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Sustainable management of urban rivers & floodplains

Environmental Sustainability Indicators for Urban River Management

LIFE02 ENV/UK/000144

March 2004

Environmental Sustainability Indicators For Urban River Management

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March 2004

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Acknowledgements

The authors would particularly like to thank Professor G.E. Petts, University of Birmingham, and Dr P Armitage, Centre for Ecology and Hydrology, Dorset, for their valuable discussions whilst we were developing the present research and writing this report. We should also like to thank Ms M. Lee for her assistance with the field survey of the River Tame. The methodology described in this report has its foundation in an approach that was developed under funding from the Natural Environment Research Council's URGENT Thematic Programme.

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1. Introduction

This report describes a method for deriving Environmental Indicators for urban river assessment. The method is based upon the following stages:

- Conceptualising the functioning of urban rivers within a spatially hierarchical framework (Section 2).
- Recognising that urban river stretches affected by different levels of engineering intervention form the key spatial scale for urban river assessment, but that processes and forms at other spatial scales are also of importance (Section 2)
- Proposing an Urban River Survey which provides data to characterise the environmental characteristics of engineered stretches whilst maintaining compatibility with the widely-used River Habitat Survey (Section 3)
- Evaluating summary indices from URS data to provide quantitative information on environmental properties of engineered stretches. The values of these summary indices are ***Primary Environmental Indicators*** since they provide a quantitative description of a range of specific properties of engineered stretches (e.g. bank and bed material calibre, in-channel and bank vegetation biomass, extent of bank or bed reinforcement of different types) and thus provide a detailed description of each stretch (Section 4)
- Classifying engineered stretches into a few (6 to 8) classes according to groups of primary environmental indicators describing channel and bank 'Materials'; the number and types of 'Physical Habitats'; the distribution, biomass and type of 'Vegetation'. 'Materials', 'Physical Habitat' and 'Vegetation' are ***Secondary Environmental Indicators.*** The classes ascribed to each of these environmental indicators can be arranged along a gradient of diversity, abundance or modification where each class represents a typical combination of the primary environmental indicators. In some cases the class to which a stretch is allocated could be directly altered by engineering intervention (e.g. the introduction of increased reinforcement materials could change the 'Materials' class), whereas in other cases stretch classes may be associated with engineering intervention as a result of more indirect links between engineering and stretch properties (e.g. the biomass and character of bank vegetation, the number and types of in-channel physical habitats). If association with engineering is apparent, then the classifications can be used to consider the likely consequences of change in channel engineering for the class to which a stretch might be allocated (Section 5). If there is no direct link with engineering, the class of a stretch can still be used to assess scenarios of natural recovery or imposed change.
- Incorporating ***Tertiary Environmental Indicators*** operating at the sector scale (e.g. properties of the flow regime) or observed within the same sector as the engineered stretch (e.g. water quality or biotic indices and scores), and assessing their relative importance in constraining recovery potential (Section 6). Such indicators allow an assessment of the potential of a stretch for modification, enhancement or rehabilitation as a result of just changes in the way it is engineered (e.g. flow energy, water quality, availability of propagules, flood plain extent and land use).

2. Engineered stretches within a spatial hierarchical framework

Frissell *et al*.(1986) proposed a hierarchical framework for stream habitat assessment and classification, based on the assumption that river ecosystems are largely controlled by physical patterns and processes which interact at a range of spatial scales. The framework had a spatially nested, hierarchical structure, with five spatial scales of river unit in the hierarchy: stream network, segment or sector, stretch or reach, pool-riffle, and microhabitat. Small objects, such as patches of river-bed sediment are set within a framework of intermediate scale units (e.g. pool-riffles) and larger scale units (e.g. sectors of river between tributary confluences). This hierarchical framework has been adopted in parts of the United States and South Africa as a basis for river assessment (Beechie and Sibley, 1990; Wadeson and Rowntree, 1994). It is a robust starting point for designing the spatial structure and sampling regime of new monitoring programmes, as well as providing a conceptual framework for integrating data from different sources and for devising river classification schemes.

A spatially hierarchical framework is particularly useful for storing, analysing and classifying information on urban rivers because the character of urban rivers at all spatial scales is heavily constrained by the range of engineering works undertaken at different times for a variety of purposes. An hierarchical framework can be constructed around the engineering modifications that have been made to urban rivers. Figure 1 illustrates that there are five spatial scales within the framework that we have devised for urban rivers: the catchment (entire stream network), sector (major tributaries and unbranched sections of river between tributary junctions), stretch (river reach exhibiting a single engineering ‘type’), habitat (individual pool, riffle, bar etc.) and patch. Engineered stretches that reflect differences in the nature and degree of engineering intervention are the key spatial units to which units at other spatial scales can be linked. Thus engineered stretches may be aggregated into river sectors and catchment networks, or subdivided into habitats and patches.

Engineered stretches have a single ‘type’ of engineering intervention based on a combination of (i) the river planform; (ii) the channel cross section, and (iii) the amount of bank and bed reinforcement. Tables 1 lists the various subdivisions of these three properties that can be combined to identify 144 potential engineering ‘types’.

Figure 2 summarises the catchment and local controls on the geomorphology of river stretches and provides the rationale for defining the scale of the engineering stretch as the key to understanding and classifying urban river channels. Under natural conditions, the form of a river channel is determined by interactions between the river flow and sediment transport regimes and the boundary materials within which the channel is developed. The flow and sediment regimes of urban rivers are heavily modified by catchment-scale, sector-scale and stretch-scale influences on hydrological and hydraulic processes, and on the availability of sediment. The channel margin materials are frequently modified at the stretch-scale as a result of engineering intervention.

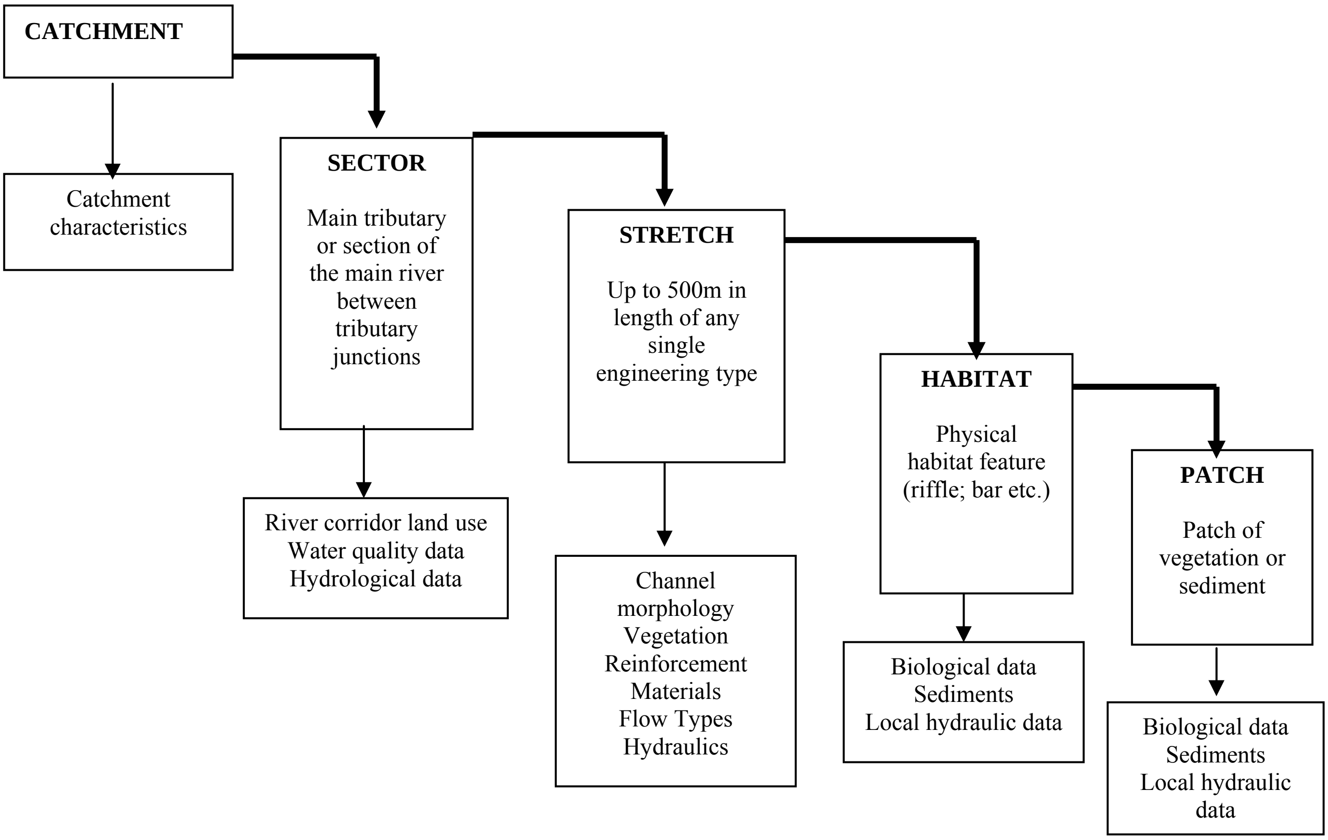

Figure 1 ***A hierarchy of six spatial scales at which urban river data may be collected, stored and analysed, with examples of the data types that might be collected at each scale***

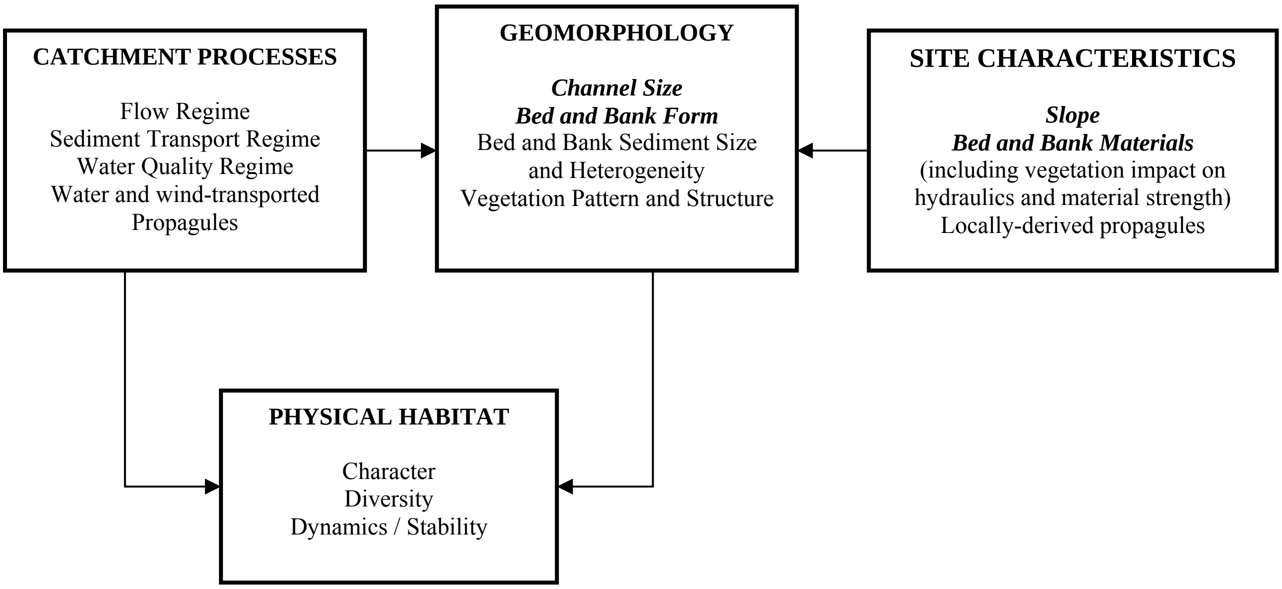

Figure 2 ***Catchment and local controls on the geomorphology of river stretches (the bold text in italics refers to factors which can adjust in many rural river channels but which are frequently fixed by engineering works in urban river channels)***

This stretch-scale modification places severe constraints on the degree to which the river form can adjust to variations in river flow and sediment transport, and it suggests that the fundamental scale for differentiating the nature and diversity of physical habitat within urban rivers is the river stretch, distinguished by engineering 'type'.

Table 1 Subdivisions of river channel planform character, cross section character and bed and bank reinforcement that can be combined to define the engineering type for a reach of urban channel.

(i) Alterations to the river's planform	(ii) Re-engineering of the channel cross section	(iii) Re-inforcement of the channel bed and banks
Semi-Natural	Semi-Natural	No re-inforcement
Straight	Restored	Bed only
Meandering	Cleaned	1 bank only
Recovered	Enlarged	Bed and 1 bank only
	Two-stage	Both banks only
	Resectioned	Full

Because the engineered stretch is the key spatial scale for defining the characteristics of urban rivers within the hierarchical framework of Figure 1, this report concentrates on a methodology for defining environmental indicators for urban river stretches. Nevertheless, the position of a stretch within a sector or the entire river network influences the flow and water quality regime to which it is subject and also the availability of plant and faunal propagules to colonise the stretch (Figure 2) and so some sector-scale summary process indicators are also relevant to the assessment of urban river stretches. It is, therefore, the interaction of stretch (i.e. primary and secondary) and sector scale (i.e. tertiary) indicators that provide an assessment of the present state of the stretch, its likely response to changes in management, and its potential for recovery.

3. A methodology for surveying urban river stretches

The majority of river geomorphological and habitat surveys have been devised for the appraisal of rural rivers (Newson, 2002). Whilst such surveys can be applied to urban rivers, they may not be sufficiently sensitive to urban river characteristics to produce discrimination between different urban river reaches. Whereas the dimensions of rural channels closely reflect the magnitude and frequency of the fluvial processes that they transmit (Wharton, 1995) and the frequency of geomorphological features, such as pools and riffles are also scaled to the channel dimensions (e.g. Leopold and Wolman, 1957), this is not often the case for urban channels. Not only is the channel size frequently a product of channel engineering, but urban channels often contain artificial structures and materials which have significant hydraulic impacts that control sediment dynamics and the creation of particular habitat types, such as bars and pools. Thus, urban channels may not display the number or pattern of physical habitats that are encountered in less heavily impacted channels. As a result, any physical assessment of urban rivers must place heavy emphasis on channel engineering. Channels subject to single types of engineering can range in length from a few metres to several hundred metres, but commonly fall in a range of 200m to 1km. Since a 500m reach of river is now widely adopted as the basis for many surveys of rural rivers in the UK, especially for the River Habitat Survey (RHS), surveys of a standard 500m reach length of a single engineering type are adopted here for surveys of urban rivers.

3.1 THE RIVER HABITAT SURVEY

The current operational habitat survey technique in the UK is the Environment Agency's River Habitat Survey (RHS). Its provides a rapid assessment of physical and hydraulic habitat, riparian structure, and ecological potential of 500m stretches of river, that can be completed by non-specialists following a short training course (Raven *et al.,* 1997). The spatial scale and widespread usage of the RHS method provides a good foundation for the development of a survey methodology specifically focussed on urban rivers. Moreover, the usefulness of both surveys is enhanced if compatibility between them can be maintained.

In brief, the RHS is comprised of 4 basic components: (i) Background Measurements; (ii) Spot-check Measurements; (iii) Once-Only Measurements; and (iv) Cumulative Measurements.

