4 DELINEATION OF SPATIAL UNITS.

4.1 Regional Context:

At this scale, no delineation is strictly necessary, since most catchments will fall within a single biogeographic region (various regionalisations are available, but www.globalbioclimatics.org is recommended). However some large or steep catchments may encompass more than one biogeographical region or subregion, and this information is likely to help to confirm delineation at the landscape unit scale, where factors within the catchment, such as topography, have a significant impact on biogeographical character.

4.2 Catchment:

Delineation is based entirely on topographic and river network information. The catchment boundary to any required point on the river network is defined by applying GIS tools to an appropriate digital elevation model. In theory, this process should be relatively easy using existing digital elevation models (e.g. SRTM, ASTER GDEM) and widely available GIS algorithms. However, in practice the process is often quite difficult. In particular, delineation of headwater streams can become problematic if valley width is less than DEM resolution, while vertical accuracy of DEMs often causes problems in flat, coastal plain regions. Further complications in terms of subsequent interpretation of hydrology can arise due to water transfer infrastructure and changes in underlying geology, which may lead to the effective watershed not coinciding with the topographic watershed.

Simple GIS tools are available (e.g. for ArcGIS) to identify the catchment boundary for any location on a river network and a variety of DEMs are also freely available (e.g. SRTM, ASTER, GDEM). Accurate digital mapping products could also be utilised (e.g. OS Mastermap dataset for the UK). At pan-European scale, the CCM2 River and Catchment Database v2.1 (Table 3.2) is a purpose-designed product. The CCM2 database was originally defined using the SRTM 90m DEM but it has been refined continually to remove errors in river line positions. While exact channel planform boundaries are not defined in CCM2, the database can be utilised to accurately define catchment boundaries and quantify the size of upstream contributing areas to any point on a river network.

Within a catchment, the river course is best delineated using a digital representation of the actual network rather than any inferred network based on DTM analysis

4.3 Landscape units:

At this scale, the aim is to delineate substantial areas of the catchment that are physiographically similar. The number of landscape units should not be large (typically up to four), but a higher number may be necessary if the catchment is particularly large and complex. These units are important for understanding the hydrological responsiveness of a catchment and also its sediment source / delivery characteristics, and so topography and rock type are the key characteristics underpinning unit delineation, although other factors (e.g. climate, vegetation cover and land use) may be considered to help confirm the appropriateness of divisions based on topographic and geological information. In addition to national data sets, there are several readily-available pan-European data sets that can contribute to the delineation of landscape units, including ASTER GDEM, NASA SRTM3 DEM, CCM2 data base, One Geology Europe, European Soil Database, JRC Forest Cover Maps, Corine land cover data (Table 3.2).

Overall, topographic information underpins delineation of areas of internally consistent elevation range, relief and topographic dissection. Geology (lithology and tectonics) is also a fundamental control on topography as well as hydrological processes and the delivery of sediment to the fluvial system. Landscape units can be composed of many rock types, but broad groupings, as they affect landform and hydrological processes, are needed.

As a first step in delineation of landscape units, consideration is given to topography in terms of the broad elevation, relief and degree of dissection of the landscape. This enables the catchment to be subdivided into major landscape units such as: *plains;* undulating, lower elevation, *hilly areas;* and higher elevation, *mountain areas.* Appropriate threshold elevations or elevation ranges at which to separate plains from low (hills) and high (mountain) areas are likely to depend on the biogeographic region or subregion within which the catchment or its subcatchments are located. However, variations in rock type, land use and ‘natural’ vegetation cover may all be informative for delineation, since they often show a clear structure with increasing elevation. Furthermore, guidance from the Water Framework Directive (high: > 800 m; mid-altitude: 200-800 m; lowland: < 200 m) is a potentially useful starting point.

It may then be important to introduce subdivisions of these initial landscape units, into any clear, characteristic sub-types that are likely to be important for understanding hydromorphology (e.g. *very steep mountain zones; intermontane plains*, etc). Geology (lithology) can also be highly relevant when identifying subdividisions of the initial landscape units. For example, a subdivision of the initial units according to the hydrological (aquifers, aquicludes, aquifuges) or stability characteristics of the major groupings of rock type could be crucial for understanding hydromorphology. Thus, it might be appropriate to subdivide a single initial landscape unit such as a mountainous area, into a unit characterized by metamorphic rocks and a unit characterised by sedimentary rocks, because of differences in their detailed morphology (e.g. slope failures, landslide tracks, tallus slopes) that are indicative of their different resistance to erosion.

4.4 River Segments

The boundaries of landscape units form the first delineation of segments of the river valley network. However, subdivision of these large segments is likely to be necessary. The aim is to delimit major segments of the river network (at least 10 km in length but often much longer) that are subject to similar valley-scale influences and energy conditions. Therefore, as with the delineation of landscape units, excessive numbers of segments should be avoided, with typically between one and three segments delineated along a river valley within a single landscape unit.

