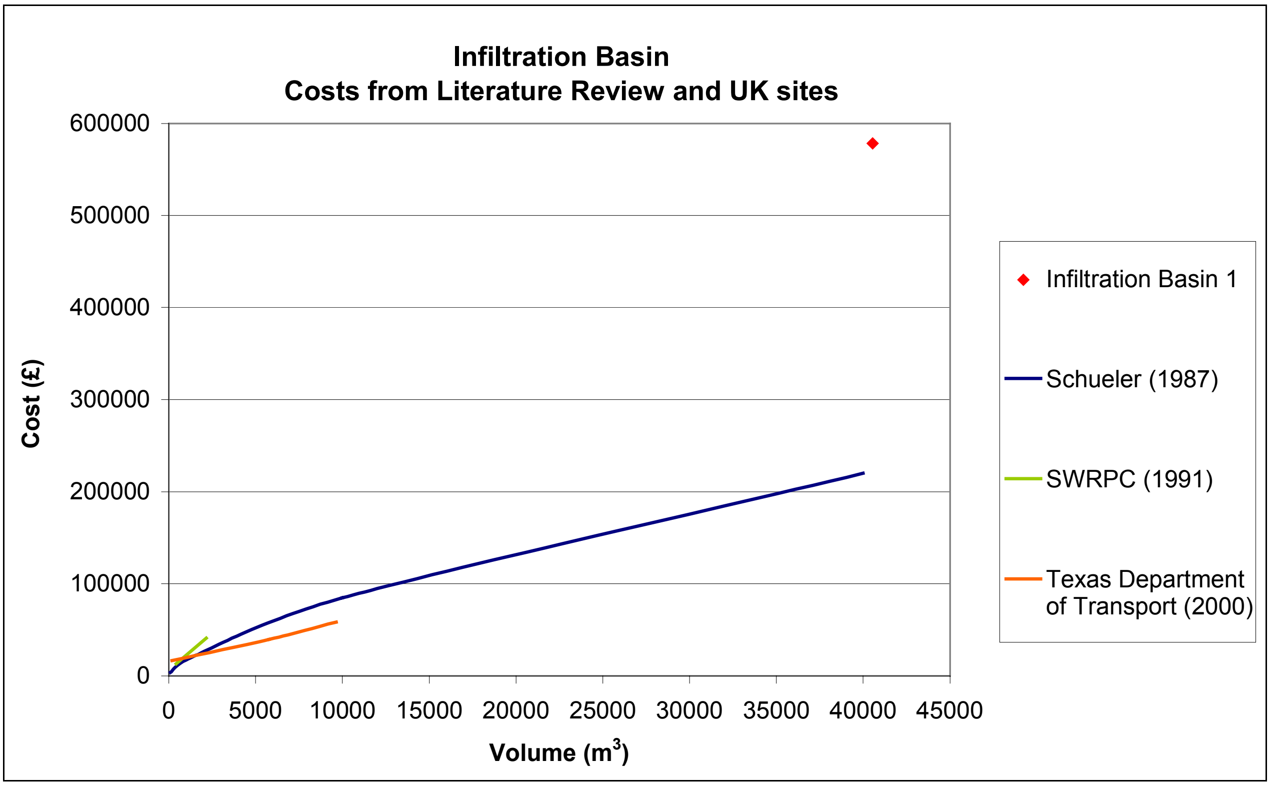

Figure 6.5 Infiltration basin costs from literature and UK schemes

Notes:

1. High UK scheme cost may be due to unusual site specific characteristics.
2. Only one UK scheme cost.
3. From the limited data available to this study, detention basins may cost in the region of £10 - £15 / m^3 of detention volume provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.5.5 Permeable / porous pavements

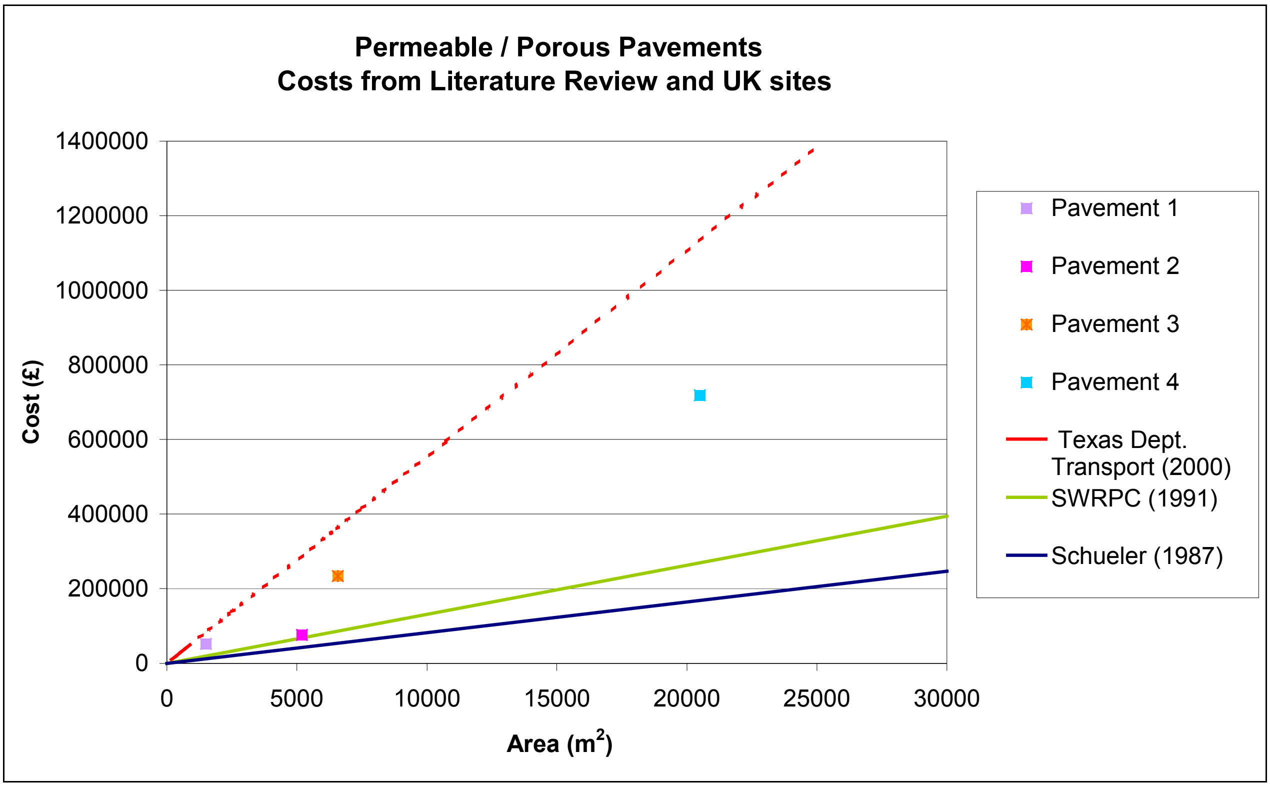

Figure 6.6 Permeable and porous pavement costs from literature and UK schemes

Notes:

1. Costs emanating from Texas Department of Transport (highest line) are likely to be primarily associated with schemes directly adjacent to major highways. Traffic management costs, together with costs associated with working in difficult / hazardous locations may contribute to this line being high.
2. SWRPC and Schueler cost curves derived for porous pavement, for which the costs are likely to be lower.
3. From the limited data available to this study, permeable pavements may cost in the region of £35 - £40 / m^2 of permeable surface provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.5.6 Soakaways

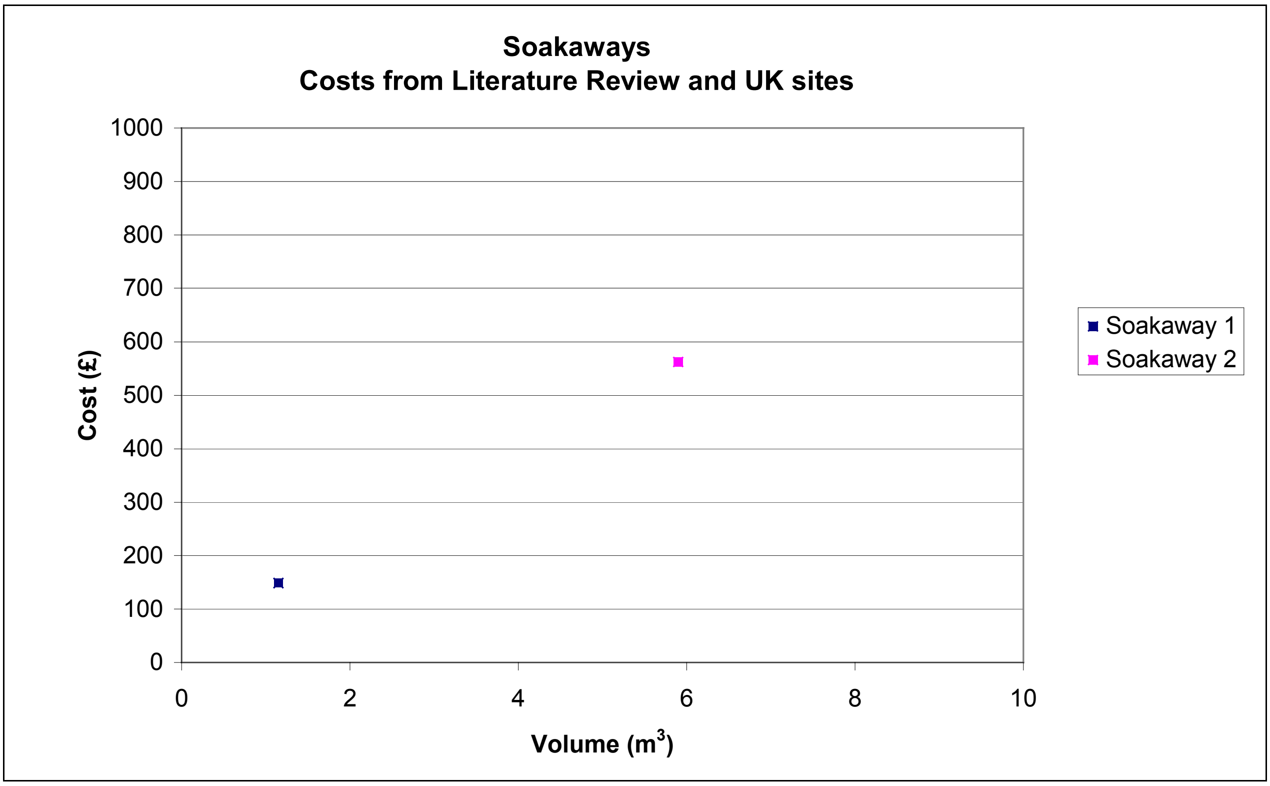

Figure 6.7 Soakaway costs from literature and UK schemes

Notes:

1. Only one UK data source.
2. From the limited data available to this study, soakaways may cost in excess of £100 / m^3 of stored volume provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.5.7 Infiltration trenches

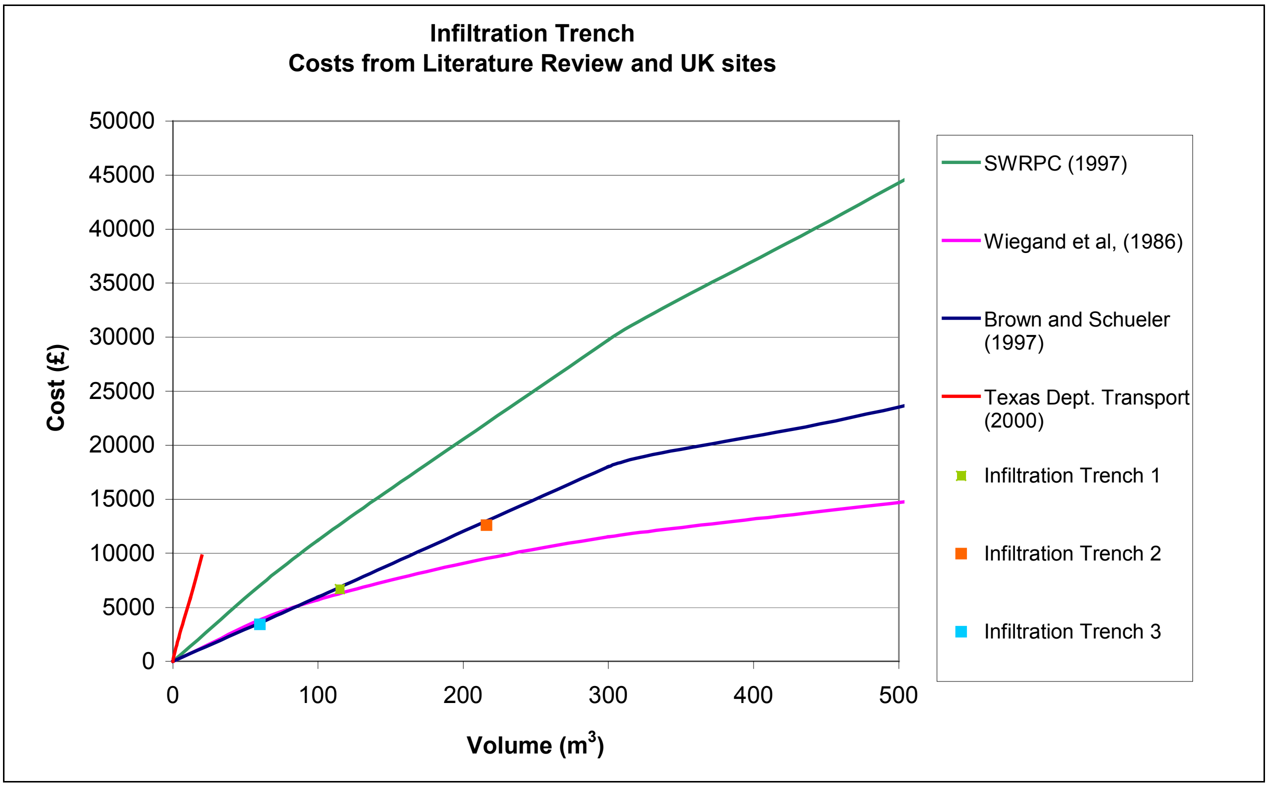

Figure 6.8 Infiltration trench costs from literature and UK schemes

Notes:

1. Only one UK data source.
2. From the limited data available to this study, infiltration trenches may cost in the region of £55 - £65 / m^3 of stored volume provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.5.8 Filter drains

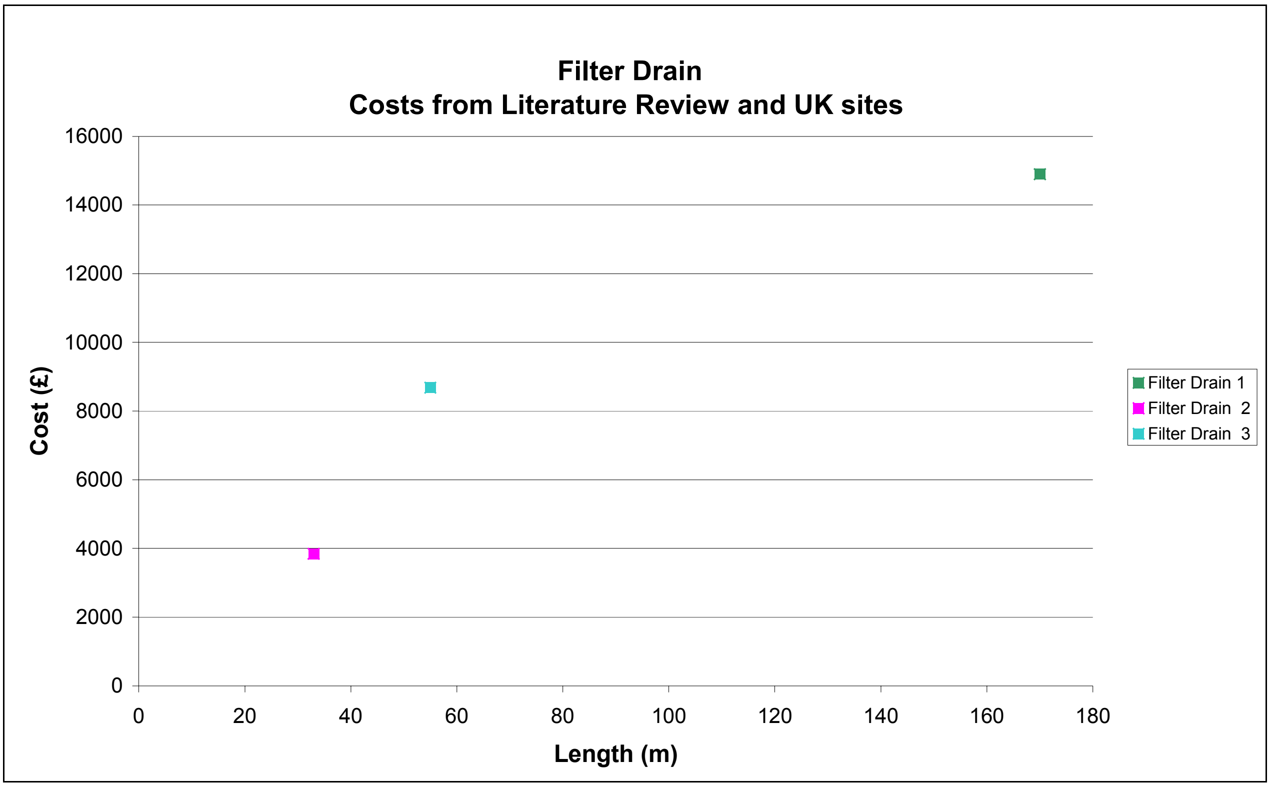

Figure 6.9 Filter drain costs from literature and UK schemes

Notes:

1. Only one UK data source.
2. From the limited data available to this study, filter drains may cost in the region of £100 - £140 / m^3 of stored volume provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.5.9 Filter strips

