ISPRA
Istituto Superiore per la Protezione
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IDRAIM – stream hydromorphological evaluation, analysis and monitoring system

Illustrated Guide to the Answers

Appendix to

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

Rome, March 2011

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

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Rome, March 2011

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INDEX

General Setting and Segmentation

1. GENERAL SETTING AND PHYSIOGRAPHIC UNITS

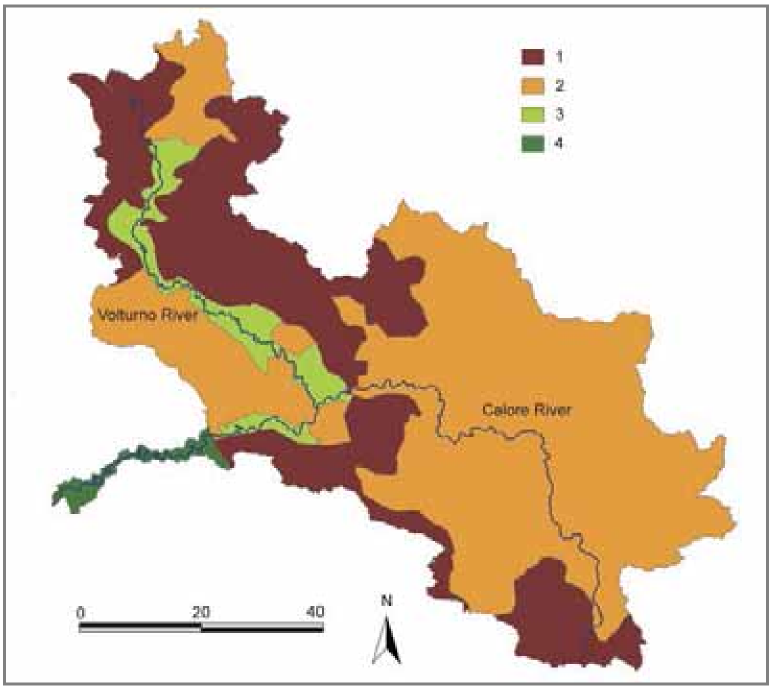


Figure 1 – Division of the watershed of the Volturno River into physiographic units. (1) Mountainous unit; (2) Hilly unit; (3) Intermontane plain unit; (4) Low plain unit.

Figure 2 – Panoramic views of the physiographic units in the Volturno River watershed. (1) Mountainous unit; (2) Hilly unit; (3) Intermontane unit; (4) Low plain unit.

2. CONFINEMENT

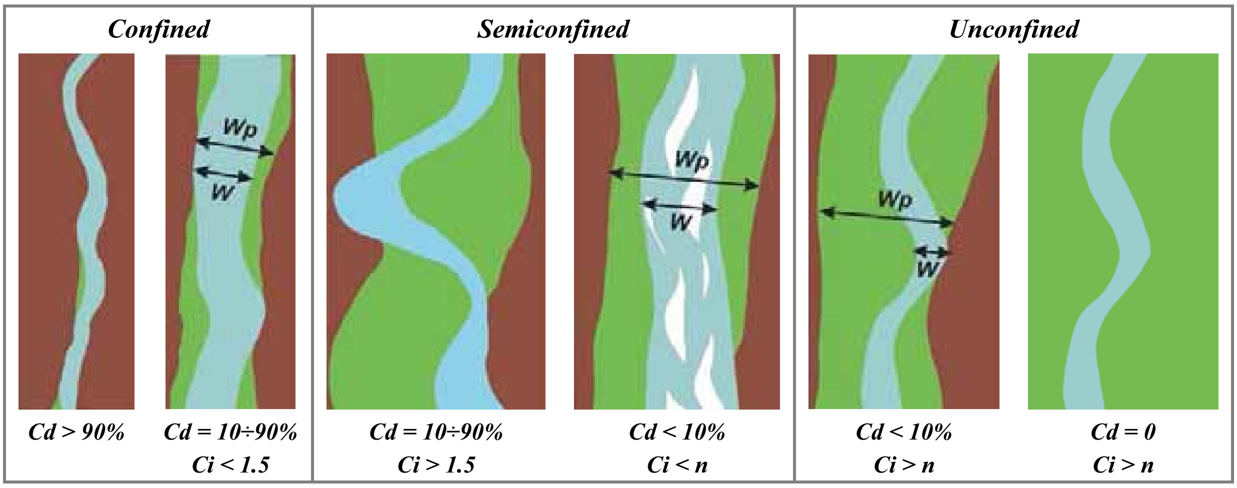


Figure 3 – Confinement classes. In green: alluvial plain; in brown: hillslopes (or ancient terraces). *Cd*: confinement degree; *Ci*: confinement index = *Wp/W*, where *Wp*: alluvial plain width (including the channel) and *W*: channel width.

