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# REFORM

# REstoring rivers FOR effective catchment Management




Deliverable D6.2 Part 4
Title The Geomorphic Units survey and classification System (GUS)

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## *Summary*


Background and Introduction to Deliverable 6.2

Work Package 6 of REFORM focuses on monitoring protocols, survey methods, assessment procedures, gudelines and other tools for characterising the consequences of physical degradation and restoration, and for planning and designing successful river restoration and mitigation measures and programmes.

Deliverable 6.2 of Work Package 6 is the final report on methods, models and tools to assess the hydromorphology of rivers. This report summarises the outputs of Tasks 6.1 (Selection of indicators for cost-effective monitoring and development of monitoring protocols to assess river degradation and restoration), 6.2 (Improve existing methods to survey and assess the hydromorphology of river ecosystems), and 6.3 (Identification and selection of existing hydromorphological and ecological models and tools suitable to plan and evaluate river restoration).

The deliverable is structured in five parts. Part 1 provides an overall framework for hydromorphological assessment. Part 2 includes thematic annexes on protocols for monitoring indicators and models. Part 3 is a detailed guidebook for the application of the Morphological Quality Index (MQI). Part 4 (this volume) describes the Geomorphic Units survey and classification System. Part 5 includes a series of applications to some case studies of some of the tools and methods reported in the previous parts.

Summary of Deliverable 6.2 Part 4

This part provides a detailed description of the Geomorphic Units survey and classification System (GUS). This method is used to identify, characterise and analyse the assemblage of geomorphic units within a given reach. The system is suitable for integrating the MQI and is also aimed at allowing the establishment of links between hydromorphological conditions at reach scale, characteristic geomorphic units, and related biological conditions.

The document is organised in two parts. Part A provides the general background and describes characteristics, analysis, testing, and typical applications of the method. Part B is an Illustrated Guidebook to the identification and classification of geomorphic units. A series of Forms for the application of the GUS are reported in Appendix 1. The list of gemorphic units included in the GUS is reported in Appendix 2. A brief glossary of significant terms is reported in Appendix 3.


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# Table of Contents

# A. The Geomorphic Units survey and classification system (GUS)

## A.1.Introduction

The assessment of stream hydromorphological conditions is required for the classification and monitoring of water bodies by the Water Framework Directive 2000/60, and is useful for establishing links between their physical and biological conditions. The spatial scales of geomorphic units and smaller (hydraulic, river element) units are the most appropriate to assess these links, since geomorphic units represent the physical template for habitats.

Geomorphic units (e.g., riffles, pools, etc.) constitute distinct habitats for aquatic fauna and flora, and may also provide temporary habitats for organisms (refugia from disturbance or predation, spawning, etc.). Procedures to assess physical habitats need to be ecologically and geomorphologically meaningful, enabling ecologically relevant scales and physical variables to be placed into a geomorphological characterisation template. Because geomorphic units constitute the physical structures that underpin habitat units, an assessment of the assemblage of geomorphic units can provide information about the existing range of habitats occurring in a given a reach.

Several methods for the survey or assessment of physical habitats have been developed worldwide since the 1980s. However, physical habitat methods are affected by a series of important limitations (Rinaldi et al., 2013a; Belletti et al., 2015) (see section 2.1). First, in most methods the spatial scale of investigation is not well placed within a multi-scale approach, encompassing rather small areas (‘site’ scale) that are often of a fixed length. Second, these procedures tend to associate high status conditions with maximum morphological diversity for all types of rivers, failing to recognise that in some cases the natural geomorphic structure of a particular stream type may be very simple whereas in other cases it may be complex (Fryirs, 2003). Lastly, a notable gap exists in the terminology used to describe geomorphic units in most habitat surveys when compared to the present state of the art in fluvial geomorphology.

To address some of these limitations, a new system for the survey and classification of geomorphic units (GUS, Geomorphic Units survey and classification System) in streams and rivers has been developed. The system fits within the multi-scale, hierarchical framework developed in REFORM Deliverable 2.1, is suitable for integration with the MQI, and also allows links to be established between hydromorphological conditions at reach scale, characteristic geomorphic units, and related biological conditions.

# A.2. General background

## *2.1 Existing methods for characterising physical habitats*

Several methods and protocols have been developed for the survey, characterisation, and classification of physical habitat elements which can be described as '*river habitat surveys*' or '*physical habitat assessments*' (e.g., Platts et al. 1983; Plafkin et al. 1989; Raven et al. 1997; Ladson et al. 1999; National Environmental Research Institute 1999; LAWA 2000, 2002a, b). They provide a framework within which habitat units can be efficiently inventoried and sampled, and so they are useful for characterising the range of physical habitats that are present, their heterogeneity and the contemporary physical structure of ecosystems. Additionally, these methods often inventory some features of ecological relevance, which are not addressed within truly morphological assessment methods, such as the presence of refuge areas, organic matter, shading, etc. Therefore, they are potentially helpful in establishing links between morphology and ecological conditions and communities (e.g., supporting explanation of the distribution patterns of organisms, the composition and structure of biological communities or aspects of ecosystem functioning).

Nevertheless, existing physical habitat assessment methods have a series of limitations (Belletti et al., 2015). Among these, is the way that physical habitat methods characterize channel forms and geomorphic units. There is a notable gap in the terminology used to describe geomorphic units in most habitat surveys when compared to the present state of the art in fluvial geomorphology. For example, most refer only to riffles and pools when describing the configuration of the river bed, probably because most habitat survey methods have been developed to address small, single-thread, sand- or gravel-bed rivers. As a result, the wide variety of bed morphologies found in steep, mountain, cobble- or boulder- bed streams, where other geomorphic units may occur (cascades, rapids, glides, step-pools, etc.) is not considered. Although considerable progress has been made recently in naming and describing geomorphic units found in mountain streams (e.g., Halwas and Church 2002; Wohl, 2010; Comiti and Mao 2012), these have not being incorporated in most physical habitat assessment methods. Furthermore, the variety of geomorphic units found in rivers with complex, transitional or multi-thread patterns (i.e., wandering or braided) is poorly incorporated in these methods, although some effort has been made recently to represent some of these morphologies (including ephemeral or temporary streams typical of some Mediterranean regions in Southern Europe). In the case of large rivers with complex morphologies (e.g., many piedmont Alpine rivers), field surveys alone are insufficient to characterize channel forms and geomorphic units, thus the incorporation of remote sensing techniques is essential. This implies that existing procedures fail to identify correctly the variability and complexity of geomorphic units that exist in nature. At the same time, they tend to associate high status conditions with maximum morphological diversity for all types of rivers, failing to recognize that in some cases the natural geomorphic structure of a particular stream type may be very simple whereas in other cases it may be more complex (Fryirs, 2003; Barquín et al., 2011). Furthermore, considerable progress has been achieved recently in developing new procedures to identify and analyse geomorphic units within the context of a more appropriate spatio-temporal framework (e.g., Fryirs and Brierley, 2013; Brierley et al., 2013), but existing physical habitat assessment methods do not appear to adopt this type of approach and so are not placed within an appropriate spatio-temporal framework that takes account of recent progress in the field of fluvial geomorphology.

Besides the methods discussed above, other procedures, developed since the early 1990s to map, characterise and/or classifying physical habitats (e.g. Thomson et al., 2001; Hill et al., 2013; Zavadil & Stewardson, 2013), but which do not include a quality assessment based on one or more synthetic indices, are worthy of some consideration.

These include the methods described by Hawkins et al. (1993), Jowett (1993), Wadeson (1995), Maddock & Bird (1996), Padmore et al. (1996), and more recently, by Thomson et al. (2001), Clifford et al. (2006), Harvey & Clifford (2009), and Zavadil et al. (2012). Most of these methods focus on aquatic habitats, in response to the interest of scientists and river managers in aquatic organisms. Many of these approaches are based on the identification and classification of *flow types* (e.g., free fall, broken standing waves, etc.; Padmore, 1998; Newson & Newson, 2000; Zavadil & Stewardson, 2013), which are used to indicate the template of physical habitats at the microhabitat scale. However, it is important to note that such flow types are highly temporally variable, depending strongly on discharge conditions at the moment of observation (Zavadil & Stewardson, 2013).

Another methodological advance has been the development of habitat modelling tools. Habitat simulation models quantify the spatial variability of hydraulic parameters (e.g., flow velocity, water depth, etc.) for different flow discharges. Modelling methods include: (i) 1D models applied at the micro-habitat scale and based on preference curves for different species and their life stages (e.g., PHABSIM, Bovee et al., 1998); (ii) models based on fuzzy logic (e.g., CASIMIR, Jorde et al., 2000); and (iii) 2D models applicable at the meso-habitat scale (e.g., MesoHabsim, Parasiewicz, 2001, 2007; Vezza et al., 2015; RHASIM, Liefeld & Schulze, 2005; MEM, Hauer et al., 2007; MesoCASiMiR, Schneider et al., 2006). Various hydromorphological and habitat indices have also been developed, providing a quantitative assessment of spatio-temporal habitat variability (e.g., HDMI, Gostner et al., 2013; IHQ and IHSD, Vezza et al., 2015).

Due to the shortcomings and limitations these existing methods, a systematic procedure for collecting and interpreting data and information on physical habitats at appropriate spatial scales and based on the present state of the art in fluvial geomorphology remains to be developed. Procedures to assess physical habitat need to be ecologically and geomorphologically meaningful, incorporating ecologically relevant scales and physical variables (Frissell et al., 1986) into a geomorphological characterisation. An assessment of the assemblage of geomorphic units provides information about the range of habitats occurring in a given a reach, because geomorphic units constitute the physical foundation of habitat units.

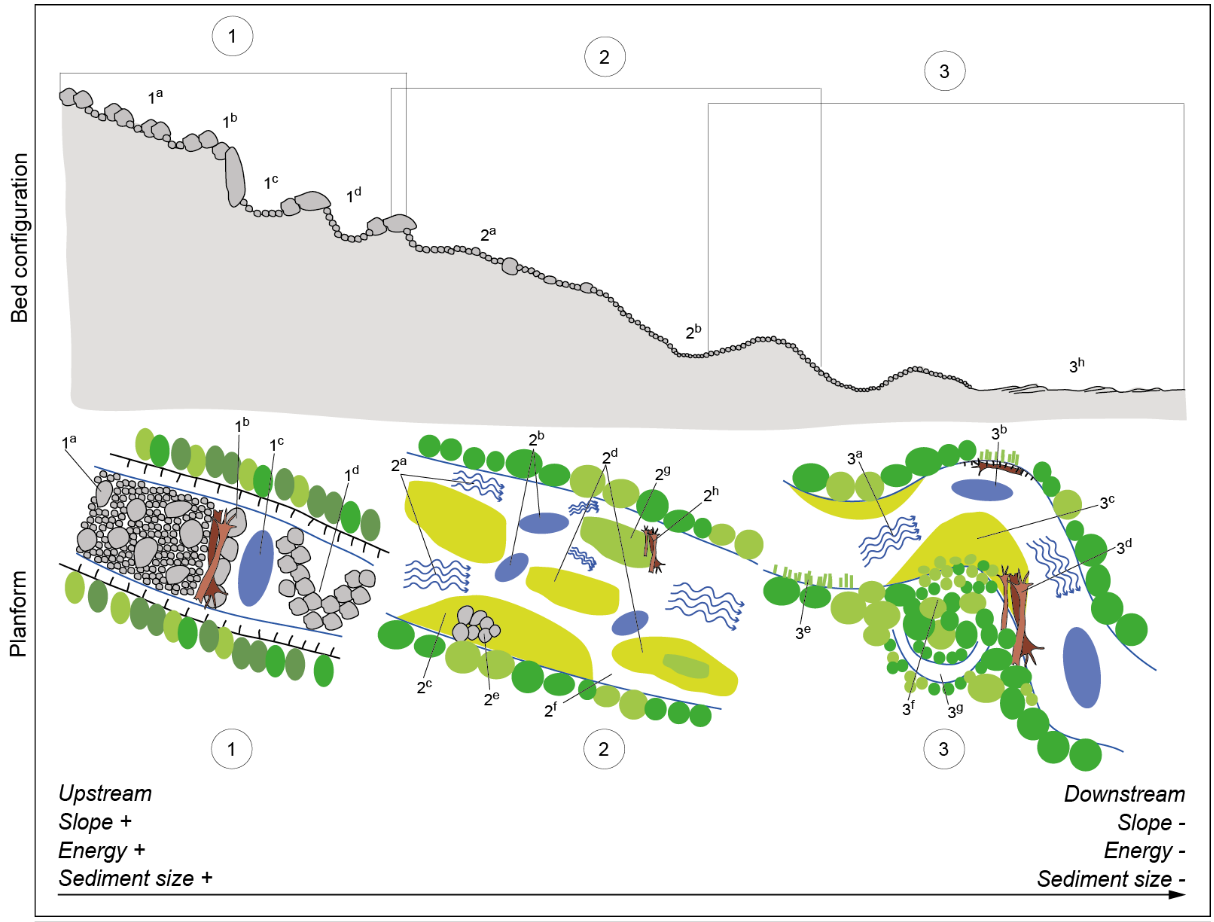
## *2.2 The geomorphic units*

A *geomorphic unit* is defined as an area containing a landform created by erosion and/or deposition inside (in-channel or bankfull geomorphic unit) or outside (floodplain geomorphic unit) the river channel. Geomorphic units can be sedimentary units, or can include living or dead (e.g. large wood) vegetation ('biogeomorphic units').

Referring to the multi-scale, hierarchical framework developed in REFORM Deliverable 2.1, a geomorphic unit may include one to several *hydraulic units* (i.e. spatially distinct patches of relatively homogeneous surface flow and substrate character), each of which can include a series of *river elements* (i.e. individuals and patches of sediment particles, plants, wood pieces, etc).

The spatial scales of geomorphic and smaller (hydraulic, river element) units are the most appropriate to assess the presence and diversity of *physical habitats*. Geomorphic and hydraulic units are generally associated with the *mesohabitat* scale (about $10^{-1}$ - $10^{3}$ m; Bain & Knight, 1996; Kemp et al., 1999; Hauer et al., 2011; Parasiewicz et al., 2013; Zavadil & Stewardson, 2013), whereas river elements coincide with the *microhabitat* scale (approximately 1 - 50 cm). Geomorphic units (e.g., riffles, pools, bars, islands, etc.) constitute distinct habitats for fluvial (aquatic and riparian) fauna and flora, and may also provide temporary habitats (refugia from disturbance or predation, spawning, etc.).

Geomorphic units are linked to the *reach scale*, because the processes of water flow and sediment transport that control the geomorphic units are influenced by factors acting at the reach (e.g., slope, substrate, and valley configuration) and larger scales. Reaches of the same morphological type usually exhibit similar assemblages of geomorphic units. As a consequence, physical habitat characteristics and associated biotic conditions are strongly influenced by reach scale physical factors, which in turn are constrained by regional-, catchment-, and segment scale considerations.




| 1 | | 2 | | 3 | |
|---|---|---|---|---|---|
| Pothole<br>Cascade[a]<br>Rapid[d]<br>Step[b]<br>Pool[c]<br><br>Boulder berm<br>Boulder mound<br>Bedrock outcrop | Large wood jam<br><br>Bench<br><br>(Modern floodplain)<br>Scarp | Rapid<br>Riffle[a]<br>Step<br>Glide<br>Pool[b]<br><br>Bank-attached bar[c]<br>Mid-channel bar[d]<br>Bank-attached high bar<br>Mid-channel high bar<br>Boulder berm[e]<br>Boulder mound<br>Dry channel[f]<br>Bedrock outcrop | Island[g]<br>Large wood jam[h]<br>Aquatic vegetation<br><br>Bench<br><br>Modern floodplain<br>Recent terrace<br>Scarp<br>Secondary channel<br>Overbank deposit<br>Wetland | Riffle[a]<br>Glide<br>Pool[b]<br>Dune[h]<br>Ripple<br><br>Bank-attached bar[c]<br>Mid-channel bar<br>Bank-attached high bar<br>Mid-channel high bar<br>Dry channel<br>Bedrock outcrop<br><br>Island<br>Large wood jam[d]<br>Aquatic vegetation[e] | Bench<br><br>Modern floodplain[f]<br>Recent terrace<br>Scarp<br>Secondary channel[g]<br>Levée<br>Overbank deposits<br>Ridges and swales<br>Floodplain island<br>Terraced island<br><br>Floodplain lake<br>Wetland |

**Figure A2.1 Sketch of a typical succession of geomorphic units occurring from upstream to downstream.**

Moving downstream along the fluvial system, different geomorphic units may occur as a result of changing boundary conditions, such as valley and bed slope, flow discharge, sediment size, etc. (Fig. A2.1). Erosional units sculpted into bedrock (e.g. plunge pools, rock steps) and/or composed of coarse sediment (e.g. cascades, rapids) prevail along confined, high-gradient reaches. Along unconfined, alluvial reaches, riffles, pools, glides, depositional bars and islands become dominant, along with floodplain features (e.g.

secondary channels, oxbows, backswamps, etc.). Downstream transitions in the assemblage of geomorphic units may occur as a function of overall boundary conditions (slope, discharge, etc.) and local factors (e.g. local change in bed slope, presence of a tributary, as well as the presence of a dead tree or a local bedrock outcrop).

The typical assemblage of geomorphic units occurring along a river reach is one of the factors determining the overall channel pattern (or type). In the REFORM Extended River Typology (ERT, Fig. 2.2 and 2.3), characterisation of geomorphic units supports the assessment of the functioning of each type. The set of distinguishing morphological attributes determining each river type may vary between biogeographical regions and may be degraded or reduced by human interventions, but a check-list of the geomorphic units that may be present within the channel and its floodplain is provided in Table A2.1.

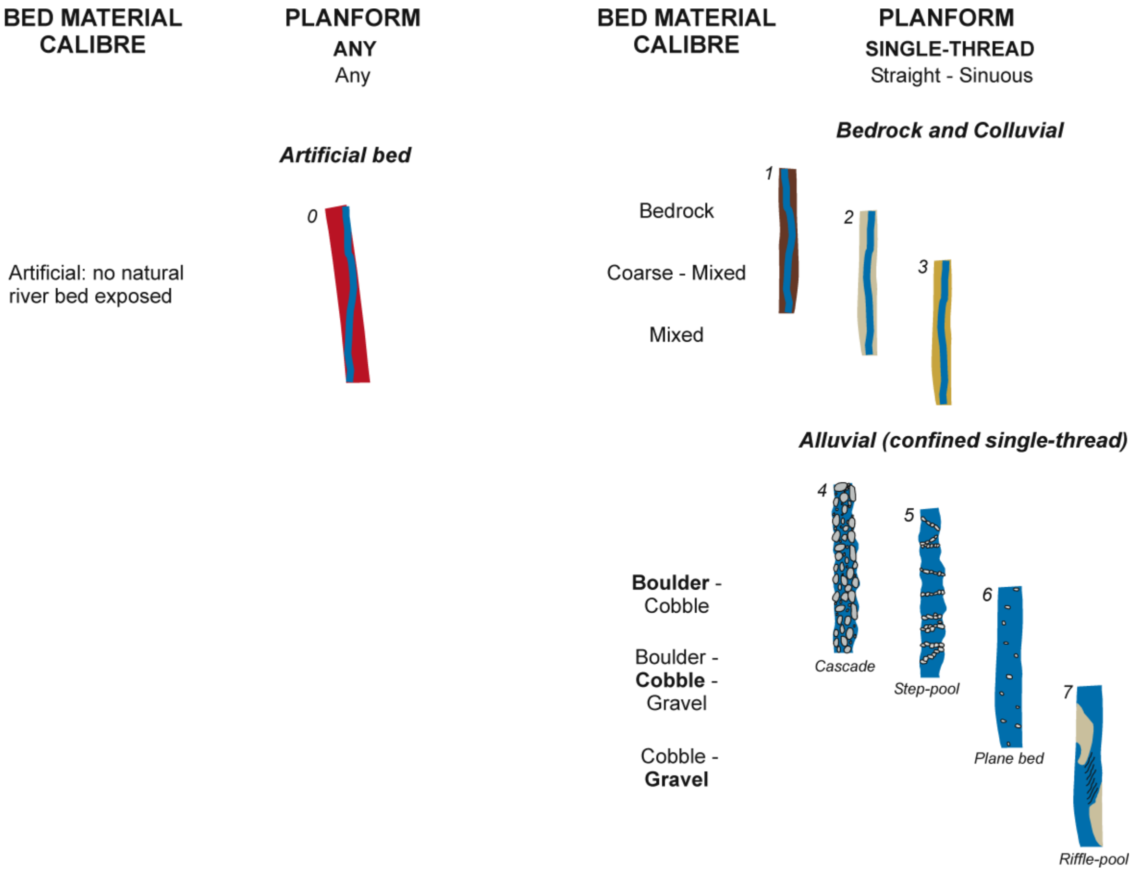



**Figure A2.2 River types 0 to 6 of the Extended River Typology.**

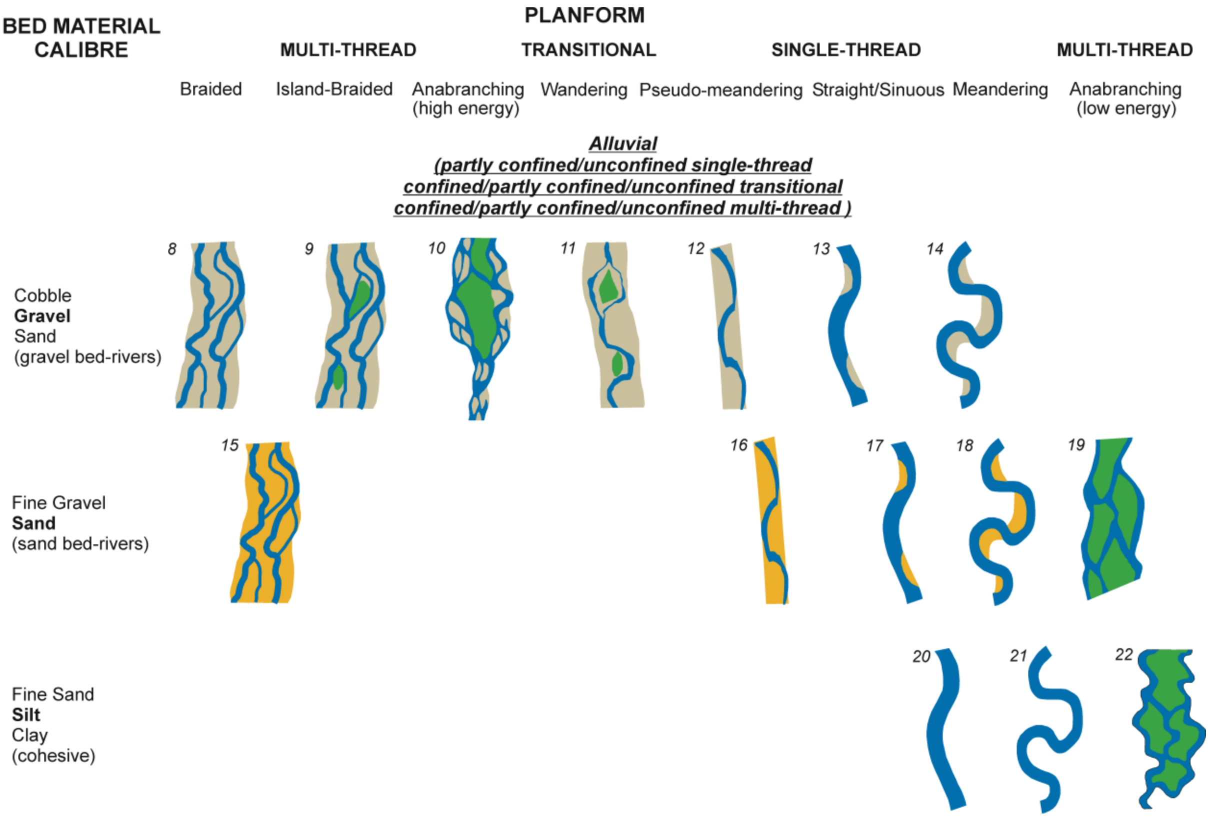



**Figure A2.3 River types 7 to 22 of the Extended River Typology.**

**Table A2.1 Description of the 22 morphological types of the ERT. Geomorphic units: AB: Alternate bar; AC: Abandoned channel; B: Bar; Be: Bench; BL: Boulder levées; Bs: Backswamp; C: Cascade; CC: Crevasse channel; Ch: Chutes; Co: Cut-off channel; CS: Crevasse splay; F: Forced; G: Glide; I: Island; L: Levées; LB: Lateral bar; MB: Marginal bar; MCB: Mid-channel bar; P: Pool; PB: Point bar; PBe: Point bench; Po: Pond; R: Riffle; Ra: Rapids; RD: Ripples (and Dunes); RS: Rock step; RSw: Ridge and Swale; SB: Scroll bar; Sc: Scroll; SP: Step-Pool; SS: Sand splay; VI: Vegetation induced.**

| ERT | Geomorphic Units | Stability | Description |
|---|---|---|---|
| **0** | Possible occasional B | Very Stable | Highly modified reaches |
| **1** | RS, C, Ra | Usually strongly confined and highly stable | Sediment supply-limited channels with no continuous alluvial bed |
| **2** | BL, C, SS, AC | Can be highly unstable | Small, steep channels at the extremities of the stream network |
| **3** | Poorly defined, featureless channels. | Very stable, shallow (often ephemeral) channels | Small, relatively low gradient channels at the extremities of the stream network |
| **4** | C, P | Stable for long periods but occasional catastrophic destabilisation | Very steep with coarse bed material consisting mainly of boulders and local exposures of bedrock |
| **5** | SP | Stable for long periods but occasional catastrophic destabilisation | Sequence of channel spanning accumulations of boulders and cobbles (steps) separated by pools |
| **6** | G, Ra, FB, FP | Relatively stable for long periods, but floods can induce lateral instability and avulsions | Predominantly single thread but secondary channels are sometimes present |

**Table A2.1 Description of the 22 morphological types of the ERT (continued).**

| ERT | Geomorphic Units | Stability | Description |
|---|---|---|---|
| **7** | R, P, G, LB | Subject to frequent shifting of bars | Coarse cobble-gravel sediments sorted to reflect the flow pattern and bed morphology |
| **8** | MCB, R, P | Usually highly unstable both laterally and vertically | Multiple channels separated by active bars (bar-braided) |
| **9** | I, MCB, R, P | Usually unstable both laterally and vertically | Distinguished from type 11 by > 20% channel area covered by islands of established vegetation |
| **10** | I, R, P | Lateral instability usually present | Islands covered by mature vegetation extend between channels |
| **11** | I, MCB, MB, R, P | Usually highly unstable both laterally and vertically | Exhibit switching from single to multi-thread |
| **12** | Large, continuous AB, R, P | Usually unstable both laterally and vertically | Differs from type 11 in its lower sinuosity and very pronounced alternating lateral bar development |
| **13** | Large alternate (continuous) PB, R, P | Subject to frequent shifting of bars | Sinuous pattern with discontinuous bars of coarse sediment |
| **14** | R, P, PB, Ch, Co, SB, Pbe | Laterally unstable channels subject to lateral migration | Meandering pattern with frequent point bars of coarse sediment |
| **15** | B, RD | Unstable both laterally and vertically | Same morphology of 8 but with predominant sand material |
| **16** | Continuous, large AB, P, RD | Vertically unstable due to bar movement and sometimes migrate laterally | Highly sinuous baseflow and alternating bars within a straight to sinuous channel |
| **17** | R, P, PB, RD, occasional Be, SB, L, Bs | Laterally unstable channels subject to lateral migration | Same morphology of 13 but with predominant sand material |
| **18** | P, PB, RD, S, L, RSw, Bs, AC | Unstable channels subject to meander loop progression and extension with cut-offs | Same morphology of 14 but with predominant sand material |
| **19** | I, RD, L, VIB, VIBe, RD, AC | Stable | Vegetation stabilising bars between channel threads, forming islands that develop by vertical accretion of fine sediment |
| **20** | L, Bs | Very stable | Silt to silt-clay banks often with high organic content are highly cohesive |
| **21** | L, Bs, Pbe | Very stable | Similar to 20 but with higher sinuosity |
| **22** | I, L, CC, CS, Po, VIB, VIBe, AC, Bs | Very stable | Silt to silt-clay banks often with high organic content are highly cohesive; extensive islands covered by wetland vegetation |

# A.3. Description of the GUS

## *3.1 Overall characteristics of the method*

The overall characteristics of the GUS can be summarized as follows:

- The method is designed to provide a general framework for the survey and classification of geomorphic units. However, it does not aim to assess the deviation from any given reference conditions and/or to assess the status or quality of the stream by the use of synthetic indices.
- It is an open-ended, flexible framework, where the operator can set up the level of characterisation and the specific focus of the survey, depending on the objectives and on available resources.
- The system is embedded into an appropriate spatially-nested hierarchical framework.
- The analysis of geomorphic units could be inserted within a wider spatial-temporal framework of analysis of morphological conditions (e.g. Brierley et al., 2013). The collected information can be used to better understand the morphology of a given reach and to support the analysis of river reach behavior and evolution.
- The collected information may allow a link to be established between river hydromorphology at the reach scale and the biota.

## *3.2 The Geomorphic Units and the spatial hierarchical framework*

Geomorphic units are organized within a nested hierarchical framework as follows:
(1) Macro-unit: assemblage of units of the same type, e.g. water, sediment, vegetation. The spatial scale of the Macro-units is the reach or the sub-reach. The minimum size of a macro-unit coincides with the size of the corresponding unit (e.g. a bar, an island).
(2) Unit: basic spatial unit, and corresponds to a feature with distinctive morphological characteristics and significant size located within a macro-unit, e.g. riffle, bar, island.
(3) Sub-unit: corresponds to patches of relatively homogeneous characteristics in terms of vegetation, sediment and/or flow conditions located within a unit.

Units and Sub-units correspond to the *mesohabitat* scale. Small Sub-units can also correspond to the *microhabitat* scale (i.e. river elements).
These spatial units are analyzed at the reach or sub-reach scale, where sub-reaches contain characteristic assemblages of geomorphic units that characterize the morphology at the reach scale.

## *3.3 Spatial settings*

The overall spatial domain of application of the GUS is potentially the entire genetic floodplain, i.e. the part of the valley floor delimited by hillslopes or ancient terraces which can be directly affected or potentially influenced by fluvial processes. The main focus of the survey is the portion of the fluvial corridor that is most directly or frequently connected with contemporary fluvial processes, that is the relatively natural corridor of spontaneous riparian vegetation. However, depending on the aims of the study, the survey can be extended to human-dominated portions of the floodplain (agricultural lands, urbanized areas).