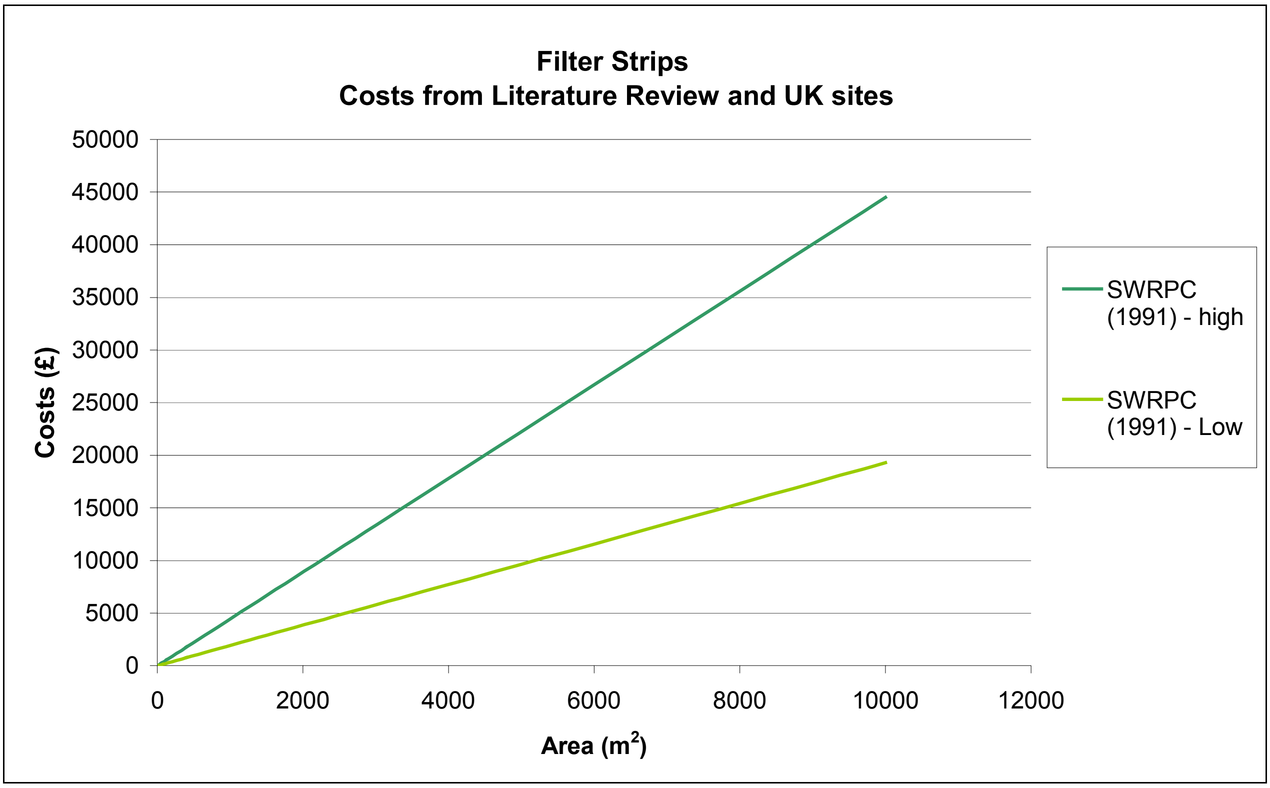

Figure 6.10 Filter strip costs from literature and UK schemes

Notes:

1. Wide ranges in the US dependent on type of turfing or planting utilised.
2. No UK data.
3. From the limited data available to this study, filter strips may cost in the region of £2 - £4 / m^2 of filter strip area provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.5.10 Swales

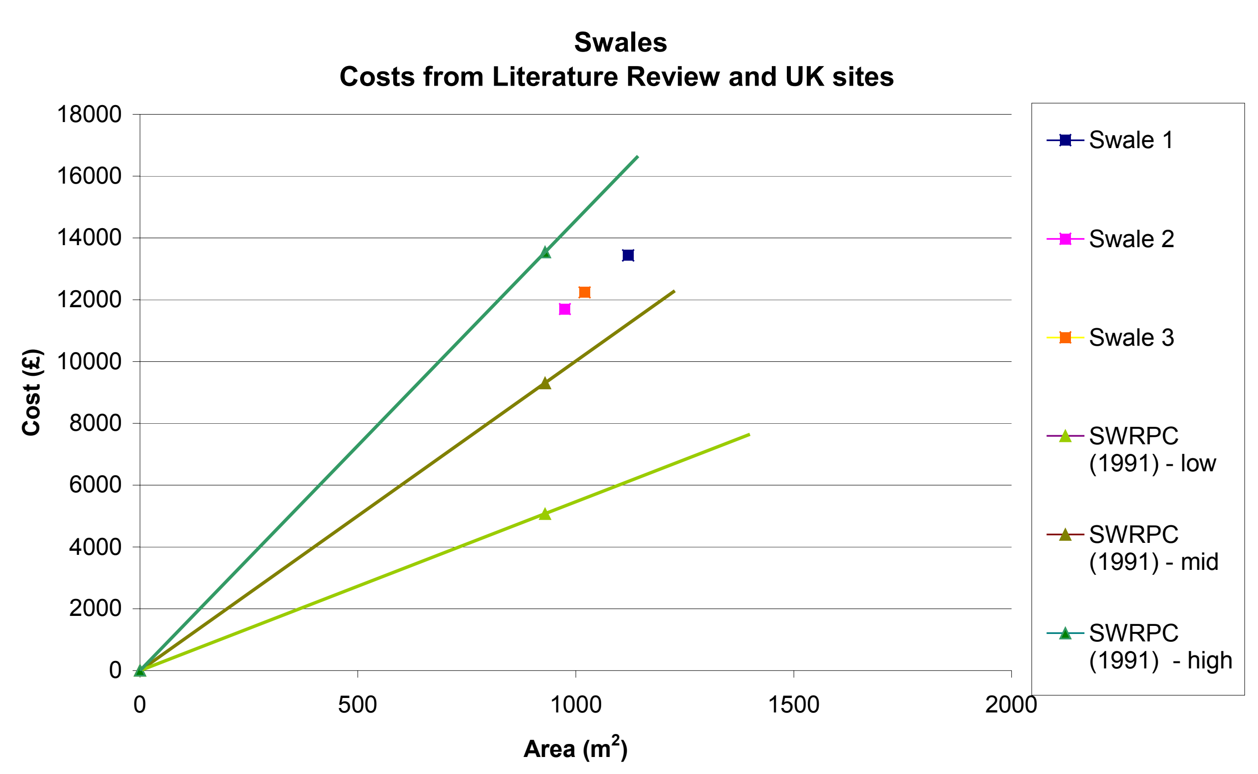

Figure 6.11 Swale costs from literature and UK schemes

Notes:

1. Wide ranges in the US dependent on type of turfing or planting utilised.
2. Only one UK data source.
3. From the limited data available to this study, filter strips may cost in the region of £10 - £15 / m^2 of swale area provided. However, costs can be influenced by many different factors, and site-specific cost appraisals should be undertaken in all circumstances.

6.6 Summary of SUDS components capital costs

Based on the limited cost information collected from UK schemes, together with cost relationships extracted from literature, the following capital cost summary is presented for SUDS components.

Table 6.5 Summary of SUDS components capital cost ranges

Component	Unit Cost		Relative Costs
Filter drain	£100 - £140	/ m^3 stored volume	High
Infiltration trench	£55 - £65	/ m^3 stored volume	Moderate to High
Soakaway	> £100	/ m^3 stored volume	High
Permeable pavement	£35 - £40	/ m^2 permeable surface	Moderate
Infiltration basin	£10 - £15	/ m^3 detention volume	Moderate
Detention basin	£15 - £20	/ m^3 detention volume	Moderate
Wetland	£25 - £30	/ m^3 treatment volume	Moderate
Retention pond	£15 - £20	/ m^3 treatment volume	Moderate
Swale	£10 - £15	/ m^2 swale area	Low to Moderate
Filter strip	£2 - £4	/ m^2 filter strip area	Low

6.7 Capital cost influences

The cost of constructing any SUD is inherently variable and will depend to a large extent on local conditions, and size of the development. Design criteria, together with topographic constraints, will determine flow rates and the volume of detention storage that is required. It should be remembered that design and performance criteria for SUDS should provide for health and safety, amenity and ecological benefits, in addition to hydraulic control and water quality treatment, and an economic appraisal of whole life costs will include environmental costs and benefits.

Influences on capital cost include:

(a) Hydraulic design criteria

There is a move towards national criteria, but at present these may vary regionally, and will determine throttle rates and therefore volumes of attenuation storage required.

(b) Water quality design criteria

This will determine the volume of permanent storage required for water quality treatment.

(c) Region

Region may influence the design rainfall and rainfall runoff characteristics of a site, but will also impact directly on unit costs. Comparable unit costs vary between –40 % (Northern Ireland) and + 25 % (Channel Islands) from costs observed in outer London areas (SPON’S, 2003). Land costs may vary more widely (see below).

(d) Land costs

Land may be allocated for the SUD scheme alone, or may include amenity area, areas dedicated to extracted sediment dewatering, vegetation harvesting, access for maintenance purposes etc.

The cost of land is extremely variable, both regionally and depending on surrounding land use. Through careful design, the Government’s guidance (PPG 3) on open space allocations within the developed site (DETR, 2000a), may mean that the effective cost of land allocated to SUDS can be reduced to zero. On the other hand, for some SUDS components in very dense urban settings, the cost of land may far outweigh construction and design costs. For this reason, some underground SUD systems that are relatively more expensive to construct, may be attractive in such situations (providing sub-surface conditions are appropriate). Land costs may include both purchase and legal costs.

(e) Soil type / groundwater vulnerability

These will dictate whether infiltration methods can be used to dispose of excess runoff volumes on site, or whether additional storage and attenuation in tanked / lined systems will be required.

Soil type will also dictate the level of erosion protection / grass reinforcement required, and may influence planting opportunities. The catchment sediment yield will influence the scale of the sediment management infrastructure required.

(f) Materials availability

Many SUDS components require granular fill as the attenuation and filtering media, and costs will vary depending on distance of the site from a potential source. Topsoil costs will also depend on source locations.

(g) Planting

The level of planting planned for a particular SUDS component will have a significant influence on costs, as both shrubs and aquatic plants are high value components. Low levels of planting can reduce the amenity benefit provided by a scheme (see Figure 6.12), and may reduce the water quality treatment potential of a component. Aquatic and barrier planting provide ecological habitat and raise the biodiversity potential of a site (see Figure 6.13). Shallow benching in ponds will enable biological processes, improving water quality and habitat.

Figure 6.12 Storage area, Kirkby, Lancashire

Figure 6.13 Retention pond with high density vegetation, DEX site, Dunfermline

(h) Public education

Public awareness and education strategies for SUDS (e.g. sign boarding, information leaflets, public awareness meetings) will require investment prior to the development of any new scheme, or during and post the sale of new properties. Such strategies are vital if the scheme is to be accepted within a residential community.

(i) Amenity / recreational facilities

If the systems is to be used as a high value public resource, then investment will be required in ensuring high public safety (e.g. sign boarding, barrier planting, raising awareness) and in recreational infrastructure (e.g. walkways, seating).

(j) Inlet / outlet infrastructure

The cost of inlet / outlet infrastructure can vary depending on the level of control required, the design of the retention system (e.g. above or below surrounding ground level), overflow units, aesthetic criteria, etc. Figures 6.14 and 6.15 demonstrate different scales of infrastructure.

Figure 6.14 Outfall infrastructure at Elvetham Heath, Hampshire

Figure 6.15 Outfall infrastructure, North Common, Bristol

(k) Construction programming

Effective construction programming requires investment, but will reap dividends when commissioning a system. Poor programming can lead to high volumes of construction silt being processed by the system causing reduced infiltration, reduced water quality (and attenuation) volumes, and reduction in conveyance capacity of pipes or swales. Blockage of pipes and through inlet / outlet infrastructure may also take place.

(l) Scale of development

Costs associated with a sustainable drainage system will depend, to a certain extent, on the size of the system being considered. There will inevitably be economies of scale as system size increases, due to the existence of certain fixed initial costs and reduction in unit rates with volume of work.

7. OPERATION, MAINTENANCE AND REHABILITATION COSTS

7.1 Introduction

In general, there are two methods for developing maintenance cost plans:

- The historic approach draws on past experience and uses historic data on the magnitude and frequency of costs of requirements of each element.
- The predictive approach asks the following questions for each component separately:
  1. What maintenance / replacement period is needed?
  2. When and how often?
  3. How much needs to be done?
  4. What is the unit cost of each task?

The latter method may present costs that are considerably more expensive than what has been undertaken historically. However, it is probable that historic maintenance of SUD systems has been negligible, or at least insufficient to ensure that performance risks are minimised.

Both approaches are followed in this report. HR Wallingford employed Robert Bray, of Robert Bray Associates (Landscape Architects and Sustainable Drainage Consultants) to undertake a review of sustainable drainage operation and maintenance requirements. A report has been produced that proposes appropriate maintenance schedules for each drainage component, based on current best practice and knowledge (HR Wallingford, 2004). Unit costs for activities, however, will vary widely depending on many factors, e.g. contractor experience, whether the SUD system management forms part of the management of a larger area, complexity of inlet / outlet structures, access arrangements, size of system etc. It is, therefore, considered inappropriate to suggest unit rates for this work.

A literature review and cost collation exercise identified published estimates of operation and maintenance expenditure, and costed maintenance schedules for some UK SUDS sites. The collated costs are generally representative of regular, annual maintenance activities. Remedial maintenance/rehabilitation requirements can often be managed out through good design. Where such activities are found to be necessary, this is likely to be due to site-specific characteristics, or unforeseen events, and as such their likely frequency of occurrence and cost cannot be predicted.

7.2 Literature review

The United States Environmental Protection Agency (EPA) 1999 report 'Preliminary Data Summary of Urban Stormwater Best Management Practices' summarises maintenance cost estimates from US literature. The costs are given as percentages of construction costs.

The US studies used slightly different estimation procedures. Livingston *et al*, (1997) reported maintenance costs from the maintenance budgets of several cities. For the other studies, percentages were derived from costs.

Table 7.1 summarises cost data found in the literature review (all from US sources):

Table 7.1 Maintenance costs from literature review

BMP	Annual Maintenance Cost (% of Construction Cost)	Sources
Retention Ponds	3%-6%	Wiegand *et al*, (1986) Schueler, (1987) SWRPC, (1991)
Constructed Wetlands	2% £600 / ha	Livingston *et al*, (1997) Brown and Schueler, (1997) US EPA National Stomwater BMP database (1999)
Detention Basins	<1%	Livingston *et al*, (1997) Brown and Schueler, (1997)
Infiltration Trench	5% - 20%	Schueler, (1987) SWRPC, (1991)
Infiltration Basin	1%-3%	Livingston *et al*, (1997) SWRPC, (1991
	5% - 10%	Wiegand *et al*, (1986) Schueler, (1987) SWRPC, (1991
Swales	5% - 7%	SWRPC, (1991)
Filter Strips	£0.079/m^2	SWRPC, 1991

Ellis *et al* (2003) suggest the following operation and maintenance costs for highway treatment systems:

Table 7.2 Capital and maintenance costs for highway treatment systems (Ellis *et al*, 2003)

Treatment device	Capital cost (£'000's)	Maintenance cost (£/per year)	Average O&M costs as perc. of average capital costs (%)	Comments
Conventional system	150 – 220	1000	0.5	Not including fin drainage
Grass swale	15-40	350	1.3	Requires replacement after 10-12 years
Oil interceptor (with grit chamber)	5 – 30	300 – 400	2	
Sedimentation tank	30 – 80	300 – 350	0.6	Without sediment disposal
Sedimentation lagoon/ basin	45- 100	500 – 2000	1.7	Without sediment disposal
Retention (balancing) basin	15 – 300	250 – 1000	0.5	With no vegetation or off-site dewatering and disposal of sludge and cuttings
Wetland basin	15 – 160	200 – 250	0.26	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	1.3	Assume grass swale, oil/grit interceptor, sediment forebay and wetland cells.

Additional material is provided in this reference on operation and maintenance costs for surface and sub-surface flow constructed wetlands.

Middlesex University (2003) quotes that the construction and O&M costs of various types of BMPs developed by CERTU (1999) and used by consulting firms and civil engineers in France are given in the following table.

Table 7.3 The cost of various BMPs (not including land cost) according to CERTU (1999)

Technique	Maintenance	Observation
Soakaway	0.15 Euro / m^2 (treated area)/ year	
Retention basin	0.15 to 0.45 Euro / m^3 / year	6 – 7 % of investment in civil engineering
Detention basin	0.3 to 1.52 Euro / m^3 / year	
Filter drain	0.3 to 0.45 Euro / m^2 / year	
Porous paving	0.3 to 1.52 Euro / m^3 / year	

The same reference also publishes material from another French study, Baptista *et al*, 2003.

Table 7.4 Economic indicators of stormwater drainage systems (Baptista *et al*, 2003)

Technique	Maintenance (Euro / m^3) in 1999
Underground storage tanks	361
Retention basin	3

It is unlikely that any of the costings given in US literature or for UK sites take any account of sediment or vegetation disposal costs. It is possible that dredged sediment (especially where the system inflow is particularly contaminated) may be classified as special waste due to high levels of oil and metals. Revitt and Ellis (2000) comment that wetland systems have low intrinsic operation and maintenance costs, but disposal of contaminated sediment as a hazardous waste, replanting, and macrophyte harvesting are identified as expensive and labour-intensive items, as shown in the following table:

Table 7.5 Costs of disposal of contaminated sediment and replanting (Revitt and Ellis, 2000)

Activity	Cost
1. Disposal of contaminated sediment 2. Replanting	£50 - £60 / m^3 £3-5 / m^2

Middlesex University (2003) describes various wetland sites where removal costs of large volumes of sediment (required to reinstate system performance) and subsequent disposal to landfill, were between £10,000 and £250,000. The wetlands were very large and had become totally swamped with sediment. Costs included fencing, lighting, lagooning, berming and other security considerations which were required as part of the on-site de-watering facility. Such costs are not standard, and with good design and appropriate, regular maintenance can be avoided.

7.3 UK SUD scheme operation and maintenance costs

Historically, in the UK, limited operation and maintenance of sustainable drainage schemes has been undertaken and, where it is ongoing, such activities tend to occur on an ad-hoc basis. This problem is now being addressed, with planned maintenance schedules being developed in advance of the drainage implementation.

An extensive consultation exercise was undertaken in an attempt to secure real operation and maintenance costs for sustainable drainage schemes across the UK. However, as with capital costs, gathering of operation and maintenance cost information was extremely difficult due to a number of issues:

1. There is no fixed body responsible for a large number of SUDS sites. Therefore there is no consistent way in which this information is currently being recorded or presented.

2. Many local authorities who are maintaining systems do not have the time or resources to collect (or extract) information of this nature.

3. SUDS often deliver multiple benefits e.g. they are likely to have both a drainage and a public amenity function. This means that the division of responsibility may not be clear and different maintenance activities may be being undertaken by different organisations or teams.

4. The SUD system may be being maintained on a reactive rather than proactive basis, and/or there may be no formal maintenance routines.

5. At many sites, routine maintenance was being undertaken at a reduced frequency to that specified in the design schedules.

It was also common to find that there was no information available on the design criteria or size of the SUDS, so some systems for which operation and maintenance costs were available, could not be adequately characterised to enable the information to be used.