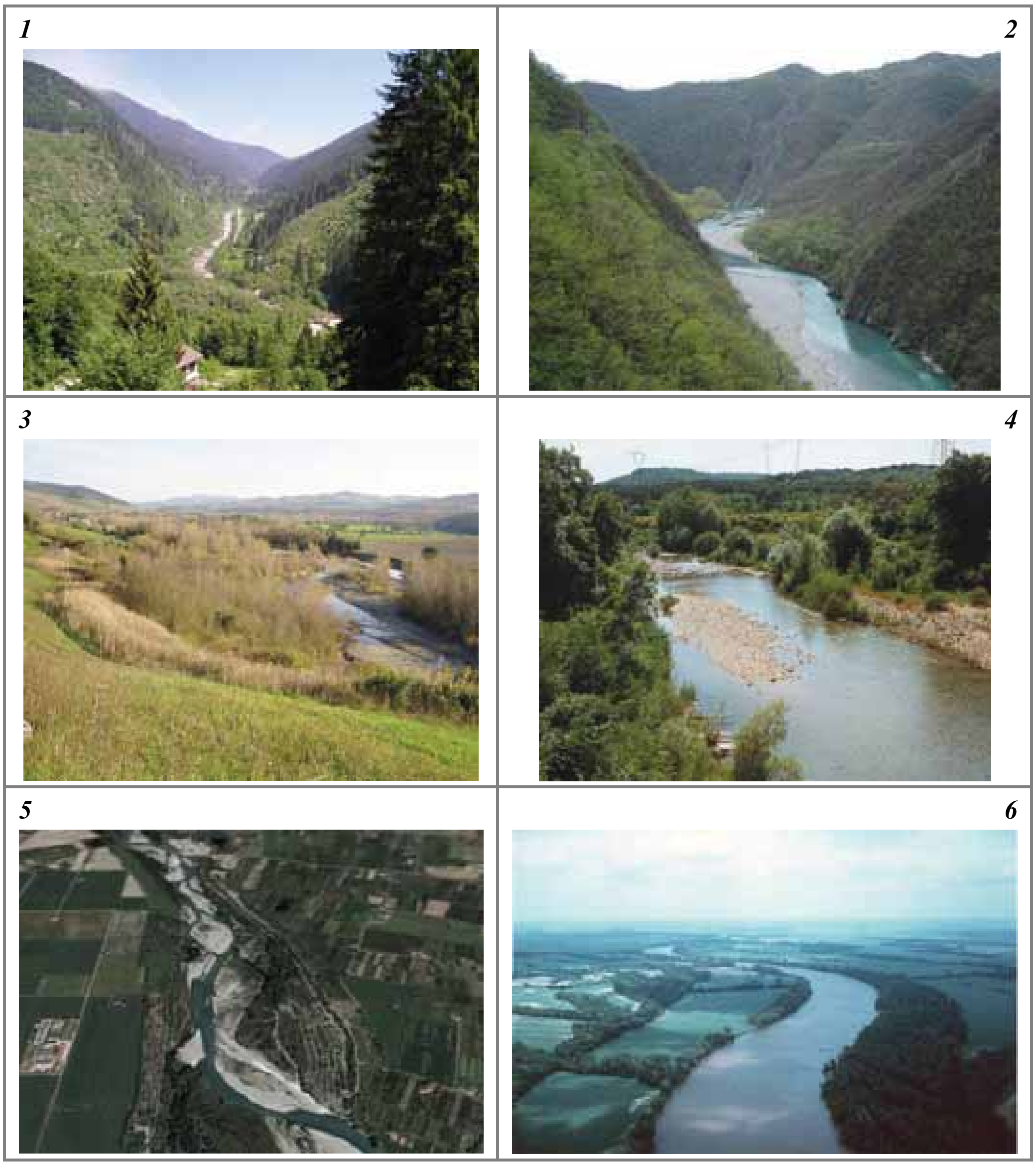


Figure 4 – Examples of different confinement classes. (1), (2) Confined channels; (3), (4) semiconfined channel; (5), (6) unconfined channels.

