Classifying urban rivers

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Abstract Classification systems have been developed over the last century as a tool to aid managers in the preservation, conservation, enhancement and management of rivers. The classification systems developed to date have been designed to differentiate between relatively unimpacted, mainly rural rivers. Urban rivers typically show poor water quality and biological diversity, and so most current classification systems tend to group urban rivers into a single “poor” category. In this paper we describe a hierarchical framework for recording information about urban rivers that allows a more sensitive description of these rivers enabling subdivision into several classes according to the purpose of the classification. The different levels in the hierarchy, the types of attributes that are to be recorded at each level, and the relational database structure for storing the data are described. The 100–500 m river stretch level in the hierarchy relates to the engineered modification of urban rivers and is the key to their classification. An example classification at this scale illustrates a link between engineering modification, bank and bed materials and the number and diversity of physical habitats present. This classification underlines the importance of adopting a hierarchy of nested spatial scales for data collection, classification and interpretation since it illustrates a clear link between characteristics at the stretch scale and at the finer habitat scale. The classification also illustrates the varied nature of urban rivers and the fact that even quite heavily engineered stretches can contain a diversity of habitat types.

Keywords Urban rivers; river classification; hydroecology

River classification

Classification is the process by which “objects”, such as river catchments, networks and sections of river channel or corridor are grouped into classes according to the similarity of their “attributes”. Therefore, classification depends upon two processes: the identification of “objects” to be classified, and the assembly and interpretation of “attributes” of the objects to help assign the objects to classes.

Early classifications of sections of river systems reflected observations of their longitudinal zonation. Rivers were subdivided into three or four longitudinal zones, which were then given names according to the purpose of the classification. For example, Davis (1890) described the morphology and processes forming river channels and their valleys according to three classes: youth, mature and old age; Huet (1954) identified four longitudinal zones for western European rivers by key fish species: trout, grayling, barbell and bream zones; and Schumm (1977) recognised a downstream progression from sediment production to transfer to deposition zones, according to the balance between erosion and deposition of sediment by the river.

Whilst such broad longitudinal zonations are quite easily observed, classification systems that can aid management decision-making usually need to highlight more subtle longitudinal, lateral and temporal variations within river systems. Within the United Kingdom, many classification systems have been devised to aid management of the river environment. For example, water quality indices are based on routinely observed point samples of physical and chemical properties, that have been identified by fisheries experts and river ecologists as being important in determining the biotic quality of the river envi-
The UK Environment Agency (EA) has two systems for assessing water quality. The River Ecosystem Classification, developed in 1994 by the EA’s predecessor, the National Rivers Authority, classifies rivers into five categories (1 to 5) according to their performance on 8 different parameters. The General Quality Assessment (Nixon et al., 1996) classifies rivers into six categories, A to F, A being Excellent and F being Very Bad. Other systems for evaluating rivers are based upon purpose-specific sampling programmes. For example, the EA’s River Habitat Survey (RHS) is a system for recording information on the environmental characteristics of 500 m reaches of rivers and their corridors, which includes a field survey methodology, a database within which national RHS data is stored and from which data sets may be retrieved for analysis and classification (Raven et al., 1997, 1998). The RHS database provides a resource for classifying and assessing habitat quality and also for identifying physical modifications of river channels. Two indices are routinely estimated using RHS data to classify river reaches: the habitat quality assessment (HQA) and habitat modification score (HMS) (Raven et al., 1998).

A major difficulty with most of the systems currently employed in the UK for recording, analysing or classifying information about rivers is that they provide limited detail on the characteristics of urban rivers. At worst the properties or variables for which data are routinely available are not relevant to heavily modified urban rivers and so they cannot be used to classify them. Even where information is available, urban rivers frequently fall into a single (poor/heavily modified/low quality) category when current classification systems are applied. Whilst there is no doubt that urban rivers often possess poor water quality and limited morphological and biological diversity, there is also variety amongst urban rivers, which requires characterisation and classification to support management decision-making. This paper reports on research undertaken as a part of the UK Natural Environment Research Council’s thematic research programme on Urban Regeneration and the Environment (URGENT). The research is part of a project concerned with modelling urban rivers and it aims to develop a method for storing and classifying urban rivers according to their hydroecological characteristics.