The scheme operation and maintenance costs that were collated during the study are presented in Table 7.6.

Table 7.6 Operation and maintenance rates for UK schemes from literature review

SUD	Region	Surface area	£/per annum	% of capital cost	Description
Retention pond	SE England	$1500m^2$	£1500		
	Midlands		£4381		An average price for six large ponds. The price includes annual and occasional maintenance.
	SE England	$600m^2$	£960 £1248 £1280 £240 Average (£932)		Ornamental ponds, that require maintenance four times per year. The price is for three small ponds combined, The price does not include inlet and outlet inspection costs.
	SE England	$5000m^2$	£700 £1248 £1920 £675 Average (£1,136)		'Natural' ponds, that require maintenance two times per year. The price is for three small ponds combined. The price does not include inlet and outlet inspection costs.
	Midlands	$600m^2$	£280 £1100 £1400 Average (£927)		Ornamental ponds, that require maintenance four times per year. The price does not include inlet and outlet inspection costs.
	Midlands	$850m^2$	£80 £480 £750 Average (£437)		'Natural' ponds, that require maintenance two times per year. The price is for seven small ponds combined. The price does not include inlet and outlet inspection costs.
Detention basin	Northampton	$1,011\ m^2$	£11850 £24394 Average (£18122)		Contractor estimates
	Scotland	$3150m^2$	£400	4.5%	
	Scotland	$1425m^2$	£230	0.3%	
	Scotland	$2600\ m^2$	£540	1.4%	
	Scotland	$12000\ m^2$	£265	1.2%	
	Scotland	$676m^2$	£230	0.9%	
	Scotland	$2320m^2$	£145	0.4%	
Infiltration basin	SE England	$10400m^2$	£3470	0.4%	The maintenance includes occasional maintenance. The rate only includes maintenance of the engineering elements, and does not include mowing, litter-picking and inlet-outlet checks.
Filter drain	Midlands	$1.8m^2$	£80		Price does not include occasional rehabilitation.

Table 7.6 Operation and maintenance rates for UK schemes from literature review (continued)

SUD	Region	Surface area	£/per annum	% of capital cost	Description
Swale	SE England	21 000m^2	£255 £2080 Average (£1168)		The lowest price is from the experienced contractor. The swale stays wet and will on average only require three cuts per year.
	Midlands	400m^2	£200 £960 £280 Average (£720)		The lowest price is from the experienced contractor. There are two swales, these are mown much like the rest of the amenity grass at the site.

7.4 Comparison of UK scheme operation and maintenance costs with costs extracted from literature review

The UK scheme costs collated in the previous section are presented, together with the relationships extracted from literature, in the following figures. Brief commentary is also given.

7.4.1 Wetlands

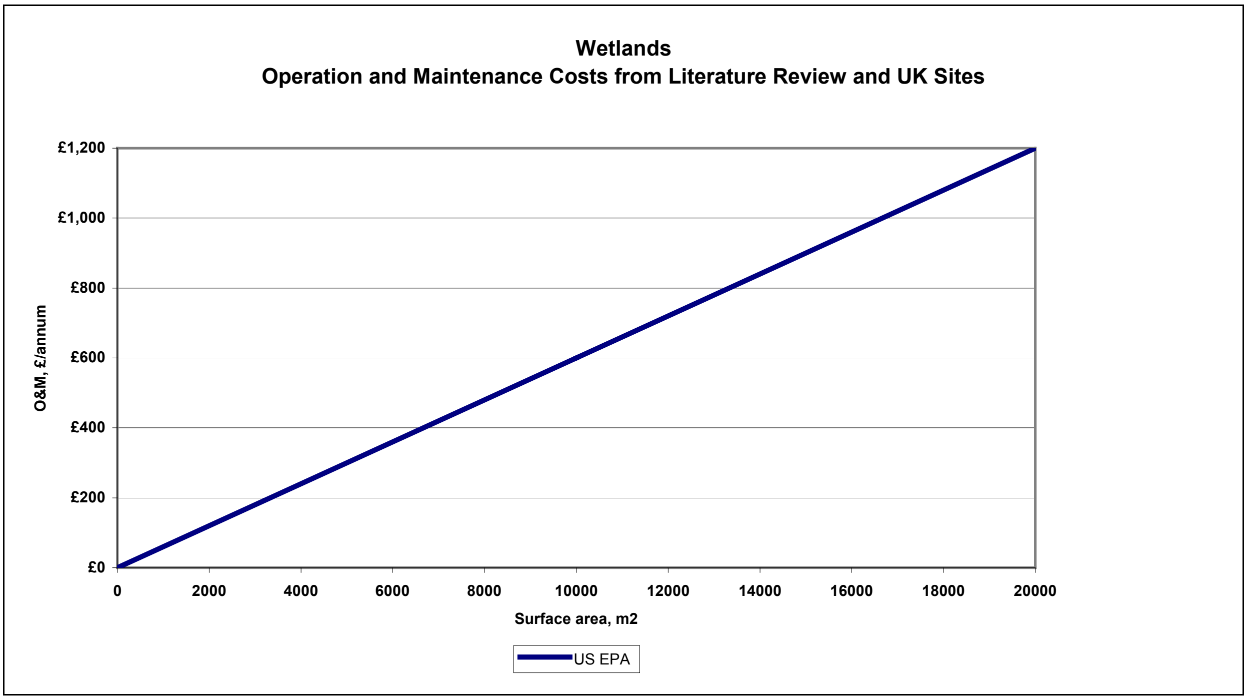

Figure 7.1 Wetland operation and maintenance costs from literature and UK schemes

Notes:

1. Only one cost relationship, from US source.
2. This relationship is likely to account for regular, annual maintenance costs only, such as:
    - Grass cutting
    - Litter removal

- Inlet / outlet cleaning
- Management of bank side vegetation and barrier planting
- Control of aquatic planting
- Management of organic silt
- Regular (and following large storms) inspection and monitoring for debris, erosion, and silt accumulation.

3. Irregular / rehabilitation activities may include (but not be limited to) the following:
    - Repair of erosion or other damage
    - Realignment of riprap or other erosion control
    - Repair / rehabilitation of inlet / outlet / overflows
    - Major silt removal (due to heavy silt loads or inappropriate silt management upstream)
    - Plant replacement following a severe pollution event.

4. From the limited data available to this study, annual wetland operation and maintenance may cost in the region of £0.1/ m^2 of wetland surface area. This cost does not include for any irregular maintenance or rehabilitation that may be required and may not be appropriate for small wetlands. Costs can be influenced by many different factors, and site-specific operation and maintenance cost estimates should be made in all circumstances.

7.4.2 Retention ponds

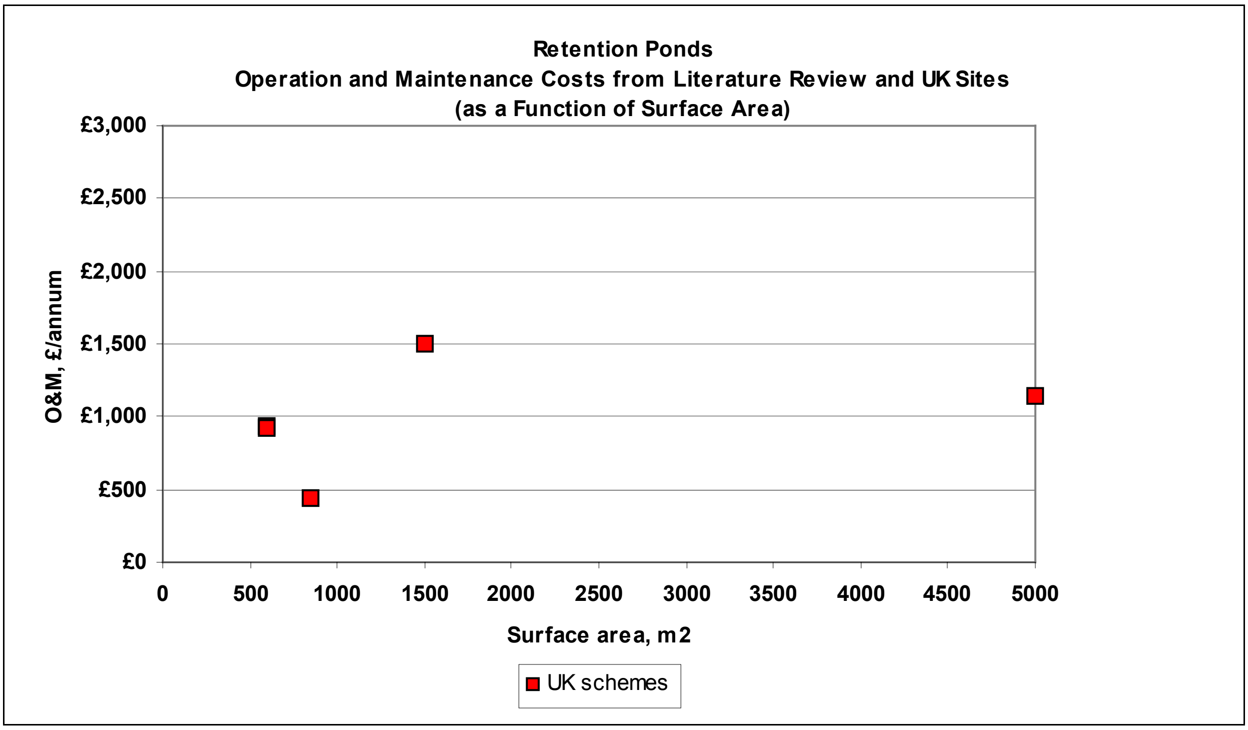

Figure 7.2 Retention pond operation and maintenance costs from literature and UK schemes (as a function of pond surface area)

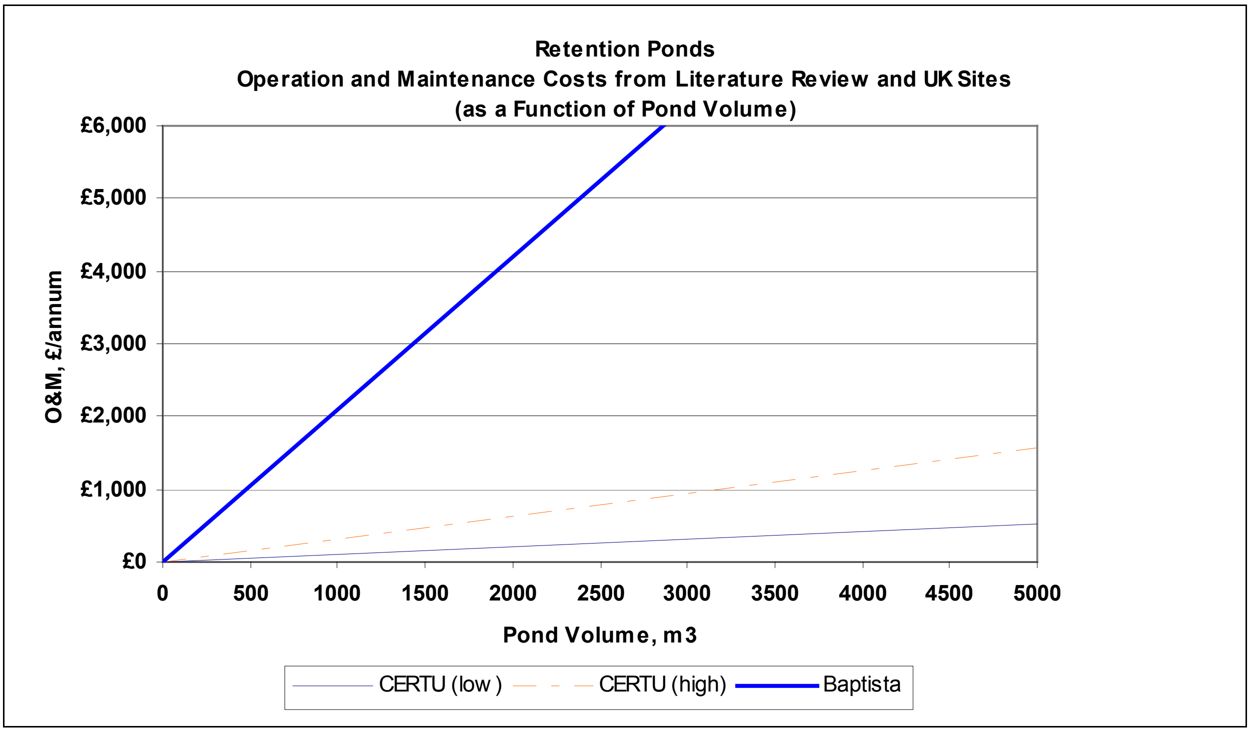

Figure 7.3 Retention pond operation and maintenance costs from literature and UK schemes (as a function of pond volume)

Notes:

1. The costs are likely to account for regular, annual maintenance costs only, such as:

    - Grass cutting
    - Litter removal
    - Inlet / outlet cleaning
    - Management of bank side vegetation and barrier planting
    - Control of aquatic planting
    - Management of organic silt
    - Regular (and following large storms) inspection and monitoring for debris, erosion, and silt accumulation.

2. Irregular / rehabilitation activities may include (but not be limited to) the following:

    - Repair of erosion or other damage
    - Realignment of riprap or other erosion control
    - Repair / rehabilitation of inlet / outlet / overflows
    - Major silt removal (due to heavy silt loads or inappropriate silt management upstream)
    - Plant replacement following a severe pollution event.

3. From the limited data available to this study, annual retention pond operation and maintenance may cost in the region of £0.1 - £2/ m^3 of retention pond volume or £0.5 - £1.5 / m^2 of pond surface area. This does not include for any irregular maintenance or rehabilitation that may be required, and may not be appropriate for small ponds. Costs can be influenced by many different factors, and site-specific operation and maintenance cost estimates should be made in all circumstances.

7.4.3 Detention / infiltration basins

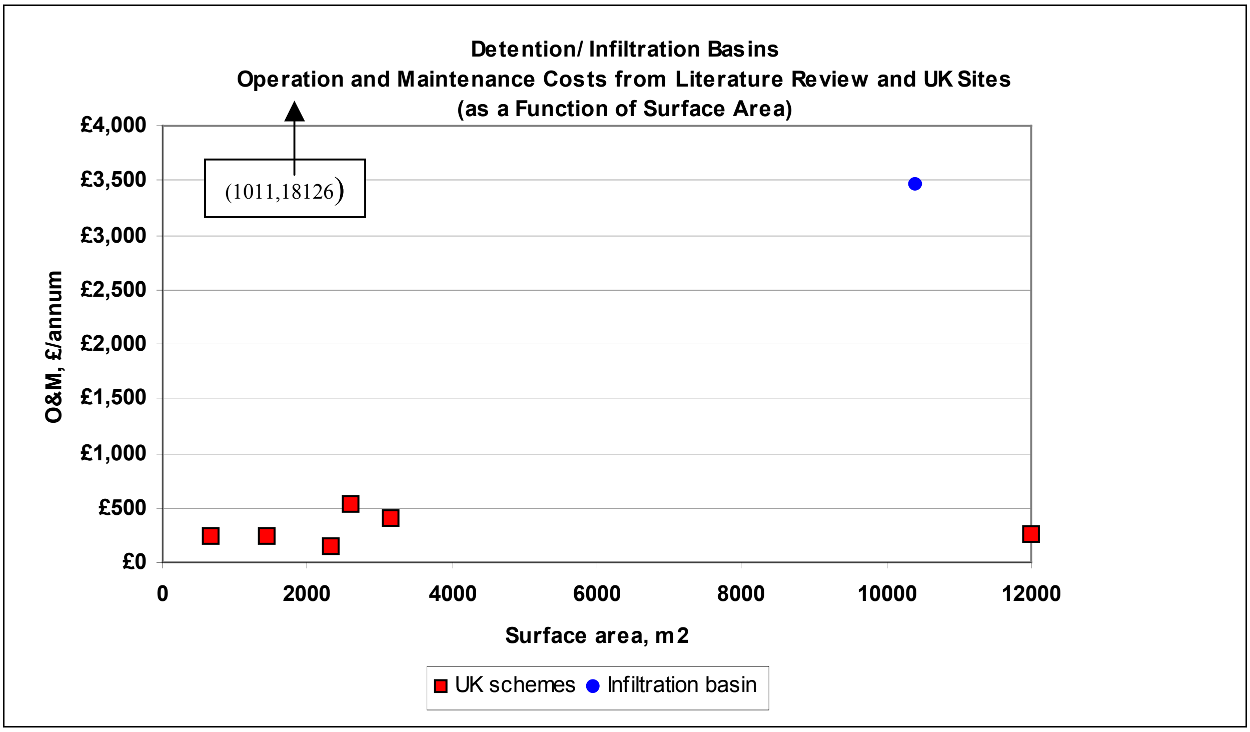

Figure 7.4 Detention and infiltration basins operation and maintenance costs from literature and UK schemes (as a function of surface area)

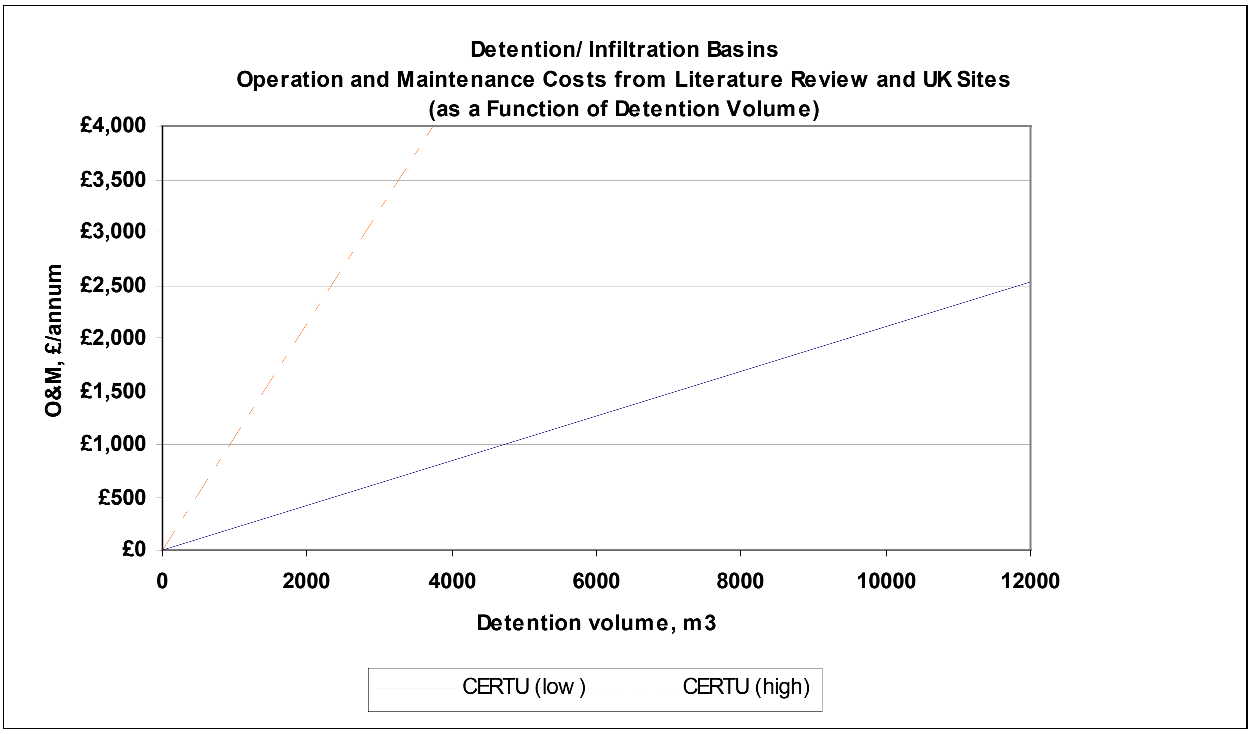

Figure 7.4 Detention and infiltration basins operation and maintenance costs from literature and UK schemes (as a function of detention volume)

Notes:

1. There is no supporting information on why the Northampton basin annual costs are estimated to be so high.
2. This relationship is likely to account for regular, annual maintenance costs only, such as:
    - Grass cutting
    - Litter removal
    - Inlet / outlet cleaning
    - Re-seeding and fertilisation of small areas
    - Regular inspection and monitoring (and following large storms) of the basin surface for debris, erosion, damage, and silt accumulation.
3. Irregular / rehabilitation activities may include (but not be limited to) the following:
    - Repair of erosion or other damage
    - Realignment of riprap or other erosion control
    - Repair / rehabilitation of inlet / outlet / overflows
    - Major silt removal (due to heavy silt loads or inappropriate silt management upstream)
    - Collection of leaves, silt and other debris from the grassed surface (infiltration basins only)
    - Scarifying and aerating the infiltration surface in the event of reduced permeability of the infiltration surface (infiltration basins only)

- Removal and replacement of the infiltration surface (grass and topsoil), where scarifying and aeration are not found to improve permeability sufficiently (infiltration basin only).

