ISPRA
Istituto Superiore per la Protezione
e la Ricerca Ambientale

IDRAIM – **stream hydromorphological evaluation, analysis and monitoring system**

Guidebook for the evaluation of stream morphological conditions by the Morphological Quality Index (IQM)

Version 1

Massimo RINALDI
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ISPRA – Istituto Superiore per la Protezione e la Ricerca Ambientale
Via Vitaliano Brancati, 48
00144 Roma
www.isprambiente.it

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Index

List of figures

List of tables

Introduction

The Water Framework Directive (WFD) (*EUROPEAN COMMISSION, 2000*) introduces hydromorphology as one of the elements to be evaluated, besides water quality and biological aspects, in order to obtain an evaluation and classification of the stream ecological state. Notwithstanding the innovations of the WFD, some limitations are recognised, amongst which hydromorphology appears to be the component taken least into consideration to eventually compromise the achievement of the fundamental objectives of the directive.

Nowadays a full comprehension of the morphological aspects and parameters more strictly correlated to the ecological state of a stream are still missing, even though several efforts have recently been devoted to this issue (see for example: *KAIL & HERING, 2009*; *WYŻGA et al., 2009*; *GURNELL et al., 2009*). A wide consensus, however, exists on the fact that geomorphic processes of streams and their dynamic equilibrium conditions spontaneously promote habitat diversity and the functioning of aquatic and riparian ecosystems (e.g. *CLARKE et al., 2003*; *PALMER et al., 2005*).

However, the approaches used up to now in most European countries tend to reflect "*River Habitat Survey*" procedures (see for example the *RHS* in UK – *RAVEN ET AL., 1998*), which are suitable for defining the presence and diversity of physical habitats but which have not been developed to comply with the WFD requirements. Therefore, there is an increasing need for an approach based on the consideration and understanding of the geomorphological processes responsible for river functioning which can be used not only for a classification but also for supporting analyses of any interventions and impacts, and the design of mitigation measures. Some examples of new methods currently developed in Spain (*Indice Idro-Geomorfologico, IHG – OLLERO ET AL., 2007*) and in France (*SYRAH procedure – CHANDESRIS et al., 2008*) are a step in this direction.

A new system has been developed for stream morphological assessment and classification at a national level with a series of the requisites previously detailed (adequate spatial scales, consideration of processes and trends of channel evolution, etc.) and which, at the same time, would be sufficiently simple and practical (*RINALDI et al., 2010*). This document reports the main characteristics of the method and a concise guide for its application.

The Illustrated Guide To The Answers is part of the Guidebook and is published in a separated volume.

AUTHORS AND ACKNOWLEDGEMENTS

Lead authors

Massimo RINALDI: *Dipartimento di Ingegneria Civile e Ambientale, Università di Firenze*

Nicola SURIAN: *Dipartimento di Geografia, Università di Padova*

Francesco COMITI: *Facoltà di Scienze e Tecnologie, Libera Università di Bolzano*

Martina BUSSETTINI: *Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), Roma*

Acknowledgements

CONTRIBUTORS

- Phase of methodological definition:

Luisa Pellegrini (*Università di Pavia*), Andrea Colombo, Federica Filippi e Tommaso Simonelli (*Autorità di Bacino del Fiume Po*);

- ISPRA contributors:
  - Giovanni Braca, Barbara Lastoria, Francesca Piva, Saverio Venturelli;
- Testing phase:
  - P. Aucelli, V. Benacchio, M. Ceddia, C. Cencetti, A. Colombo, S. De Gasperi, P. De Rosa, A. Dignani, G. Duci, F. Filippi, A. Fredduzzi, M. Micheli, E. Morri, O. Nesci, L. Pellegrini, C. Rosskopf, R. Santolini, V. Scorpio, T. Simonelli, D. Sogni, S. Teodori, V. Tiberi, F. Troiani, C. Zuri.
- Final revision of the manuscript:
  - B. Lastoria, C. Zuri, B. Golfieri.
- *Illustrated Guide To The Answers*:
  - B. Lastoria, C. Zuri.

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CHAPTER 1
METHODOLOGICAL FRAMEWORK

1.1 Review of existing methods for hydromorphological evaluation

The term "*hydromorphology*" was introduced by the WFD (EUROPEAN COMMISSION, 2000), and includes the consideration of: (a) the extent of modification to the flow regime; (b) the extent to which water flow, sediment transport and the migration of biota are impacted by artificial barriers; (c) the extent to which the morphology of the river channel has been modified, including constraints to the free movement of a river across its floodplain (SEAR *et al.*, 2003). Following the WFD, and according to definitions adopted by various authors (e.g. CEN, 2002; NEWSON & LARGE, 2006; MAAS & BROOKES, 2009; VOGEL, 2011), hydromorphology can be defined as the discipline that, by integrating hydrology and fluvial geomorphology, aims to study fluvial form and processes, their interactions with human impact, and the consequent implications on ecological processes.

Over recent years, several methods have been developed in many countries that are based on a census of physical habitats and diversity of fluvial forms, also known as river habitat survey procedures. Examples of those adopted in Europe and included in this category are as follows : the *River Habitat Survey* (*RHS*) (RAVEN *et al.*, 1997), the *National Physical Habitat Index* (National Environmental Research Institute) in Denmark, the *Physical S.E.Q.* (AGENCES DE L'EAU, 1998) in France, and the *Caravaggio* (BUFFAGNI *et al.*, 2005), the latter deriving from the RHS and adapted to the Italian and Mediterranean context. However, such methods were not originally developed to satisfy the requirements of the WFD. Among the main limitations of these methodologies, we note the following: (a) they make use of a "form-based approach" and do not include considerations on processes and trends of adjustment; (b) as a consequence, they define "reference conditions" in terms of forms (presence and number of given features) making use of "reference reaches" in present conditions (although they can be partially altered); (c) the spatial scale of investigation (coinciding with the "site", with a length to the order of some hundreds of meters) is inadequate for a real diagnosis and comprehension of morphological problems, as the physical degradation of a site is generally the consequence of processes and causes on a wider scale; (d) these procedures are not appropriate for an analysis of interventions and impacts aimed at the design of restoration actions, as required by the WFD. For example, let us consider a channel reach subject to intense adjustments (incision, narrowing) during the last decades, as very frequently occurred along many Italian rivers (e.g. SURIAN & RINALDI, 2003; SURIAN *et al.*, 2009*a*). By using the *RHS* method, a census of present forms (i.e. bars, riffles, pools) and their number is carried out, and so the result could be relatively good (e.g. a reach changing from a braided to a single-thread morphology, but still maintaining a diversity of forms), completely neglecting the alterations of processes related to the channel adjustments (e.g. disconnection with floodplain, loss of aquatic and riparian habitats, etc.). Furthermore, the *RHS* value could vary significantly depending on the site of application (length of 500 m) that could reflect local conditions.

In Italy, besides the *Caravaggio*, the *IFF* is certainly worth mentioning (*Indice di Funzionalità Fluviale*: SILIGARDI *et al.*, 2007), which evaluates the overall ecological functionality of a river reach. This, however, was not developed to evaluate the degree of deviation from a given reference condition, neither does it include hydromorphological aspects in any detail. Recently, a methodological framework of integrated assessment of the ecological status was proposed (*FLEA: Fluvial Ecosystem Assessment*) (*Nardini et al., 2008*), which is specific for the requirements of the WFD and also includes the elements of hydromorphological quality.

Recently, there has been an increasing development of new methods denoting a stronger geomorphological component, with an increasing consideration of physical processes, and the employment of sufficiently wide temporal scales and additional methods (remote sensing, GIS) integrated into field surveys. In this context, new methods developed in Spain (*Indice Idro-Geomorfologico*, *IHG*: *Ollero et al., 2007*) and in France (*SYRAH: Système Relationnel d'Audit de l'Hydromorphologie des Cours d'Eau*, *Chandesris et al., 2008*) are of particular note.

Finally, it is useful to mention some other methods existing in other countries not directly aimed at the application of the WFD but to stream evaluation and geomorphological analysis for management and restoration purposes. The *Fluvial Audit* (*EA, 1998*) can be included in this category, being a structured procedure aimed at the definition of management strategies and/or interventions. Another particularly significant example is that of the *River Styles Framework* (Australia), an organic methodological procedure for the detailed geomorphological analysis of a fluvial system developed by *Brierley & Fryirs (2005)*.

1.2 Overall structure of the method

The definition of the stream Morphological Quality Index (*IQM*) lies in a wider methodological framework named ***IDRAIM*** (***stream hydromorphological evaluation, analysis and monitoring system***) also aimed at a subsequent analysis of the causes and the monitoring of evolution trends, further to a classification of the present morphological state.

The general procedure of classification and monitoring is based, according to the WFD requirements, on evaluating the deviation of present conditions from a given reference state. The definition of a reference state for hydromorphology is problematic, and the scientific community nowadays agrees to renounce considering a "pristine", completely undisturbed condition. This is because, besides being extremely difficult to define, it would be associated with watershed conditions completely different from the present. It is therefore more appropriate to refer to the conditions that would exist in the present watershed conditions, but in the absence of human disturbances along the channel and adjacent river corridor. Recently, it has been increasingly necessary to refer to a "guiding image" coinciding with a condition of "dynamic equilibrium" (*Clarke et al., 2003*; *Palmer et al., 2005*), i.e. of channel mobility, and to consider "reference processes" or "reference process-form interactions" (*Bertoldi et al., 2009*) rather than "reference forms". Furthermore the comprehension of the fluvial system evolutive trends (in some cases also indicated as "trajectory": *Brierley & Fryirs, 2005*; *Dufour & Piégay, 2009*) is important not in the perspective of the recovery to a past condition but to ensure that future actions would be compatible with the trends of channel adjustment. To this aim, we refer to recent research in the fields of fluvial geomorphology and dynamics carried out on a national scale during the last years, by which the procedures of channel change analysis have been improved and channel evolution conceptual models have been developed (see for example *RINALDI, 2008*; *RINALDI et al., 2008*; *SURIAN, 2009a*).

Starting from these premises, the evaluation of present conditions and future monitoring are based on an integrated approach, making a synergic use of the two main methodologies employed in the geomorphological study of rivers: **field survey and interpretation**, and **remote sensing and GIS analyses**.

Regarding the **spatial scales**, a hierarchical nested approach is adopted (*BRIERLEY & FRYIRS, 2005*), considering the following spatial units of decreasing hierarchy: (1) CATCHMENT; (2) PHYSIOGRAPHIC UNITS AND FLUVIAL SEGMENTS (the latter having lengths to the order of tens of km); (3) STREAM REACHES (with lengths normally to the order of 1÷5 km), corresponding to the basic unit for remote sensing and GIS analyses; (4) SITES, consisting of a representative sub-reach and corresponding to the basic unit for field survey; (5) SEDIMENTARY UNITS, useful for measurements of detail (for example grain size analysis of bed sediments).

The overall procedure of morphological analysis includes (*Figure 1.1*):

(1) **Initial setting and classification**: the main physical aspects determining the configuration and characteristics of the hydrographic network are identified, and a first delineation of the rivers in segments and reaches is carried out.
(2) **Evaluation of the current morphological conditions**: the morphological state of the river reaches previously defined is evaluated in terms of present conditions (functionality, artificiality), and recent channel changes.
(3) **Monitoring**: for some reaches, selected as representative, a series of parameters are measured to evaluate if the morphological quality of the stream remains unaltered or is changing.

For the current morphological state assessment, coherently with *CEN (2002)* standards and WFD requirements, the following aspects are considered: (a) *longitudinal and lateral continuity*; (b) *channel pattern*; (c) *cross-section configuration*; (d) *bed structure and substrate*; (e) *vegetation in the riparian corridor*.

Then, the following three components of morphological analysis are considered:

(1) **Geomorphological functionality**: based on the observation of forms and processes in the present conditions, and their comparison with forms and processes normally associated with that river typology.
(2) **Artificial elements**: presence, frequency and continuity of artificial structures and interventions.
(3) **Channel changes**: recent morphological variations (with particular reference, for the planimetric changes, to the last 50÷60 years).

Following this framework, the **reference conditions** for a study reach can be identified with the following: (a) functionality of the processes, corresponding to dynamic equilibrium conditions; (b) absence of artificiality; (c) absence of significant adjustments of form, size and bed elevation in a time interval of the last decades.

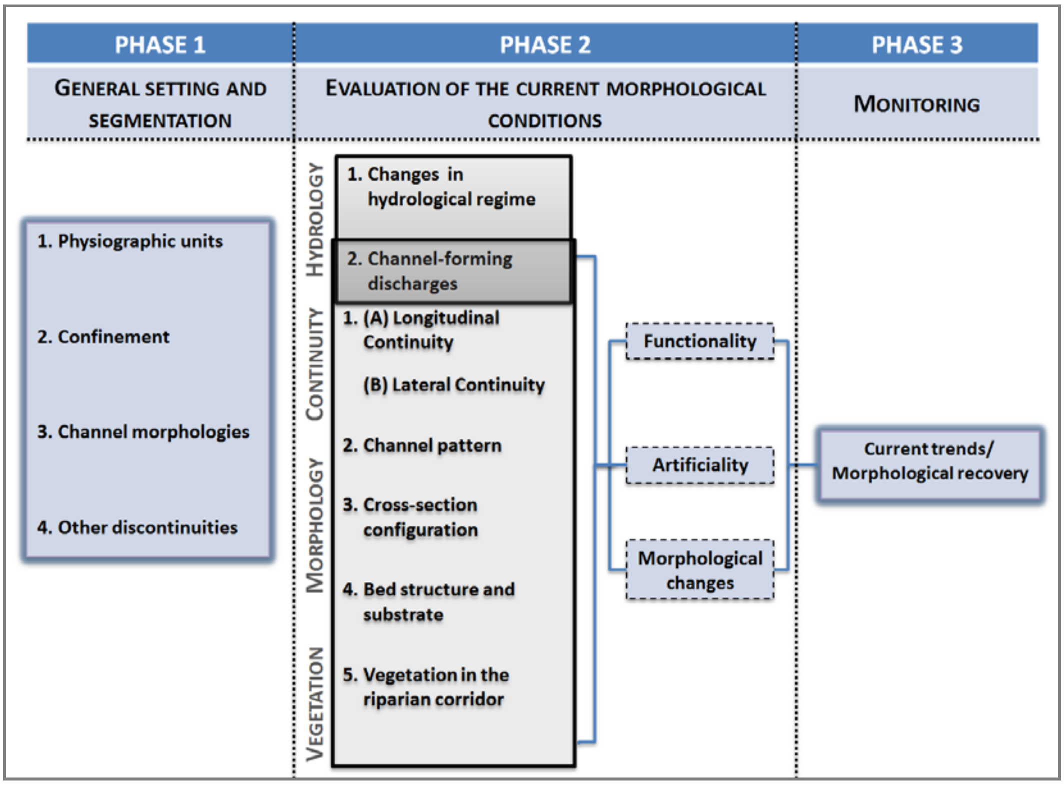

Figure 1.1 – General methodological framework illustrating the division in three phases and a list of the main aspects for each one.

As schematically represented in *Figure 1.1*, the morphological analysis described here only includes those hydrological aspects related to alterations of channel-forming discharges, i.e. those with more significant effects on morphological processes. The overall changes in the hydrologic regime (with particular emphasis on low discharges) are analysed separately and described in *ISPRA (2009)*. In short, the analysis of the hydrological regime is carried out on a stream section on the basis of a *Hydrological Regime Alteration Index*, *IARI*, that provides a measure of the deviation between the observed hydrological regime and the natural regime in the absence of human intervention. The *IARI* index is obtained, dependent on available river discharge data quality and consistency, by comparing the daily and/or monthly discharges actually flowing through the cross section and the corresponding natural discharges. The integration of morphological and hydrological aspects allows for a complete characterization and classification of stream hydromorphology.

CHAPTER 2
GENERAL SETTING AND SEGMENTATION

2.1 General framework

The first phase of the evaluation procedure provides a general setting of the river's physical conditions and for a first classification in relatively homogeneous reaches, functional to subsequent analyses. This phase is divided into the following steps:

(1) **General setting and identification of the physiographic units.** A first division of the watershed into macro-areas (physiographic units) and into corresponding macro-reaches (segments) is carried out.

(2) **Definition of the confinement degree.** River confinement (confined, semi-confined, unconfined) is defined more in detail, obtaining a preliminary subdivision of segments into reaches.

(3) **Definition of channel morphology.** Channel morphology is then defined, using different criteria for confined and semi- unconfined river reaches.

(4) **Division into reaches.** The final definition of reaches takes into account, besides confinement and channel morphology, additional factors such as hydrologic discontinuities, channel slope, artificiality, alluvial plain size, etc.

2.2 STEP 1: General setting and physiographic units

Aim: to obtain a general setting of the physiographic context and carry out a first division into macro-areas (physiographic units) and macro-reaches (segments).
Information/data necessary: watershed area, dominant lithologies, climate and hydrologic regime, land use, longitudinal profiles.
Methods: consultation of geological, geomorphological, and land use maps; existing studies; hydrological data collection and analysis; Remote sensing /GIS; field reconnaissance.
Results: division of the catchment into physiographic units and of the rivers into segments.

Description: based on the collection and consultation of existing materials, the main **physiographic units** in the catchment are identified (these correspond to the *landscape units* of according to *BRIERLEY & FRYIRS, 2005*). They can be included in two general **physiographic areas**: (1) *hills – mountains*; (2) *plains*.

In Italy, the following main physiographic units can be identified:

(A) *Alpine and Po plain sectors*: (1) Alpine mountain areas; (2) Pre-alpine mountain and hilly areas; (3) High plains; (4) Low plains.

(B) *Apenninic and island sectors*: (1) Mountain Apenninic areas; (2) Hilly Apenninic areas; (3) Intermontane Apenninic plains; (4) Inner reliefs; (5) High plains; (6) Low plains.

The portions of streams included within a physiographic unit are defined as **segments**. However, within a same physiographic unit, a stream may be further divided into more segments depending on the macro-characteristics of the valley (e.g. main changes of direction due to tectonic controls) and/or on relevant changes in bed slope from the longitudinal profile (particularly in the cases of mountain confined streams). Segments normally have a length to the order of some km (mountain areas) and up to tens of km (lowland areas).

2.3 STEP 2: Confinement

Aim: to define in more detail the confinement conditions, and to sub-divide segments based on confinement parameters.
Information/data necessary: width of the alluvial plain, confinement degree, confinement index.
Methods: Remote sensing /GIS; topographic and geological maps.
Results: division of segments based on confinement parameters.
Description: to analyze the confinement in detail, two parameters are used: (1) confinement degree; (2) confinement index.

(1) **Confinement degree**. This expresses the lateral confinement in a longitudinal sense, independently from the width of the alluvial plain. It corresponds to the percentage of banks directly not in contact with the alluvial plain but with hillslopes or *ancient terraces*, over the total length of the two banks. As a practical rule, the **alluvial plain** (i.e. the maximum width of the fluvial area of investigation) is normally identified on geological maps with "present alluvium" or "Holocene alluvium". However, an altimetric criterion can be more necessary than a rigid chronological criterion: if the Holocene alluvium is terraced, only some meters of it can be included in the alluvial plain (i.e. a Holocene terrace of 10÷15 m is not part of the alluvial plain). Vice versa, a Pleistocene terrace separated by a difference in level of few meters can be considered part of the alluvial plain, except when the material is strongly cemented. In any case, terraces delimiting the alluvial plain are ancient ones: *recent terraces* generated by channel bed incision during the last 100÷200 years, as very frequently occurred in Italy, for the purpose of the confinement are part of the alluvial plain. According to BRIERLEY & FRYIRS (2005), three cases can be distinguished based on the confinement degree:

- **Confined channels**: more than 90% of the banks are directly in contact with hillslopes or ancient terraces. The alluvial plain is limited to some isolated pockets (< 10%).
- **Semiconfined (or partly confined) channels**: banks are in contact with the alluvial plain for a length from 10 to 90%.
- **Unconfined channels**: less than 10% of the bank length is in contact with hillslopes or ancient terraces. In fact, the alluvial plain is nearly continuous, and the river has no lateral constraints to its mobility.

In some cases, the confinement degree previously defined is not sufficient to appropriately define the confinement characteristics. In fact, it is not infrequent (particularly in mountain areas) to have streams with a very narrow (some meters) but quite continuous plain on the sides before entering in contact with the hillslopes. According to the previous definitions, such streams may fall into the categories of semiconfined or unconfined, while it is more appropriate for the aims of this method to consider them as confined. Therefore, an additional parameter is used here which takes into account the confinement in a transversal sense (i.e. considering the width of the alluvial plain), defined as follows.

(2) **Confinement index**. It is defined here as the ratio between the alluvial plain width (including the channel) and the channel width. Consequently, the index is inversely proportional to the confinement: a minimum value of 1 indicates that the alluvial plain and channel coincide (i.e. there is no alluvial plain), while the index increases when the alluvial plain increases its width relatively to the channel width. Based on the confinement index, the following classes are defined:

- *high confinement*: index ranging from 1 to 1.5;
- *medium confinement*: index ranging from 1.5 to *n*;
- *low confinement*: index higher than *n*;

where *n* = 5 for single-thread channels (including sinuous with alternate bars), and *n* = 2 for multi-thread or transitional morphologies. The highest value for single-thread channels reflects the fact that a sufficiently wide plain is needed for these channels to develop completely free meanders, equal to about 4.5 times the channel width (*LEOPOLD & WOLMAN, 1957*).

Based on the confinement degree and index, it is possible to define the three final classes of confinement, according to *Table 2.1*.

Table 2.1 – Definition of the confinement classes.

CONFINEMENT CLASS	DESCRIPTION
Confined	All cases with confinement degree > 90%
	Confinement degree from 10% to 90% and confinement index ≤ 1.5
Semiconfined	Confinement degree from 10% to 90% and confinement index > 1.5
	Confinement degree < 10% and confinement index ≤ n
Unconfined	Confinement degree < 10% and confinement index > n

2.4 STEP 3: Channel morphologies

Aim: to define and classify channel morphologies.
Information/data necessary: confinement, sinuosity index, braiding index, anastomosing index (bed configuration).
Methods: Remote sensing /GIS; field reconnaissance.
Results: division of segments based on channel morphology.
Description: criteria for the classification of channel morphology are slightly differentiated for semi- unconfined channels and confined channels.