**A framework for urban river classification**

Operational river classification systems are often applied at a single spatial scale (e.g. catchment, river reach or sampling point). This partly reflects the purpose of each classification, but it often also reflects the nature of the data sets that underpin the classification. However, Frissell et al. (1986) proposed a hierarchical framework for stream habitat 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 has a spatially nested, hierarchical structure, with five scales of “object” 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 objects (e.g. pool-riffles) and larger scale objects (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. A hierarchical framework can be constructed around the engineering
modifications that have been made to urban rivers. Figure 1 illustrates that there are six spatial scales of object within the framework that we have devised for urban rivers: the catchment (entire stream network), sector (unbranched tributaries and unbranched sections of river between tributary junctions), stretch (river reach exhibiting a single engineering “type”), unit (short river reach within which integrated biological sampling can be undertaken), habitat (individual pool, riffle, bar etc.) and patch. Engineered stretches that reflect differences in the nature and degree of engineering intervention, form the key spatial objects. These may be aggregated into river sectors and catchment networks, or subdivided into units, 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 and 2 illustrate how these three properties can be combined to identify 144 potential engineering “types”. Observations within the River Tame catchment, West Midlands, suggest that the length of river stretch that can be attributed to a single engineering “type” typically falls between 200 m and 1km, with the majority of engineered stretches being less than 500 m in length.

Figure 1 A hierarchy of six spatial scales used to collect and store data in a relational database

Figure 2 Catchment and local controls on the geomorphology of river stretches (the underlined 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)
Table 1 Engineering codes for use at the stretch level

<table>
<thead>
<tr>
<th>Planform</th>
<th>Semi-Natural</th>
<th>Restored</th>
<th>Channel cross section</th>
<th>Cleaned</th>
<th>Enlarged</th>
<th>Two-stage</th>
<th>Resected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-Natural</td>
<td>SNSN</td>
<td>SNRE</td>
<td>SNCL</td>
<td>SNEN</td>
<td>SNTS</td>
<td>SNRS</td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>STSN</td>
<td>STRE</td>
<td>STCL</td>
<td>STEN</td>
<td>STTS</td>
<td>STRS</td>
<td></td>
</tr>
<tr>
<td>Meandering</td>
<td>MESN</td>
<td>MERE</td>
<td>MEC</td>
<td>MEEN</td>
<td>METS</td>
<td>MERS</td>
<td></td>
</tr>
<tr>
<td>Recovered</td>
<td>RCSN</td>
<td>RCCE</td>
<td>RCC</td>
<td>RCEN</td>
<td>RCTS</td>
<td>RCES</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Reinforcement code to be added to the engineering code for use at the stretch level

<table>
<thead>
<tr>
<th>Reinforcement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No reinforcement</td>
</tr>
<tr>
<td>1</td>
<td>Bed only</td>
</tr>
<tr>
<td>2</td>
<td>1 bank only</td>
</tr>
<tr>
<td>3</td>
<td>Bed and 1 bank only</td>
</tr>
<tr>
<td>4</td>
<td>Both banks only</td>
</tr>
<tr>
<td>5</td>
<td>Full</td>
</tr>
</tbody>
</table>

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. 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”.

Attribute information at different spatial scales

The spatial hierarchy of catchment and river corridor objects illustrated in Figure 1, provides the framework for a relational database within which attributes of the urban river can be recorded. Different attributes are recorded at different hierarchical levels to characterise appropriate properties of the river system at that spatial scale. Many of the attributes vary through time and so can be recorded as time series, discrete re-surveys or summary statistics. The types of attribute that may be recorded at each level of the framework are described below.

The catchment level is the scale at which information on the characteristics of the catchment and its river network are defined, including catchment area, relief, geology, drainage density, generalised land use derived from satellite imagery (e.g. percentage impervious land cover), and also information on catchment-scale processes, such as rainfall input and gross runoff.