4. From the limited data available to this study, annual detention basin operation and maintenance may cost in the region of £0.1 - £0.3/ m^2 of detention basin area or £0.25 - £1/ m^3 of detention volume. Infiltration basin operation and maintenance is likely to be at the top of this range. This does not include for any irregular maintenance or rehabilitation that may be required, and may not be appropriate for small basins (i.e. < 500 m^2). Costs can be influenced by many different factors, and site-specific operation and maintenance cost estimates should be made in all circumstances.

7.4.4 Permeable/porous pavements

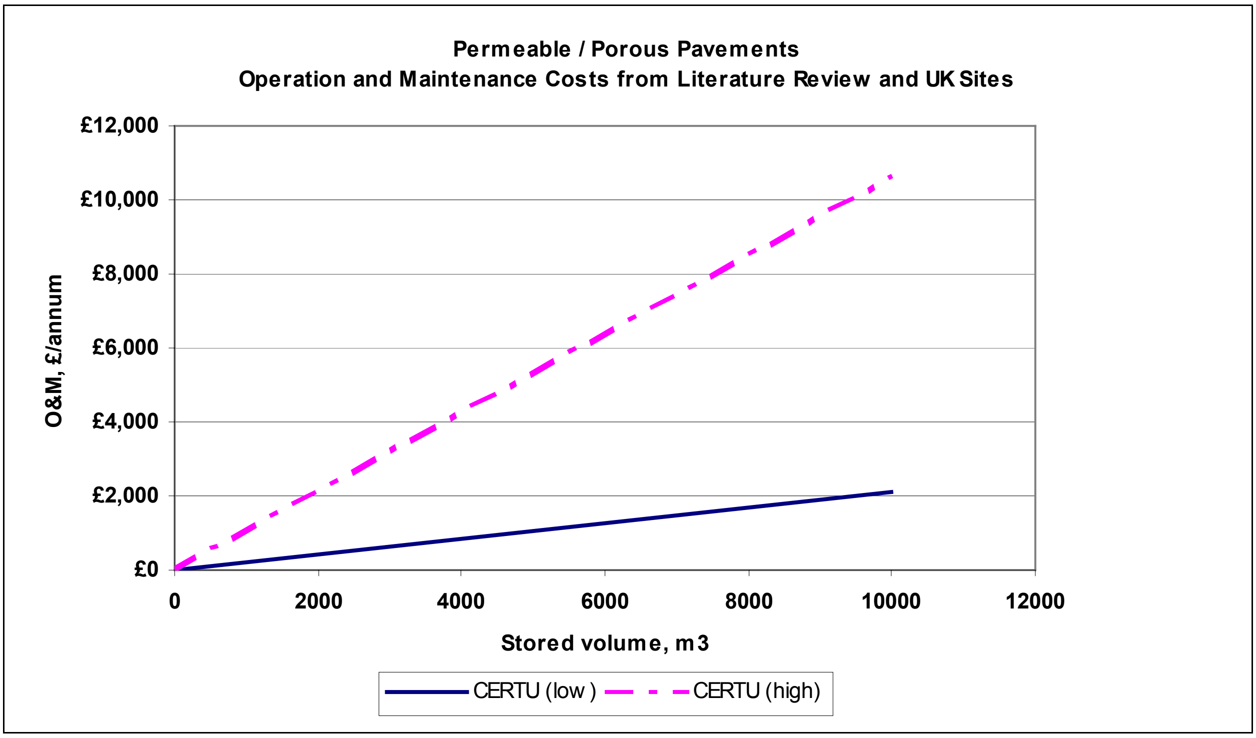

Figure 7.4 Permeable / porous pavements operation and maintenance costs from literature and UK schemes

Notes:

1. The only relationships are for France.
2. This relationship is likely to account for regular, annual maintenance costs only, such as:

    - Litter removal
    - Inlet / outlet cleaning
    - Limited weed control (if required)
    - Manual brushing
    - Vacuum suction cleaning
    - Regular inspection and monitoring (and following large storms) of the pavement surface for debris, damage, silt accumulation and reduced permeability.

3. Irregular / rehabilitation activities may include (but not be limited to) the following:

- Repair of erosion or other damage
- Surface rehabilitation, if the infiltration capacity of the surface appears to be decreasing to an unacceptable level. This is likely to include:
  - Removal of blocks and cleaning
  - Removal of bedding layer and geotextile and safe disposal
  - Replacement of geotextile, bedding layer, and blocks
  - Removal of accumulated silt from site and safe disposal (subject to toxicity test)
  - Where granular fill is found to be contaminated with silt, washing and replacement of the fill may be required.

4. From the limited data available to this study, porous pavement operation and maintenance may cost in the region of £0.5 - £1 / m^3 of storage volume. This does not include for any irregular maintenance or rehabilitation that may be required, and may not be appropriate for small pavements. Costs can be influenced by many different factors, and site-specific operation and maintenance cost estimates should be made in all circumstances.

6.4.6 Soakaways

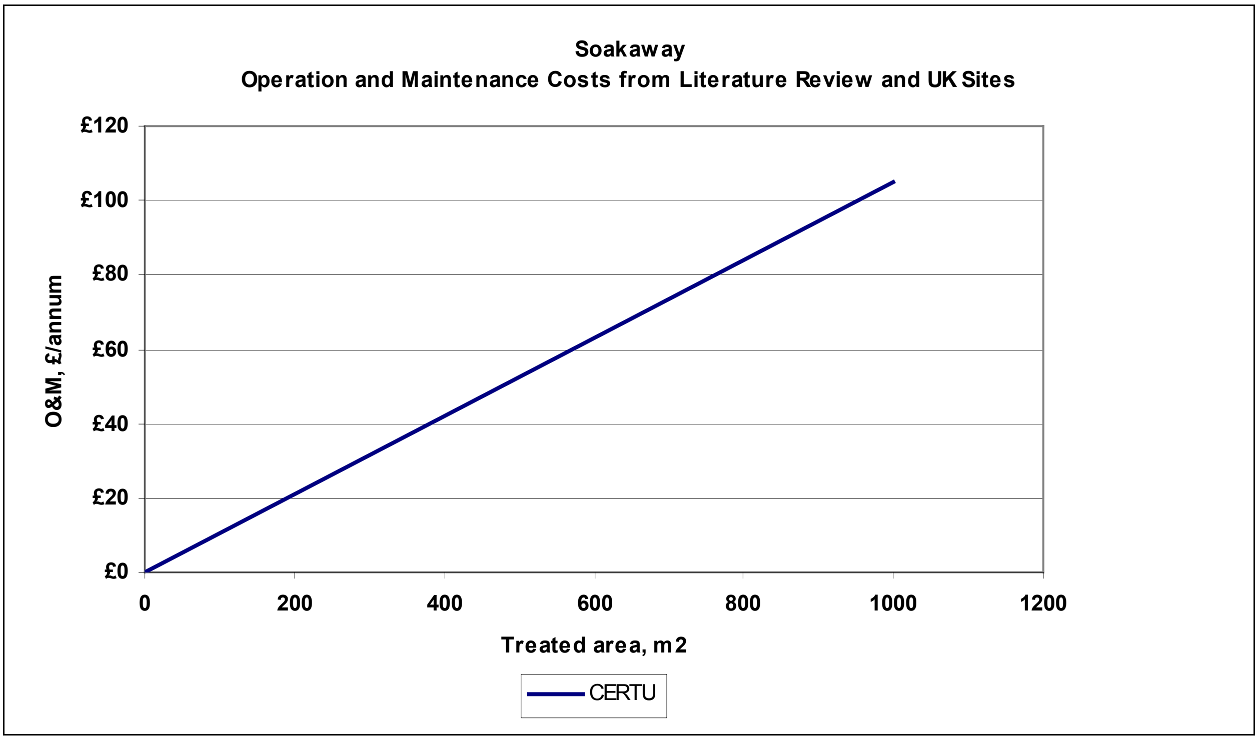

Figure 7.5 Soakaway operation and maintenance costs from literature and UK schemes

Notes:

1. The only relationship is for France.
2. This relationship is likely to account for regular, annual maintenance costs only, such as:
   - Litter removal
   - Inlet cleaning
   - Inspection and monitoring.

3. Irregular / rehabilitation activities may include (but not be limited to) the following:
    - Rehabilitation of infiltration surface due to reduced permeability.
4. From the limited data available to this study, soakaway operation and maintenance may cost in the region of £0.1 / m^2 of treated area per year. This does not include for any irregular maintenance or rehabilitation that may be required. Costs can be influenced by many different factors, and site-specific operation and maintenance cost estimates should be made in all circumstances.

6.4.7 Filter drains

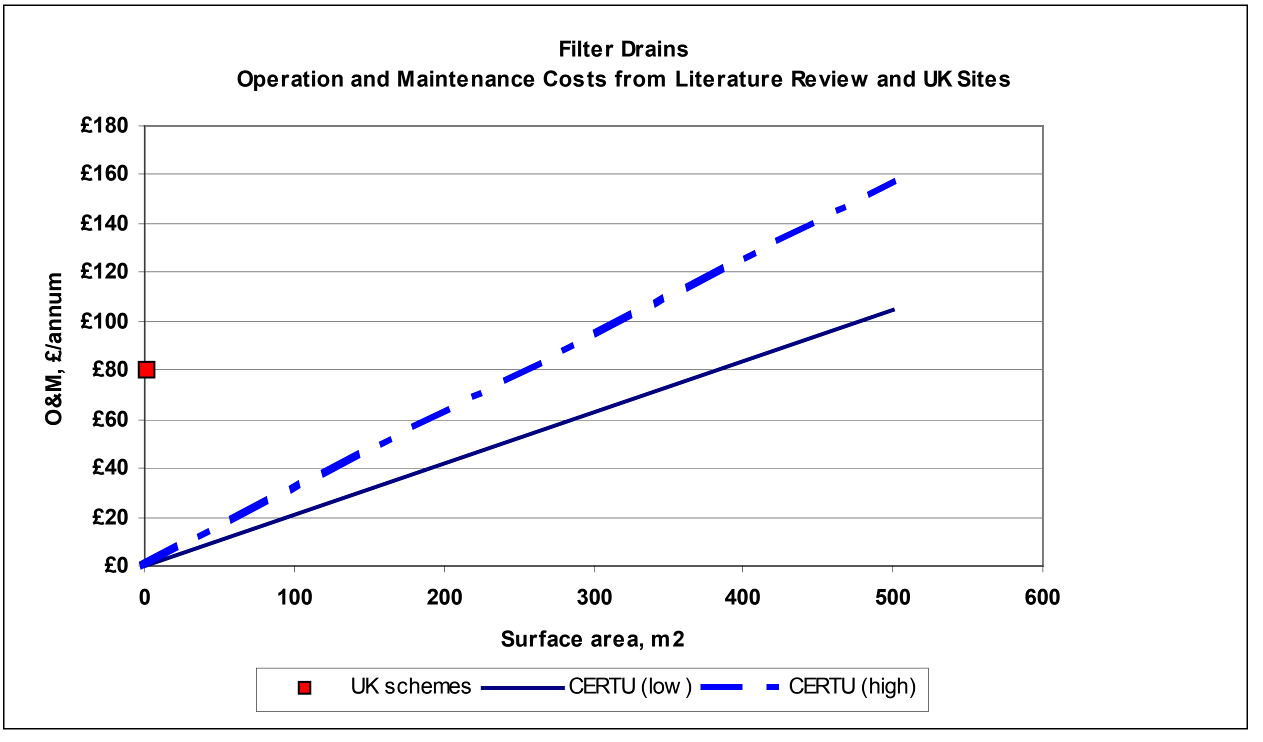

Figure 7.6 Filter drain operation and maintenance costs from literature and UK schemes

Notes:

1. The UK scheme and cost relationship for France show significant differences for small areas of filter drain surface.
2. This relationship is likely to account for regular, annual maintenance costs only, such as:
    - Litter removal
    - Weed control (if required)
    - Surface silt removal (due to slow accumulation)
    - Inspection and monitoring to check for erosion, silt / vegetation accumulation on filter drain surface, damage (from vehicles or vegetation growth).
3. Irregular / rehabilitation activities may include (but not be limited to) the following:
    - System rehabilitation resulting from reduced system permeability. This is likely to include:
        - Removal of stone above geotextile (if present)
        - Clean stone
        - Removal of geotextile and safe disposal (subject to toxicity test)

– Replacement of geotextile

– Replacement of clean stone.

4. From the limited data available to this study, filter drain operation and maintenance may cost in the region of £0.2 - £1 / m^2 of filter surface. This does not include for any irregular maintenance or rehabilitation that may be required. Costs can be influenced by many different factors, and site-specific operation and maintenance cost estimates should be made in all circumstances.

7.4.5 Filter strips

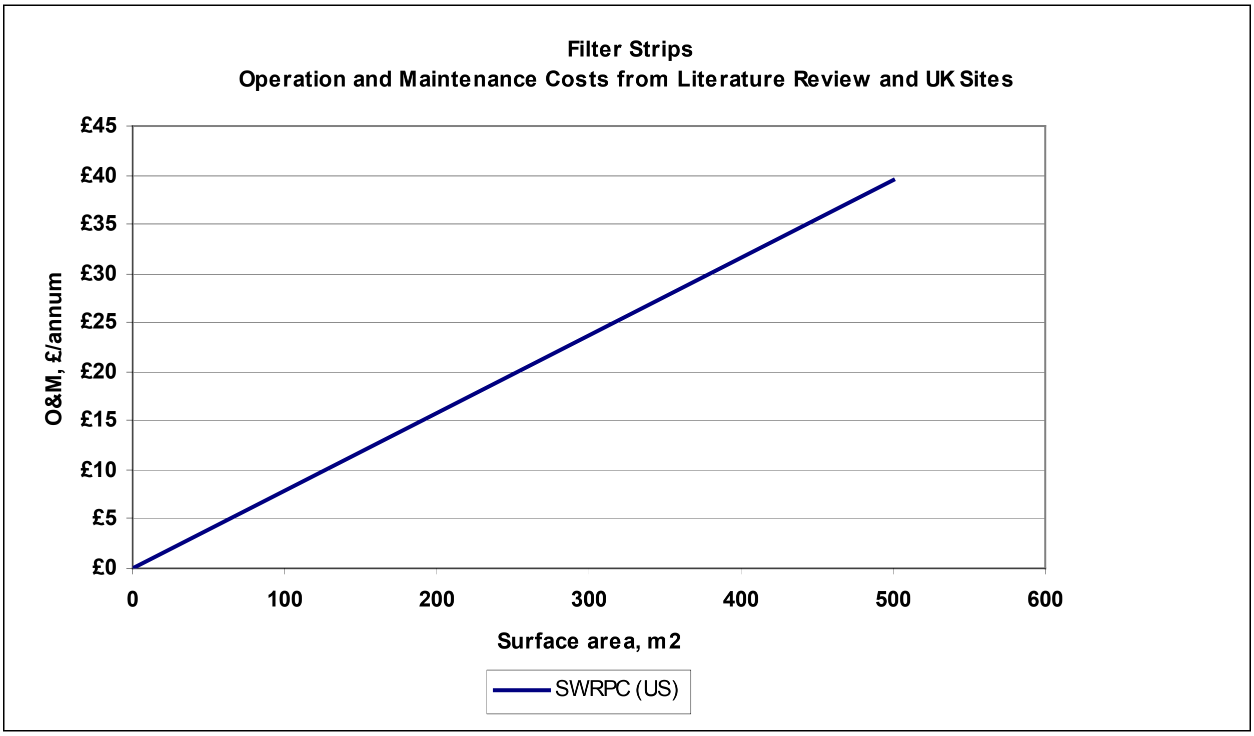

Figure 7.7 Filter strip operation and maintenance costs from literature and UK schemes

Notes:

1. The cost relationship is for the US.
2. This relationship is likely to account for regular, annual maintenance costs only, such as:
   - Regular grass cutting
   - Litter removal
   - Surface silt removal (due to slow accumulation)
   - Re-seeding and fertilisation of small areas
   - Inspection and monitoring to check for erosion, silt accumulation, damage, vegetation health, areas of waterlogging.