Background measurements include the date, time of the survey, grid reference, and general conditions for the assessment (adverse weather, and channel bed visibility). Properties that relate the stretch to its catchment, provide a context for the survey and can be derived mainly from secondary sources (e.g. altitude, geology, distance from source, slope) or a brief assessment in the field (e.g. valley form) are also recorded.

Spot-check measurements are recorded within 1m wide transects across the channel located every 50m along the stretch (10 spot checks per 500m stretch), with a 'catch-all' column for the final 50m in the stretch. The attributes associated with each spot-check are assessed by eye from either the bank or from within the channel, and include the physical attributes of the channel (channel substrate, bank materials, in-stream features such as bars, flow types, and forms and modifications of the channel and banks), in-channel macrophytes, the bank vegetation in terms of its complexity, and immediate land use (5m from the bank top),

Once only measurements are assessed once within the stretch. They include bank and channel width, water depth, bank top and bank full height, and embanked height.

Cumulative measurements comprise all of the measurements contained within the RHS 'sweep-up' section. A continuous assessment is made along the 500m stretch and a single recording made at the end of the survey. These attributes include the presence of trees and their associated features, bank profile types, land use, channel features, artificial features, special features and management attributes. A total of 12 separate categories are evaluated, comprising some 80 different measurements.

3.2 THE URBAN RIVER SURVEY (URS)

An important feature of the RHS is its success in harmonising the wide variety of data to be collected into a simple rapid survey. The basic structure of the survey and the definitions of the variables are maintained within the Urban River Survey (URS). The variables contained within each section of the URS may differ from the RHS, however, reflecting the differences between required for a survey focussing specifically upon urban channels. Much emphasis in the RHS is placed on the frequency of habitat features which are assessed using the spot-check measurements. Emphasis is also placed on artificial features found within the stretch, and the associated land use. In an urban context a different level of importance needs to be placed on these categories. For example, in urban rivers, the channel has often been heavily modified for flood defence, thus importance needs to be placed on characterising the habitat features associated with such modifications and with processes of recovery. Geomorphological features are often infrequent or lacking in urban channels, and their presence and frequency are, therefore, better represented as counts along the entire stretch (cumulative measurements) rather than by regularly spaced spot-checks. Artificial features also require a more detailed characterisation both in terms of their frequency and extent, especially measurements associated with the reinforcement of the channel bed and banks. Furthermore, water quality requires a more detailed assessment in urban channels to cover the range of water quality problems that might occur. These problems can be recorded using easily identifiable indicators such water colour, turbidity, algal growth or smell. Building on the current RHS, the types of variables within each of the four specific groups that need to be assessed within the URS are listed in Table 2, and are developed in greater detail below.

The URS methodology is designed to be compatible with the RHS, and is therefore equally simple to complete. Complex stretches of urban channel such as those located within rehabilitation schemes, and even stretches that remain unmodified can be surveyed within the average one hour time span that the RHS methodology advocates, while heavily engineered or extremely uniform stretches may take as little as 20 minutes to complete. However, the survey has been designed to be sensitive enough to recognise even small changes in channel form, which may be important in the hostile conditions that exist within urban channels. Each component of the URS is described and justified below, referring to equivalent measures in the RHS where necessary.

Table 2 Groups of variables that must be considered for incorporation into an URS

Geomorphological Variables	**Hydraulic Variables**	**Ecological Variables**	**Other Variables**
Channel Substrate Materials	Flow Type	Bank face Structure	Land use (5m and 50m from the bank)
Bank Materials	Channel Dimensions	Bank top structure	Water and Sediment odours
Channel Dimensions	Habitat features	Macrophyte type and amount	Oils
Bank profiles	Special features	Trees and associated features	Surface scum
Bank Protection type/amount		Species present	Gross pollution
Habitat Features		Nuisance species present	Clarity
Special features		Alders/Diseased alders present	Number of input pipes
		Evidence of Recent Management	Number of leach points
			Evidence of Recent Management

3.3 BACKGROUND MEASUREMENTS

Background measurements incorporate the variables that (i) relate the stretch to its catchment and to the river sector within which it is located; (ii) are survey-specific, placing it in a temporal context, and (iii) define the general character of the stretch against which the detailed attributes of the river channel and riparian corridor can be placed (Table 3). Several of the variables enable the surveyed stretch to be placed in a hierarchical catchment framework, as advocated by Frissell *et al*, (1986). The Hydrocatchment Identification Number (HC ID) relates the stretch to the catchment and the sector code relates the stretch to the network sector in which it lies. These are complemented by the river name and central grid reference.

Variables that define survey specific details (the date and time of the survey, the surveyor name and RHS accreditation number, and the location from which the survey is made, i.e. bank or channel), conditions at the time of survey (adverse conditions and bed visibility), and give a pictorial reference for the stretch (photographs taken) are retained from the RHS. The remaining variables describe the general character of the stretch including the engineering type, and indices of river quality that are generally applied by the Environment Agency. The latter include the General Quality Assessment (GQA) chemical quality and biological quality (Nixon *et al.*, 1996). The latter uses the RIVPACS programme (Wright *et al.*, 1993) to predict target values of the faunal parameters number of taxa, and BMWP score (Biological Monitoring Working Party) and ASPT (Average Score Per Taxon) that can be compared with observed values. BMWP scores are no longer used by the Environment Agency to calculate the GQA grading of rivers, but have proved a useful descriptor of biological quality (Hawkes, 1997).

Table 3 Variables included in the URS Background Information and their compatibility with those of the RHS methodology

RHS COMPATIBLE VARIABLES	URS SPECIFIC VARIABLES
River Name	Hydrocatchment ID Number (from EA)
Central Grid Reference	Sector Code
Surveyor Name	Stretch ID Code
Accreditation Number (from RHS course)	Stretch Name
Date of survey	Stretch Engineering Type
Time of survey	Observed BMWP Score
Adverse Conditions Affecting Results	Predicted BMWP Score
Bed Visible	Observed ASPT Score
Photographs Taken	Predicted ASPT Score
Site Surveyed From (Bank/channel)	RHS Data Available?
Distance from Source (km)	GQA Biological Quality Class
GQA Water Quality Class	
Solid Geology Code	
Drift Geology Code	

3.4 SPOT-CHECK MEASUREMENTS

Spot-check measurements when combined with a final 50m sweep up category represent the frequency and pattern of the features found within the river channel. Table 4 compares the properties recorded within the RHS and URS. The key changes to the RHS methodology are found in detailing the physical characteristics of the channel at each spot-check. Bank protection in urban rivers is a fundamental component of the channel structure. The frequency of different types of protection, and the mosaic of types found along each bank greatly influence flow hydraulics and the type of habitats found within the stretch. Furthermore, the composition of the bank material influences the durability of each type of protection. For example, gabions placed in a predominantly sand bank material may be washed out through erosion at a faster rate than gabions placed in a more cohesive bank. The URS therefore, records the underlying ‘natural’ bank materials in a separate category using the classes of sediment calibre adopted in the RHS (e.g. cobble, gravel/sand, clay etc.), while the bank protection is recorded using descriptors derived specifically for the URS (e.g. gabions, rip-rap, sheet piling etc.). The measurements of bank and channel modifications and features recorded in the RHS, have been omitted in the URS spot-check measurements, and included in the cumulative measurements.

Both bank modifications and some channel modifications are implicit in the definition of the urban stretch and, therefore, inclusion of these attributes within the spot-check section of the survey are unnecessary. Other features recorded by the RHS, such as dams and fords, are generally absent from urban channels, where the engineered function of the river is to transport large amounts of water away from the urban area as quickly as possible. Nevertheless, it is important to include all types of modification within the survey and for this reason these attributes are recorded in the cumulative measurements. 'Natural' bank and channel features such as bars and eroding cliffs, while important features of urban channels, are relatively infrequent, and the collection of data on these attributes is best served by an overall assessment of the stretch rather than by a regularly spaced assessment of the channel. Thus, a combination of the stretch definition, which summarises its engineering type, together with a series of cumulative measures rather than spot-checks provide an appropriate summary of bank and channel features and modifications within the URS.

Table 4 Comparison of spot-check variables between RHS and URS methodologies

RHS SPOT-CHECK PARAMETERS	URS SPOT-CHECK PARAMETERS
Bank Materials	Bank Materials
Bank Modifications	Bank Protection
Bank Features	
Channel Substrate	Channel Substrate
Flow Type	Flow Type
Channel Modifications	
Channel Features	
Bank Top structure	Bank Top Structure
Bank Face Structure	Bank Face Structure
Bank Top Land Use (5m)	Bank Top Land Use (5m)
Channel Vegetation	Channel Vegetation

Channel substrate is an important component of urban rivers, especially where artificial substrates have been placed within the channel. The measurement of this attribute is similar to the RHS methodology, with the categories of channel substrate being retained within the URS. Where artificial substrates occur, however, the presence of mobile substrates overlaying artificial materials is also recorded. This is important for evaluating the channel's capacity for forming features such as riffles and bars despite the rigid bed reinforcement, which ultimately may affect the ecological diversity of the channel. Measurements of flow type, bank face and bank top structure remain unchanged within the URS methodology.

The dominant land use on the bank top is also recorded in the URS. The RHS methodology categorises the typical land use types found across a range of river environments and classifies urban and suburban development as a single homogenous category. However, the urban environment is not a single expanse of land development but a complex mix of fragmented 'natural' land cover types set within and between different types of urban development. Moreover, different land use types, even in urban areas, affect stretches of rivers differently (i.e. industrial, residential, parkland). Any measurements of land use must therefore reflect this heterogeneity. The URS, therefore adopts a two-tiered classification of land-use proposed by Anderson *et al.* (1976) and modified by Meador *et al.* (1993) (Table 5). Level 1 uses entirely remotely sensed data to categorise the land into 6 broad categories: Urban, Agricultural, Rangeland, Forest land, Wetland, and Barren land, and is typically applied at a catchment scale. These broad categories are then subdivided into 21 Level 2 land use types (Table 5) that can be assessed either by using aerial photographs or during the field survey of river stretches. The URS also records the available floodplain width, which is the width of any open land use adjacent to the channel.

The final attribute measured in this section of the URS survey is that of channel vegetation. Channel vegetation in the urban environment is important for three reasons. Firstly, the diversity of the aquatic macrophytes is important for the ecological integrity of the system. Secondly, channel vegetation affects flow patterns, and excessive growth of some types of macrophyte, such as submerged fine leaved species (e.g. *Potamogeton pectinatis*) can affect channel conveyance, creating problems for flood management. Thirdly, excessive growth of macrophyte types such as filamentous algae induce marked diurnal fluctuations of dissolved oxygen within the water column (Pitcairn and Hawkes, 1973; Kirk, 1994), affecting the ecology of the system. The RHS method for measuring channel vegetation has been retained within the URS, but with one important change, the extent of each vegetation type is recorded, reflecting the importance of excessive macrophyte and algal growth (Table 6). An additional category that is critical to the ecological interpretation of the urban river is the explicit recording of non-visible channels in comparison with those that possess no vegetation cover. Modified channels frequently possess high concentrations of suspended material, especially after rainfall, which reduce the visibility of the channel bed, whilst low levels of shading combined with increased nutrient inputs from sewage effluents increase the extent of aquatic macrophytes. It is important, therefore, to make the distinction between no vegetation cover, and vegetation that is not visible. It is also important to note that although the macrophyte type ‘Filamentous Algae’ is not strictly a macrophyte, algal species such as Cladophora are a characteristic indicator of organic pollution and may grow to lengths of up to 10m (Pitcairn and Hawkes, 1973). Therefore, they are included in the appraisal of channel vegetation.

3.5 ONCE-ONLY MEASUREMENTS

The channel dimensions assessed in the RHS have been retained within the URS (i.e. bankfull width, water width, water depth, banktop height, embanked height, trashline height, and location of measurement), and an additional measurement of the amount of macrophyte cover at this point within the stretch is included for completeness. Channel dimensions are important properties of urban rivers. Although these dimensions may not always be able to adjust freely in response to fluvial processes in urban rivers, they nevertheless impact on the geomorphological features that are found within the channel. For example, depositional berms and marginal bars might be expected in overwidened channels, whilst reinforced straightened, or narrow, overdeepened channels, might produce fewer geomorphological features of a coarser sediment calibre than natural channels with a similar flow and sediment transport regime.

Table 5 Land use types used to describe land use at the catchment scale (Level 1) and finer spatial scales (Level 2)

Level 1 Land Use Codes	Level 2 Land Use Codes	Description
UR (Urban)	Re	Residential
	Cm	Commercial
	In	Industrial
	Ic	Industrial/Commercial
	Tr	Transport
	Sw	Sewage Treatment Works
	Ld	Landfill/Refuse Deposits
	Dr	Derelict Land
	Cn	Contaminated land
AG (Agricultural)	Cr	Cropland
	Pa	Pasture
	Or	Orchard
	Fe	Close Feeding (Battery Farms etc.)
FO (Forested)	Co	Coniferous
	Dd	Deciduous
	Ow	Open Woodland
PA (Pasture)	He	Heathland
	Sc	Scrub
	Op	Open Parkland (Community Grass etc.)
	Rc	Recreational Land (Playing Fields)
	Ce	Cemeteries/Crematoria
	Es	Estate Lands (Inc. MOD)
OW (Open Water)	La	Lake
	Rv	Reservoir
	Ca	Canal
	Rq	Reclaimed Quarry
	Tb	Tributary
WE (Wetland)	Fo	Forested
	Nf	Non-forested
BA (Bare)	Sm	Strip mines/Open Cast
	Ex	Exposed Rock
	Tn	Transitional

Table 6 URS channel vegetation types and example species (Adapted from EA, 1997).

RHS Channel Vegetation Type	Macrophyte Code	Example Species
None	NON	No vegetation present
Non Visible Channel	NVC	Channel bed not visible
Mosses/liverworts/ lichens	LML	Exposed or submerged
Emergent broad leaved herbs	EBH	*Apium* spp; *Rorippa* spp
Emergent reeds/sedges/rushes	RSR	*Sparganium erectum*; *Glyceria maxima*; *Schoenoplectus*; *Typha*; *Phragmites; Juncus* spp; *Carex* spp
Floating leaved (rooted)	RFL	*Nuphar lutea*; *Potamogeton natans*; *Sparganium emersum*
Free-floating	FFL	*Lemna* spp; *Hydrocharis*; *Ceratophyllum*; *Stratiotes.*
Amphibious	AMP	*Polygonum amphibium; Agrostis stolonifera; Glyceria fluitans; Alopecurus geniculatus; Myosotis scorpiodes.*
Submerged Broad-leaved	SBL	*Nuphar* spp; *Elodea* spp; *Callitriche* spp.
Submerged linear-leaved	SLL	*Sparganium erectum*; *Butomus umbellatus*; *Typha* spp; *Sagittaria sagittifolia*
Submerged fine-leaved	SFL	*Ranunculus* spp; *Myriophyllum* spp; *Ceratophyllum* spp.
Filamentous algae	FAL	*Cladophora; Enteromorpha*

3.6 CUMULATIVE MEASUREMENTS

The attributes included in this section of the survey are intended to provide an overall impression of the quality of the stretch, and how well the channel may be recovering from past modifications (Table 7). Within the urban context, quality can be determined by the diversity of the channel morphology, the vegetational structure of the riparian zone, the level of water pollution, and the recovery potential of the stretch.