Two spatial settings are distinguished: (1) the bankfull channel; (2) the floodplain. Accordingly, the geomorphic units can be first classified in the following groups:

(1) Bankfull channel units: this group includes all the geomorphic units located within the bankfull channel, comprising 'submerged' units (bed configuration, submerged vegetation) and 'emergent' units (bars, islands, large wood jams), and features located within the bankfull channel margins at the interface with the floodplain (e.g., banks, berms, benches).

(2) Floodplain units: they comprise all the units occupying the floodplain (e.g., modern floodplain, recent terraces, wetlands, oxbow lakes, natural levées etc.). The size of the floodplain units is generally larger than the bankfull channel.

## *3.4 Methods and levels of characterisation*

### 3.4.1 Methods

Methods for the survey and characterisation include: (1) remote sensing - GIS analysis; (2) field survey. It is preferable to combine remote sensing and field survey methods, but in some cases it may only be possible to use one of these methods, depending on the selected level of characterisation (see later), the size of the river, and the resolution of the available remotely sensed data and imagery.

For remote sensing, aerial photos of sufficient resolution are needed. Satellite images can also be used for preliminary reconnaissance of morphological characteristics and range of possible units, but the delineation of macro-units within a GIS requires the higher spatial resolution of aerial photos and LiDAR data, which is especially useful for defining floodplain units (e.g. different levels of recent terraces) and emergent units within the bankfull channel (e.g. bars, benches and high bars). The increasing development of remote sensing platforms and techniques (e.g. ultra-light systems, bathimetric LiDAR, structure from motion photogrammetry, hyper spectral image systems; Carbonneau & Piégay, 2012) will very likely lead to their increasing use for characterising geomorphic units, although a field check of their geomorphological interpretation is strongly recommended.

### 3.4.2 Types of data and information

The following data and information can be obtained through the application of the GUS, to provide an increasing level of detail.
(1) list of existing geomorphic units (i.e. presence/absence) in a given reach (or sub-reach);
(2) number (frequency) of each unit;
(3) size (length and/or area) of each unit.
(4) detailed characterisation of geomorphic unit sub-types (i.e. presence/absence);
(5) description of sediment characteristics (size, substrate alteration), hydraulic conditions, vegetation characteristics;
(6) identification of formative processes;
(7) additional size measures (e.g. width, height);
(8) other physical characteristics (e.g. $D_{50}$, water temperature, etc.).

### 3.4.3 Levels of characterisation

The survey of geomorphic units can be carried out at different levels of detail (Fig.3.1 and 3.2, Tab.3.1), as follows:
(1) Broad level: a general characterisation of macro-units, i.e. presence/absence, areal extent and/or percentage cover in relation to the two spatial settings (i.e. bankfull channel, floodplain). The broad level characterisation is entirely based on remotely sensed data sources, analysed within a GIS analysis. Therefore, it can only be applied to rivers of sufficient size in relation to image resolution.
(2) Basic level: a complete delineation and first level of characterisation of all geomorphic units, i.e. presence/absence, number, area/length. Some macro-unit types can also be described at this level. It is mainly carried out by field survey, but remote sensing and GIS analysis can also be used for large rivers or where very high spatial resolution imagery is available.
(3) Detailed level: (i) provides more detailed information and data for units (and some macro-units) on genetic processes, morphological, hydrological, vegetation and sediment properties; (ii) describes macro-units and unit sub-types (when applicable); (iii) characterises sub-units.

In Table A3.1, 'large rivers' generally indicate channels of relatively large size, i.e. with a channel width >30 m, whereas 'small rivers' indicate channels with a size ranging from intermediate to small (channel width ≤30 m).

The survey methods for each level of characterisation, spatial scale and setting are summarised in Table A3.2.

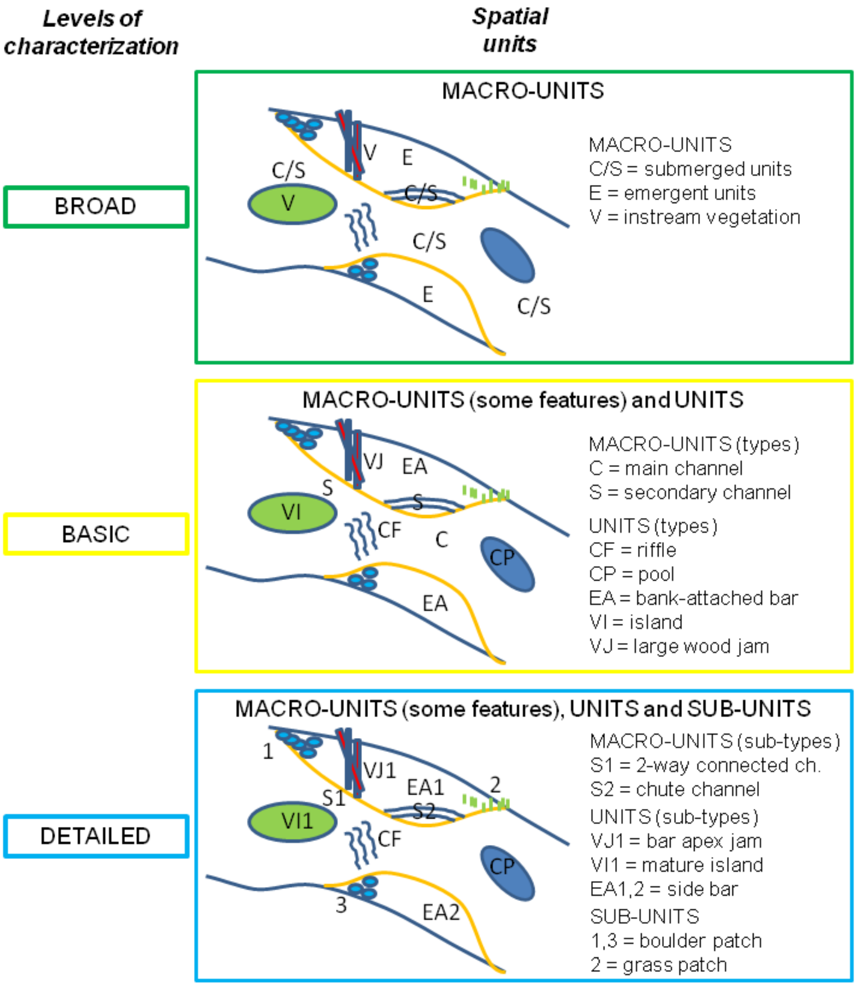



**Figure A3.1 Levels of characterisation and spatial units associated with a bankfull channel setting; examples of geomorphic units (types and sub-types) for different spatial contexts are also reported.**

**Table A3.1 Levels of characterisation, methods, and types of collected information.**

| | *Broad* | *Basic* | *Detailed (optional)* |
|---|---|---|---|
| ***Spatial unit*** | Macro-units | Macro-units<br>(some)<br>Units | Macro-units<br>(some)<br>Units<br>Sub-units |
| ***Method*** | Remote sensing | Field survey<br>Remote sensing<br>(when possible) | Field survey |
| ***Type of collected information*** | Presence/absence<br>(minimum level) | Presence/absence<br>(minimum level) | Presence/absence<br>(Sub-types / Sub-units) |

| | | | |
|---|---|---|---|
| | Area (optional)<br>(necessary for application of GUS sub-indices)<br>Frequency (%)<br>(optional) | Number<br>(minimum information for application of GUS indices)<br>Linear or areal extension (%)<br>(optional) | Number<br>Formative processes, morphological characteristics, hydraulic conditions, vegetation type, sediment<br>Specific measures |
| ***Applications*** | Required for large rivers<br>(all morphologies) | Required for single-thread and small rivers | Always optional |
| | Required for unconfined / partly confined large rivers<br>(floodplain units) | Optional for multi-thread and transitional channels<br>(always required for application of GUS indices) | |

**Table A3.2 Survey methods for each level of characterisation, spatial scale and setting: RS = remote sensing; FS = field survey.**

| | | Bankfull channel | | Floodplain |
|---|---|---|---|---|
| | | **Submerged** | **Emergent** | |
| Broad | **Macro-units** | RS | | RS |
| Basic | **Macro-units (types)** | RS**/FS | | |
| Detailed | **Units** | RS*/FS | RS*/FS | RS*/FS |
| | **Macro-units** | RS**+FS | | |
| | **Units** | FS | FS | FS |
| | **Sub-units** | FS | FS | FS |

(*large rivers and VHR images; **large rivers and HR/VHR images)

### 3.4.4 Survey and compilation of the GUS forms

In this section, some general information related to the survey and compilation of the GUS forms is provided. A detailed **Illustrated Guide** to the classification and the **Forms** for the survey and classification of geomorphic units are reported in Part B and Appendix 1, respectively.

As previously described, the GUS is applied through a combination of remote sensing - GIS analysis and field survey. A collection of existing material (images, previous surveys, other available data and information) precedes the **remote sensing - GIS analysis** phase (e.g. delineation of macro-units, measurement of their sizes, etc.). **Field survey** is essential to characterise the units. Field survey is applied to the entire investigated reach or to a sub-reach that is selected to include the range of geomorphic units observed along and so characteristic of the investigated reach.

For safety reasons, the **timing of the field survey**, should avoid periods of high flows, and seasons of typically high to intermediate flows should be avoided as these conditions make identification of submerged units difficult. Low-flow periods are the most suitable for field survey not only because they are safest and also allow better visibility of submerged units, but also because macro-units (i.e. Broad level) are most consistently identified during such flow conditions. Partially or totally dry conditions should be excluded because they would impede the classification of submerged units (except in the case of intermittent or temporary streams, see below). However, depending on the survey objectives, surveys under a range of different flow conditions may be informative. For example multiple, stage-dependent surveys may help to quantify spatio-temporal variations in habitat availability. In the case of intermittent or temporary streams, the field survey is carried out during periods that represent the dominant hydrological regime conditions, and in any case in the same conditions observed during the remote analysis (i.e. Broad level).

The GUS should be carried out by **surveyors trained in fluvial geomorphology**. Similar to other fields of the river sciences (e.g., freshwater biology), application of geomorphological methods without the necessary background and skills could seriously affect the quality of the survey data that are obtained.

**Time required for the application of the GUS**

The time required for an application of the GUS depends on many factors, including: (1) the expertise and experience of the operator; and (ii) the availability of necessary materials (particularly aerial photographs at good resolution). The time required for surveying a single reach (or sub-reach) also depends on the number of investigated reaches within the same river segment or in the same area, since this affects the number and diversity of data sources incorporated in the remote sensing – GIS analysis and the time taken travelling between field survey sites. Approximately one day is required to survey one or more sub-reaches within a single reach but this time may be significantly reduced when surveying streams with a simple and relatively uniform channel morphology, and may increase when surveying large rivers and/or those with a complex channel morphology (e.g. braided or wandering reaches).

# A.4. Analysis of geomorphic units and GUS indices

The analysis carried out through the GUS can be used to address several aims and at different Stages of the Deliverable 6.2 framework, including:
(i) as a characterisation tool to support the extended classification of the river type (ERT) (Stage I);
(ii) to support the analysis of morphological quality of the reach by integrating a morphological assessment method (e.g. the MQI) (Stage II);
(iii) as a monitoring tool, in order to detect small scale morphological changes (Stage II);
(iv) to evaluate the effects of management actions on hydromorphology (Stage IV).

To support these applications, two synthetic indices have been developed to describe the spatial heterogeneity of a given reach in terms of its geomorphic units.

## *4.1 GUS Indices*

Two synthetic GUS indices (GUSI) are defined using information from the survey of geomorphic units. They can be used (i) to better characterise the assemblage of geomorphic units, and (ii) to monitor the trend of changes in geomorphic units in a given reach (decrease or increase in richness and density) as a consequence of possible pressures or interventions. The results of the GUS (including the indices) at the site-scale must be combined with a morphological assessment at reach-scale to properly interpret the significance and relevance of the diversity (richness and density) of geomorphic units.

(1) Geomorphic Units Richness Index (GUSI-R)
The Geomorphic Units Richness Index (GUSI-R) evaluates how many types of geomorphic units and macro-units (e.g. bar, island, riffle, secondary channel: see Part B, Appendix 2) are observed within a given reach in comparison with the maximum number of possible units:

$$GUSI\text{-}R = \Sigma\ NT_{GU} / n$$

where $NT_{GU}$ is the total number of types of units and macro-units within the investigated reach (or sub-reach) (e.g., in the case of presence of riffles, pools and side bars, $NT_{GU}$ =3), whereas n is the total number of possible types of units and macro-units, i.e. 35.
For the calculation of this index, the presence/absence of each type of unit is required (this is carried out at the Basic level).

(2) Geomorphic Units Density Index (GUSI-D)
The Geomorphic Units Density Index (GUSI-D) calculates the total number of geomorphic units (independently of the type) within the investigated reach per unit length:

$$GUSI\text{-}D = \Sigma\ N_{GU} / L$$

where $N_{GU}$ is the total number of geomorphic units observed along the investigated reach (or sub-reach) (e.g., in the case of 7 riffles, 6 pools and 3 bars, $N_{GU}$ = 16), whereas L is the length (in km) of the investigated reach (or sub-reach).
The calculation of this index requires the number of units and macro-units of each type to be measured (this is carried out at the Basic level).

(3) Sub-indices
It is also possible to calculate a series of sub-indices expressing the abundance and density of geomorphic units for each spatial setting, i.e. bankfull channel and floodplain. The following richness and density sub-indices are defined:

$$GUSI\text{-}R_{BC} = \Sigma\ NT_{BCGU} / n$$

$$GUSI\text{-}R_{FP} = \Sigma\ NT_{FPGU} / n$$

$$GUSI\text{-}D_{BC} = \Sigma N_{BCGU} / n$$
$$GUSI\text{-}D_{FP} = \Sigma N_{FPGU} / n$$

where GUSI-$R_{BC}$ is the richness sub-index of bankfull channel geomorphic units, $NT_{BCGU}$ is the total number of types of bankfull channel geomorphic units, GUSI-$R_{FP}$ is the richness sub-index of floodplain geomorphic units, $NT_{FPGU}$ is the total number of types of floodplain geomorphic units, GUSI-$D_{BC}$ is the density sub-index of bankfull channel geomorphic units, $N_{BCGU}$ is the total number of bankfull channel geomorphic units (independent of the type), GUSI-$D_{FP}$ is the density sub-index of floodplain geomorphic units, $N_{FPGU}$ is the total number of floodplain geomorphic units (independent of the type).

Lastly, it is possible to calculate a series of sub-indices expressing the density of geomorphic units for each macro-unit (see Part B for the definition of macro-units). The calculation requires measurement of the area of each macro-unit (this is carried out at Broad level). The sub-indices are defined as follows:

$$GUSI\text{-}D_{C} = \Sigma N_{CGU} / A_{C}$$
$$GUSI\text{-}D_{E} = \Sigma N_{EGU} / A_{E}$$
$$GUSI\text{-}D_{V} = \Sigma N_{VGU} / A_{V}$$
$$GUSI\text{-}D_{F} = \Sigma N_{FGU} / A_{F}$$
$$GUSI\text{–}D_{W} = \Sigma N_{WGU} / A_{W}$$

where, for bankfull channel macro-units, GUSI-$D_C$ is the density sub-index of baseflow channel geomorphic units, $N_{CGU}$ is the number of baseflow channel geomorphic units, $A_C$ is the area (in $km^2$) of the baseflow channel macro-unit, GUSI-$D_E$ is the density sub-index of emergent sediment geomorphic units, $N_{EGU}$ is the number of emergent sediment geomorphic units, $A_E$ is the area (in $km^2$) of the sediment emergent macro-unit, GUSI-$D_V$ is the density sub-index of in-channel vegetation geomorphic units, $N_{VGU}$ is the number of in-channel vegetation geomorphic units, $A_V$ is the area (in $km^2$) of the in-channel vegetation macro-unit; for floodplain macro-units, GUSI-$D_F$ is the density sub-index of riparian zone geomorphic units, $N_{FGU}$ is the number of riparian zone geomorphic units, $A_F$ is the area (in $km^2$) of the riparian zone geomorphic units, GUSI-$D_W$ is the density sub-index of floodplain aquatic zones geomorphic units, $N_{WGU}$ is the number of floodplain aquatic zones geomorphic units, $A_W$ is the area (in $km^2$) of floodplain aquatic zones macro-unit.

## *4.2 Interactions between GUS and MQI*

Use of GUS in combination with MQI can provide an overall assessment of stream reaches that is useful for understanding their functioning, and, therefore, for supporting the identification of appropriate management actions.

It is important that the outputs of the GUS are interpreted in combination with the results of the MQI and MQIm. For example, an increase in the abundance and diversity of geomorphic units in a given reach is not necessarily related to an improvement of morphological conditions but may be associated with the presence of artificial structures (e.g., weirs). On the contrary, a low diversity of geomorphic units can be the result of the 'natural' simple geomorphic structure of a particular stream type. Therefore, the survey of geomorphic units at the site-scale must be combined with a MQI assessment at reach-scale to better interpret the significance and relevance of the diversity of geomorphic units. Some examples include:

(1) Reach-scale morphological assessment (MQI) results in very good status. This means that geomorphic processes are unaltered or scarcely altered, and the geomorphic units at site-scale represent the typical assemblage that could be expected for this river type under current conditions.

(2) Reach-scale morphological assessment results in a very poor status. This implies that geomorphic processes are intensely altered, and the geomorphic units at site-scale do

not represent the typical assemblage that could be expected for such a river in undisturbed conditions.

(3) A repeated application of GUS reveals an increase in abundance and/or diversity of geomorphic units. If the MQIm tends to increase as well, the increase of geomorphic units is likely due to enhanced morphological processes. On the contrary, an increase of geomorphic units associated with a decrease in MQIm may be the result of additional artificial elements within the reach.

# A.5. Testing phase

The main case study is the Cecina River (Tuscany, Central Italy), which has also served as a Case Study for the REFORM hierarchical framework (REFORM Deliverable 2.1 Part 3, Case study 4). The main test sites (Fig. 5.1) are located along an unconfined reach flowing within a relatively narrow plain in a hilly physiographic unit (reach 3.7 in REFORM D2.1 Part 3). The reach length is 6500 m, and it has a watershed area of about 635 km$^2$. The channel type is 'pseudo-meandering' (ERT type 12), with a gravel bed, a mean slope of about 0.003, and mean width of about 50 m. The main artificial elements within the reach are some sills and a bridge. The MQI of the reach is 0.78 (i.e. 'good' morphological quality).

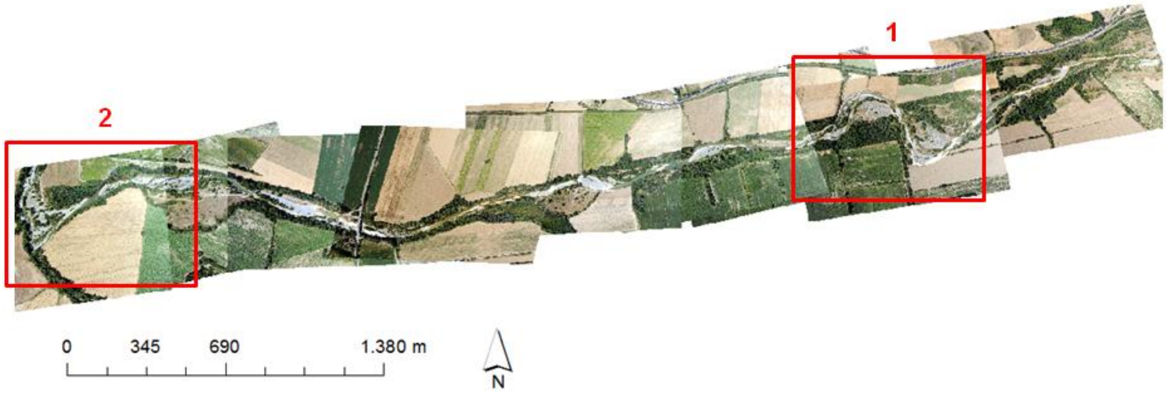



**Figure A5.1 Cecina River, reach 3.7 (near Casino di Terra, Pisa), and location of the two sub-reaches used for testing the GUS.**

The GUS was applied at the Broad level to the entire reach, and at the Basic level to two sub-reaches (sub-reach 1: 1500 m; sub-reach 2: 1100 m), which were selected as representative of the full range of geomorphic units observed along the entire reach. For the remote sensing analysis, high-resolution (15 cm) aerial photographs were used. The remote sensing – GIS analysis was integrated with a detailed field survey. Figure 5.2 shows an example of GIS mapping of the geomorphic units.
Lastly, the GUS indices and sub-indices for the two sub-reaches were calculated and are summarised in Table A5.1.

**Table A5.1 Results of the application of the GUS indices and sub-indices.**

| | **Sub-reach 1** (upstream) | **Sub-reach 2** (downstream) |
|---|---|---|
| **GUSI-R** | **0.43** | **0.37** |
| GUSI-$R_{BC}$ | 0.34 | 0.31 |
| GUSI-$R_{FP}$ | 0.09 | 0.06 |
| **GUSI-D** | **62** | **73.64** |
| GUSI-$D_{BC}$ | 57.33 | 67.27 |
| GUSI-$D_{FP}$ | 4.67 | 6.36 |
| GUSI-$D_C$ | 29.88 | 16 |
| GUSI-$D_E$ | 5.75 | 9.17 |
| GUSI-$D_V$ | 12.56 | 19.21 |
| GUSI-$D_F$ | 0.46 | 0.77 |
| GUSI-$D_W$ | / | / |

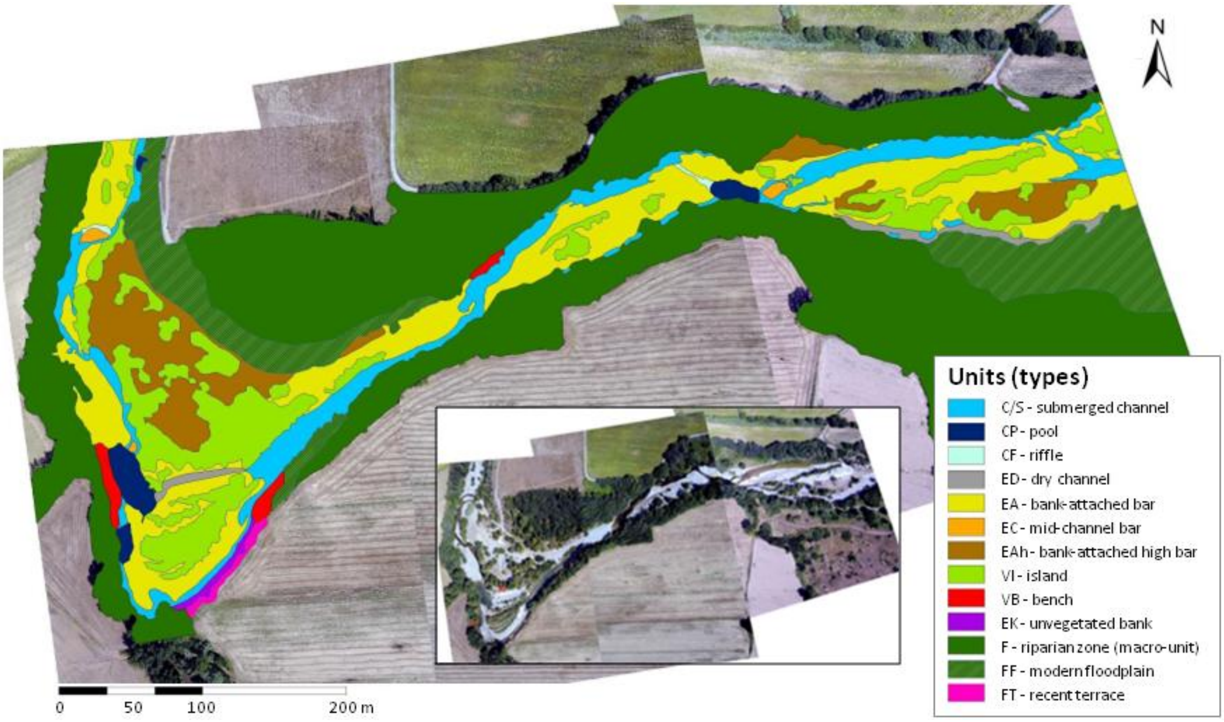



**Figure A5.2 Example of the application of the GUS to the Cecina River (Base level): map of the types of geomorphic units within sub-reach 2 (downstream).**

# A.6. Applications of GUS

The data and information collected through the GUS can be used for a series of potential applications, including the following:

(i) Spatial and temporal analyses of geomorphic units at different spatial scales

- Survey and characterisation of physical habitats at the meso (Units, Sub-units) and micro (substrates, flow types, etc.) scale, as well as analysis of the fluvial landscape at the Macro-unit scale; these can be carried out by calculating diversity indices (e.g. Shannon, richness, dominance, etc.) and landscape description metrics (e.g. patch form, connectivity, ecotones length, etc.).
- More detailed characterisation of the morphology at the reach scale and its evolution through time.
- Monitoring of the geomorphic units across time, in order to assess the effect of interventions (e.g. restoration) or of different hydrological conditions.

(ii) Analyses of the relationships between geomorphic units (i.e. physical habitats) and biota

- As a physical basis for biological surveys at a scale that is geomorphologically meaningful.
- As a key tool to link the morphological status at the reach scale with the biological status at the site scale.
- As a tool for the survey and mapping of mesohabitats in order to: (i) apply habitat simulation models for the fauna (e.g. MesoHABSIM, Parasiewicz et al., 2013); (ii) calculate the spatio-temporal variation of habitats for the fauna (e.g. Vezza et al., 2014, 2015).

# B. Guide to the application of the GUS

## B.1. Guide to the compilation of the survey forms

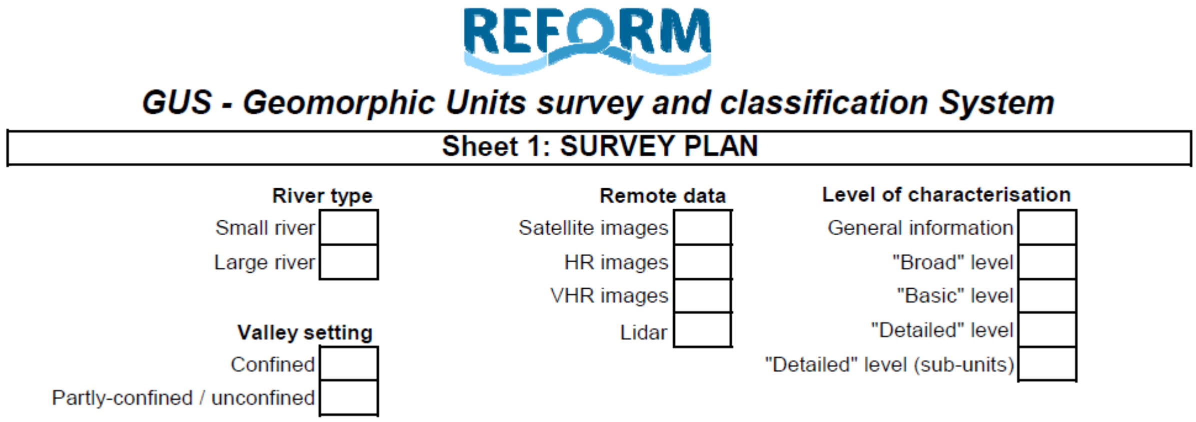
In this section a detailed description of the compilation of the survey forms is provided. The survey form is composed of several sheets:

- The method requires the compilation of a first sheet (Survey plan), which aims to organize the survey in the context of its objectives, by recording (i.e. using a *tick*) the kind of information that is planned to be collected (which spatial setting, which level, and which spatial scale).
- The second sheet records general information on the river, the surveyed reach and sub-reach; a part of the sheet is reserved for a field sketch.
- The following sheets are the core of the survey (Broad, Basic and Detailed levels).

### *1.1 Sheet 1: Survey plan*

The first part of the sheet requires the following **basic information** (*tick* when the case; Fig. B1.1):

- The type of river (small, ≤ 30 m; large, > 30 m) and of valley setting (confined vs. partly confined/unconfined);
- The kind of remotely-sensed data available: satellite images, high resolution (HR, i.e. 20-50 cm) or very high resolution (VHR, < 15 cm) photographs, Lidar;
- Information on the kind of survey and data that will be recorded (i.e. which sheets will be completed).


REFORM

GUS - Geomorphic Units survey and classification System

Sheet 1: SURVEY PLAN

**River type**
Small river ☐
Large river ☐

**Valley setting**
Confined ☐
Partly-confined / unconfined ☐

**Remote data**
Satellite images ☐
HR images ☐
VHR images ☐
Lidar ☐

**Level of characterisation**
General information ☐
"Broad" level ☐
"Basic" level ☐
"Detailed" level ☐
"Detailed" level (sub-units) ☐

**Figure B1.1 Detail of the first part of Sheet 1 (Survey plan).**

The second part **summarises the macro-unit and unit information recorded on subsequent survey sheets** (sheets 3 to 15) for all the levels of characterisation (Broad, Basic and Detailed) and all spatial settings (Bankfull channel, Floodplain; Fig. B1.2). The operator must *tick* the box when he/she plans to survey a specific feature:

- Broad level: presence/absence (P/A), area (Are) or percentage (%) (for macro-units);
- Basic level: presence/absence (P/A), number (Num), length or area (L/A) (for types of macro-units and units);
- Detailed level: characteristic features for macro-units and units, i.e. sub-types of units and macro-units (S-T), sediment characteristics (Sed), hydraulic conditions

(Hyd), vegetation characteristics (Veg), bank morphology (Mor) and composition (Com), type of processes (Pro), specific measures (Mea), other (Oth).

At the Basic level, the survey method (remote sensing or field survey) is indicated. The Broad and Detailed levels are applied using remote sensing and field survey, respectively. Finally, for the Basic level it is possible to indicate whether the GUS indices have been calculated.