At the next level, the catchment river network is divided into sectors. Each major tributary of the river is classed as a sector, and the main river is divided into sectors at each main tributary junction. At this scale, attribute information focuses on river corridor land use (a zone extending 100 m from each bank) at a higher spatial resolution than the satellite-derived data used at the catchment level, and providing a more detailed break down of land...
use types (developed from the system proposed by Meador et al., 1993). Land use is assessed using aerial photographs. Other attributes recorded at the sector scale include gross channel properties, such as sinuosity and slope; flow regime and flow frequency indices; and water quality indices.

Each sector is then further subdivided into engineered stretches. A survey method has been developed from that used in the EA’s River Habitat Survey to record geomorphological, hydraulic and ecological attributes of the river channel and its margins. Additional attributes highlight the forms and materials imposed by channel engineering. The survey is applied to stretches of river exhibiting a single engineering “type”.

Biological and more detailed hydraulic and sedimentological data are collected at the unit, habitat and patch levels. The unit level corresponds to approximately 100m lengths of river channel within which invertebrate or macrophyte data that have been pooled from the range of different habitats within the unit can be recorded. It is also used to record information on sedimentary and hydraulic characteristics that determine local physical habitat variability. The habitat level corresponds to particular geomorphological features such as a riffles, bars, runs, pools etc. At this scale, records of invertebrate and other ecological data can be linked to specific habitat types. Objects at the unit and habitat scales are further subdivided into patches, such as a patch of macrophyte, or a patch of sand on a gravel bar (equivalent to the mesohabitats of Armitage et al., 1995 or the functional biotopes of Harper 1995). At this level even more detailed physical habitat and biological attributes can be recorded.

Attributes of objects at different hierarchical levels are drawn from different sources. Those for the catchment and sector levels can largely be assembled from maps, existing databases and other secondary sources. Attributes for engineered stretches are assembled using the purpose-designed field survey. Surveys to provide the mainly biological information at the unit, habitat and patch scales are relatively time-consuming and costly, and so these levels are designed within the database to archive biological survey information as it becomes available from various sources.

An example classification of urban river stretches
The River Tame network in the West Midlands of England has been used to support the development of the methods for recording, storing, and classifying information on urban rivers. The river network has been subdivided according to the spatial hierarchical framework; a relational database has been designed to store attribute data; and data have been collected at the various spatial scales. To date, 57 engineered stretches have been surveyed to test the survey method that has been devised and to undertake prototype hydroecological classifications. This section details a classification of stretches that is based on the natural and artificial materials that line the channel. This example shows how (i) classifying stretches based on a set of attributes describing the nature of channel margin materials produces (ii) five well defined groups that appear to reflect the overall intensity of engineering intervention and which (iii) include different frequencies and types of physical habitat. Therefore, this example not only shows how classifications can be developed but, more importantly, it illustrates the hierarchical nature of the river system, whereby particular types of river stretch include particular types and frequencies of habitat.

Channel margin materials
Channel substrate, bank materials, and bank protection type (e.g. gabions, sheet piling) were noted at 50 m intervals along the entire length of each of the 57 stretches and cumulative measures of the type and the amount (% total stretch length) of bank protection were also estimated. Each of these observations was ranked on a scale of 1 to 10 or 12, where 1 represented the smallest particle size, no protection, or < 10% of the stretch.
Classification

The 57 stretches were then classified using cluster analysis (Ward linkage method) according to their channel margin material scores. The cluster dendrogram suggested subdivision of the stretches into 5 classes (n = 17, 7, 7, 2, 24). The characteristics of the stretches allocated to each of the channel margin boundary classes were inspected and were interpreted to correspond to the broad level of engineering intervention as follows:

**Semi-natural/recovering** (n=24): Stretches with very low levels of bank protection, mixed substrates and mixed bank materials. These stretches have relatively sinuous planforms, predominantly unmodified bank profiles and include stretches that either show no sign of past engineering modification; or that have recovered from modification through natural readjustment; or that have been subject to channel restoration to a “natural” condition.