Pollution exerts influence over river ecology through direct means such as toxic chemicals and leachates, or indirectly by degradation of potential habitats for biota. The RHS methodology limits the identification of pollution to a simple presence or absence within the stretch. Within the urban river, however, pollution is an important consideration where sewage effluent is often a primary component of the river's base flow, and industrial effluents and runoff from roads are also frequently major water quality impacts. To address the increased potential for pollution in urban river channels, eight pollution characteristics are recorded (Table 8). The first five of these measures are assessed on an Absent/Present/Extensive (APE) scale, where extensive relates to more than 33% of the stretch being affected by a particular pollution type. Clarity of the water is assessed as being good (water is clear and channel substrate is clearly visible), poor (the channel substrate is not visible due to high turbidity) or average (where the clarity of the water falls between these two extremes). This measurement is partly dependant upon discharge. However, the survey should be carried out under dry conditions when water levels are 'normal', thereby reducing adverse effects on the clarity of the water through increased water flows. The final two pollution measures (number of input pipes and number of leach points) are assessed as a total count of each within the stretch. The number of input pipes within a stretch serves to identify likely points of pollution pulses characteristic of urban rivers, while the leach points identify more diffuse pollution that may be important in the general water quality of the river.

Table 7 ***Comparison of attributes assessed in the cumulative measurements within the RHS and URS surveys.***

RHS CUMULATIVE MEASUREMENTS	URS CUMULATIVE MEASUREMENTS
Land use (within 50m of bank top)	Land use (within 50m of bank top)
Bank Profiles	Bank Profiles
Trees and associated features	Trees and Associated Features
Channel Features	Habitat Features
Recent Management	Recent Management
Features of Special Interest	Features of Special Interest
Choked Channel	Choked Channel
Nuisance Plant Species	Nuisance Plant Species
Alders	Alders
Overall Characteristics	
Number of Riffles, Pools and Point bars	
Artificial Features	
	Wildlife Species Present
	Extent of Pollution
	Bank Protection
	Other Information

Other measures of quality relate to the riparian structure of the channel. Riparian structure is particularly important in the urban environment where rivers may act as wildlife corridors (Goode, 1989) and so the RHS assessment of trees within the stretch has been retained within the URS. Measurements describing the structure of the bank top and face, overlying vegetation (such as trees) and the recent management of the riparian zone give an integrated impression of the riparian structure of the stretch being surveyed, that is fundamental to its ecological potential. Trees are often not present along modified channels, where appropriate substrates for tree growth are frequently limited. Furthermore, trees may be removed from stretches where they are perceived to be a significant contributing factor to flooding. Their presence, however, is important where shading reduces macrophyte growth within the channel, and also for providing cover for both aquatic and riparian species.

Nuisance plant species are another major problem in urban environments where frequent disturbance of the banks and surrounding corridors provide ideal habitats for species such as Himalayan balsam and Japanese knotweed, allowing them to out-compete native vegetation and degrade the riparian zone. The RHS method of recording nuisance species using a presence/absence measure is expanded to incorporate a simple cover scale within the URS, to reflect the increased extent and potential importance of these species: Absent; Single Individual (a single plant within the stretch); Isolated Clumps (a few small clusters of plants within the stretch); Frequent (present in 25-33%of the stretch); Extensive (>33% of the stretch).

Table 8 Types of pollution recorded in the URS.

Pollution Type	Description
Water Odours	Typically refers to the classic sewage effluent odours, but may also include industrial chemical aromas such as ammonia. Especially important where the pollutant is colourless.
Sediment Odours	Describes the characteristic odour emitted by anoxic sediments, and can easily be tested by inserting a ranging pole through the surface of the sediments.
Oils	Can be extensive in urban channels where surface runoff from roads is a major source of pollutants, and is characteristically seen floating on the water surface, or released from toxic sediments during testing for sediment odours.
Surface scum	Consists of foams caused by the presence of phosphate detergents during surface mixing. It is usually seen by sewage outfalls, but may also refer to floating mats of small particles of debris and thin foams forming in slow flowing waters.
Gross pollution	A characteristic of urban channels and incorporates larger items of urban trash including shopping trolleys, mechanical parts, and litter
Clarity	Primarily assessing the level of suspended materials, but may also include the discharge of coloured effluents
Number of input pipes	These include outfalls, land drainage pipes and small industrial outfalls.
Number of leach points	Characteristic of drainage from contaminated land. The leachate may contain ferric matter which can be readily identified by its orange colour.

Other measures of quality include recent management, wildlife species present, alders/diseased alders present (required for the national assessment of the incidence of Phytophthora root disease – Environment Agency, 1997), choked channel and other information (i.e. presence of weirs etc). These are recorded as presence/absence measurements in an identical manner to the RHS methodology. Land use 50m from the bank top is also recorded in the URS, but using the Level 2 land use types described in Table 5. Furthermore, land use for each bank is also recorded as a percentage cover to provide greater resolution in the assessment of the riparian structure and quality in the urban channel.

The presence of habitat features (equivalent to the RHS channel features) can be useful in the assessment of both urban channel quality, and urban channel recovery. Habitat features can be grouped into two distinct types: flow habitats or flow types (e.g. riffles, runs), and physical features such as bars (Table 9). Flow types are the surface expression of three-dimensional flow structures, and are associated with characteristic circulation patterns, ranges of flow velocities and bed forms within the river. The RHS methodology recognises ten categories of flow type, ranging from free fall to no flow (dry bed). It is important to assess their extent in urban channels, where even the smallest amount of variation in flow type may provide enough refugia for fauna to successfully inhabit a relatively hostile environment. Physical habitat features, such as riffles, pools and bars, are both an influence on and a result of hydraulic factors and are, therefore, important in both rural and urban habitat surveys as their varied morphological, sedimentological and hydraulic characteristics define the mosaic of physical habitats seen at the stretch scale. The RHS methodology assesses the presence of habitat features on an APE scale. However, some types of engineered stretch may produce a relatively homogenous channel in terms of its habitats, and the presence of even small amounts of variation may be sufficient to increase the ecological quality of the channel. Therefore, a more accurate assessment of the frequency of these habitats is required for the URS. To this end, the flow habitats are measured as a percentage of the stretch, whereas other habitat features are recorded as a total count of each type present within the stretch. The presence of special features such as open waters, and adjacent wetland types such as bogs and fens are recorded in the URS in an identical manner to the RHS

Table 9 Categories of habitat features recorded in the URS.

FLOW HABITATS RECORDED AS % OF STRETCH	OTHER HABITATS RECORDED AS TOTAL NUMBERS IN STRETCH
Cascade	Exposed bedrock
Rapid	Rock/boulder
Riffle	Waterfall
Run	Backwater
Boil	Sand/Silt deposits
Glide	Mature Island
Pool	Unvegetated mid-channel bar
Ponded Reach	Vegetated mid-channel bar
Marginal Deadwater	Unvegetated point bar
Stagnant water	Vegetated point bar
	Unvegetated side bar
	Vegetated side bar
	Woody debris

Other measures of channel heterogeneity and recovery are also included in the cumulative measurements. The amount of each bank protection type is recorded as a percentage of the stretch. This expands upon the URS spot-check measurements which can be used to describe the mosaic of protection types along the stretch. When the two measures (spot-check and cumulative) are combined they can be used to assess which types of protection are more important in the urban channel. Bank profiles are of fundamental importance for the assessment of channel recovery through erosion and sediment deposition. Two different types of bank profile can be present in a stretch, namely natural and artificial profiles. Artificial bank profiles are particularly significant in urban channels since they provide particular riparian habitats and offer characteristic controls on flow hydraulics. However, ‘natural’ features of recovery, which are incorporated in the RHS, such as eroding banks are also important in the urban channel, as are natural components of the bank profile such as undercutting of the bank toe, which provide refugia during spate flows, and may also be indicative of the onset of recovery processes in highly modified stretches. Recovery processes allow natural profiles to become superimposed upon the artificial profiles. Artificial and natural bank profiles are, therefore, grouped separately within the URS, and each bank profile type within these two groups is recorded as a percentage of the stretch, rather than the APE scale used in the RHS. This allows even small amounts of recovery, for example through undercutting of the bank toe, to be incorporated into the survey, whilst still maintaining a reliable assessment of the actual level of modification.

4. Aggregate indices from URS data (primary environmental indicators)

Many aggregate indices can be developed using the URS data and can mainly be attributed to one of three groups, which describe ‘Materials’, ‘Physical Habitat’ and ‘Vegetation’ features (Table 10). The derivation of each index is described in this section, where each index is constrained to have a similar numerical range (typically 0 to 10 or, –9 to +9).

Table 10 Synthetic Indices derived from the Urban River Survey relating to three different sets of characteristics of urban river stretches: ‘Materials’, ‘Physical Habitat’ and ‘Vegetation’.

MATERIALS	PHYSICAL HABITAT	VEGETATION
Proportion Immobile Substrate	Number of Flow Types	No. Channel Vegetation Types
SEDCAL	Dominant Flow Type	Channel Vegetation Cover
Proportion Immobile Left Bank Materials	Number Natural Bank Profiles	Dominant Channel Vegetation Type
BANKCAL (left bank)	Proportion Natural Bank Profiles	Total Tree Score
Proportion Immobile Right Bank Materials	Number Artificial Bank Profiles	Total Tree Feature Score
BANKCAL (right bank)	Proportion Artificial Bank Profiles	BANKVEG (left top)
BANKPROT (left bank)	Number of Habitat Types	BANKVEG (left face)
BANKPROT (right bank)		BANKVEG (right top)
Proportion No Bank Protection (NONE)		BANKVEG (right face)
Proportion Biodegradable Protection (BIO)		
Proportion Open Matrix Protection (OMP)		
Proportion Solid Protection (SOL)		

4.1 INDICES DESCRIBING MATERIALS

Channel Substrate: The channel substrate was separated into two components: immobile materials (concrete, brick, and bedrock) and mobile materials (silt, sand, gravel etc). The URS records the predominant mobile substrate at each spot check (10 cross sections along a 500m stretch) according to categories compatible with the Wentworth particle size scale. The **SEDCAL index** converts these spot-check measurements into an approximate average particle size for the stretch in phi units.

$$\text{SEDCAL} = \frac{(-8*BO) + (-7*CO) + (-3.5*GP) + (1.5*SA) + (1.5*SI) + (9*CL)}{(BO + CO + GP + SA + SI + CL)}$$

(BO=boulder; CO=cobble; GP=gravel-pebble; SA=sand; SI=silt; CL=clay)

An index of the proportion of the stretch with bed reinforcement is:

$$\textbf{Proportion Immobile Substrate} = \frac{\text{number of spot-checks with immobile materials}}{\text{number of spot-checks}} \times 10$$

Bank Materials: Since data are gathered separately for the two river banks in the URS, the synthetic indices were also estimated for both banks, although they could also be combined to give a stretch summary.

The URS records similar measurements for mobile bank materials as for the channel substrate based upon the Wentworth scale. The **BANKCAL index** converts these spot-check measurements into an approximate average particle size for the stretch banks in phi units

$$\text{BANKCAL} = \frac{(-9*BO) + (-8*CO) + (-2.5*GS) + (4*EA) + (9*CL)}{(BO+CO+GS+EA+CL)}$$

(EA=earth)

The **proportion of Immobile Bank Materials** (concrete, concrete and brick, laid stone, sheet piling, and bedrock) is calculated in the same way as for the Immobile Substrate.

Bank Protection: The various types of protection used in urban channels can be placed into different categories according to their attributes, and then be ascribed a numerical value relating to their durability and permeability (Table 11).

Table 11 Bank Protection Types

CATEGORY	BANK PROTECTION TYPES	NUMERICAL VALUE
None	None; Washed Out	0
Biodegradable	Reeds; Wood piling; Willow spiling	1
Open Matrix	Rip-rap; Gabions; Builders waste	2
Solid	Concrete; Concrete and Brick; Brick/Laid stone; Sheet piling	3

The numerical value given to each category can then be used to calculate the level of protection for each bank.

$$\textbf{BANKPROT} = \frac{(0*NONE) + (1*BIO) + (2*OMP) + (3*SOL)}{(NONE+BIO+OPM+SOL)} \times 3$$

The overall type and level of protection for the stretch can be taken from the URS cumulative measurements. The types of protection are grouped into the four categories of none, biodegradable, open matrix and solid, and the proportion of the stretch that these types represent is then calculated. From this the **Proportion of No Bank Protection (NONE), Biodegradable Protection (BIO), Open Matrix Protection (OMP)** and **Solid Protection (SOL)** can be estimated.

4.2 INDICES DESCRIBING PHYSICAL HABITAT FEATURES

Flow Types: The water surface pattern of flow types reflects the three-dimensional flow patterns induced by the form and roughness of the channel, and is therefore an important indicator of flow hydraulics and channel bed morphology.

Two indices help to characterise this hydraulic and morphological diversity. Firstly, the **dominant flow type** gives an indication of the general character of the stretch. This can be easily determined from the spot-check measurements, by selecting the flow type which is recorded the most times. Where two categories occur with equal frequency, the flow habitats recorded in the cumulative measurements can be used to determine the dominant flow type within the stretch. The flow types in part reflect the flow velocity, and so the dominant flow type can be arranged along a flow velocity gradient (Table 12) from faster flow types (index value 1) to slower flow types (index value 10). Secondly, the **number of flow types** within a stretch is important for looking at hydraulic and bed form variability, and can be ascertained by a count of the number of different flow types recorded in the spot-checks. Together these indices give an indication of the heterogeneity of the stretch in terms of its hydraulics, and associated channel morphology.

Table 12 Index Values for the dominant flow type within the stretch.

Flow Type	Index Value
Free Fall (FF)	1
Chute Flow (CH)	2
Chaotic Flow (CF)	3
Broken Standing Waves (BW)	4
Unbroken Standing Waves (UW)	5
Rippled (RP)	6
Smooth (SM)	7
Upwelling (UP)	8
No Perceptible Flow (NP)	9
Dry Channel (DR)	10

Habitat features: While the nature and extent of habitats within a stretch can be drawn from the raw URS data, a simple count of the **number of different habitat types** observed within the stretch (not the total number of habitats) provides a simple, integrative index of the diversity of habitats that are present. This integrative index represents a count of in-channel habitat types, including both the morphological (e.g. bars, islands, riffles, pools etc.), and hydraulic (flow type) habitats that are present.

Bank Profiles: The URS recognises two different categories of bank profiles, artificial and natural, reflecting the historical management practises and the level of bank profile recovery from past modification. Where the urban channel shows evidence of recovery processes through erosion, natural profile components become superimposed on artificial profiles, giving a total of observed profiles of over 100%. Similarly, where an urban channel displays two different types of modification (e.g. two stage channel and reinforced banks), the total proportion of artificial profiles can exceed 100%. It is important to distinguish channels that show evidence of recovery, in order to explore the effects that different types of engineering may have on the urban channel. To this end, separate indices are developed for natural and artificial bank profiles. The **number of natural profiles** and the **number of artificial profiles** comprise two of the indices from this group of measurements, which can be ascertained from the cumulative measurements. This gives an impression of the heterogeneity of the channel in terms of its bank characteristics, and provides an indication of the processes involved in the recovery of the channel. The **proportion of artificial profiles**, and the **proportion of natural profiles** comprise the final two indices to come from this group of measurements. The quantitative nature of these measurements allows a simple index to be derived by dividing the recorded percentage by 10.