3. Irregular / rehabilitation activities may include (but not be limited to) the following:
   - Reinstatement of edgings to hard surfaces
   - Repair or relocation of damaged barriers
   - Reinstatement of levels and turf due to erosion by rills or gullies
   - Realignment of riprap or other erosion controls

- Repair/rehabilitation of inlets, outlets and overflows
- System rehabilitation resulting from high silt loads. This is likely to include:
  – Remove (re-use or compost) turf
  – Remove and dispose of accumulated silt (subject to toxicity test)
  – Cultivate remaining topsoil to levels
  – Re-use or re-turf area to agreed levels.

4. From the limited data available to this study, filter strip operation and maintenance may cost in the region of £0.1 / m^2 of filter strip surface. This does not include for any irregular maintenance or rehabilitation that may be required. Costs can be influenced by many different factors, and site-specific operation and maintenance cost estimates should be made in all circumstances.

7.4.6 Swales

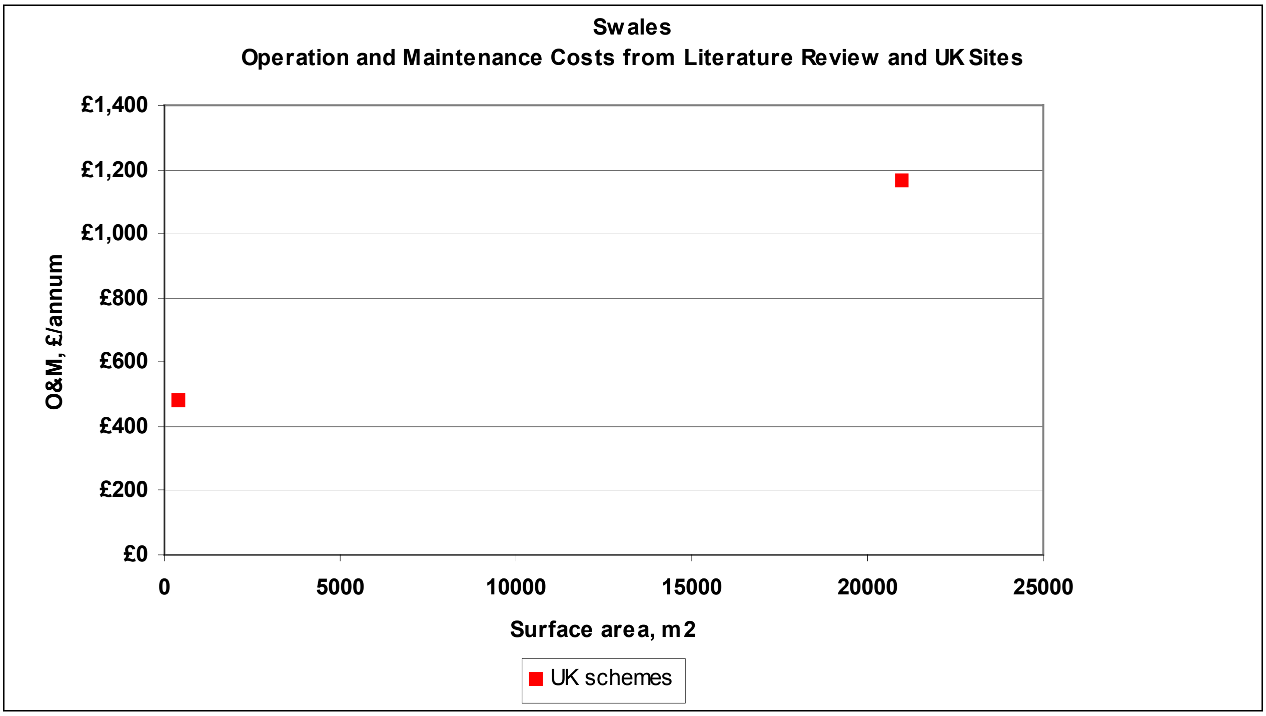

Figure 7.8 Swale operation and maintenance costs from literature and UK schemes

Notes:

1. There are only costs for two schemes available.
2. This relationship is likely to account for regular, annual maintenance costs only, such as:
   - Regular grass cutting
   - Litter removal
   - Surface silt removal (due to slow accumulation)
   - Re-seeding and fertilisation of small areas
   - Inspection and monitoring to check for erosion, silt accumulation, damage, vegetation health, areas of waterlogging.
3. Irregular / rehabilitation activities may include (but not be limited to) the following:

- Reinstatement of edgings to hard surfaces
- Repair or relocation of damaged barriers
- Reinstatement of levels and turf due to erosion by rills or gullies
- Realignment of riprap or other erosion controls
- Repair/rehabilitation of inlets, outlets, check dams and overflows
- Collection of leaves, silt and other debris from the grassed
- Scarifying and aerating the infiltration surface in the event of reduced permeability of the infiltration surface (infiltration swales only)
- Removal and replacement of the infiltration surface (grass and topsoil), where scarifying and aeration are not found to improve permeability sufficiently (infiltration swales only)
- System rehabilitation resulting from high silt loads. This is likely to include:
  - Remove (re-use or compost) turf
  - Remove and dispose of accumulated silt (subject to toxicity test)
  - Cultivate remaining topsoil to levels
  - Re-use or re-turf area to agreed levels.

4. From the limited data available to this study, swale operation and maintenance may cost in the region of £0.1 / m^2 of swale surface. This does not include for any irregular maintenance or rehabilitation that may be required. Costs can be influenced by many different factors, and site-specific operation and maintenance cost estimates should be made in all circumstances.

7.5 Summary of SUDS components operation and maintenance unit costs

Based on the limited cost information collected from UK schemes, together with cost relationships extracted from literature, the following operation and maintenance cost summary is presented for SUDS components.

Table 7.7 Summary of SUDS components operation and maintenance cost ranges

Component	Unit cost	Relative costs
Filter drain / Infiltration trench	£0.2 - £1 / m^2 of filter surface area	Moderate
Swale	£0.1 / m^2 of swale surface area	Low
Filter strip	£0.1 / m^2 of filter surface area	Low
Soakaway	£0.1 / m^2 of treated area	Low
Permeable pavement	£0.5 - £1 / m^3 of storage volume	Moderate
Detention / Infiltration basin	£0.1 - £0.3 / m^2 of detention basin area £0.25 - £1 / m^3 of detention volume	Low
Wetland	£0.1 / m^2 of wetland surface area	Low
Retention pond	£0.5 - £1.5 / m^2 of retention pond surface area £0.1 - £2 / m^3 of pond volume	Moderate

7.6 Annual operation and maintenance costs as a % of construction cost

The following figure also presents data from the literature review, but gives operation and maintenance costs as a percentage of construction cost.

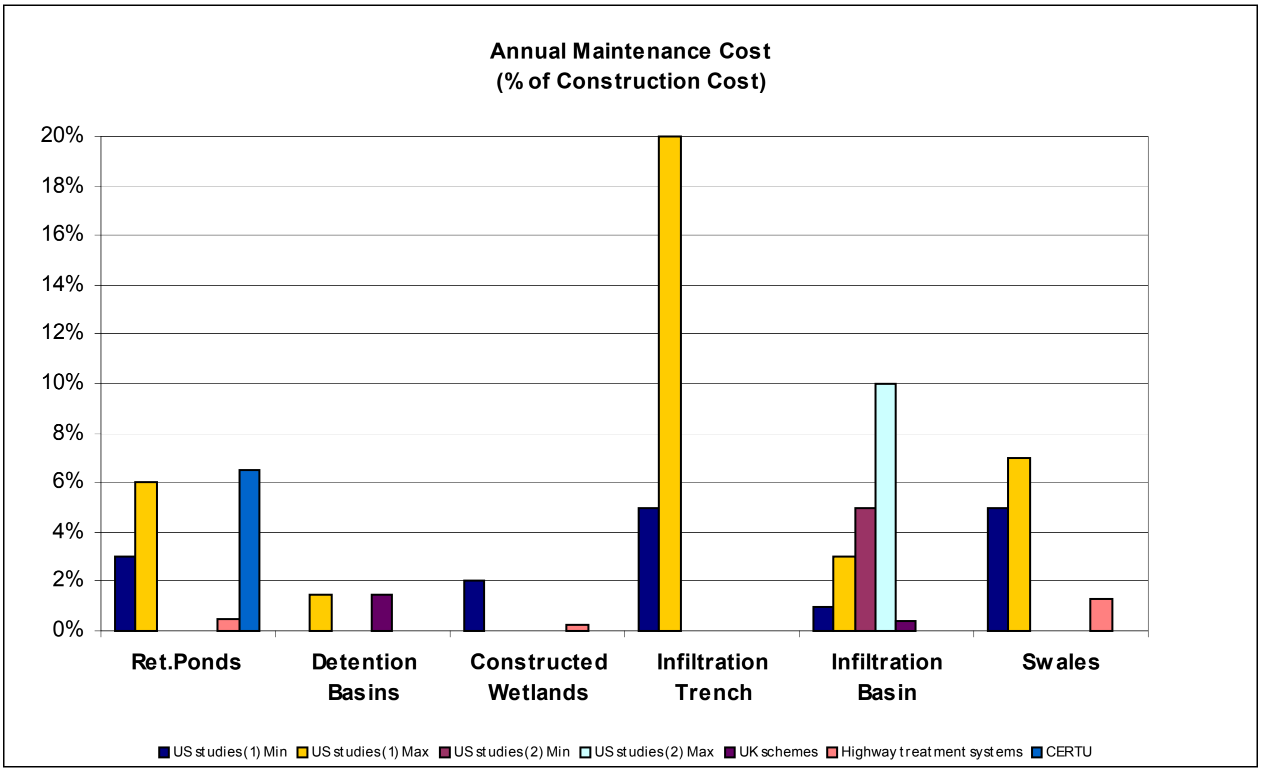

Figure 7.9 Annual operation and maintenance costs as a percentage of construction cost

The estimates of annual operation and maintenance costs as a percentage of construction cost range from 0.5 – 10 % for all components except the infiltration trench for which a 20 % figure is cited as a maximum limit by US literature.

7.7 Design lives

With appropriate design and effective regular maintenance, the lives of sustainable drainage components should be unlimited. However, some level of system rehabilitation may be required within the timeframe of a WLC analysis. Actual intervals will depend on site characteristics, system design, and system history. Possible intervals that could be used to develop conservative future cost profiles are indicated in the following table.

Table 7.8 Suggested effective lives prior to system rehabilitation

Component	Effective life [1]
Filter drain	10 – 15 years before replacement of filter material
Infiltration trench	10 – 15 years before replacement of filter material
Soakaway	
Permeable pavement	20 – 25 years before replacement of filter material
Infiltration basin	5 – 10 years before deep tilling required and replacement of infiltration surface
Detention basin	20 – 50 years
Wetland	20 – 50 years
Retention pond	20 – 50 years
Swale	5 – 20 years before deep tilling required and replacement of infiltration surface
Filter strip	20 – 50 years before replacement of the filter surface

Adapted from Young et al. (1996); Claytor and Schueler (1996); USEPA (1993); and others

[1] **Assumes regular maintenance, occasional removal of accumulated materials, and removal of any clogged media.**

7.8 Operation and maintenance cost influences

The cost of maintaining a SUDS scheme will vary depending on system design, system location and local conditions. Influences include:

(a) Region

Costs for labour and materials are likely to vary across the UK. SPON'S (2003) suggests that comparable unit costs may vary between –40 % (Northern Ireland) and +25 % (Channel Islands) from costs observed in outer London areas.

(b) Materials availability

Many SUDS components require granular fill as the attenuation and filtering media, and costs will vary depending on distance of the site from a potential source. Topsoil costs will also depend on source locations.

(c) Construction programming

Poor construction programming can lead to high volumes of construction silt being passed into the system prior to operation. This can lead to increased operation and maintenance requirements.

(d) Sediment management

Sediment should be extracted using SUDS pre-treatment facilities (e.g. sediment forebays, filter strips) or proprietary silt management products at the top end of the treatment train. Where significant volumes of silts / sediments are discharged into SUDS systems, the maintenance burden will increase.

Wherever silt is extracted, consideration must also be given to disposal options. Where land is not available on-site for silt dewatering and disposal, silt must be transported to an alternative disposal location. It is likely that silts extracted on a regular basis will not require disposal as special waste.

8. SUDS WHOLE LIFE COSTING CASE STUDY

8.1 Introduction

In this chapter, the WLC methodology presented in this report is applied to the SUDS scheme at Hopwood Park Motorway Service Area (Junction 2, M42), near Bromsgrove in Worcestershire. The SUDS were designed by Bob Bray of Robert Bray Associates, together with the Engineer for the site, Baxter Glaysher Associates. A new wildlife reserve was implemented as a planning requirement for the development. The site comprises 34 hectares, of which 9 hectares is developed as Motorway Service Area and 25 hectares as wildlife reserve. The site slopes down to the Hopwood Stream, which is a tributary of the River Arrow.

The system was designed to manage runoff from the 1 in 25 year return period design event, and the ‘greenfield runoff rate’ discharge limit from the site was set to 5 l/s/ha. The 10mm ‘first flush’ volume is treated by stone trench filtering or wetland treatment prior to slow release to the stream or wildlife area. Storm events in excess of the 10mm ‘first flush’ can by-pass ‘primary treatment’ but must pass through a balancing pond which is designed to have a wetland treatment zone to ‘polish’ water passing through the system. Separate spillage containment is provided to areas at risk from severe pollution.

The site can be split into three main areas (excluding the runoff from the amenity building itself), and the characteristics of each drainage system are summarised below:

The HGV lorry park

- Water is collected across a grass filter strip to trap silt
- 10mm ‘first flush’ runoff enters a stone collector trench which treats oils and other pollutants naturally
- A spillage basin with wetland ‘treatment zone’ and outlet valve isolates any spillage event
- Heavy rain passes across the trench into a grass swale
- A balancing pond with marginal wetland ‘treatment zone’ receives all water before release to the wildlife reserve wetland.

Main access road, fuel filling area and coach park

- A proprietary silt and oil interceptor begins treatment of runoff which has been collected by conventional gully and pipe drainage
- 2 spillage basins with wetland ‘treatment zones’ and outlet valves isolate any spillage event
- A ‘constructed wetland’ cleans 10mm ‘first flush’ runoff with an additional outlet valve to isolate any spillage event
- A wetland ditch, receiving water at a controlled rate to prevent erosion, conveys treated ‘first flush’ runoff to the balancing pond with marginal wetland ‘treatment zone’
- A bypass swale collects storm overflow and conveys it parallel to the ditch over the riprap cascade into the pond
- A final balancing pond and treatment wetland receive all water as the last link in the ‘management train’ before release to the ‘stilling area’ and Hopwood Stream.

Car park

- A sub-surface collector trench treats 10mm ‘first flush’ runoff
- A bypass channel conveys stormwater directly to the pond
- A pipe outlet delivers all runoff to a balancing pond and marginal wetland ‘treatment zone’ before release to the ‘stilling area’ and Hopwood Stream.

A plan of the development is shown in Figure 8.1.

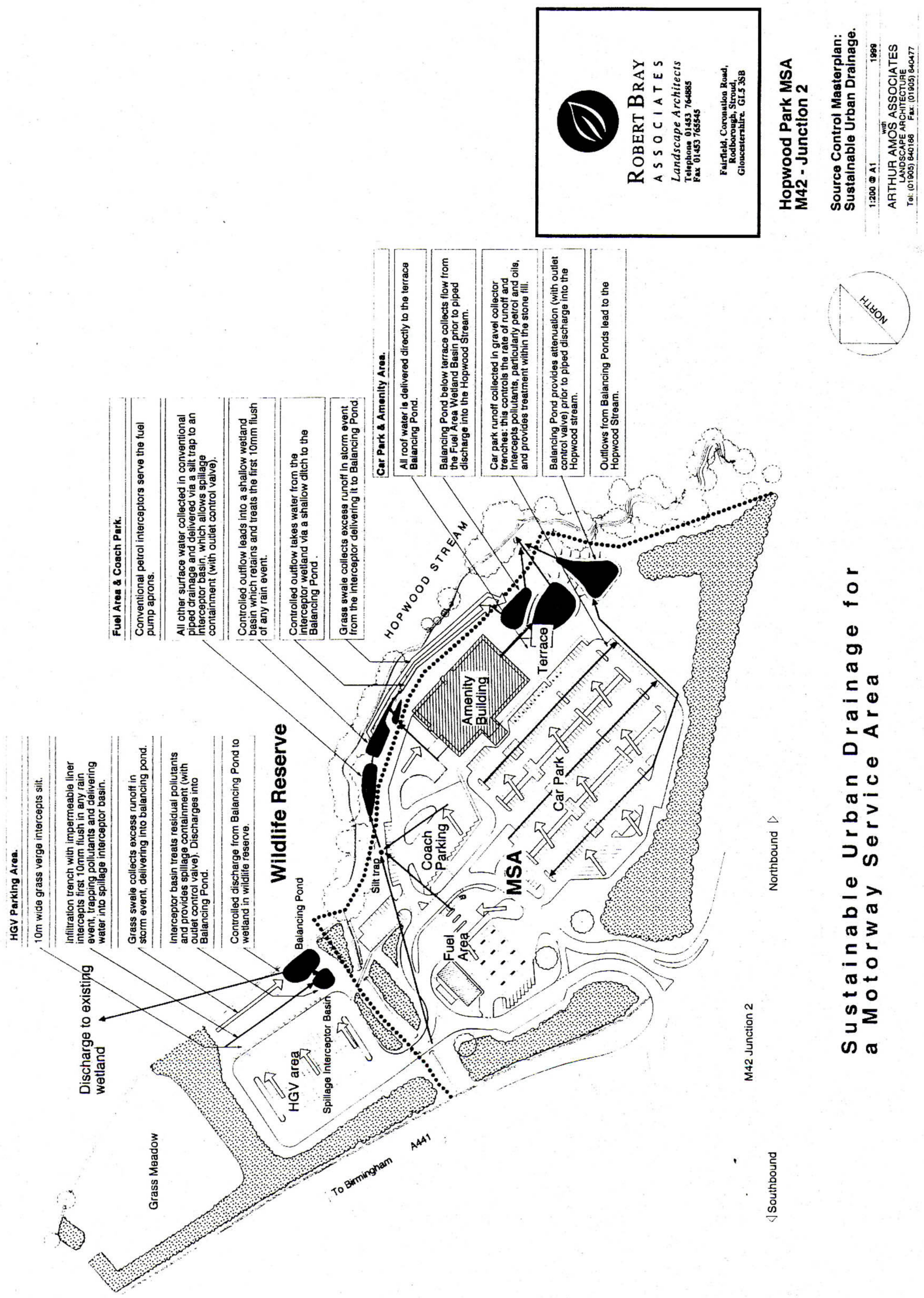

Figure 8.1 Hopwood Park sustainable drainage scheme

8.2 Capital costs

Actual capital costs for this scheme are not known, so a pricing exercise was undertaken based on activities associated with SUDS construction and using unit costs taken from standard UK pricing schedules. Due to the wide variability in unit costs and the influence of site-specific characteristics, these figures may not be accurate for this particular site. However, the exercise does demonstrate the process of building up capital costs for a typical sustainable drainage scheme. A check was then made against the graphs plotted in Chapter 6 (costs from literature and UK sites) to ensure that the estimates were conservative but not unreasonable.