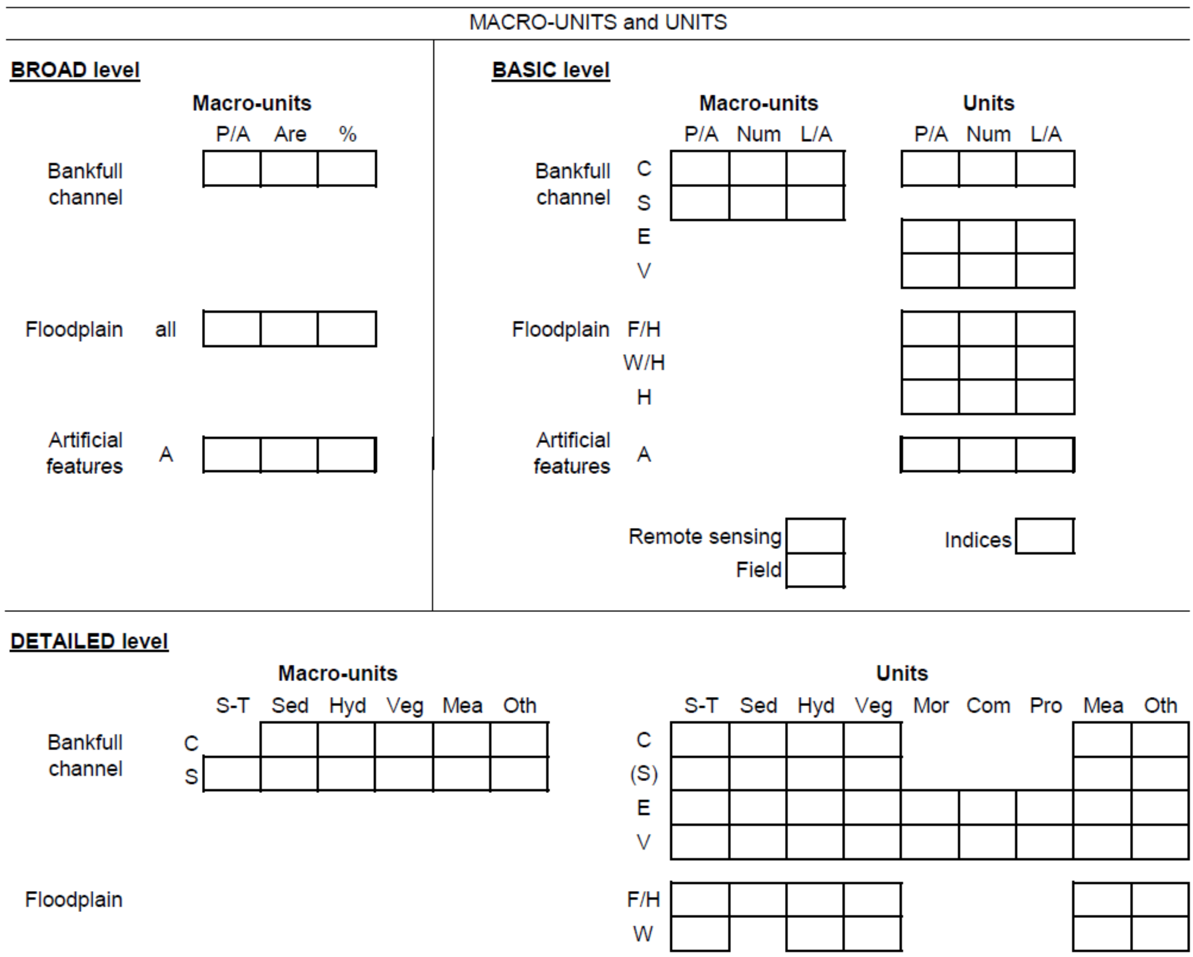



**Figure B1.2 Detail of the second part of Sheet 1 (Survey plan). C, S, E, V, F/H, W, A represent the identifcation codes of the macro-units; see Section 2 for more details.**

The third part **summarises the sub-unit information recorded on the sub-unit survey forms**, carried out at the Detailed level, for all spatial settings.

At the end of the survey, the operator should return to this page and check if all required information has been correctly acquired (last two parts). When a specific feature could not be analyzed, it must be marked N.S. (i.e. not surveyed) in the appropriate box.

## *1.2 Sheet 2: General information and field sketch*

The first part of this page concerns an **initial desk-study phase**, during which the operator should collect all the available information on the studied river (Fig. B1.3). The sub-reach is selected during this phase, as representative of the variety of geomorphic units observed at the reach scale (see Part A, section 2.2). Some of the information required can be obtained from other morphological surveys (i.e. the overall bed configuration and channel pattern), such as the delineation and characterisation phases of the REFORM D2.1 framework (Gurnell et al., 2014a, 2015a, 2015b; see also D6.2

Main report) or the segmentation phase of the MQI (Rinaldi et al., 2013b, 2014; see also D6.2 part 3).
The information concerns:
(i) General information on the river and the survey:

- Name of the surveyor;
- Date of the survey;
- Name of the river;
- A place name for location;
- Reach mean altitude (m a.s.l.);
- Reach length (m);
- Sub-reach length (m);
- Sub-reach X and Y coordinates (upstream point).

(ii) General morphological characteristics at the reach scale:

- Mean floodplain width (m);
- Mean width of the river corridor (m), that includes the bankfull channel and the entire 'functioning' riparian zone (in some cases the river corridor may encompass the entire floodplain);
- Mean bankfull width (m);
- Degree of confinement (i.e. the % of bank in contact with hillslopes; Rinaldi et al., 2013b);
- Mean reach slope (%);
- Dominant surrounding land use (3 classes: NA, natural; AG, agricultural areas; UR: urban and industrial areas including transport infrastructure);
- Mean baseflow channel width (m); it can be measured from remote sensing if high-resolution images are available;
- Mean baseflow channel depth (m or classes: < 20 cm, between 20 cm and 1 m, more than 1 m); it is defined in the field (or from previous surveys);
- River is wadeable/not wadeable (W/NW);
- Bed morphology: colluvial, bedrock, alluvial, semi-alluvial, artificial;
- Channel pattern: straight, sinuous (including pseudo-meandering), meandering, wandering, braided, anabranching;
- Hydrological regime: permanent, intermittent, temporary stream or other;
- Other available information: it is possible to indicate the discharge during the survey (field or remote images), as well as further information (i.e. date, flood magnitude or return period when available) of recent flood events (e.g. greater than the 1.5 years return period discharge) which may have modified the presence and extent of geomorphic units. It is also possible to indicate the number of events (if known), which have occurred between two consecutive observations or during the last hydrologic year, having a discharge greater than the bankfull or 1.5 years return period discharge.

**Sheet 2: GENERAL INFORMATION AND FIELD SKETCH**

**General information**

| | | | | | |
|---|---|---|---|---|---|
| Surveyor | _____ | Location | _____ | Sub-reach length (m) | _____ |
| Date | _____ | Reach altitude (m a.s.l.) | _____ | Upstream end (x) | _____ |
| River | _____ | Reach length (m) | _____ | Upstream end (y) | _____ |

**General morphological characteristics**

| | | | | | |
|---|---|---|---|---|---|
| Floodplain width (m) | ☐ | Confinement degree | ☐ | Baseflow channel width (m) | ☐ |
| River corridor width (m) | ☐ | Reach slope (%) | ☐ | Channel depth* (m/class) | ☐ |
| Bankfull channel width (m) | ☐ | Land use | ☐ | Wadeable/not wadeable | ☐ |

| **Bed morphology** | | **Channel pattern** | | **Hydrological regime** | |
|---|---|---|---|---|---|
| Colluvial | ☐ | Single-thread | | Permanent | ☐ |
| Bedrock | ☐ | Straight | ☐ | Intermittent | ☐ |
| Alluvial | ☐ | Sinuous | ☐ | Temporary | ☐ |
| Semi-alluvial | ☐ | Meandering | ☐ | Other | ☐ |
| Artificial | ☐ | Transitional | | | |
| | | Wandering | ☐ | | |
| | | Multi-thread | | | |
| | | Braided | ☐ | | |
| | | Anabranching | ☐ | | |

*Baseflow channel

**Other available information**

| | | | | | |
|---|---|---|---|---|---|
| Q field survey | ☐ | Flood discharge: Q | ☐ | N. events Q>1.5 | ☐ |
| Q remote images | ☐ | Flood discharge: year | ☐ | | |

**Figure B1.3 Detail of the first part of Sheet 2 (General information).**

The second part of the sheet is reserved for a **field sketch**. This should represent, in a schematic way, all the geomorphic units present in the surveyed reach or sub-reach. See the section titled "Sheets 4 to 6: Basic level" for a detailed description of the survey of geomorphic units (and some macro-units).

## *1.3 Sheet 3: Broad level*

The first part of the sheet concerns the following **information on the remotely sensed data** used for the survey (Fig. B1.4):

- Date of the photo;
- Source/ownership of the photo;
- Scale and/or the resolution (m) of the photo;
- Scale at which macro-units (or units) are mapped;
- Spatial scale of application (reach or sub-reach).

A photo of the reach or sub-reach can be included in the sheet (this is also useful for the field survey).

**Sheet 3: BROAD LEVEL**

**Bankfull channel and Floodplain**

**Photo**

| | | | | | |
|---|---|---|---|---|---|
| Date | __________ | Scale | __________ | Scale of mapping | __________ |
| Source | __________ | Resolution (m) | __________ | Reach / Sub-reach | __________ |

**Picture of the reach / sub-reach**

**Figure B1.4 Detail of the first part of Sheet 3 (Broad level).**

The second part of the sheet contains the **macro-unit survey form** (Fig. B1.5). According to their spatial setting (bankfull channel, floodplain), macro-units are organized as follows (see section 2 for the definition of single macro-units):

(i) Bankfull channel macro-units: *baseflow or 'submerged' channels* (C/S), *'emergent' sediment units* (E), *in-channel vegetation units* (V);
(ii) Floodplain macro-units: *riparian zone* (F), *floodplain aquatic zones* (W); *human-dominated areas* (H; land use included);
(iii) All spatial settings: *artificial features* (A).

The following information can be recorded:

- Presence/absence of a macro-unit (minimum level) (P/A);
- Area of each macro-unit ($m^2$);
- Percentage of each macro-unit relative to the spatial setting (Bankfull channel, Floodplain) (%).

| Macro-units | | | | |
|---|---|---|---|---|
| Spatial setting | Macro-units | P/A | Area | % |
| Bankfull channel | Baseflow channel or submerged channels (C/S) | | | |
| | Emergent sediment units (E) | | | |
| | In-channel vegetation (V) | | | |
| Floodplain | Riparian zone (F) | | | |
| | Floodplain aquatic zones (W) | | | |
| | Human-dominated areas (H) | | | |
| All | Artificial features (A) | | | |

**Figure B1.5 Detail of the second part of Sheet 3 (Broad level, macro-units survey c).**

The survey of macro-units is always required for large rivers (all spatial settings), and for small unconfined or partly-confined rivers (but only for the Floodplain). The scale of analysis (reach or sub-reach) must be defined, based on the objective of the analysis, as follows:

- if it is planned to survey only the macro-units at the Broad level, the entire reach length must be surveyed;
- if it is planned to survey also units (Basic level), the choice of the survey scale for macro-units is optional (reach or sub-reach).

In the case of small confined rivers, the survey of macro-units is always optional (it depends on available data), as well as the choice of the scale of survey (reach or sub-reach). Finally, the survey of features such as human-dominated areas (H, land use included) and artificial features (A) is always optional.
It should be noted that the survey and calculation of the areal extent of macro-units is needed for the calculation of some GUS sub-indices.

## *1.4 Sheets 4 to 6: Basic level*

The survey of units (and some macro-units) at the Basic level is carried out **in the field** (Fig. B1.6). On the basis of available remotely-sensed data (high or very high resolution images) the Basic level can be carried out from **remote sensing**, but a field check is always recommended.
The first column of the sheet corresponds to the identification code of the corresponding macro-unit. The recorded information is:

- Presence/absence of macro-units (baseflow or 'submerged' channels) and unit types (minimum level) (P/A);
- Their number (N or code): indicate the unit identification code and progressive number, in order to match with the field sketch of sheet 2 (e.g.: 3 rapids = CR1, CR2, CR3 both in the sketch and in the sheet);
- Length (by field survey) or area (by remote sensing) for each identified unit (and/or macro-unit) (L/A);

- Number or reference of the photograph taken during the field survey, for each unit (optional) (Picture number).

**Sheet 4: BASIC LEVEL**

**Bankfull channel units**

| Macro-unit type | P/A | N (or code) | L/A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Main channel (C) | | | | | | | | | | | | |
| | | Picture number | | | | | | | | | | |
| Secondary channel (within bankfull) (S) | | | | | | | | | | | | |
| | | Picture number | | | | | | | | | | |

| Macro -unit | Unit type | P/A | N (or code) | L/A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| C | Pothole (CH) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |

**Figure B1.6 Detail of the Sheet 4 (Basic level).**

It is possible to indicate information for a limited number of units. If more units are present, use an additional sheet (the same for the Detailed level).
At the end of sheet 5, the total number of unit types and units can be indicated in order to calculate the GUS indices (GUSI-R and GUSI-D) and sub-indices (see part A, section 4.1).
Below, there are some recommendation on how to conduct the field survey at the Basic level:
(i) Proceed from upstream to downstream and for spatial settings (i.e. bankfull channel, floodplain; mainly in case of large rivers).
(ii) According to the survey objectives:

- 1 surveyor, if only presence/absence and number of units is required;
- At least 2 surveyors, if the unit size must be measured (length and/or area).

The survey of units at the Basic level is required for single-thread and small rivers, but is optional for multi-thread and transitional rivers. However it is necessary if the GUS indices and sub-indices (presence/absence and unit number) are to be calculated (see Part A, section 4.1).

## *1.5 Sheets 7 to 15: Detailed level (macro-units and units)*

The Detailed level is an **optional in-depth characterisation** of units and some macro-units (for sub-units, see below) conducted mainly using **field survey,** although some characteristics of units and macro-units can be obtained from remote sensing if sufficiently high resolution data are available.
At this level, the method allows collection of data on morphological, hydrological, and sedimentary features, as well as on genetic mechanisms (Fig. B1.7).
The **detailed characterisation of units** is accomplished by recording:

- Presence/absence of a specific unit 'sub-type', which reflects:
    i. the genetic mechanisms, such as a 'forced pool' for bankfull channel submerged units;
    ii. the development stage, such as a 'mature island' for islands.
- Dominant substrate (sediment size) and any substrate alteration: bedrock (Bed), boulder (Bou), cobble (Cob), gravel (Gra), sand (San), silt (Sil), clay (Cla), clogging (Clo), armouring (Arm), artificial (Art).
- Dominant hydraulic conditions, which convey information on hydrological connectivity between units and the water channel:
    i. Three classes of flow velocity are assigned to bankfull channel 'submerged' units (i.e., bed configuration): high (Hig), intermediate (Int) and low (Low);

ii. Three classes of frequency of submersion in relation to the Bankfull channel, for 'emergent' units (i.e., bars, islands and LW jams) (excluding bank-related features, see below): below bankfull (<BC), bankfull (BC) and above bankfull level (>BC);
iii. Two classes of flow depth, for in-channel aquatic vegetation: < 1m, > 1m;
iv. Two classes of topographic height with respect to the Bankfull level, for Floodplain units: modern floodplain (Flo), recent terrace (Ter);
v. For banks, the information on hydraulic conditions is provided in terms of connection with other surfaces:
    - Modern floodplain bank (Flo), i.e. bank connecting a Bankfull channel unit with the modern floodplain;
    - Recent terrace bank (Ter), i.e. bank connecting a Bankfull channel unit with a recent terrace.

- Presence of vegetation features:
    i. Spatial structure: absent (Abs), sparse (Spa), patches (Pat), dense (Den);
    ii. Height structure: trees (Tre), shrubs (Shr), herbs (Her); for submerged units: presence of algae or floating vegetation (Alg), rooted vegetation that has floating leaves (Flo), submerged leaves (Sub), emergent leaves (Eme);
    iii. Dominant species or vegetation type (Species);
    iv. Presence of large wood (not jam) (Woo);
    v. Presence of roots (only for banks and benches) (Roo).
- In terms of processes:
    i. The formative process for islands: floodplain dissection island (Dis) and mid-channel island (Mid) (*sensu* Gurnell et al. 2001);
    ii. The acting (or dominant) process for benches: channel incision (Inc), channel narrowing (Nar).
    iii. Bank stability/instability 'status': retreating (Ret), stable (Sta), advancing (Adv) bank.
- Some relevant measures (Mea):
    i. Mean width (Wid) (m), for almost all units;
    ii. Mean size (Siz) (m) and number (Num) (three classes: < 5, > 5, > 10) of logs, for large wood jams;
    iii. Mean height (Hei) (m), for aquatic vegetation and benches;
    iv. Bank length (Len) (m), height (Hei) (m) and slope (Slo) (%).
- Number or reference of the picture taken during the field survey (Pic).
- Other additional available information, as for example the determination of the $D_{50}$, the dominant flow type during the survey, the presence of moss or peryphyton on the bed substrate, the water temperature (Other).

**Sheet 11: DETAILED LEVEL - Bankfull channel**

**(c) In-channel vegetation units (continue)**

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic conditions | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | <BC | BC | >BC | Abs | Spa | Pat | D |
| VJ | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |
| | Meander jam | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |
| | Bench jam | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |
| | Bar apex jam | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |

**Figure B1.7 Detail of the Sheet 11 (Detailed level).**

For banks, further information is provided in terms of (see section 2 for detailed description):

- Bank morphology (geometry): near vertical (Ver), vertical undercut (Und), planar (Pla), with toe (Toe), convex upwards (Con), concave upwards (Coc), complex (Com).
- Bank composition (material): non-cohesive (NoC), cohesive (Coe), composite (Com), multi-layered (Lay).

It is worth noticing that, for the banks, the characterisation is averaged for all the bank profile and length. If the operator is interested in the detailed characterisation of banks, it is suggested to divide the bank length into smaller portions and to characterise them separately.

In some cases, also **selected macro-units** (i.e. baseflow channels) can be optionally further characterised at the Detailed level, by means of remote sensing and/or coupled with field survey, as follows:

- The definition of 'sub-types' of secondary channels on the basis of their size and their connection to the main channel (from remote sensing and validation on the field).
- The characterisation of macro-units types and sub-types, in terms of:
    i. Sediment characteristics (same as units);
    ii. Three classes of hydraulic conditions, in terms of frequency of the connection to the main channel/network: below bankfull (<BC), bankfull (BC) and above bankfull (>BC) level;
    iii. Vegetation characteristics (same as units);
    iv. Relevant measures, i.e. width (Wid);
    v. Number or reference of the picture taken during the field survey (Pic);
    vi. Other additional information as, for example, water temperature or conductivity, to determine the connection with the groundwater (Other).

The characterisation of units and macro-units at the Detailed level is always optional for all types of rivers.

## *1.6 Sheet 16: Detailed level (sub-units)*

The Detailed level also allows, if needed, the **definition (mapping) and characterisation of sub-units** (Fig. B1.8). Once identified (see section 2.5 for a list of some example of sub-units for each spatial setting) the operator can characterise sub-units in a similar manner to units:

- Indicate the macro-unit and unit (code and progressive number) at which the sub-unit belongs.
- Name of the sub-unit.
- Number of the sub-unit (Num): this can be "total", i.e. the sum of all the sub-units of a same type, or "progressive", if the aim is to map and characterise each sub-unit of a same type.
- Sediment characteristics (same as units).
- Presence of vegetation features:
    i. Spatial structure: absent (Abs), dense (Den), sparse (Spa);
    ii. Presence of other (secondary) types of vegetation structures: trees (Tre), shrubs (Shr), herbs (Her);
    iii. Presence of other (secondary) types of aquatic vegetation: algae (Alg), floating (Flo), rooted with floating leaves (Rfl), submerged leaves (Sub), emergent leaves (Eme);
    iv. Dominant species or vegetation type (Species);
    v. Presence of woody debris (not jam) (Woo);
    vi. Presence of roots (only for banks) (Roo).

- Some relevant measures in terms of length (Len), width (Wid) and height (Hei) (m), or surface area (Are) ($m^2$).
- Number or reference of the picture taken during the field survey (Pic);
- Other additional information which can be relevant for the characterisation of the sub-unit.

The characterisation of sub-units at the Detailed level is always optional for all types of rivers.

| Sheet 16: DETAILED LEVEL - SUB-UNITS | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Macro-unit | Unit | Sub-unit name | Num | Sediment characteristics | | | | | | | | | | Vegetation characteristics | | | | | | | | |
| | | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | Abs | Spa | Den | Tre | Shr | Her | Alg | Flo | Sub |
| | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
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**Figure B1.8 Detail of the Sheet 16 (Detailed level for sub-units).**

Table B1.1 summarises the characteristics surveyed at the Detailed level for each spatial unit and spatial setting.

**Table B1.1. Summary of the characteristics surveyed at the Detailed level for each spatial unit and spatial setting.**

| | **Bankfull channel** | | **Floodplain** |
|---|---|---|---|
| | *Submerged* | *Emergent* | *(Land use excluded)* |
| **Macro-units** | Sub-type | | |
| | Sediment characteristics | | |
| | Hydraulic conditions | | |
| | Vegetation characteristics | | |
| | Measures | | |
| | Picture number | | |
| | Other (e.g. temp.) | | |
| **Units** | Sub-type | Sub-type | Sub-type |
| | Sediment characteristics | Sediment characteristics | Sediment characteristics |
| | Hydraulic conditions | Hydraulic conditions | Hydraulic conditions |
| | Vegetation characteristics | Vegetation characteristics | Vegetation characteristics |
| | | Processes | |
| | | Bank morphology | |
| | | Bank composition | |
| | Measures | Measures | Measures |
| | Picture number | Picture number | Picture number |
| | Other (e.g. D50) | Other (e.g. D50) | Other |
| **Sub-units** | Macro-unit (code) | Macro-unit (code) | Macro-unit (code) |
| | Unit (code) | Unit (code) | Unit (code) |
| | Type/Name | Type/Name | Type/Name |
| | Number | Number | Number |
| | Sediment characteristics | Sediment characteristics | Sediment characteristics |
| | Vegetation characteristics | Vegetation characteristics | Vegetation characteristics |
| | Measures | Measures | Measures |
| | Picture number | Picture number | Picture number |
| | Other | Other | Other |

# B.2. Illustrated guidebook for the identification and delineation of spatial units

In this section geomorphic units (and related macro-units and sub-types, as well as examples of sub-units) that can be identified in fluvial systems are listed and described, organised following the spatial setting to which they belong.
Appendix 2 reports the list of all geomorphic units (and relative macro-units and sub-types).

## *2.1 Bankfull channel units*

The bankfull channel corresponds to the area occupied by baseflow channels, bars, islands, and other possible vegetation units. Bankfull channel units include all geomorphic units located within the bankfull channel. They comprise three macro-units: (1) baseflow or 'submerged' channel units; (2) 'emergent' sediment units, i.e. 'emergent' depositional and erosive sediment features; (3) in-channel vegetation units.

### 2.1.1 Macro-unit: baseflow or 'submerged' channels

This macro-unit includes all the geomorphic units which are part of the baseflow channels (i.e. submerged at baseflow).
All the portions within the bankfull channel can be flooded with different frequency of inundation. For practical reasons, at the *Broad level* of classification, baseflow channels are considered the portions of the bankfull channel that are submerged at the time of observation (provided that the survey is never carried out during high flow conditions). This also includes submerged bars that are considered as part of the submerged channel and are not further classified and characterised within the GUS. Intermittent or temporary channels which do not have flow during the survey are included within the emergent sediment units (see the definition of *dry channel*).
It should be noted that although baseflow is usually maintained in perennial rivers and streams during extreme low-flow conditions by groundwater seepage, in some hydrologic (prolonged dry periods without precipitation) or hydrogeologic conditions, even 'perennial' rivers may dry up for short periods of time.
At the *Basic level*, two types of baseflow channels can be distinguished: (1) baseflow channel or main channel; (2) secondary channel/s. At the *Detailed level*, further sub-types of secondary channels can be identified (see below).

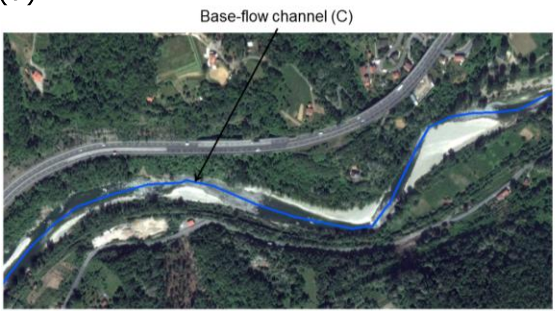
*Identification code* of the macro-unit*:* C or S (see macro-unit types and sub-types below).

<u>*Macro-unit types*</u>

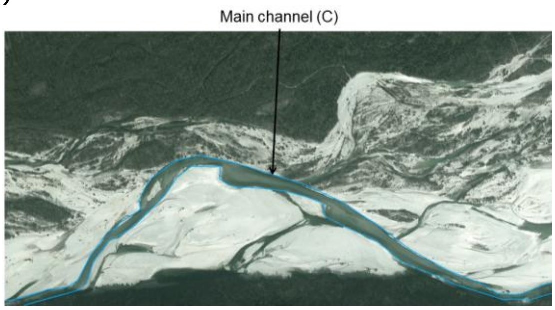
| **Baseflow channel or main channel** |
|---|
| *Identification code*: C |
| *Definition*<br>In *single-thread* perennial streams, this corresponds to the single channel containing flowing water, and is termed the *baseflow channel*. Where depositional bars are absent or scarce the baseflow channel can occupy most of the bankfull channel.<br>In *multi-thread* patterns, this is identified as the *main channel*, i.e. the one carrying the larger proportion of water. If a main channel is not clearly recognizable, more than one *baseflow channel* can be recorded. |
| *Equivalent terms*: low-flow channel, low-water flow, main thread or main branch or main anabranch (in multi-thread systems) |

*Distinctive characteristics:* In transitional and multi-thread systems, the main channel (C) can be easily distinguished from remotely sensed imagery (high resolution aerial and satellite photos) as it is wider and deeper (i.e. dark blue color) than the other branches.

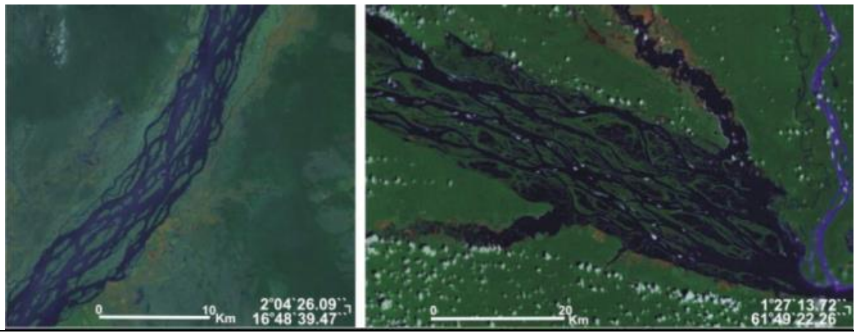
(a)




(b)




(c)




Macro-unit type *baseflow channel* or *main channel* in (a) single-thread river, (b) multi-thread braided river and (c) multi-thread anabranching (anastomosing) rivers (which may possess several baseflow channels).

**Secondary channel (within the bankfull channel)**

*Identification code*: S

*References:* Arscott et al. (2000, 2002); Tockner & Malard (2003); Van der Nat et al. (2003); Ashmore (2013); Belletti et al. (2013)

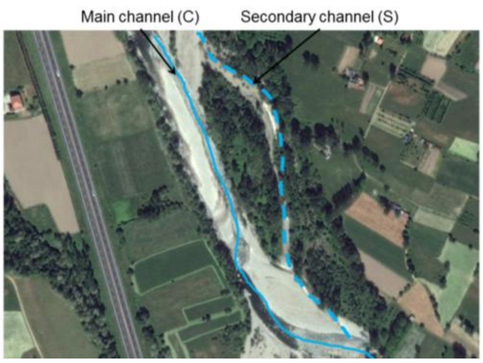
*Definition*

Baseflow channels are classified as 'secondary' when their size (and corresponding flow) is significantly smaller than the main channel. They may exist in single-thread, transitional or multi-thread systems.

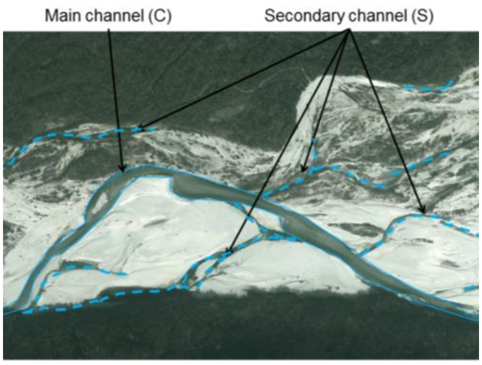
*Equivalent terms:* secondary thread, branch or anabranch, side channel

*Distinctive characteristics:* secondary channels are smaller, narrower and shallower than the main channel.

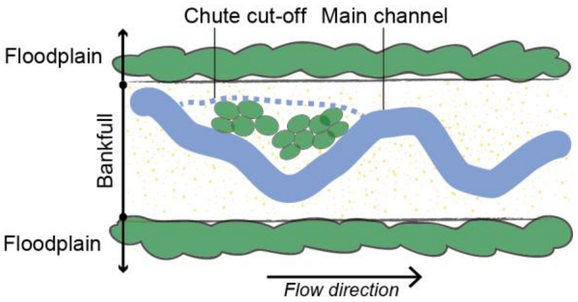
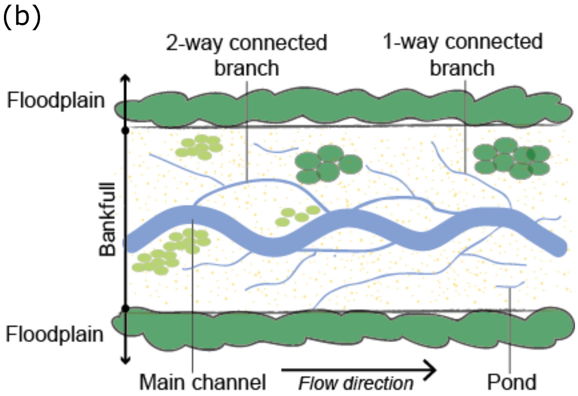
(a)




(b)




Macro-unit type *secondary channel* in (a) single-thread river, (b) multi-thread braided river.

| *Macro-unit sub-types* |
|---|
| *References:* Arscott et al. (2000, 2002); Tockner & Malard (2003); Van der Nat et al. (2003); Bertoldi et al. (2009); Ashmore (2012); Belletti et al. (2013); Welber et al. (2012) |
| (a)   (b)   Sub-types of macro-unit *secondary-channel* (S) in (a) single-thread and (b) transitional and multi-thread (braided) rivers (modified from Belletti et al. (2013) and Belletti (2012). |
| **Chute cut-off channel** |
| *Definition*<br>In single-thread or transitional systems, a chute cut-off channel is a secondary channel located on the inner portion of a side or point bar and generated by a chute cute-off, that is a shortcut across an emergent bar, typically a bank-attached bar.<br>*Equivalent terms:* side channel, side arm |
| **Two-way connected branch** |
| *Definition*<br>In multi-thread or transitional systems, a two-way connected branch is a secondary channel connected upstream and downstream to the main channel. Two-way connected branches are narrower and shallower than the main channel. Some authors also identify primary, secondary and tertiary order of two-way connected branches, depending on the degree of connection to the main channel or to other branches.<br>*Equivalent terms*: upstream-to-downstream channel, surface-connected channel, side braid/channel |
| **One-way connected branch** |
| *Definition*<br>In multi-thread or transitional systems, a one-way connected branch is a secondary channel connected usually only at the downstream end to the main channel although sometimes the connection may be at the upstream end (*mixed channels*: Tockner & Malard, 2003; Belletti et al., 2013). The downstream connected channels are fed by groundwater seepage from the alluvial aquifer, whereas those with an upstream connection disappear as their flow seeps into the alluvial aquifer. Upstream connected channels are most frequent in alpine and glacial systems with a highly variable flow regime (i.e. snow and glacier melt) and coarse bed material. Some authors also identify primary, secondary and tertiary order of one-way connected branches (e.g. Arscott et al., 2000).<br>*Equivalent terms:* upstream-connected channel, groundwater-fed channel, backwater, mixed channel |
| **Pond** |
| *Definition*<br>A pond is a geomorphic unit, more common in multi-thread systems, consisting of a portion of secondary channel that becomes completely disconnected from the channel network at baseflow.<br>*Equivalent terms:* isolated pool or isolated standing water |

*Bed configuration units*

Within each *baseflow channel* macro-unit, a series of geomorphic units can be identified that are associated with the configuration of the river bed.
In confined single-thread streams, the spatial scale (longitudinal extent) of these units is similar to the bankfull channel width, whereas in relatively large alluvial rivers featuring wandering or braided patterns, their spatial scale is similar to the baseflow channel width.
Most units are found in alluvial or semi-alluvial channels (Fig. B2.1), but some are exclusively found in bedrock channels. Geomorphic units of alluvial and semi-alluvial channels can be erosional (e.g. pool), depositional (e.g. step) or mixed (e.g. cascade), whereas bedrock channels are characterised by specific erosional units (e.g. pothole).
In ecohydraulics, bed configuration geomorphic units are commonly named 'hydromorphological units' (HMU; e.g. Vezza et al., 2014).