4.3 INDICES DESCRIBING VEGETATION STRUCTURE AND BIOMASS

Bank Face and Top Structure: One of the characteristics of urban channels is the uniformity of the bank in terms of its vegetation. To reduce the roughness of the channel, tall vegetation tends to be removed, thus increasing the capacity of the channel. The URS records the vegetation structure in the same way as the RHS (B = bare, U = uniform, S = simple and C = complex). The spot check measurements can be combined into a simple index of the bank vegetation, where higher values represent increased vegetation complexity. The engineered channel may display different complexities of vegetation between the banks, and between the top and face of the bank. Therefore a calculation is made for each bank top and face structure using the following calculation:

$$\mathbf{BANKVEG} = \frac{(0*B) + (1*U) + (2*S) + (3*C)}{(B+U+S+C)} \quad x3$$

The presence of trees is calculated on a scale of absent to continuous for the entire length of the stretch river banks, and the right and left bank can be added together to give a representative index of cover or **total tree score** for the whole stretch (None = 0, Isolated/Scattered = 1, Regularly spaced = 2, Occasional Clumps = 3, Semi-continuous = 4, Continuous = 5).

Tree features (shading of channel, overhanging boughs, exposed bankside roots, underwater tree roots, fallen trees, coarse woody debris) represent the degree to which marginal trees directly influence the river channel environment. They are measured on the APE scale, where Absent, Present, and Extensive score 0,1 and 2 respectively. The scores for each of the 6 features are added together to give an index of tree influence along the stretch called the **total tree feature score**. Combined, these two scores represent the extent and level of impact of the different tree associated features.

Channel vegetation: To fully assess the nature of the macrophytes within the channel, the measurements taken in the spot-checks can be separated into 3 important components.

The **number of channel vegetation types** can be used to indicate the macrophyte diversity, which in turn can help to indicated water quality. The number of vegetation types consists of a simple count of the number of different macrophyte groups over the stretch. The number of types could therefore be as high as 10 in stretches that possess high species numbers.

The **dominant channel vegetation type** can be easily determined by a simple addition of the percentage cover each species has at each spot-check. However, in order to represent this numerically for future analysis, the vegetation types must be ranked according to the properties they possess, or the effect they have on urban channels. In terms of management, each macrophyte type will have a greater or lesser effect on the attenuation of flow in the channel. Thus the macrophyte types can be arranged on a linear scale, from low to high, according to their potential effects on the hydraulic regime of the stretch (Figure 3). Where non-visible channels are recorded two possible options exist to explore the data fully. Where a complete spot-check is recorded as being non-visible the measurement is excluded from the result and the number of spot-checks used is reduced. Where partial measurements of channel vegetation have been recorded and the rest of the channel is not-visible at any individual spot-check, the vegetation measurements are extrapolated to represent the entire channel at that spot-check.

The average cover of the channel combined with the dominant vegetation type, can be used to assess diversity, but may also help to highlight areas where the management of macrophytes is important. The calculation of the **average channel vegetation cover** is taken for the entire stretch. Again where non visible channels are present, the same principles apply for assessing the entire stretch as for calculating the dominant macrophyte species. Once this has been achieved, a simple average is taken of all the macrophyte types to give the % cover for the stretch. To maintain the same range as other indices, the percentage result is divided by a factor of 10. It is reasonable to hypothesise that different engineering types will promote different levels of channel cover, and diversity in terms of the macrophyte growth, although this might be confounded by the amount of shading present at different stretches.

Low attenuation of flow	**0** = NON	none
	1 = LML	Liverworts / mosses / lichens
	2 = FFL	Free-floating
	3 = AMP	Amphibious
	4 = EBH	Emergent broadleaved herbs
	5 = FAL	Filamentous algae
	6 = RFL	Floating leaved (rooted)
	7 = SLL	Submerged linear-leaved
	8 = SBL	Submerged broadleaved
	9 = SFL	Submerged fineleaved
High attenuation of flow	**10** = RSR	Emergent reeds/sedges/rushes

Figure 3 Macrophyte types grouped according to their perceived attenuation of flow in urban channels.

The pollution measurements can be divided into three different indices. The **total pollution score** can be calculate from the first 5 variables listed in Table 8, which are measured on the APE scale, and the clarity which can be assigned a similar score where good, average and poor score 0,1 and 2 respectively: the higher the score, the higher the extent of pollution within the stretch.

The **number of leach points** and the **number input pipes** comprise the other 2 indices for pollution. The total number of each that is measured in the URS (Table 8) is converted into a score as follows:

Number of pipes		Score
0	=	0
1	=	1
2	=	2
3	=	3
4	=	4
5	=	5
6-9	=	6
10-14	=	7
15-20	=	8
20-30	=	9
>30	=	10

5. *Classification of urban river stretches (secondary environmental indicators)*

A set of secondary environmental indicators have been devised by analysing URS surveys of 106 stretches of the river Tame catchment. The surveys were undertaken during summer 2003, and the secondary environmental indicators are derived by classifying groups of the primary indicators described in section 4. The classifications and resultant secondary environmental indicators presented in this section represent the refined versions of classifications that were developed previously by Davenport et al (in press) from a smaller dataset.

5.1 DATA ANALYSIS

Cluster analysis was applied to the derived aggregate indices (primary environmental indicators) that are described in section 4 and listed in Table 10. Because of the similar numerical range in these aggregate indices, cluster analysis was applied to the untransformed data. Davenport et al (in press) tested various clustering algorithms (within-group average linkage, between-group average linkage, centroid, and Ward's algorithm) using a more restricted data set based on applying the URS to stretches of the River Tame. Ward's clustering algorithm was finally selected because it produced distinct, compact clusters of similar size conforming to the view that the algorithm generates 'the most appealing overall results in terms of cluster size, shape (compactness), density and internal homogeneity' (Griffith and Amrhein 1997, p220). Therefore, Ward's algorithm was used in the present analyses.

Once each cluster analysis was complete, and a dendrogram describing the hierarchical agglomeration of the objects produced, the identification of the number of clusters or classes that best described the data was, inevitably, somewhat subjective. The dendrogram was inspected to identify agglomerations to between 3 to 8 clusters and the number of clusters selected within this range was based on the generation of the most clearly defined groups within the dendrogram and the degree to which the clusters had an interpretable meaning.

The validity and meaning of the clusters was assessed by (i) applying non-parametric (Kruskal Wallace) analysis of variance (ANOVA) to identify which of the individual attributes provided a statistically significant ($P<0.05$) discrimination between the clusters; (ii) inspecting box and whisker plots for each of the discriminatory attributes to identify which clusters were discriminated by each attribute and the strength of the discrimination; and (iii) identifying whether the clusters were comprised of any distinct engineering types, which might suggest a causal impact of engineering on cluster characteristics.

Using the indices listed in Table 10, cluster analysis was applied separately to stretch scores on the 'Materials', 'Physical Habitat' and 'Vegetation' aggregate indices. The aim was to identify groupings within the data that could be arranged along a gradient reflecting increasing complexity or naturalness in relation to these three secondary environmental indicators, so that the defined classes could represent 'intensities' of the 'Materials', 'Physical Habitat' and 'Vegetation' Environmental Indicators. The clusters or classes to which each surveyed stretch was allocated for each of these three environmental indicators was also compared with the type of engineering that had been applied to assess whether there were links that would support the direct modelling of scenarios of changed engineering modification on stretch characteristics or whether the defined clusters were independent of engineering type.

5.2 MATERIALS ATTRIBUTES

The indices used within the Materials cluster analysis (Table 10), reflect the character of the natural bed and bank materials and of the artificial materials used to reinforce the channel banks and/or bed. Therefore, the attributes that underpin the cluster analysis reflect the potential susceptibility of the river bed and banks to modification through fluvial processes. 7 classes of stretches were identified (Figure 4). The proportion of Immobile Substrate and the proportion of Biodegradable Protection were not significant in discriminating between the clusters, although the former provides a useful index for discriminating the Heavily Engineered Class of stretches. In contrast, the calibre of the sediment and bank materials (SEDCAL and BANKCAL respectively) and the type and amounts of bank protection (BANKPROT, Proportion No Bank Protection, Proportion Open Matrix Protection, Proportion Solid Protection) were found to be important discriminatory attributes. Although the engineering type was not included in the analysis, this is clearly reflected in the level of reinforcement and so, not surprisingly, each cluster is comprised of stretches that possessed distinct types of engineering modification (Table 13). The combination of engineering and natural materials is reflected in the names given to the clusters.

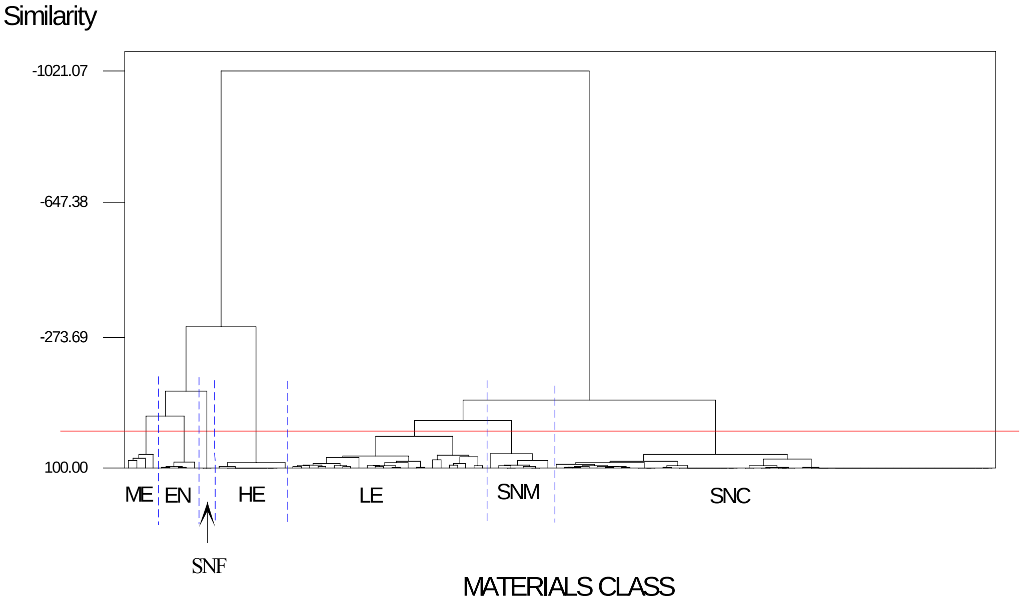

Figure 4 7 clusters of urban river stretches defined by their materials characteristics

Table 13 Descriptions of the characteristics of stretches attributed to different Materials clusters

Group Name: abbreviation	Description of discriminating Primary (Materials) Indicators	Description of broad Engineering Characteristics
SEMI-NATURAL (COARSE): SNC	Low proportions of bank protection. Coarser substrates (SEDCAL) and bank materials (average BANKCAL).	More natural planforms and cross sections (developed through natural processes, recovery or restoration), typically with some sinuosity
SEMI-NATURAL (MIXED): SNM	Low proportions of bank protection, with mixed substrates typically corresponding to silt/sand with some gravels (SEDCAL).	Artificial (mainly straight) planforms, and cross-sections but with limited reinforcement
SEMI-NATURAL (FINE): SNF	Low proportions of bank protection. Finer (typically clay) substrates (SEDCAL) and bank materials (BANKCAL).	Natural sinuous planforms and cross-sections with limited reinforcement
LIGHTLY ENGINEERED: LE	Coarser bed and bank materials (SEDCAL, BANKCAL). Moderate proportions (ca. 30-85%) of open matrix protection (gabions, rip rap etc).	Artificial (usually sinuous) planforms, and cross-sections with significant reinforcement
ENGINEERED: EN	High (ca. 90-100%) proportions of open matrix bank protection and moderate proportions (ca. 20-50%) of solid bank protection. Low proportions of immobile substrate.	Artificial (mainly straight) planforms and cross-sections with extensive reinforcement
MODERATELY ENGINEERED: ME	High proportions (50-90%) of solid bank protection (concrete, laid stone etc.) but low proportions of immobile substrate (i.e. bed reinforcement).	Artificial (mixed sinuosity) planforms and cross-sections with extensive reinforcement
HEAVILY ENGINEERED: HE	High proportions (ca. 100%) of solid bank protection (concrete, laid stone etc.) and immobile substrate.	Heavily engineered, straight planforms and high levels of reinforcement on the banks and the bed.

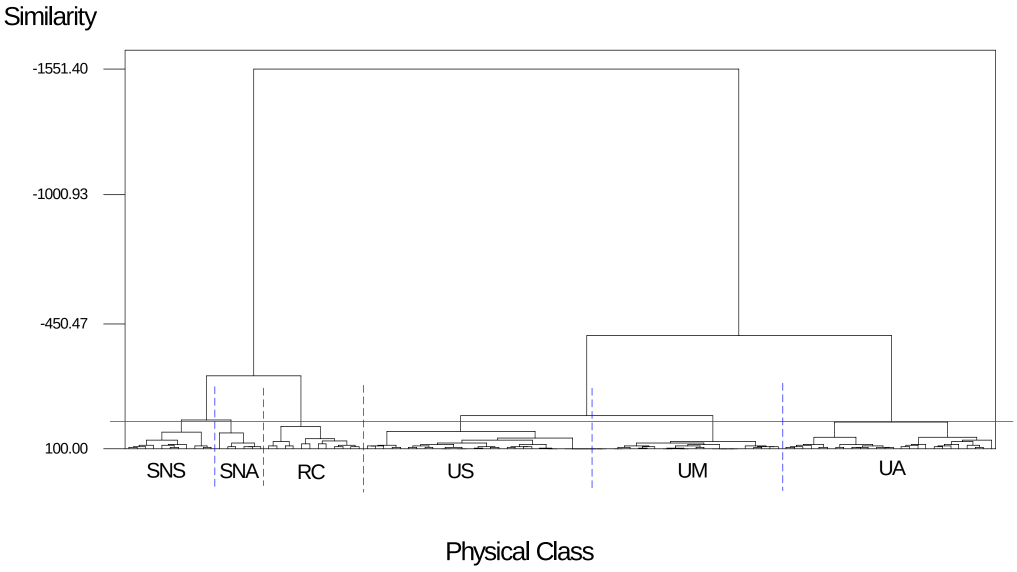

Figure 5 6 clusters of urban river stretches defined by their physical habitat characteristics

Table 14 Descriptions of the characteristics of stretches attributed to different Physical Habitat clusters.