2.4.1 *Classification of semiconfined and unconfined channels*

Semiconfined and unconfined channels are classified based on their planimetric characteristics, therefore using the following classical indexes: (1) *sinuosity index*; (2) *braiding index*; (3) *anastomosing index*.

- **SINUOSITY INDEX** (***Si***) is defined as the ratio between the distance measured along the channel and the distance measured following the direction of the overall planimetric course.

- **Braiding index** (***Bi***) is defined as the number of active channels separated by bars.
- **Anastomosing index** (***Ai***) is defined as the number of active channels separated by vegetated islands.

Based on these parameters and, in some cases, on additional qualitative features (see Table 2), the following seven channel morphologies included in three main categories are defined:

- *Single-thread channels*: straight, sinuous, meandering
- *Transitional channels*: sinuous with alternate bars, wandering
- *Multi-thread channels*: braided, anastomosed.

In *Table 2.2* the criteria and threshold values of the indexes are reported. These have been defined according to the existing literature (e.g. *Leopold & Wolman, 1957*; *Schumm, 1977*; *Brice, 1984*; *Church, 1992*; *Thorne, 1997*; etc.), but also taking into account specific experience relative to the Italian context (e.g. *Rinaldi, 2003*; *Surian & Rinaldi, 2003*; *Surian et al., 2009b*). For example, sinuous with alternate bars (or "*pseudomeandering*": *Bartholdy & Billi, 2002*; *Rinaldi, 2003*) are here considered as a separate morphology, although in the following phase of assessment they are often grouped with single-thread channels for practical reasons, while wandering are grouped with multi-thread channels.

Table 2.2 – Criteria and threshold values of indexes or other distinctive characteristics for the morphological classification of semiconfined and unconfined channels.

Typology	**Sinuosity index**	**Braiding index**	**Anastomosing index**
Straight (*ST*)	$\mathbf{1} \le Si < \mathbf{1.05}$	1÷1.5 (normally equal or close to 1)	1÷1.5 (normally equal or close to 1)
Sinuous (*S*)	$\mathbf{1.05} \le Si < \mathbf{1.5}$	1÷1.5 (normally equal or close to 1)	1÷1.5 (normally equal or close to 1)
Meandering (*M*)	≥ 1.5	1÷1.5 (normally equal or close to 1)	1÷1.5 (normally equal or close to 1)
Sinuous with alternate bars (*SAB*)	< 1.5	Close to 1	Close to 1
Wandering (*W*)	< 1.5	$1 < Ii < 1.5$	$1 < Ia < 1.5$
Braided (*B*)	Any (normally low)	≥1.5	<1.5
Anastomosed (*A*)	any (even > 1.5)	1÷1.5	≥ 1.5
	Other distinctive characteristics		
Straight (*ST*) or sinuous (*S*)	Compared to *SAB/W*: discontinuous (or absent) side bars (length of side bars < 80% of reach length)		
Sinuous with alternate bars (*SAB*)	Compared to *ST/S*: nearly continuous presence of side bars (length of side bars normally > 80%). Compared to *W*: relatively narrower channel; absence (or localized presence) of braiding and anastomosing.		
Wandering (*W*)	Compared to *ST/S*: nearly continuous presence of side bars (length of side bars normally > 80%). Compared to *SAB*: relatively wider channel; significant presence of braiding and/or anastomosing phenomena.		

2.4.2 *Classification of confined channels*

Confined channels are classified, at a first level, based on the same criteria used for semi- and unconfined channels. The main difference is that the sinuosity index is not used, as it is not a significant parameter in distinguishing channel morphologies, given that the planimetric configuration of a single-thread confined channel is controlled by the hillslopes. Therefore, all single-thread morphologies (including transitional sinuous with alternate bars) are not further classified. This results in four possible morphologies, divided in two main categories:

- *Confined single-thread* (including sinuous with alternate bars);
- *Confined multi-thread / Wandering*: braided, anastomosed, wandering.

A *second level of classification* of confined channels is based on bed configuration. This level is not necessary for the segmentation, but additional information on bed configuration is useful for channel definition and as an indicator in the following phase of morphological assessment. According to existing literature (e.g. *MONTGOMERY & BUFFINGTON, 1997*; *WOHL, 2000*; *LENZI et al., 2000*; etc.), the following bed morphologies are distinguished:

- *Bedrock channels;*
- *Colluvial channels;*
- *Mobile bed*: cascade/step pool, plane bed, riffle pool, dune ripple;
- *Artificial bed.*

2.4.3 *Fluvial typologies*

From the combination of confinement and morphology, 18 fluvial typologies are obtained, as listed in *Table 2.3*.

Table 2.3 **–** Fluvial typologies deriving from the combination of confinement and morphology.

CONFINEMENT	MORPHOLOGY	TYPOLOGY
Confined	Single-thread Wandering Braided Anastomosed	(1) Confined single-thread (2) Confined wandering (3) Confined braided (4) Confined anastomosed
Semiconfined	Straight Sinuous Meandering Sinuous with alternate bars Wandering Braided Anastomosed	(5) Semiconfined straight (6) Semiconfined sinuous (7) Semiconfined meandering (8) Semiconfined sinuous with alternate bars (9) Semiconfined wandering (10) Semiconfined braided (11) Semiconfined anastomosed
Unconfined		(12) Unconfined straight (13) Unconfined sinuous (14) Unconfined meandering (15) Unconfined sinuous with alternate bars (16) Unconfined wandering (17) Unconfined braided (18) Unconfined anastomosed

2.5 STEP 4: Other discontinuities

Aim: to finalize the segmentation into relatively homogeneous reaches accounting also for additional factors.

Information/data necessary: hydrologic discontinuities (tributaries, dams), artificiality, width of alluvial plain, channel width, longitudinal profile.

Methods: Remote sensing/GIS; longitudinal profile by topographic maps; field reconnaissance.
Results: segments are divided into reaches that are the elementary units for the following morphological assessment.
Description: the following additional aspects are considered in this step as criteria for a further division into channel reaches.

- ***Discontinuities in bed slope***. This is particularly important in the case of confined channels where the morphology is not a sufficient criterion in many cases to finalize the segmentation.
- ***Natural or artificial hydrological discontinuities***. Tributaries determining significant changes in discharges or sediment transport can be considered. Artificial discontinuities are mainly identified with **dams** that necessarily correspond to a limit between reaches. Similarly, **check dams** or diversion structures of relevant sizes are normally considered as a limit of the reach, excluding the cases of a sequence of check dams that can be included in the same reach (if their distance is small relatively to the channel width).
- ***Artificiality***. Normally, the segmentation is quite independent from artificial elements, being based on physical characteristics. An exception (besides the presence of dams or other transversal structures described in the previous point) may be the case of a portion of stream with a very high degree of artificiality, well distinguished from its upstream and downstream reaches. An example can be a river crossing an urban area, with completely fixed banks and artificial levees, or a mountain stream with a sufficiently long portion with bed revetments and/or a sequence of consolidation check dams.
- ***Changes in width of the alluvial plain and/or confinement index***: in some cases, this can be considered as an additional criterion.
- ***Changes in channel width***: marked variations in channel width can be an additional criterion.
- ***Changes in sediment size***: cases of a considerable and sudden change in sediment size, e.g. a passage from gravel-bed to sand-bed, can be considered a criterion of separation in different reaches.

2.6 Example of segmentation

As an example of initial classification, the case of the Cecina River (Tuscany) is illustrated in *Figure 2.1*, where the physiographic units, river segments and reaches are reported. The watershed is divided into three physiographic units: (1) hilly – mountainous unit (*HM*): this is a mainly hilly zone but with portions up to 1,000 m a.s.l., included in the inner Apenninic reliefs (“Metalliferous hills”), with a substrate predominantly composed of sedimentary rocks of the Ligurian and Tuscan units, with a significant presence of magmatic intrusive rocks; (2) hilly unit (*H*): this includes a wide area occupying most of the watershed, predominantly characterized by soft rocks of Miocene and Pliocene, and Quaternary marine and fluvial deposits; (3) coastal plain unit (*CP*): this is limited to about the last 4 km of the Cecina River, and is characterized by recent alluvial deposits and coastal dunes, absence of confinement, and low gradients. From the intersection of the physiographic units with the Cecina river course, a first division into 3 segments is obtained. However, the portion of river included in the hilly unit is further divided into two segments based on the confinement: segment 2 is an alternation of semiconfined and confined reaches; segment 3 is characterized by the continuous presence of alluvial deposits and, as a consequence, only by semi-unconfined reaches. The further division into reaches accounts for the differences in channel morphology and other elements of discontinuity. The result is that the river is divided into a total of 18 reaches (on a total length of the river of about 80 km, implying that the reaches have a mean length of 4.45 km), with the codes of each reach defined in increasing order for each segment (as reported in *Figure 2.1*).

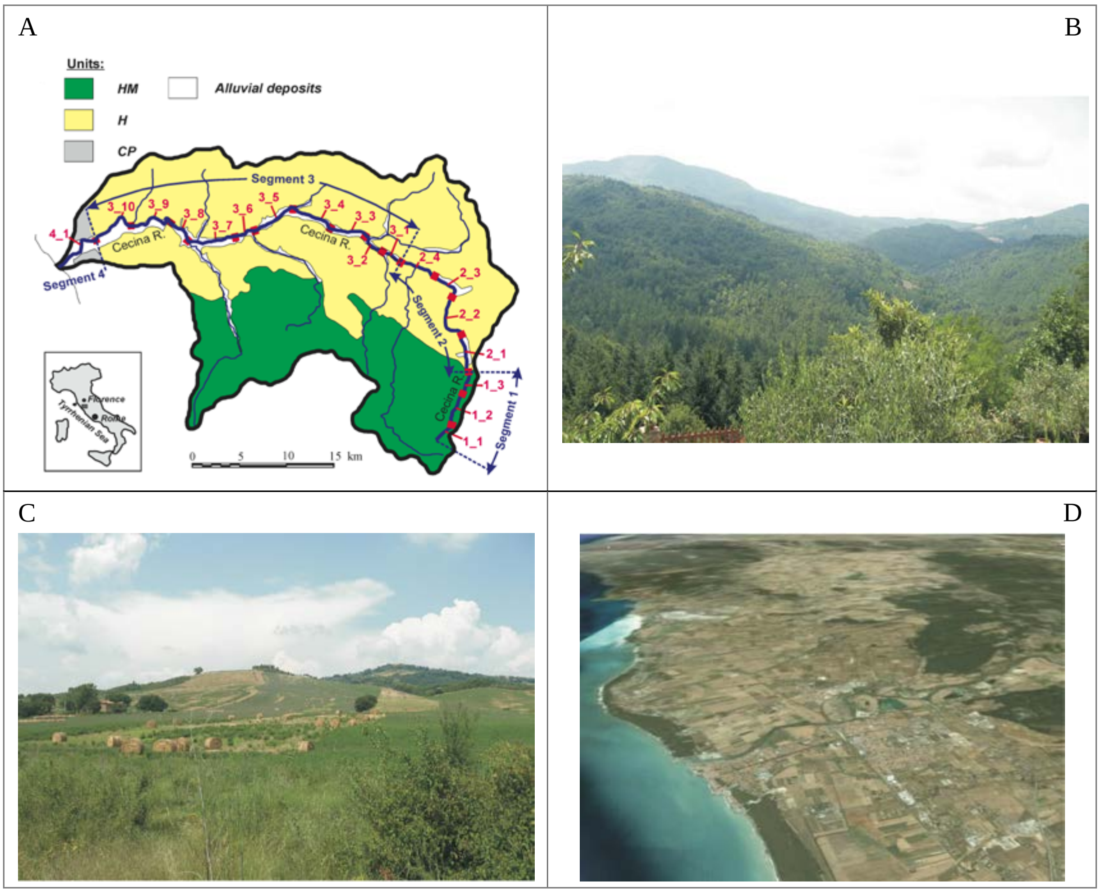

Figure 2.1 – Example of segmentation for the Cecina River (Central Italy). (*HM*): Hilly – Mountainous unit; (*H*): Hilly unit; (*CP*): Coastal Plain unit.

2.7 Other available data and information

To conclude the general setting and segmentation phase, a further series of data/information can be collected, when available, concerning the following aspects.

- ***Drainage area***. The drainage area of the watershed at the closure of a given reach is useful for some indicators in the following morphological assessment.
- ***Sediment size***. Measurements of sediment size are not strictly required in the following phase of assessment. However, this information is very useful when it is available (e.g. from previous studies).
- ***Water discharges***. In this phase, it is useful to identify all gauging stations in the catchment with a series of discharges over a sufficiently long time,

and to obtain the main representative discharges, such as the mean annual daily discharge, $Q_{1.5}$, and discharges with higher return intervals.

- ***Sediment discharges***. Although this type of information is difficult to obtain, existing estimations or measurements of sediment transport or sediment budgets are very useful when available (e.g. from previous projects or scientific literature).
- ***Alterations of water and sediment discharges in the catchment***. It is already helpful at this stage to carry out a complete collection of available information and data on the possible alterations of water and sediment discharges. This will be needed for the definition of some indicators (*A1* and *A2*) in the following phase. It is important to know the existence and position of the main structures of interception of sediment transport (dams, check dams, weirs, etc.), as well as the interventions of the possible alteration of water discharges (dams, diversions, spillways, retention basins, etc.). It is also important to collect information about the use of some of these interventions from the agencies in charge of their management and maintenance (e.g. use of a dam for hydropower or for a reduction in peak discharges, changes in discharge for given return intervals, existence of measures for sediment release, etc.). Possibly, a GIS-based map with identification of the main structures potentially altering sediment and water discharges and relative information should be produced.

CHAPTER 3
EVALUATION OF MORPHOLOGICAL CONDITIONS

3.1 Evaluation procedure

The assessment of present morphological conditions is applied to any reach defined in the previous phase by analyzing the following aspects, coherently with CEN (2004) standards and WFD requirements: (1) continuity of river processes, including (a) longitudinal continuity, and (b) lateral continuity; (2) channel morphological conditions, including (a) channel pattern, (b) cross-section configuration, and (c) bed structure and substrate; (3) vegetation. These aspects are analyzed according to three components: (1) geomorphological functionality; (2) artificiality; (3) morphological channel changes. The complete set of indicators can be schematically represented by crossing the previous aspects (in rows) and components (in columns) (*Table 3.1*), while the list of indicators is reported in *Table 3.2*.

Table 3.1 **–** General framework of the indicators used to assess the morphological state. Artificiality: the indicators having a secondary impact on the morphological aspect indicated in the row are in parentheses.

		FUNCTIONALITY	ARTIFICIALITY	CHANNEL CHANGES
CONTINUITY	*Longitudinal*	*F1*	*A1, A2, A3, A4, A5*	
	Lateral	*F2, F3, F4, F5*	*A6, A7*	
MORPHOLOGY	*Channel pattern*	*F6, F7, F8*	*A8 (A6)*	*V1*
	Cross-section	*F9*	*(A4, A9, A10)*	*V2, V3*
	Bed substrate	*F10, F11*	*A9, A10, A11*	
VEGETATION		*F12, F13*	*A12*	

All indicators are investigated by using specific **evaluation forms** that allow for a guided analysis using an integrated approach of remote sensing / GIS and field surveys. The evaluation forms are presented in two formats: (a) “field evaluation forms” (hard copy are in this Guidebook); (b) “electronic evaluation forms” (Excel format, that can be downloaded from the web page http://www.sintai.sinanet.apat.it/view/index.faces), to be compiled after the field survey.

A number of indicators are used, where each indicator is evaluated by one or more quantitative or qualitative variables (for some indicators, particularly for functionality, interpretative observations rather than quantitative parameters are used). Two evaluation protocols are defined for the two situations of: (1) ***confined channels***; (2) ***semi- unconfined channels***. Morphological changes are evaluated for large channels (width > 30 m), either for semi- unconfined and for confined streams.

For each indicator, in most cases three possible answers are defined (except for a limited number with two or four answers): (*A*) unaltered conditions or no significant alterations; (*B*) intermediate conditions; (*C*) high level of alterations. A Guide to the compilation of the evaluation forms is to be found at the end of this report.

In order to obtain a classification, it was necessary to define an objective evaluation procedure. The criterion utilized here is included within the evaluation scoring systems: scores are assigned to each indicator proportionally to its importance in the overall evaluation.

The procedure developed, although relatively simple, includes a high number of indicators (28): rather than selecting a few significant indicators, it was preferable to consider all aspects for an overall assessment or audit in order to achieve a systematic and organized analysis of the problem. For example, human disturbances are evaluated in two ways: on the one hand, their assessment as artificial elements and on the other, the assessment of their impacts on the functionality of processes and on channel adjustments. Indicators of functionality require some interpretative level of morphological forms and processes, rather than the measurement of given parameters, therefore they need expertise and specific knowledge of the field of investigation.

The evaluation is carried out by making a synergic use of two types of observations and measurements: (1) remote sensing and GIS analysis; (2) field survey. A succession of the following **operative phases** is recommended: (1) collection of existing material and information on the reach and catchment; (2) observation and analysis of remote sensing images: during this phase many indicators can be already determined, and a list of the critical points which need to be resolved in the field; (3) field survey: this phase is concentrated on a representative sub-reach, but also includes a check on some specific points along the reach (the "*field evaluation forms*" are compiled during phases 2 and 3); (4) final measurements from remote sensing – GIS and/or collection of additional information: once the critical points have been resolved in the field, it is possible to finalize the evaluation (the "*electronic evaluation forms*" are compiled at this stage). In some cases in this phase, additional information may be needed for some indicator (e.g. information on interventions or management activities by public agencies).

Table 3.2 – List of indicators.

GEOMORPHOLOGICAL FUNCTIONALITY	
Longitudinal continuity	
F1	Longitudinal continuity in sediment and wood flux
Lateral continuity	
F2	Presence of a modern floodplain
F3	Hillslopes – river corridor connectivity
F4	Processes of bank retreat
F5	Presence of potentially erodible corridor
Channel pattern	
F6	Bed configuration – valley slope
F7	Forms and processes typical of the channel pattern
F8	Presence of typical fluvial forms in the alluvial plain
Cross-section configuration	
F9	Variability of the cross-section
Bed structure and substrate	
F10	Structure of the channel bed
F11	Presence of in-channel large wood
Vegetation	
F12	Width of functional vegetation in the fluvial corridor
F13	Linear extension of functional vegetation
ARTIFICIALITY	
Upstream alteration of longitudinal continuity	
A1	Upstream alteration of discharges
A2	Upstream alteration of sediment discharges
Alteration of longitudinal continuity in the reach	
A3	Alteration of discharges in the reach
A4	Alteration of sediment discharges in the reach
A5	Crossing structures
Alteration of lateral continuity	
A6	Bank protections
A7	Artificial levees
Alteration of channel morphology and/or substrate	
A8	Artificial changes of river course
A9	Other grade control structures
Interventions of maintenance and removal	
A10	Sediment removal
A11	Wood removal
A12	Vegetation management
CHANNEL CHANGES	
V1	Changes in channel pattern
V2	Changes in channel width
V3	Bed-level changes

3.2 Scoring system

For each indicator, the scores to be assigned to each answer are reported on the evaluation form, proportionally to the degree of alteration, that is, in increasing order from *A* (score 0) to *C* (maximum score for that indicator). Furthermore, in the evaluation system a judgement on the degree of confidence is introduced for each answer, considering high, medium, and low confidence. In fact, cases with missing information or data are possible. It is therefore useful to distinguish the different cases *a posteriori*. This system will yield a simplified estimation of the overall uncertainty degree associated with the final evaluation. This is the range of variation of the final score, calculating for low confidence answers values which should be assigned in the case of answer variations.

Regarding the final score, initially the total deviation S_{tot} from non altered conditions is calculated as the sum of the scores assigned to all indicators. A **Morphological Alteration Index** (***IAM***) is then defined as:

$$\boldsymbol{IAM} = S_{tot} / S_{max}$$

where S_{max} is the maximum possible deviation for the given stream typology (corresponding to the sum of the scores of class *C* for all the questions applicable to the study case). Such an index ranges therefore from a minimum of 0 (no alteration) to a maximum of 1 (maximum alteration).

Regarding the score of artificiality, an additional score (of 12) is assigned to conditions of extremely high density for some types of intervention (weirs, revetments, bank protections, and levees).

A stream **Morphological Quality Index** (***IQM***) is then defined as complementary to the previous one, that is:

$$\boldsymbol{IQM} = 1 - IAM$$

Such an index, contrary to the *IAM*, assumes a value of 0 in the case of maximum alteration, and a value of 1 in the case of reference conditions (corresponding to maximum functionality, minimum artificiality and minimum channel changes). Based on *IQM*, five classes of morphological quality are defined as follows:

(1) *very good or high: IQM > 0.85*;
(2) *good*: *IQM = 0.7÷0.85*;
(3) *moderate*: *IQM = 0.5÷0.7*;
(4) *poor*: *IQM = 0.3÷0.5*;
(5) *very poor or bad*: *IQM = 0÷0.3*.

The scores assigned to the indicators and to the limits of the quality classes have been verified and better defined on the basis of a testing phase carried out on about 60 reaches representative of different morphological conditions (confined, semi-unconfined, meandering, braided, etc.) and of various situations of artificiality (ranging from relatively natural to highly artificial streams).

3.3 Applications

A series of examples of applications (in decreasing order of *IQM*) to a range of Italian rivers is reported as follows.

3.3.1 *Sentino stream along the Frasassi gorge.*

The first example is a mountain stream along a confined reach, with a mean channel width of 12 m and slope of 0.004. The channel is classified as confined single thread, banks are often composed of rock outcropping (*Figure 3.1A*), the channel bottom alternates between areas of substrate outcropping and subreaches with cobble and gravel and a riffle-pool configuration (*Figure 3.1B*). Channel gradient is in fact not very high, as the stream is not in its initial part but at the passage between two semi-confined reaches. Channel changes are not considered given the limited channel width (< 30 m). There are no significant alterations compared to the expected conditions, except for the indicators *F3* and *F12* (hillslopes – stream connection and width of functional vegetation) which are in class *B* given the presence of a road on the side of the stream along the whole reach. There are no significant structures upstream that can produce alterations to channel-forming discharges, while the existence of weirs upstream slightly alters the sediment discharge (*A2* in class *B1*). The final result is *IQM* = 0.92 and the reach is classified as *very good*.

A B

Figure 3.1 – Sentino stream along the Frasassi Gorge (*IQM* = 0.92: *Very good*). (A) Rocky bank; (B) channel bed composed of sediments and riffle-pool configuration.