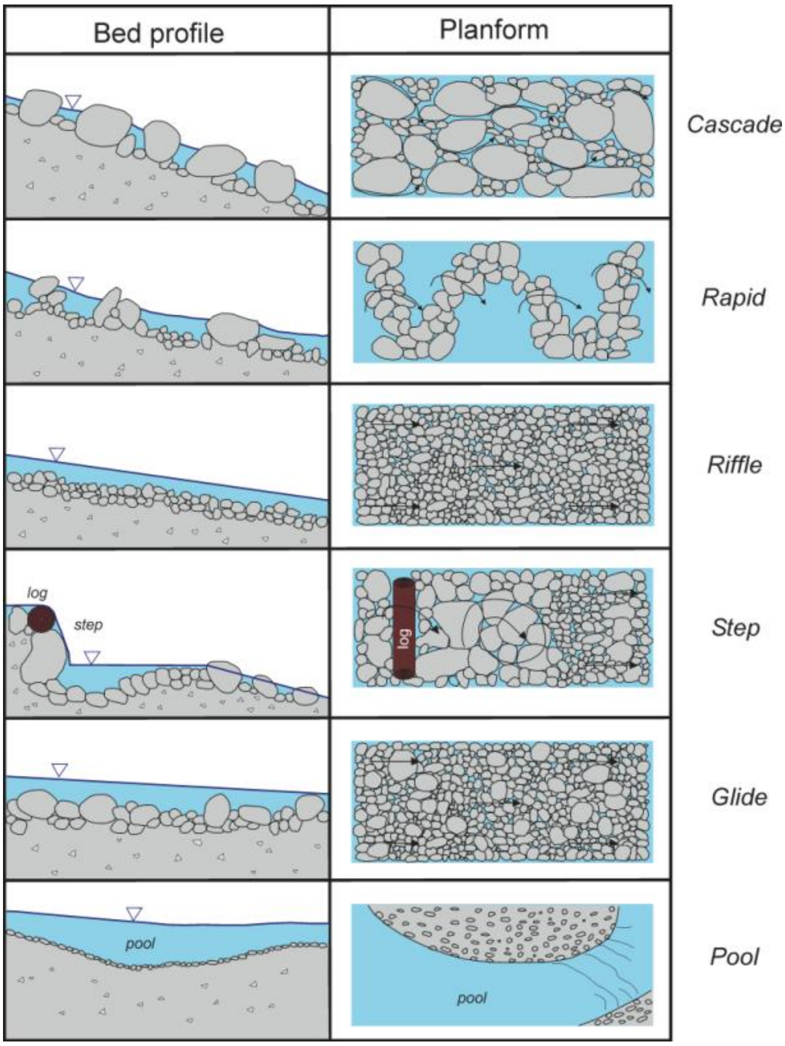
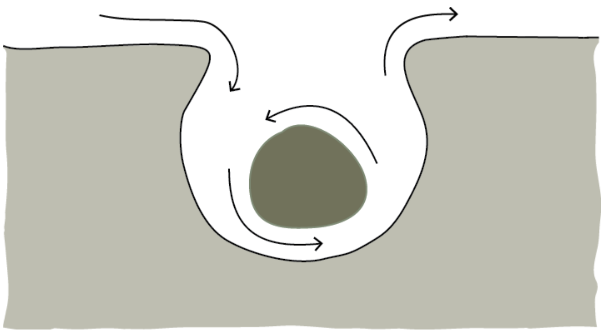



**Figure B2.1 Main geomorphic units of mountain alluvial bed streams (modified from Halwas & Church, 2002).**

| **Pothole** |
|---|
| *Identification code*: CH |
| *References:* Brierley & Fryirs (2005); Fryirs & Brierley (2013) |
| *Definition*<br>Erosional geomorphic unit, typical of bedrock channels. It is a deep, circular scour feature that occurs in areas where flow energy is highly concentrated. These features are sculpted from bedrock due to the abrasion induced by transported particles trapped in the hole. They are commonly associated to weak lithological layers or to the presence of structural discontinuities. |
| *Distinctive characteristics:* in contrast to *pools* (*plunge pool*), *potholes* are not located downstream of a *step* unit. |

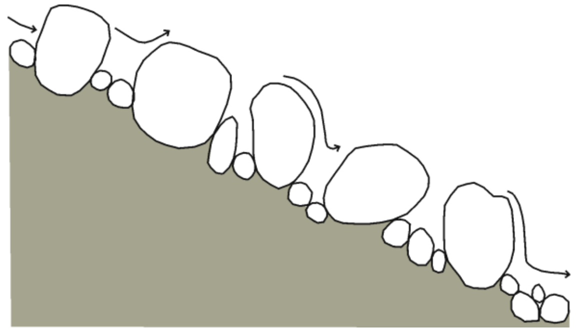
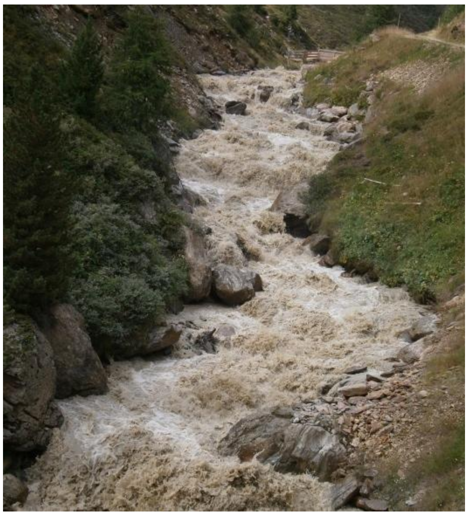
(a)



(b)

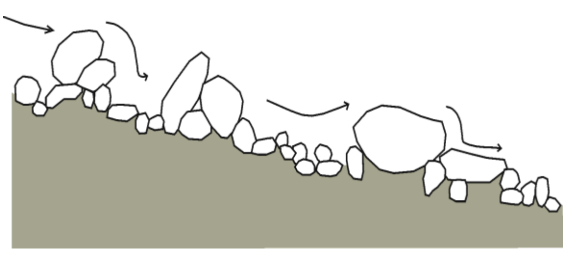
Bed configuration unit type: *pothole* (a, b). (a) Modified from Brierley & Fryirs (2005).

| **Cascade** |
|---|
| *Identification code*: CC |
| *References*: Halwas & Church (2002); Montgomery & Buffington (1997); Buffington & Montgomery (2013) |
| *Definition*<br>Alluvial or semi-alluvial geomorphic unit mainly formed by boulders and/or large cobbles. Sediments are not organized either in lateral ribs or longitudinal stone lines, and are transported only by infrequent large floods. Small pools between boulders are shallow, characterised by very turbulent flow, and are usually smaller than the channel width (named *pocket pools*; see the sub-units). Tumbling flow dominates at all flow stages, and so energy dissipation is controlled by spill resistance with the additional contribution of wake turbulence around large clasts. These units are typical of very steep (S>7%), confined reaches, that are well connected to a supply of coarse sediment (hillslopes, debris-flow channels, etc.). |
| *Distinctive characteristics:* in comparison to sequences of *step* and *pool* units, which also feature tumbling flow, the organization of the large clasts in *cascade* units is more chaotic and channel-spanning pools are lacking. In comparison with *rapids*, *cascades* maintain a dominant tumbling flow characteristic at flood stage, and clasts show less organization. |

(a)  (b) 

Bed configuration unit type: *cascade* (a, b). (a) Modified from Halwas & Church (2002).

| **Rapid** |
|---|
| *Identification code*: CR |
| *References:* Grant et al. (1990); Halwas & Church (2002) |
| *Definition*<br>*Rapids* are an alluvial or semi-alluvial geomorphic unit, mainly formed by boulders and large cobbles. Boulders are very stable and partially organized into irregular ribs or stone lines oriented more or less perpendicular to the channel and partly or totally spanning the channel width. These *transverse ribs* (see sub-units), if present, are visible only at low flow, being fully submerged during bankfull flows. Pools are shallow and poorly developed, and do not form distinct, separate geomorphic units. |
| *Distinctive characteristics:* compared to *cascade* and *step units*, the larger clasts within *rapids* become submerged at bankfull flows, such that tumbling flow only occurs at low to medium flows. In contrast to *riffles*, *rapids* are characterised by coarser grains, some of which are organized in lines or *transverse ribs* which protrude from the flow at low to medium stages, and flow is more turbulent with higher air concentrations (white-water), producing broken standing waves during low flows. |

(a)  (b) 

Bed configuration unit type: *rapid* (a, b). (a) Modified from Halwas & Church (2002).

**Riffle**

*Identification code*: CF

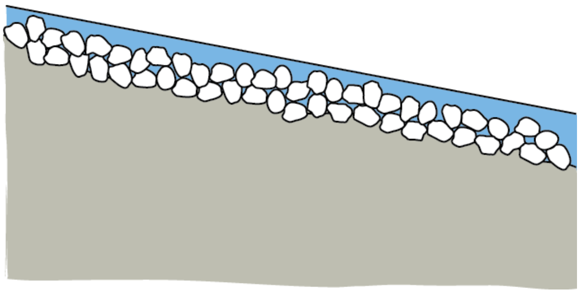
*References:* Grant et al. (1990); Church (1992); Wood-Smith & Buffington (1996); Knighton (1998)

*Definition*

*Riffles* are characterised by relatively shallow and fast flow (near to super-critical) compared to adjacent units, and by relatively uniform sediment (gravel to small cobbles) which rarely protrude out of the flow. Differences in water depth and velocity between *riffles* and nearby units (typically *pools* and *glides*) decrease as stage increases. *Riffles* tend to occur at the inflection point between bends in sinuous alluvial channels, where the channel is dominated by a sequence of alternating bars at the bends.

*Distinctive characteristics:* compared to *rapids*, *riffles* are characterised by less turbulent flows, frequently showing unbroken standing waves at intermediate to high stage, before they get completely drowned out. Compared to *glides*, *riffles* are characterised by a locally higher bed slope inducing accelerating flow velocity, and presenting an undulating but unbroken flow surface (waves may become broken on steeper *riffles* composed of relatively coarser sediment).

(a)



(b)

Bed configuration unit type: *riffle* (a, b). (a) Modified from Halwas & Church (2002) and Brierley & Fryirs (2005).

*Sub-types*

*References:* Brierley & Fryirs (2005)

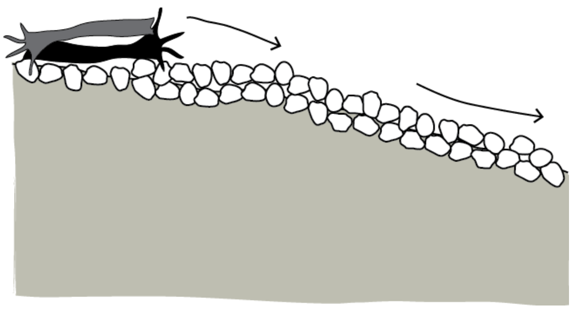
**Forced riffle**

*Definition*

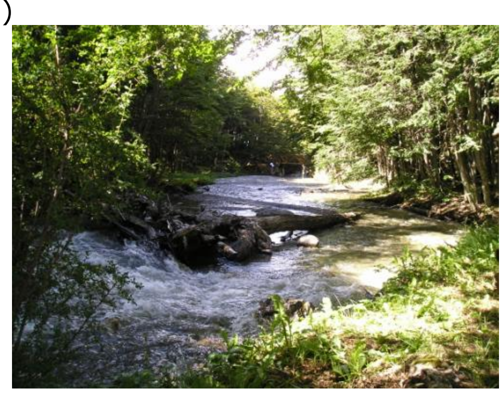
Longitudinally undulating alluvial sediment accumulation that acts as a locally high area on the river's longitudinal profile. These features are formed by bedrock outcrops, accumulation of coarse sediments or large wood elements. They tend to occur at wider sections and in bedrock-confined systems (Brierley & Fryirs, 2005).

*Equivalent terms:* constriction riffle

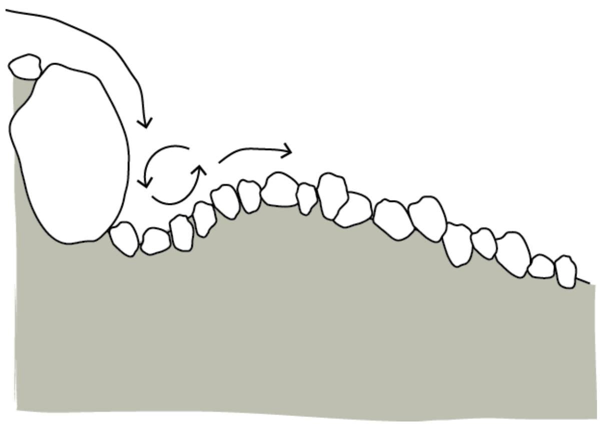
(a)

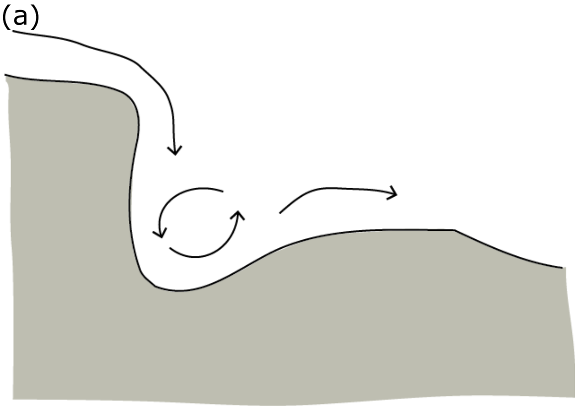
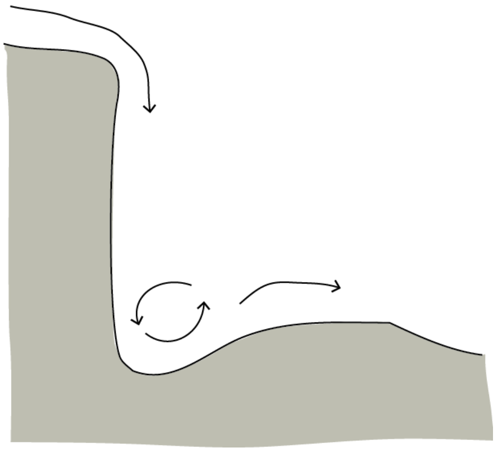


(b)



Bed configuration unit sub-type: *forced riffle* (a, b). (a) Modified from Brierley & Fryirs (2005).

| **Step** |
| --- |
| *Identification code*: CT |
| *References:* Chin (2003); Halwas & Church (2002); Church (1992); Comiti & Mao (2012) |
| *Definition*<br>A relatively short unit typical of alluvial, semi-alluvial and bedrock steep channels. *Steps* are characterised by near-vertical drops in the channel bed which span the entire width, and are higher than the bankfull flow depth just upstream of the crest of the step, such that the relative jet is not submerged during bankfull flows (Comiti & Mao, 2012). Steps feature accelerating and convergent flow conditions as a consequence of the downstream overfall of water, thus turbulence fluctuations are limited (Wilcox et al., 2011) and the water surface is fairly smooth. Besides *steps* composed of sediment (alluvial or semi-alluvial), these features can be totally or partially created by wood (*log steps*) or they can be scoured into the bedrock (*rock steps*) (see the sub-types). |
| *Distinctive characteristics: step* units span the entire channel cross section with the same natural drop structure, and so they differ from *cascade* units which present drops that only extend across a part of the channel cross section (partial steps). In contrast to *transverse ribs* and stone lines that are found in *rapids or glides,* the drops created by *steps* are not submerged by bankfull flows, and so tumbling flow occurs up to the annual flood stage and flow is dominated by spill resistance (Comiti & Mao, 2012). |
| (a)  (b) <br>Bed configuration unit type: *step* (a, b). (a) Modified from Brierley & Fryirs (2005) and from Halwas & Church (2002). |

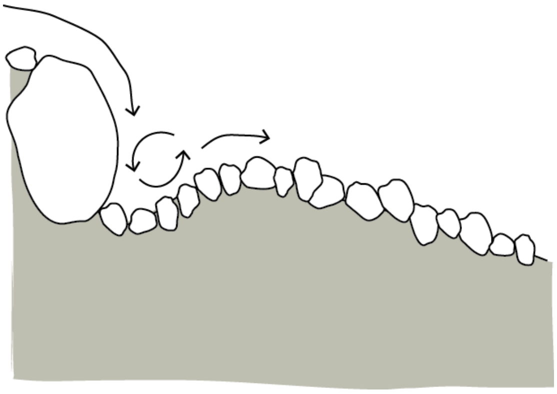
| |
|---|
| *Sub-types* |
| *References*: Knighton (1998); Brierley & Fryirs (2005); Zimmermann et al. (2010); Waters & Curran (2012); Comiti & Mao (2012); Wohl (2010) |
| **Rock step** |
| *Definition*<br>This is an erosional feature formed by turbulent flow plunging over a locally resistant area of bedrock, forming a channel-wide drop. Transverse *rock steps* >1m high may separate a *backwater pool* upstream from a *plunge pool* downstream (Brierley & Fryirs, 2005).<br>*Equivalent terms:* bedrock step, rockstep |
| (a)  (b) <br>Bed configuration unit sub-type: *rock step* (a, b). (a) Modified from Brierley & Fryirs (2005). |
| **Waterfall** |
| *Definition*<br>A *waterfall* is a near-vertical step of significant height formed by high turbulent flow plunging over a locally resistant area of bedrock that forms a channel-wide drop. *Waterfalls* are higher than *rock steps,* typically exceeding 3m in height, and are observed as single units rather than being part of a regularly spaced sequence of steps.<br>*Equivalent terms:* knickpoint |
| (a)  (b) <br>Bed configuration unit sub-type: *waterfall* (a, b). (a) Modified from Brierley & Fryirs (2005); (b) from www.gocime.com. |

**Boulder step**

*Definition*

A *boulder step* is a step unit composed of large clasts (mainly boulders, but also cobbles). Typically these *steps* are not entirely alluvial but contain large boulders supplied from local hillslopes which, because of their size, are very stable. The stability of *boulder steps* depends on: the size of clasts composing the *step*, the channel width (greater the width lower the stability), the dowstream distance from other *steps* (greater the distance lower the stability), and the magnitude of peak flows. *Boulder steps* can occasionally be disrupted by over-bankfull floods, and when they collapse the instability may migrate headward or downstream to other *steps*.

(a)



(b)

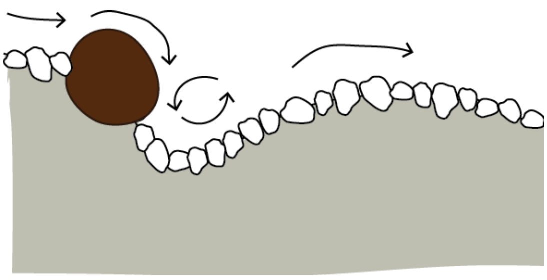
Bed configuration unit sub-type: *boulder step* (a, b). (a) Modified from Brierley & Fryirs (2005).

**Log step**

*Definition*

A *step* unit totally or partially imposed by a large wood element (log) fallen from the bank and spanning completely or partially the channel. *Log steps* units are very common in temperate old-growth forested basins. *Log steps* can be oriented normal or oblique to flow.

(a)



(b)

Bed configuration unit sub-type: *log step* (a, b). (a) Modified from Halwas & Church (2002) and Abbe & Montgomery (2003).

**Glide**

*Identification code*: CG

*References:* Bisson et al. (1982); Church (1992); Grant (1990); Sullivan (1986); Halwas & Church (2002)

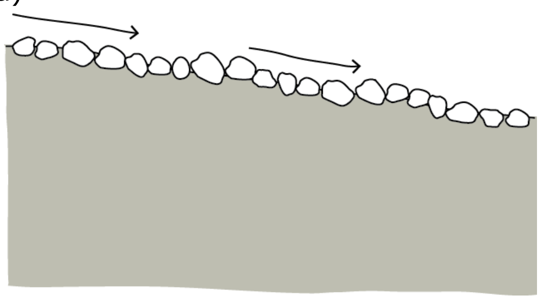
*Definition*

*Glides* feature a regular longitudinal bed profile, with a smooth or rippled water surface that is approximately parallel to the bed, with low turbulence.
In relatively steep gravel-bed rivers, *glides* are often armoured, and in the steepest cases may incorporate some coarse grains (cobbles and boulders) but these rarely protrude from the flow. *Glides* are also common in low gradient gravel-bed and sand-bed rivers, where they are typically located downstream of *pools* and upstream of *riffles*.

*Distinctive characteristics:* compared to *riffles* or *rapids*, *glides* are characterised by a lower local slope and rippled or smooth water surface. Standing waves are not present, except where isolated boulders emerge through the water surface. Compared to *pools*, *glides* are characterised at low stages by a more disturbed water surface and a channel bed that is approximately parallel to the water surface.

*Equivalent terms:* run (generally used to indicate a *glide* of limited length located between a *pool* and a *step* or a *riffle* unit and/or in low slope reaches)

(a)



(b)

Bed configuration unit type: *glide* (a, b). (a) Modified from Brierley & Fryirs (2005).

*Sub-types*

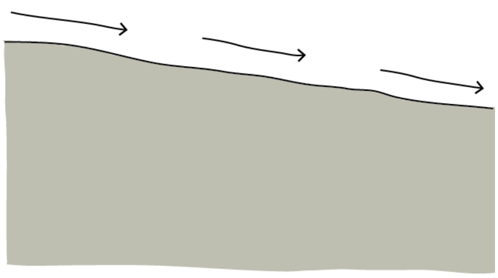
*References:* Wohl (1998)

**Rock glide**

*Definition*

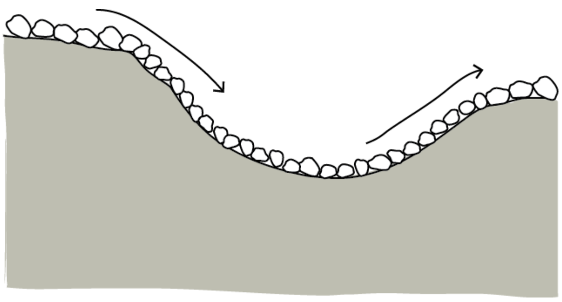
This unit is found in bedrock channels and features the hydrodynamic characteristics described above for *glides* (smooth or rippled flow and a water surface that is near parallel to the channel bed).
*Equivalent terms:* bedrock glide

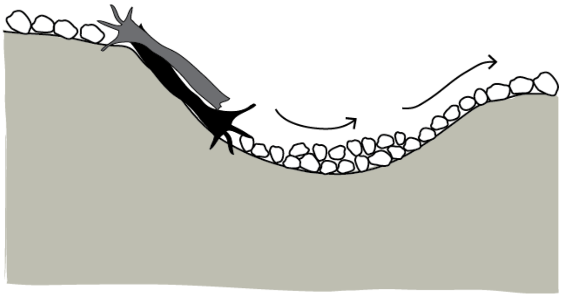
(a)

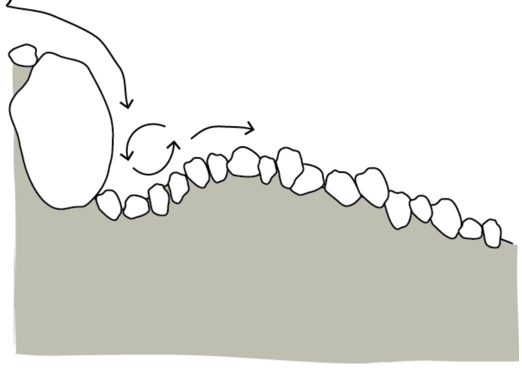
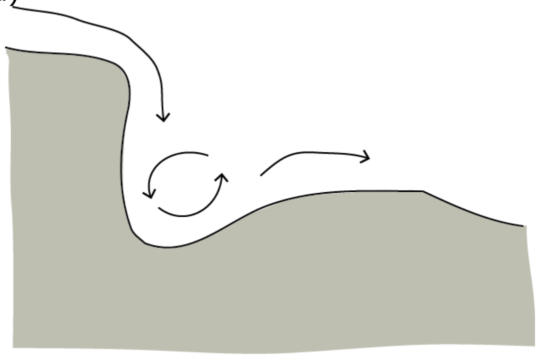


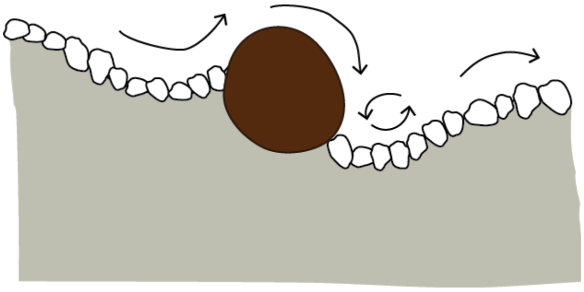
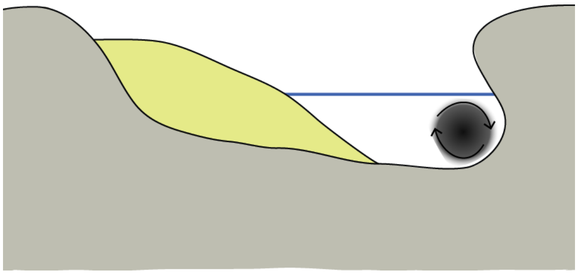
(b)

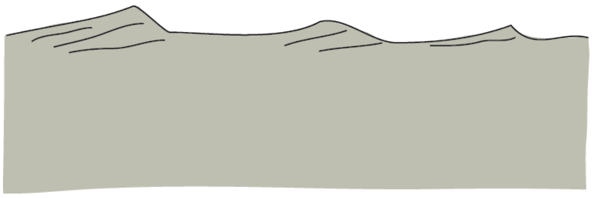
Bed configuration unit sub-type: *rock glide* (a, b). (a) Modified from Wohl (1998).

| **Pool** |
|---|
| *Identification code*: CP |
| *References:* Church (1992); Grant et al. (1990); Wood-Smith & Buffington (1996); Halwas and Church (2002) |
| *Definition*<br>A *pool* unit is a channel-spanning topographic depression in the channel bed, with a reversed bed slope at the downstream end. *Pools* are characterised by deep, relatively slow velocity flows but with complex hydrodynamic patterns. Bed sediments often appear to be finer than the adjacent units if deposition has occurred, but the substrate can also be coarse. *Pools* reflect the interactions between flowing water and sediment transport, often alternating with *steps* or *riffles*, along boulder- and gravel-bed rivers. *Pools* are also found in sand-bed rivers in association with channel bends. Indeed, different flow processes are responsible for pool formation, and thus several sub-types can be identified. |
| *Distinctive characteristics:* All types of *pools* are characterised by a topographic depression with a reverse bed slope in their downstream part which makes them quite different from all the other units characterised by low flow velocity (e.g. low gradient *glides*). |
| (a)  (b) <br>Bed configuration unit type: *pool* (a, b). (a) Modified from Knighton (1998). |

| *Sub-types* |
|---|
| *References*: Bisson et al. (1982); Montgomery et al. (1995); Brierley and Fryirs (2005) |
| **Forced pool** |
| *Definition*<br>*Pool* unit originated by constriction scouring associated with irregularly spaced bedrock outcrops, large wood elements, forced *riffles*, and from the deposition of coarse material of several origins (e.g. from glacial deposits in north-European rivers formed on glacial valleys). Often they form from erosional processes due to local reduction of the flow section or due to the formation of vortex with vertical axis.<br>*Equivalent terms:* constriction pool |
| (a)  (b) <br>Bed configuration unit sub-type: *constriction pool* (a, b). (a) Modified from Montgomery et al. (1995). |

| **Scour pool** | |
|---|---|
| *Definition*<br>*Pool* unit derived from local scouring of the bed sediment downstream of rock, clast or wood *step* units. | |
| (a)<br> | (b)<br> |
| Bed configuration unit sub-type: *scour pool* (a, b). (a) Modified from Brierley & Fryirs (2005) and from Halwas & Church (2002). | |
| **Plunge pool** | |
| *Definition*<br>*Pool* unit, typically quite deep and circular, formed in bedrock channels by corrosion and cavitation processes below *rock steps* or *waterfalls* by the action of a plunging jet. | |
| (a)<br> | (b)<br> |
| Bed configuration unit sub-type: *plunge pool* (a, b). (a) Modified from Brierley & Fryirs (2005). | |

| **Dammed pool** | |
|---|---|
| Definition<br>A *dammed pool* may form immediately upstream of a *rock step, boulders,* a *log step, or* a *wood accumulation* and it persists until it is completely filled by sediment or the obstruction (boulders, wood) is removed.<br>*Equivalent terms:* backwater pool | |
| (a)<br> | (b)<br> |
| Bed configuration unit sub-type: *dammed pool* (a, b). (a) Modified from Bisson et al. (1982), Brierley & Fryirs (2005) and from Halwas & Church (2002). | |
| **Meander pool** | |
| *Definition*<br>Deep pool unit formed by erosion by secondary flows close to the concave bank of a meander bend. | |
| (a)<br> | (b)<br> |
| Bed configuration unit sub-type: *meander pool* (a, b). Modified from Knighton (1998). | |

| **Dune system** |
|---|
| *Identification code*: CD |
| *References:* Simons & Richardson (1966); Knighton (1998) |
| *Definition*<br>This unit is typical of low-gradient, alluvial sand-bed rivers. The surface flow is influenced by the presence of the dunes, showing 'bulges' not in phase with the dunes.<br>A single dune or a few occasional dunes should be classified as sub-units (same for a single boulder or a single tree). A set of dunes is classified as a geomorphic unit (*dune system*) if dunes extend to the length of a channel width. A *dune system* is often associated with *ripples* (see the sub-units) generating a *dune-ripple* morphology (Montgomery & Buffington, 1997).<br>*Dune systems* are difficult to observe, particularly in deep channels when the bed is frequently not visible (except in case of availability of a detailed bathymetric survey). In most cases the presence of this bed morphology can be assumed on the basis of the knowledge of the bed material (mainly sand) and from the undulating water surface, showing well-structured and recurring turbulent fluctuations. |
| (a)  (b)  <br>Bed configuration unit type: *dune system* (a, b). (a) Modified from Montgomery & Buffington (1997). |

### 2.1.2 Macro-unit: emergent sediment units

In alluvial and semi-alluvial streams, in-channel 'emergent' (exposed at baseflow) sediment units are mainly depositional bars and unvegetated banks, but some erosional units can be identified such as channels which are dry at the time of observation and thus not baseflow channels, and bedrock outcrops may also be present.
At the *Broad level*, depositional bars and erosional channels are included in the same macro-unit (Fig. B2.2). At the *Basic level* and *Detailed level*, the following geomorphic units and related sub-types are classified.