Group Name: abbreviation	**Description of discriminating Primary (Physical) Indicators**	**Typical Physical Habitat Characteristics**	**Description of Broad Engineering Characteristics**
SEMI-NATURAL (ACTIVE): SNA	Very low Proportions of Artificial Bank Profiles and very high Proportions of Natural Bank Profiles. ≥7 different Habitat Types.	Mixed flow regime (20-30% riffle), some evidence of pool formation. Typically contain 7-8 vegetated/ unvegetated bars.	Predominantly natural sinuous planforms.
SEMI-NATURAL (STABLE): SNS	Very low Proportions of Artificial Bank Profiles and very high Proportions of Natural Bank Profiles. <7 different Habitat Types.	Flow dominated by glides (50-90%) with no evidence of pool formation. Typically contain 0-4 vegetated/unvegetated bars.	Predominantly natural sinuous planforms.
RECOVERING: RC	Moderate Proportions of Artificial Bank Profiles (40-100%) and high Proportions of Natural Bank Profiles (50-100%). < 7 different habitat types.	High levels of active bank recovery from engineering intervention. Some evidence of mixed flow regime (5-20% riffle, 60% glide) with some pool formation. Typically contain 1-4 vegetated/ unvegetated bars.	Predominantly artificial sinuous planforms.
UNIFORM ACTIVE; UA	High Proportions of Artificial Bank Profiles (ca. 100%), and moderate to high Proportions of Natural Bank Profiles (ca. 0-50%). 5-9 different habitat types.	Some evidence of active channel recovery through bank erosion. Some evidence of mixed flow regime (10-25% riffle, 40-60% glide) but no distinct pool formation. Typically contain 2-6 vegetated/unvegetated bars.	Predominantly artificial planforms most with some sinuosity.
UNIFORM MODERATELY ACTIVE: UM	High Proportions of Artificial Bank Profiles (ca. 100%) and low Proportions of Natural Bank Profiles (ca. 0-30 %). Lower numbers (3-4) of Habitat Types.	Little evidence of channel recovery through bank erosion. Channel dominated by glides (70-90%). Typically contain 1-2 vegetated/unvegetated bars.	Predominantly artificial straight planforms
UNIFORM STABLE: US	High Proportions of Artificial Bank Profiles (ca. 100%). Very Low Proportions of Natural Bank Profiles (ca. 0%). Very low Numbers (1-2) of Habitat Types.	No evidence of active channel recovery through bank erosion. Flow almost entirely glides (90-100%) Typically contain 0 bars.	Predominantly artificial straight planforms.

5.3 VEGETATION ATTRIBUTES

The final cluster analysis is primarily concerned with the characteristics of the in-channel and bank vegetation. 8 clusters were identified and all of the variables included in the cluster analysis showed significant discrimination between clusters. The dominant channel vegetation type (unvegetated channels, algal dominated channels, and vegetated channels) discriminated two large clusters: an unvegetated cluster and a cluster that was predominantly vegetated with the algal – dominated channels forming a distinct subgroup (Figure 6). The total tree score and average bank face and top complexity provide additional discriminatory factors. Again, the clusters were associated with different types of engineering, especially with the sinuosity of the channel (Table 15).

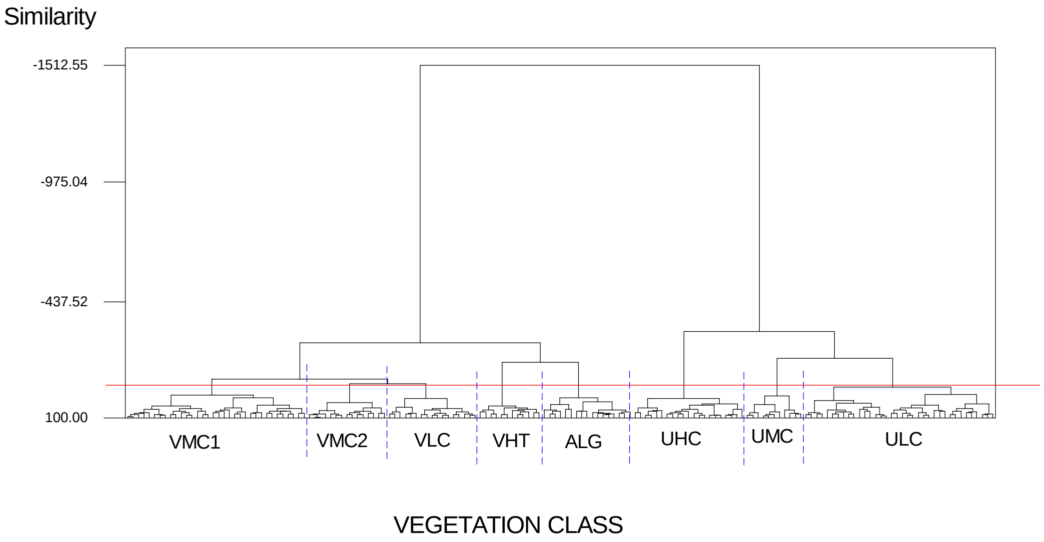

Figure 6 8 clusters of urban river stretches defined by their Vegetation characteristics

Table 15 Descriptions of the characteristics of stretches attributed to different vegetation clusters.

Group Name: abbreviation	Description of discriminating Primary (Vegetation) Indicators	Description of broad Engineering Characteristics
Vegetated Moderate Complexity: VMC1	Vegetated channels with low Total Tree Scores (< 6) representing isolated scattered to occasional clumps, and a higher mean bank top than bank face vegetation complexity (average top BANKVEG>4 and average face BANKVEG <5).	Mainly sinuous channels, either natural or artificial.
Vegetated Moderate Complexity: VMC2	Vegetated channels with low Total Tree Scores (< 6), and a higher bank face than bank top complexity (average top BANKVEG <4 and average face BANKVEG >5 resp.).	Mainly artificial straight channels.
Vegetated Low Complexity: VLC	Vegetated channels with low Total Tree Scores (< 6), and low bank face BANKVEG and top BANKVEG indices.	Mainly artificial straight planforms with some natural planforms (typically running through farmland).
Vegetated High Trees: VHT	Vegetated channels with high Total Tree Scores (>6) equivalent to semi-continuous – continuous tree cover.	Artificial planforms usually straight but some display sinuosity.
Algal Channels: ALG	Channels dominated by algae (Dominant Vegetation Type = Algae)	Mainly artificial straight planforms.
Unvegetated Low Complexity: ULC	An aggregate group comprised of unvegetated channels with either relatively low levels of Total Tree Scores (<6) or with a higher tree cover combined with low bank face and top complexity (average face BANKVEG <6.5 and average top BANKVEG <6).	Mainly artificial planforms usually straight but some display sinuosity.
Unvegetated Moderate Complexity: UMC	Unvegetated stretches with higher Total Tree Scores (>6), combined with low average top BANKVEG (<6.5) and high average bank face BANKVEG (>6).	Mainly artificial planforms usually straight but some display sinuosity.
Unvegetated High Complexity: UHC	Unvegetated stretches with high Total Tree Scores (>6), combined with high bank top vegetation complexity (average top BANKVEG >6.5).	Mainly artificial planforms with some sinuosity.

5.4 ENVIRONMENTAL INDICATORS

The classifications presented in sections 5.2 to 5.4 illustrate that there are three broad secondary environmental indicators (Materials, Physical Habitat, Vegetation) which can be used to allocate engineered stretches to 7, 6 and 8 different classes, respectively. These secondary environmental indicators all appear to be related to the level and type of engineering to some degree, although the strongest associations are with Materials and the weakest are with Vegetation. In order to identify the class to which any new stretch should be allocated without re-running the entire cluster analysis this section proposes three decisions trees (Figures 7 to 9) for this purpose. These decision trees enable a newly-surveyed stretch to be allocated to an appropriate ‘Materials’, ‘Physical habitat’ and ‘Vegetation’ class. The decision trees do not incorporate all of the variables (Primary Environmental Indicators) that were used to define the classes because many of these are highly correlated. Thus, the decision trees incorporate the minimum number of key variables that are needed to allocate a newly-surveyed stretch to the various classes.

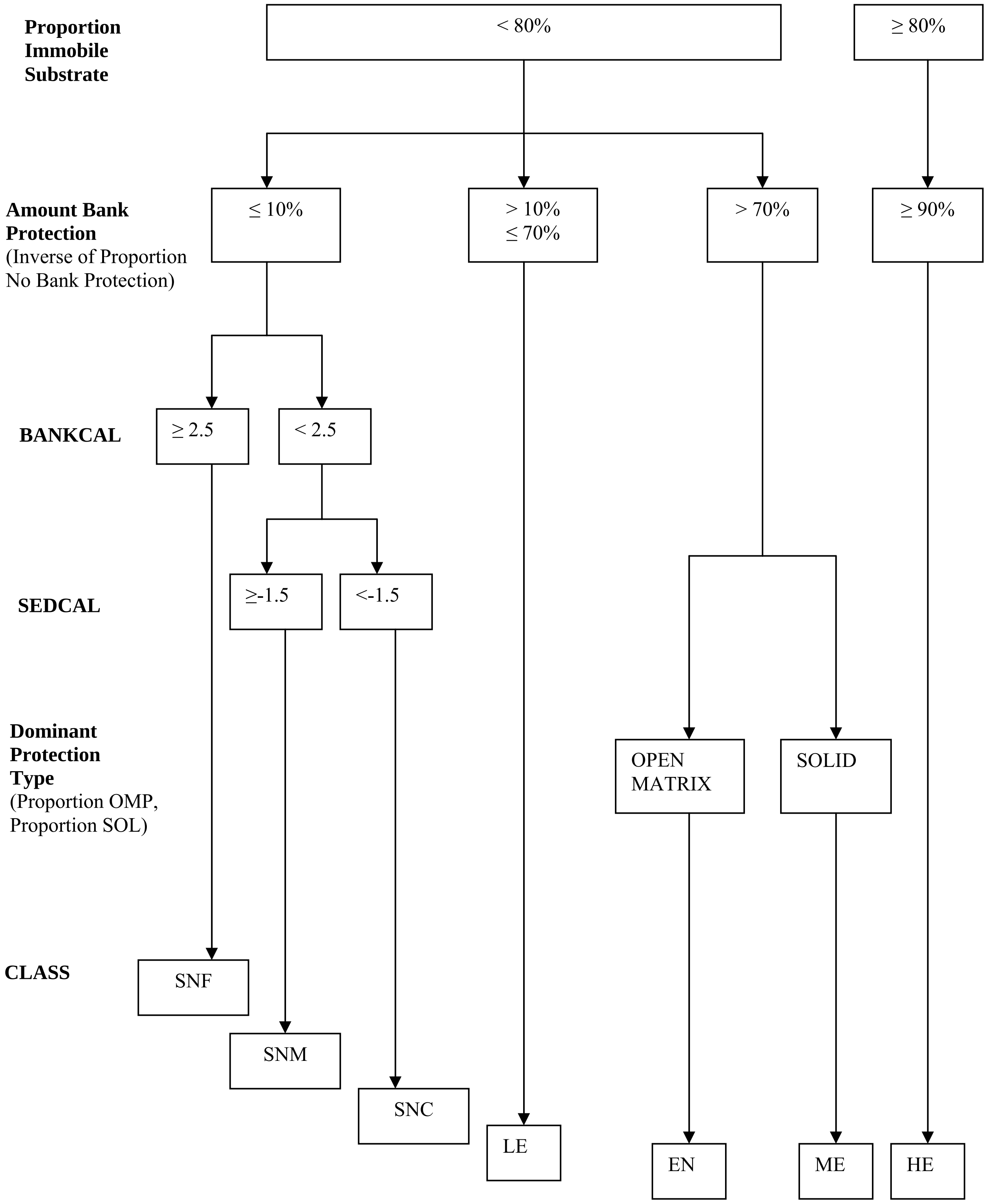

Figure 7 Flow chart for allocating urban river stretches to the relevant Materials Class

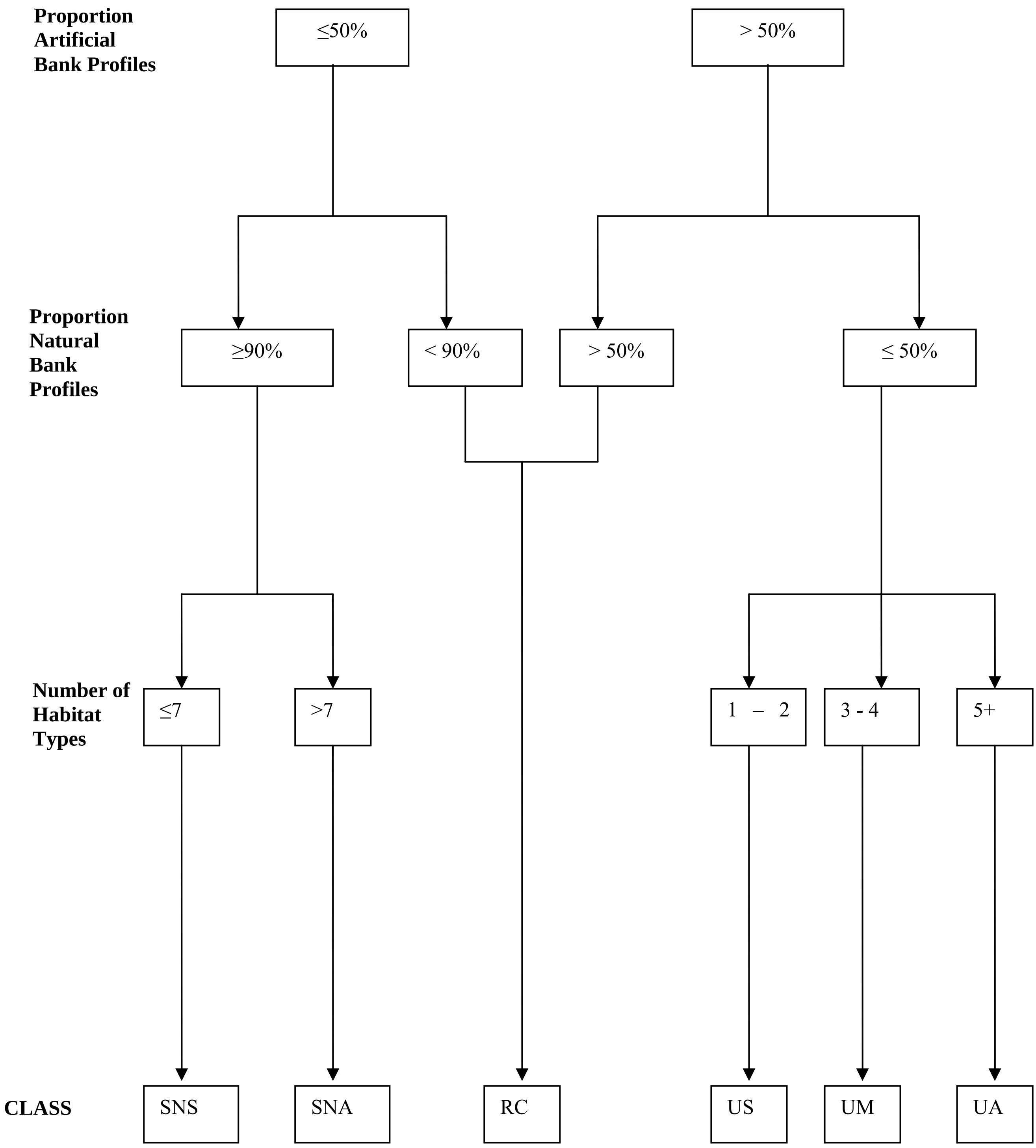

Figure 8 Flow chart for allocating urban river stretches to the relevant Physical Class