3.3.2 *Tagliamento River near Turrida.*

In this reach, located in the Upper Friulian Plain, the river is unconfined since the old terraces (one terrace is clearly visible in the right side of *Figure 3.2A*) are far apart allowing a wide space for lateral mobility (more than 3 km). The river displays a braided morphology and has the following characteristics: the bed is mainly made up of gravels; channel width ranges from 800 m to 1,000 m; average channel slope is 0.003. The elements which determine alterations of morphological quality are very few, due to a relatively low level of human intervention, if compared to other Italian rivers, in the drainage basin and in the alluvial plain. The elements of alteration are: (1) in-channel sediment removal, which occurred mainly in the 1970s and 1980s, and, likely, removal of large woody debris; (2) channel adjustments which have led to significant channel narrowing (about 50%, referring to channel width in the 1950s) and moderate incision (about 1.5 m). The reach has *IQM* = 0.87, and is classified as *very good*.

Figure 3.2 – Tagliamento River near Turrida (*IQM* = 0.87: *Very good*).
(A) Aerial photo dated 2009 of the study reach showing a typical braided morphology and a riparian zone which has a notable extent; (B) photo of channels and bars; (C) large woody debris within the channel and riparian vegetation (in the background).

3.3.3 *Cecina River near Casino di Terra.*

This is an unconfined river which flows within a relatively narrow plain in a hilly physiographic unit (*reach 3_7* in *Figure 2.1*), with watershed area of about 635 km^2. The channel is classified as sinuous with alternate bars (*Figure 3.3A*), with a gravel bed and riffle-pool configuration, mean slope of about 0.003 and mean width of about 50 m. The main elements of alteration are: (1) presence of some weirs upstream (*A2* in class *B1*); (2) moderate sediment mining in the past, in turn responsible for some significant channel adjustments (moderate narrowing and incision, with *V2* and *V3* both in class *B*); (3) some localized artificial elements in the reach (bridge, sills, etc.). Notwithstanding such alterations, the river presents some positive aspects, being characterized by some lateral mobility, a good morphological diversity (*Figure 3.3B*), the presence of a modern floodplain (even though narrow and discontinuous) and of a potential erodible corridor, absence of levees, presence of a corridor of spontaneous vegetation (continuous but of intermediate width). The final result is *IQM* = 0.78, therefore the reach is classified as *good*.

Figure 3.3 – Cecina River near Casino di Terra (*IQM* = 0.78: *Good*).
(A) Aerial photo dated 2006 of part of the reach highlighting the typical sinuous morphology with alternate bars; (B) detail of the reach showing the morphological variability associated with a diversification of forms and the presence of retreating banks (on the back).

3.3.4 *Furkelbach (Furcia Torrent) in Val Pusteria.*

The Furkelbach (or Furcia) torrent is a left tributary of the Rienza River (Val Pusteria, Provincia Autonoma di Bolzano), entirely belonging to a physiographic unit of "alpine mountain area". Its drainage area is 23.4 km^2. The analysed reach (length of 1.7 km, from 1,310 to 1,148 m a.s.l., with a mean bed slope of 9.5%) is a single-thread confined stream with a mean channel width of about 8 m. The Furkelbach represents a typical case of an alpine torrent strongly altered by hydraulic structures, the presence of an adjacent road which alters the hillslope – stream continuity, and maintenance interventions on riparian vegetation. However, the geomorphic functionality results in being of an intermediate level. Regarding artificiality, the highest criticality is represented by the presence of 67 weirs in the reach (*Figure 3.4A*), with a resulting frequency of about 4 for each 100 m (therefore *A4* is in class C with further 14 scores assigned to it because of the very high density). Furthermore, slightly upstream (400 m) there is a big open check dam (*Figure 3.4B*, *A2* in class *B1*). Other artificiality elements include some bank protections (*A6* in class *B*), and the relative removal and cutting of riparian vegetation and wood (*A11* and *A12* in class C). Summarising, *IAM* is equal to 0.54 and *IQM* to 0.46, meaning that the quality of the reach is *poor*.

A B

Figure 3.4 – The Furkelbach (Furcia) Torrent in Val Pusteria (*IQM* = 0.46: *Poor*).
(A) The reach analysed downstream: the influence of the several weirs on the channel morphology is evident from the fact that it does not present a natural channel bed configuration with cascades as would be expected for the given channel slope (9.5%), as well as the artificiality of riparian vegetation subject to periodic cutting, and the total absence of woody material within the channel; (B) the open check dam immediately upstream of the reach.

3.3.5 *Panaro River near Vignola.*

This is an unconfined reach between Vignola and Savignano (length of about 2 km), along the apex of an alluvial fan (physiographic unit of high Apenninic plain), having a mean channel slope of 0.007, and a mean width of 96 m. It represents a case of very strong physical degradation, although the artificiality is not at maximum levels, demonstrated by drastic changes in the channel pattern and width (*Figure 3.5A* and *Figure 3.5B*), and of the channel bed (incision > 6 m), mainly related to past intensive mining activity and the reduction of upstream sediment supply. Therefore the channel changes indicators (*V1*, *V2* and *V3*) result as having maximum scores. Other main critical points are represented by the presence of weirs upstream and in the reach (*A2* in class *B2* and *A4* in class *B*), the absence of a modern floodplain (*Figure 3.5C*), the alteration of bed substrate with widespread clay outcrops (*F10* in class *C2*) (*Figure 3.5D*), and the reduction of morphological diversity, in turn related to the strong incision. The final result is *IQM* = 0.40, therefore the reach is classified as *poor*.

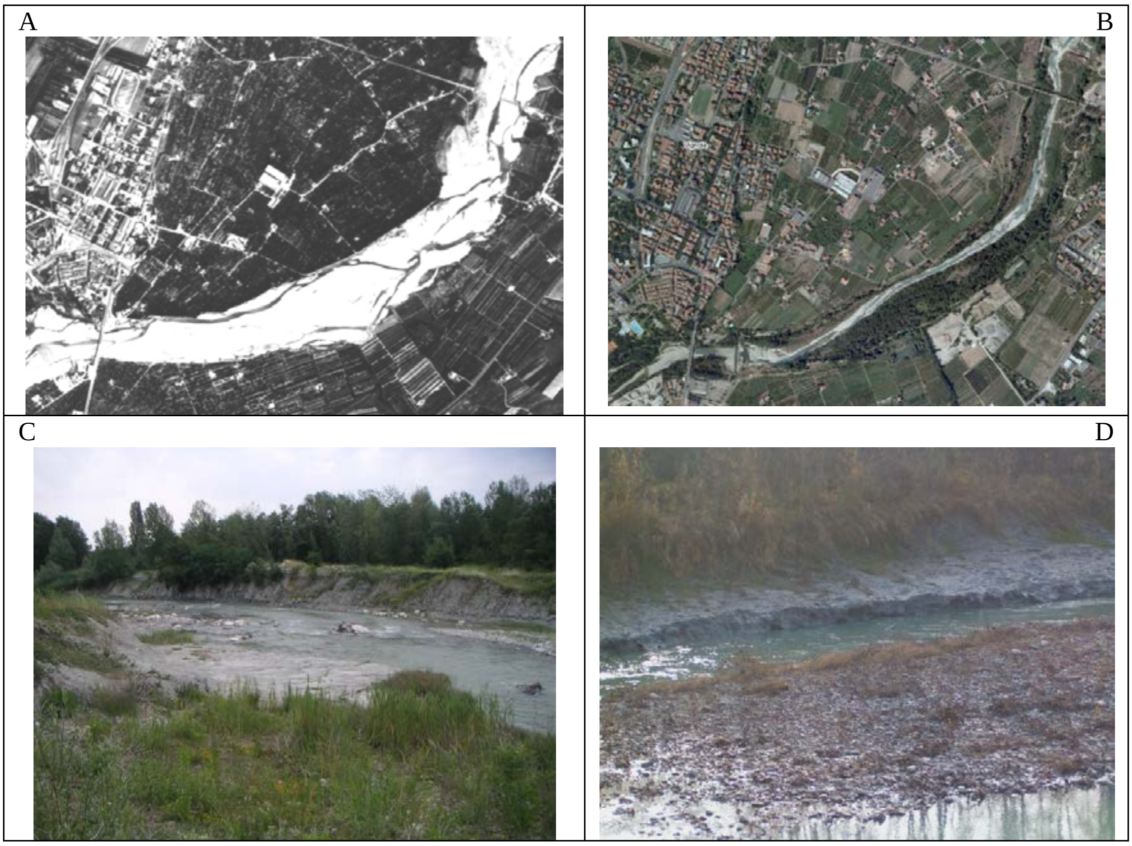

Figure 3.5 – Panaro River near Vignola (*IQM* = 0.40: *Poor*).
(A) Aerial photo dated 1954 showing a wide braided channel; (B) aerial photo dated 2003 highlighting the drastic narrowing and change in channel pattern (single thread); (C) detail of the reach showing high unstable banks and terraced surfaces deriving from the strong incision; (D) detail showing the clay outcropping on the channel bed and basal banks.

3.3.6 *Arno River in Florence.*

This is an unconfined reach within a plain (physiographic unit of intermountain plain), well representative of a large river crossing a densely urbanized area *Figure 3.6A*). The channel is classified as straight, with mean slope of 0.0018, and mean channel width of 115 m. The artificiality of the reach is very high, because of the continuous presence of lateral structures, and in part transversal, that prevent any kind of lateral and vertical dynamics (*Figure 3.6B*), compromising most of the morphological functionalities. Upstream longitudinal continuity is also altered due to the presence of dams and several weirs. The continuous presence of bank protection elements and levees in the reach entails the assignment of additional scores to the indicators *A6* and *A7*, therefore the artificiality reaches the maximum score. The final result is *IQM* = 0.11, therefore the reach is classified as *very poor*.

Figure 3.6 – Arno River in Florence (*IQM* = 0.11: *Very poor*).
(A) Satellite image dated 2007 showing how the reach crosses a highly urbanized area. (B) Detail showing the presence of bank protection elements (with the function of levees) and the homogeneity of cross section.

3.3.7 *Gadria Torrent near Lasa.*

This is a left tributary of the Adige River, subject to very frequent channelized debris flow, 1÷2 per year in average. The catchment (drainage area of about 14 km^2) is very steep and subject to frequent surface landslides. The analyzed reach (2.2 km) crosses the Gadria alluvial fan, one of the biggest in Europe, and consequently presents the characteristics of an unconfined reach in a mountain physiographic context. The channel was channelized at the end of the 19th century, when a straight course with bed revetment was created (*Figure 3.7*), with the aim of conveying the debris flow down to the Adige River. Later, an open check dam was built just upstream to stop all the sediment. Geomorphological functionality is at the minimum for most of the indicators (except *F1*). The artificiality is high (class *C*) only for relatively few indicators. However, the continuous presence of bank protection elements, levees, and bed revetments entails the assignation of additional scores to indicators *A6*, *A7* and *A9*, causing a maximum artificiality score. The resulting *IQM* is equal to 0.04 (*very poor*).

Figure 3.7 – Gadria Torrent near Lasa (*IQM* = 0.04: *Very poor*).
(A) Aerial photo dated 2006 showing the alluvial fan crossed by the stream along the study reach. B) Detail showing the artificial configuration of the stream.

CHAPTER 4
MONITORING

Two monitoring methodologies can be identified:

(1) Non instrumental monitoring: this consists of periodically repeating the procedure for the assessment of the current morphological conditions. Besides a new field survey and updating the artificial elements, it possibly requires an analysis of new images to evaluate possible channel changes. This monitoring activity allows the verification of the conservation of the previous morphological state or of the evidence of recovery or further reduction of the morphological quality. It is a relatively rapid procedure which does not, however, allow a detailed analysis of the possible causes of alteration or trends of adjustment.

(2) Instrumental monitoring: this requires carrying out periodic field measurements (other than from remote sensing) to analyze in a more systematic way possible channel changes (i.e. channel width or bed elevation changes). This monitoring activity is obviously more onerous but can permit the more detailed analysis of the causes and trends of channel adjustments. A list of the natural morphological elements to monitor is shown in *Table 4.1*, while monitoring artificial elements corresponds to an updating of the data base of interventions.

For the WFD implementation, non instrumental monitoring is identified with the so called surveillance monitoring and is applied to a relatively high number of reaches in the watershed representative of different physiographic and morphologic conditions, while instrumental monitoring is identified with the operative or investigative monitoring, to be carried out for a limited number of reaches at risk or in particular cases.

Table 4.1 – Morphological aspects, parameters, methodologies, and spatial scale for Instrumental Monitoring.

MORPHOLOGICAL ELEMENT	METHOD OF SURVEY AND RELATIVE SPATIAL SCALE	STREAM TYPOLOGY
1.1 Discharge	Hydrometric measurements on existing gauging stations	All
1.2 Lateral extension and continuity of modern floodplain	Remote sensing (reach)	Only semi- unconfined channels
1.3 Length of retreating banks and rates of retreat	Remote sensing (reach)	Only semi- unconfined channels
2.1 Sinuosity index	Remote sensing or field measurement (small channels) (reach)	All
2.2 Braiding index	- Remote sensing (reach) - Field measurement (site)	All excluding single thread
2.3 Anastomosing index	- Remote sensing (reach) - Field measurement (site)	All excluding single thread
2.4 Bar and island sizes	Remote sensing (reach)	Only large channels
2.5 Morphological pattern	- Remote sensing (reach) - Field measurement (site and/or reach)	- Only large channels - All
2.6 Channel slope	Survey of bed profile, possibly extended from site to reach	All
3.1 Channel width	- Remote sensing (reach) - Survey of cross-sections (site)	- Only large channels - All
3.2 Channel depth	Survey of cross-sections (site)	All
3.3 Width to depth ratio	Survey of cross-sections (site)	All
3.4 Bed-level changes	Survey of bed profile extended from site to reach	All
4.1 Grain size of bed sediment	- Pebble counts (sedimentary unit) - Volumetric sample (sedimentary unit)	- Wadable gravel-bed rivers - Sandy and/or not wadable rivers
4.2 Bed structures: armouring ratio and clogging	- Qualitative evaluation (site) - Grain size analysis (sedimentary unit) in case of high armouring	Only wadable gravel-bed rivers
4.3 In-channel large woody storage	- Field counting (site) - Remote sensing (site)	- Single thread rivers - Large wandering/ braided rivers

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APPENDIX 1

GUIDE TO THE COMPILATION OF THE EVALUATION FORMS

GUIDE TO THE COMPILATION OF THE EVALUATION FORMS

In this section, a definition of each indicator and an extended version of the possible answers is reported. Furthermore, for each indicator the following information is reported:

- Spatial scale (longitudinal and lateral);
- Type of measurements (e.g. field survey, remote sensing, or other sources of information);
- Typology (confined, semiconfined or unconfined);
- Range of application (for those indicators that are not applied in specific cases).

GENERALITY AND INITIAL SEGMENTATION

The first part of the evaluation form is dedicated to a series of general information, including the **date** of the field survey (although the complete compilation of the evaluation form requires a preparation phase and a conclusion phase of the measurements after the field visit), and the name(s) of the **operators**. Then the name of the **catchment** and of the **stream/river** is indicated. The **upstream and downstream limits** of the reach must be clearly defined (e.g. name of a tributary, if this represents a limit, or planimetric coordinates). It follows the identification code of the **segment** and **reach**, and the stream **length**.

The following part is dedicated to all information and measurements made during the four steps of the general setting and initial segmentation. During STEP 1, the **physiographic setting** (area and unit) is specified. During STEP 2, the details for the classification of **confinement** are provided. Note that, as for all the indexes reported in this section, the operator can report the precise value of the index, or only specify the class (e.g. > 90%, 10÷90% or < 10% for the confinement degree). STEP 3 is dedicated to **channel morphology**. First of all, the name of the image (aerial photo or satellite image) used as a reference for all observations aimed at morphological classification is indicated. Then, all the indexes and other information are reported, including the mean bed slope and the mean channel width along the reach. In STEP 4, information regarding **other elements for reach delimitation** is reported. Finally, it is possible to report additional available data or information which are useful for the assessment (e.g. sediment sizes and discharges).

GEOMORPHOLOGICAL FUNCTIONALITY

CONTINUITY

F1: Longitudinal continuity in sediment and wood flux

DEFINITION

This is the evaluation of whether the longitudinal continuity of sediment and wood solids is altered by human structures that intercept or create obstacles to their flow (discontinuities due to natural factors, such as rock outcroppings, lakes or landslide dams are not considered).

SPATIAL SCALE	
LONGITUDINAL: Site/Reach	*LATERAL*: Channel
MEASUREMENTS: Remote sensing and field survey	

The assessment does not depend on the number of alterations, but on their relevance: just one structure can cause a complete alteration of the flux, or differently, many structures may have no significant effects. The main artificial structures are dams, check dams, and weirs. Other alterations can be due to crossing structures (bridges, fords) or also groins. In the case of a **structure located at the upstream reach limit, this is conventionally assigned to the upstream reach** (see *artificiality indicators*)**, but the effects on the longitudinal continuity are considered for the downstream reach**. Therefore, a structure located at the downstream limit is not evaluated for that reach, but for the one downstream.

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence or very negligible presence of alterations in the continuity of sediment and wood flux, that is, there are no significant obstacles or interceptions to the free passage of solid material related to transversal and/or crossing structures (e.g. bridge with no piers or wide span, etc.).
B	Slight alteration in the continuity of sediment and wood flux, that is, most solid material is able to flow along the reach. Depositional forms may exist, indicating sedimentation of the coarsest fractions of bedload by crossing structures and/or groins, but with no complete interception (e.g. bridges with narrow spans and piers, series of consolidation check dams in mountain areas); larger sizes of wood is held by bridge piers and/or open check dams.
C	Strong alteration in the continuity of sediment and wood flux, that is, a strong discontinuity of depositional forms (sediments) exist in upstream and downstream structures because bedload is strongly intercepted (e.g. not filled weirs or check dams).

F2: Presence of a modern floodplain

DEFINITION

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). Channel adjustments (specifically bed incision) or artificial structures (levees) can alter this characteristic form and disconnect the floodplain from channel processes. Lateral extension and longitudinal continuity of a modern floodplain is here considered as an indicator of existing lateral continuity of water and sediment fluxes.

SPATIAL SCALE	
LONGITUDINAL: Site/Reach	*LATERAL*: Alluvial plain
MEASUREMENTS: Remote sensing and field survey	

EXTENDED ANSWERS

TYPOLOGY	SEMICONFINED- UNCONFINED
RANGE OF APPLICATION	NOT EVALUATED IN THE CASE OF MOUNTAIN STREAMS ALONG STEEP (>3%) ALLUVIAL FANS
A	Presence of a relatively continuous (> 66% of the reach length) and sufficiently wide floodplain, that is, when the mean width (sum on the two sides) is at least twice the channel width (*W*) in the case of single-thread channels (including sinuous with alternate bars), or at least 1 *W*.
B	Presence of a discontinuous floodplain (10÷66% of the reach length) of any width, or presence of a continuous (> 66% of the reach length) but not sufficiently wide floodplain, that is, when the mean width (sum on the two sides) is ≤ 2 *W* in the case of single-thread channels (including sinuous with alternate bars), or ≤ 1 *W* in the case of multi-thread or wandering channels.
C	Absence of a floodplain or negligible presence (≤ 10 of the reach length of any width).

F3: Hillslopes – river corridor connectivity

DESCRIPTION

The linkage between hillslopes and river corridor is evaluated here in the case of confined channels, as this is very important for the natural supply of sediment and large wood. This is evaluated based on the presence and percentage on the reach length of elements of disconnection (e.g. roads) in a **strip conventionally 50 m wide for each river side**.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Plain/adjacent hillslopes
MEASUREMENTS: Remote sensing and field survey	

EXTENDED ANSWERS

TYPOLOGY	CONFINED
A	A full connectivity exists between hillslopes and river corridor (channel and floodplain), extending for most of the reach (> 90%).
B	The connectivity between hillslopes and river corridor exists for a significant portion of the reach (33÷90%).
C	The connectivity between hillslopes and river corridor exists for a small portion of the reach (≤ 33%).

F4: Processes of bank retreat

DEFINITION

Bank erosion is a key process contributing to sediment supply and recovery. An evaluation is necessary as to whether bank erosion processes occur as expected for a given river typology, or if there is a significant difference, such as absence due to widespread bank control, or excessive bank failures due to instability of the system (e.g. due to incision).

SPATIAL SCALE	
LONGITUDINAL: Site/Reach	*LATERAL*: Channel
MEASUREMENTS: Remote sensing and/or field survey	

EXTENDED ANSWERS

TYPOLOGY	SEMICONFINED- UNCONFINED
RANGE OF APPLICATION	NOT EVALUATED IN THE CASE OF STRAIGHT – SINUOUS CHANNELS WITH LOW ENERGY (LOWLAND PLAIN, LOW BED-SLOPE AND/OR BEDLOAD)
A	Frequent retreating riverbanks: bank erosion is observed in a number of points along the reach. Erosion is concentrated on the outer bank of bends (single-thread sinuous – meandering channels) and/or in front of bars (braided or wandering channels).
B	Retreating riverbanks less frequent than expected for a given channel morphology, because impeded by protective elements and/or scarce channel dynamics: erosion is observed locally and for limited lengths.
C	Complete absence or negligible presence (very localized erosion) of retreating riverbanks due to excessive human control (bank protection) and/or absent channel dynamics (except for reaches at low energy: see range of application). Or presence of unstable banks for mass movements (due to excessive bank height) very common along a predominant portion of the reach (very unstable reaches because of bed incision).

F5: Presence of a potentially erodible corridor

DEFINITION

The presence of a potentially erodible corridor is nowadays widely recognised as a positive attribute of rivers. A rapid assessment is performed by evaluating whether the width and longitudinal continuity of areas without relevant human structures or infrastructures (e.g. houses, roads) are within or out of given ranges.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Alluvial plain
MEASUREMENTS: Remote sensing	

EXTENDED ANSWERS

TYPOLOGY	SEMICONFINED OR UNCONFINED
A	Presence of a relatively continuous (> 66% of the reach length) and sufficiently wide potentially erodible corridor (EC), that is, the mean width (sum of the two sides) is at least twice the channel width (*W*) in the case of single-thread channels (including sinuous with alternate bars), or at least 1 *W*.
B	Presence of a potentially erodible corridor (EC) with medium continuity (33÷66% of the reach length) and width , that is, the mean width (sum of the two sides) is at least twice the channel width (*W*) in case of single-thread channels (including sinuous with alternate bars), or at least 1 *W*; or a potentially EC for > 66% of the reach length but not sufficiently wide.
C	Presence of a potentially erodible corridor (EC) of any width but with low continuity (≤ 33% of the reach length).