3. CHANNEL MORPHOLOGY

Semiconfined and unconfined channels

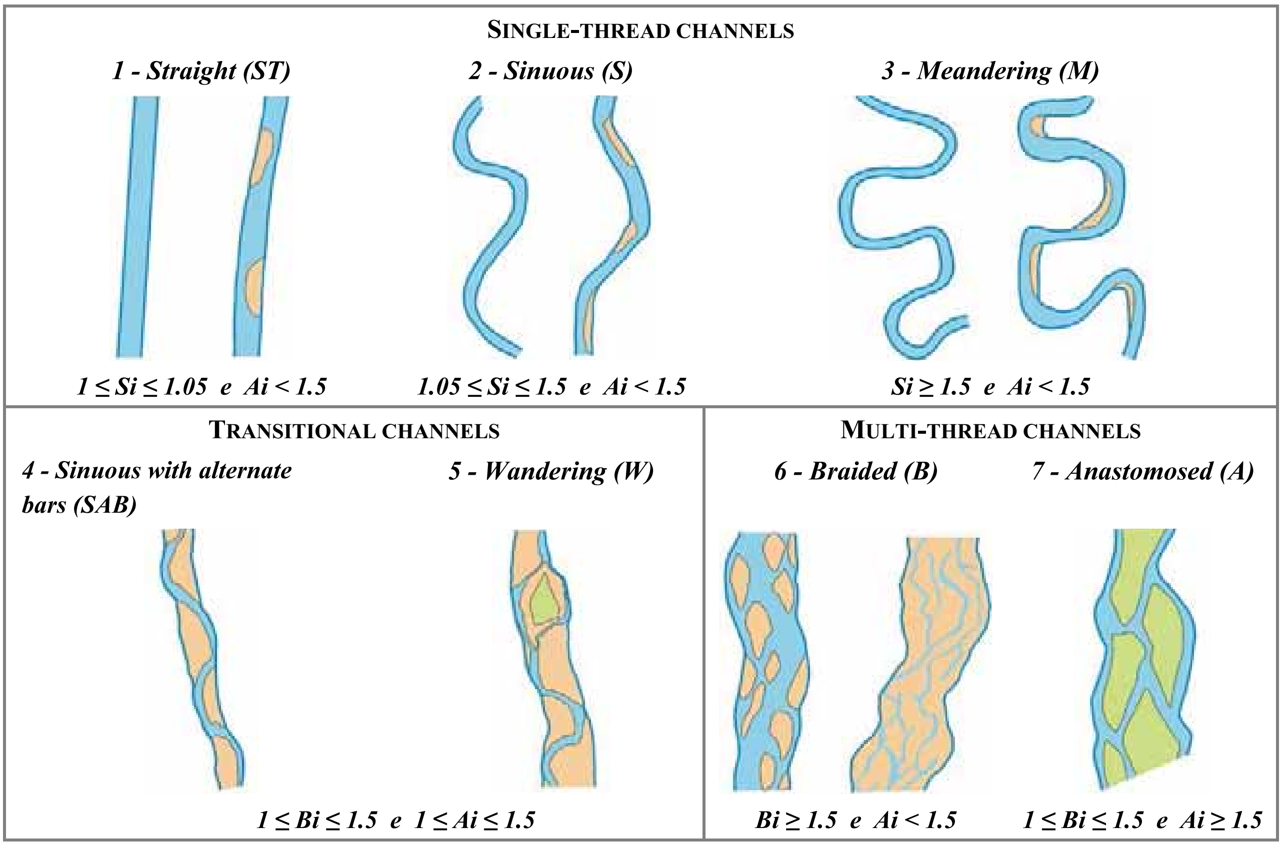


Figure 5 – Morphologies of semiconfined and unconfined channels. *Si*: sinuosity index; *Bi*: braiding index; *Ai*: anastomosing index.

Figure 6 – Examples of morphologies of semiconfined and unconfined channels. (1) Straight; (2) sinuous; (3) meandering; (4) sinuous with alternate bars.