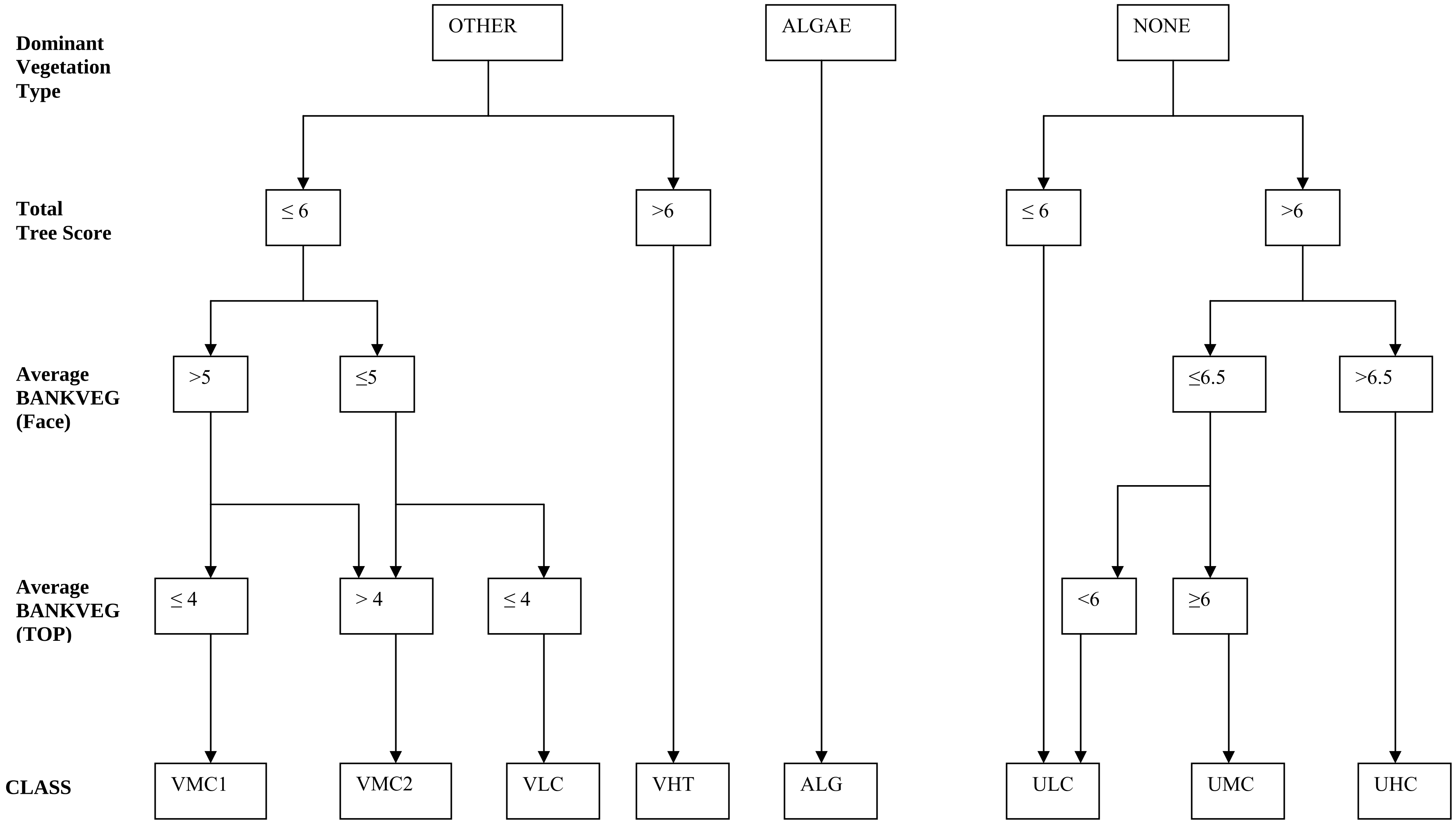

Figure 9 Flow chart for allocating urban river stretches to the relevant vegetation class.

6. Sector scale indices (tertiary environmental indicators)

Whilst the secondary environmental indicators can be used to assess the likely outcomes of applying different management and engineering options to a stretch, the success of such actions may be constrained by other, largely sector-scale, characteristics. For example:

- If water quality or transported sediment quality are low, changes in physical habitat are unlikely to yield any ecological benefit.
- If sediment supply from upstream is low, then changes in physical habitat dependent upon geomorphological adjustment within a stretch will not be sustained.
- Certain changes in the engineering of reaches may be inherently unstable because of the energy of sector-scale river flows, or may not meet flood-defence requirements.
- Even if water quality, sediment supply and flow regimes do not present constraints on the outcomes of changes in the secondary environmental indicators, land use and land availability may restrict the space available for such changes.

Thus the tertiary environmental indicators provide simple indicators of such constraints on the potential to achieve particular stretch – scale objectives.

(N.B. Where surveys are available within a stretch, many of the indicators described in this section are recorded in the URS using existing data sources (see section 3). However, as a result of the limited availability of such surveys, they may only be available for locations elsewhere within the sector and so they are presented here as sector-scale indices).

6.1 FLOW-RELATED INDICATORS

The river flow regime is a constraint in terms of achieving flood defence targets (high flow magnitude), ensuring that any stretch–scale modifications do not result in major channel instabilities (high flow energy), and ensuring that there is sufficient aquatic habitat to support species during low flows (low flow magnitude and depth).

To reflect the above sensitivities, flow indices including the mean annual flood magnitude (and its unit stream power within stretches of differing width), the maximum recorded flow and the 5, 50 and 95 percentiles of the flow duration curve are required for channel network sectors.

6.2 SEDIMENT-RELATED INDICATORS

The concentration, calibre and quality of sediment transported by the river are constraints in terms of the range of geomorphological adjustment that can occur and the biota that can be supported. Whilst the flow regime provides the energy to move sediments and construct and erode landforms, the availability of sediment for transport is essential for landform construction, and the calibre of the sediment constrains the degree of adjustment and the types of landform that can be supported. The concentration of transported fine sediment is sometimes determined as a component of analyses of water quality (see below), but coarser sediments are also required for landform construction and their transport is not routinely monitored. Thus, the availability of sediment for driving morphological change can only be determined by evidence of the presence of active sediment sources (e.g. eroding banks, sedimentary bedforms) upstream of any particular stretch. Such information can be derived from URS surveys of upstream stretches as can the likely calibre of sediment delivered from those sources. Sediment quality or contamination is also an important constraint on the success of river channel modifications. Both water quality and sediment quality can severely limit the ecological benefits of channel modifications.

6.3 WATER QUALITY INDICATORS

Water quality modifications found in urban rivers arise from three key sources: domestic and sewage effluents, industrial effluents, and road runoff. Each of these effluents include different and characteristic types of pollutant. Domestic and sewage effluents primarily contribute to the nutrient enrichment of the river system through inputs of nitrogenous and phosphate compounds. The exact nature of industrial effluents largely depends upon the industrial processes being used. However, heavy industrial processes such as metal working may create an increase in metal concentrations within the river (copper, lead, aluminium, iron cadmium etc.). Surface runoff from roads increases levels of electrical conductivity, especially in winter where salting of the roads is employed for de-icing. Lead and petrol derived hydrocarbons are also components of road surface runoff.

Water quality indices have been developed across Europe in response to legislation controlling the safety limits of sanitary determinants for bathing and drinking waters (e.g. EEC, 1975; EC 1991; 1994) and the perceived impacts that poor water quality has upon the ecology of river, lake and marine systems. Typically, these individual indices have been combined to provide a basic classification of water quality for any given sector of river. The water quality indicators can, therefore, based upon the requirements of the water quality classification developed for use in each member country.

Whilst many indicators could be used to represent sector-scale water quality, the SMURF study of the River Tame catchment will use the River Ecosystem Classification (RE), which is currently used within the UK and combines 8 key parameters to assign a river to one of 5 classes (Table 16). The listed indices are derived from either continuously monitored data, or from spot-check samples taken monthly. The former is clearly preferable as the indices are based on a larger sample of determinations. However, continuous monitoring in urban rivers is typically limited to only one or two sites within a catchment and therefore, the RE classification is often based upon a spot sampling regime. In order to ensure that results are not biased by uncharacteristic local events (such as a single pollution episode), the RE rating is based upon a minimum of 12 samples, with a recommended monthly sampling regime.

Table 16 Water Quality Criteria for defining River Ecosystem Classes (from NRA, 1994)

Class	Do (%)	BOD Mg/L	Total Ammonia	Un-Ionised Ammonia	pH	Hardness	Dissolved Copper	Total Zinc
RE1	80	2.5	0.25	0.021	6-9	<10	5	30
						>10 and <50	22	200
						>50 and <100	40	300
						>100	112	500
RE2	70	4.0	0.6	0.021	6-9	<10	5	30
						>10 and <50	22	200
						>50 and <100	40	300
						>100	112	500
RE3	60	6.0	1.3	0.021	6-9	<10	5	300
						>10 and <50	22	700
						>50 and <100	40	1000
						>100	112	2000
RE4	50	8.0	2.5	-	6-9	<10	5	300
						>10 and <50	22	700
						>50 and <100	40	1000
						>100	112	2000
RE5	20	15.0	9.0	-	-	-	-	-

6.4 BIOTIC INDICATORS

The combined effects of degraded channel morphology and water quality within urban rivers is often an equally poor ecological community. Contemporary bioassessment classification systems are typically based upon the natural distribution of species within river systems and their tolerance to environmental conditions and pollution, and can be used to assess levels of sub-lethal stress within the system. Most European countries have developed, or are developing, biotic classification systems similar to those developed for water quality, based upon the response of the benthic macroinvertebrate community to poor water quality. Therefore, the indicators for biotic integrity of the river can be based upon the classification developed by each member country.

The present study will adopt the UK approach to biological classification of rivers. This has been based the Biological Monitoring Working Party (BMWP) scoring system, developed between 1976 to 1978, and revised in 1981 (Hawkes, 1997). It assigns a score from 1 to 10 to families of taxa according to their perceived tolerance to pollution (mainly organic pollution). Each family scores once within the sample, and the scores for each taxa are added together to give a total score for a site. This score can then be used within a classification index such as the General Quality Assessment to assign each site to a class according to its quality of benthic invertebrate community (Nixon *et al.*, 1996).

The need for a more predictive approach to river management instigated the development of the River InVertebrate Prediction And Classification System (RIVPACS), a computer-based tool that predicts the list of taxa that should be found at any given site according to the physical and chemical conditions within the channel (Wright *et al.*, 1993). This type of prediction can be used as a reference condition for assessing the level of degradation at a site due to water quality problems. In order to ensure that the system can be fully integrated into river management, the taxa list can be used to produce predicted BMWP and ASPT scores. The predictive capability of RIVPACS and its ability to produce a reference condition for polluted rivers, has allowed its incorporation into the General Quality Assessment (GQA) employed by river managers in the UK (Nixon *et al.*, 1996).

The GQA scheme grades rivers into 6 classes ranging from A to F where A represents high quality and F represents poor quality rivers (Table 17). The observed and predicted BMWP and

ASPT scores are used to produce an ecological quality index (EQI) which is used to classify each site, where the observed value is divided by the predicted value.

***Table 17** The GQA classification of rivers according to their biological quality incorporating RIVPACS derived EQI indices (EA, Pers. Comm).*

GQA GRADE	INFERRED QUALITY	EQI TAXA (BMWP)	EQI ASPT	BMWP SCORE
A	Very good	> 0.85	1.00	>95
B	Good	0.70-0.84	0.90-0.99	68-95
C	Fairly good	0.55-0.69	0.77-0.89	51-67
D	Fair	0.45-0.69	0.65-0.76	35-50
E	Poor	0.30-0.44	0.50-0.64	13-34
F	Bad	<0.30	<0.50	0-12

6.5 LAND USE AND LAND AVAILABILITY

The URS directly records land use at both stretch and sector scale (Table 5). These data form a final class of tertiary environmental indicator since they represent land use, land quality or open land availability constraints on the engineering options that may be considered for a particular stretch.

7. Combining indicators to address scenarios of change

The preceding sections have described the derivation of primary and secondary environmental indicators at the stretch scale and tertiary indicators at the sector scale. However, in order to enable river managers to consider management scenarios these different levels of indicators need to be combined.

The **secondary environmental indicators** allocate a stretch to different classes according to its Materials, Physical Habitat and Vegetation characteristics. The work has shown that the type of engineering applied to a stretch has a significant influence on the class to which a stretch is allocated, with the strongest associations being apparent in the Materials classes and the weakest in the Vegetation classes. As a result, the consequences of changed engineering can be explored in relation to these three classifications, and the influence of scenarios of vegetation management can be additionally explored in relation the Vegetation classification. Thus the secondary environmental indicators provide a simple means of characterising the physical properties of a stretch and their dependence upon engineering and to some extent vegetation management. In the case of algal channels, pollution management is also significant. These secondary environmental indicators also permit consideration of the consequences of changes primarily in engineering but also in vegetation management.

7.1 STRETCH SCORES

In order to combine the three different classifications to produce a single index of the overall quality of a stretch, scores have been assigned to each group within the Materials, Physical and Vegetation classifications (Table 18)

The scores assigned to the materials classes reflect the change from semi-natural (score = 1) to heavily engineered stretches (score = 5). The semi-natural coarse (SNC) and fine (SNF) classes essentially reflect the different alluvial sediments bounding the river channel and are, therefore, assigned the same score of 1. The semi-natural mixed class (SNM), with its coarser banks and finer substrates is actually comprised of straightened channels with resectioned banks. The lightly engineered (LE) class also displays engineering modification but with more sinuous than SNM with some reinforcement usually applied to eroding banks on the outside of the bends. As a result of the similar (low) degree of engineering modification both of these groups have been assigned a score of 2. The engineered (EN) and moderately engineered (ME) classes are distinguished from each other by the difference in dominant protection type (open matrix and solid, respectively), and the ME class contains less overall reinforcement than the EN class. Both of the classes also show a marked increase in the level of engineering from the SNC, SNF, SNM and LE classes and have, therefore, each been assigned a score of 4. The final heavily engineered (HE) class comprises stretches that have both reinforced bed and banks and is assigned a score of 5

Scores assigned to the physical classes reflect the degree to which the channel has been modified and the degree to which the channel is recovering either some or all of its physical habitat features. The semi-natural active class is assigned a score of 1 reflecting the fact that this class possesses a high degree of naturalness with many different habitat types. The recovering class (RE) is characterised by some engineering intervention but also high levels of recovery, creating a greater variety in physical habitat features and flow types than the semi-natural stable (SNS) class. Therefore, scores of 2 and 3 have been assigned to the RE and SNS classes, respectively. The remaining, more heavily engineered classes display less habitat types and lower levels of recovery than any of the previously-discussed classes. The uniform active (UA), uniform moderately active (UM) and uniform stable classes (US) display decreasing levels of sinuosity, natural bank profiles and habitats with increasing channel stability and so these classes have been assigned scores of 4, 5, and 6 respectively.