MORPHOLOGY

F6: Bed configuration – valley slope

DEFINITION

This indicator evaluates whether or not the presence of transversal structures has altered the expected bed configuration (cascade, step-pool, plane bed, riffle-pool, dune-ripple) based on the mean bed slope of the reach. In fact, a strong correlation exists between bed slope and configuration, that is, for increasing slopes the following order of forms is expected: dune-ripples, riffle-pool, plane bed, step-pool / cascade. These morphologies have ecological implications as each of them is characterized by a mosaic of typical habitats.

The existence of a transversal structure can cause an artificial lowering of the local energy slope and therefore a possible alteration of the bed configuration and, consequently, of the associated habitats. This indicator intends therefore to evaluate the magnitude of change caused by transversal structures.

SPATIAL SCALE	
LONGITUDINAL: Site/Reach	*LATERAL*: Channel
MEASUREMENTS: Field survey and Remote sensing	

This indicator is evaluated only in the case of single thread confined channels (in case of multi-thread or wandering channels, it is substituted by *F7*, therefore *F6* and *F7* are necessarily alternatives).

The operator should determine the mean valley slope along the reach (based on the longitudinal bed profile already used during the phase of segmentation), and then define the **expected bed form** according to *Table 1*.

Table 1 – Relations between range of bed slope and expected bed forms.

BED FORMS	**DOMINANT GRAIN SIZE**	**RANGE OF BED SLOPE**
Dune-ripple	Sand and fine gravel	≤ 0.2
Riffle-pool	Gravel and cobbles	< 2
Plane bad	Cobbles and gravel	1÷4
Step-pool/cascade	Boulders and cobbles	> 3

EXTENDED ANSWERS

TYPOLOGY	CONFINED
RANGE OF APPLICATION	APPLIED TO SINGLE-THREAD CHANNELS. NOT EVALUATED IN THE CASE OF CONFINED WITH BEDROCK, AND IN THE CASE OF DEEP STREAMS WHEN IT IS NOT POSSIBLE TO OBSERVE THE BED CONFIGURATION
A	Bed forms consistent with the mean valley slope: bed configuration corresponds to that expected, based on the mean valley slope along the reach (*Table 1*). Included in this class are also the morphologies imposed by natural factors (e.g. log steps, landslides, etc.) which locally can determine unexpected bed forms (e.g. riffles in a steep reach, etc.).
B	Bed forms not consistent with the mean valley slope: bed configuration does not correspond to that expected, based on the mean valley slope along the reach (*Table 1*), because of presence of transversal structures (dams, check dams, weirs, sills, ramps, etc.). Included in this class are also the morphologies imposed by natural factors (e.g. log steps, landslides, etc.) which locally can determine unexpected bed forms (e.g. riffles in a steep reach, etc.).
C	Complete alteration of bed forms: all cases in which the bed is completely artificial (revetments) or the distance between transversal structures is so close as to not allow the creation of natural bed forms. Generally this is the case when the scour pool downstream of each structure extends for a length > 40÷50% of the distance between two successive structures.

F7: Forms and processes typical of the channel pattern

DEFINITION

The aim of this indicator is to qualitatively assess whether the active processes and resultant forms expected for a given morphological type are present along the reach. For example, a channelized reach classified as meandering based on its planimetric configuration may not exhibit typical processes of that morphology.

SPATIAL SCALE	
LONGITUDINAL: Site/Reach	*LATERALE*: Channel
MEASUREMENTS: Field survey and/or remote sensing	

EXTENDED ANSWERS

TYPOLOGY	ALL
RANGE OF APPLICATION	IN THE CASE OF CONFINED CHANNELS IT IS APPLIED ONLY TO MULTI-THREAD OR WANDERING MORPHOLOGIES
A	Absence or negligible presence (< 5% of the reach length) of alteration of the natural heterogeneity of forms expected for that river type. *Braided:* typical presence of a multi-thread configuration with several bifurcations and longitudinal bars, frequent pioneer islands and some mature islands. *Wandering*: typical alternate side bars, chute cut-offs, low-water channel highly sinuous and relatively narrow within the bankfull channel, localized braiding phenomena, presence of pioneer islands and in some cases mature islands. *Sinuous with alternate bars*: typical alternate side bars, chute cut-offs, low-water channel highly sinuous and relatively narrow within the bankfull channel, succession of riffles and pools (except in sand-bed rivers). *Sinuous or meandering with bars*: side or point bars, frequent erosion of outer banks (particularly in meandering channels), possible chute cut-offs, succession of riffles and pools (except in sand-bed rivers). *Straight, sinuous or meandering at low energy*: they do not necessarily exhibit a significant heterogeneity of forms: they can be stable and with no bars.
B	Alteration for a limited portion of the reach (≤ 33% of the reach length) of the natural heterogeneity of forms expected for that river type.
C	Consistent alteration for a significant portion of the reach (> 33% of the reach length) of the natural heterogeneity of forms expected for that river type.

F8: Presence of typical fluvial forms in the alluvial plain

DEFINITION

This indicator is applied only to lowland meandering rivers, and accounts for the presence or not of typical fluvial forms (such as oxbow lakes, secondary channels, etc.) that are normally expected to exist in the alluvial plain.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Alluvial plain
MEASUREMENTS: Remote sensing	

EXTENDED ANSWERS

TYPOLOGY	SEMICONFINED OR UNCONFINED
RANGE OF APPLICATION	IT IS APPLIED ONLY TO MEANDERING CHANNELS (NOW OR IN THE PAST) OF LOWLAND PHYSIOGRAPHIC UNITS
A	Presence of natural fluvial forms in the alluvial plain related to the meandering channel dynamics (oxbow lakes, secondary channels, traces of abandoned meanders, wet zones, etc.).
B	Presence of traces of fluvial forms in the alluvial plain (abandoned after the 1950s), now not in connection with the present channel but with possible reactivation by recovery interventions.
C	Complete absence of fluvial forms in the alluvial plain related to the meandering channel dynamics.

F9: Variability of the cross-section

DEFINITION

This indicator accounts for the variability and heterogeneity of forms and surfaces in cross-section expected for a given channel morphology, and the percentage of the reach with altered conditions is evaluated.

SPATIAL SCALE	
LONGITUDINAL: Site/Reach	*LATERAL*: Channel
MEASUREMENTS: Field survey and remote sensing	

EXTENDED ANSWERS

TYPOLOGY	CONFINED
A	Absence or localized presence (≤ 5% of the reach length) of alteration of the cross-section natural heterogeneity along the entire reach: a natural variability of the cross section (channel width and depth) exists – in relation to the presence of bars, vegetation, boulders, influence of hillslopes – and/or presence of frequent zones of flow separation adjacent to the banks. Or presence of alteration only on one side for ≤ 10 % of the total length of the banks (that is, the sum of both banks) (except for large channels, i.e. $W > 30$ m).
B	Presence of alteration of the cross-section natural heterogeneity for a limited portion of the reach (≤ 33% of the reach length): a natural variability of the cross section (channel width and depth) exists for >66% of the reach length, and/or occasional zones of flow separation. Or presence of alteration only on one side for ≤ 66 % of the total length of the banks (that is, the sum of both banks) (except for large channels, i.e. $W > 30$ m).
C	Presence of alteration of the cross-section natural heterogeneity for a significant portion of the reach (> 33% of the reach length): the cross section is nearly homogeneous for a significant portion of the reach (> 33%), and/or absence of zones of flow separation adjacent to the banks. Or presence of alteration only on one side for > 66 % of the total length of the banks (that is, the sum of both banks) (except for large channels, i.e. $W > 30$ m).

TYPOLOGY		SEMICONFINED OR UNCONFINED
RANGE OF APPLICATION		NOT EVALUATED IN THE CASE OF STRAIGHT, SINUOUS OR MEANDERING CHANNELS WITH NATURAL ABSENCE OF BARS (LOWLAND RIVERS, LOW GRADIENTS AND/OR LOW BEDLOAD) (NATURAL CROSS-SECTION HOMOGENEITY)
A	Absence or localized presence (≤5% of the reach length) of alteration of the cross-section natural heterogeneity (width and depth) along the reach: a natural variability of channel width exists, in relation to the presence of bars and curvatures, combined with a natural altimetric variability in cross-section, in relation to the presence of side or point bars, eventual high bars, islands (pioneer or mature), secondary channels, and natural banks. Or presence of alteration only on one side for ≤ 10 % of the total length of the banks (that is, the sum of both banks) (except for large channels, i.e. W > 30 m).	
B	Presence of alteration of the cross-section natural heterogeneity (width and depth) for a limited portion of the reach (≤ 33% of the reach length); or presence of alteration only on one side for ≤ 66 % of the total length of the banks (that is, the sum of both banks) (except for large channels, i.e. W > 30 m).	
C	Presence of alteration of the cross-section natural heterogeneity (width and depth) for a significant portion of the reach (> 33%); or presence of alteration only on one side for > 66 % of the total length of the banks (that is, the sum of both banks) (except for large channels, i.e. W > 30 m).	

F10: Structure of the channel bed

DEFINITION

This indicator takes into account possible alterations of the bed sediment, such as armouring, clogging, substrate outcrops or bed revetments.

SPATIAL SCALE	
LONGITUDINAL: Site	*LATERAL*: Channel
MEASUREMENTS: Field survey	

There are differences between the cases of confined channels and semi- or unconfined channels. In the former case, armouring is not considered, as normally confined channels with a mobile bed (the indicator is not applied in the case of bedrock) have a naturally strong heterogeneity of sediments. Therefore, armouring is assessed only in the case of semiconfined and unconfined channels.

A field evaluation is necessary for this indicator. The evaluation is concentrated at the scale of the representative **site**, although additional checks at other sites of the reach can be considered. A quantitative assessment of armouring requires sediment sampling and measurements of the surface layer and sub-layer, which are beyond the scope of this procedure. Therefore **armouring**, as well as **clogging**, are **visually assessed**. Only cases of evident and widespread clogging or armouring are taken into consideration . For example, the presence of clogging can be normal in particular situations (e.g. in the pools or along a stream close to hillslopes composed of clay), but it is considered an alteration when it is evident and present in various portions of the site. Two cases are considered: (1) where armouring or clogging is well marked and evident in various portions of the site, but not widespread along most of it (class *B*); (2) where there is well marked and evident armouring or clogging along the entire site (> 90% of the site length) (class *C1*).

In the case of semiconfined and unconfined channels, an additional element of alteration is **bedrock outcropping**. However, it requires careful evaluation: it is to be considered as alteration only when it is evidently related to bed-incision, that is, in alluvial reaches with a mobile bed far from the hillslopes, while it has to be excluded in those cases with hillslopes not far from the channel and where they can represent natural outcrops.

EXTENDED ANSWERS

TYPOLOGY	CONFINED
RANGE OF APPLICATION	NOT EVALUATED FOR BEDROCK OR SAND-BED RIVERS, OR FOR DEEP RIVERS WHEN IT IS NOT POSSIBLE TO OBSERVE THE CHANNEL BED
A	Natural heterogeneity of bed sediments in relation to the different sedimentary units (steps, pools, riffles, etc.), with absence of or localized situations of clogging.
B	Evident clogging in various portions of the site.
C1	Evident and widespread clogging (> 90% of the site length).
C2	Widespread substrate alteration by bed revetments (any type) (> 33% of the reach length).

TYPOLOGY	SEMICONFINED OR UNCONFINED
RANGE OF APPLICATION	NOT EVALUATED FOR BEDROCK OR SAND-BED RIVERS, OR FOR DEEP RIVERS WHEN IT IS NOT POSSIBLE TO OBSERVE THE CHANNEL BED
A	Natural heterogeneity of bed sediments in relation to the different sedimentary units (bars, channel bed, pools, riffles, etc.) and also within the same unit, with absence of or localized situations of armouring and/or clogging.
B	Evident armouring or clogging in various portions of the site.
C1	Evident and widespread (> 90%) armouring or clogging, or occasional substrate outcrops (≤ 33% of the reach length) due to incision of the alluvial substrate.
C2	Widespread substrate outcrops (> 33% of the reach length) due to incision of the alluvial substrate or widespread substrate alteration by bed revetments (any type) (> 33% of the reach length).

F11: Presence of in-channel large wood

DEFINITION

An evaluation is carried out to determine whether altered conditions exist compared to the expected presence of large wood along the reach. Large wood includes trees, trunks, branches, butts having a length > 1 m and diameter > 10 cm. This material has several effects on geomorphic-hydraulic processes, and has various implications on ecological processes (habitat diversity, input of organic matter, etc.). On the other hand, it is widely recognized that this material represents an important hydraulic hazard factor.

SPATIAL SCALE	
LONGITUDINAL: Site	*LATERAL*: Channel
MEASUREMENTS: Field survey	

The indicator is evaluated for both types of streams (confined and semi- unconfined). Given the high spatial and temporal variability of the quantity of wood material, it is not possible to define precise values for the number of woody elements to observe. Reaches are evaluated as altered when the presence of wood is extremely limited or completely absent (approximately < 5 elements every 100 m of channel length).

The operator will carry out the evaluation based on **field observations** at the **spatial scale of the site**. In some cases (large channels), remote sensing images can be useful. The evaluation area includes the channel (including islands) and the banks (wood on the floodplain is not considered). Additional rules accounting for particular situations of natural scarcity of wood are reported at the end of the Extended answers. Lastly, the indicator is not evaluated for reaches above the tree-line or where riparian vegetation is completely absent due to natural factors in the reach and in the upstream reaches.

EXTENDED ANSWERS

TYPOLOGY	ALL
RANGE OF APPLICATION	NOT EVALUATED ABOVE THE TREE-LINE AND IN STREAMS WITH NATURAL ABSENCE OF RIPARIAN VEGETATION
A	Significant presence of large woody debris: the presence of large woody debris (plants, trunks, branches, butts) within the channel and/or on the banks.
C	Very limited presence or absence of large woody debris: when a significant presence of large woody debris is not observed within the channel (including islands) and/or on the banks.
*1) **In confined channels**: in the case of bankfull width > mean tree height, mean bankfull depth > mean tree diameter, and in the absence of significant obstacles (e.g. large boulders), class A is assigned (reach of wood transport: natural absence).* *2) **In semiconfined - unconfined**: in the case of the absence of bars (lowland plain), the relative abundance of woody debris has to be evaluated near the banks.*	

VEGETATION IN THE FLUVIAL CORRIDOR

The following two indicators (*F12* and *F13*) concern the vegetation existing in the **river corridor** that includes the adjacent areas extending from the channel to the hillslopes, and that is functional to the normal geomorphic processes (flow resistance, bank stabilization, wood recruitment, sediment trapping, etc.). No ecological considerations are made on the type of vegetation (i.e. invasive species, etc.). Plantations with an industrial purpose (e.g. populus, eucalyptus, paulownia, etc.) are considered as partially functional, as they are characterized by markedly lower densities and consequently do not fully carry out their geomorphic functions. Therefore, lower scores are assigned to this type of vegetation. Other plantations of woody vegetation (e.g. olive tree, grape vine, apple tree, etc.) are not considered as functional.

It is necessary that the vegetation is connected with the channel, in relation to the geomorphic processes considered here (erosion, flooding). Therefore, vegetation external to **artificial levees** is completely excluded, whereas vegetation external to bank protections is taken into consideration as it may interfere with a number of processes (flow resistance, flooding, wood supply, etc.). In the case of confined channels, **roads** interrupt this connection (similarly to the artificial levees for unconfined channels).

Indicators *F12* and *F13* are not applied above the natural tree-line, which is quite variable on Italian territory (approximately around 1,800 ÷2,300 m a.s.l.). In many cases, grazing has lowered this limit: in such a case, it is considered as an alteration. Lastly, the indicators are not evaluated in cases of particular climatic conditions (e.g. along "*fiumare*" in Mediterranean regions) where woody vegetation is not able to colonize the river corridor.

F12: Width of functional vegetation in the fluvial corridor

DEFINITION

This indicator assesses the width of functional vegetation directly connected with the channel. In the case of confined channels, the functional width is evaluated up to a distance of 50 m from each bank, excluding the cases of near vertical hillslopes or the presence of landslides, where woody vegetation may be naturally absent. In the case of semiconfined and unconfined channels, the width of functional vegetation is evaluated as a function of channel width.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Alluvial plain (semiconfined / unconfined); Plain/ adjacent hillslopes (confined)
MEASUREMENTS: Remote sensing	

The evaluation is carried out by **remote sensing** and **GIS** analysis, by delimitating the woody/shrub vegetation in the river corridor, up to the limit of 50 m in the case of confined channels. Note that any islands present within the channel are included in the computation.

EXTENDED ANSWERS

TYPOLOGY	ALL
RANGE OF APPLICATION	NOT EVALUATED ABOVE THE TREE-LINE AND IN STREAMS WITH NATURAL ABSENCE OF RIPARIAN VEGETATION
A	High width of functional vegetation, that is: - for *CONFINED CHANNELS*, functional vegetation occupying > 90% of adjacent plain (if present) and hillslopes (50 m from each bank, excluding portions with rock or landslides). The functional vegetation includes either woody species (with significant cover, i.e. > 33% of the width) and spontaneous shrub species. - for *SEMI- UNCONFINED CHANNELS*, functional vegetation with a total width (sum of the two sides) of at least *nLa*, where *La* is the channel width, *n* = 2 for single-thread channels, *n* = 1 for multi-thread or wandering channels. The functional width includes either woody and shrub species, with a significant presence of the former (> 33% of the width occupied by woody vegetation).
B	Medium width of functional vegetation, that is: - for *CONFINED CHANNELS*, functional vegetation occupying 33÷90% of adjacent plain (if present) and hillslopes (50 m from each bank, excluding portions with rock or landslides). Functional vegetation includes either woody species (with significant cover, i.e. > 33% of the functional width) and spontaneous shrub species. Or, as in case **A**, but with largely prevailing shrub species (i.e. woody vegetation ≤ 33% of the functional width). - for *SEMI- UNCONFINED CHANNELS*, functional vegetation with a total width (sum of the two sides) between 0.5 *La* and *nLa*, where La is the channel width, *n* = 2 for single-thread channels, *n* = 1 for multi-thread or wandering channels. Or, as in case **A**, but where the width > *nLa* is determined by the presence of partially functional species (e.g. artificial plantations of *populus*), or in the case of largely prevailing shrub species (i.e. woody vegetation ≤ 33% of the functional width).
C	Limited width of functional vegetation, that is: - for *CONFINED CHANNELS*, functional vegetation ≤ 33% of adjacent plain (if present) and hillslopes (50 m from each bank, excluding portions with rock or landslides). Functional vegetation includes either woody species (with significant cover, i.e. > 33% of the functional width) and spontaneous shrub species. Or, as in case **B**, but with largely prevailing shrub species (i.e. woody vegetation ≤ 33% of the functional width). - for *SEMI- UNCONFINED CHANNELS*, functional vegetation with a total width (sum of the two sides) ≤ 0.5 *La* (any channel typology), where La is the channel width. Or, as in case **B**, but where the width > 0.5 *La* is determined by the presence of partially functional species (e.g. artificial plantations of *populus*), or in the case of largely prevailing shrub species (i.e. woody vegetation ≤ 33% of the functional width).

F13: Linear extension of functional vegetation along the banks

DEFINITION

This indicator evaluates the longitudinal continuity of functional vegetation along the banks, as a percentage of the length covered by vegetation against the total length of the reach (both banks). Rows of trees for ornamental scopes are considered as partially functional, and they are assimilated to industrial plantations (see previous indicator).

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Banks
MEASUREMENTS: Remote sensing	

The evaluation is carried out by **remote sensing** and **GIS** analysis. The same delimitation of woody/shrub vegetation in the river corridor carried out for *F12* will be used, measuring the length (sum of the two banks) at direct contact with the channel. Then, this length will be compared to the total potential length (sum of the two banks) where functional vegetation can be present (i.e. excluding portions of banks with rock or landslides). In case of difficulties in the interpretation of remote images (confined channels), a check at the scale of the **site** may be required (e.g. to identify banks with rock).

EXTENDED ANSWERS

TYPOLOGY	ALL
RANGE OF APPLICATION	NOT EVALUATED ABOVE THE TREE-LINE OR IN STREAMS WITH NATURAL ABSENCE OF RIPARIAN VEGETATION
A	Linear extension of functional vegetation for a length > 90% of maximum available length (i.e. sum of both banks excluding those in rock or landslides). Presence of either woody species (> 33% of the length of functional vegetation) or spontaneous shrub species.
B	Linear extension of functional vegetation for a length of 33÷90% of maximum available length (i.e. sum of both banks excluding those in rock or landslides). Or, as in case **A**, but the extension > 90% is determined by the presence of partially functional species (e.g. industrial plantations of *populus* or rows for ornamental purposes), or in the case of shrub species largely prevailing (woody species < 33% of the length of the functional vegetation).
C	Linear extension of functional vegetation for a length of ≤ 33% of maximum available length (i.e. sum of both banks excluding those in rock or landslides). Or, as in case **B**, but the extension > 33% is determined by the presence of partially functional species (e.g. industrial plantations of *populus* or rows for ornamental purposes), or in the case of shrub species largely prevailing (woody species < 33% of the length of the functional vegetation).

ARTIFICIALITY

UPSTREAM ALTERATION OF LONGITUDINAL CONTINUITY

The first four indicators of artificiality consider the alteration of the driving variables for channel morphology, which are water discharges and sediment transport. It is useful to conceptually separate the alterations of the same variables occurring upstream and within the reach. Indicators *A1* and *A2* are the only two concerned with the conditions existing upstream (catchment location scale) of the analyzed reach, while the next two indicators *A3* and *A4* concern the alterations of the same characteristics, but within the reach.

For this purpose, in the case of a **structure** (e.g. a dam) **located at the limit between two reaches** (e.g. between an upstream reach *n1* and a downstream reach *n2*), **conventionally the structure is assigned to the one upstream**. In other terms, the effects of the structure are considered as alterations in the reach (by the indicators *A3* and *A4*) for the upstream reach *n1*, while they are accounted as upstream alterations (by the indicators *A1* and *A2*) for the downstream reach *n2*.