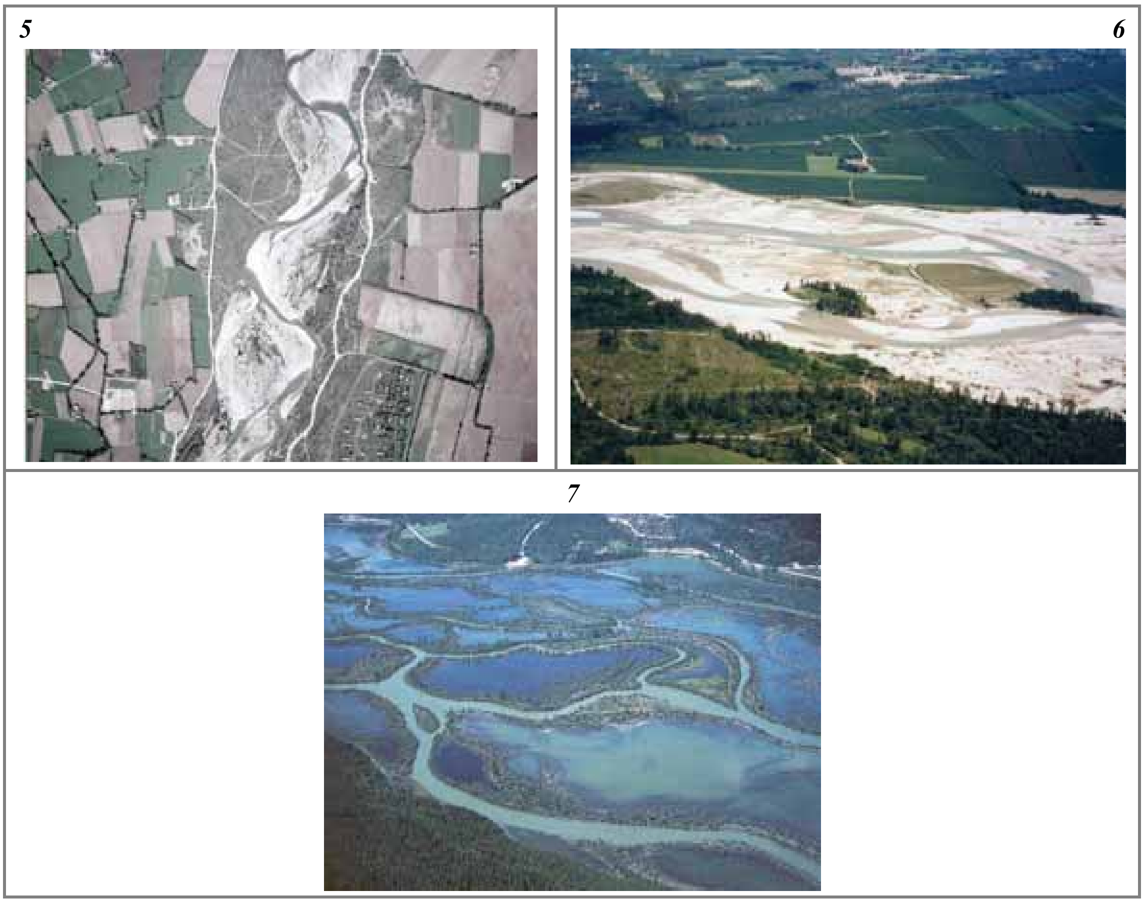


Figure 6 (continued) – Examples of morphologies of semiconfined and unconfined channels. (5) Wandering; (6) braided; (7) anastomosing (the islands and floodplain are inundated).

<u>Confined channels</u>

Figure 7 – Morphologies of confined channels. (1) Confined single-thread; (2) confined wandering; (3) confined braided; (4) confined anastomosed.

<u>SECOND LEVEL OF CLASSIFICATION BASED ON BED CONFIGURATION</u>

Bed configuration of mountain streams can be classified with reference to the two following **spatial scales**:

(1) **morphological unit**: length of the same order of channel width;
(2) **reach**: length of at least 8÷10 times the channel width.

Note that in this case the term "reach" is not identified with that defined in the segmentation, but corresponds more precisely to the site scale, and is therefore to be intended as a minimum length of application of the IQM index.