*Identification code:* E


**Figure B2.2 Example of macro-unit 'emergent sediment units' (E).**

**Bank-attached bar**

*Identification code*: EA

*References:* Kellerhals et al. (1976); Brierley & Fryirs (2005)

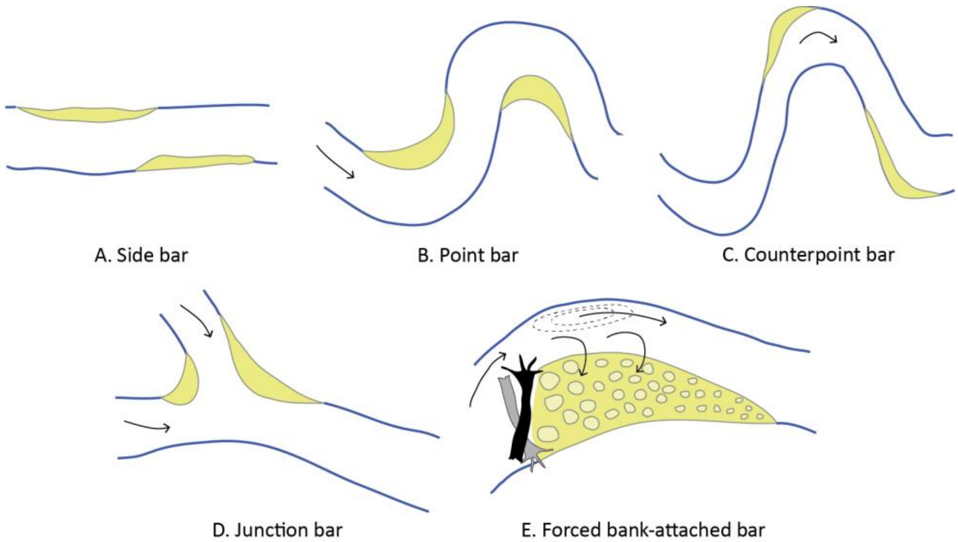
*Definition*

Bars are macro-scale bed features consisting of a depositional surface composed of channel bed sediment. They are elevated above the water surface for most of the year, but are submerged as flow increases towards bankfull. Vegetation may be completely absent from bar surfaces, but in some cases a partial, discontinuous cover of grasses and herbaceous vegetation, shrubs or isolated trees may exist.

*Bank-attached bars* are located along one side of the bankfull channel and are attached to the channel bank or to other units located at the bankfull margins (i.e. benches) or are separated from the bankfull channel edge by an emergent (dry) channel.

*Equivalent terms:* more specific terms are used as sub-types

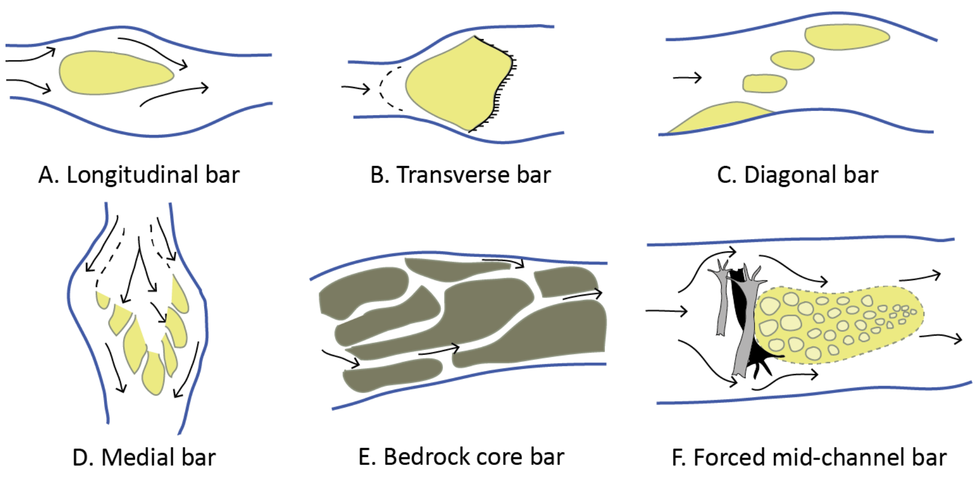

*Sub-types*




Sub-types of *bank-attached bars*. Modified from Church & Jones (1982) and Brierley & Fryirs (2005).

| |
|---|
| **Side bar** |
| *References:* Kellerhals et al. (1976); Church & Jones (1982); Hooke (1995) |
| *Definition*<br>Lateral bar, generally elongated and located on one side of a channel. *Side bars* often alternate from one side of the channel to the other and are normally attached to the bank, although they may occasionally be separated by a dry chute cut-off channel. *Side bars* are typical of straight to sinuous sand- or gravel-bed channels with alternate bars (or 'pseudomeandering'). They may occur as an early phase of meander development.<br>*Equivalent terms:* lateral bar, alternate bar (Thorne, 1998), bank-attached or attached bar (Hooke, 1995) |
| **Point bar** |
| *References:* Kellerhals et al. (1976); Church & Jones (1982); Hooke (1995); Thorne (1998) |
| *Definition*<br>Arc-shaped bar developed along the convex side of meander bends. Bank-attached or in some cases separated from the bank by a dry chute cut-off channel. *Point bars* are characteristic of meandering rivers, but can also occur locally along sinuous channels. |
| **Counterpoint bar** |
| *References:* Thorne and Lewin (1979); Page and Nanson (1982); Lewin (1983); Hickin (1984) |
| *Definition*<br>Bar type that develops in the flow separation zone along the concave bank of tight river bends. Sediments are usually finer than nearby point bars because of differences in the local hydrodynamic conditions associated with each bar type.<br>*Equivalent terms:* concave bar (Hooke, 1995) |
| **Junction bar** |
| *References:* Kellerhals et al. (1976); Thorne (1998) |
| *Definition*<br>Bar that develops immediately downstream of a tributary confluence. These delta-like features have an avalanche face and are generally comprised of poorly sorted gravel, sand and mud with complex and variable internal sedimentary structures.<br>*Equivalent terms:* tributary confluence bar (Brierley & Fryirs, 2005) |
| **Forced bank-attached bar** |
| *References:* Brierley & Fryirs (2005) |
| *Definition*<br>Bar formation induced by a flow obstruction (e.g. bedrock outcrop, boulder, large wood jam, vegetation). |

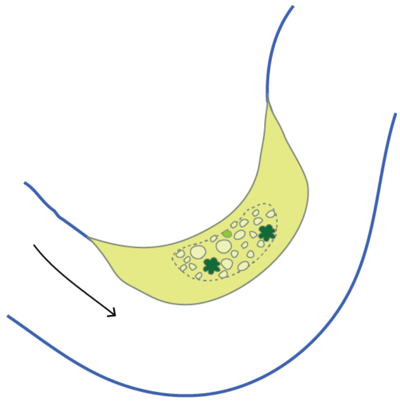
| **Mid-channel bar** |
|---|
| *Identification code*: EC |
| *References:* Hooke (1995); Thorne (1998) |
| *Definition*<br>Mid-channel bars are macro-scale depositional features located within the bankfull channel and clearly separated by flowing water (i.e. baseflow channels) from the banks or other units on both sides. The separation from floodplain, due to flowing channels on both sides, makes their distinction from lateral bars ecologically relevant (habitat disconnection). Under extreme low flow conditions as well as in the case of temporary or ephemeral streams, a mid-channel bar may be surrounded by *dry channels* (see the definition of *dry channel* and *chute cut-off*). |
| *Equivalent terms:* more specific terms are used as sub-types |
|  |

| *Sub-types* |
|---|
| <br>Sub-types of *mid-channel bars*. Modified from Church & Jones (1982), Kellerhas et al. (1976) and Brierley & Fryirs (2005). |
| **Longitudinal bar** |
| *References:* Kellerhals et al. (1976); Church & Jones (1982) |
| *Definition*<br>Mid-channel, elongate bar, with variable shape (lozenge, diamond, teardrop or lobate shaped). Multiple *longitudinal bars* are common in braided rivers, but may also occur in wandering or single-thread channels with local flow bifurcation and braiding. |

| |
|---|
| **Transverse bar** |
| *References:* Church & Jones (1982); Brierley & Fryirs (2005) |
| *Definition*<br>Mid-channel bar, oriented perpendicular to flow. They are generally found at points of abrupt channel and flow expansion. They have a lobate or sinuous front with avalanche face. The upstream ramp may be concave creating an arc shape.<br>*Equivalent terms:* linguoid bar (Church & Jones, 1982) |
| **Diagonal bar** |
| *References:* Kellerhals et al. (1976); Thorne (1998) |
| *Definition*<br>Mid-channel bar that runs obliquely across the channel (bank-attached bars included in a sequence of bars forming an overall *diagonal bar* are classified as *side bars*).<br>*Equivalent terms:* diamond bar (Brierley & Fryirs, 2005) |
| **Medial bar** |
| *References:* Church & Jones (1982) |
| *Definition*<br>Large, complex mid-channel bar made up of a mosaic of erosional and depositional forms comprising an array of smaller-scale geomorphic units. Variable morphology depends on material texture, flow energy and flood history responsible of its formation and subsequent re-working. *Medial bars* may include *chute cut-off* channels and a series of sub-units such as ramps, dissection features, lobes, ridges, vegetation patches. |
| **Bedrock core bar** |
| *References:* Brierley & Fryirs (2005) |
| *Definition*<br>Elongated bedrock ridge over which sediments have been draped (after a large flood event) and in some cases colonized by vegetation. |
| **Forced mid-channel bar** |
| *References:* Brierley & Fryirs (2005) |
| *Definition*<br>Mid-channel bar induced by a flow obstruction (e.g. bedrock outcrop, boulder, large wood jam, vegetation). |

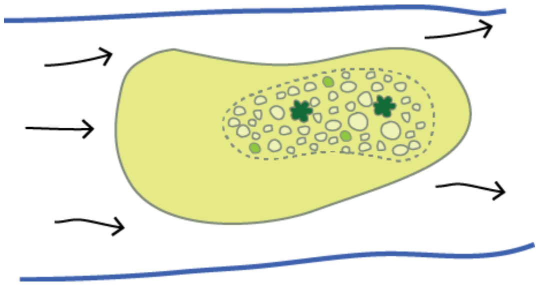
| **Bank-attached high bar** |
|---|
| *Identification code*: EAh |
| *References:* Hupp & Rinaldi (2007); Surian et al. (2009) |
| *Definition*<br>*High bars* are not usually distinguished in morphological classifications, but represent significant and distinctive habitat units in terms of morphological and sedimentary characteristics.<br>High bars are depositional features which differ from the previous types of bars as a result of their: (1) higher topographic elevation; (2) higher sediment heterogeneity (mainly gravel, cobble and sand), with coarse sediment associated with a significant proportion of fine material; (3) sparse grass, herbaceous and/or shrub vegetation cover (highest areas with fine sediment may be colonized by scattered trees).<br>In many cases they represent transitional features between bars and modern floodplain or islands. For these specific characteristics, the distinction between high bars and other types of 'lower' bars is ecologically relevant.<br>While bars are commonly deposited and reshaped during formative (e.g. 1 to 2 year and even lower discharges), high bars are generally deposited during more intense flood events (typically a return period >10 years, often of the order of 30÷50 years) and are generated by intense bedload and coarse-grained bedload sheets (Whiting et al., 1988). Indeed, high magnitude events are able to erode and deposit large amounts of coarse material (even coarser than those present in the channel bed or on bars). Although high bars are commonly submerged during formative flow events that produce overbank deposition of fine material, higher discharges are generally required for a full remobilization of coarse sediments and high bar reshaping (Surian et al., 2009). Because of these characteristics, high bars are commonly observed along cobble- or gravel-bed streams with relatively high energy (e.g. partly confined single-thread, wandering or braided).<br>*Bank-attached high bars* are located along one side of the bankfull channel and are attached to the bank or to other units located at the bankfull margins (i.e. benches) or are separated from the bank by an emergent or *dry channel* (e.g. a dry cut-off). |
| *Distinctive characteristics: Bank-attached high bars* differ from *bank-attached bars* because of (1) higher sediment heterogeneity; (2) higher vegetation cover (herbaceous and shrubs); (3) higher topographic position. *Bank-attached high bars* differ from the *modern floodplain* because coarse-grained sediment still prevails and the vegetation cover is less dense. *Bank-attached high bars* differ from *bank-attached boulder berms* because the latter are characterised by coarser sediment (prevailing cobble and boulders) and by a more pronounced topography. |

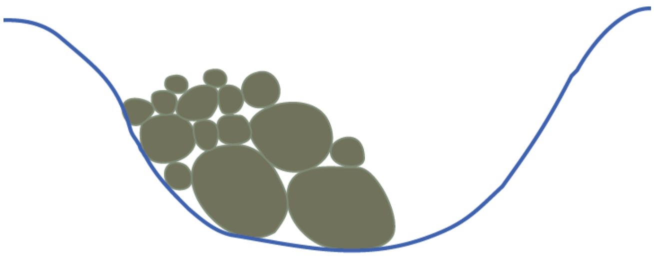
(a)

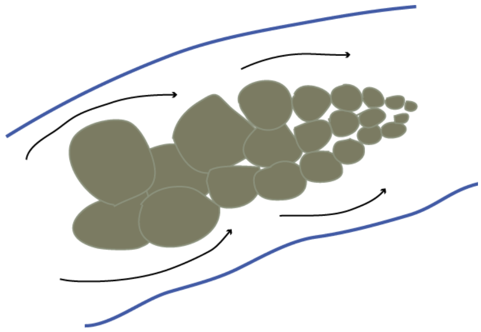


(b)

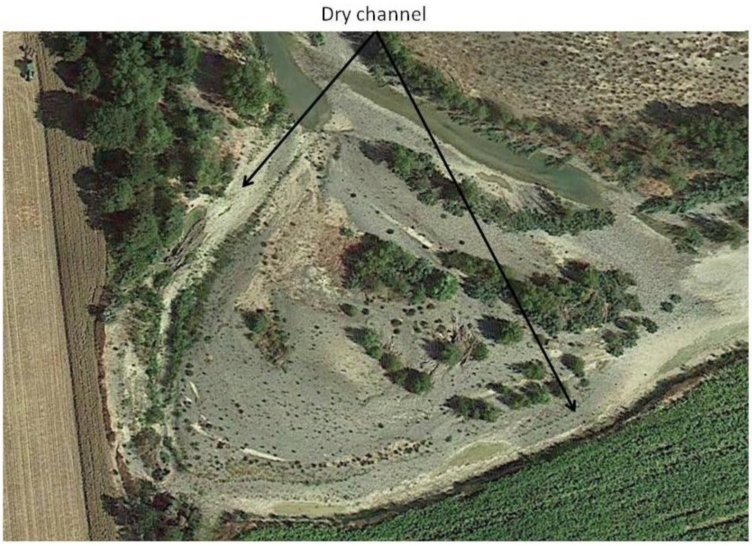
Emergent sediment unit type: *bank-attached high bar*.(a, b). Photo in (b) is taken from Surian et al. (2009).

| **Mid-channel high bar** |
| --- |
| *Identification code*: ECh |
| *References:* Hupp & Rinaldi (2007); Surian et al. (2009) |
| *Definition*<br>*Mid-channel high bars* have the same characteristics of *bank-attached high bars*, except that they are separated from the banks or other units by a baseflow channel on both sides. |
| *Distinctive characteristics: mid-channel high bars* differ from *bank-attached high bars* only because of their relative position within the channel. Differences with *mid-channel bars*, *mid-channel boulder berms* or *islands* are the same as for *bank-attached high bars*. |
| <br>Emergent sediment unit type: *mid-channel high bar*. |

| **Bank-attached boulder berm** |
| --- |
| *Identification code*: EB |
| *References:* Stewart & La Marche (1967); Carling (1987, 1989) |
| *Definition*<br>This is an elongated, bank-attached, stepped feature commonly occurring along mountain confined or partly-confined, high energy streams. It is composed of coarse materials (mainly boulder, with some cobble or gravel) with a very limited finer grained matrix and may have a characteristic convex cross-section.<br>Boulder berms are characteristic overbank coarse deposits associated with large, high energy, mainly flash or catastrophic floods, during which sediment transport may occur as a 'debris flood' (i.e. a very rapid, surging flow of water, heavily charged with debris, that typically occurs in steep channels (Hungr, 2005)). They are normally deposited in a single flood event under very high velocity conditions during the flood peak, and they are formed in the zone of expansion and large velocity gradients (Carling, 1987; 1989).<br>Similar to other emergent depositional units (bars and high bars), *bank-attached* and *mid-channel boulder berms* are distinguished according to their position within the bankfull channel. *Bank-attached boulder berms* are located along one side of the bankfull channel and are attached to the bank or to other units located at bankfull margins (i.e. benches). |
| *Equivalent terms:* (bank-attached) boulder bar, cobble berm, boulder bench (Brierley & Fryirs, 2005) |
| *Distinctive characteristics:* They differ from *bank-attached high bars* or *bars* because of their coarser material and higher topographic position. *Bank-attached boulder berms* differ from *mid-channel boulder berms* because of their relative position within the channel. |
| (a)  (b) <br>Emergent sediment unit type: *bank-attached boulder berm*. |

| **Mid-channel boulder berm** |
|---|
| *Identification code*: EM |
| *References:* Stewart & La Marche (1967); Carling (1987, 1989) |
| *Definition*<br>*Mid-channel boulder berms* have the same characteristics as *bank-attached boulder berms,* with a linguoid shape that is separated from the banks or other units located at the bankfull margins (i.e. benches) by a baseflow channel on both sides. *Mid-channel boulder berms* are deposited under high velocity conditions and are characterised by a cluster of boulders without any significant fine matrix, and they fine distinctly in a downstream direction. |
| *Equivalent terms:* (mid-channel) boulder bar, boulder mound (Brierley & Fryirs, 2005) |
| *Distinctive characteristics:* They differ from *mid-channel high bars* or *bars* because of the coarser material and higher topographic position. *Mid-channel boulder berms* differ from *bank-attached boulder berms* because of their relative position within the channel. |
| (a)  (b) <br>Emergent sediment unit type: *mid-channel boulder berm*. |

| **Dry channel** |
|---|
| *Identification code*: ED |
| *Definition*<br>A dry channel is an erosional feature that occupies a portion of the bankfull channel bed where water flow is absent at the time of observation (i.e. baseflow). It forms a preferential flow path during flows in excess of baseflow. Rivers and streams with a temporary or ephemeral hydrological regime have an entirely *dry channel* (or channels) since they support no surface flow under baseflow conditions. |
| *Equivalent terms:* emergent channel, dry cut-off |
| *Distinctive characteristics:* a *dry channel* differs from a *baseflow channel* because of the absence of flowing water at the time of observation (i.e. under baseflow conditions). |




Emergent sediment unit type: *dry channel*.

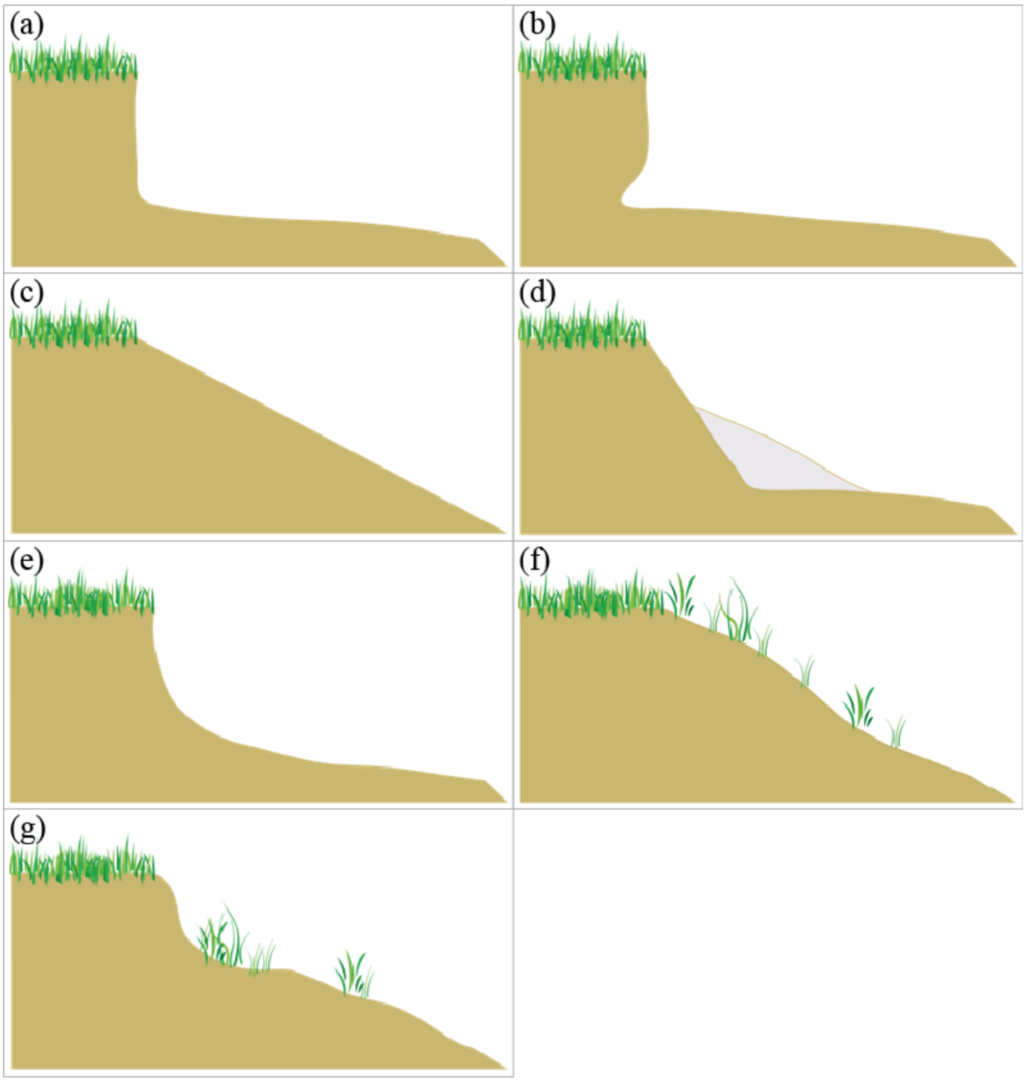
| **Bedrock outcrop** |
|---|
| *Identification code*: EO |
| *Definition*<br>Emergent *bedrock outcrops* within the bankfull channel can be observed not only along confined or semi-alluvial channels, but also along alluvial streams, especially where bed incision has occurred. |

Emergent sediment unit type: *bedrock outcrop*.

| **Unvegetated bank** |
| --- |
| *Identification code*: EK |
| *References:* Thorne (1982, 1999) |
| *Definition*<br>A *bank* is a sloping surface that usually separates the bankfull channel from the floodplain. Therefore, *banks* included in the margins of a bankfull channel are only those delimiting the edge of the bankfull channel (other sloping surfaces that do not delimit the edge of the bankfull channel but are found within the floodplain are termed *scarps*). Only *banks* composed of alluvial sediments are characterised (hillslopes or old terraces delimiting the bankfull channel of confined streams are not classified as *banks* because their upper surface does not correspond to the level of the floodplain).<br>*Unvegetated banks* are distinguished from *vegetated banks* (see 'in-channel vegetation' units) because are characterised by the absence or scarce presence of vegetation. |
| *Equivalent terms:* streambank, riverbank |
| *Distinctive characteristics:* sloping surface composed of alluvial sediments. Compared to *vegetated banks* the vegetation is absent or negligible. |
| <br>Emergent sediment unit type: Eroding, cohesive, *terrace bank* (on the left) connecting the channel with a low terrace. |

Even if sub-types are not considered, at the Detailed level banks (both unvegetated and vegetated) can be further characterised depending on: (1) bank morphology; (2) bank material; (3) stability/instability ‘status’.

*(1) Characterisation of bank morphology*




Bank morphologies: (a) Near-vertical; (b) Vertical undercut; (c) Planar; (d) With toe sediment deposition; (e) Convex upwards; (f) Concave upwards; (g) Complex.

**(a) Near vertical:** bank having a steep slope up to 90 degree. Frequently this shape is the result of slab or cantilever failures occurring more frequently on cohesive bank.

**(b) Vertical undercut:** near-vertical bank having scour at the toe, which is related to the erosion processes exerted by the flow (hydraulic action). This shape is frequently observed in composite banks.

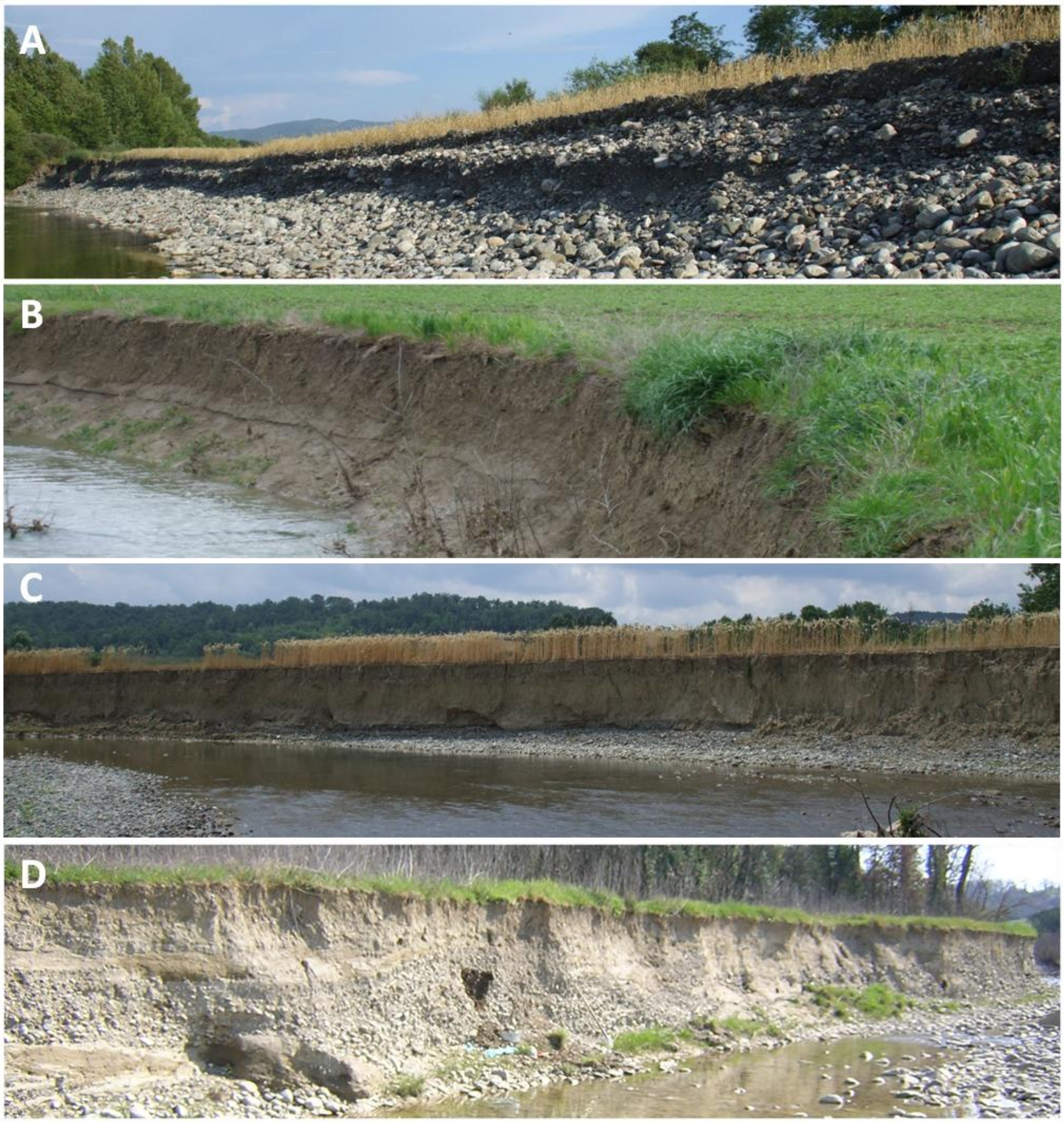
**(c) Planar:** bank presenting a nearly flat and graded surface with a variety of slope-height ratios depending on the degree of cohesion of the sediments, sediment packing or cementation. This shape is the result of mass failure which occurs by shearing along shallow, planar or slightly curved surfaces and it is often observed on non-cohesive banks.