**Lightly modified** (n=17): Stretches with mixed substrates and earth banks and a very low level (<5%) of bank protection that is mainly associated with the local protection of man-made features such as pipe outfalls. Most of the stretches have artificially straightened channels with simplified bank profiles.

**Modified** (n=7): Stretches with gravel/sand banks and gravel/pebble bed material and a relatively low level (<5%) of bank protection. Stretches are similar to those in the “moderately modified” group (below) but possess lower levels of bank protection, less artificial modification of bank profiles and higher planform sinuosities.

**Moderately modified** (n=7): Stretches are similar to the “modified” stretches with gravel/sand banks and gravel/pebble bed material. However, this group possesses a higher level of bank protection (<50%) usually in the form of stone rip-rap or small gabions, more artificially modified bank profiles and lower planform sinuosities.

**Heavily modified** (n=2): Stretches contain high levels of bank protection and are 100% concreted. The stretches also possess concrete beds overlain with some gravel/pebble sediment, and typically are straight with very simple, artificial bank profiles.

Physical habitat types and frequencies

Figures 3 to 5 illustrate associations between the classes of stretch based on their boundary materials and the types and frequencies of physical habitat that are found within them.

Hydraulic habitats (Figure 3) were recorded using flow type descriptors. The most frequently occurring habitats were glides, riffles, and runs. Figure 3 subdivides glide-dominated stretches into two categories, 75–100% glide and 50–75% glide, and illustrates the frequency of stretches dominated by runs and mixed flows (usually a riffle-run-glide sequence). Bars are ecologically important, particularly as habitat for many invertebrates. Figure 4 records the frequency of all types of bars (both vegetated and unvegetated side, mid channel, and point bars) standardised to a stretch length of 500 m. Figure 5 illustrates the total number of types of habitat found in each surveyed stretch, including flow type habitats such as riffles, deadwaters, runs, and morphological features such as bars, islands, backwaters and pools. A count of the types of habitats indicates the physical habitat diversity of the stretch.

Figures 3 to 5 show a clear correspondence between the class of engineered stretch (based on boundary materials) and the physical habitats found within the stretch and so illustrate the importance of adopting a spatial, hierarchical approach to urban river assessment. Figures 3 to 5 also illustrate that urban rivers exhibit a variety of characteristics that
require further investigation and understanding if urban rivers are to be managed, enhanced or restored in the most effective way. Whilst, as expected, the semi-natural stretches show good diversity of habitat, mixed flows and high numbers of bars; stretches within the other four classes show some more surprising trends. It is particularly interesting that the more
modified stretches of river generally fare better in terms of physical habitat than the lightly modified stretches. The modified group tend to possess a greater proportion of stretches with bars (50% with at least 1 bar) than the lightly modified group (17% with at least 1 bar). They characteristically show more habitat types (71% of stretches fall in the intermediate category) than those in the other modified groups. They also show a mixture of flow type groups, and over half of the stretches have at least one bar.

Conclusions
This paper has described a spatial framework for collecting, storing, and classifying information on the character of urban river networks. Within this framework the engineered stretch is the key spatial unit. Preliminary analysis of attributes of the boundary materials of engineered stretches has resulted in a five-fold classification that reflects the level of engineering intervention. The classes exhibit different types and frequencies of hydraulic and morphological habitats, illustrating the importance of a hierarchical approach to data collection and analysis.

The single classification presented here is the first of many that are being developed and refined. In addition, it is important to investigate associations between patterns at more than the two spatial scales (stretch and habitat) discussed here and to consider more than the physical characteristics at those scales. For example, we have illustrated different frequencies of occurrence of particular habitat types, but analysis of water quality and biological data will undoubtedly reveal enormous ecological variability within a single habitat type. Such analyses will support further classifications of urban rivers in relation to their hydro-ecological characteristics, quality and potential for enhancement and restoration.

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References