The costs do not include any of the conventional pipework, proprietary silt traps / oil interceptors, penstocks or valves. The costs also exclude the sub-surface treatment trenches, deep manholes and pipework associated with the main carpark drainage as this system is very site-specific.

Table 8.1 Estimated capital costs for case study site

Cost components	Cost (£)
Swales 1. Ground works, clearance, excavation, disposal of excavated material, geotextiles, topsoil, turfing, outlet infrastructure, erosion control.	15,000
Filter drain 2. Ground works, clearance, excavation, disposal of excavated material, upstream filter strip, geomembrane, bedding, perforated pipe, granular fill, outlet infrastructure, erosion control.	10,500
Ponds and wetlands 3. Inlet infrastructure, groundworks, clearance, excavation, disposal of excavated material, geomembrane liners, replacement and preparation of topsoil, grassing, barrier planting, bankside planting, aquatic planting, outlet infrastructure, erosion control.	17,500
Supporting costs 4. Planning, design, legal, permitting fees, construction supervision etc. Assume 30 % of base construction cost.	13,000
Land take 5. Assume value of land taken by SUDS at Hopwood has no opportunity cost value, i.e. the areas taken by the SUDS components would have been open space / wildlife reserve irrespective of drainage design.	0
Total (£)	56,000

8.3 Operation and maintenance costs

8.3.1 Regular operation and maintenance activities

The following costed maintenance schedules have been based on material in HR Wallingford, 2003 (Operation and Maintenance of Sustainable Drainage Systems (And Associated Costs)).

Table 8.2 Annual operation and maintenance activities

Peripheral planting	**Annual frequency**	**Unit rate (£)**	**Total cost (£)**
All grass verges 1.2 - 3M wide or as drawings All grass around source control areas All cuttings collected and removed from site, at first and last cut annually Cuts at 35-50mm with 75mm max	12 cuts	150.00	1800.00
Meadow grass to all mounds and native planting areas will require 2 no cuts at 75mm at an agreed frequency, probably July and October. All raisings to be raked off and stacked in wildlife piles on site	2 cuts	400.00	800.00
Woodland grass to woodland edge and along the stream corridor on the MSA side of the Hopwood Stream 1 cut at 75mm, all arisings to be raked off and stacked in wildlife piles on site	1 cut	250.00	250.00
All native planting to be checked at grass maintenance visits and stakes and guards kept in good order at all times All losses to be made good Oct-Dec each year	3 visits	60.00	180.00
Allowance to pick up all litter in planting at monthly site visits	10 visits	30.00	300.00
Sustainable drainage features			
Litter: pick up all litter in planting at monthly site visits	12 visits	20.00	240.00
Grass generally as required 35 - 50mm not to exceed 75mm Fortnightly or as required April 1 to Oct 30 plus 2 additional visits Nov and March as specification	16 visits	25.00	400.00
Swale grass as required 100mm minimum - 150mm maximum as required	8 visits	25.00	200.00
Wetland ditch vegetation management. Autumn and spring if necessary	2 visits	40.00	80.00
Aquatic plant management (Sept to Nov). Remove nuisance plants, end of season clearance of up to 25 % of growth	5 visits	500.00	100.00
Inlets and outlets			
1. Inlets and Outlets 22 no. Remove debris, strim and remove arisings, remove accumulated silt from aprons	12 visits	50.00	600.00
2. Valves Ensure fully operational	2 visits	10.00	20.00
Rip-rap inspection	12 visits	10.00	120.00
Grass weir inspection	12 visits	10.00	120.00
Stilling area inspection	12 visits	10.00	120.00

Table 8.2 Annual operation and maintenance activities (continued)

Peripheral planting	Annual frequency	Unit rate (£)	Total cost (£)
Undertake monthly visual monitoring of the site			
Inspect surfaces and ponds for sediment accumulation and damage, monitor aquatic vegetation, monitor system effectiveness and identify requirements for rehabilitation works	12 visits	15.00	180.00
		TOTAL	**£5,910.00**

8.3.2 Occasional / Infrequent Maintenance

The frequency at which occasional / infrequent maintenance is required is dependent to a large extent on site characteristics and system design, and is therefore difficult to predict. If regular monitoring of the system is undertaken over, for example, a 3 year period, then these frequencies can be defined with more confidence and long-term maintenance costs re-evaluated.

Table 8.3 indicates the types of activities that should be considered, with estimated frequencies. For more information, see HR Wallingford, 2003.

Table 8.3 Occasional / infrequent maintenance

	Estimated frequency (years)	Unit rate (£)
Swale		
Removal of excess silt due to slow accumulation and dispose of to land (subject to toxicity test)	3	250.00
Surface treatment to encourage infiltration in the case of reduced permeability	3	250.00
Replace topsoil and dispose of accumulated silts and topsoil to land (subject to toxicity test)	25	2,000.00
Filter drain and filter strip		
Removal of excess silt due to slow accumulation and dispose of to land (subject to toxicity test)	3	250.00
Limited weed control (using non-toxic / biodegradable substances)	3	50.00
Removal and cleaning of stone, removal and safe disposal of geotextile, replacement of geotextile and clean stone	25	1,000.00
Ponds and wetlands		
Partial silt removal and disposal to land (subject to toxicity test)	3	500.00

8.3.3 Rehabilitation / Remedial Maintenance

Remedial maintenance can generally be managed out through good design. Where such activities are found to be necessary, this is likely to be due to site-specific characteristics or unforeseen events. Frequencies are presented here in order to allow rehabilitation costs to feature in this example whole life cost appraisal. However, it should be noted, that Hopwood Park SUDS were constructed over 5 years ago, and no such maintenance has yet been required. A lump sum contingency is entered into the 'unit rate' column, as it is not likely that all the identified activities would be required.

Table 8.4 Rehabilitation / Remedial Maintenance

	Estimated frequency (years)	Unit rate
Swale Reinstatement and repair of edgings Reinstatement of levels and turf due to erosion by rills and gullies Repair / rehabilitation of outlets System rehabilitation as a result of high silt loads discharged during a single event	10	3,000.00
Filter drain and filter strip Reinstatement and repair of edgings Reinstatement of levels and turf due to erosion by rills and gullies System rehabilitation as a result of high silt loads discharged during a single event Repair / rehabilitation of inlets, outlets, overflows, rip rap and erosion control	10	3,000.00
Ponds and wetlands Removal of silt Repair of erosion or other damage Replacement of aquatic or barrier planting Repair / rehabilitation of inlets, outlets, overflows, rip rap and erosion control	10	5,000.00

8.3 Risk costs

The costs associated with hydraulic system performance failure have been managed out, through good design and established monitoring and maintenance regimes. The impact of water quality failure will be borne by the environment, and there will be no cost to the SUDS owner. Therefore risk costs in this case can be ignored.

8.4 Environmental costs

There are a range of environmental benefits ('negative' costs) that will accrue from implementing SUDS at this site, as opposed to conventional drainage. These include amenity and recreation opportunities, biodiversity and ecological enhancement, base flow augmentation for the receiving watercourse, water quality improvements, and net flood risk reduction. Very few of these benefits will be seen as tangible value to the SUD owner, however it is felt beneficial to highlight potential values as part of this case study and so the assumption is made that the benefits will be felt in terms of increased revenue in the amenity building.

There is good access to the SUDS, the site is available at all times of year, public facilities have been provided (e.g. footpaths), and the characteristics of the site are relatively rare for a motorway service area. Although a large proportion of the visitors will only be interested in purchasing fuel and food and drink, and will pay little attention to their environment, there is undoubtedly an improved environmental quality associated with the site. In the summer, there will be a much greater appreciation of the features when many people will eat outside. Dog walkers also appreciate the systems. In such cases, the SUDS owner may experience increased revenue as a result of the SUDS. The per annum value of recreation benefits arising from the scheme could be estimated using the following relationship:

Benefits = Number of Visits x Transfer Value (per visit per year)

There are no guidelines on estimating transfer values of this type, but from material collated in Section 4.6.1, a preliminary conservative value could be taken to be £0.10 per car per visit.

The number of car parking spaces is approximately 500 – it is assumed that number of visitors per day is 1000, and that 2 % of these visitors appreciate the SUDS features. This gives an environmental benefit (related to recreation and amenity) value of 0.02 x 0.1 x 1000 = £2/ day (or £730 / year).

It is very difficult to estimate the economic value of changes in water quality or improvement in biodiversity, so no attempt is made to do so here.

8.5 Disposal costs

Costs associated with the disposal of vegetation, granular fill, geotextile and sediments have been accounted for within the operation and maintenance estimates. No additional allowance is therefore required.

8.6 Residual costs

The land taken by the SUDS components is not land that would otherwise be available for development. The site is located away from residential areas and is now an established wildlife park, therefore the residual land cost at the end of the study period can be ignored / assumed to be zero.

8.7 Discount rate

The discount rate currently recommended by the Treasury is 3.5 %, and this is used for the WLC example.

8.8 Whole Life Cost example

Table 8.5 and the following figures demonstrate an assessment of SUDS investment costs through time using a WLC approach.

Table 8.5 Derivation of net present values of SUDS expenditure

Hopwood Services

Discount rate 3.5%

year	Discount Factor	Capital	Environmental Benefits	Risks	Regular Maintenance	Irregular Maintenance	Irregular Refurbishment	Cash	PV
	Cash Sum (£)	56,000	35,770	0	289,590	22,200	44,000	376,020	206,786
0	1.000	56,000	0	0	0	0	0	56,000	56,000
1	0.966	0	730	0	5910	0	0	5,180	5,005
2	0.934	0	730	0	5910	0	0	5,180	4,836
3	0.902	0	730	0	5910	1,200	0	6,380	5,754
4	0.871	0	730	0	5910	0	0	5,180	4,514
5	0.842	0	730	0	5910	0	0	5,180	4,361
6	0.814	0	730	0	5910	1,200	0	6,380	5,190
7	0.786	0	730	0	5910	0	0	5,180	4,071
8	0.759	0	730	0	5910	0	0	5,180	3,934
9	0.734	0	730	0	5910	1,200	0	6,380	4,681
10	0.709	0	730	0	5910	0	11,000	16,180	11,470
11	0.685	0	730	0	5910	0	0	5,180	3,548
12	0.662	0	730	0	5910	1,200	0	6,380	4,222
13	0.639	0	730	0	5910	0	0	5,180	3,312
14	0.618	0	730	0	5910	0	0	5,180	3,200
15	0.597	0	730	0	5910	1,200	0	6,380	3,808
16	0.577	0	730	0	5910	0	0	5,180	2,987
17	0.557	0	730	0	5910	0	0	5,180	2,886
18	0.538	0	730	0	5910	1,200	0	6,380	3,435
19	0.520	0	730	0	5910	0	0	5,180	2,694
20	0.503	0	730	0	5910	0	11,000	16,180	8,132
21	0.486	0	730	0	5910	1,200	0	6,380	3,098
22	0.469	0	730	0	5910	0	0	5,180	2,430
23	0.453	0	730	0	5910	0	0	5,180	2,348
24	0.438	0	730	0	5910	1,200	0	6,380	2,794
25	0.423	0	730	0	5910	3,000	0	8,180	3,461
26	0.409	0	730	0	5910	0	0	5,180	2,118
27	0.395	0	730	0	5910	1,200	0	6,380	2,520
28	0.382	0	730	0	5910	0	0	5,180	1,977
29	0.369	0	730	0	5910	0	0	5,180	1,910
30	0.356	0	730	0	5910	1,200	11,000	17,380	6,192
31	0.344	0	730	0	5910	0	0	5,180	1,783
32	0.333	0	730	0	5910	0	0	5,180	1,723
33	0.321	0	730	0	5910	1,200	0	6,380	2,050
34	0.310	0	730	0	5910	0	0	5,180	1,608
35	0.300	0	730	0	5910	0	0	5,180	1,554
36	0.290	0	730	0	5910	1,200	0	6,380	1,849
37	0.280	0	730	0	5910	0	0	5,180	1,451
38	0.271	0	730	0	5910	0	0	5,180	1,402
39	0.261	0	730	0	5910	1,200	0	6,380	1,668
40	0.253	0	730	0	5910	0	11,000	16,180	4,087
41	0.244	0	730	0	5910	0	0	5,180	1,264
42	0.236	0	730	0	5910	1,200	0	6,380	1,504
43	0.228	0	730	0	5910	0	0	5,180	1,180
44	0.220	0	730	0	5910	0	0	5,180	1,140
45	0.213	0	730	0	5910	1,200	0	6,380	1,357
46	0.205	0	730	0	5910	0	0	5,180	1,064
47	0.199	0	730	0	5910	0	0	5,180	1,028
48	0.192	0	730	0	5910	1,200	0	6,380	1,224
49	0.185	0	730	0	5910	0	0	5,180	960

The expenditure profiles are shown in Figures 8.2 and 8.3.

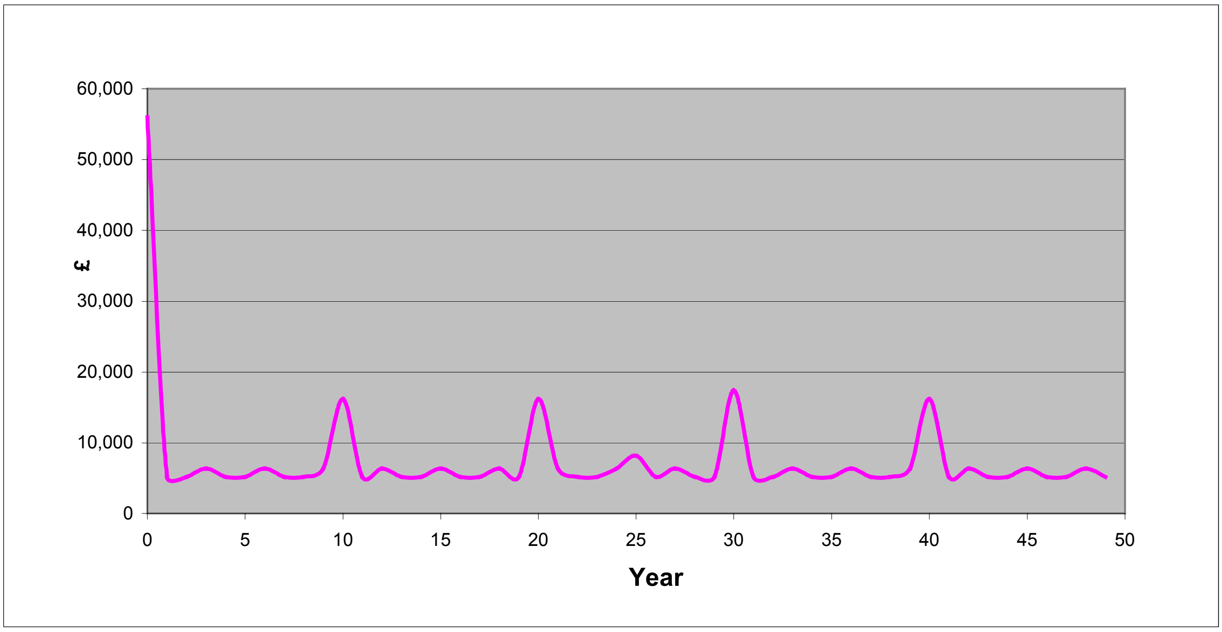

Figure 8.2 SUDS expenditure with time (net present costs): case study example

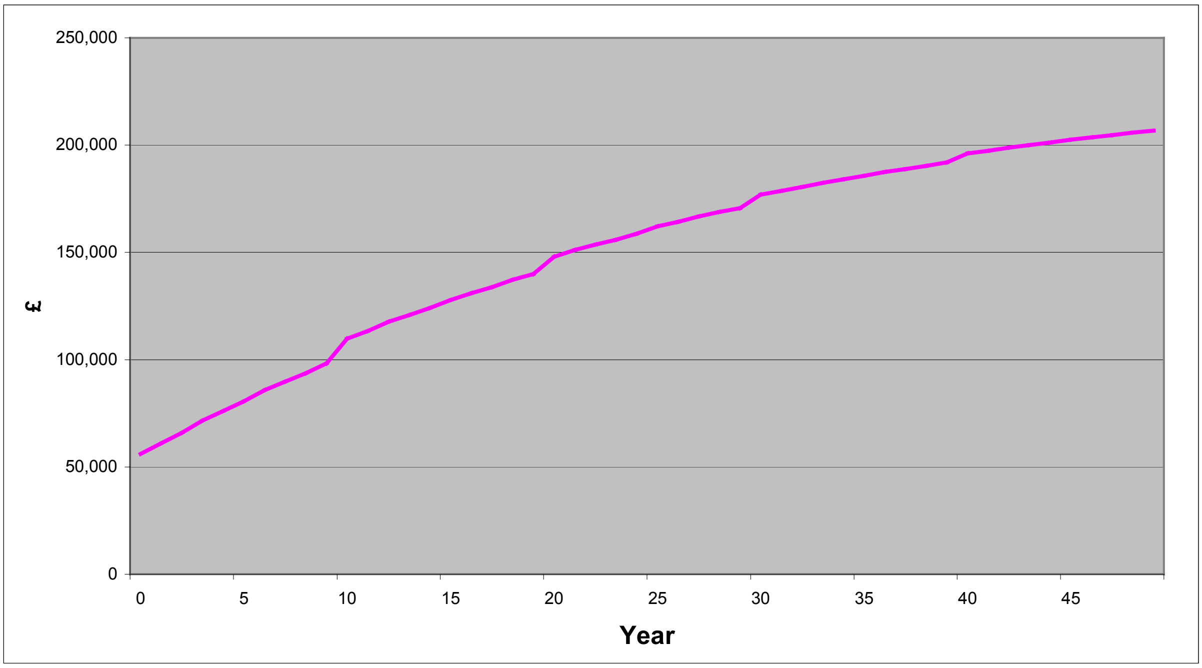

Figure 8.3 Cumulative SUDS expenditure (net present costs): case study example

9. CONCLUSIONS

- This report presents a Whole Life Costing methodology that is appropriate for undertaking an appraisal of the costs and benefits of sustainable drainage systems. A Whole Life Costing framework allows the planning costs, capital costs, land-take costs, residual costs, environmental benefits, operation and maintenance, and disposal costs to be accounted for in a consistent manner.