A1: Upstream alteration of discharges

DEFINITION

This indicator evaluates the possible alterations of channel-forming discharges and/or discharges with higher return intervals due to interventions at the catchment scale (dams, diversions, spillways, retention basins, etc.).

SPATIAL SCALE	
LONGITUDINAL: Catchment	*LATERAL*: Alluvial plain
MEASUREMENTS: Census of interventions, remote sensing	

Identification of existing interventions having effects on discharges can be carried out by a census of interventions and remote sensing. This indicator also requires data and information about the management of the structures (e.g. dams) and their effects on discharges. This can be achieved from agencies in charge of the river management. Note that this type of information and hydrologic data collected at the catchment scale is an essential part of the **Phase 1** (*general setting-up*), and this knowledge is then used for all the reaches of a given catchment.

Also note that this indicator can be estimated starting from the data required to calculate the Hydrological Regime Alteration Index, ***IARI***, which provides a measure of the deviation between the observed hydrological regime and the natural regime in the absence of human intervention. The index *IARI* is obtained, dependent on available river discharge data quality and consistency, by comparing the daily and/or monthly discharges actually flowing through the cross section and the corresponding natural discharges. The integration of morphological and hydrological aspects allows for a complete definition and classification of stream hydromorphology.

To evaluate the indicator A1, **two classes of discharge** are considered: (1) channel-forming discharges; (2) discharges with a return interval > 10 years.

(1) **Channel-forming discharges**. These are intended as the discharges having the most relevant effects on channel morphology. A value of $Q_{1.5}$ is used here to represent the channel-forming discharges, however the range of discharges with important effects on channel morphology can be widened to return intervals of the order of 10 years. In fact, in braided or wandering morphologies, there are different values which can affect channel form, with islands being modelled by discharges with return interval up to 10 years. Furthermore, in case of steep and armoured mountain streams, only the discharges with return periods > 2÷3 years are able to determine relevant processes of sediment transport, and the morphological channel configuration is determined by even higher discharges.

(2) **Discharges with return interval (*RI*) >10 years**. These also have relevant morphological and hydraulic effects, although their effect on channel morphology is lower than the channel-forming discharges. There are interventions which only have an effect on discharges with a high return interval, as they are designed to start working only above a given threshold (e.g. spillways, retention basins, some dams).

Data needed for estimating the discharges with given return intervals, and information to evaluate the effects of interventions on such discharges, are often not available. Therefore, **two procedures** can be considered, as follows.

<u>1. Data available.</u>

It is necessary to evaluate if and how much any interventions existing upstream in the catchment produce alterations on the channel-forming discharges and/or discharges with return interval >10 years.

(1) **Channel-forming discharges**. Estimation of $Q_{1.5}$ *ante* or *post operam* (or of other *Q* with *RP* between 1.5 and 10 years) can be obtained by a statistical analysis of a sufficiently long series of maximum annual peak discharges, from the closest gauging station to the reach, or on the basis of rainfall – runoff models or models of regionalization of discharges (these estimations are often available at the public agencies responsible for the river management). Normally, this analysis is performed only on the $Q_{1.5}$, but in some cases (e.g. braided rivers or mountain streams) further analysis on discharges with *RP* = 10 years may be necessary. When there are significant changes (> 10%) in these discharges due to artificial interventions, the reach is assigned to class *C*.
   - *Example*. In the reach it is found that $Q_{1.5}$ = 300 m^3/s and a reservoir existing upstream has the effect of reducing this discharge by about 60 m^3/s.

(2) **Discharges with *RP* > 10 years**. In the case of interventions upstream working for this class of discharge and producing significant changes (> 10%), the reach is assigned to class *B*.
   - *Example*. Presence of a retention basin upstream designed to work only for discharges with *RP* > 20 years, and producing a reduction of 30 m^3/s, compared to a Q_{20} estimated to be about 150 m^3/s.

<u>EXTENDED ANSWERS</u>

TYPOLOGY	ALL
A	Absence of interventions altering water discharges (dams, spillways, diversions, retention basin, etc.) or interventions however with no significant effects (induced changes ≤ 10%) on channel-forming discharges and on discharges with *RP* > 10 years.
B	Presence of interventions (dams, spillways, diversions, retention basin, etc.) having significant effects (induced changes > 10%) on discharges with *RP* > 10 years, but with no significant effects (≤ 10%) on channel-forming discharges.
C	Presence of interventions (dams, spillways, diversions, retention basin, etc.) having significant effects (induced changes > 10%) on discharges with *RP* > 10 years and on channel-forming discharges.

2. Data not available

In such a case, a **simplified procedure** is adopted that is based on the typology of intervention and on available information about its use (e.g. dam for hydroelectric production or for retention purposes), described as follows.

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence of interventions altering water discharges or existence of interventions, but with no effects on channel-forming discharges and discharges with higher return intervals.
B	Presence of dams (watershed area > 5% of the reach drainage area) with retention of peak discharges, or spillways or retention basins functioning only for infrequent discharges (*RI* > 10 years).
C	Presence of dams (watershed area > 5% of the reach drainage area) with retention of peak discharges, or spillways or retention basins functioning also for relatively frequent discharges (*RI* < 10 years).

A2: Upstream alteration of sediment discharges

DEFINITION

An indirect evaluation of the alterations in sediment transport is obtained based on the existence in the catchment of main structures of bedload interception (dams, check dams, weirs) and in function of their drainage area compared to the reach drainage area.

SPATIAL SCALE	
LONGITUDINAL: Catchment	*LATERAL*: Channel
MEASUREMENTS: Census of interventions, remote sensing	

The degree of alteration in sediment discharges is evaluated as a function of two aspects: (1) the type of structure and its impact on bedload (i.e. full interception or partial interception, depending on the sediment filling); (2) the ratio between the drainage area upstream of the structures and the drainage area of the watershed at the section of the reach closure. Furthermore, some differences exist depending on the physiographic context (mountain areas, hilly areas, lowland).

Concerning the **typology of structures**, the following three cases are considered:

- **(*T1*) Dams**. They create a complete and permanent (in a future perspective) interception of bedload (except in the cases of measurements of sediment release downstream, which are accounted for).
- **(*T2*) Structures with total interception of bedload**. These determine a complete interception (e.g. not filled check dams of a significant size), but their impact is considered to be lower than dams, because of their temporary effect (until they are filled).
- **(*T3*) Structures with partial or no interception of bedload**. These are smaller sized structures , often with the purpose of bed stabilization rather than sediment retention, or also bigger structures (check dams) with the purpose of sediment retention but now completely filled by sediment.

Concerning the **drainage area** upstream of the structures as opposed to that upstream of the reach, the following cases are considered:

(1) ***As* ≤ 5% *Ar***, that is the area upstream the from structures (*As*) is smaller than 5% of the area upstream of the reach (*Ar*) (e.g. a dam upstream with a drainage area of 40 km^2 compared to a drainage area of the reach of 500 km^2);

(2) 5**% *Ar* < *As* ≤ 33% *Ar***, that is the area upstream from the structures (*As*) is between 5% and 33% of the area upstream the reach (*Ar*) (e.g. a dam upstream with a drainage area of 40 km^2 compared to the reach’s drainage area of 400 km^2);

(3) **33% *Ar* < *As* ≤ 66% *Ar***, that is the area upstream from the structures (*As*) is between 33% and 66% of the area upstream of the reach (*Ar*) (e.g. a dam upstream with a drainage area of 120 km^2 compared to the reach’s drainage area of 200 km^2);

(4) ***As* > 66% *Ar***, that is the area upstream from the structures (*As*) is > 66% of the area upstream from the reach (*Ar*) (e.g. a dam upstream with a drainage area of 150 km^2 compared to the reach’s drainage area of 200 km^2);

(5) The structure is located at the **upstream limit of the reach**.

The differences depending on the physiographic context are described as follows.

1. Mountain areas.

Structures included in the **category T2** are **check dams with total sediment retention** (retention check dams: usually of large dimensions). Usually these structures are characterized by a small reservoir immediately upstream. Included in this category are also **abstraction weirs** of **relevant size** (in the order of various meters), which are **not filled**, and which have the effect of a temporary complete interception (until filling) of bedload.

Structures included in the **category T3** can be identified with **filled retention check dams**, **open check dams**, and **consolidation check dams**. The latter are considered only when they are a long **sequence of stepped check dams**, determining the stabilization of the longitudinal bed profile. The drainage area is referred to the check dam furthest downstream. Therefore, isolated consolidation check dams that are unable to significantly reduce the upstream sediment supply are not considered.

Assignation to the alteration class as a function of typology and drainage areas is reported in *Table 2*.

Table 2 – Definition of classes in mountain areas.

TYPOLOGY \ As/Ar	**5÷33%**	**33÷66%**	**> 66%**	**UPSTREAM LIMIT**
(T1) Dams	*B1*	*B2*	*C1*	*C2*
(T2) Check dams with total sediment retention	*A*	*B1*	*B2*	*B2*
(T3) Filled or open check dams or sequence of consolidation check dams	*A*	*A*	*B1*	*B1*

2. Hilly and lowland areas.

Structures included in the **category T2** can be identified with **consolidation check dams or abstraction weirs** of **relevant size** (in the order of several meters), which are **not filled**, and which have the effect of temporary complete interception (until filling) of bedload.

Structures in the **category T3** include **consolidation check dams or abstraction weirs**, but of a **smaller size**, or of a bigger size but **filled** with sediment.

Assignation to the alteration class as a function of typology and drainage areas is reported in *Table 3*.

Table 3 – Definition of classes in hilly or lowland areas.

TYPOLOGY \ As/Ar	**5÷33%**	**33÷66%**	**> 66%**	**UPSTREAM LIMIT**
(T1) Dams	*B1*	*B2*	*C1*	*C2*
(T2) Consolidation check dams or abstraction weirs (big in size) with complete interception	*A*	*B1*	*B2*	*B2*
(T3) Consolidation check dams or abstraction weirs with partial or no interception (or small in size)	*A*	*B1*	*B1*	*B1*

Measures of sediment release or removal.

In the case of **measures of sediment release downstream from a dam** (or other structure), the score is reduced according to the following rules (in any physiographic context):

(1) Measures allowing for the flux *of all bedload downstream* (complete by-pass): two classes lower are assigned (e.g. from *C2* to *B2*, or from *B1* to *A*).

(2) Measures allowing for a *high but not total bedload flux downstream*: a class lower is assigned (e.g. from *C2* to *C1*).

Vice versa, if the maintenance agency in charge of a structure carries out a periodic **sediment removal upstream from a check dam** (that is not released downstream) in order to prevent it from filling completely, the structure is considered as causing a complete interception of bedload (*T2*).

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence of structures that can alter the normal flux of sediment along the hydrographic network, or presence of weirs and/or dams but with no significant effects. Dams are considered as not significant when *As* ≤ 5% *Ar*, i.e. the area upstream from the structures (*As*) is lower than 5% of the area upstream from the reach (*Ar*). Other structures are considered as not significant when *As* ≤ 33% *Ar*.
B1	Presence of a dam (*any physiographic context*) for 5% *Ar* < *As* ≤ 33% *Ar*. - *Mountain areas*: one or more check dams not filled for 33% *Ar* < *As* ≤ 66% *Ar*, or one or more open or filled check dams or a sequence of consolidation check dams for *As* > 66% *Ar*. - *Hilly or plain areas*: one or more consolidation check dams or abstraction weirs with complete interception (large sizes) for 33% *Ar* < *As* ≤ 66% *Ar*, or one or more consolidation check dams or abstraction weirs with partial or no interception for *As* > 33% *Ar*.
B2	Presence of a dam (*any physiographic context*) for 33% *Ar* < *As* ≤ 66% *Ar*. - *Mountain areas*: one or more check dams not filled for *As* > 66% *Ar* or at the upstream reach limit. - *Hilly or plain areas*: one or more consolidation check dams or abstraction weirs with complete interception (large sizes) for *As* > 66% *Ar* or at the upstream reach limit.
C1	Presence of a dam (*any physiographic context*) for *As* > 66% *Ar*.
C2	Presence of a dam at the upstream reach limit (*any physiographic context*).
Measures of sediment release downstream*: in case of measures allowing for the flux of all bedload downstream (complete by-pass), the structure is assigned to two classes lower. in case of measures allowing for a high but not total bedload flux downstream, the structure is assigned to one class lower.*	

ALTERATION OF LONGITUDINAL CONTINUITY IN THE REACH

A3: Alteration of discharges in the reach

DEFINITION

This is evaluated in the same way as *A1*, but refers to interventions along the reach. Interventions include spillway, diversions, and retention basins. Dams are excluded as they are necessarily identified with the limit of a reach, therefore their effects in terms of the alteration of discharges is evaluated in the reach downstream

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Alluvial plain
MEASUREMENTS: Census of interventions, remote sensing	

All the considerations made for A1 are applied to this indicator, including two procedures (data available or not available), as follows.

1. Data available.

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence of interventions altering water discharges (spillways, diversions, retention basin, etc.) or interventions but with no significant effects (induced changes ≤ 10%) on channel-forming discharges and on discharges with *RP* > 10 years.
B	Presence of interventions (spillways, diversions, retention basin, etc.) having significant effects (induced changes > 10%) on discharges with *RP* > 10 years, but with no significant effects (≤ 10%) on channel-forming discharges.
C	Presence of interventions (spillways, diversions, retention basin, etc.) having significant effects (induced changes > 10%) on discharges with *RP* > 10 years and on channel-forming discharges.

2. Data not available.

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence of interventions altering water discharges or existence of interventions, but with no effects on channel-forming discharges and discharges with higher return intervals.
B	Presence of spillways, diversions or retention basins functioning only for infrequent discharges (*RP* > 10 years).
C	Presence of spillways, diversions or retention basins functioning also for relatively frequent discharges (*RP* < 10 years).

A4: Alteration of sediment transport in the reach

DEFINITION

This is based on the typology and frequency of structures intercepting bedload in the reach (check dams, weirs, diversion structures, etc.) or other structures causing its alteration (e.g. retention basins, dam downstream).

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Channel
MEASUREMENTS: Census of interventions, Remote sensing, Field survey	

In the case of a **dam located at the downstream limit of the reach**, as previously explained, its effects in terms of bedload interceptions are considered in the downstream reach by the indicator *A2*. However, the dam also alters the normal bedload flux for the portion of the reach immediately upstream from the structure (class *C*), by decreasing flow velocity and inducing sedimentation. If the artificial reservoir due to the dam is of a relevant size, it will not be subject to the assessment procedure (because the stream will have completely changed its original characteristics). Relevant size is normally intended to be equivalent to the spatial scale of a site (i.e. length not lower than 10 times the channel width). For reservoirs of a smaller size, they are included within the stream reach.

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence of any type of structures altering sediment discharges: there are no structures in the reach aimed to intercept sediment and wood (check dams, abstraction weirs, etc.) or which cause an alteration of sediment discharges (retention basins, dam downstream) although not designed for this purpose.
B	- *Mountain areas (confined channels, or semi- unconfined steep channels, e.g. along alluvial fans):* consolidation check dams with relatively low density (≤ 1 every 200 m on average in the reach) and/or one or more open check dams. - *Hilly – plain areas:* one or more consolidation check dam and/or abstraction weirs (≤ 1 every 1000 m on average in the reach).
C	- *Mountain areas* (confined channels, or semi- unconfined steep channels, e.g. along alluvial fans): consolidation check dams with relatively low density (>1 every 200 m on average in the reach) and/or one or more check dams. - *Hilly – plain areas*: one or more consolidation check dam and/or abstraction weir (>1 every 1000 m on average in the reach) and/or presence of a dam. And/or artificial reservoir at the downstream reach limit (*any physiographic context*).
If the total density of transversal structures, including bed sills and ramps (see A9) is very high, i.e. > 1 every 100 m in mountain areas, or >1 every 500 m in hilly – plain areas, add 12.	

A5: Crossing structures

DEFINITION

This accounts for the presence and frequency of crossing structures, including bridges, fords, and culverts. Only **bridges** which interfere with the fluvial corridor are considered, that is, those bridges with some artificial element (piers or abutment) in the channel or adjacent plain, or potentially interfering with water fluxes although for exceptional flood events only. Bridges that are completely unrelated to the fluvial corridor are not counted (e.g. a viaduct crossing a valley markedly higher than the channel and with piers and/or abutments standing directly on hillslopes). Regarding **fords**, only those with fixed crossing structures are accounted for here (i.e. dirt roads are not considered). Finally, the cases where streams cross urban areas underground are considered as **culverts**.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Channel
MEASUREMENTS: Remote sensing, topographic maps, field survey	

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence of crossing structures (bridges, fords culverts).
B	Presence of some crossing structures (≤ 1 every 1000 m on average in the reach).
C	Presence of many crossing structures (> 1 every 1000 m on average in the reach).

ALTERATION OF LATERAL CONTINUITY

A6: Bank protections

DEFINITION

Various types of bank protection are considered, including walls, gabions, groynes, and bioengineering bank stabilizations. The indicator is based on the percentage of protected banks over the total length (sum of both banks).

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Banks
MEASUREMENTS: Census of interventions, remote sensing, field survey	

Only bank protections along the bank lines (which are the limits of the bankfull channel) or in the close surroundings are considered: bank protections built in past periods, at present far from the channel and therefore having no immediate effects on channel mobility are not assessed (they may be considered in the indicator *F5*, having the effect of limiting the erodible corridor).

A particular case is that of the **groynes**. Similarly to the previous rule, only groynes in contact or within the channel are considered. In the latter case, an evaluation of the greater size between the groyne width and the protruding length is obtained (generally from aerial photos).

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence or localized presence of bank protections, i.e. for a length ≤ 5% total length of the banks (sum of both banks).
B	Presence of protections for ≤ 33% total length of the banks (sum of both banks).
C	Presence of protections for > 33% total length of the banks (sum of both banks).
In the case of bank protections along most of the reach (i.e. >80% of total length of the banks) add 12.	

A7: Artificial levees

DEFINITION

This indicator accounts for the presence of artificial levees (or embankments). It is based on their longitudinal continuity and distance from the channel.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Alluvial plain
MEASUREMENTS: Remote sensing, topographic maps, field survey	

Regarding the **length**, the percentage of the artificial levee's length over the total length of the banks is considered (similarly to the previous indicator) though, in this case, the length of banks directly in contact with hillslopes is excluded. Regarding the **distance**, three possible cases are considered: (1) "*distant*" (set-back embankments): in case of distance > of the mean channel width (*W*); (2) "*close*": in case of distance ≤ *W*; (3) "*in contact*": when they are immediately in contact with the top of the bank, or maximum at a distance of the same order of magnitude as the bank height. Selection of the class is made according to the extended answers and *Table 4*. Note that the calculation is made separately for the two river sides: e.g. in the case of a left bank with 100% in contact and a right bank with 20% in contact and 80% close, the total in the reach will be 60% in contact and 40% close.

In the case of **two artificial levee systems**, the distance will be referred to the levees closest to the channel.

Table 4 – Definition of classes as a function of the length of levees *in contact* and *close* (in % over the total length of both banks).

CLASS	IN CONTACT + CLOSE [%]	IN CONTACT [%]
A	0÷10	0÷10
B	10÷90	0÷50
	90÷100	0÷33
C	50÷90	50÷90
	90÷100	33÷100

EXTENDED ANSWERS

TYPOLOGY	SEMICONFINED OR UNCONFINED
A	Levees absent or distant (i.e. distance > *W*) for any length, or localized presence of close levees and/or in contact (≤ 10% of the total length of the banks).
B	Close levees and/or levees in contact for > 10% of the total length of the banks, including the following cases: (*a*) levees in contact for ≤ 50% (independently from % of close levees); (*b*) if the total length of close levees plus those in contact is > 90%, then levees in contact must be ≤ 33% of the total length of the banks.
C	Close levees or levees in contact not included in the previous class, that is: (*a*) levees in contact > 50% (independently by % of close levees); (*b*) total length close and in contact levees > 90%, with levees in contact > 33% of the total length of the banks.
In the case of artificial levees along most of the reach (i.e. > 80% of total length of the banks) add 12.	

ALTERATION OF CHANNEL MORPHOLOGY AND/OR SUBSTRATE

A8: Artificial changes of river course

DEFINITION

This indicator accounts for historical changes in the river course. It has to be remarked that this indicator does not require a historical research of channel changes, which would be out of the range of this evaluation, but only well known and relevant changes should be considered (e.g. meander cut-off, change of position of river mouth, etc.).

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Alluvial plain
MEASUREMENT: Historical sources and/or remote sensing	

EXTENDED ANSWERS

TYPOLOGY	SEMICONFINED OR UNCONFINED
A	Absence of artificial changes of river course in the past (meanders cut-off, channel diversions, etc.);
B	Presence of artificial changes of river course in the past for ≤ 10% of the reach length;
C	Presence of artificial changes of river course in the past for > 10% of the reach length.

A9: Other grade control structures

DEFINITION

With this indicator other crossing structures (bed sills, ramps) and revetments of the channel bed are considered, accounting for their frequency or percentage and typology (permeable or impermeable) respectively for sills/ramps and revetments.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Channel
MEASUREMENTS: Census of interventions, remote sensing, field survey	

EXTENDED ANSWERS

TYPOLOGY	ALL
A	Absence of other bed stabilization structures (bed sills, ramps) and/or localized revetments (≤ 5% of the reach length) not altering significantly the vertical continuity and bed structure.
B	Presence of bed sills and/or ramps with relatively low density, i.e. ≤ 1 every *n* m on average along the reach, where *n* = 200 for confined and mountain semi- unconfined streams (e.g. piedmont alluvial fans) or *n* = 1000 for semi- unconfined streams of lowland plains or hilly areas, and/or limited presence of revetments: bed revetments occupy a length ≤ 25% of the reach with permeable systems and/or ≤ 15% with impermeable systems.
C1	Presence of bed sills/ramps with a density of > 1 every *n* m on average in the reach and/or significant presence of revetments: bed revetments occupy a length ≤ 50% of the reach with permeable systems and/or ≤ 33% with impermeable systems.
C2	Widespread presence of revetments: bed revetments occupy a length > 50% of the reach with permeable systems or > 33% with impermeable systems.
1) *If the density of transversal structures, including check dams and abstraction weirs (see A4) is extremely high, i.e. >1 every 100 m for confined and mountain semi- unconfined streams, or >1 every 500 m for semi-unconfined streams of lowland plains or hilly areas, add 12.* 2) *If bed revetments (either permeable and impermeable) occupy most of the reach length (i.e. >80 %), add 12.*	

INTERVENTIONS OF MAINTENANCE AND REMOVAL

A10: Sediment removal

DEFINITION

This indicator aims to provide an evaluation on the existence and relative intensity of sediment mining activity.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Channel
MEASUREMENTS: Census of interventions, remote sensing, field survey	

The evaluation is slightly different from **confined** to **semi- unconfined channels**. In the former case, the investigated time period is exclusively that of the **last 20 years** (coherently with the following two indicators). The difference between the three classes is determined by the extension of any removal activity (absent, localized, widespread in the reach) during this time period. In the case of semi- and unconfined channels, two time periods are distinguished: (a) recent activity (last 20 years, as for confined channels); (b) **past activity**, extended to the 1950s (generally the decade of maximum activity in many areas of Italy). Regarding past activity, the indicator intends to provide a gross evaluation based on available information, since a quantification of extracted volumes is not possible. To this aim, **three situations** are considered: (1) absent; (2) moderate: when there is reliable information that the number of mining sites and the extracted volumes are significant (not negligible) but not high; (3) intense: when there is reliable information that the number of mining sites and the extracted volumes are particularly relevant. Indirect indicators of intense activity may be the number of mining sites nowadays or in the past (from aerial photos of the 1950s) in the surroundings of the river channel, intense incisions (see *V3*) that are attributable to mining activity, etc.