To achieve any necessary subdivision of the initial segments based on landscape units, three main factors are taken into account: (i) major discontinuities in valley gradient; (ii) major changes in catchment area (which takes account of major tributary junctions) and (iii) the degree to which the fluvial system is laterally confined (limited in its lateral mobility) by its valley. In addition, in steep mountainous areas, (iv) major lateral inputs of sediment from, for example, major debris flows and torrents moving massive sediment quantities may form additional points for segment delineation, although the largest of these will also cause discontinuities in valley gradient that will be identified under factor (i). All of these segment properties are investigated using topographic data, with (i) and (ii) readily assessed using GIS tools, whereas (iii) and (iv) are probably best assessed visually. ASTER GDEM, NASA SRTM3 DEM, and the CCM2 data base are all useful data sets for this purpose, but additional useful information with regard to valley confinement can be drawn from Google Earth imagery, air photographs or, when available, LiDAR data.

Thus, (i) an overlay of the river network on a DEM, allows abrupt changes in valley gradient to be recognised; (ii) it also allows the upstream catchment area to be calculated to regularly spaced points along the river network, thus capturing large, abrupt changes in catchment area. Boundaries based on (i) and (ii) often occur at the same location. Finally (iii) inspection of DEM and other data sources, allows the presence of a floodplain to be recognised within the river valley with the aim of distinguishing between river segments that abut directly onto the valley edges or ancient terraces (confined) to be distinguished from segments where discontinuous floodplains exist (partly-confined) and segments that possess a continuous floodplain along both sides of the river (unconfined).

Based on Brierley and Fryirs (2005) and Rinaldi et al. (2012, 2013), the following approach to defining segment confinement is recommended.

Confined: more than 90% of the river banks are directly in contact with hillslopes or ancient terraces. The alluvial plain is limited to some isolated pockets (< 10% bank length).
Partly-confined: river banks are in contact with the alluvial plain for between 10 and 90%of their total length.

Unconfined channels: less than 10% of the river bank length is in contact with hillslopes or ancient terraces - the alluvial plain is virtually continuous, and the river has no lateral constraints to its mobility.

4.5 Reach

A reach is a section of river and floodplain along which boundary conditions are sufficiently uniform that the river maintains a near consistent internal set of process-form interactions. As a general rule, the length of a reach should not be smaller than 20 times the mean channel width, although shorter reaches can be defined where local circumstances are particularly complex.

The boundaries of river segments form the first delineation of river reaches. However, subdivision may be necessary, since the aim is to define reaches of similar channel and floodplain morphology, which are likely to reflect local changes in bed slope that were too small to demarcate a segment, and changes in sediment calibre, discharge and sediment supply associated with smaller tributary confluences or artificial discontinuities such as dams, major weirs / check dams that disrupt water and sediment transfer. Changes in confinement as indicated by the ratio of channel width to alluvial plain width within a segment can also affect channel and floodplain characteristics and so a confinement index (Rinaldi et al., 2012, 2013), defined as the ratio between the alluvial plain width (including the channel) and the channel width (or the reciprocal, defined as ‘entrenchment’, e.g. Polvi et al., 2010), can help in delineating reaches.

At this scale, the controlling factors are mainly reflected in the planform characteristics of the river channel and floodplain, including the geomorphic units that are present, which can be viewed on aerial imagery. The following provides a simple working definition and classification, based on Rinaldi et al. (2012) and summarised in Table 4.1 and Figure 4.1.

Confined reaches

In the case of confined reaches, streams are first divided into three broad categories based on the number of threads, i.e. single-thread; transitional (wandering); multi-thread.

Type 1: Single-thread confined reaches. In the case of single-thread, confined reaches, sinuosity is not meaningful as it is determined by the valley rather than the channel planform. Therefore, single-thread confined channels are not further sub-divided at this stage, because it is not possible to make accurate distinctions based on other characteristics, particularly the bed configuration, from remotely sensed sources.

Transitional and multi-thread confined reaches are identified using the same criteria as for unconfined and partly-confined transitional and multi-thread channels (see below). These confined channel types are usually sufficiently large to be discriminated by remote sensing. It is also possible that some small transitional or multi-thread streams can only be confirmed following field survey. In which case they are classified as type 1 reaches during the delineation phase.

Unconfined and partly-confined reaches

Six broad types (*2. Single-thread: Straight; 3. Single-thread: Sinuous; 4. Single-thread: Meandering; 5. Transitional: Wandering; 6. Multi-thread: Braided; 7. Multi-thread: Anabranching*) are distinguished, based on a planform assessment (from aerial imagery) of three indices:

The *sinuosity index (Si)* is the ratio between the distance measured along the (main) channel and the distance measured following the direction of the overall planimetric course (or 'meander belt axis' for single thread rivers).

The *braiding index (Bi)* is the number of active channels separated by bars at baseflow. (Recommended method for estimating *Bi* is the *a*verage count of wetted channels in each of at least 10 cross sections spaced no more than one braid plain width apart - Egozi and Ashmore (2008) suggest that this is the least sensitive to flow stage, channel sinuosity and channel orientation).