**(d) With toe sediment deposition:** bank with generally planar morphology but exhibiting a typical basal wedge of sediment with slope near to the angle of repose, which is generated from failures that have occurred in the upper part of the bank. The toe has no direct effects on the stability of the upper cohesive layer, but it acts as a protection from toe erosion, until it is entrained by the flow.

**(e) Convex upwards:** bank presenting a curved (convex upwards) surface. Along convex upwards banks gradual mass movements mechanisms may be inferred (Brierley & Fryirs, 2005).

| |
|---|
| **(f) Concave upwards:** bank composed of a curved (concave upwards) surface which is frequently the result of rotational slip failures. This geometry is often observed in cohesive banks. |
| **(g) Complex:** a bank is complex when its surface is irregular and cannot be described by one of the aforementioned types. |

*(2) Characterisation of bank material*




Bank material: (A) Non-cohesive; (B) Cohesive; (C) Composite; (D) Multi-layered (pictures from the Cecina River, Italy).

| |
|---|
| **(A) Non-cohesive:** the bank is entirely composed of non-cohesive sediments (gravel, cobble, coarse sand). The maximum slope angle of loose, non-cohesive banks is equal to the angle of repose of the material. However, higher slope angles can be observed in case of packing or partially cemented banks (Nardi et al., 2012) or in the presence of apparent cohesion which develops within a finer matrix. |
| **(B) Cohesive:** the bank is entirely composed of cohesive soils (in general sandy-silt, silt, clay). Thanks to the apparent cohesion, cohesive banks are stable for very steep angles, up to vertical, and can reach a considerable height (of the order of meters). |
| **(C) Composite:** the bank is composed of two different layers of sediments. Typically, in composite banks non-cohesive deposits formed from relic bars are overlain by cohesive |

| |
|---|
| materials deposited by overbank flow on emergent bars. Composite banks are often cantilevered, as a result of erosion of the underlying gravels by the action of the flow which produces an overhanging of the cohesive layer. Piping and seepage processes are also frequently observed at the boundary of different bank sediment layers. |
| **(D) Multi-layered:** also known as stratified, a multi-layered bank is composed of more than two different layers of sediments. Similarly to the composite banks, multi-layered banks often exhibit cantilevered blocks. Piping and seepage processes are also frequently observed at the boundary of different bank sediment layers. |

| *(3) Bank stability/instability 'status'* |
|---|
| **Retreating:** a retreating bank is an unstable bank on which one or more erosion processes are active. Processes that act on a retreating bank can be both erosion processes and mass failure. Piping, seepage, and particle-by-particle detachment exerted by the near-bank flows are the main erosion processes, whereas all the mechanisms related to the failure of blocks under the action of gravity (e.g. planar, rotational, slab and cantilever failures) are defined as mass failure (Thorne, 1982).<br>Referring to the 'basal point control' concept (Thorne, 1982), a bank can display: (1) a condition of equilibrium, when the processes of sediment supply and removal balance each other (*unimpeded removal*), determining a retreat parallel to the bank and through which the bank is in a condition of dynamic equilibrium; (2) the erosion causes a complete removal of material at the bank toe and in some case is able to entail a bed scour, causing further instability (*excess basal capacity*); (3) a condition of accumulation (*impeded removal*), where the rate of material deposition by mass movements at the bank toe is greater than the rate of removal by fluvial erosion. In the latter case the bank is evolving into a stable or advancing bank. |
| **Stable:** a stable bank is a bank on which no eroding or deposition processes are active. Frequently stable banks are vegetated. |
| **Advancing:** an advancing bank is a bank where depositional processes prevail, determining a progressive shifting towards the opposite bank. |

### 2.1.3 Macro-unit: in-channel vegetation

In-channel vegetation macro-unit include geomorphic features of a significant size (see below) that include: (i) well-developed vegetation cover on emergent sediment surfaces (islands), (ii) large wood jams, (iii) rooted aquatic vegetation often associated with submerged sediment units, (iv) vegetated features located at the margins of the bankfull channel (benches), and (v) vegetated banks. At the *Broad level*, all in-channel vegetation units are included in the same macro-unit (Fig. B2.3). At the *Basic level*, several geomorphic units are classified.

*Identification code*: V

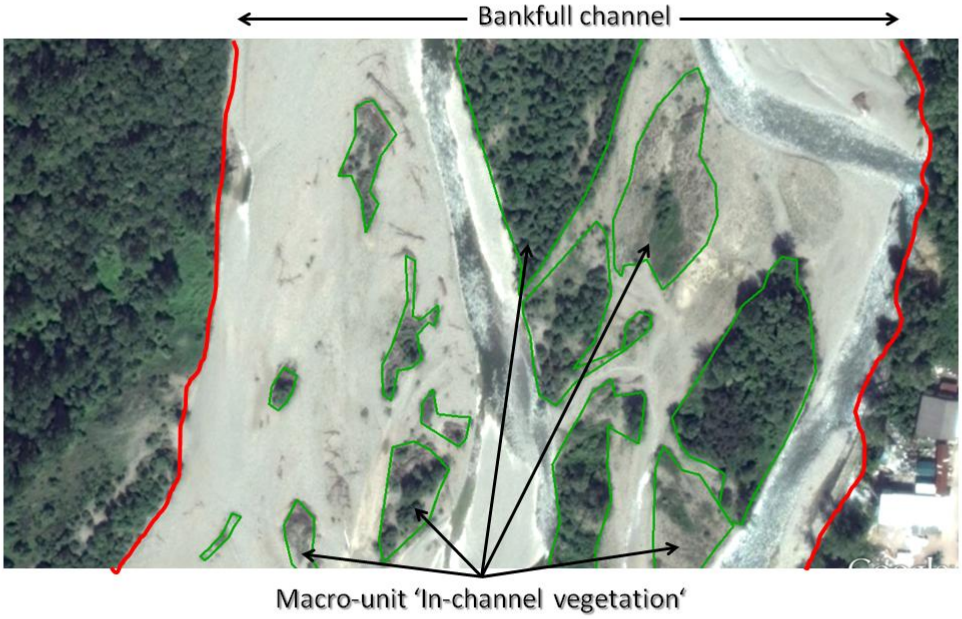



**Figure B2.3 Example of 'in-channel vegetation' macro-unit (V).**

| **Island** |
|---|
| *Identification code*: VI |
| *Definition*<br>Islands are units within the bankfull channel characterised by a cover of perennial vegetation and by other features common to the floodplain (e.g. a significant layer of fine sediment superimposed on the top of gravel layers in gravel-bed rivers, and a higher elevation than unvegetated or sparsely vegetated bars), but they differ from the floodplain in that they are entirely surrounded by *baseflow channels* or *emergent sediment units* (e.g. bars). In the past, some authors have used the term vegetated islands, but the adjective 'vegetated' is not needed as islands, by definition, have a cover of established vegetation. A bar covered with entirely annual or biennial plants, no matter how dense, cannot be considered as an *island*.<br>Vegetation (perennial grasses, herbs, shrubs, young or mature trees) does not need to cover the entire *island* unit surface, as patches of bare sediment can occupy a minor part (<1/3) of the *island*.<br>The unit surface is typically but not always higher than bar surfaces and approaches or is equal to that of the floodplain.<br>A patch of in-channel vegetation should only be classified as an *island* unit if the following conditions are satisfied: (1) the vegetation cover is comprised of at least 3 individual plants; and (2) the patch has an area larger than approximately 5 $m^2$.<br>These are meant to provide a broad indication of the scale of *island* units. They do not need to be strictly applied, but a single large tree, for example, cannot be classified as an *island* in the same way as a single large boulder does not represent a channel units, unless it forms a *step*.<br>*Island* characterisation in terms of vegetation type (e.g. herbaceous vs. woody, woody pioneer vs. woody mature) is carried out at the unit sub-type level (*Detailed level*).<br>*Islands* form under different processes, that involve sediment retention around vegetation, surface aggradation to approach floodplain level accompanied by continuing vegetation colonisation and growth: (i) colonization of bar surfaces by germination of deposited seeds; (ii) large wood (jam or not) deposition on bars, which induces fine sediment deposition and colonization by seedlings; (iii) regeneration (vegetative sprouting) of uprooted trees or tree fragments deposited on bars or within the baseflow channel; (iv) fine sediment retention by rooted aquatic vegetation in low energy streams, promoting bed aggradation and stabilization to form emergent bars that are further colonised by plants. In all of these cases the resulting *island* is classified as a 'building island' (Gurnell et al., 2001). *Islands* can also form by avulsion of main or secondary channels across the floodplain. In this case the resulting islands are classified as 'dissection islands' (Gurnell et al., 2001). |
| *Equivalent terms:* vegetated island; see sub-types |
| *Distinctive characteristics:* in order to be classified as a geomorphic unit and to be distinguished from *mid-channel bars*, *mid-channel high bars* and *mid-channel boulder berms* or part of them, the vegetated patch of an *island* should: (1) be composed of at least 3 perennial plants; (2) occupy an area greater than 5 $m^2$; (3) have a distinct surface layer of finer sediment when found in a gravel or coarser bed river; (4) have a surface elevation typically bu not always higher than bar surfaces and close to that of the floodplain; (5) the perennial vegetation cover does not have to be continuous but the area of bare sediment or annual/biennial vegetation cover should not occupy more then 1/3 of the *island* surface). |

| *Sub-types (all having >5 $m^2$ area)* |
| --- |
| **Grassy island** |
| Island with a predominantly perennial grass and herb cover. These islands are frequently found in low-gradient sandy rivers. |
|  |
| **Young woody island** |
| Island with a cover of woody vegetation (shrubs or trees) typically < 10 m tall. Canopy height is a surrogate for island age, although tree height-age relationships vary widely with species and environmental conditions. However, for the poplar and willow species, typical of European rivers, this type of island is likely to be <10 yr old. |
|  |

| **Established or adult woody island** |
| --- |
| Island formed by woody vegetation (shrubs or trees) whose typical height is 10÷20 m. Canopy height is a surrogate for island age, although tree height-age relationships vary widely with species and environmental conditions. However, for the poplar and willow species typical of European rivers, this type of island is likely to be 10-20 yr old. |
|  |
| **Mature woody island** |
| Island formed by woody vegetation (shrubs or trees) whose dominant height is > 20 m. Canopy height is a surrogate for island age, although tree height-age relationships vary widely with species and environmental conditions. However, for the poplar and willow species typical of European rivers, this type of island is likely to be > 20 yr old. In most river systems, trees growing on islands rarely reach an age exceeding 50 yr because the rate of turnover of islands (growth, establishment, erosion) is usually < 50 yrs. |
|  |

| **Complex woody island** |
|---|
| Island formed by woody vegetation (shrubs or trees), with or without grassy patches, often show a mosaic-like pattern of patches of different age. They typically result from the dissection and coalescence of *mature*, *adult* or *young islands*, by processes of erosion, deposition and vegetation establishment and growth. |
|  |

| **Large wood jam** |
|---|
| *Identification code*: VJ |
| *References:* Wallerstein et al. (1997); Gurnell et al. (2002); Abbe & Montgomery (2003) |
| *Definition*<br>Elements of large wood or LW (i.e. wood pieces or entire uprooted trees >10 cm in diameter and > 1 m in length) - lying within the bankfull channel either dead or still able to sprout – may form a unit <u>if both of the following conditions</u> are satisfied: (1) LW elements are organized in a jam or accumulation (≥ 3 logs); (2) the LW jam has an area (an envelope that encloses the wood pieces and intervening air/sediment gaps) larger than approximately 5 $m^2$.<br>As for islands, these conditions should be considered as general indications. Nonetheless, a single log forming a *step* will be characterised as a bed configuration unit (*log step*), and not as a vegetation unit. A large LW jam determining a step unit will be characterised both as *LW jam* unit and *step* unit.<br>*LW jams* are further characterised at the *Detailed level* (sub-types). |
| *Equivalent terms:* LW accumulation; see sub-types |
| *Distinctive characteristics:* in order to be classified as geomorphic unit, the LW accumulation: (1) should be composed by ≥ 3 logs (being >10 cm in diameter and > 1 m in length); (2) should have an area larger than approximately 5 $m^2$. |

| |
|---|
| *Sub-types (all having >5 $m^2$ area)* |
| *References*: the terminology for the classification of sub-types is mainly taken from Abbe & Montgomery (2003). Other relevant references: Wallerstein et al. (1997); Gurnell et al. (2002, 2014b, 2015c) |
| **Meander jam** |
| Accumulation of transported LW on the outer banks of river bends (which do not have to be meanders in strict terms) determined by the flow curvature and leading floating material becoming trapped against that bank or on the bank top. These jams are typical of meandering rivers, but can be found on all river types if relatively sharp bends exist including in bedrock channels.<br>*Equivalent terms:* counterpoint jam |
|  |
| **Bench jam** |
| Accumulation of transported or locally fallen LW retained by oblique key wood pieces which are wedged into irregularities in the channel margins (banks). The key pieces create a physical barrier to water flow behind which fine sediment and additional wood accumulates to form a *bench* (see the definition of *bench* unit). Picture is taken from Gurnell et al. (2014b). |
|  |

| **Bar apex jam** |
|---|
| Accumulation of transported LW that forms on the upstream face of (mid-channel) *medial bars* which intercept floating wood due to the decrease in water depth. These jams are typical of braided rivers but can be observed anywhere on *medial bars*. *Pioneer islands* (see the definition in the sub-unit section) often develop from *bar apex jams,* as a result of seed germination in the lee of the wood and/or sprouting of new shrubs from the deposited wood. The jam should be ascribed to such a sub-type if there is evidence that the island has been initiated by the jam, otherwise, where the jam appears to have been trapped by a pre-existing (and usually larger) island it should be classified as a *vegetation-trapped jam* (see later). |
|  |
| **Bar top jam** |
| Accumulation of transported LW found on the surface of bars of any kind, where floating material becomes stranded due to the decrease in water depth. These jams are typical of braided and transitional rivers but can be observed anywhere on *medial bars* and *lateral bars*. *Pioneer islands* (see the definition in the sub-unit section) often develop from *bar top jams,* as a result of seed germination in the lee of the wood and/or sprouting of new shrubs from the deposited wood. The jam should be ascribed to such a type if there is evidences that the island has been initiated by the jam, otherwise where the jam appears to have been trapped by a pre-existing and usually larger island it should be classified as a *vegetation-trapped jam* (see later). |
|  |

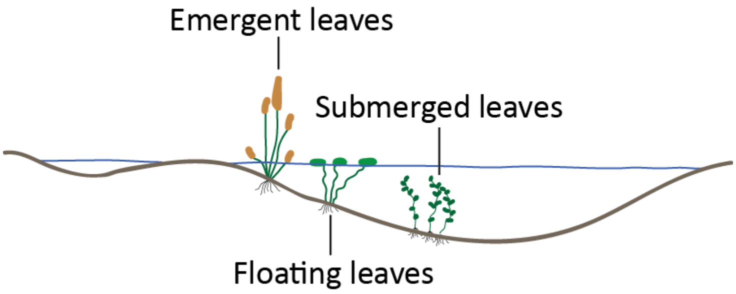
| **Dam jam** |
|---|
| Accumulation of mainly transported LW that spans the entire channel width (baseflow or bankfull channel), and so forms a channel dam whose porosity varies widely. In some cases (particularly where wood supply is high and where the channel is fairly confined) these jams can occupy the entire valley width (*valley jam*; Abbe & Montgomery, 2003). A *log step* formed by a single wood element cannot be classified as a jam. Often *dam jams* form where LW elements are retained in channel constrictions, by riparian trees and shrubs on the channel margins, or by islands within the bankfull channel. *Equivalent terms:* debris dams, channel-spanning jam, valley jam |
|  |
| **Bank input jam** |
| Accumulation of *in situ* LW produced when trees or other large wood pieces fall from the banks as a result of wind throw or bank erosion (Abbe & Montgomery, 2003). These jams are typical, but not confined to, confined or partly-confined mountain rivers. |
|  |

| **Flow deflection jam** |
|---|
| Accumulation of mainly transported LW which extends from the bank in a direction that is oblique with respect to the flow. These are typically but not always triggered by a large tree that has fallen from the bank. Compared to *bank input jams*, *flow deflection jams* are largely comprised of transported rather than *in situ* wood and are typical of, but not confined to, larger rivers, where large wood piece or entire tree can lie oblique to the flow while only occupying a part of the channel width, causing flow deflection and trapping other floating material and fine sediment. |
|  |
| **Landslide jam** |
| Accumulation of LW generated by mass wasting processes or by a debris flow which has transported and deposited the wood in the river channel. These jams are typical of confined mountain rivers, where debris flows may occur down hillslopes or along confined valleys depositing very large and chaotic accumulations of wood.<br>*Equivalent terms:* the sub-type also includes *debris flow jams* (confined channels) and *debris torrent jams* (steep confined channels) |
|  |

| **Vegetation-trapped jam** |
|---|
| Accumulation of large wood which does not fall into any of the preceding types but is retained by standing trees/shrubs lying within the bankfull channel (islands, pioneer islands or isolated woody plants). These jams are formed at flood flows and can achieve very large dimensions. If the LW accumulation occupies the entire channel width then is classified as a *dam jam* (or *debris dam*).<br>*Equivalent terms:* flood jam, wood ridge, wood pile |
|  |

| **Aquatic vegetation** |
|---|
| *Identification code*: VA |
| *Definition*<br>Perennial aquatic vegetation rooted in the channel bed can form a geomorphic unit when the patch has an area larger than approximately 5 $m^2$ and can induce sediment retention to support the development of sediment units on the channel bed such as *shelves,* particularly in low energy, sand and finer bed rivers.<br>At *Detailed level* different aquatic vegetation sub-types can be classified according to whether the leaves are emergent, floating or submerged (see the sub-types). |
| *Distinctive characteristics:* area at least 5 $m^2$ composed of perennial aquatic plants that are rooted into the channel bed. |

*Sub-types*




| **Floating leaves** |
|---|
| Perennial aquatic vegetation rooted in the channel bed with floating leaves; the latter are usually large and leathery. |
| **Submerged leaves** |
| Perennial aquatic vegetation rooted in the channel bed with submerged leaves; the latter are usually thin and narrow. |
| **Emergent leaves** |
| Perennial aquatic vegetation rooted in the channel bed with emergent leaves whose shape is usually similar to terrestrial plants in the surrounding. |

| **Bench (berm or shelf)** |
| --- |
| *Identification code*: VB |
| *References:* Hupp & Osterkamp (1996); Brierley & Fryirs (2005); Rinaldi (2008); Surian et al. (2009); Gurnell et al. (2012, 2014b); Gurnell (2014) |
| *Definition*<br>*Bench, berm, or shelf*, are generic terms used to indicate features with a flat or slightly convex upper surface and steeper edge that are deposited at the margins within the bankfull channel. They are vegetated features that form at an intermediate position between submerged or emergent bars within the baseflow channel and the floodplain (if any) and are distinguished from bars by their relatively flat, vegetated upper surfaces, their steeper inner (towards the baseflow channel) surfaces and the presence of vegetation that has usually retained sediment to produce the relatively flat upper surface.<br>The terms *bench, berm, or shelf* have been used with slightly different meanings by various authors, but for the scope of this classification, they have been included in a generic type termed *bench*, but various sub-types can be distinguished.<br>A clear distinction between *bench*, *berm* and *shelf* is provided by Gurnell (2014) and Gurnell et al. (2012, 2014b), on the basis of the degree of surface development and of vegetation submersion. According to these authors, these features are quite common along one or both banks in low energy single-thread sinuous and meandering systems, and are formed by fine sediment trapping and stabilization by aquatic vegetation (macrophytes) which is then replaced by riparian species as the surface of the feature emerges above the baseflow water surface (see sub-types). These features are indicative of channel adjustments (migration, narrowing), which in low energy, finer sediment systems, requires vegetation to stabilise the deposited fine sediments. Initially, submerged *shelves* are formed, which evolve into *berms* when the surface reaches that of the baseflow water surface, and then *benches* as the surface becomes elevated above the baseflow water surface level.<br>Tree roots can also contribute to the development of *bench* features, by trapping fine sediment (tree-induced shelf, berm or bench; Gurnell et al., 2014b; see sub-types).<br>As well, wood material can contribute to the development of *benches* along banks (Camporeale et al., 2013; *bench jams*, according to Abbe & Montgomery, 2003). In that case these surfaces are classified as *LW jams* (see sub-types of *LW jams*), and can develop until reaching the floodplain level. In all of these cases, the wood, roots or aquatic plants provide structures that retain and stabilise mobile sediment.<br>As already noted, these features are indicative of channel adjustments (e.g. channel migration or narrowing) and may be very significant features when major channel changes are occurring (Brierley & Fryirs, 2005; Hupp & Rinaldi, 2007). According to Brierley & Fryirs (2005), *benches* are a major mechanism of channel contraction (narrowing) in over-widened channels, whereas the term *ledge* is preferred to indicate depositional features associated to channel expansion (widening) (see sub-types). In other cases, *benches* (or *berms*) may represent relic bar surfaces abandoned by incision and small amounts of narrowing in meandering rivers. In such cases they may occur at intermediate positions between *bars* and *modern floodplain* or between *modern floodplain* and *terrace* (Hupp & Rinaldi, 2007).<br>Additionally, on the basis of their position within the channel, Brierley & Fryirs (2015) define two sub-types of *benches* (*point bench*; *concave bank bench*; see sub-types).<br>Hupp & Osterkamp (1996) describe a channel *shelf* along relatively steep-gradient reaches (see sub-types).<br>Finally, *bench* features are also attributed to bank processes (mass movement) and to the scouring and abrasive effect of ice on banks or on the channel bed, as observed in low energy north-European rivers (Kling, pers. comm.; see sub-types). |
| *Equivalent terms:* see sub-types |
| *Distinctive characteristics:* these features are generally narrow and discontinuous. They |

form within the margins of the bankfull channel at the bank toe and in some cases may progressively aggrade to floodplain level as their vegetated surface retains sediment.

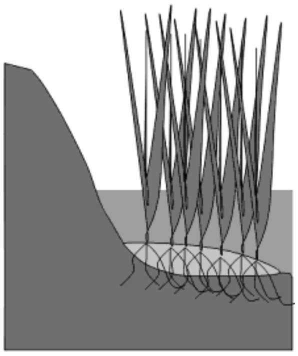
*Sub-types*

**Submerged shelf**

*References:* Gurnell (2014); Gurnell et al. (2012, 2014b)

It is a vegetation-induced feature located between the baseflow channel and the floodplain and is completely submerged under baseflow condition. It is usually associated with aquatic vegetation, but can also form in association with submerged tree roots (tree-induced shelf) that trap fine sediment. It should be noted that in some cases this tree-induced feature may in part represent erosional processes in that the tree roots may become exposed by sediment removal, but it is difficult to identify the precise balance of deposition, retention and erosion without considering the geomorphological context of the feature.
A *submerged shelf* is indicative of channel migration or narrowing (i.e. they occur along one or both banks) in low energy single-thread sinuous and meandering systems.

(a)



(b)

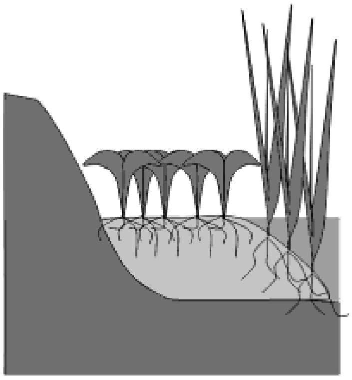
Sub-type of bench: *submerged shelf*. (a, b) From Gurnell et al. (2014b).

**Berm**

*References:* Gurnell (2014); Gurnell et al. (2012, 2014b)

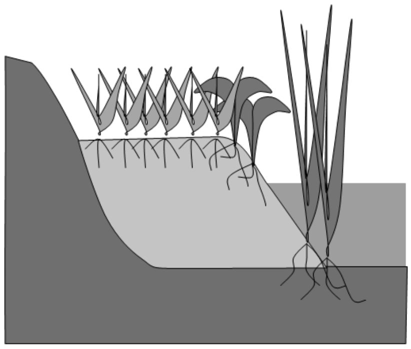
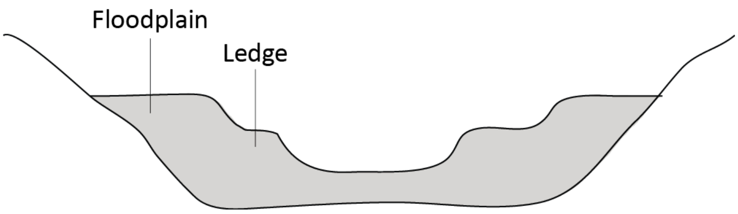
It is a vegetation-induced feature, whose upper surface approximates the baseflow water surface within the bankfull channel. It is quite common along one or both banks in low energy single-thread sinuous and meandering systems, usually colonised by wetland species following aggradation of a *submerged shelf* to baseflow level.
Like for *submerged shelf*, this feature can also form in association with tree roots (tree-induced berm) that trap fine sediment. It should be noted that in some cases this tree-induced feature may in part represent erosional processes in that the tree roots may become exposed by sediment removal, but it is difficult to identify the precise balance of deposition, retention and erosion without considering the geomorphological context of the feature.
*Equivalent terms:* emergent shelf

(a)



(b)

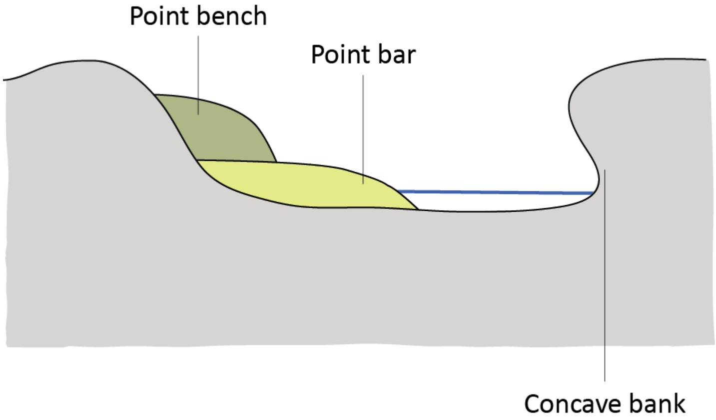
Sub-type of bench: *berm.* (a, b) From Gurnell et al. (2014b).

| **Bench (sensu strictu)** |
|---|
| *References:* Gurnell (2014); Gurnell et al. (2012, 2014b) |
| It is a vegetation-induced feature located between the baseflow channel and the floodplain, is completely emerged at baseflow condition and is colonised by riparian species following the surface aggradation of an *emergent shelf* or *berm*. It is quite common along one or both banks in low energy single-thread sinuous and meandering systems.<br>Like for *submerged shelf* and *berm*, this feature can also form in association with tree roots (tree-induced bench) that trap fine sediment. It should be noted that in some cases this tree-induced feature may in part represent erosional processes in that the tree roots may become exposed by sediment removal, but it is difficult to identify the precise balance of deposition, retention and erosion without considering the geomorphological context of the feature. |
| (a)  (b) <br>Sub-type of bench: *bench (s.s.)*. (a, b) From Gurnell et al. (2014b). |
| **Ledge** |
| *References:* Brierley & Fryirs (2005) |
| According to Brierley & Fryirs (2005), *ledges* reflect channel widening and/or incision, whereas *benches* are a major mechanism of channel contraction (narrowing) in over-widened channels. *Ledges* are composed of the same material as the basal floodplain, whereas the sedimentary structure of a *bench* is quite different from the floodplain. |
| <br>Sub-type of bench: *ledge*. Modified from Brierley & Fryirs (2005). |

**Point bench**

*References:* Brierley & Fryirs (2005)

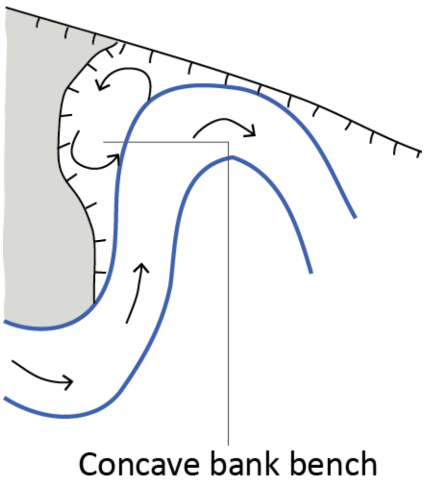
*Bench* that develops at the convex bank in meandering rivers, slightly above the level of the point bar. It displays a convex planform with planar surface. The sediment deposit shows a vertical or oblique gradient (layers of sand and mud) indicating slow lateral migration or lateral accretion within an overwidened bend. However, in some cases, point benches may simply be aggraded, vegetated point bars, where vegetation has interacted with flows to trap finer sediment and the inner edge of the point bench has become trimmed to a steeper slope by fluvial processes, creating the classic bench profile described above as an aggradational extension of the point bar within a migrating meander bend.



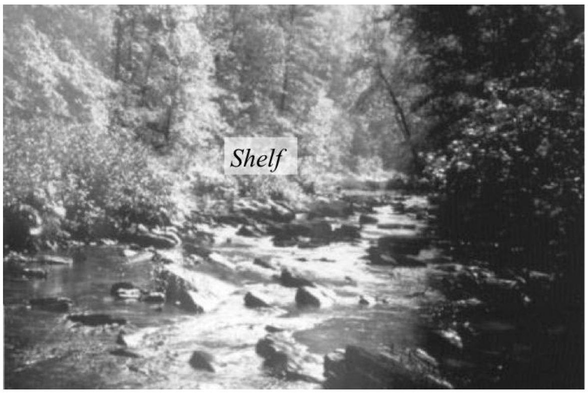

**Concave bank bench**

References: Brierley & Fryirs (2005); Gurnell et al. (2014b)

It forms along the concave bank of relatively tight bends that usually abut bedrock valley margins or a flow obstruction (e.g. wood accumulation), because of the formation of secondary flows during high flood-stage. However, neither are essential for the formation of this feature, which is usually characterized by finer, more organic-rich sediments than a *point bench* within the same system. It is often characterised by the presence of a *ridge* (for definition see sub-units) on the top of the feature, parallel to *the baseflow channel*. This feature is often inset against the floodplain. The sediment is mainly fine-grained (layers of sand, silt and clay) and organic material.
In meandering rivers, these features may form from *LW jam*s that accumulate in the low velocity zone upstream the meander bend at the concave bank (*counterpoint* or *meander jam*; Gurnell et al., 2014b; see sub-types of *LW jam*). The *LW jam* entails the deposition of fine sediment as well as of organic material (small wood pieces).