EXTENDED ANSWERS

TYPOLOGY	CONFINED
A	Evidence/reliable information of absent significant sediment removal activity during the last 20 years.
B	Evidence/reliable information of significant but localized (only one site) sediment removal activity during the last 20 years.
C	Evidence/reliable information of significant and widespread (more sites along the reach) sediment removal activity during the last 20 years.

TYPOLOGY	SEMICONFINED OR UNCONFINED
A	Absence of significant sediment removal activity either in the past (from 1950s) or during about the last 20 years.
B	Moderate sediment removal activity in the past (from 1950s) but absent during about the last 20 years, or sediment removal activity during the last 20 years but absent in the past.
C	Intense sediment removal activity in the past (from 1950s), or sediment removal activity during the last 20 years and moderate in the past (from 1950s).

A11: Wood removal

DEFINITION

Wood removal can periodically be carried out by various public agencies in charge of river management and maintenance, usually in conjunction with cutting vegetation (see next indicator) and/or sediment removal. Typically, only larger sized woody material is removed, while fine woody debris (small trunks, branches) is left in the channel.

Wood removal is justifiable for safety reasons, however has a significant impact on the fluvial system (e.g. reduction of hydrodynamic complexity, and therefore morphological and sedimentary diversity, with the disappearance of physical habitats for fishes and invertebrates).

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Channel and floodplain
MEASUREMENTS: Information by public agencies	

For this indicator, it is necessary to acquire information on total or partial wood removal during the last 20 years. This time interval is motivated both by the availability of information from public agencies, and by the natural capability of streams to once again achieve a sufficient quantity of wood from the banks, hillslopes and upstream reaches. In case of a lack of reliable information, the answer is *B*. Cases where *F11* has not been applied are not evaluated.

EXTENDED ANSWERS

TYPOLOGY	ALL
RANGE OF APPLICATION	NOT EVALUATED ABOVE THE TREE-LINE AND IN STREAMS WITH NATURAL ABSENCE OF RIPARIAN VEGETATION
A	Reliable information/evidence of the absence (or only in localized situations) of interventions for the removal of large wood (diameter > 10 cm and length > 1 m), at least in the last 20 years.
B	Reliable information/evidence of partial removal interventions during the last 20 years, that is, the removal of some elements only, often following flood events. Here are also included the cases of permission for removal by private citizens, even without any intervention from public agencies. Some woody material could be cut into elements < 1 m and left within the channel.
C	Reliable information/evidence of removal interventions by public agencies during the last 20 years. Some woody material could be cut into elements < 1 m and left within the channel.

A12: Vegetation management

DEFINITION

Similarly to the previous indicator, periodic interventions of vegetation cutting by public agencies are motivated by safety reasons, but they have various impacts on the natural processes related to riparian vegetation. In order to reduce such impacts, public agencies are recently oriented towards selective cutting (involving only the oldest trees) rather than a total removal. Note that grazing activity is here assimilated to vegetation cutting, as it prevents vegetation growth.

SPATIAL SCALE	
LONGITUDINAL: Site/Reach	*LATERAL*: channel and portions of alluvial plain (semi-unconfined) adjacent to the banks, or adjacent plain / hillslopes (confined)
MEASUREMENTS: Information from public agencies and field site check (presence of butts)	

The operator has to collect information from the public agencies responsible for the vegetation management, and to observe in the field any possible evidence of past cuttings (i.e. presence of butts). The indicator is applied in the case of significant cutting activity (just a few plants cut along the reach are not considered). The investigated area corresponds to the width of functional vegetation identified with the indicator *F12*. For the same reasons as for the previous indicator, the time interval considered includes the last 20 years. The indicator is not applied for those reaches where *F12* and *F13* have not been evaluated.

EXTENDED ANSWERS

TYPOLOGY	ALL
RANGE OF APPLICATION	NOT EVALUATED ABOVE THE TREE-LINE AND IN STREAMS WITH NATURAL ABSENCE OF RIPARIAN VEGETATION
A	Vegetation not subject to cutting interventions along the banks, or only affected by selective cutting within the areas external to the banks (alluvial plain for semi- unconfined, hillslopes for confined) during the last 20 years.
B	Vegetation subject to interventions of selective cutting along the banks for any distance, or total cutting for a length < 50% of the reach; or total cuttings of any distance within the areas external to the banks (last 20 years).
C	Vegetation subject to total cutting along the banks for a distance > 50% of the reach during the last 20 years.

CHANNEL CHANGES

V1: Changes in channel pattern

DEFINITION

This indicator (and the following *V2*) is based on observation and analysis of aerial photos from the 1950s, compared to the most recent aerial photos. It evaluates whether there has been a change in the morphological type.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Alluvial plain
MEASUREMENTS: Remote sensing / GIS analysis	

As for all the indicators of channel changes, it is applied only to large channels (width > 30 m, at present or in the 1950s). In Italy, aerial photos of the 1950s correspond to the flight IGM GAI covering the entire national territory, at a scale of about 1:33,000. In other countries, flights from the same period can be used. It applies both to confined and semi- unconfined, although some differences in the classes exist.

In the cases of semi- unconfined channels, the assignation to classes *B* or *C* depends on whether the change has occurred between similar morphologies (e.g. from meandering to sinuous) or between markedly different morphologies (e.g. from braided to sinuous), as defined in *Table 5*.

Table 5 – Classes for the different possible changes in channel morphologies. MORPHOLOGIES: *ST* = straight, *S* = sinuous, *M* = Meandering, *SAB* = Sinuous with Alternate Bars, *W* = Wandering, *B* = Braided, *A* = Anastomosed; ⇔ = change in both directions. CLASS: *B* = change to a similar morphology; *C* = change to a markedly different morphology.

MORPHOLOGY	CLASS	MORPHOLOGY	CLASS
ST ⇔ S	*B*	*M ⇔ SAB*	*B*
ST ⇔ M	*C*	*M ⇔ W*	*C*
ST ⇔ SAB	*B*	*M ⇔ B*	*C*
ST ⇔ W	*C*	*M ⇔ A*	*B*
ST ⇔ B	*C*	*SAB ⇔ W*	*B*
ST ⇔ A	*C*	*SAB ⇔ B*	*C*
S ⇔ M	*B*	*SAB ⇔ A*	*C*
S ⇔ SAB	*B*	*W ⇔ B*	*B*
S ⇔ W	*C*	*W ⇔ A*	*C*
S ⇔ B	*C*	*B ⇔ A*	*C*
S ⇔ A	*B*		

EXTENDED ANSWERS

TYPOLOGY	CONFINED
RANGE OF APPLICATION	EVALUATED ONLY FOR LARGE CHANNELS (CHANNEL WIDTH > 30 m)
A	Absence of changes of channel pattern from 1950s.
B	Change of channel pattern from 1950s.

TYPOLOGY	SEMICONFINED OR UNCONFINED
RANGE OF APPLICATION	EVALUATED ONLY FOR LARGE CHANNELS (CHANNEL WIDTH > 30 m)
A	Absence of changes of channel pattern from 1950s.
B	Change to a similar channel pattern from 1950s (*Table 5*).
C	Change to a different channel pattern from 1950s (*Table 5*).

V2: Changes in channel width

DEFINITION

This indicator evaluates the occurrence and amount of changes in channel width from the 1950s to now.

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Alluvial plain
MEASUREMENTS: Remote sensing / GIS analysis	

As for the previous indicator, this indicator is applied only to large channels (width >30 m, at present or in the 1950s), both to confined and semi- unconfined, although some differences in the classes exist. In confined channels, only two classes are defined (in fact significant change in channel width would determine a change to an unconfined channel). The precise measurement of changes in channel width requires a GIS analysis, including the georectification of the different images, the digitizing of channel margins and the measurement of the channel width.

EXTENDED ANSWERS

TYPOLOGY	CONFINED
RANGE OF APPLICATION	EVALUATED ONLY FOR LARGE CHANNELS (CHANNEL WIDTH > 30 m)
A	Absent or limited changes in channel width (≤ 15%) from 1950s.
B	Changes in channel width > 15% from 1950s.

TYPOLOGY	SEMICONFINED OR UNCONFINED
RANGE OF APPLICATION	EVALUATED ONLY FOR LARGE CHANNELS (CHANNEL WIDTH > 30 m)
A	Absent or limited changes in channel width (≤ 15%) from 1950s.
B	Moderate changes in channel width (15÷35%) from 1950s.
C	Intense changes in channel width (> 35%) from 1950s.

V3: Bed-level changes

DEFINITION

Bed-level changes (incision or aggradation) are considered among the most relevant physical alterations affecting a number of processes (e.g. lateral connection with floodplain, alteration of in-channel habitats, etc.).

SPATIAL SCALE	
LONGITUDINAL: Reach	*LATERAL*: Channel
MEASUREMENTS: Data from cross-sections / longitudinal profiles, field survey	

Similarly to *V1* and *V2*, this indicator applies only to large channels (width > 30 m), both to confined and semi- unconfined with some differences. In the case of semi- unconfined channels, a class *C2* is defined to account for cases of dramatic changes in bed elevation (> 6 m). Small-sized mountain streams may experience intense bed-level changes during exceptional flood events; however this indicator is not envisaged for such streams, coherently with the other two indicators of channel changes. This indicator is based on existing data (e.g. longitudinal profiles or cross sections), information from existing literature, and field evidence of bed-level changes. Differently from planimetric changes, in this case bed-level changes are referred to a wider temporal scale, i.e. about the last 100 years. This is due to the fact that, according to existing research on a national scale (e.g. SURIAN & RINALDI, *2003*; SURIAN *et al., 2009d*), one or more phases of incision followed by a period of predominant aggradation or equilibrium occurred until about the end of the 19th century. This simplification allows a better utilization of field evidence, consisting of an evaluation of the differences in elevation between modern floodplain and recent terraces, the latter coinciding with the historical floodplain before the incision. In the cases of an absolute lack of data, field evidence or other sources of information, this indicator is omitted and is not included in the final score.

EXTENDED ANSWERS

TYPOLOGY	CONFINED
RANGE OF APPLICATION	EVALUATED ONLY FOR LARGE CHANNELS (CHANNEL WIDTH > 30 m)
A	Negligible bed-level changes (≤ 0.5 m).
B	Limited or moderate bed-level changes (0.5÷3 m).
C	Intense bed-level changes (> 3 m).

TYPOLOGY	SEMICONFINED OR UNCONFINED
RANGE OF APPLICATION	EVALUATED ONLY FOR LARGE CHANNELS (CHANNEL WIDTH > 30 m)
A	Negligible bed-level changes (≤ 0.5 m): bed elevation unchanged due to altimetric stability or to recovery by aggradation of a previous phase of incision (e.g. due to a weir).
B	Limited or moderate bed-level changes (≤ 3 m). Incised channel: differences in elevation exist between new floodplain (if existing) and recent terraces, but in many cases not evident. Aggraded channel: bed-elevation higher than floodplain elevation.
C1	Intense bed-level changes (3÷6 m). Highly incised channel: very evident differences in elevation between new floodplain (if existing) and recent terraces, with the presence of evidence in several forms , including high and unstable banks, destabilization of transversal structures, exposed bridge piers, etc. Highly aggraded channel: marked differences in elevation between channel bed (much higher) and floodplain.
C2	Very intense bed-level changes (> 6 m). Exceptionally incised channel (e.g. following intense mining activity in the past). Usually, as well as the aforementioned evidence, data or reliable information about such an important incision will exist. Exceptionally aggraded channel.

SCORES

For each indicator, the **partial score** relative to classes *A*, *B* or *C* must be circled in the apposite column on the right (first column on the right side of the answers). In the following column, the **progressive score** is reported, so that the total deviation is immediately available at the end of the compilation of the evaluation form. In the last column on the right (inside the dotted lines), operator should express a **degree of confidence** in the answer, considering three possible cases: (1) *High*, (2) *Medium*, (3) *Low*. This can be indicated between class *A* and *B*, or between *B* and *C*. A simplified estimation of the overall uncertainty degree associated with the final evaluation can be obtained that is the range of variation of the final score. An example of the procedure can be visualized in the **compiled evaluation form** (see later).

On the bottom of the evaluation form, the Morphological Alteration Index and the Morphological Quality Index are calculated.

The **Morphological Alteration Index** (***IAM***) is calculated as:

$$IAM = S_{tot} / S_{max}$$

where S_{max} is the maximum possible deviation for the given stream typology (it corresponds to the sum of the class C scores for all the questions applicable to the study case).

The **Morphological Quality Index** (***IQM***) is expressed as:

$$IQM = 1 - IAM$$

SUB-INDEXES

Given the structure divided into various aspects and categories, it is possible to calculate a series of sub-indexes, that is, to sub-divide the two main indexes *IAM* and *IQM* into their components. This can be useful for identifying the negative and positive points of a reach.

The **functionality**, **artificiality** and **channel changes sub-indexes** (or "vertical sub-indexes") can be obtained as follows:

---

1. **FUNCTIONALITY**

$IAM_F = S_F\ tot/Smax$

$IQM_F = (S_F\ max/Smax) - IAM_F = (S_F\ max - S_F\ tot) / Smax$

Where

$S_F\ tot = F1 + \ldots + F13$ *(sum of scores of applied F indicators);*

$Max(S_F\ tot) = Max(F1) + \ldots + Max(F13)$ *(sum of maximum scores of all F indicators);*

$Max(S_A\ tot) = Max(A1) + \ldots + Max(A12)$ *(sum of maximum scores of all A indicators);*

$Max(S_V\ tot) = Max(V1) + \ldots + Max(V3)$ *(sum of maximum scores of all V indicators);*

$Max(Stot) = Max(S_F\ tot) + Max(S_A\ tot) + Max(S_V\ tot)$ *(sum of maximum scores of all indicators);*

$Sna(_F)$ = *sum of maximum scores of not applied F indicators;*

Sna = *sum of maximum scores of not applied F, A, V indicator;*

$S_F\ max = Max(S_F\ tot) - Sna(_F)$;

$Smax = Max(Stot) - Sna$.

---

2. **ARTIFICIALITY**

$IAM_A = S_A\ tot/Smax$

$IQM_A = (S_A\ max/Smax) - IAM_A = (S_A\ max - S_A\ tot) / Smax$

Where:

$\boldsymbol{S_A tot}$ $= A1 + \ldots + A12$ *(sum of scores of applied A indicators);*

$\boldsymbol{Max(S_F\, tot)}$ $= Max(F1) + \ldots + Max(F13)$ *(sum of maximum scores of all F indicators);*

$\boldsymbol{Max(S_A\, tot)}$ $= Max(A1) + \ldots + Max(A12)$ *(sum of maximum scores of all A indicators);*

$\boldsymbol{Max(S_V\, tot)}$ $= Max(V1) + \ldots + Max(V3)$ *(sum of maximum scores of all V indicators);*

$\boldsymbol{Max(Stot)}$ $= Max(S_F\, tot) + Max(S_A\, tot) + Max(S_V\, tot)$ *(sum of maximum scores of all indicators);*

$\boldsymbol{Sna(_A)}$ *= sum of maximum scores of not applied A indicators;*

Sna *= sum of maximum scores of not applied F, A, V indicator;*

$\boldsymbol{S_A\, max}$ $= Max(S_A\, tot) - Sna(_A)$;

Smax $= Max(Stot) - Sna$.

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3. **CHANNEL CHANGES**

$\boldsymbol{IAM_V}$ $= S_V\, tot/Smax$

$\boldsymbol{IQM_V}$ $= (S_V max/Smax) - IAM_V = (S_V\, max - S_V\, tot) / Smax$

Where:

$\boldsymbol{S_V tot}$ $= V1 + \ldots + V3$ *(sum of scores of applied V indicators);*

$\boldsymbol{Max(S_F\, tot)}$ $= Max(F1) + \ldots + Max(F13)$ *(sum of maximum scores of all F indicators);*

$\boldsymbol{Max(S_A\, tot)}$ $= Max(A1) + \ldots + Max(A12)$ *(sum of maximum scores of all A indicators);*

$\boldsymbol{Max(S_V\, tot)}$ $= Max(V1) + \ldots + Max(V3)$ *(sum of maximum scores of all V indicators);*

$\boldsymbol{Max(Stot)}$ $= Max(S_F\, tot) + Max(S_A\, tot) + Max(S_V\, tot)$ *(sum of maximum scores of all indicators);*

$\boldsymbol{Sna(_V)}$ *= sum of maximum scores of not applied V indicators;*

Sna *= sum of maximum scores of not applied F, A, V indicator;*

$\boldsymbol{S_V\, max}$ $= Max(S_V\, tot) - Sna(_V)$;

Smax $= Max(Stot) - Sna$.

To make the analysis more effective, the sub-indexes can be related to the maximum value that they can reach for a given category (functionality, artificiality, channel changes). For this purpose, the overall value of IAM and IQM is divided in the part relative to each category as follows:

1. **FUNCTIONALITY**

$IAM_F\, max = IQM_F\, max = S_F\, max/Smax$

2. **ARTIFICIALITY**

$IAM_A\, max = IQM_A\, max = S_A\, max/Smax$

3. **CHANNEL CHANGES**

$IAM_V\, max = IQM_V\, max = S_V\, max/Smax$

Note that, in case of additional scores for the indicators *A4*, *A6*, *A7*, *A9* such that $Stot > Smax$, the sum of the three sub-indexes $IAM_F + IAM_A + IAM_V$ results >1.

Similarly, **continuity**, **morphology** and **vegetation sub-indexes** (or "horizontal sub-indexes") can be obtained. For this purpose, some element of artificiality needs to be shared in more categories: in such cases the score assigned to a given indicator is simply divided by the number of categories. The sub-indexes are defined as follows.

1. **CONTINUITY**

$IAM_C = IAM_{CL} + IAM_{CLA}$

$IQM_C = IQM_{CL} + IQM_{CLA}$

Where:

C is for continuity, CL is for longitudinal continuity and CLA is for lateral continuity

1.1. LONGITUDINAL CONTINUITY

$IAM_{CL} = (F1+A1+A2+A3+A4/2+A5)/Smax$
$IQM_{CL}=(S_{CL}\ max/Smax) - IAM_{CL}$

Where:
S_{CL} max= $Max(S_{CL}\ tot) - Sna(_{CL})$;
Max(S_{CL} tot) = Max(F1)+Max(A1)+Max(A2)+Max(A3)+Max(A4/2)+ Max(A5)
(sum of maximum scores of all CL indicators);

Sna($_{CL}$) = *sum of maximum scores of not applied CL indicators.*

1.2. LATERAL CONTINUITY

$IAM_{CLA} = (F2+F3+F4+F5+A6/2+A7)/Smax$
$IQM_{CLA}=(S_{CLA}\ max/Smax) - IAM_{CLA}$

Where:
S_{CLA} max= $Max(S_{CLA}\ tot) - Sna(_{CLA})$;
Max(S_{CLA} tot) = Max(F2)+Max(F3)+Max(F4)+Max(F5)+Max(A6/2)+ Max(A7)
(sum of maximum scores of all CLA indicators);

Sna($_{CLA}$) = *sum of maximum scores of not applied CLA indicators.*

2. MORPHOLOGY

$IAM_M=IAM_{CM}+IAM_{CS}+IAM_S$

$IQM_M=IQM_{CM}+IQM_{CS}+IQM_S$

Where:

M is for morphology, CM is for morphological pattern, CS is for cross-section configuration and S is for substrate.