- Sustainable drainage systems need regular inspection and maintenance in order that risks to performance are minimised and the system life is maximised.

- Whole Life Costing can be used as a tool to quantify the level of financial commitment required at the outset to ensure long term operational performance of a SUDS scheme, to design standards. If operation and maintenance requirements are evaluated and costed during the early planning stages of a development, agreement can then be sought for the sustainable, long-term resourcing of these activities.

- The literature review and cost collation exercise undertaken as part of this project identified a range of capital costs and theoretical cost relationships.

  Poor availability of capital cost information can be attributed to:
  - Drainage costs being hidden within larger landscaping / road budgets
  - Drainage costs hidden within lump sum fixed prices
  - Reluctance to publish costs due to confidentiality / competition issues
  - Lack of requirement to record costs in a systematic way.

- The literature review and cost collation exercise undertaken as part of this project identified a small body of information on operation and maintenance costs.

  Poor operation and maintenance cost data availability can be attributed to:
  - Low levels of operation and maintenance of SUDS undertaken to date and lack of formalised maintenance regimes
  - Maintaining authorities have little time to record and archive information of this nature
  - Split of responsibilities between landscape and drainage maintenance
  - Lack of requirement to record costs and activities in a systematic way.

- Where costs have been published, there is often little or no system design criteria with which to characterise the system and appraise the costs.

- The best indication of capital costs for a specific SUDS scheme would be arrived at by pricing the design using unit costs from published manuals and/or price guides.

- The best indication of operation and maintenance costs for a specific SUDS scheme would be arrived at by pricing appropriate maintenance schedules, based on site-specific characteristics.

- Using a rate of 3.5 % (as currently recommended by the Treasury) rather than the 6 % previously recommended to discount future costs to present day values, means that future costs are given increased importance. This should lead to a more sustainable consideration of operation and maintenance costs at scheme planning stage.

- Regular, annual monitoring and maintenance is relatively straight forward and low cost. However, where poor design or lack of regular maintenance means that rehabilitation and remedial works are required, costs can rise rapidly. Sediment excavation and disposal are, for example, high cost activities that could pose a significant burden to any adopting authority. Schemes must be designed to facilitate and enable appropriate future maintenance, and construction processes (which are a major source of silts and sediments) must be managed effectively.

- Capital costs vary widely as they depend on a range of site-specific factors, including:
  - Design criteria
  - Design and construction detailing
  - Diversity and density of planting
  - Amenity function
  - Land take and land value.

- Breakdowns of capital costs should be recorded, together with site characteristics and design criteria. Proposed operation and maintenance schedules and costs should be archived, together with monitoring records, any schedule revisions, and unplanned, rehabilitation and remedial works that may be required during the life of the drainage system. Systematic recording of such information will enable Whole Life Costs of SUDS to be predicted with confidence in the future.

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Appendices

Appendix A Literature Review – Whole Life Costing

1. Buildings and Constructed Assets – Service Life Planning Part 1: General Principles BS ISO 15686 – 1:2000

The standard provides a methodology forecasting the service life and estimating the timing of necessary maintenance and replacement components. Service life planning is a design process which seeks to ensure, as far as possible, that the service life of a building will equal or exceed its design life, while taking into account the life cycle costs of the building

Definitions

Service life: period of time after installation during which a building or its parts meets or exceeds the performance requirements.
Reference service life: Service life that a building or parts of a building would expect in a certain set of in-use conditions.
Estimated service life: Service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, calculated by adjusting the reference in-use conditions in terms of material, design, environment, use and maintenance.
Design life: service life intended by the designer.

Factor method for estimating service life

ESLC=RSLC x A x B x C x D x E x F x G

Where:

ESLC is Estimated service life component
RSLC is Reference service life component

Modifying Factors:

Agents	Factor	Relevant Conditions(examples)	
Related to the inherent quality characteristics	A	quality of components	Manufacture, storage, transport, materials, protective costings
	B	design level	Incorporation, sheltering by rest of structure
	C	work execution level	Site management, level of workmanship, climatic conditions during execution of the work
Environment	D	Indoor environment	Aggressiveness of the environment, ventilation, condensation
	E	Outdoor environment	Elevation of the building, microenvironment conditions, traffic emissions, weathering factors
Operations conditions	F	In-use conditions	Mechanical impact, category of users, wear and tear
	G	maintenance level	Quality and frequency of maintenance, accessibility for maintenance

The standard suggests that it may be desirable to consider the consequences of failure when estimating service lives using the factor method.

Life Cycle Costing (LCC)

A technique that enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors, including capital costs and future operations costs.

- Only designs and or components that meet design life, function and performance requirements should be considered as alternatives
- Alternative with lower LCC should be favoured
- LCC should be taken over the entire estimated service life
- All relevant economic factors including opportunity costs should be included
- Initial costs include design, construction, installation, fees and charges
- Future costs include all operating (e.g. energy and clearing), maintenance, inspection, replacement and demolition or removal costs
- Maintenance costs include costs of replacement, repair, refurbishment, disassembly and re-assembly. Planned cyclical maintenance and day-today maintenance s well as improvement and alterations should be included; an allowance should be made for unplanned remedial maintenance, based wherever possible on recorded historic costs and experience. Depending on the use of the building, costs associated with availability or provision of replacement during maintenance work may also be required
- Timing of future costs should be taken into account in LCC.

2. Life Cycle costing – theory, information acquisition and application. David Woodward

International Journal of Project Management, Vol 15, 1997

LCC seeks to optimise the costs of acquiring, owning and operating physical assets over their useful lives by attempting to identify and quantify all the significant costs involved in that life.

It enables total LCC, and the trade-off between cost elements during the asset life phases, to be studied to ensure optimum selection.

Kaufman's life cycle formulation

- Establish the operating profile
- Establish the utilisation factors
- Identify all the cost elements
- Determine the critical cost parameters (e.g. mean time between failure, mean time to repair, mean period of repairs, period of maintenance, energy use rates)
- Calculate all costs at current prices
- Escalate current costs at assumed inflation rates
- Discount all costs to the base period
- Sum discounted costs to establish the net present value.

The operating profile

The operating profile describes the periodic cycle through which the system will go, i.e. it informs when the system will and will not be operating.

The utilisation factors

The utilisation factors tell us the utilisation rate of a particular system during the operating profile.

Cost escalation

All costs need to be projected forward at appropriate (that is, differential) rates of inflation.

The discount rate

Selection of a suitable discount rate is a crucial decision in LCC analysis. A high discount rate will tend to favour options with low capital costs, short life and high recurring costs, whilst low discount rate will have the opposite effect. The discount rate may reflect the effect of only the real earning power of money invested over time or it may also reflect the effects of inflation.

Uncertain parameters

The following have been identified as major sources of uncertainty:

1. Differences between the actual and expected performance of the system subsystems, which could affect future operation and maintenance costs
2. Changes in operational assumptions arising from modifications in user activities
3. Future technological advances that could provide lower cost alternatives and hence shorten the economic life of any of the proposed systems
4. Changes in the price levels of a major resource such as energy or manpower, relative to other resources can affect future alteration costs
5. Errors in estimating relationships, price rates for specific resources and the rate of inflation in overall costs from the time of estimation to the availability of the asset.

Sensitivity analysis should be undertaken to determine how sensitive the results are to variations in the uncertain parameters. The following should be tested:

- Frequency of maintenance
- Extent of the systems self diagnostic system
- Variation of the corrective maintenance hours per operating hour
- Product demand rate
- Product distribution rate
- The discount rate.

3. Study on Whole Life Costing
Mike Clift and Kathryn Bourke
BRE, 1999

There are emerging drivers to take up WLC. For example: There is a growing awareness that of the annual turnover of the construction industry, some 45% is spent on maintenance and refurbishment that is unplanned or unexpected.

The Latham Report states:

- Life cycles, and all life costs, of buildings and their fittings must be a principle part of design and maintenance considerations.

The Egan report states that:

- Design needs to encompass whole life costs, including costs of energy consumption and maintenance costs. Sustainability is equally important. Increasingly clients take the view that construction should be designed and costed as a total package to include costs in use and final decommissioning.

A whole life costing approach encourages a decision making that takes account of durability, future running costs, maintenance and refurbishment requirements. It can highlight significant refurbishment needs which involve the use of new material and additional energy, and thus further resource depletion.

Whole life costing therefore is a tool for encoring the design of buildings that are more compatible with the concept of sustainable construction.

Barriers to using WLC:

- The scale of the data collection exercise
- The lack of universal methods and standard formats for calculating whole life costs, the difficulty in integration of operating and maintenance strategies at the design phase
- A general lack of perception of client and industry pull.

Tax Implications

In general, expenditure incurred as a running cost of a building is deductible against liability for tax. Implications for SUDS ?

4. Life Cycle Costing for Construction
Edited by: John Bull
Department of Civil Engineering, University of New Castle upon Tyne
Blackie Academic and Professional, 1993

Introduction to life cycle costing
SJ Dale

Methods:

(a) Simple payback: defined as the time taken for the return on an investment to repay the investment.

P= I/R

Where P= payback period, I= capital invested, and R = money returned or saved as a result of the investment.

In practice, a maximum period of 2 or 3 years is set as a criterion for investment because the calculation makes no allowance for:

- Inflation
- Interest
- Cash flow
- Tax.

This method is fraught with difficulties, and only has real use in quick elimination of unrealistic options.

(b) Net present value (NPV): defined as the sum of money that needs to be invested today to meet all future financial requirements as they arise throughout the life of the investment.

Flannagan *et al*. (1989) express NPV as:

$$NPV = \sum_{t=0}^{T} Ct / (1 + r)^{t}$$

Where C is the estimated cost in year t, r is the discount rate and T is the period of analysis in years.

The discount rate is a method to determine the time value of money. Eg. £100 invested today at 11% per annum would be worth:

=PV(1 + r)

=100(1 + 0.11)

=£111 in 1 year's time.

The formula allows for expenditure to vary from year to year, allowing for differing intervals of replacement of equipment.

The above example makes allowance for interest receivable on the sum invested. In reality, the value of our investment will be eroded by the pernicious effects of inflation. The equation above can however be modified to take into account inflation. Inflation will increase the costs at year n and therefore increase the present day investment level. The modified factor is known as the 'nett of inflation discount rate' (ndr) where:

ndr = [(1 + interest %) / (1 + inflation %)) –1]

This modified discount factor can then be substituted into the equation.

(c) Internal Rate of Return: defined as the percentage earned on the amount of capital invested in each year of the life of the project after allowing for the repayment of the sum originally invested.

Using IRR the capital cost is balanced against income to obtain a NPV of zero. The discount rate necessary is the IRR. This method is only useful where investment produces a return on capital employed.

Selection of the Nett of inflation discount rate.

Most texts suggest a discount rate of between 7% and 10% with nett inflation between 2.% and 5%. These rates are based on values that can be demonstrated from secure fixed-interest investments such as treasury bonds.

5. Life Cycle Costing – a radical approach
DJ Ferry and R Flanagan
CIRIA, 1991

Annualised equivalent cost

Costs can be expressed as the equivalent cost that would occur each year. This is useful for projects where cash flow is broadly constant over the life, and should produce the same ranking as an NPV approach.

AEC = (present cost) x { 9r/100) 91 +r/100)^N / (1 + R/100)^N –1)

Where
R = discount rate %
N = number of interest periods.

The expression in the brackets is the periodic payment factor and is obtainable form annuity tables.

Overall Life Cycle Costing (LCC) Procedure

- Identify the objectives, constraints and alternatives
- Establish basic assumptions and determine the LCC procedure to be adopted
- Compile data

- Compute and discount the life cycle costings
- Compare results
- Evaluate results for uncertainty and risk
- Report on the findings and conclusions.

Assumptions and Procedures

LCC will always involve some fairly sweeping assumptions about the future. These assumptions, and their accompanying LCC procedures, need to be specifically identified, including e.g. the study period, the timing of cash flows, residual values, inflation, the discount rate, the sources and the reliability of the data, the treatment of non-monetary items, the organisation's maintenance policies and the comprehensiveness of the LCC evaluation.

Asset Lives

There are five possible determinants of an asset's life expectancy:-

a) Functional life – the period over which the need for the asset is anticipated. This often equates to perpetuity.

b) Physical life – the period over which the asset may be expected to last physically i.e. when replacement or major rehabilitation is physically required.

c) Technological life – the period until technical obsolescence dictates replacement due to the development of a technologically superior alternative.

d) Economic life – the period until economic obsolescence dictates replacement with a lower cost alternative.

e) Social and legal life – the period until human desire or legal requirement dictates replacement.

In the majority of cases, the physical life or the social and legal life will determine the life expectancy. As a result, unless impending legislation is well signposted, asset life expectancies are often indeterminate.

The Study Period

The study period is defined by its start (year 0) and its finish (year N). In order to permit proper comparison between alternatives it is necessary to use the same study period for each. Year 0 is usually selected as the first year in which expenditure occurs, which is not necessarily the current year.

Selection of the time horizon, year N, is crucial to how the life cycle costing study is to be treated. To maximise the effectiveness and realism of the exercise, short time horizons are essential. While hard and fast rules on time horizons are inappropriate, a maximum of 20-25 years for capital projects might be considered reasonable, and 5 years for maintenance assessment.

The view has been expressed that life cycle costing is inappropriate for long life assets such as structures. If, however, it is required, the most valid approach might be to curtail the discounted cash flow at say year 20 and to assign a residual value to the asset in recognition of its usefulness beyond this time. This seems a more reasonable approach than simply relying on forecasts extending say 100 years into the future, which can have little basis of reality.

Differing life expectancies

Identical time horizons must be adopted in order for comparisons between alternatives to be fair. The options are:

- Set the time horizon to the shorter and assign a residual value to the asset with the longer life
- Set the time horizon to the longer life, and allow for the replacement costs of the shorter life asset during the study period and for any residual value at the end
- Use the Annualised equivalent cost technique.

Residual values

The residual value of an asset is its value at the end of the study period (year N). For assets that are going to remain in service beyond the end of the study period, estimation of residual value is difficult. The ongoing functional value may be much higher than the cost of replacing it with a new but similar asset.

The ongoing functional value of an asset could be assessed by discounting to year N the value of the net cash flows subsequent to year N attributable to the ownership of the asset. However, despite being theoretically sound, there are many drawbacks to this strategy:

a) It would in effect extend the time horizon of the study, whereas this report has argued for reduced time horizons in order to minimise uncertainty.
b) For life cycle costing studies with short time horizons, the emphasis should correctly lie on the costs arising within the study period. Use of the on-going functional value could place more emphasis on events subsequent to the study period and thus residual value could dominate the calculations to an undesirable degree.
c) For many publicly owned assets, the value of the net cash flow cannot readily be quantified in monetary terms and therefore the residual value cannot be assessed in this manner.

An alternative approach could be to estimate the asset's residual value by depreciating the asset's capital cost from new usually using the straight line method or the declining balance method (accelerated depreciation). However, this approach then fails to take account of the full, on-going functional value of the asset.

The difficulty in dealing with residual values underlines the argument that LCC is better suited to short life assets. The shorter the life, the lower is residual value is likely to be.

Monetary Costs

These are cash outflows defined in terms of quantity and time. They can be classified under a number of standard headings, comprising:

a) Capital/Replacement/Refurbishment Costs:
Land purchase. Professional fees. All design and site supervision costs. Purchase, construction, installation and commissioning costs paid to the supplier and/or contractor.

b) Operating Costs:
Direct labour, materials, power.

c) Maintenance Costs:
Direct labour, materials, power, equipment and purchased services. Maintenance costs can normally be broken down into smaller classifications such as:
   i) Regular, planned maintenance
   ii) Unplanned maintenance (responding to faults)
   iii) Intermittent maintenance – for major mid-life refurbishments, alterations etc.

d) Downtime Costs:
The direct losses arising from loss of service due to downtime, and the direct costs of providing an alternative service.

e) Disposal Costs
The costs which are incurred at the end of the asset's working life in disposing of an asset.

6. Whole Life Costs and Sustainable Project procurement in Port, Coastal and Fluvial Engineering. HR Wallingford (Neal Masters). June 2001.

Definitions: Whole Life Costing

ISO 15686 (CCF, 2000)

" a tool to assist ion assessing the costs performance of construction work, aimed at facilitating choices where there are alternative means of achieving the clients objectives and where those alternatives differ, not only in their initial costs a but also in their subsequent operational costs"

CRISP (Clift *et al* 1999)
" the systematic consideration of all relevant costs and revenues associated with the acquisition and ownership of an asset"

Equivalent Terminology

- Whole life costing
- Life cycle costing
- Through life costing
- Costs in use
- Total cost of ownership.

Discount rate

Generally quoted by financial institutions as between 5% - 10%. 6% is currently recommended by UK government.

Barriers to implementation of Whole Life Costing

- Classic WLC forms cut across traditional separation of capital and maintenance budgets and funding arrangements. The starting point with any WLC approach should be that capital and maintenance costs are intimately linked and should not be treated separately
- No formal requirements for it
- There are uncertainties associated with forecasting future maintenance costs
- There are difficulties defining the realistic life expectancy of assets
- There is a lack of consistent historic cost data on which to base future cost forecasts
- Long lead times on many capital works can decrease the validity of assumptions made at the outset
- Capital costs can swamp the effects of smaller recurrent costs (which are made smaller still through discounting)
- The sensitivity of the results to discount rates.

7. Whole Life Costing Approach to Distribution Network Management Skipworth and Saul Sheffield University

Within water distribution systems, regulatory requirements and operational realities are leading the operators to balance the cost implication of rehabilitation strategies with the consequences of the risks associated with them.

The advantages of WLC are that:

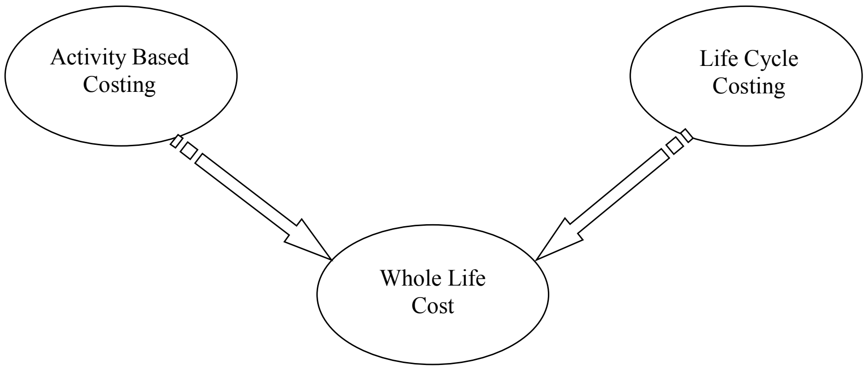
- The process is more explicit and easily adaptable

- The process is fully auditable
- It meets the requirements of OFWAT's MD161 in providing a more economically based rationale to asset management
- It considers both costs and performance over extended periods
- If required, it provides the flexibility to extend the analysis to incorporate sustainability issues related to resource use and impacts on environment and society.