Scores assigned to the vegetation classes reflect the level and type of in-channel vegetation, and the complexity of the riparian vegetation. In general a vegetated channel is more desirable than an unvegetated channel (with the exception of Algal channels), a complex riparian habitat is more desirable than a uniform one, and a moderate to high tree cover is preferable to either no trees or a channel completely shaded by trees. Therefore, the two vegetated moderate complexity channels (VMC1 and VMC2) are given the best score of 1. The vegetated high tree (VHT) class scores higher than the unvegetated high complexity (UHC) class (2 and 3 respectively). Both of these classes possess high levels of trees, however, the fact that one class is vegetated suggests that less shading is present allowing vegetation to grow in the channel. As stated, a moderate riparian complexity is preferable to a low complexity, and therefore the unvegetated moderate complexity (UMC) class is assigned a score of 4. The vegetated low complexity (VLC) class is assigned a score of 5, whereas the unvegetated low complexity (ULC) class is assigned a score of 6. Finally the algal dominated channels (ALG) are assigned a score of 7 reflecting the fact that these filamentous algae are an indicator of poor water quality, and therefore represent the least desirable class of all. **Nevertheless, it should be stressed that, with the exception of the ALG class, a mixture of these vegetation classes is required at the catchment or sector level, to provide variation along the river.**

Table 18 Scoring system for defining the quality and potential of urban river channels.

MATERIALS		**PHYSICAL HABITAT**		**VEGETATION**	
Class	Score	Class	Score	Class	Score
SNF (semi-natural fine)	1	SNA (semi-natural active)	1	VMC1(vegetated moderate complexity)	1
SNC (semi-natural coarse)	1	RC (recovering)	2	VMC2 (vegetated moderate complexity)	1
SNM (semi-natural mixed)	2	SNS (semi-natural stable)	3	VHT (vegetated high trees)	2
LE (lightly engineered)	2	UA (uniform active)	4	UHC (unvegetated high complexity)	3
EN (engineered)	4	UM (uniform moderately active)	5	UMC (unvegetated moderate complexity)	4
ME (moderately engineered)	4	US (uniform stable)	6	VLC (vegetated low complexity)	5
HE (highly engineered)	5			ULC (unvegetated low complexity)	6
				ALG (algal low complexity)	7

Each stretch can therefore be assigned a score according to its Materials, Physical and Vegetation class, and these scores can then be added to give an overall score for the stretch, where a low score represents a good quality channel.

The decision trees and scoring system were applied to each of the 106 stretches of the River Tame surveyed during summer 2003. The frequency distribution of these overall scores (Figure 10) shows a good range of scores, although none of the stretches display a 'perfect environmental score' of 3 or a 'worst environmental condition' score of 18.

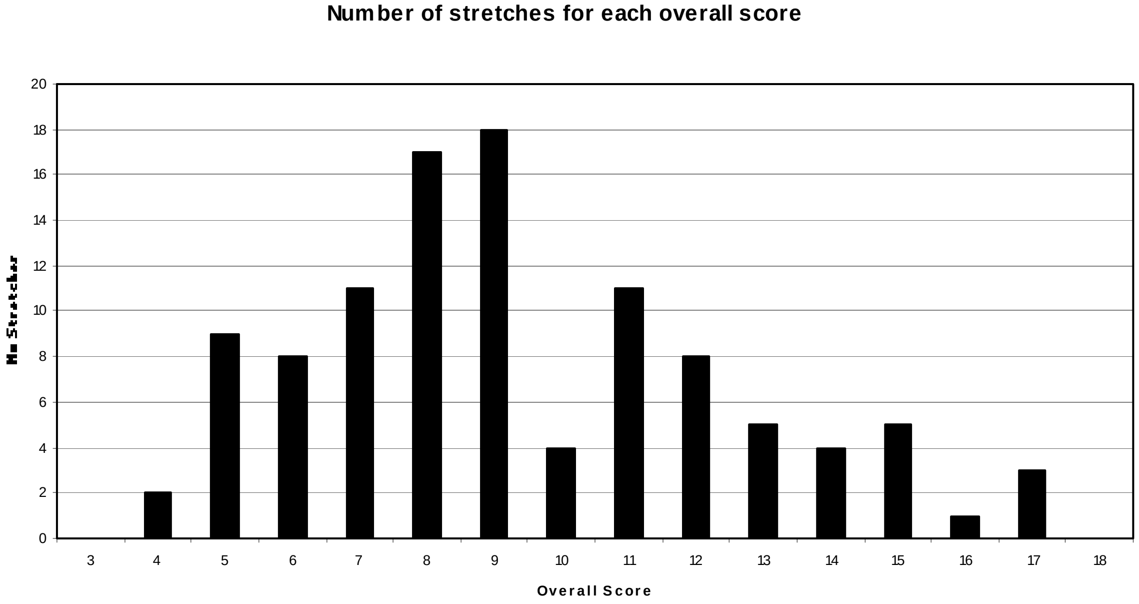

Figure 10 Frequency distribution of overall scores for 106 stretches of the River Tame.

7.2 MANAGEMENT RECOMMENDATIONS

This report has described how urban rivers may be comprehensively assessed to provide a detailed overall score indicative of the current condition of any individual stretch of river. However, management of urban rivers requires an understanding of the potential condition of a stretch if modifications for flood defence or rehabilitation were to be undertaken. This section presents a basic model of how the potential condition of a stretch may be defined, and how to model likely scenarios for rehabilitation of urban rivers.

Section 7.1 described how each stretch can be given individual scores for each of the Materials, Physical and Vegetation classes (Table 18). These scores can be added to give an overall score for each stretch. Table 19 defines 6 categories of urban river stretches, assigns the overall scores associated with each category, defines the type of material, physical, and vegetation class that comprises these scores, and describes the type of management that might be undertaken to rehabilitate a stretch falling in each category.

Table 19 ***Overall scores, classes and management recommendations associated with categories of urban river stretch.***

CATEGORY	OVERALL SCORES	CLASSES MOST ASSOCIATED WITH SCORES (M=Materials; P=Physical; V=Vegetation)	MANAGEMENT RECOMMENDATIONS
Very Good	3-5	**M:** SNC/SNF **P:** SNA/RC/SNS **V:** VMC1 & 2/ UHC/VHT	Predominantly semi-natural and recovering stretches, with good vegetation and tree cover. The recommendation is to leave these stretches free of management and to protect them from development.
Good	6-8	**M:** SNC/LE **P:** RC/SNS/UA/UM **V:** VMC1 & 2/ UHC/VHT	Semi-natural, recovering and a few uniform channels displaying some activity, with good vegetation complexity and tree cover. The recommendation is to remove any remaining reinforcement to allow the channel to recover more freely. These stretches should also be protected from further development.
Average	9-11	**M:** SNC/SNM/LE/ME **P:** RC/UA/US/SNS **V:** ULC/UHC/VMC2	Stretches with varying levels of engineering, but displaying some level of either recovery or activity, with little vegetation complexity or too much tree cover. The recommendation is, where possible, to reduce the levels of immobile substrates and bank materials and increase sinuosity. Tree cover and bank top and face vegetation should be managed to provide increased variety and complexity. These channels show moderate to high levels of activity and should be targeted for rehabilitation where opportunities arise.
Below Average	12-13	**M:** SNC/LE/HE **P:** UA/UM **V:** ULC/UMC/ALG	Stretches with varying levels of modification but showing high levels of activity, combined with low bank vegetation complexity or algal dominated channels with few trees. These channels show moderate to high levels of activity and should be targeted for rehabilitation where opportunities arise. The recommendation is to reduce or alter the level and/or type of reinforcement and increase channel sinuosity where possible. Increased tree cover through planting, and management of the bank face and top vegetation to improve complexity should be undertaken. Algal dominated channels should also be assessed for improvements to water quality.
Poor	14-16	**M:** HE/ME/EN **P:** UM/US/UA **V:** ULC/UMC/ VLC/ALG	Moderate to heavily engineered channels with low to moderate levels of activity, low complexity of bank vegetation, few trees and often algal dominated channels. The recommendation is to assess the water quality for improvement of in-channel vegetation diversity, and undertake a detailed assessment of the level of rehabilitation required to improve the physical condition of the channel. Where possible, a reduction of reinforcement level and/or type and an increase in sinuosity of the channel is desirable. Tree planting should be introduced to improve riparian complexity.
Very Poor	17-18	**M:** HE **P:** US **V:** ULC/ALG	Heavily engineered, algal-dominated, stable channels with little vegetation complexity. Significant improvements to water quality should be initiated, followed by a detailed assessment of rehabilitation needs. Aesthetic rehabilitation may be the best option in the short term. Wherever possible this should be followed by some reduction in the level of reinforcement and an increase in channel sinuosity.

7.3 A SCORING SYSTEM TO UNDERPIN SCENARIO MODELLING OF ENGINEERING AND MANAGEMENT CHANGE

To scenario-model the impact of changed engineering, the decision trees that are used to allocate a reach to a particular class (Figures 7, 8 and 9) can, to some extent, be re-used. However, direct human modification can only be applied to certain components of the decision trees, since others are not directly physically manipulable:

- All components of the Materials decision tree apart from BANKCAL and SEDCAL (which discriminate between the SNF, SNM and SNC classes) can be directly manipulated and so Figure 7 can be used to assess a new Materials score based on a scenario of changed engineering within 5 classes.
- For the Physical Habitat decision tree (Figure 8), the proportion of artificial bank profiles can be manipulated but the proportion of natural bank profiles (which distinguishes SNS & SNA from RC and from US, UM & UA) cannot be manipulated. However, one important reason why there are more natural / active bank profiles in the SNS & SNA classes than in the US, UM & UA is that reaches in the US, UM & UA class tend to be relatively straight, whereas those in the SNS & SNA tend to be more sinuous, with those in the RC class having a mixed, intermediate sinuosity. Therefore a highly sinuous, intermediate or straight channel planforms have been introduced to discriminate between these three groups of classes for scenario modelling.
- For vegetation, the algal channels reflect relatively poor water quality and so cannot be influenced by physical modification of reaches. For the other classes, presence or absence of in-channel vegetation cover cannot easily be manipulated, although shading of the channel will reduce the in-channel vegetation. However, tree cover (as reflected in the Total Tree Score) and bank top and face vegetation complexity (BANKVEG) are manipulable factors that discriminate between the classes. Thus the presence or absence of in-channel vegetation cover provides a context around which manipulation of vegetation on the banks can be undertaken.

Thus, Materials, Physical habitat and Vegetation have manipulable properties that can be scored (Table 20) to closely match the scores allocated in Table 18. This revised and simplified scoring system can be used to compare the current state of a stretch with a range of scenarios based upon the physical manipulation of materials, level of bank protection, sinuosity and bank vegetation retention, planting and management. Because the properties in Table 20 are manipulable, stretches can be given a score for their current state or for any manipulated state, so that the level of ‘improvement’ or ‘degradation’ resulted from specific management changes can be broadly assessed.

Table 20 ***Stretch scoring system based on manipulable stretch properties to support scenario modelling.***

Class	**Threshold values for discriminating indicators**				**Score**
MATERIALS	**Proportion Immobile Substrate**	**Proportion Bank Protection**	**Predominantly Open Matrix Protection**	**Predominantly Solid protection**	
SN (F, M & C)	<80%	≤10%			1
LE	<80%	>10%, ≤70%			2
EN	<80%	>70%	Yes		4
ME	<80%	>70%		Yes	4
HE	≥80%	≥90%			5
PHYSICAL	**Proportion Artificial Bank Profiles**	**Sinuosity**			
SNS, SNA	≤50%	Natural, relatively high, sinuosity			1
RC		Artificial moderate sinuosity			2
UA	>50%	Artificial low sinuosity			4
US, UM	>50%	Artificial Straight			5
VEGETATION	**Dominant Vegetation Type**	**Total Tree score**	**Average BANKVEG (face)**	**Average BANKVEG (top)**	
VMC1	Vegetated-Other	≤6	>5	≤ 4	1
VMC2	Vegetated-Other	≤6		> 4	1
VHT	Vegetated-Other	>6			2
UHC	Unvegetated	>6	> 6.5		3
UMC	Unvegetated	>6	≤ 6.5		4
VLC	Vegetated-Other	≤6	≤ 5	≤ 4	5
ULC	Unvegetated	≤6			6
		OR			
		>6		<6	
ALG	Vegetated-Algae				7

N.B. Note that scenario modelling of the vegetation should not involve manipulation of the dominant in-channel vegetation. This represents a controlled condition around which scenarios of bank vegetation change can be explored.

7.4 DETAILED ASSESSMENT OF STRETCH CHARACTERISTICS AND CONSTRAINTS

Whilst the previous sections link broad management recommendations to the overall score for a stretch it is important to realise that such an approach is extremely generalised. **The overall score** is a very simple index of stretch character and quality, which provides a simple basis for selecting groups of stretches for a more detailed assessment. Such a detailed assessment should incorporate the other indicators and supporting information included in this report.

The individual **secondary environmental indicators** based on the Materials, Physical and Vegetation characteristics of the stretch provide a far more detailed assessment of its character, and inspection of the individual **primary environmental indicators** can provide even grater detail, supported where necessary by information from the raw URS records.

However, in considering scenarios of engineering change **the tertiary environmental indicators** provide initial information on constraints which may limit the potential success of any particular option. Thus water and sediment quality indicators can support an assessment of whether any genuine in-channel ecological benefit can be gained. In essence, if water and/or sediment quality are poor, then no improvement in physical habitat will yield an improvement in the aquatic ecology of the stretch. Under such circumstances, changes in engineering may yield aesthetic benefits and improvements in riparian ecology, but water quality improvement will be essential before the in-channel ecosystem can benefit.

In addition, flow-related indicators can provide an initial assessment of the likely stability of a change in engineering by considering (e.g. the unit stream power at bank-full stage), and sediment calibre and supply indicators may be relevant to stability and also to the degree to which morphological change may be achieved. Such indicators may also be of ecological significance in indicating whether low flows will be sufficient to support an enhanced aquatic ecosystem. Moreover, a combination of flow and water quality indices, may allow consideration of the consequences of different flow regulation scenarios for water quantity and quality within a stretch.

Finally, some simple sector-scale tertiary indicators relating to floodplain land use and flood plain width indicate whether there are constraints in land availability or land quality that may prevent certain engineering options. For example, a restricted flood plain or presence of contaminated land could place severe constraints on engineering options that include a change from a straight to sinuous river planform.

8. References

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SMURF, Sustainable Management of Urban Rivers and Floodplains, is supported by the EC LIFE-Environment programme (Ref LIFE02 ENV/UK/000144).

The project is a partnership between Birmingham City Council, Environment Agency, Severn Trent Water, HR Wallingford, Staatliches Umweltamt Herten, University of Birmingham and King's College London.

SMURF

Sustainable management of
urban rivers
&
floodplains

Environmental Sustainability Indicators for Urban River Management

Appendix 1

Application of the Assessment and Scoring System to Rivers in Other EU Member States

LIFE02 ENV/UK/000144

April 2004

Environmental Sustainability Indicators For Urban River Management

Appendix 1
Application of the Assessment and Scoring System to Rivers in Other EU Member States

Produced by

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The SMURF project**, Sustainable Management of Urban Rivers and Floodplains,** is a partnership between Birmingham City Council, Environment Agency, Severn Trent Water, HR Wallingford, Staatliches Umweltamt Herten, University of Birmingham and King's College London.