2.1. MORPHOLOGICAL PATTERN

$IAM_{CM} = (F6+F7+F8+A6/2+A8+V1)/Smax$
$IQM_{CM}=(S_{CM}\ max/Smax) - IAM_{CM}$

Where:
S_{CM} max= $Max(S_{CM}\ tot) - Sna(_{CM})$;
Max(S_{CM} tot) = Max(F6)+Max(F7)+Max(F8)+ Max(A6/2)+ Max(A8)+ Max(V1)
(sum of maximum scores of all CM indicators);
Sna($_{CM}$) = *sum of maximum scores of not applied CM indicators.*

2.2. CROSS-SECTION CONFIGURATION

$IAM_{CS} = (F9+A4/2+A9/2+A10/2+V2+V3)/Smax$
$IQM_{CS}=(S_{CS}\ max/Smax) - IAM_{CS}$

Where:
S_{CS} max= $Max(S_{CS}\ tot) - Sna(_{CS})$;
Max(S_{CS}tot)=Max(F9)+Max(A4/2)+Max(A9/2)+Max(A10/2)+Max(V2)+Max(V3)
(sum of maximum scores of all CS indicators);
Sna($_{CS}$) = *sum of maximum scores of not applied CS indicators.*

2.3. SUBSTRATE

$IAM_S = (F10+F11+A9/2+A10/2+A11)/Smax$
$IQM_S=(S_S\ max/Smax) - IAM_S$

Where:
S_S max= $Max(S_S\ tot) - Sna(_S)$;
Max($S_S$tot)=Max(F10)+Max(F11)+Max(A9/2)+Max(A10/2)+Max(A11)
(sum of maximum scores of all S indicators);

Sna$(_{S})$ *= sum of maximum scores of not applied S indicators.*

3. **VEGETATION**

$IAM_{VE} = (F12+F13+A12)/Smax$

$IQM_{VE}=(S_{VE}\,max/Smax) - IAM_{VE}$

Where:

VE is for vegetation;

$\mathbf{S_{VE}\,max} = Max(S_{VE}\,tot) - Sna(_{VE})$;

$\mathbf{Max(S_{VE}\,tot)} = Max(F12)+Max(F13)+ Max(A12)$ *(sum of maximum scores of all VE indicators);*

$\mathbf{Sna(_{VE})}$ *= sum of maximum scores of not applied VE indicators.*

As before, the sub-indexes can be related to the maximum value that they can reach for a given category, by dividing overall value of *IAM* and *IQM* in the part relative to each category as follows:

1. **CONTINUITY**

$IAM_{C}\,max = IQM_{C}\,max = S_{C}\,max/Smax$

Where:

$\mathbf{S_{C}\,max} = Max(S_{C}\,tot) - Sna(_{C}) = S_{CL}\,max + S_{CLA}\,max;$

$\mathbf{Max(S_{C}\,tot)} = Max(S_{CL}\,tot) + Max(S_{CLA}\,tot)$

(sum of maximum scores of all C indicators, or sum of maximum scores of all CL and CLA indicators);

$\mathbf{Sna(_{C})} = Sna(_{CL}) + Sna(_{CLA})$

(*sum of maximum scores of not applied C indicators, or sum of maximum scores of not applied CL and CLA indicators).*

2. **MORPHOLOGY**

$IAM_{M}\,max = IQM_{M}\,max = S_{M}\,max/Smax$

Where:

$\mathbf{S_{M}\,max} = Max(S_{M}\,tot) - Sna(_{M}) = S_{CM}\,max + S_{CS}\,max + S_{S}\,max;$

$\mathbf{Max(S_{M}\,tot)} = Max(S_{CM}\,tot) + Max(S_{CS}\,tot) + Max(S_{S}\,tot)$

(sum of maximum scores of all M indicators, or sum of maximum scores of all CM, CS and S indicators);

$\mathbf{Sna(_{M})} = Sna(_{CM}) + Sna(_{CS}) + Sna(_{S})$

(*sum of maximum scores of not applied M indicators, or sum of maximum scores of not applied CM, CS and S indicators).*

3. **VEGETATION**

$IAM_{VE}\,max = IQM_{VE}\,max = S_{VE}\,max/Smax$

EXAMPLE OF COMPILED EVALUATION FORM

An example of a compiled evaluation form is reported as follows. This example is useful in understanding how to compile the forms and in calculating the confidence value.

IDRAIM: stream hydromorphological evaluation, analysis and monitoring system

EVALUATION FORMS FOR SEMI- AND UNCONFINED CHANNELS

Version 1 - January 2011

GENERALITY

Date 01 / 01 / 20 10 Operators M. Rossi

Catchment Idraim Stream/river Idraim River

Upstream limit confluence Idraim branch Downstream limit nearby S.Anna

Segment code 4 Reach Code 4_3 Reach length (m) 2.4 km

GENERAL SETTING AND INITIAL SEGMENTATION

1. Physiographic setting

Physiographic area P *HM*=Hills-mountains, *P*=Plain Physiographic unit High plain

2. Confinamento

Confinement degree (%) 10- 90 >90, 10-90, ≤10

Confinement index >n 1-1.5, 1.5-*n*, >*n* *(n=5 single-thread channels; n=2 multi-thread or wandering channels)*

Confinement class SC *SC*=Semiconfined, *UNC*=Unconfined

3. Channel morphology

Aerial photo or satellite image Aerial Flight Tuscany Region 2007 (name, year)

Sinuosity index ~ 1.2 1-1.05, 1.05-1.5, >1.5

Braiding index ~ 1.3 1-1.5, >1.5 Anastomosing index 1 1-1.5, >1.5

Typology W *ST*=Straight, *S*=Sinuous, *M*=Meandering, *SAB*= Sinuous with alternate bars, *W*= Wandering, *B*= Braided, *A*= Anastomosed

Bed configuration ____ *BR*=bedrock, *C/SP*=Cascade/Step Pool, *PB*=Plane bed, *RP*=Riffle Pool, *DR*=Dune ripple
(only for *ST*, *S*, *M, SAB* morphologies) *A*= Artificial, *NC*= not classified (high depth or strong alteration)

Mean bed slope 0.0035 Mean channel width (m) 42

Bed sediment (dominant) G-C *C*=Clay, *Si*=Silt, *Sa*=Sand, *G*=Gravel, *C*=Cobbles, *B*=Boulders

4. Other elements for reach delimitation

Upstream Tributary Downstream ____

bed slope discontinuity, tributary, dam, artificialization, changes in width of alluvial plain and/or in confinement, changes in channel width, changes in grain sizes, other (specify) ____

Additional available data / information

Drainage area (at the downstream limit) (km^2) 760

Sediment size D_{50} (mm) 35 Unit Ba(SU) *Be*=Bed, *Ba*=Bar (*SU*=surface layer, *SUB*=sublayer)

Discharges NA *M*=measured, E=estimated, *NA*=not available

Gauging station (if *M*) ____ Mean annual discharge (m^3/s) ____ $Q_{1.5}$ (m^3/s) ____

Maximum discharges (indicate year and Q when known) Intense flood in 2004

GEOMORPHOLOGICAL FUNCTIONALITY

Continuity

		part.	prog.	conf.
F1	**Longitudinal continuity in sediment and wood flux**			
A	Absence of alteration in the continuity of sediment and wood	0		
B	Slight alteration (obstacles to the flux but with no interception)	3		
C	Strong alteration (discontinuity of channel forms and interception of sediment and wood)	(5)	5	

There is a large check dam intercepting most of the bedload and creating a discontinuity of channel forms (disappearence of bars downstream)

		part.	prog.	conf.
F2	**Presence of a modern floodplain**			
A	Presence of a continuous (>66% of the reach) and wide floodplain	0		
B	Presence of a discontinuous (10÷66%) floodplain of any width or >90% but narrow	(3)		M +2
C	Absence of a floodplain or negligible presence (≤10 of any width)	5	8	

Not evaluated in the case of mountain streams along steep (>3%) alluvial fans

There is some uncertainty for part of the reach whether it is a modern floodplain or a low terrace

part.: partial scores (to circle) *prog.*: progressive scores *confidence level between A and B*
*conf.*confidence level in the answer, with *M*=Medium, *L*=Low *(High is omitted)* *confidence level between B and C*

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F4	Processes of bank retreat		
A	Presence of frequent retreating banks particularly along outer banks of bends	(0)	
B	Infrequent retreating banks because impeded by bank protections and/or scarce channel dynamics	2	
C	Complete absence or widespread presence of unstable banks by mass failures	3	8

Not evaluated in the case of straight – sinuous channels of low energy (lowland rivers, low gradients and/or bedload)

F5	Presence of a potentially erodible corridor		
A	Presence of a wide potentially erodible corridor (EC) for a length >66% of the reach	0	
B	Presence of a narrow potentially EC for >66%, or wide but for 33-66% of the reach	(2)	
C	Presence of a potentially EC of any width but for ≤33% of the reach	3	10

Morphology

Morphological pattern

F7	Forms and processes typical of the channel pattern		
A	Absence (<5%) of alteration of the natural heterogeneity of forms expected for that river type	0	
B	Alterations for a limited portion of the reach (≤33%)	(3)	
C	Consistent alterations for a significant portion of the reach (>33%)	5	13

F8	Presence of typical fluvial forms in the alluvial plain		
A	Presence of alluvial plain forms (oxbow lakes, secondary channels, etc.)	0	
B	Presence of traces of alluvial plain forms (abandoned after the 1950s) but with possible reactivatio	2	
C	Complete absence of alluvial plain forms	3	No

Evaluated only in the case of meandering rivers (now or in the past) within a lowland plain physiographic unit

Cross-section configuration

F9	Variability of the cross-section		
A	Absence (≤5%) of alteration of the cross-section natural heterogeneity (width and depth)	0	
B	Presence of alteration (cross-section homogeneity) for a limited portion of the reach (≤33%)	(3)	
C	Presence of alteration (cross-section homogeneity) for a significant portion of the reach (>33%)	5	16

Not evaluated in the case of straight, sinuous or meandering channels with natural absence of bars (lowland rivers, low gradients and/or low bedload) (natural cross-section homogeneity)

Bed structure and substrate

F10	Structure of the channel bed		
A	Natural heterogeneity of bed sediments and no significant clogging	0	
B	Evident armouring or clogging in various portions of the site	2	
C1	Evident and widespread (>90%) armouring or clogging, or occasional substrate outcrops	(5)	
C2	Widespread substrate outcrops or alteration by bed revetments (>33% of the reach)	6	21

Not evaluated for sand-bed rivers, and for deep rivers when it is not possible to observe the channel bed

F11	Presence of in-channel large wood		
A	Presence of large wood	(0)	
C	Negligible presence or absence of large wood	3	21

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

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Vegetation in the fluvial corridor

F12	Width of functional vegetation in the fluvial corridor		
A	High width of functional vegetation	0	
B	Medium width of functional vegetation	(2)	
C	Low width of functional vegetation	3	23

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

F13	Linear extension of functional vegetation along the banks		
A	Linear extension of functional vegetation >90% of maximum available length	0	
B	Linear extension of functional vegetation 33÷90% of maximum available length	(3)	
C	Linear extension of functional vegetation ≤33% of maximum available length	5	26

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

ARTIFICIALITY

Upstream alteration of longitudinal continuity

		part.	*prog.*	*conf.*
A1	**Upstream alteration of discharges**			
A	No significant alteration (≤10%) of channel-forming discharges and with return interval>10 years	0		
B	Significant alteration (>10%) of discharges with return interval>10 years	(3)		
C	Significant alteration (>10%) of channel-forming discharges	6	29	

A2	Upstream alteration of sediment transport		
A	Absence or negligible presence of structures for the interception of sediment fluxes (dams for drainage area <5% and/or check dams/abstraction weirs for drainage area <33%)	0	
B1	Dams (area 5-33%) and/or check dams/weirs with total bedload interception (area 33-66%) and/or check dams/weirs with partial interception (area >33% *plain/hills* or >66% *mountains*)	3	
B2	Dams (drainage area 33-66%) and/or check dams/weirs with total bedload interception (drainage area >66% or at the upstream boundary)	(6)	
C1	Dams for drainage area >66%	9	
C2	Dam at the upstream boundary of the reach	12	35

Alteration of longitudinal continuity in the reach

A3	Alteration of discharges in the reach		
A	No significant alteration (≤10%) of channel-forming discharges and with return interval>10 years	(0)	
B	Significant alteration (>10%) of discharges with return interval>10 years	3	
C	Significant alteration (>10%) of channel-forming discharges	6	35

A4	Alteration of sediment transport in the reach		
A	Absence of structures for the interception of sediment fluxes (dams, check dams, abstraction weirs	0	
B	*Plain/hills units*:consolidation check dams and/or abstraction weirs ≤1 every 1000 m *Mountain units*:consolidation check dams ≤1 every 200 m and/or open check dams	(4)	
C	*Plain/hill units*: consolidation check dams and/or abstraction weirs >1 every 1000 m *Mountain units*: consolidation check dams >1 every 200 m and/or retention check dams or presence of a dam or artificial reservoir at the downstream boundary (*any physiographic units*)	6	39
	In case of density of interception structures, including bed sills and ramps (see A9), is >1 every n , add where n=100 m in mountain units, or n=500 m in plain/hills units	12	

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A5	Crossing structures		
A	Absence of crossing structures (bridges, fords culverts)	0	
B	Presence of some crossing structure (≤1 every 1000 m in average in the reach)	(2)	
C	Presence of many crossing structure (>1 every 1000 m in average in the reach)	3	*41*

Alteration of lateral continuity

A6	Bank protections		
A	Absence or localized presence of bank protections (≤5% total length of the banks)	(0)	
B	Presence of protections for ≤33% total length of the banks (sum of both banks)	3	
C	Presence of protections for >33% total length of the banks (sum of both banks)	6	*41*
	In case of extremely high density of bank protection (>80%) add	12	

A7	Artificial levees		
A	Absent or distant levees, or presence of levees close or at contact ≤10% total length of the banks	(0)	
B	Medium presence of levees close and/or at contact (at contact ≤50% bank length)	3	
C	High presence of levees close and/or at contact (at contact >50% bank length)	6	*41*
	In case of extremely high density of levees at contact (>80%) add	12	

Alteration of channel morphology and/or substrate

A8	Artificial changes of river course		
A	Absence of artificial changes of river course in the past (meanders cut-off, channel diversions, etc.)	(0)	
B	Presence of changes of river course for ≤10% of the reach length	2	
C	Presence of changes of river course for >10% of the reach length	3	*41*

A9	Other grade control structures		
A	Absence of structures (bed sills/ramps) and revetments absent or localised (≤5%)	0	
B	Sills or ramps (≤1 every *m*) and/or revetments ≤25% permeable and/or ≤15% impermeable	(3)	
C1	Sills or ramps (>1 every *m*) and/or revetments ≤50% permeable and/or ≤33% impermeable	6	
C2	Revetments >50% permeable and/or >33% impermeable	8	*44*

m=200 m in mountain units; m= 1000 m in plain/hills units

	In case of widespread bed revetment (>80%) add	12	

Intervention of maintenance and removal

A10	Sediment removal		
A	Absence of recent (last 20 years) and past (from 1950s) significant sediment removal activities	0	
B	Moderate activities in the past (from 1950s) but absent during last 20 years, or absent in the past but present recently (last 20 years)	3	*M* -3
C	Intense activities in the past, or moderate in the past but present during last 20 years	(6)	*50*

There is some uncertainty whether the activity in the past was intense or moderate.
There was not sediment removal activity during the last 20 years.

A11	Wood removal		
A	Absence of removal of woody material at least during the last 20 years	0	
B	Selective cuts and/or clear cuts over ≤50% of the reach during the last 20 years	(2)	
C	Total removal of woody material during the last 20 years	5	*52*

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

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A12	Vegetation management		
A	No cutting interventions on riparian vegetation during the last 20 years	(0)	
B	Selective cuts and/or clear cuts over ≤50% of the reach during the last 20 years	2	
C	Clear cuts over >50% of the reach during the last 20 years	5	52

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

CHANNEL CHANGES

V1	Changes in channel pattern *(applied only to channels wider than 30 m)*	part.	prog.	conf.
A	Absence of changes of channel pattern since 1950s	0		
B	Change to a similar channel pattern since 1950s	(3)		
C	Change to a different channel pattern since 1950s	6	55	

V2	Changes in channel width *(applied only to channels wider than 30 m)*		
A	Absent or limited changes (≤15%) since 1950s	0	
B	Moderate changes (15÷35%) since 1950s	3	
C	Intense changes (>35%) since 1950s	(6)	61

V3	Bed-level changes *(applied only to channels wider than 30 m)*		
A	Negligible bed-level changes (≤0.5 m)	0	
B	Limited to moderate bed-level changes (0.5÷3 m)	(4)	
C1	Intense bed-level changes (>3 m)	8	
C2	Very intense bed-level changes (>6 m)	12	65

Not evaluated in the case of absolute lack of data, information and field evidences

Total deviation:	***Stot =***	65	62÷67
Maximum deviation:	***Smax* = 142 - *Sna*=**	139	
where Sna = sum of maximum scores for those indicators that have not been applied			
Morphological Alteration Index:	***IAM = Stot / Smax =***	0.47	0.45÷0.48
	if Stot>Smax it is assumed IAM=1		
Morphological Quality Index:	***IQM=1-IAM =***	0.53	0.52÷0.55
Quality class of the reach	Moderate		

0≤*IQM*<0.3: Very Poor or Bad; 0.3≤*IQM*<0.5: Poor; 0.5≤*IQM*<0.7: Moderate;
0.7≤*IQM<0.85*: Good; 0.85≤*IQM*<1.0: Very Good or High

As it can be observed, the only indicator that has not been applied is *F8* (exclusive for meandering). Consequently, the maximum deviation is 142 – 3 (the latter is the maximum possible value for *F8*). It gives *IAM* = 0.47 (= 65/139), and *IQM*=0.53. For example, two answers do not have a high degree of confidence (*F2* and *A10*), and their relative possible deviation is +2 (*F2*) and -3 (*A10*). The result is that the total deviation of 65 could actually vary between 62 (=65–3) and 67 (=65+2), and consequently the *IAM* from 0.45 (= 62/139) to 0.48 (67/139). The result is a final range of *IQM* from 0.52 to 0.55. Therefore, the total confidence in the final score is relatively high, and does not affect the final class which remains in any case *moderate*.

Sub-indexes are not calculated on the "field evaluation forms", but they are automatically obtained in the "electronic evaluation forms". For example, all calculations of the sub-indexes are reported here for the compiled form (a final summary is reported in Table 6).

Vertical sub-indexes

SUB-INDEX OF FUNCTIONALITY

$IAM_F = S_F\,tot/Smax$ = 26/139 = 0.19 *on 0.31*
$IQM_F = (S_F\,max/Smax) – IAM_F = (S_F\,max – S_F\,tot) / Smax$ = (43 – 26)/139 = 0.12 *on 0.31*

being $IAM_F\,max = IQM_F\,max = S_F\,max/Smax = 43/139 = 0.31$

SUB-INDEX OF ARTIFICIALITY

$IAM_A = S_A\,tot/Smax$ = 26/139 = 0.19 *on 0.52*
$IQM_A = (S_A\,max/Smax) – IAM_A = (S_A\,max – S_A\,tot) / Smax$ = (72 – 26)/139 = 0.33 *on 0.52*

being $IAM_A\,max = IQM_A\,max = S_A\,max/Smax = 72/139 = 0.52$

SUB-INDEX OF CHANNEL CHANGES

$IAM_V = S_V\,tot/Smax$ = 13/139 = 0.09 *on 0.17*
$IQM_V = (S_V\,max/Smax) – IAM_V = (S_V\,max – S_V\,tot) / Smax$= (24 – 13)/139 = 0.08 *on 0.17*

being $IAM_V\,max = IQM_V\,max = S_V\,max/Smax = 24/139 = 0.17$

Horizontal sub-indexes

SUB-INDEX OF CONTINUITY

$IAM_C = IAM_{CL} + IAM_{CLA}$ = 0.13 + 0.04 = 0.17 *on 0.40*
$IQM_C = IQM_{CL} + IQM_{CLA}$ = 0.12 + 0.11 = 0.23 *on 0.40*

being $IAM_C\,max = IQM_C\,max = S_C\,max/Smax = (S_{CL}\,max + S_{CLA}\,max)/ Smax = (35+20)/139 = 0.40$

LONGITUDINAL CONTINUITY

$IAM_{CL} = (F1+A1+A2+A3+A4/2+A5)/Smax$ = 18/139 = 0.13
$IQM_{CL}=(S_{CL}\,max/Smax) – IAM_{CL}$ = (35/139) – 0.13 = 0.12

LATERAL CONTINUITY

$IAM_{CLA} = (F2+F3+F4+F5+A6/2+A7)/Smax$ = 5/139 = 0.04
$IQM_{CLA}=(S_{CLA}\,max/Smax) – IAM_{CLA}$ = (20/139) – 0.04 = 0.11

SUB-INDEX OF MORPHOLOGY

$IAM_M=IAM_{CM}+IAM_{CS}+IAM_S$ = 0.04 + 0.14 + 0.08 = 0.26 *on 0.51*
$IQM_M=IQM_{CM}+IQM_{CS}+IQM_S$ = 0.08 + 0.10 + 0.07 = 0.26 *on 0.51*

being $IAM_M\,max = IQM_M\,max = S_M\,max/Smax = (S_{CM}\,max + S_{CS}\,max + S_S\,max)/ Smax = (17 + 33 + 21)/139 = 0.51$

MORPHOLOGICAL CONFIGURATION

$IAM_{CM} = (F6+F7+F8+A6/2+A8+V1)/Smax$ = 6/139 = 0.04
$IQM_{CM}=(S_{CM}\,max/Smax) – IAM_{CM}$ = (17/139) – 0.04 = 0.08

CROSS-SECTION CONFIGURATION

$IAM_{CS} = (F9+A4/2+A9/2+A10/2+V2+V3)/Smax$ = 19.5/139 = 0.14
$IQM_{CS}=(S_{CS}\,max/Smax) – IAM_{CS}$ = (33/139) – 0.14 = 0.10

SUBSTRATE

$IAM_S = (F10+F11+A9/2+A10/2+A11)/Smax$ = 11.5/139 = 0.08
$IQM_S=(S_S\ max/Smax) - IAM_S$ = (21/139) – 0.08 = 0.07

SUB-INDEX OF VEGETATION

$IAM_{VE} = (F12+F13+A12)/Smax$ = 5/139 = 0.04 *on 0.09*
$IQM_{VE}=(S_{VE}\ max/Smax) - IAM_{VE}$ = (13/139) – 0.04 = 0.06 *on 0.09*
being $IAM_{VE}\ max = IQM_{VE}\ max = S_{VE}\ max/Smax = 13/139 = 0.09$

Table 6 **–** Summary of sub-indexes for the example in the compiled form. In the last column on the right the maximum possible value for the sub-index of each category is reported.