WLC Accounting Module

This is an accounting framework where the direct, indirect and external costs are identified and reported. The relationship between different cost elements is explicitly identified and draws on a combination of Activity Based Costing and Life Cycle Assessment Costing to provide a complete accounting description of the system.

Activity Based Costing recognises the operator's internal or private costs and assigns them all to the activities that ultimately give rise to their being incurred. Following a causal chain, Life Cycle Assessment Costing looks at the environmental and societal impact of operation. In this way costs can be assigned to activities. There are increasing moves towards the use of economic instruments (e.g. green taxes) and regulation as a means of internalising externalities, highlighting the importance of their inclusion at the outset. The determination of social and environmental costs is not straight forward. Tools available for their determination are travel cost methods, contingent valuation and benefit. A particular problem is the determination of the boundaries of an assessment. In order to make the determination tractable the assumption (open to modification) is made that social and environmental costs associated with input materials such as pipes are already included in their supply cost.



In summary, this accounting framework is able to link operational changes in system performance to costs thus facilitating the investigation of alternative management and least cost policies. When evaluating operating and rehabilitation strategies, inclusion of the Life Cycle Assessment Costing allows the operator to consider the wider impacts of their activities.

8. Life Cycle cost for Drainage Structures
J.C. Potter
US Army Corps of Engineers, Washington DC.
1988

Service life

The most difficult and controversial aspect of life cycle cost analyses is establishing service life. Service life is a function of pipe material, the environment in which it is installed and the effect of additional measures taken to protect the pipe from deterioration.

- A 50-yr-service life can be used for most types of structures. Limits on pH and resistivity can be used to ensure that metal pipes will perform satisfactorily for this period
- Limits on pH and sulphides can be used to ensure the satisfactory performance of concrete pipes
- Plastic pipes should provide more than 50yrs service as long as it is not exposed to UV light
- Clay pipe is the most inert; 100-yr. service life can be assumed.

Life cycle cost methodology

- LCC is the total, overall estimated cost for a particular design alternative. Direct and indirect initial costs plus periodic or continuing costs for operation and maintenance are included
- Costs incurred over time can for drainage should be expressed in constant dollars – this is the cost of savings stated at a price level in effect at some given time
- The LCC is expressed either in terms of Present worth (PW) or equivalent uniform annual costs (EUAC) – PW is the primary measure – it is the amount of money required now to fund the project for the entire analysis period
- The same analysis period must be used.

Analysis Period

- Economic studies consider projects to have a service life, an economic life, and an analysis period.
  - Service life: the total useful life of the project or time to replacement
  - Economic life: The time during which a project is economically profitable or provides the required service at a price cheaper than an alternative (usually the same as service life for drainage)
  - Analysis period: is the comparison period over which costs are counted in determining PW of EUAC.

Based on the service life guidelines a 50 year analysis period is justifiable and should be used.

Costs

- The initial and recurring costs considered in an economic analysis are sometimes categorised as agency costs, user costs and non-user costs (Hass and Hudson 1978)
  - Agency Costs: initial capital cots, future capital costs of rehabilitation or replacement, maintenance and or operational costs during the analysis period, salvage of retention/residual value(a negative cost) and engineering and administration costs
  - User costs: usually included on the costs of the facility being drained by the drainage structure and include travel time, vehicle operating costs, accident costs and inconvenience
  - Non-user costs: result from the imapct of the facility such as increased flood damage
- Analysis usually only include Agency costs, one exception is the user costs associated with replacement of structures under high volume facilities may cause expensive delays and detour costs, as well as reconstruction costs well in excess of the marginal costs associated with initial installation of the structure
- Maintenance and operations costs are highly dependent on local conditions and the maintaining agency
- The savlage or retention /residual value is the residual value at the end of the analysis period. . If the analysis period coincides with the service life = zero, other wise it is included as a negative costs.

Discount Rate

- The time value of money is expressed by the discount rate. The discount rate is the amount that the value of money in the future is reduced or discounted to reflect its current value. It can also be viewed as the minimum real or net rate of return, after inflation to be achieved by public sector investments.

Computing PW

- One time costs

- Estimate the amount of the one-time costs as of the base date.
- Escalate this cost to the time at which it is actually incurred using the differential escalation rate e
- Discount the escalated future one-time costs to PW using the discount rate d.

- Re-curring costs
  - Estimate the amount A_o of the annually recurring costs as of the base date and determine the number of costs K, in the series
  - Escalate A_o to A_I at the time at which the first cost in the series is to be incurred using the escalation rate e
  - Determine the date on which A_I is incurred, the single costs that is the equivalent to a series of K uniformly escalating annual costs where the amount of the first costs is A_I and the escalation rate is e
  - Discount the single equivalent cost, form the time the first annual cost is to be incurred to a PW on the base date using the discounted rate d.

Decision Criteria

- The data for LCC are based on estimates and are therefore uncertain, there may uncertainty as to the scope or quantity of thing (pounds of steel, man-hours) the unit costs of things in the market place at the time the costs will actually be incurred and the timing of costs (when will the item require replacement)
- Uncertainty assessments need not be performed if either of the following conditions applies:
  - The relative rankings of the alternatives ca not be affected by the results
  - The results appear to be clear-cut
- Two approaches – probabilistic and sensitivity. The probabilistic approach is preferred
- In the case of a tie between two options, or when there is so much uncertainty so as to render apparent LCC difference inconclusive then the relative rankings can be determined as follows:
  - A positive Net LCC difference between two alternatives is conclusive if it can be shown that the probability of that difference exceeding zero is no less than 0.60
  - If it can be demonstrated that one of the alternatives satisfies any of the following conditions then that alternative will be assigned the higher relative ranking:
    1. Less expensive in terms of initial procurement costs
    2. It will consume less energy per year and will be no more expensive in initial procurement costs
    3. It will consume as least 15% less energy per year and will no be more that 15% more expensive in terms of initial procurement costs
    4. It will be at least 155 less expensive in terms of initial procurement costs and will consume in more that 15% more energy per year.

9. Using life cycle revenue loss and Monte Carlo simulation as prior and indirect assessment of consequences of un-wished events.

M. Chang and J. D. Lewins
Ann. Nucl. Energy, Vol 25, No.1-3, pp. 117-217, 1998.

A drawback of WLC is the difficulty in assessing and measuring things that have yet to occur. Monte Carlo simulation has been used to assess system reliability and provides a probabilistic approach to modelling cash flows, based on estimates of the range of frequency of failure.

The example given is for a pump control system and the LCA analysis includes revenue loss due to equipment failure as well as system design, installation, repair and routine maintenance costs.

10. Reconciling theory and practice of life-cycle costing.

R. J. Cole and E. Sterner

Building Research Information, 28(5/6), pp368-375, 2000

Life cycle costing is defined "as a means by which initial and operating costs are combined into a single economic figure to be then used as the basis for making informed and effective decisions."

A useful classification of different types of cost accounting are provided as shown in Fig 1 and in this definition LCC are limited to Direct and Indirect financial costs and some identifiable contingency costs that may or may not arise in future.

The stages of LCC are identified as:
- Declaration of alternatives. The assumption here is that LCC is used to ascertain the most cost effective strategy amongst a range of competing alternatives
- Identify relevant economic criteria. Choice of discount rates, analysis period, frequency of component replacement etc.
- Obtaining and grouping relevant costs. Annual v "once off".

Performing risk assessment to test the robustness of the decision. Sensitivity testing and probabilistic methods are mentioned.

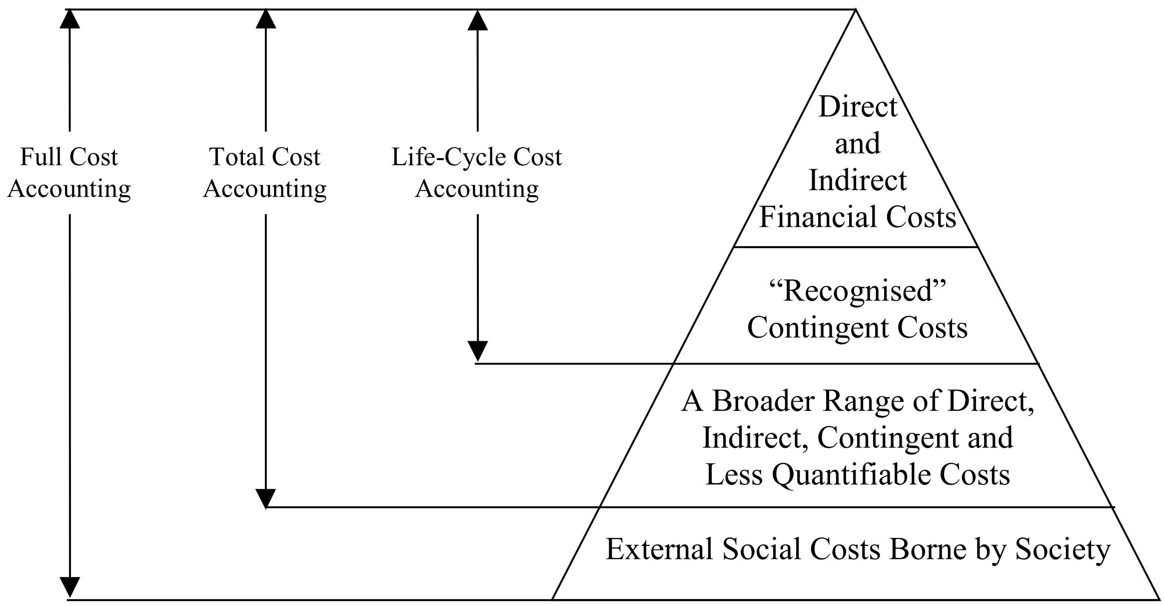


Figure 1 Alternative cost accounting methods (adapted from BC MELP, 1997)

Four barriers are mentioned
- Motivation to use the methods
- Contextual issues. The perception of the analyst, bias towards a type of solution, need to consider alongside other decision making criteria, split responsibilities between "capital" and "revenue" budgets
- Methodological Limitations: Uncertainty in cost data, lack of a universal method, difficulties in application to areas with longer life components and projects i.e. contrast construction with manufacturing
- Access to reliable data. The problem of innovative materials and approaches where long term performance is unknown is highlighted. The paper contrasts views that a comprehensive data-base of cost is required with those that cost estimates based on experience and judgement are as suitable.

11. Activity based life-cycle costing

J Emblemsvag

Managerial Auditing Journal, 16/1, pp 17-27, 2001

Describes an approach to "LCA" (WLC) based on activity based accountancy practice, whereby costing is done on the basis that objects consume activities not resources and that costs should be allocated to objects through the identification and costing of these activities. The activities are identified using a work-breakdown structure approach. The LCC is integrated with the problem-solving process and the consequences of changes are assessed as the decision making process proceeds. Variability in maintenance intervals and the performance of component assets are represented using Monte Carlo simulation.

The paper provides an example of activity based LCC for a shipping problem and concludes that probabilistic models are more useful than deterministic.

12. Life Cycle Costing and its use in the Swedish Building Sector

E Sterner

Building Research Information, 28, (5/6) 387-393, 2000

Applications of LCC to the construction sector in Sweden are reviewed and constraints to its application are identified with proposals for improving the usability of LCC given.

The constraints identified are:

- Historical focus on construction rather than operational or maintenance costs
- Uncertainty of the relevance of LCC analysis due to: insufficient cost data particularly limited by the problem of foreseeing future consequences and occurrences, uncertainty over the appropriate time-scale of the analysis and discount factors.

A survey of LCC users confirmed these constraints and identified two approaches in use as shown in Table 1. The advanced model approach was the most prevalent and this included simulation in sensitivity testing. The costs included are acquisition, energy usage, operational costs maintenance costs, salvage value, environmental costs and disposal costs. The first three were the most commonly used and the paper gave no useful guidance on the evaluation of environmental and disposal costs.

Table 1 Calculation methods used

	Advanced model	Simple model
Number of users	5	3
Parameters included in the analysis	Acquisition cost Salvage value Life-cycle Interest Energy costs Operation Maintenance Environmental costs	Acquisition costs Operation Maintenance
Sensitivity analysis	Yes	Sometimes
Parameters included in the sensitivity analysis	Energy prices Discount rate Life cycle	Discount rate
Calculation made for	Ventilation, heating systems, Building elements and materials	Ventilation, heating systems, Building materials

13. Probability distributions of facilities management costs for whole life cycle costing in acute care NHS hospital buildings.

R J Kirkham, A H. Boussabaine and B. H. Awwad.
Construction Management and Economics, 20, pp 251- 261

WLCC can be used "as a means of comparing options or as a tool for assessing long term ownership in existing facilities through stochastic modelling and key performance indicators". WLCC is significantly dependent on assumptions on future costs of operation and maintenance but these are uncertain and therefore need to be represented in WLCC as probability distributions. An approach to transform available data into usable cost information is described. A cost parameter of cost per square meter of gross floor area was used and data from 450 sites was collated. Probability density functions were established to represent variability on a number of cost centres including water supply, sewerage services, waste disposal, cleaning costs, capital charges costs. The method demonstrated that, given a large volume of data, probability distributions of cost components can be determined.

14. Estimating the life expectancies of building components in life-cycle costing calculations

A. Ashworth
Structural Survey, Volume 14, number 2, pp 4-8, 1996

Consideration is given as to how life expectancy of building components can be determined so that this information can be included in life cycle cost calculations. Factors affecting life expectancy of an element include:

- The maintenance policies applied; preventative v corrective
- The causes of failure, influence by location and site specific issues
- The use of non-identical replacements
- Time lag delays in replacement.

It is noted that for these reasons, LCC, by attempting to estimate far into the future, has a strong likelihood that its forecasts will be incorrect. The wide range of possible replacement ages for softwood windows is demonstrated (median 30 years, mean 32 years, SD 22 years, minimum 1year, maximum 150years). The paper concludes that sensitivity testing can-not properly represent the effects of such variation in LCC analysis but suggests that simulation may be appropriate.

15. Elicitation of subjective probabilities for economic risk analysis: An investigation.

M Ranasinghe and A. D. Russel
Construction Management and Economics, 11, pp 326-340, 1993

A methodology for the elicitation of subjective probabilities for cost data is presented and illustrated by an empirical study. The approach adopted is that uncertainty in a decision variable (e.g. WLC) can be more accurately quantified by decomposing the variable into a related set of primary input variables. The elicitation technique involves:

- Pre-elicitation; briefing on the process, definition of variables, avoidance of cognitive bias
- Elicitation; determination of 5th, 25th 50th 75th and 95th percentiles through a structured interview
- Feedback and consensus judgements. Combining the opinions of a number of experts
- Analysis determining the parameters of the distributions
- Verification of the validity of the determined distribution.

The elicitation process was tested under experimental conditions and found to be robust.

16. Disposal costs for environmentally regulated facilities: LCC approach.

D. M. Abraham, R. J. Dickinson
Journal of Construction Engineering and Management. March/April, pp 146 - 154. 1998.

The premise of the paper is that “responsible” decision making cannot be limited to considering only acquisition and ownership costs but should also consider disposal costs. Life-cycle cost equations that allow estimation of disposal costs are generated, containing three parameters; unit of measure, cost per unit of measure, and influence factors. The paper identifies reasons why disposal costs are not considered and these are similar to other authors’ views on barriers to WLC application. However, a useful concept of “divergent participant focus” is identified, whereby the short term involvement of various participants in the life of the facility leads to a reduction in their interests in its ultimate disposal.

The cost components of disposal are identified as:

- Environmental Assessment of the current environmental condition of the facility and its land.Removal and disposal – all physical work involved in decommissioning, demolition, and disposal
- Monitoring to prevent the spread of contamination
- Land remediation to return the site to its natural condition.

Furthermore these costs are classified in three ways depending on the location of the cost item, these classifications being “facility contained”, “soil contained”, and “water contained”.

An example to illustrate the approach, the disposal of an underground storage tank, is presented. Each of the cost items are broken down into cost items based on activities and basic unit costs were determined for these. Unfortunately the paper does not explain how these standard cost items were determined. The only reference to actual recorded costs is for total disposal costs for tanks and these were extremely variable. The basic rates are converted to costs using measured quantities and this is adjusted using influence factors which adjust basic rates to reflect site specific requirements such as varying regulatory requirements, contaminant levels and facility layouts.

It was concluded that whilst the methodology gave viable results, encouraging its application by industry would be difficult since owners of facilities do not think about disposal costs early in the design stage and may have no financial involvement in final disposal. Nevertheless, the work suggest that disposal costs can be significant and should be included in WLC's.

17. Construction Productivity Network, Members Reports

a. Members Report E2134, Bristol April 2002.

Two examples given:

(i) WLC costing by TRRL for road pavements includes:

- Capital costs: Design life, construction type, materials and standards
- Operating costs: Energy consumption and deterioration
- Maintenance costs: Surface defects (minor repairs), Structural defects (overlay and resurfacing
- Social Costs: difficult to quantify and cannot be simply numerical
- Replacement costs: depends on traffic, maintenance, user costs, society costs.

WLC is used in scheme prioritisation at project level and at network level.

(ii) WLC in Property Management:

Presents two approaches to WLC

- Historic costs, based on an analysis of similar facilities in use
- Predictive costs based on an assessment for each building element of the nature of required replacement, when and how often, how much of it and at what cost.

It is recommended that predictive costs are preferable and that historic costs should be used only as a check. A number of sources relating to durability of building elements are cited as data for predictive cost estimating.

b. Members Report E1151, Sheffield, December 2001

The importance of liaison with component manufacturers to secure performance data for WLC was highlighted.

WLC used by a materials supplier (block paving) was presented. The manufacturer are compiling a database of:

- Capital cost: production, transport to site and (approximate) installation costs
- Operating costs: changes in use, up-lift and relay, weed control, cleaning, site variations.

Problems in comparing sites in different locations of different complexity were noted and an approach of grouping similar types of projects was adopted when trying to determine comparative costs. The importance of credible data in WLC analysis was highlighted.

c. Members Report 1144, Bristol, November 2001

This workshop focused on WLC in the housing sector. A survey was reported indicating limited use of WLC cost analysis. This is in an area where data is more readily available than in other sectors as exemplified below.

The Housing Association Property Manual (HAPM) Technical Unit identified methodologies that have been developed for the evaluation of building component life and they have produced a number of publications in this area. It was found possible to construct a failure distribution curve for a component and to fit low, high and average specification examples within this curve.