Modified from Brierley & Fryirs (2005).

| **Shelf** |
|---|
| *References:* Hupp & Osterkamp (1996) |
| It is a horizontal to gently sloping surface that normally extends the short distance between the break in the relatively steep bank slope and the lower limit of persistent woody vegetation that marks the channel bed edge. The *shelf* is best developed along relatively steep-gradient reaches where its presence is related to the presence of colonising vegetation, but it is more patchy and irregular than the finer sediment *shelf-berm-bench* features that depend upon vegetation for their presence in lower energy systems, and an extensive development of both *floodplain* and channel *shelf* along the same reach is rare, although they are not mutually exclusive. |
|  Sub-type of bench: *shelf* in the Passage torrent (USA). Picture from Hupp & Osterkamp (1996). |

| **Slump bench** |
|---|
| *References:* Kling (pers. comm.), Gurnell (1997) |
| Its formation can be attributed to bank processes (mass movement). It is commonly observed along low energy north-European rivers, mainly in meandering rivers with silty soils. In these systems, a large part of the meandering morphology can be related to slides or slumps along the river, and the meander migration occurs jerkily. Most of the slides occur along the outer bank, but may also be found in between two meanders. Once vegetation is established and sediment is trapped and smooths feature morphology, it can be quite difficult to distinguish this feature from an erosional or sedimentary bench.<br>*Equivalent terms:* subsidence bench, slide bench |
|  Sub-type of bench: *slump bench* in northern Sweden (picture: J. Kling). |

| **Ice abrasion and ice ploughing bench** |
|---|
| *References:* Kling (pers. comm.) |
| Bench features that are formed under the scouring and abrasive effect of ice on banks or on the channel bed when moving downstream. The term *ice abrasion bench* can be employed to indicate the scouring effect of ice on banks; *ice ploughing bench*, can be employed to indicate the scouring effect of ice on the channel bed. These features are commonly observed along low energy north-European rivers that are subject to significant ice build-up during the winter. In the spring, when the ice may break up quickly, large volumes of ice move rapidly downstream during meltwater floods, and severe ice scouring of the channel may occur.<br>*Equivalent terms:* ice scouring bench |
| <br>Sub-type of bench: *ice abrasion bench* in northern Sweden (picture: Åsa Widén). |

| **Vegetated bank** |
|---|
| *Identification code*: VK |
| *References:* Thorne (1982, 1999) |
| *Definition*<br>Vegetated banks have the same characteristics as *unvegetated banks* but are characterised by the significant presence of vegetation.<br>As for unvegetated banks, at the Detailed level vegetated banks can be further characterised depending on: (1) bank morphology; (2) bank material; (3) stability/instability 'status' (see *unvegetated banks*). |
| *Equivalent terms:* streambank, riverbank |
| *Distinctive characteristics:* compared to *unvegetated banks* the presence of vegetation is significant. The criterion for considering the presence of vegetation as significant can be assumed as the same for the identification of islands and aquatic vegetation, i.e. at least 5 $m^2$. |
| <br>In-channel vegetation unit: stable, vegetated, *modern floodplain banks* (both sides). |

## *2.2 Floodplain units*

Floodplain units consist of surfaces and morphological features included in the overall floodplain delimited by hillslopes or ancient alluvial deposits (i.e. old terraces).

### 2.2.1 Macro-unit: riparian zone

This includes the portion of the **floodplain** affected by various fluvial processes (e.g. channel mobility, flooding) and characterised by spontaneous vegetation or **relatively natural conditions,** where there is a natural absence of vegetation. Agricultural and urbanised lands are not included. This macro-unit includes Floodplain units which normally cannot be discriminated by remote sensing at the Broad level because they need some field information on their elevation (e.g. *modern floodplain* or *terrace*) (Fig B2.4).

*Identification code:* F


**Figure B2.4 Example of macro-unit 'riparian zone' (F).**

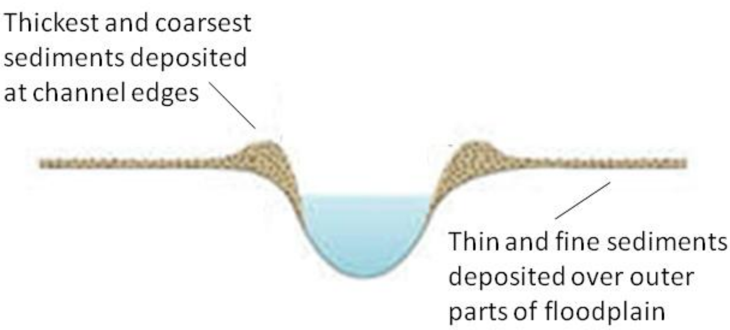
| **Modern floodplain** |
|---|
| *Identification code*: FF |
| *References:* Hupp & Osterkamp (1996); Simon & Castro (2003) |
| *Definition*<br>It is an alluvial, flat surface adjacent to the river, created by lateral and vertical accretion under the present river flow and sediment regime. A river in dynamic equilibrium builds a floodplain that is generally inundated for discharges just exceeding channel-forming flows (return interval of 1÷3 years).<br>In many cases, such as where there has been recent channel incision, areas that fit this definition represent a minor part of the whole floodplain. In other cases, it corresponds to the entire floodplain (e.g., when no significant bed level adjustments have occurred in historical time). Where several, longitudinally extensive, alluvial surfaces are present at different levels, the lowest surface is considered as the *modern floodplain*, while the higher surfaces are classified as *recent terraces*.<br>The *modern floodplain* is identified in the field as follows: (1) morphological-topographic continuity with depositional features within the bankfull channel (bank-attached bars); (2) presence of finer sediment material (from overbank deposition) compared to bankfull units; (3) extensive cover by vegetation (perennial grasses herbaceous plants, shrubs and trees, both young and adult), with significant presence of woody vegetation where the vegetation has not been removed or modified by humans; (4) evidence of reasonably frequent flooding such as large wood deposition. In addition, some limited areas of bare sediment may be present, particularly following a recent flood. Note that the types of field evidence described in (1) to (4) are not always observed together. For example, bare fields close to the bankfull channel can still form part of the *modern floodplain* if there is no channel incision. Furthermore, the extensive vegetation cover described in (3) would also characterise terraces that have not been cleared or modified by human activities. |
| *Equivalent terms:* active floodplain, genetic floodplain |
| *Distinctive characteristics:* compared to *bank attached bars*, *high bars* or *boulder berms*, the modern floodplain is characterised by finer sediment and extensive vegetation cover (the same characteristics that distinguish an *island* from a *mid-channel bar*); compared to *benches*, a *modern floodplain* is commonly wider and continuous; compared to a *recent terrace*, the *modern floodplain* is topographically lower and inundated with smaller return periods (commonly 1÷3 years). |
| (a)  (b) <br>(a) Vegetated *modern floodplain*, on the left. On the right it is possible to see the transition between a *bank-attached bar* and the *modern floodplain* (the latter is topographically higher). (b) A *modern floodplain* on both sides. It is characterised by grasses and herbaceous vegetation because of the agricultural activity. |

| **Recent terrace** |
|---|
| *Identification code:* FT |
| *References:* Hupp & Osterkamp (1996); Simon & Castro (2003) |
| *Definition*<br>A *recent terrace* is a former floodplain that has become a terrace because of recent channel incision (i.e. the last 100-200 years), which in most cases is driven by human alterations. The relative level of a *recent terrace* above the *modern floodplain* can vary widely, but the likelihood of inundation is always lower than that for the *modern floodplain* (i.e. an average frequency greater than once in 3 years, Hupp & Osterkamp, 1996).<br>Frequently, more than one terrace level can be found. In such a case, an order (by roman numerals) is assigned to each different terrace level. |
| *Equivalent terms:* modern terrace, terrace, low terrace |
| *Distinctive characteristics:* compared to a *modern floodplain*, a *recent terrace* is topographically higher and inundated with a larger return periods (i.e. >3 years). |
| (a)  (b) <br>(a) *Recent terrace* due to incision delimited by a cohesive bank. (b) Cultivated *recent terrace* delimited by a steep and high, cohesive bank. |

| **Scarp** |
|---|
| *Identification code*: FS |
| *Definition*<br>This is a generic term to indicate various types of slopes included in the floodplain, which are not at the interface with the bankfull channel (in this latter case the scarp is included in the bankfull channel units and indicated as *bank*). The interface between a *recent terrace* and a *modern floodplain* is represented by a *scarp*. Another example is represented by *meander scars*, i.e. steep scarp slopes left in the floodplain by meander progression. |
| *Distinctive characteristics:* compared to the *banks*, the *scarps* are located within the floodplain and not at the boundary of the bankfull channel. |

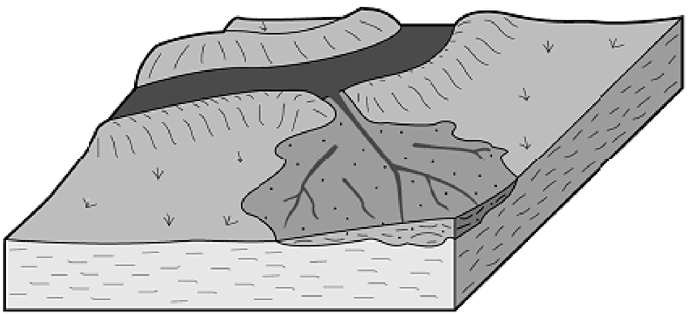

Floodplain unit type: *scarp* (Cecina River, picture: G. Consoli).

| **Levée** |
|---|
| *Identification code*: FL |
| *Definition*<br>A natural *levée* is a raised, elongated ridge above the floodplain surface adjacent to the channel, usually containing relatively coarser overbank sediments (although finer than the bed sediments and usually finer than the bank sediments) deposited as flood flows spread out from the channel across the floodplain. These are most frequently found at the concave banks. *Levée* crests may be up to some meters higher than the floodplain or may be absent or nearly imperceptible. |
| *Distinctive characteristics:* compared to the *modern floodplain* is (slightly) topographically higher; it displays an inverse slope from the channel. |




Floodplain unit type: natural *levée*.

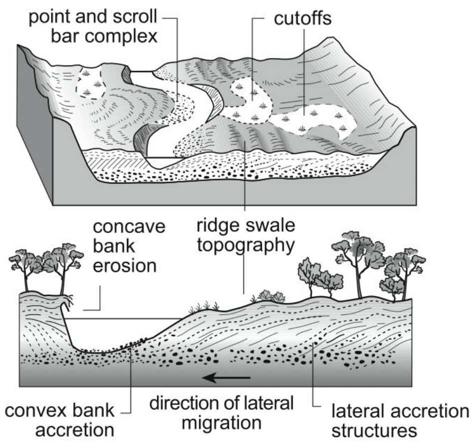
| **Overbank deposits** |
|---|
| *Identification code*: FD |
| *References:* Brierley & Fryirs (2005); Fryirs & Brierley (2013) |
| *Definition*<br>This terms indicates several sedimentary features close to the channel generated by overbank deposition. |
| *Equivalent terms:* see sub-types |
| <br>Floodplain unit type: *overbank deposits* (Cecina River; picture: G. Consoli). |

| *Sub-types* |
|---|
| *References:* Brierley & Fryirs (2005); Fryirs & Brierley (2013) |
| **Crevasse splay** |
| *Definition*<br>It is a lobate or fan-shaped feature composed of relatively coarser sediment (gravel, sand), fining from the channel, generated by breaching of *levée*. The surface may have multiple distributary channels.<br>Compared to other overbank deposits, *crevasse splays* are only found in the context of *levées*.<br>The term *floodout* is employed when a similar deposit forms not in relation to levée breaching but where the channel bed becomes raised to the level of the floodplain during a flood.<br>*Equivalent terms:* crevasse channel-fill, floodout |
| <br>Sub-type of overbank deposit: *crevasse splay* (http://www.geodz.com/deu/d/crevasse_splay) |

| **Sand wedge** |
|---|
| Sandy deposit with wedge-shaped cross-section at channel margins in non-levee settings. They form on the proximal floodplain surface in moderate to high energy systems. |
| **Sand sheet** |
| Flat, tabular, laterally extensive sheet in non-levee setting with massive, often poorly sorted facies. It shows little lateral variation in thickness, mean grain size or internal structure. They are associated with rapid sediment charged bedload deposition on the floodplain surface during extreme flood events.<br>A *sand sheet* is differentiated from other floodplain deposits by its shape, extensive area, and lack of distal thinning. |

| **Ridges and swales** |
|---|
| *Identification code*: FR |
| *Definition*<br>*Ridges and swales* are arcuate, alternating features, where the ridge is a rising, elongated deposit and the swale is a depression, and which have been incorporated in the floodplain. They have been produced by *point bar* (or *scroll bar*, see sub-units for definition) migration on the advancing, convex bank during meander growth, and through aggradation of their surfaces, they are elevated sufficiently to have become incorporated into the floodplain. |
| *Distinctive characteristics:* compared to overbank deposits, they are characterised by a typical undulating surface. |

(a)

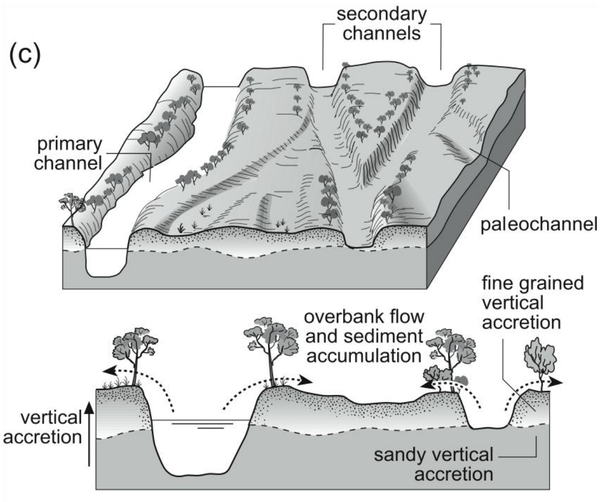



(b)

Floodplain unit type: *ridges and swales*. (a) Modified from Brierley & Fryirs (2005).

| **Floodplain island** |
| --- |
| *Identification code*: FI |
| *Definition*<br>In anabranching systems, sufficiently large islands separating the anabranches can be classified as *floodplain islands* because their surface elevation and surface sediment texture corresponds to that of the floodplain. They may be formed by a combination of within bankfull channel, coalescence and aggradation of pioneer islands and vegetated mid-channel bars (termed building islands by Gurnell et al., 2001) or they may be dissected from the floodplain as a result of avulsions (termed floodplain dissection islands by Gurnell et al., 2001) but in either case, their surface elevation at floodplain level leads them to be described as *floodplain islands* (or *established islands;* Gurnell et al., 2001). |
| *Equivalent terms:* established island (Gurnell et al., 2001) |
| *Distinctive characteristics:* compared to most of the *islands* of the bankfull channel units, these islands are larger in size and, because their surface elevation, correspond to the level of the floodplain. Therefore, they cannot be considered to be located 'within' the bankfull channel but form part of the floodplain. |
| <br><br>Floodplain unit type: *floodplain island.* |

| **Terrace island** |
| --- |
| *Identification code*: FN |
| *Definition*<br>*Terrace islands* may (locally) occur in anabranching systems, where bed incision has generated island surfaces which are significantly higher than the level of the *modern floodplain* (see the characteristics of *recent terraces*). |
| *Distinctive characteristics:* compared to the *floodplain islands, terrace islands* are topographically higher and thus inundated by higher return period floods (>3 years). |

| **Secondary channel (within the floodplain)** |
|---|
| *Identification code*: FC |
| *Definition*<br>Floodplain *secondary channels* indicate erosive features periodically conveying water during high flow events, or even containing continuous flow but having a distinctly smaller size than the baseflow channel within the bankfull channel, and being located outside of the bankfull channel. These channels may occur in single-thread, transitional or braided systems. |
| *Equivalent terms:* see sub-types |
| *Distinctive characteristics:* compared to the *secondary channels* included in the bankfull channel units, these channels are within the floodplain, at a significant distance from the bankfull channel. |
| <br><br>Floodplain unit type: *secondary channel*. Modified from Nanson and Croke (1992) and Brierley & Fryirs (2005). |

| *Sub-types* |
|---|
| **Flood channel (back channel)** |
| *References:* Brierley & Fryirs (2005)<br>*Definition*<br>A *flood channel* is a subsidiary channel, occupied by flow starting at approximately bankfull stage. It can be located behind natural *levées* (if any; see the definition of *levées*). Where the channel is weakly defined (smaller depression) and conveys floodwater with a relatively higher return period, it is termed a *flood runner.*<br>*Equivalent terms:* flood runner, back channel |
| **Abandoned channel** |
| *Definition*<br>It indicates an old, inactive channel on the floodplain left by a previous channel cut-off or an avulsion. It may be partially or entirely filled by sediment, and it may be occasionally inundated during high flow events.<br>*Equivalent terms:* paleochannel, prior channel, ancestral channel, side arm, inactive secondary channel |

| **Abandoned meander** |
| --- |
| *Definition*<br>It is a specific case of an abandoned channel incorporating only one meander wavelength and thus generated by a meander cut-off. It is formed by neck cut-off (abrupt) or chute cut-off (gradual). The terms *paleochannel* is employed to indicate an abandoned channel including more than one meander wavelength.<br>An abandoned channel created meander cut-off and occupied by water is called an *oxbow lake* (see later). |
| <br><br>Sub-type of secondary channel: *abandoned meander* formed by a recent meander cut-off. |

### 2.2.2 Macro-unit: floodplain aquatic zones

This macro-unit represents the presence of water within the floodplain (e.g. lakes, ponds, wetlands). However, it may incoprorate emergent sediment or vegetation (submerged and emergent) within its units.

*Identification code:* W

| **Floodplain lake** |
| --- |
| *Identification code*: WO |
| *Definition*<br>Floodplain lakes are relatively deep features that are also larger in area than ponds. The limnetic zone is significantly developed and these features display lake-like temperature stratification. Aquatic vegetation may be present but not in the deepest areas. |

Floodplain unit type: *floodplain lake* (picture from: http://commons.wikimedia.org/wiki/File:Lake_Chicheri._Volga-Akhtuba_floodplain.JPG).

| *Sub-types* |
| --- |
| **Oxbow lake** |
| *Definition*<br>It is a water body which was once part of a meander bend, but which has been abandoned because of a meander cut-off and continues to contain water (unlike floodplain *secondary channels* and, particularly, *abandoned meanders*. |

Sub-type of floodplain lake: *oxbow lakes* generated by meander cut-off (picture from: http://clasfaculty.ucdenver.edu/callen/1202/Landscapes/Fluvial/Fluvial.html).

| **Wetland** |
|---|
| *Identification code*: WW |
| *References:* Brierley & Fryirs (2005) |
| *Definition*<br>Wetland is a general term to indicate shallow areas including minor depressions that are occupied by water, including *floodplain ponds* and *swamps* (see the sub-types). These features commonly form where lower order tributaries drain directly onto the floodplain, or where surface water (from precipitation, flooding, or groundwater seepage) persists on the floodplain surface. Wetlands are naturally colonised by dense aquatic/wetland vegetation that can trap fine grained suspended sediments to form cohesive, mud- and organic-rich floodplain surface deposits. |
| *Equivalent terms:* see sub-types |
| *Distinctive characteristics:* compared to *floodplain lakes*, *wetlands* are smaller and shallower. |

| *Sub-types* |
|---|
| **Swamp** |
| *Definition*<br>*Swamps* form on relatively flat surfaces covered by water and usually contain vertically accreted mud that is usually organic-rich and forms around the swamp vegetation. *Swamps* form as a consequence of insufficient drainage of surface water or are fed by near-surface groundwater. They may include ponds and discontinuous channels or drainage lines.<br>*Equivalent terms:* backswamp or swampy meadow (Brierley & Fryirs, 2005) |
| <br>Sub-type of wetland: *swamp* (picture from: http://www.tulane.edu/~bfleury/envirobio/swamp.html) |

| **Floodplain pond** |
| --- |
| Ponds located in floodplain deposits are relatively small, often elongated and scoured features formed along preferential drainage lines. They are often fed by small tributaries. They displays a significant, aquatic vegetation cover, even in the deepest areas (up to 5 m). Compared to *floodplain lakes*, *floodplain ponds* are smaller, shallower and the shore areas is more developed than the limnetic area (which is usually absent). |
|  Sub-type of wetland: *floodplain pond* (picture from: http://tangalor.blogspot.it/2010/03/lassenza-di-verita-crea-una-palude.html). |

### 2.2.3 Macro-unit: human-dominated areas (land use included)

This macro-unit includes the portion of overall floodplain external to the fluvial corridor, that is dominated by human elements or activities (urbanised areas, infrastructures, agriculture), i.e. not occupied by relatively natural areas and infrequently interested by fluvial processes (Fig. B2.5).
The units are basically the same as for the macro-unit 'riparian zone', but they are classified in this macro-unit when they are dominated by human elements (urban and industrial areas, infrastructures) or activities (agriculture).
This macro-unit can be absent (e.g. confined streams) or very wide (e.g. in very large lowland river systems). Its definition is not mandatory for the classification system and the outer limit can be defined by the operator on the basis of the objectives.
This macro-unit allows, if needed, to include the **land use** adjacent to the fluvial corridor in the analysis, as well as to contextualise typical fluvial forms plunged in a human-dominated matrix, as typically occurs in lowland rivers. For this aim, the following generic types of land use are distinguished and can be added to the denomination of each geomorphic unit. For further detailed analysis of land use, see the Corine Land Cover (CLC) project.

*Identification code:* H

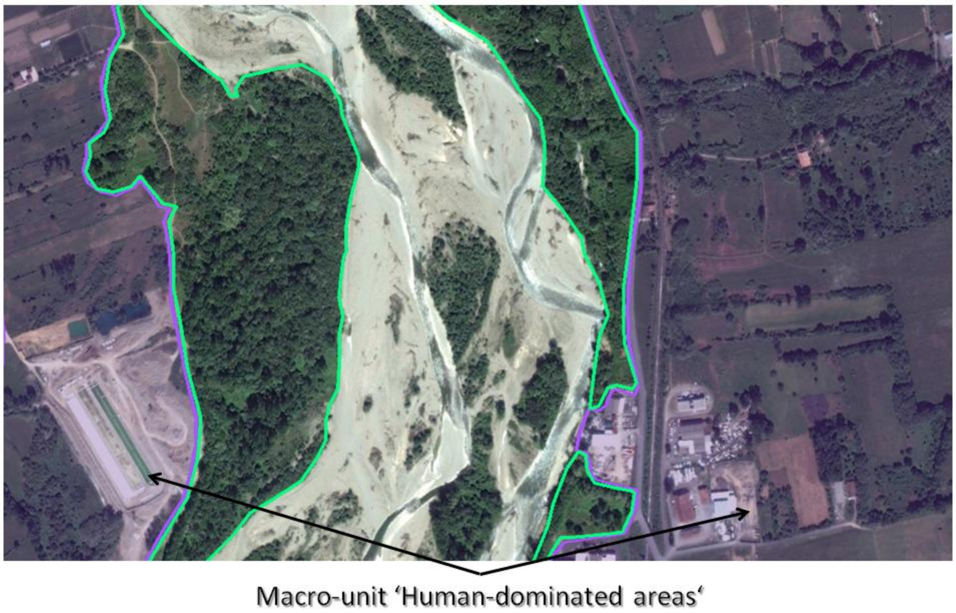



**Figure B2.5  Example of macro-unit 'human-dominated areas' (H).**

| **Land use types** |
|---|
| **Agriculture** |
| *Definition*<br>It includes all areas dominated by agriculture activities (plantation excluded), where tree vegetation does not dominate: arable lands, pastures and heterogeneous areas (i.e. with presence of natural vegetation).<br>*Identification code:* Hag |
| **Plantation** |
| *Definition*<br>It includes all permanent agriculture areas, i.e. orchards, vineyards, olive tree groves. This are distinguished from previous category in terms of vertical structure. Heterogeneous areas are also included (i.e. with presence of natural vegetation), where tree vegetation dominates.<br>*Identification code:* HPi |
| **Urban** |
| *Definition*<br>It includes all those areas occupied by human settlements: urban and factory areas, highways, railways, including artificial vegetated areas (urban parks, resorts, etc.).<br>*Identification code:* HPi |

## 2.3 Artificial features

Artificial features cannot be defined as geomorphic units, but are important elements of the fluvial landscape, given that they can significantly modify the fluvial processes and the morphology and assemblage of units. Therefore, a range of artificial features that should be mapped during the survey of geomorphic units have been defined, and which may allow to better understand the mosaic of geomorphic units at a given reach. The list of artificial features reported below is extracted from the indicators of artificiality of the Morphological Quality Index (MQI, Rinaldi et al. 2013b, 2014).

*Identification code:* A

| **Artificial features** | |
|---|---|
| **Dam** | |
| *Definition*<br>Structure that creates a reservoir and induces a significant alteration of flow and sediment discharges with complete (and permanent) interception of bedload.<br>*Identification code*: AA |  |
| **Check dam** | |
| *Definition*<br>In mountain areas are distinguished: (a) retention check dams (on the left) aiming at intercepting the bedload; in case of great size (> 5-6 m height) it can be considered as a dam; (b) consolidation check dams (on the right), aiming at stabilizing the channel bed by reducing the channel slope<br>*Identification code*: AB | |
| <br>*Retention check dam* | <br>*Consolidation check dam* |

**Weir**

*Definition*

In lowland areas, the following types of weirs can be identified: (a) weirs or consolidation check-dams (on the left), aiming at stabilizing the channel bed and/or at intercepting the bedload; (b) abstraction weirs (on the right), for water diversion purposes (e.g. for agriculture), but having significant effect on the bedload. Run-of-the-river structures used for hydropower generation where little or no water storage is provided are also included in this category.

*Identification code*: AC

Weri or consolidation check-dam

Abstraction weir

**Retention basin**

*Definition*

Two types are distinguished: (1) lateral retention basin (located outside of the channel, delimited by artificial levées and periodically flooded (picture); (2) instream retention basin (transversal structure within the bankfull channel that causes a partial storage of peak discharges).

*Identification code*: AD

**Diversion or spillway**

*Definition*

Diversion is an in and out-flow channel which conveys water flow from other water courses at all flow discharges.

Spillways are specific diversion channels for flood protection purposes.

*Identification code*: AE

| **Culvert** | |
|---|---|
| *Definition*<br>It is a structure aiming at crossing the water channel and located below other structures (e.g. a road, a town).<br>*Identification code*: AF |  |
| **Ford** | |
| *Definition*<br>It is a structure aiming at crossing the water channel that can be submerged at high flow conditions. It can be associated with culverts to allow the water flow at low-flow condition.<br>*Identification code*: AG |  |
| **Bridge** | |
| *Definition*<br>It is a above-ground structure aiming at crossing the river channel (road, railway, crosswalk). It can have piles within the channel.<br>*Identification code*: AH |  |
| **Bed revetment** | |
| *Definition*<br>It concerns revetements of the channel bed (and in case of the banks). They can be formed by large wood, concrete and unconsolidated coarse material.<br>*Identification code*: AI |  |

**Bed sill**

*Definition*

Transverse structure with low height (< 1÷2 m), aiming at stabilizing the channel bed and at reducing bed erosion.

*Identification code*: AJ

**Ramp**

*Definition*

Transverse structure with low height (< 1÷2 m), aiming at stabilizing the channel bed and at reducing bed erosion. In general it is made with boulders arranged longitudinally along the water channel.

*Identification code*: AK

**Bank protection**

*Definition*

Structure aiming at preventing bank erosion and/or bank mass movement (on the left). Different techniques and materials can be employed, such as bio-engineering techniques based on the use of vegetation and geotextile, or rigid structures such as windrows and trenches, sacks and blocks or gabions and mattresses. In some case the bank can be completely covered by artificial material (artificial bank; on the right).

*Identification code*: AL

Bank protection.

Artificial bank.

**Artificial levée or embankment**

*Definition*

Longitudinal structure located above-ground, aiming at protecting against floods for discharges higher than bankfull discharge.

*Identification code*: AM

| **Mining site / sediment removal** | |
|---|---|
| *Definition*<br>It includes sites for alluvial sediment mining (commercial purposes; on the left), as well as sediment removal for channel maintenance or prevention of the flood risk (on the right).<br>*Identification code*: AN | |
| <br>Mining site | <br>Sediment removal |

## *2.4 Sub-units*

Here below a list (not complete) of sub-units that can be identified on the field during the survey.

### 2.4.1 Bankfull channel sub-units

*Baseflow channel sub-units*

***Backwater* area**. Small pocket located at the margins of the baseflow channel, along the channel shoreline as consequence of local erosion (e.g. between two consecutive trees) or of the presence of single element of large wood which determines slow flow condition and backwater effect. It may form also usptream large wood jams (e.g. *dam jams*). These areas often represent refugia from flow for several aquatic organisms and promote the development of aquatic vegetation even in reaches where this is commonly absent (i.e. because of high flow velocity conditions).

**Boulder patch**. Small accumulation of boulders (>256 mm in diameter) deposited in the baseflow channel; the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. hydraulic and sediment conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

**Cobble patch**. Small accumulation of cobbles (64÷256 mm in diameter) deposited in the baseflow channel; the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. hydraulic and sediment conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

**Dune**. Bed form typical of low-gradient, alluvial sand-bed (>0.1 mm in diameter) rivers. Dunes can be distinguished from *ripples* (see later) by their larger height ($10^{-1}$÷$10^{1}$ m) and wavelength (proportional to the water depth). Dunes migrate downstream and water surface is only in part influenced by the presence of dunes. Dunes and ripples are often associated and superimposed, generating *dune-ripple* morphology.

**Gravel patch**. Small accumulation of gravels (2÷64 mm in diameter) deposited in the baseflow channel; the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. hydraulic and sediment conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

**Isolated emergent boulder**. An individual boulder (> 256 mm in diameter) or a group of few boulders partially emerged within the baseflow channel, form a sub-unit since they are significant in terms of physical habitats for aquatic flora and fauna. Around them specific local conditions (i.e. hydraulic and sediment conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

***Pocket pool***. Small pool areas which form between boulders in cascade units, shallow and with turbulent flow, having smaller size compared to the channel width.

***Ripple*** (Simons & Richardson, 1966; Knighton, 1998). Sub-unit typical of alluvial fine-grained (i.e. sand) and unconfined, low-gradient channels. Ripples are usually less than 0.04 h high and 0.6 m long, and tend not to interact with the water surface, which is usually quite even. With active sand transport, ripples migrate downstream. Ripples and dunes are often associated and superimposed, generating *dune-ripple* morphology.

**Sand patch**. Small accumulation of sand (0.06÷2 mm in diameter) deposited in the baseflow channel; the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. hydraulic and sediment conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

**Silt-clay pacth**. Small accumulation of silt-clay (<0.06 mm in diameter) deposited in the baseflow channel; the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. hydraulic and sediment conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

***Transverse rib*** (Lenzi et al., 2000). Group of cobbles or boulders organized in lines across the baseflow channel width, protruding from the flow at low to medium stages. Transverse ribs generally constitute a portion of rapid.