The *anabranching index (Ai)* is the number of active channels at baseflow separated by vegetated islands (*Ai*). (Recommended method for estimating Ai is the average count of wetted channels separated by vegetated islands in each of at least 10 cross sections spaced no more than the maximum width of the outer wetted channels apart)

Single-thread
Bi and *Ai* equal or very close to 1 (i.e. only local braiding or anastomosing is possible).
2. Single thread: Straight (*Si*<1.05)
3. Single thread: Sinuous (1.5<*Si*<1.05)
4. Single thread: Meandering (*Si*>1.5)

Transitional
Transitional channels exhibit intermediate characteristics in terms of braiding and/or anabranching between single-thread and multi-thread channel types. As a consequence, *Ai* and *Bi* indices are between 1 and 1.5.

Type 5. Transitional: Wandering
A distinctive characteristics of many wandering rivers is the presence of a relatively wide channel (high w/d ratio) occupied by active bars, similarly to braided rivers. Therefore, 1 < *Bi* < 1.5, but bars are continuously present, occupying most of the channel bed. This morphology is close to multi-thread, with a relatively wider channel than single-thread rivers and a significant presence of braiding and/or anastomosing phenomena. Rivers with a relatively high value of *Ai* (but <1.5) and no braiding phenomena can also be classified as wandering. The latter type could be described as 'wandering anabranching' whereas the former could be described as 'wandering braiding'.

Multi-thread
Multi thread (channel) planforms have *Bi* and/or *Ai* >1.5. Two types are distinguished: braided systems have individual threads (low flow channels) that are highly unstable within the 'bankfull' channel bed, while anabranching/anastomosing systems have relatively stable low flow channels.

Type 6. Multi-thread: Braided (*Bi*>1.5 and *Ai*<1.5).
Type 7. Multi-thread: Anabranching (*Ai*>1.5 and *Bi*<1.5 or *Bi*>1.5)

Highly altered reaches
Type 0. It is important to identify reaches of sufficient length with highly modified characteristics (e.g. urban and other highly channelised / reinforced reaches) as a separate category, since their lateral stability and geomorphic units cannot reflect 'natural' boundary conditions.

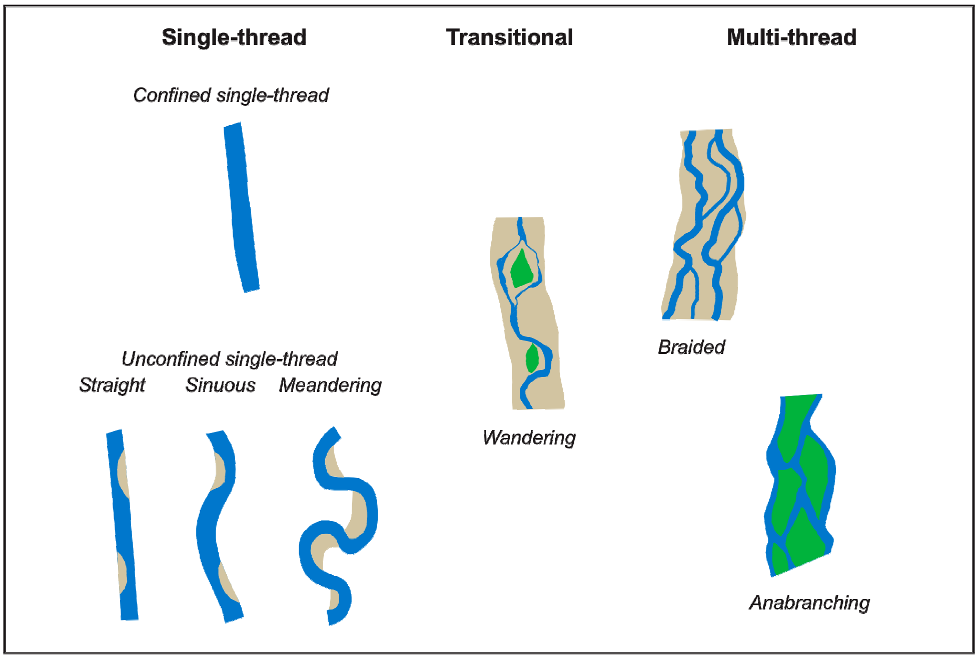

Figure 4.1 Seven types of channel configuration identified from the analysis of areal imagery

Table 4.1 Simple Classification of River Types based on Confinement and Planform

Type	Confinement	Threads	Planform	*Si*	*Bi*	*Ai*
1	Confined	Single	Straight-Sinuous	n/a	approx. 1	approx. 1
2	Partly confined / Unconfined	Single	Straight	< 1.05	approx. 1	approx. 1
3	Partly confined / Unconfined	Single	Sinuous	1.5 < *Si* < 1.05 *	approx. 1	approx. 1
4	Partly confined / Unconfined	Single	Meandering	>1.5	approx. 1	approx. 1
5	Confined / Partly Confined / Unconfined	Transitional	Wandering		1 < *Bi* < 1.5	*Ai* < 1.5
6	Confined / Partly Confined / Unconfined	Multi-thread	Braided		*Bi* < 1.5	Ai < 1.5
7	Confined / Partly Confined / Unconfined	Multi-thread	Anabranching		*Bi* < 1.5 or *Bi* > 1.5	Ai > 1.5

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