SUB-INDEXES	IAM	IQM	TOTAL
Vertical			
FUNCTIONALITY	0.19	0.12	0.31
ARTIFICIALITY	0.19	0.33	0.52
CHANNEL CHANGES	0.09	0.08	0.17
Horizontal			
CONTINUITY	0.17	0.23	0.40
Longitudinal	0.13	0.12	
Lateral	0.04	0.11	
MORPHOLOGY	0.26	0.25	0.51
Morphological pattern	0.04	0.08	
Cross-section configuration	0.14	0.10	
Substrate	0.08	0.07	
VEGETATION	0.04	0.06	0.09

APPENDIX 2

EVALUATION FORM FOR CONFINED CHANNELS

IDRAIM: stream hydromorphological evaluation, analysis and monitoring system

EVALUATION FORMS FOR CONFINED CHANNELS

Version 1 - January 2011

GENERALITY

Date ____________ Operators ____________

Catchment ____________ Stream/river ____________

Upstream limit ____________ Downstream limit ____________

Segment code ________ Reach Code ________ Reach length (m) ________

GENERAL SETTING AND INITIAL SEGMENTATION

1. Physiographic setting

Physiographic unit ____________

2. Confinement

Confinement degree (%) ______ >90, 10-90 Confinement index ______ (1-1.5)

3. Channel morphology

Aerial photo or satellite image ____________ (name, year)

Channel type ______ *ST*=single-thread, *MT/W*=multi-thread or wandering

Confined single-thread (ST):

Bed configuration ______ *BR*=Bedrock, *CO*=Colluvial, *C/SP*=Cascade/Step Pool, *PB*=Plane bed, *RP*=Riffle Pool, *DR*=Dune ripple, *A*= Artificial, *NC*= not classified (high depth or strong alteration)

Confined multi-thread or wandering (MT/W):

Braiding index ______ 1-1.5, >1.5 Anastomosing index ______ 1-1.5, >1.5

Tipology ______ *W*= wandering, *B*= Braided, *A*= Anastomosed

Mean bed slope ______ Mean channel width (m) ______

Bed sediment (dominant) ____ *C*=Clay, *Si*=Silt, *Sa*=Sand, *G*=Gravel, *C*=Cobbles, *B*=Boulders

4. Other elements for reach delimitation

Upstream ____________ Downstream ____________

bed slope discontinuity, tributary, dam, artificialization, changes in confinement, changes in channel width, changes in grain sizes or bed configuration, other (specify) ____________

Additional available data / information

Drainage area (at the downstream limit) (km^2) ________

Sediment size D_{50} (mm) ______ Unit ______ *Be*=Bed, *Ba*=Bar (*SU*=surface layer, *SUB*=sublayer)

Discharges ______ *M*=measured, E=estimated, *NA*=not available

Gauging station (if *M*) ________ Mean annual discharge (m^3/s) ______ $Q_{1.5}$ (m^3/s) ______

Maximum discharges (indicate year and Q when known) ____________

GEOMORPHOLOGICAL FUNCTIONALITY

Continuity

F1	Longitudinal continuity in sediment and wood flux	*part.*	*prog.*	*conf.*
A	Absence of alteration in the continuity of sediment and wood	0		
B	Slight alteration (obstacles to the flux but with no interception)	3		
C	Strong alteration (discontinuity of channel forms and interception of sediment and wood)	5		

F3	Hillslopes - river corridor connectivity	*part.*	*prog.*	*conf.*
A	Full connectivity between hillslopes and river corridor (>90%)	0		
B	Connectivity for a significant portion of the reach (33÷90%)	3		
C	Connectivity for a small portion of the reach (≤33%)	5		

part.: partial scores (to circle) *prog.*: progressive scores *confidence level between A and B*

*conf.*confidence level in the answer, with *M*=Medium, *L*=Low *(High is omitted)* *confidence level between B and C*

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Morphology

Morphological pattern

F6	**Bed configuration - valley slope** *(applied to single-thread channels)*		
A	Bed forms consistent with the mean valley slope	0	
B	Bed forms not consistent with the mean valley slope	3	
C	Complete alteration of bed forms for the presence of artificial bed	5	

Not evaluated for bedrock streams, and for deep streams when it is not possible to observe the channel bed

F7	**Forms and processes typical of the channel pattern** *(applied to multi-thread or wandering channels)*		
A	Absence (<5%) of alteration of the natural heterogeneity of forms expected for that river type	0	
B	Alterations for a limited portion of the reach (≤33%)	3	
C	Consistent alterations for a significant portion of the reach (>33%)	5	

Cross-section configuration

F9	**Variability of the cross-section**		
A	Absence (≤5%) of alteration of the cross-section natural heterogeneity (width and depth)	0	
B	Presence of alteration (cross-section homogeneity) for a limited portion of the reach (≤33%)	3	
C	Presence of alteration (cross-section homogeneity) for a significant portion of the reach (>33%)	5	

Bed structure and substrate

F10	**Structure of the channel bed**		
A	Natural heterogeneity of bed sediments and no significant clogging	0	
B	Evident clogging in various portions of the site	2	
C1	Evident and widespread (>90%) clogging	5	
C2	Complete alteration of substrate due to bed revetment (>33% of the reach)	6	

Not evaluated for sand-bed or bedrock streams, and for deep streams when it is not possible to observe the channel bed

F11	**Presence of in-channel large wood**		
A	Presence of large wood	0	
C	Negligible presence or absence of large wood	3	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

Vegetation in the fluvial corridor

F12	**Width of functional vegetation in the fluvial corridor**		
A	High width of functional vegetation	0	
B	Medium width of functional vegetation	2	
C	Low width of functional vegetation	3	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

F13	**Linear extension of functional vegetation along the banks**		
A	Linear extension of functional vegetation >90% of maximum available length	0	
B	Linear extension of functional vegetation 33÷90% of maximum available length	3	
C	Linear extension of functional vegetation ≤33% of maximum available length	5	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

IDRAIM: stream hydromorphological evaluation, analysis and monitoring system

ARTIFICIALITY

Upstream alteration of longitudinal continuity

A1	Upstream alteration of discharges	part.	prog.	conf.
A	No significant alteration (≤10%) of channel-forming discharges and with return interval>10 years	0		
B	Significant alteration (>10%) of discharges with return interval>10 years	3		
C	Significant alteration (>10%) of channel-forming discharges	6		

A2	Upstream alteration of sediment transport	part.	prog.	conf.
A	Absence or negligible presence of structures for the interception of sediment fluxes (dams for drainage area <5% and/or check dams/abstraction weirs for drainage area <33%)	0		
B1	Dams (area 5-33%) and/or retention check dams with total bedload interception (area 33-66%) and/or check dams with partial bedload interception or consolidation check dams (area>66%)	3		
B2	Dams (area 33-66%) and/or retention check dams with total bedload interception (area>66%)	6		
C1	Dams for drainage area >66%	9		
C2	Dam at the upstream boundary of the reach	12		

Alteration of longitudinal continuity in the reach

A3	Alteration of discharges in the reach	part.	prog.	conf.
A	No significant alteration (≤10%) of channel-forming discharges and with return interval>10 years	0		
B	Significant alteration (>10%) of discharges with return interval>10 years	3		
C	Significant alteration (>10%) of channel-forming discharges	6		

A4	Alteration of sediment transport in the reach	part.	prog.	conf.
A	Absence of structures for the interception of sediment fluxes (dams, check dams, abstraction weirs)	0		
B	Consolidation check dams ≤1 every 200 m and/or open check dams	4		
C	Consolidation check dams >1 every 200 m and/or retention check dams or presence of a dam or artificial reservoir at the downstream boundary	6		
	In case of density of interception structures, including bed sills and ramps (see A9), is >1 every 100 m , add	12		

A5	Crossing structures	part.	prog.	conf.
A	Absence of crossing structures (bridges, fords, culverts)	0		
B	Presence of some crossing structure (≤1 every 1000 m in average in the reach)	2		
C	Presence of many crossing structure (>1 every 1000 m in average in the reach)	3		

Alteration of lateral continuity

A6	Bank protections	part.	prog.	conf.
A	Absence or localized presence of bank protections (≤5% total length of the banks)	0		
B	Presence of protections for ≤33% total length of the banks (sum of both banks)	3		
C	Presence of protections for >33% total length of the banks (sum of both banks)	6		
	In case of extremely high density of bank protection (>80%) add	12		

Alteration of channel morphology and/or substrate

A9	Other bed stabilization structures	part.	prog.	conf.
A	Absence of structures (bed sills/ramps) and revetments absent or localised (≤5%)	0		
B	Sills or ramps (≤1 every 200 m) and/or revetments ≤25% permeable and/or ≤15% impermeable	3		
C1	Sills or ramps (>1 every 200 m) and/or revetments ≤50% permeable and/or ≤33% impermeable	6		
C2	Revetments >50% permeable and/or >33% impermeable	8		
	In case of widespread bed revetment (>80%) add	12		

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Intervention of maintenance and removal

A10	**Sediment removal**		
A	Absence of significant sediment removal activities during the last 20 years	0	
B	Localized sediment removal activities during the last 20 years	3	
C	Widespread sediment removal activities during the last 20 years	6	

Not evaluated in the case of bedrock streams

A11	**Wood removal**		
A	Absence of removal of woody material at least during the last 20 years	0	
B	Selective cuts and/or clear cuts over ≤50% of the reach during the last 20 years	2	
C	Total removal of woody material during the last 20 years	5	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

A12	**Vegetation management**		
A	No cutting interventions on riparian vegetation during the last 20 years	0	
B	Selective cuts and/or clear cuts over ≤50% of the reach during the last 20 years	2	
C	Clear cuts over >50% of the reach during the last 20 years	5	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

CHANNEL CHANGES

		part.	*prog.*	*conf.*
V1	**Changes in channel pattern** *(applied only to channels wider than 30 m)*			
A	Absence of change of channel pattern since 1950s	0		
B	Change of channel pattern since 1950s	3		

V2	**Changes in channel width** *(applied only to channels wider than 30 m)*		
A	Absent or limited changes in channel width (≤15%) since 1950s	0	
B	Changes in channel width >15% since 1950s	3	

V3	**Bed-level changes** *(applied only to channels wider than 30 m)*		
A	Negligible bed-level changes (≤0.5 m)	0	
B	Limited to moderate bed-level changes (0.5÷3 m)	4	
C	Intense bed-level changes (>3 m)	8	

Not evaluated in the case of absolute lack of data, information and field evidences

Total deviation: ***Stot*** **=**

Maximum deviation: ***Smax*** **= 119 -** ***Sna*****=**

where Sna = sum of maximum scores for those indicators that have not been applied

Morphological Alteration Index: ***IAM = Stot / Smax =***

if Stot>Smax it is assumed IAM=1

Morphological Quality Index: ***IQM=1-IAM =***

Quality class of the reach

0≤*IQM*<0.3: Very Poor or Bad; 0.3≤*IQM*<0.5: Poor; 0.5≤*IQM*<0.7: Moderate;
0.7≤*IQM<0.85*: Good; 0.85≤*IQM*<1.0: Very Good or High

APPENDIX 3

EVALUATION FORM FOR SEMICONFINED OR UNCONFINED CHANNEL

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EVALUATION FORMS FOR SEMI- AND UNCONFINED CHANNELS

Version 1 - January 2011

GENERALITY

Date ____________ Operators ____________
Catchment ____________ Stream/river ____________
Upstream limit ____________ Downstream limit ____________
Segment code ________ Reach Code ________ Reach length (m) ________

GENERAL SETTING AND INITIAL SEGMENTATION

1. Physiographic setting

Physiographic area ______ *HM*=Hills-mountains, *P*=Plain Physiographic unit ____________

2. Confinamento

Confinement degree (%) ______ >90, 10-90, ≤10
Confinement index ______ 1-1.5, 1.5-*n*, >*n* *(n=5 single-thread channels; n=2 multi-thread or wandering channels)*
Confinement class ______ *SC*=Semiconfined, *UNC*=Unconfined

3. Channel morphology

Aerial photo or satellite image ____________ (name, year)
Sinuosity index ______ 1-1.05, 1.05-1.5, >1.5
Braiding index ______ 1-1.5, >1.5 Anastomosing index ______ 1-1.5, >1.5
Typology ______ *ST*=Straight, *S*=Sinuous, *M*=Meandering, *SAB*= Sinuous with alternate bars, *W*= Wandering, *B*= Braided, *A*= Anastomosed
Bed configuration ______ *BR*=bedrock, *C/SP*=Cascade/Step Pool, *PB*=Plane bed, *RP*=Riffle Pool, *DR*=Dune ripple
(only for *ST*, *S*, *M, SAB* morphologies) *A*= Artificial, *NC*= not classified (high depth or strong alteration)
Mean bed slope ______ Mean channel width (m) ______
Bed sediment (dominant) ____ *C*=Clay, *Si*=Silt, *Sa*=Sand, *G*=Gravel, *C*=Cobbles, *B*=Boulders

4. Other elements for reach delimitation

Upstream ____________ Downstream ____________
bed slope discontinuity, tributary, dam, artificialization, changes in width of alluvial plain and/or in confinement, changes in channel width, changes in grain sizes, other (specify) ____________

Additional available data / information

Drainage area (at the downstream limit) (km^2) ________
Sediment size D_{50} (mm) ______ Unit ______ *Be*=Bed, *Ba*=Bar (*SU*=surface layer, *SUB*=sublayer)
Discharges ______ *M*=measured, E=estimated, *NA*=not available
Gauging station (if *M*) ________ Mean annual discharge (m^3/s) ______ $Q_{1.5}$ (m^3/s) ______
Maximum discharges (indicate year and Q when known) ____________

GEOMORPHOLOGICAL FUNCTIONALITY

Continuity

		part.	*prog.*	*conf.*
F1	**Longitudinal continuity in sediment and wood flux**			
A	Absence of alteration in the continuity of sediment and wood	0		
B	Slight alteration (obstacles to the flux but with no interception)	3		
C	Strong alteration (discontinuity of channel forms and interception of sediment and wood)	5		

		part.	*prog.*	*conf.*
F2	**Presence of a modern floodplain**			
A	Presence of a continuous (>66% of the reach) and wide floodplain	0		
B	Presence of a discontinuous (10÷66%) floodplain of any width or >90% but narrow	3		
C	Absence of a floodplain or negligible presence (≤10 of any width)	5		

Not evaluated in the case of mountain streams along steep (>3%) alluvial fans

part.: partial scores (to circle) *prog.*: progressive scores *confidence level between A and B*
*conf.*confidence level in the answer, with *M*=Medium, *L*=Low *(High is omitted)* *confidence level between B and C*

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F4	**Processes of bank retreat**		
A	Presence of frequent retreating banks particularly along outer banks of bends	0	
B	Infrequent retreating banks because impeded by bank protections and/or scarce channel dynamics	2	
C	Complete absence or widespread presence of unstable banks by mass failures	3	

Not evaluated in the case of straight – sinuous channels of low energy (lowland rivers, low gradients and/or bedload)

F5	**Presence of a potentially erodible corridor**		
A	Presence of a wide potentially erodible corridor (EC) for a length >66% of the reach	0	
B	Presence of a narrow potentially EC for >66%, or wide but for 33-66% of the reach	2	
C	Presence of a potentially EC of any width but for ≤33% of the reach	3	

Morphology

Morphological pattern

F7	**Forms and processes typical of the channel pattern**		
A	Absence (<5%) of alteration of the natural heterogeneity of forms expected for that river type	0	
B	Alterations for a limited portion of the reach (≤33%)	3	
C	Consistent alterations for a significant portion of the reach (>33%)	5	

F8	**Presence of typical fluvial forms in the alluvial plain**		
A	Presence of alluvial plain forms (oxbow lakes, secondary channels, etc.)	0	
B	Presence of traces of alluvial plain forms (abandoned after the 1950s) but with possible reactivation	2	
C	Complete absence of alluvial plain forms	3	

Evaluated only in the case of meandering rivers (now or in the past) within a lowland plain physiographic unit

Cross-section configuration

F9	**Variability of the cross-section**		
A	Absence (≤5%) of alteration of the cross-section natural heterogeneity (width and depth)	0	
B	Presence of alteration (cross-section homogeneity) for a limited portion of the reach (≤33%)	3	
C	Presence of alteration (cross-section homogeneity) for a significant portion of the reach (>33%)	5	

Not evaluated in the case of straight, sinuous or meandering channels with natural absence of bars (lowland rivers, low gradients and/or low bedload) (natural cross-section homogeneity)

Bed structure and substrate

F10	**Structure of the channel bed**		
A	Natural heterogeneity of bed sediments and no significant clogging	0	
B	Evident armouring or clogging in various portions of the site	2	
C1	Evident and widespread (>90%) armouring or clogging, or occasional substrate outcrops	5	
C2	Widespread substrate outcrops or alteration by bed revetments (>33% of the reach)	6	

Not evaluated for sand-bed rivers, and for deep rivers when it is not possible to observe the channel bed

F11	**Presence of in-channel large wood**		
A	Presence of large wood	0	
C	Negligible presence or absence of large wood	3	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

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Vegetation in the fluvial corridor

F12	Width of functional vegetation in the fluvial corridor		
A	High width of functional vegetation	0	
B	Medium width of functional vegetation	2	
C	Low width of functional vegetation	3	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

F13	Linear extension of functional vegetation along the banks		
A	Linear extension of functional vegetation >90% of maximum available length	0	
B	Linear extension of functional vegetation 33÷90% of maximum available length	3	
C	Linear extension of functional vegetation ≤33% of maximum available length	5	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

ARTIFICIALITY

Upstream alteration of longitudinal continuity

part. | *prog.* | *conf.*

A1	Upstream alteration of discharges		
A	No significant alteration (≤10%) of channel-forming discharges and with return interval>10 years	0	
B	Significant alteration (>10%) of discharges with return interval>10 years	3	
C	Significant alteration (>10%) of channel-forming discharges	6	

A2	Upstream alteration of sediment transport		
A	Absence or negligible presence of structures for the interception of sediment fluxes (dams for drainage area <5% and/or check dams/abstraction weirs for drainage area <33%)	0	
B1	Dams (area 5-33%) and/or check dams/weirs with total bedload interception (area 33-66%) and/or check dams/weirs with partial interception (area >33% *plain/hills* or >66% *mountains*)	3	
B2	Dams (drainage area 33-66%) and/or check dams/weirs with total bedload interception (drainage area >66% or at the upstream boundary)	6	
C1	Dams for drainage area >66%	9	
C2	Dam at the upstream boundary of the reach	12	

Alteration of longitudinal continuity in the reach

A3	Alteration of discharges in the reach		
A	No significant alteration (≤10%) of channel-forming discharges and with return interval>10 years	0	
B	Significant alteration (>10%) of discharges with return interval>10 years	3	
C	Significant alteration (>10%) of channel-forming discharges	6	

A4	Alteration of sediment transport in the reach		
A	Absence of structures for the interception of sediment fluxes (dams, check dams, abstraction weirs)	0	
B	*Plain/hills units*:consolidation check dams and/or abstraction weirs ≤1 every 1000 m *Mountain units*:consolidation check dams ≤1 every 200 m and/or open check dams	4	
C	*Plain/hill units*: consolidation check dams and/or abstraction weirs >1 every 1000 m *Mountain units*: consolidation check dams >1 every 200 m and/or retention check dams or presence of a dam or artificial reservoir at the downstream boundary (*any physiographic units*)	6	

In case of density of interception structures, including bed sills and ramps (see A9), is >1 every n , add where n=100 m in mountain units, or n=500 m in plain/hills units 12

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A5	Crossing structures		
A	Absence of crossing structures (bridges, fords, culverts)	0	
B	Presence of some crossing structure (≤1 every 1000 m in average in the reach)	2	
C	Presence of many crossing structure (>1 every 1000 m in average in the reach)	3	

Alteration of lateral continuity

A6	Bank protections		
A	Absence or localized presence of bank protections (≤5% total length of the banks)	0	
B	Presence of protections for ≤33% total length of the banks (sum of both banks)	3	
C	Presence of protections for >33% total length of the banks (sum of both banks)	6	
	In case of extremely high density of bank protection (>80%) add	12	

A7	Artificial levees		
A	Absent or distant levees, or presence of levees close or at contact ≤10% total length of the banks	0	
B	Medium presence of levees close and/or at contact (at contact ≤50% bank length)	3	
C	High presence of levees close and/or at contact (at contact >50% bank length)	6	
	In case of extremely high density of levees at contact (>80%) add	12	

Alteration of channel morphology and/or substrate

A8	Artificial changes of river course		
A	Absence of artificial changes of river course in the past (meanders cut-off, channel diversions, etc.)	0	
B	Presence of changes of river course for ≤10% of the reach length	2	
C	Presence of changes of river course for >10% of the reach length	3	

A9	Other grade control structures		
A	Absence of structures (bed sills/ramps) and revetments absent or localised (≤5%)	0	
B	Sills or ramps (≤1 every *m*) and/or revetments ≤25% permeable and/or ≤15% impermeable	3	
C1	Sills or ramps (>1 every *m*) and/or revetments ≤50% permeable and/or ≤33% impermeable	6	
C2	Revetments >50% permeable and/or >33% impermeable	8	
	m=200 m in mountain units; m= 1000 m in plain/hills units		
	In case of widespread bed revetment (>80%) add	12	

Intervention of maintenance and removal

A10	Sediment removal		
A	Absence of recent (last 20 years) and past (from 1950s) significant sediment removal activities	0	
B	Moderate activities in the past (from 1950s) but absent during last 20 years, or absent in the past but present recently (last 20 years)	3	
C	Intense activities in the past, or moderate in the past but present during last 20 years	6	

A11	Wood removal		
A	Absence of removal of woody material at least during the last 20 years	0	
B	Selective cuts and/or clear cuts over ≤50% of the reach during the last 20 years	2	
C	Total removal of woody material during the last 20 years	5	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

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A12	Vegetation management		
A	No cutting interventions on riparian vegetation during the last 20 years	0	
B	Selective cuts and/or clear cuts over ≤50% of the reach during the last 20 years	2	
C	Clear cuts over >50% of the reach during the last 20 years	5	

Not evaluated above the tree-line and in streams with natural absence of riparian vegetation

CHANNEL CHANGES

		part.	prog.	conf.
V1	Changes in channel pattern *(applied only to channels wider than 30 m)*			
A	Absence of changes of channel pattern since 1950s	0		
B	Change to a similar channel pattern since 1950s	3		
C	Change to a different channel pattern since 1950s	6		

V2	Changes in channel width *(applied only to channels wider than 30 m)*		
A	Absent or limited changes (≤15%) since 1950s	0	
B	Moderate changes (15÷35%) since 1950s	3	
C	Intense changes (>35%) since 1950s	6	

V3	Bed-level changes *(applied only to channels wider than 30 m)*		
A	Negligible bed-level changes (≤0.5 m)	0	
B	Limited to moderate bed-level changes (0.5÷3 m)	4	
C1	Intense bed-level changes (>3 m)	8	
C2	Very intense bed-level changes (>6 m)	12	

Not evaluated in the case of absolute lack of data, information and field evidences

Total deviation: ***Stot* =**

Maximum deviation: ***Smax* = 142 - *Sna*=**

where Sna = sum of maximum scores for those indicators that have not been applied

Morphological Alteration Index: ***IAM = Stot / Smax* =**

if Stot>Smax it is assumed IAM=1

Morphological Quality Index: ***IQM=1-IAM* =**

Quality class of the reach

0≤*IQM*<0.3: Very Poor or Bad; 0.3≤*IQM*<0.5: Poor; 0.5≤*IQM*<0.7: Moderate;
0.7≤*IQM<0.85*: Good; 0.85≤*IQM*<1.0: Very Good or High