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Acknowledgements

The authors would particularly like to thank Professor G.E. Petts, University of Birmingham, and Dr P Armitage, Centre for Ecology and Hydrology, Dorset, for their valuable discussions whilst we were developing the present research and writing this report. We should also like to thank Dr Harald Rahm, Staatliches Umwetamt Herten, and Dr Dana Kominkova, Czech Technical Institute, for their assistance in organising the fieldwork within Europe, and Ms M. Lee, King's College London, for her assistance with the field survey of the River Tame. The methodology described in this report has its foundation in an approach that was developed under funding from the Natural Environment Research Council's URGENT Thematic Programme.

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1. Site Descriptions

In order to ensure the methodology is applicable to urban rivers in other EU countries, the Urban River Survey (URS) was applied to 19 stretches along the Botic River, Prague during May 2004, and 18 stretches along the River Emscher, Germany during July 2004.

The Botic River is a short urban river (34.5km) draining an area of 135km2. It rises in the east of Prague in a rural environment passing through a reservoir before flowing through the city and into the Vlatva river. The Botic has been highly engineered with many weirs to improve oxygenation. Industrial effluents have historically been discharged into the river, and contamination with metals, especially copper and nickel, is high.

The River Emscher drains an area of approximately 865km^2, within the highly developed area of North-Rhine Westphalia, Germany, running through the major towns of Dortmund, and Duisburg before discharging into the river Rhine (Figure 1). The river has, historically, been shortened, straightened, and deepened to allow floodplain development and mining and facilitate flood defence. The subsidence in the area caused by mining prevented the construction of sewer networks, resulting in the river itself being used to transport raw effluents away from the developed areas. Consequently, a treatment plant located near the confluence with the river Rhine was constructed to treat the entire river.

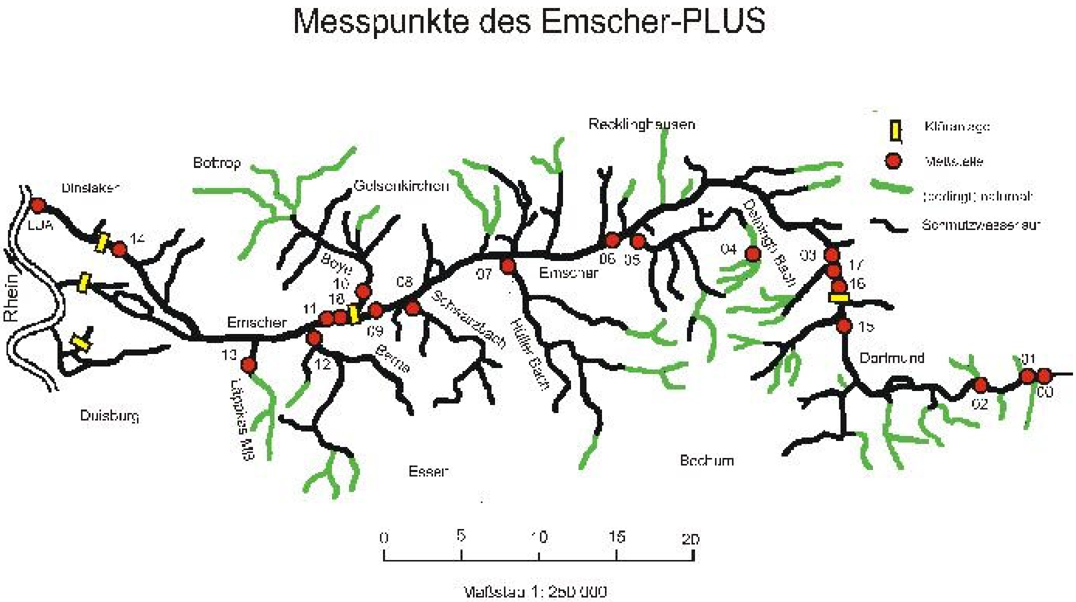

Figure 1 – River Emscher Catchment Map

The river has been subjected to very high levels of engineering, with 50% of the main channel possessing embankments up to 8m in height, and most possessing concrete trapezoidal channels, and highly maintained riparian vegetation. The water quality of the Emscher is very poor due to the levels of raw effluent being discharged to it. However, the entire river is being systematically rehabilitated, and a sewer network constructed.

2. Results: Botic River, Prague, Czech Republic.

A range stretches of the Botic river subject to different types of engineering were selected for assessment. These ranged from semi-natural stretches in the upstream section, to fully reinforced concrete stretches downstream. Table 1 provides the outcomes of various classifications applied to the surveyed stretches.

SITE	MATERIALS CLASS	PHYSICAL CLASS	VEGETATION CLASS	TOTAL SCORE	OVERALL CLASS
1CHP	SNC	SNA	UHC	5	VERY GOOD
1MAT	SNM	SNA	UHC	6	GOOD
1STY	SNC	SNA	UHC	5	VERY GOOD
1UKR	LE	RC	UHC	7	GOOD
2UBD	LE	SNA	UHC	6	GOOD
2UBU	SNC	SNA	UHC	5	VERY GOOD
3DKS	LE	SNS	UHC	8	GOOD
3ISH	SNC	SNA	UHC	5	VERY GOOD
3MAB	LE	SNS	UHC	8	GOOD
3PRA	LE	RC	UHC	7	GOOD
3ZAB	ME	UA	ULC	14	POOR
4AMV	HE	UM	UHC	13	BELOW AVERAGE
4HLS	HE	UM	UHC	13	BELOW AVERAGE
4KBT	HE	US	UHC	14	POOR
4KRM	HE	UM	ULC	16	POOR
4NFM	HE	UM	UMC	14	POOR
4PHS	HE	US	ULC	17	VERY POOR
4SEK	HE	UM	ULC	16	POOR
4UMS	HE	UM	UHC	13	BELOW AVERAGE

Table 1: Results of the application of the classification system to the Botic river, Prague.

Table 1 shows that only four of the surveyed stretches were allocated to physical classes indicative of high stability (SNS, US), with the majority showing at least some signs of activity. This stability is especially notable in the Heavily Engineered (HE) materials class where 75% of the stretches were allocated to physical classes indicative of some level of active change. Also notable are the relatively high complexity of the riparian zone of the channel indicated by the vegetation classes, with only 4 stretches displaying low complexity (ULC), and the fact that all stretches exhibit no aquatic vegetation (i.e. have codes starting with U).

The distribution of the stretches according to their overall class (Figure 2), shows a bimodal distribution, with no stretches falling into the average class. This is, in part, due to the high level of complexity displayed by the riparian areas, reflecting low maintenance, that even extends to completely reinforced stretches with concrete channels (e.g. Figure 3).

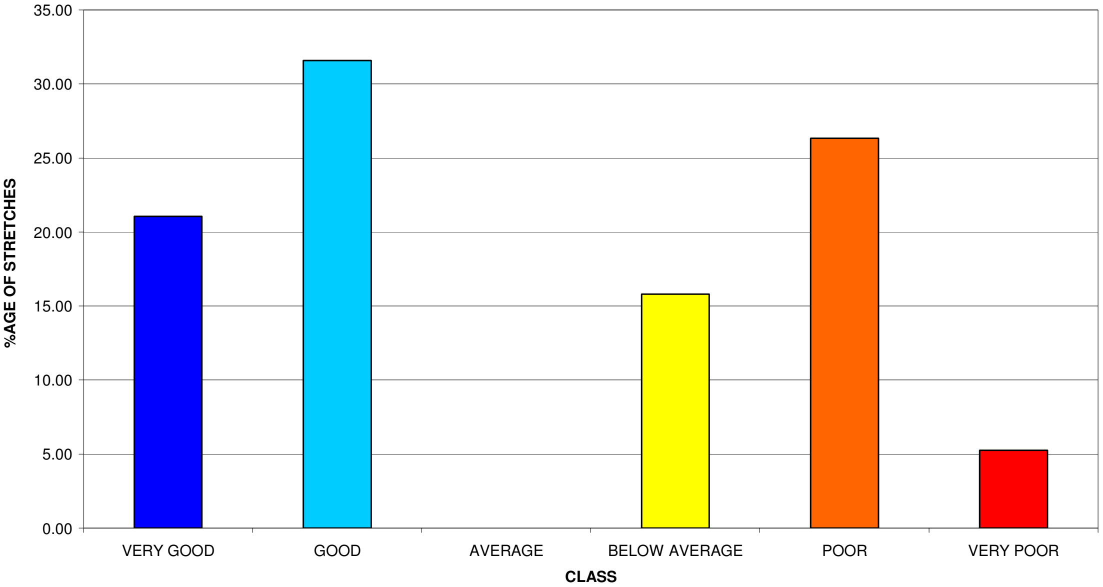

Figure 2: Distribution of stretches of River Botic according to overall class

Figure 3: Riparian complexity along the river Botic, Prague.

3. Results: River Emscher, Duisberg, Germany.

Stretches exhibiting a range of engineering types were selected for assessment in the Emscher catchment, although the selection was limited as a result of safety concerns; the width of the river at the upstream end; and the availability of engineering types. Table 2 lists the outcomes of the various classifications applied to the surveyed stretches.

SITE	MATERIALS CLASS	PHYSICAL CLASS	VEGETATION CLASS	TOTAL SCORE	OVERALL CLASS
2ESD	HE	US	ALG	18	VERY POOR
2ESU	HE	UM	ALG	17	VERY POOR
2ESS	LE	UA	VHT	8	GOOD
2HCS	SNM	US	VMC1	9	AVERAGE
2LBS	HE	US	VHT	13	BELOW AVERAGE
3ALS	HE	US	ALG	18	VERY POOR
3DLS	SNF	UM	VHT	8	GOOD
3NHS	SNF	UA	ULC	11	AVERAGE
3OST	SNF	UA	UHC	8	GOOD
3SWW	SNM	US	VMC2	9	AVERAGE
9GWP	HE	UM	ULC	16	POOR
9HGS	SNM	UM	UHC	10	AVERAGE
9INS	HE	UM	UHC	13	BELOW AVERAGE
9SML	EN	UA	ULC	14	POOR
9WHS	HE	UM	UHC	13	BELOW AVERAGE
12DLD	HE	UM	ULC	16	POOR
12DLU	HE	US	ULC	17	VERY POOR
12RAU	HE	UM	VMC2	11	AVERAGE

Table 2: Results of the application of the classification system to the River Emscher, Germany.

Although a range of materials classes was found within the catchment, it is clear from the allocation of stretches to physical classes that this is a highly modified river system, with no stretches exhibiting a physical class indicative of semi-natural characteristics. However, the river does show signs of active adjustment with 60% of the Heavily Engineered (HE) stretches displaying moderate activity (physical class UM), and only six stretches being attributed to a stable class (US). The vegetation classes illustrate a mix of in-channel and riparian characteristics and it was apparent during the survey that the vegetation was mainly managed for flood defence purposes.

The distribution of stretches according to their overall score (Figure 4) shows that 31% of the stretches fall in the average or good category, despite being so heavily modified and having very poor water quality (Figure 5).

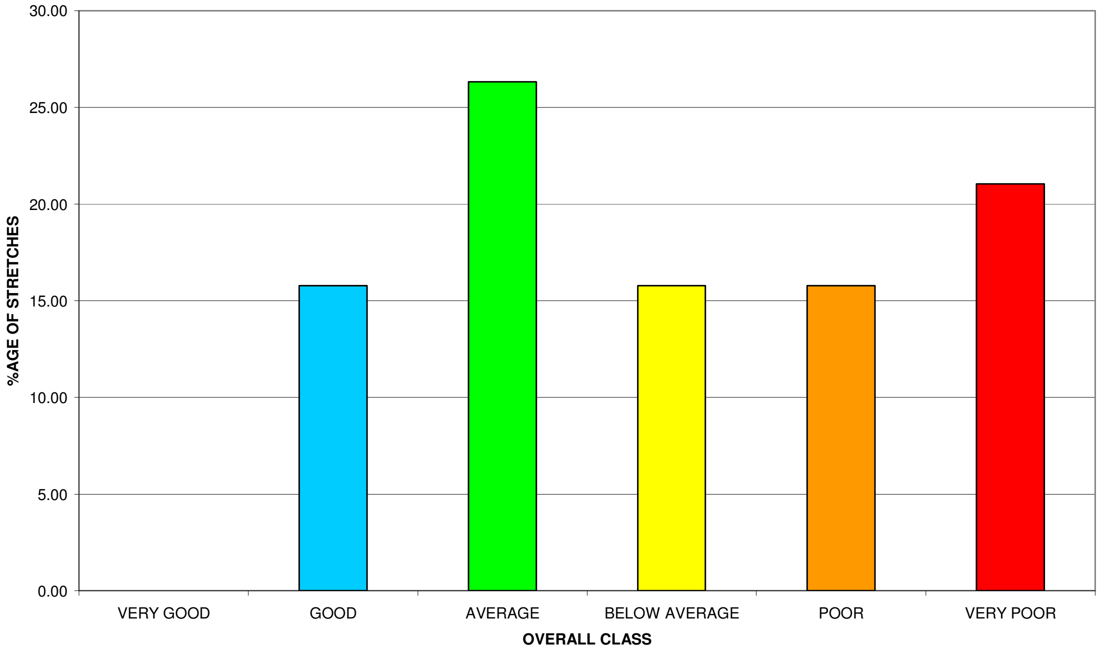

Figure 4: Distribution of surveyed stretches of River Emscher according to the overall class

Figure 5: Example of a partially rehabilitated stretch on the River Emscher, Germany.

4. Discussion

The application of the Urban River Survey to two rivers in other EU member states has shown that the method is robust in identifying stretches of river that display higher quality features such as morphological habitats and complex vegetation. The survey has proved to be very simple to apply, and the classification system developed for UK rivers has proved to be applicable to these other urban river systems. The results show that even in heavily modified stretches of river some variation exists which may be important for long term sustainability of urban rivers flowing through large conurbation.

The scoring system developed for the SMURF project enables managers to prioritise rehabilitation schemes effectively and details priorities for effective rehabilitation. However, the application of this methodology to these two additional rivers has highlighted some problems. Primarily, the scoring system that has been developed is applied unweighted to stretches of the river. However, this leads to the vegetation classification exerting greater influence on the overall score than physical changes to the channel. Thus, the manipulation of the riparian vegetation will result in a greater movement in the overall classification than manipulation of the banks or channel materials.

A further problem is highlighted by the application to the River Emscher. In this catchment, the toxic sediments and water quality that exists within much of the channel prevents the growth of any in-channel vegetation, including filamentous algae. This results in these channels being given a higher score that channels where water/sediment quality is sufficiently good to support the growth of algae. Thus, it is vitally important that the proposed scoring system is fully integrated with a water quality classification, and, where possible, to a sediment quality classification, in order to identify whether the underlying problem is one of engineering design or water quality.

5. Suggestions for further development

This work suggests that the methodology is simple, effective and robust in its application to a range of urban rivers. Further work needs to be undertaken to enable the survey to be fully integrated with the current nationally accepted survey methodologies (e.g. River Habitat Survey in the UK), and also to ensure that variation between individual surveyors is minimised.

Further assessment of the scoring system needs to be undertaken to determine an acceptable weighting system for the three components: Materials, Physical habitat and Vegetation, to ensure that each component is given equal importance within the overall system.

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