*Emergent sub-units*

**Boulder patch**. Small accumulation of boulders (>256 mm in diameter) deposited on a bar or other emergent unit (both in the bankfull or on the floodplain); the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. sediment and moisture conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

**Cobble pacth**. Small accumulation of cobbles (64÷256 mm in diameter) deposited on a bar or other emergent unit (both in the bankfull or on the floodplain); the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. sediment and moisture conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

**Gravel patch**. Small accumulation of gravels (2÷64 mm in diameter) deposited on a bar or other emergent unit (both in the bankfull or on the floodplain); the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. sediment and moisture conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

***Ramp*** (Brierley & Fryirs, 2005). Coarse sediment deposit which forms at the upstream end of a bend, raising from the baseflow channel and deposited on the bar surface like a ramp. In some case it represents the sediment filling of a chute cut-off channel.

***Ridge*** (Brierley & Fryirs, 2005). Rising, elongated and arcuate or near-straight deposit located at the bar top (bank-attached or mid-channel bars). The sediment tends to be finer downstream. Ridges may form as consequence of the presence of vegetation or other blocking structures on the bar surface.

**Sand patch**. Small accumulation of sand (0.0625÷2 mm in diameter) deposited on a bar or other emergent unit (both in the bankfull or on the floodplain); the diameter of sediment is significantly different from that of the unit where the accumulation is. Around the deposit specific local conditions (i.e. sediment and moisture conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

***Scour hole***. Local sediment erosion on the bar surface (bank-attached or mid-channel bar) as consequence of a flood event.

***Scroll bar*** (Brierley & Fryirs, 2005; Nanson, 1980, 1981). Elongated ridge-like bar formed along convex banks of meander bends, commonly on point bars. They are caused by deposition in the shear zone between the helical flow cell in the thalweg zone and flow in a separation zone adjacent to the convex bank of a bend, often cored by trees deposited on point bars during floods.

**Silt-clay patch**. Small accumulation of silt-clay (<0.0625 mm in diameter) deposited on a bar or other emergent unit (both in the bankfull or on the floodplain); the diameter of sediment is significantly different from that of the unit where the accumulation is.

Around the deposit specific local conditions (i.e. sediment and moisture conditions), different form the surrounding areas and relevant in terms of habitat, may occur.

*Instream vegetation sub-units*

**Isolated woody plants**. Group of 1 to 3 trees or shrubs located within the bankfull channel, that cannot be classified as unit (< 3 individuals).

***Pioneer island***. Sub-unit typical of large gravel-bed rivers, formed by shrubs or trees (of whatever any height), covering a small area (approximately < $10^2$), featuring little to no fine sediment (sand) deposition. Three of more woody plants should be present to classify the sub-unit as pioneer island (see the definition of island unit), otherwise it is classified as 'isolated woody plant' (see the definition below). Pioneer islands often originate by resprouting of wood elements, but this is not a condition for their identification. However, large wood jams are quite commonly associated with pioneer islands.

***Seedling-induced levee*** (Gurnell et al., 2014b). It is a characteristic type of vegetated ridge, which forms as consequence of the presence of seedlings at an elevation that is sufficiently low on the bar for the seedlings to have a sufficient moisture supply but high enough to avoid uprooting of the seedlings by flow pulses. The sediment is trapped as the seedlings grow to form a ridge-like feature which may evolve into an island. It is typical of large alluvial rivers and has small size (< $10^2$). Compared to a pioneer island, this sub-unit is characterised by fine sediment (sand).

**Small aquatic vegetation patch**. Patch of aquatic vegetation smaller than approximately 5 $m^2$ in area.

**Small herbaceous vegetation patch**. Patch of terrestrial herbaceous vegetation smaller than approximately 5 $m^2$ in area.

**Small large wood accumulation**. It concerns the large wood accumulations or individual pieces of large wood that cannot be classified as unit because of the small size (< 5 $m^2$).

***Vegetated ridge***. Compared to a ridge it is characterised by the presence of vegetation (herbs, shrubs or trees). It can't be classified as unit because of the small size.

## 2.4.2 Floodplain sub-units

**Vegetated patch**. Patch of vegetation (herbs, isolated woody plants, wood accumulations, aquatic vegetation) of whatever size, located on the floodplain.

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# Appendix 1: Survey and classification form

REFORM

## *GUS - Geomorphic Units survey and classification System*

### Sheet 1: SURVEY PLAN

**River type**

| | |
|---|---|
| Small river | |
| Large river | |

**Valley setting**

| | |
|---|---|
| Confined | |
| Partly-confined / unconfined | |

**Remote data**

| | |
|---|---|
| Satellite images | |
| HR images | |
| VHR images | |
| Lidar | |

**Level of characterisation**

| | |
|---|---|
| General information | |
| "Broad" level | |
| "Basic" level | |
| "Detailed" level | |
| "Detailed" level (sub-units) | |

MACRO-UNITS and UNITS

**BROAD level**

| | | Macro-units | | |
|---|---|---|---|---|
| | | P/A | Are | % |
| Bankfull channel | | | | |
| Floodplain | all | | | |
| Artificial features | A | | | |

**BASIC level**

| | | Macro-units | | | Units | | |
|---|---|---|---|---|---|---|---|
| | | P/A | Num | L/A | P/A | Num | L/A |
| Bankfull channel | C | | | | | | |
| | S | | | | | | |
| | E | | | | | | |
| | V | | | | | | |
| Floodplain | F/H | | | | | | |
| | W/H | | | | | | |
| | H | | | | | | |
| Artificial features | A | | | | | | |

| | |
|---|---|
| Remote sensing | |
| Field | |
| Indices | |

**DETAILED level**

| | | Macro-units | | | | | |
|---|---|---|---|---|---|---|---|
| | | S-T | Sed | Hyd | Veg | Mea | Oth |
| Bankfull channel | C | | | | | | |
| | S | | | | | | |

| | | Units | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | S-T | Sed | Hyd | Veg | Mor | Com | Pro | Mea | Oth |
| Bankfull channel | C | | | | | | | | | |
| | (S) | | | | | | | | | |
| | E | | | | | | | | | |
| | V | | | | | | | | | |
| Floodplain | F/H | | | | | | | | | |
| | W | | | | | | | | | |

SUB-UNITS

**DETAILED level**

| | | Nam | Num | Sed | Veg | Mea | Oth |
|---|---|---|---|---|---|---|---|
| Bankfull channel | C | | | | | | |
| | S | | | | | | |
| | E | | | | | | |
| | V | | | | | | |
| Floodplain | F/H | | | | | | |
| | W | | | | | | |
| | H | | | | | | |

Mark N.S. (not surveyed) when a specific feature has not been surveyed

## Sheet 2: GENERAL INFORMATION AND FIELD SKETCH

**General information**

Surveyor _____ Location _____ Sub-reach length (m) _____
Date _____ Reach altitude (m a.s.l.) _____ Upstream end (x) _____
River _____ Reach length (m) _____ Upstream end (y) _____

**General morphological characteristics**

| | | | | | |
|---|---|---|---|---|---|
| Floodplain width (m) | | Confinement degree | | Baseflow channel width (m) | |
| River corridor width (m) | | Reach slope (%) | | Channel depth* (m/class) | |
| Bankfull channel width (m) | | Land use | | Wadeable/not wadeable | |

| **Bed morphology** | | **Channel pattern** | | **Hydrological regime** | |
|---|---|---|---|---|---|
| Colluvial | | Single-thread | | Permanent | |
| Bedrock | | Straight | | Intermittent | |
| Alluvial | | Sinuous | | Temporary | |
| Semi-alluvial | | Meandering | | Other | |
| Artificial | | Transitional | | | |
| | | Wandering | | | |
| | | Multi-thread | | | |
| | | Braided | | | |
| | | Anabranching | | | |

*Baseflow channel

**Other available information**

| | | | | | |
|---|---|---|---|---|---|
| Q field survey | | Flood discharge: Q | | N. events Q>1.5 | |
| Q remote images | | Flood discharge: year | | | |

**Field sketch**

## Sheet 3: BROAD LEVEL

### Bankfull channel and Floodplain

**Photo**

| | | | | | |
|---|---|---|---|---|---|
| Date | ____________ | Scale | ____________ | Scale of mapping | ____________ |
| Source | ____________ | Resolution (m) | ____________ | Reach / Sub-reach | ____________ |

**Picture of the reach / sub-reach**

| Macro-units | | | | |
|---|---|---|---|---|
| Spatial setting | Macro-units | P/A | Area | % |
| Bankfull channel | Baseflow channel or submerged channels (C/S) | | | |
| | Emergent sediment units (E) | | | |
| | In-channel vegetation (V) | | | |
| Floodplain | Riparian zone (F) | | | |
| | Floodplain aquatic zones (W) | | | |
| | Human-dominated areas (H) | | | |
| All | Artificial features (A) | | | |

## Sheet 4: BASIC LEVEL

### Bankfull channel units

| Macro-unit type | P/A | N (or code) | L/A 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Main channel (C) | | | | | | | | | | | | |
| | | Picture number | | | | | | | | | | |
| Secondary channel (within bankfull) (S) | | | | | | | | | | | | |
| | | Picture number | | | | | | | | | | |

| Macro-unit | Unit type | P/A | N (or code) | L/A 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | Pothole (CH) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Cascade (CC) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Rapid (CR) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Riffle (CF) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Step (CT) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Glide (CG) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Pool (CP) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Dune system (CD) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| E | Bank-attached bar (EA) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Mid-channel bar (EC) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Bank-attached high bar (EAh) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Mid-channel high bar (ECh) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Bank-attached boulder berm (EB) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Mid-channel boulder berm (EM) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Dry channel (ED) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Bedrock outcrop (EO) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Unvegetated bank (EK) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| V | Island (VI) | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | LW jam (VJ) | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |

## Sheet 5: BASIC LEVEL

### Bankfull channel units (continue)

| Macro-unit | Unit type | P/A | N (or code) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V | Aquatic vegetation (VA) | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Bench (VB) | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Vegetated bank (VK) | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |

### Floodplain units

| Macro-unit | Unit type | P/A | N (or code) | L/A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| F/H | Modern floodplain (FF) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Recent terrace (FT) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Scarp (FS) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Levée (FL) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Overbank deposits (FD) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Ridges and swales (FR) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Floodplain island (FI) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Terraced island (FN) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Secondary channel (FC) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| W/H | Floodplain lake (WO) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Wetland (WW) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |

**GUS Indices**

| | | | | | |
|---|---|---|---|---|---|
| $\Sigma NT_{GU}$ | | ***GUSI-R*** | | $\Sigma NT_{GU} / n$ | $NT_{GU}$ = total number of types of units and macro-units (P/A); n = 35 |
| $\Sigma N_{GU}$ | | ***GUSI-D*** | | $\Sigma N_{GU} / L$ | $N_{GU}$ = total number of geomorphic units (N or code); L = reach length (km) |

**GUS sub-indices**

| | | | | | |
|---|---|---|---|---|---|
| $\Sigma NT_{BCGU}$ | | ***GUSI-R*** $_{BC}$ | | $\Sigma NT_{BCGU} / n$ | $NT_{BCGU}$ = total number of types of bankfull channel geomorphic units |
| $\Sigma NT_{FPGU}$ | | ***GUSI-R*** $_{FP}$ | | $\Sigma NT_{FPGU} / n$ | $NT_{FPGU}$ = total number of types of floodplain geomorphic units |
| $\Sigma N_{BCGU}$ | | ***GUSI-D*** $_{BC}$ | | $\Sigma N_{BCGU} / L$ | $N_{BCGU}$ = total number of bankfull channel geomorphic units |
| $\Sigma N_{FPGU}$ | | ***GUSI-D*** $_{FP}$ | | $\Sigma N_{FPGU} / L$ | $N_{FPGU}$ = total number of floodplain geomorphic units |
| $\Sigma N_{CGU}$ | | ***GUSI-D*** $_{C}$ | | $\Sigma N_{CGU} / A_C$ | $N_{CGU}$ = number of baseflow channel geomorphic units |
| $\Sigma N_{EGU}$ | | ***GUSI-D*** $_{E}$ | | $\Sigma N_{EGU} / A_E$ | $N_{EGU}$ = number of emergent sediment geomorphic units |
| $\Sigma N_{VGU}$ | | ***GUSI-D*** $_{V}$ | | $\Sigma N_{VGU} / A_V$ | $N_{VGU}$ = number of in-channel vegetation geomorphic units |
| $\Sigma N_{FGU}$ | | ***GUSI-D*** $_{F}$ | | $\Sigma N_{FGU} / A_F$ | $N_{FGU}$ = number of riparian zone geomorphic units |
| $\Sigma N_{WGU}$ | | ***GUSI-D*** $_{W}$ | | $\Sigma N_{WGU} / A_W$ | $N_{WGU}$ = number of floodplain aquatic zones geomorphic units |
| | | | | | $A_{(C\text{-}E\text{-}V\text{-}F\text{-}W)}$ = area of the related macro-units ($km^2$) |

Notes

## Sheet 6: BASIC LEVEL

### Human-dominated areas within the flooplain (land use)

| Macro-unit | Type | P/A | N (or code) | L/A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| H | Agriculture (HAg) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Plantation (HPl) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Urban (HUr) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |

### Artificial features

| Macro-unit | Type | P/A | N (or code) | L/A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| A | Dam (AA) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Check dam (AB) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Weir (AC) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Retention basin (AD) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Diversion or spillway (AE) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Culvert (AF) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Ford (AG) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Bridge (AH) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Bed revetement (AI) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Bed sill (AJ) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Ramp (AK) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Bank protection (AL) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Artificial levée or embankment (AM) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |
| | Mining site / sed. removal (AN) | | | | | | | | | | | | |
| | | | Picture number | | | | | | | | | | |

Notes

# Sheet 7: DETAILED LEVEL - Bankfull channel

## Baseflow or submerged channel macro-units

| Macro-unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic conditions | | | Vegetation characteristics | | | | | | | | | | Mea | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | <BC | BC | >BC | Abs | Spa | Pat | Den | Alg | Flo | Sub | Eme | Species | Woo | Wid | | |
| C | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Chute cut-off | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Two-way connected | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | One-way connected | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Pond | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## (a) Bed configuration units

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic conditions | | | Vegetation characteristics | | | | | | | | | | Mea | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | Hig | Int | Low | Abs | Spa | Pat | Den | Alg | Flo | Sub | Eme | Species | Woo | Wid | | |
| CH | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CC | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CR | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CF | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Forced riffle | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Notes

## Sheet 8: DETAILED LEVEL - Bankfull channel

### (a) Bed configuration units (continue)

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic conditions | | | Vegetation characteristics | | | | | | | | | | Mea | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | Hig | Int | Low | Abs | Spa | Pat | Den | Alg | Flo | Sub | Eme | Species | Woo | Wid | | |
| CT | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Rock step | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Waterfall | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Boulder step | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Log step | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CG | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Rock glide | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CP | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Forced pool | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Scour pool | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Plunge pool | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Dammed pool | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Meander pool | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CD | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Notes

# Sheet 9: DETAILED LEVEL - Bankfull channel

## (b) Emergent sediment units

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic conditions | | | Vegetation characteristics | | | | | | | | | Mea | Pic | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | <BC | BC | >BC | Abs | Spa | Pat | Den | Tre | Shr | Her | Spcies | Woo | Wid | | | |
| EA | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Side bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Point bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Counterpoint | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Junction bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Forced bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | bank-attached | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EC | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Longitudinal | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Transverse | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Diagonal bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Medial bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Bedrock core | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Forced bar | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | mid-channel | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Notes

# Sheet 10: DETAILED LEVEL - Bankfull channel

## (b) Emergent sediment units (continue)

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic conditions | | | Vegetation characteristics | | | | | | | | | Mea | Pic | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | <BC | BC | >BC | Abs | Spa | Pat | Den | Tre | Shr | Her | Species | Woo | Wid | | | |
| EAh | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ECh | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EB | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EM | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ED | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EO | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## (c) In-channel vegetation units

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic conditions | | | Vegetation characteristics | | | | | | | | Processes | | Mea | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | <BC | BC | >BC | Spa | Pat | Den | Tre | Shr | Her | Species | Woo | Dis | Mid | Wid | | |
| VI | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Grassy | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Young woody | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Established / Adult woody | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Mature woody | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Complex woody | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Notes

# Sheet 11: DETAILED LEVEL - Bankfull channel

## (c) In-channel vegetation units (continue)

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic conditions | | | Vegetation characteristics | | | | | | | | | | Measures | | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | <BC | BC | >BC | Abs | Spa | Pat | Den | Tre | Shr | Her | Species | Woo | Siz | Num | | |
| VJ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Meander jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Bench jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Bar apex jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Bar top jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Dam jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Bank input jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Flow deflection jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Landslide jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Vegetation-trapped jam | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | | | Hydraulic con. | | Vegetation characteristics | | | | | Measures | | Pic | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | <1m | >1m | Spa | Pat | Den | Species | Woo | Wid | Hei | | | |
| VA | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| | Floating leaves | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| | Submerged leaves | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| | Emergent leaves | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |

Notes

## Sheet 12: DETAILED LEVEL - Bankfull channel

### (c) In-channel vegetation units (continue)

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | Hydraulic conditions | | | Vegetation characteristics | | | | | | | | | | Processes | | Measures | | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | <BC | BC | >BC | Abs | Spa | Pat | Den | Tre | Shr | Her | Species | Woo | Roo | Inc | Nar | Wid | Hei | | |
| VB | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Submerged shelf | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Berm | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Bench (sensu stricto) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Ledge | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Point bench | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Concave bank bench | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Shelf | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Slump bench | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Ice abrasion /ploughing | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Notes

# Sheet 13: DETAILED LEVEL - Bankfull channel

## (d) Unvegetated and vegetated banks

| Unit | Code | Sediment characteristics | | | | | | | Hydraulic con. | | Vegetation characteristics | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bed | Bou | Clo | Gra | San | Sil | Cla | Flo | Ter | Abs | Spa | Pat | Den | Tre | Shr | Her | Species | | Woo | Roo |
| EK | | | | | | | | | | | | | | | | | | | | | |
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| VK | | | | | | | | | | | | | | | | | | | | | |
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| Unit | Codice | Bank morphology | | | | | | | Bank composition | | | | Stability/Instability | | | Measures | | | Pic | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ver | Und | Pla | Toe | Con | Coc | Com | NoC | Coe | Com | Lay | Ret | Sta | Adv | Len | Hei | Slo | | | |
| EK | | | | | | | | | | | | | | | | | | | | | |
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| VK | | | | | | | | | | | | | | | | | | | | | |
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Notes

## Sheet 14: DETAILED LEVEL - Floodplain

### (a) Floodplain units

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | Hydraulic con. | | Vegetation characteristics | | | | | | | | | | Mea | Pic | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Art | Flo | Ter | Abs | Spa | Pat | Den | Tre | Shr | Her | Species | Woo | Wid | | | | |
| FF/HF | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FT/HT | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FS/HS | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FL/HL | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FD/HD | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Crevasse splay | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Sand wedge | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Sand sheet | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FR/HR | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| FI | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| FN | | | | | | | | | | | | | | | | | | | | | | | | | | |
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Notes

# Sheet 15: DETAILED LEVEL - Floodplain

## (b) Floodplain units (continue)

| Unit | Sub-type | Code | Sediment characteristics | | | | | | | | Hydraulic con. | | Vegetation characteristics | | | | | | | | | | | | | Mea | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Art | Flo | Ter | Abs | Spa | Pat | Den | Tre | Shr | Her | Alg | Flo | Sub | Eme | Species | Woo | Wid | | |
| FC/HC | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Flood channel | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Abandoned channel | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Abandoned meander | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## (c) Floodplain aquatic zones units

| Unit | Sub-type | Code | Sediment size | | | | | | | | Hydraulic con. | | Vegetation characteristics | | | | | | | | | | | | | Mea | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Art | Flo | Ter | Abs | Spa | Pat | Den | Tre | Shr | Her | Alg | Flo | Sub | Eme | Species | Woo | Wid | | |
| WO/HO | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Oxbow lake | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| WW/HW | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| | Swamp | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Floodplain pond | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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Notes

## Sheet 16: DETAILED LEVEL - SUB-UNITS

| Macro-unit | Unit | Sub-unit name | Num | Sediment characteristics | | | | | | | | | | Vegetation characteristics | | | | | | | | | | | | | Measures | | | | Pic | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Bed | Bou | Cob | Gra | San | Sil | Cla | Clo | Arm | Art | Abs | Spa | Den | Tre | Shr | Her | Alg | Flo | Sub | Eme | Species | Woo | Roo | Len | Wid | Hei | Are | | |
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Note

# Appendix 2: Geomorphic units and macro-units list

| Spatial setting | Macro-unit | Macro-unit type | Macro-unit sub-type |
|---|---|---|---|
| Bankfull channel ('submerged' units) | Baseflow or submerged channels (C/S) | Baseflow channel or main channel (C) | |
| | | Secondary channel (within bankfull) (S) | Chute cut-off<br>Two-way connected branch<br>One-way connected branch<br>Pond |

| Spatial setting | Macro-unit | Unit (type) | Unit sub-type |
|---|---|---|---|
| Bankfull channel ('submerged' units) | Baseflow or submerged channels (C/S) | Pothole (CH) | |
| | | Cascade (CC) | |
| | | Rapid (CR) | |
| | | Riffle (CF) | Forced riffle |
| | | Step (CT) | Rock step<br>Waterfall<br>Boulder step<br>Log step |
| | | Glide (CG) | Rock glide |
| | | Pool (CP) | Forced pool<br>Scour pool<br>Plunge pool<br>Dammed pool<br>Meander pool |
| | | Dune system (CD) | |
| Bankfull channel ('emergent' units) | Emergent sediment units (E) | Bank-attached bar (EA) | Side bar<br>Point bar<br>Counterpoint bar<br>Junction bar<br>Forced bank-attached bar |
| | | Mid-channel bar (EC) | Longitudinal bar<br>Transverse bar<br>Diagonal bar<br>Medial bar<br>Bedrock core bar<br>Forced mid-channel bar |
| | | Bank attached high-bar (EAh) | |
| | | Mid-channel high-bar (ECh) | |
| | | Bank-attached boulder berm (EB) | |
| | | Mid-channel boulder berm (EM) | |
| | | Dry channel (ED) | |
| | | Bedrock outcrop (EO) | |
| | | Unvegetated bank (EK) | |
| | In-channel vegetation (V) | Island (VI) | Grassy island<br>Young woody island<br>Established/Adult woody island<br>Mature woody island<br>Complex woody island |

| | | | |
|---|---|---|---|
| | In-channel vegetation (V) | Large wood jam (VJ) | Meander jam<br>Bench jam<br>Bar apex jam<br>Bar top jam<br>Dam jam<br>Bank input jam<br>Flow deflection jam<br>Landslide jam<br>Vegetation-trapped jam |
| | | Aquatic vegetation (VA) | Floating leaves<br>Submerged leaves<br>Emergent leaves |
| | | Bench (VB) | Submerged shelf<br>Berm<br>Bench (sensu stricto)<br>Ledge<br>Point bench<br>Concave bank bench<br>Shelf<br>Slump bench<br>Ice abrasion and ice ploughing bench |
| | | Vegetated bank (VK) | |
| Floodplain | Riparian zone (F)/ Human dominated areas (H) | Modern floodplain (FF/HF) | |
| | | Recent terrace (FT/HT) | |
| | | Scarp (FS/HS) | |
| | | Levee (FL/HL) | |
| | | Overbank deposits (FD/HD) | Crevasse splay<br>Sand wedge<br>Sand sheet |
| | | Ridges and swales (FR/HR) | |
| | | Floodplain island (FI/HI) | |
| | | Terrace island (FN/HN) | |
| | | Secondary channel (FC/HC) | Flood channel<br>Abandoned channel<br>Abandoned meander |
| | Floodplain aquatic zones (W/H) | Floodplain lake (WO/HO) | Oxbow lake |
| | | Wetland (WW/HW) | Swamp<br>Floodplain ponds |

| **Spatial setting** | **"Macro-units"** | **Feature types** |
|---|---|---|
| Floodplain | Human dominated areas (H) | Agriculture (HAg)<br>Plantation (HPl)<br>Urban (HUr) |
| All | Artificial features (A) | Dam (AA)<br>Check-dam (AB)<br>Weir A(C)<br>Retention basin (AD)<br>Diversion or spillway (AE)<br>Culvert (AF)<br>Ford (AG)<br>Bridge (AH)<br>Bed revetment (AI)<br>Bed sill (AJ)<br>Ramp (AK)<br>Bank protection (AL)<br>Artificial levee or embankment (AM)<br>Mining sites / Sediment removal (AN) |

# Appendix 3: Glossary

***Alluvial channel***
It is a channel which is modelled within its alluvial sediment, previously transported and deposited. The layer of alluvial sediment is continuous and thick. In case of significant presence of bedrock or coarser sediment (e.g. large boulders) the channel is classified as semi-alluvial. Alluvial channels are typical of lowland reaches but are also common in mountain-hilly areas. In the latter case banks can be formed by bedrock. In case of single-thread channel, several morphologies of bed configuration can be observed, depending on the bed slope and the bed sediment size (see bed configuration units).

***Armouring***
Where the river bed surface is comprised of coarser particles than the underlying river bed layers as a result of removal (mobilisation and transport) of the finer particles from the bed surface layer. In gravel- and cobble-bed rivers a certain degree of armouring is common. In case of strong degree of bed armouring, it can be related to local channel alterations that cause a water flow transport capacity higher than the sediment supply.

***Bankfull channel***
It includes the water channel network, the bars and islands. Its limits coincide with banks, but often are difficult to be identified, as in case the transition between the bankfull channel and the floodplain is vague. The bankfull limits are thus identified with the bankfull stage (or level) (see the definition below).

***Bankfull discharge***
It is the discharge or river flow that fills the river channel up to the bankfull level. The frequency of bankfull discharge is usually 1 to 3 years. For rivers in dynamic equilibrium the bankfull discharge corresponds to the formative or dominant discharge, i.e. at which changes in channel forms and dimensions occur.

***Bankfull stage (or level)***
The bankfull stage determines the limit of the bankfull channel, and corresponds to the flow stage at which water starts to spill out of the channel (on one or both banks) onto the surrounding floodplain. It corresponds to the bankfull discharge (see the definition above). The identification on the field of the bankfull level is rather difficult (e.g. in case of incised rivers).

***Baseflow channel***
In its broad meaning, it corresponds to the part of the bankfull channel which conveys mean annual flow (and lower).

***Bedrock channel***
It is characterised by the absence of alluvial sediment, because the high flow energy is able to carry downstream all the material coming from the hillslopes. However some alluvial material can be stored within pools or downstream blocking structures. It is typical of mountain-hilly areas.

***Boulders***
Sediment particles having a diameter >256 mm.

***Clay***
Sediment particles having a diameter <0.002 mm.

***Cobbles***
Sediment particles having a diameter of 64÷256 mm.

***Clogging (or embeddedness)***
The infiltration of fine sediment particles (mainly silt and clay) into the gaps between the larger sediment particles of a river bed.

***Colluvial channel***
Colluvial reaches are incised within colluvial material. They are common in low order reaches (first order), are small in size with steep slopes, and the bedload transport is intermittent and impulsive (debris flow). They can be related to gullies. The channel is poorly organised in geomorphic units.

***Confined channel***
A river without floodplain, where more than 90% of the river banks are directly in contact with hillslopes, ancient terraces, landslides, tributaries' alluvial fans or glacial deposits. The floodplain is limited to some isolated pockets (< 10% bank length). It is typical of mountain and hilly areas, or locally in lowplain areas (e.g. in presence of separation zones between catchments).

***Flow type***
Above-water spatial unit formed by the interaction between local hydraulic and sediment conditions which produces a series of distinc flow patterns at the flow surface. Different flow types are distinguished: free fall, chute, broken standing waves, unbroken standing waves, rippled, upwelling, smooth, no perceptible flow.

***Fluvial or river corridor***
Near-natural area of land including the fluvial geomorphic units that are directly (or more frequently) concerned by fluvial processes. It is usually delimited by near-natural vegetation (i.e. it includes the bankfull channel and floodplain units). In some case it corresponds to the entire floodplain.

***Geomorphic unit***
Area containing a landform (e.g. bar, riffle, floodplain) created by erosion and/or deposition inside (bankfull channel geomorphic unit) or outside (floodplain geomorphic unit) the river channel. Some geomorphic features are formed in association with living and dead (e.g. large wood) vegetation (also named biogeomorphic units).

***GIS (Geographic Information System)***
It is a computerized informatic system (software) that allows the collection, entry, analysis, visualisation and return of information coming from georeferenced geographic data.

***Gravel***
Sediment particles having a diameter 2÷64 mm.

***Hydraulic unit***
Spatially distinct patch of relatively homogeneous surface flow and substrate character. It can include several single river elements or small groups of sediment, plants, wood elements, etc. A single geomorphic unit can include from one to several hydraulic units.

***Large river***
A river whose width is significantly greater than the bed sediment size and that is completely laterally unconstrained. In general it concerns lowland unconfined rivers, larger than 30 m and with bankfull discharge at least 20÷50 $m^3$/s.

***Macrohabitat***
A generic zone where a given species lives, and that is defined on the basis of geomorphic, hydrologic and climatic conditions observed at the reach or sub-catchment scale, about 10 m in size (Heggenes & Wollebaek, 2013).

***Mesohabitat***
Eco-hydraulic characteristics at the reach scale in terms of habitat types, about some meter to 10 m in size (Heggenes & Wollebaek, 2013).

***Microhabitat***
Small areas within a mesohabitat, about 10 cm in size (Heggenes & Wollebaek, 2013).

***Partly-confined channel***
A river with a discontinuous floodplain, i.e. river banks are in contact with the floodplain for between 10 and 90% of their total length. It is common in pedmont areas, alpine valleys, or in separation areas between river catchments.

***Sand***
Sediment particles having a diameter 0.0625÷2 mm.

***Silt***
Sediment particles having a diameter 0.002÷0.0625 mm.

***Small river***
A river with coarse bed sediment and width 1 to 10 times the bed sediment particles (usually ≤ 30 m). In general it concerns mountain confined rivers.

***Unconfined channel***
A river with continuous floodplain, where less than 10% of the river bank length is in contact with hillslopes or ancient terraces, and the river has no lateral constraints to its mobility. It is typical of lowplain areas, but it can be observed also in mountain and hilly areas (e.g. the case of glacial valleys or recent alluvial fans).