<u>*Morphological units of mobile bed channels*</u>

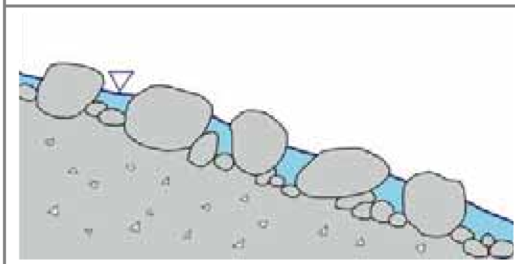
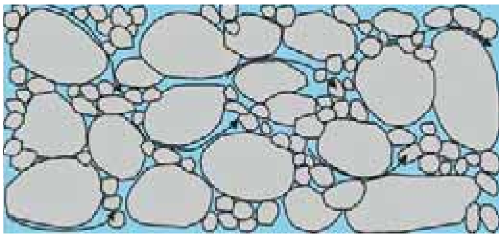
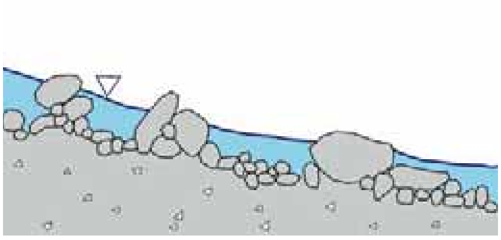
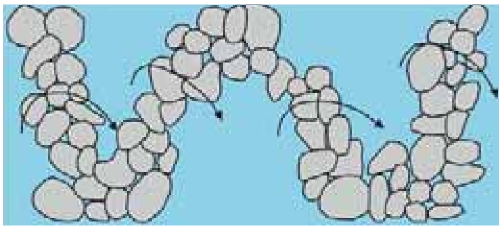
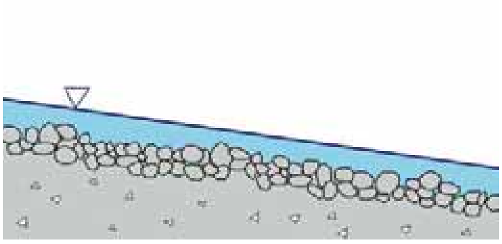
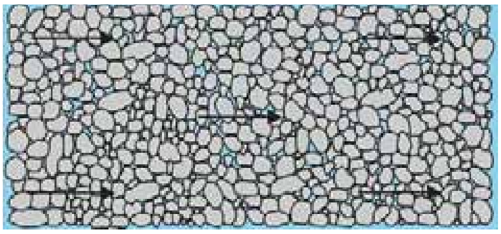
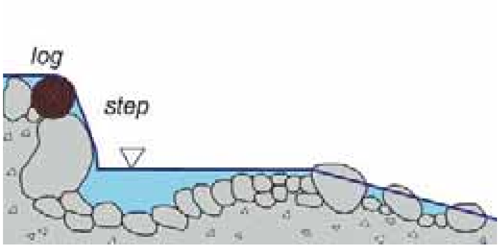
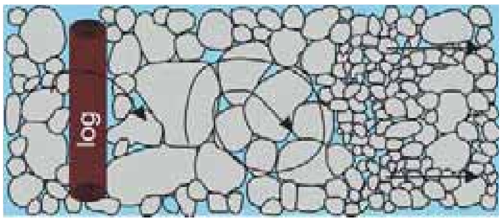
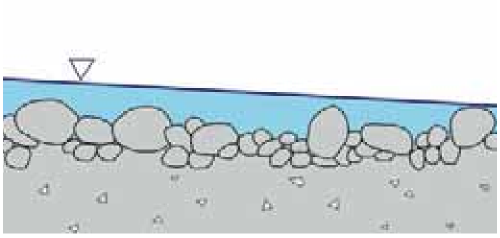
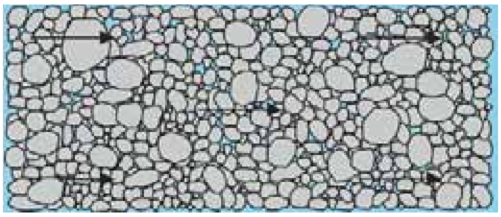
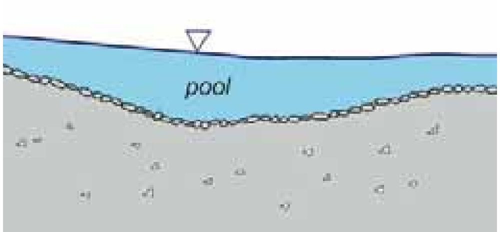
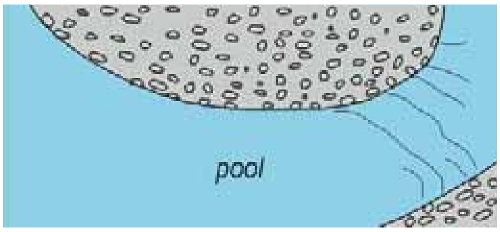
BED PROFILE	**PLANFORM**	
		***Cascade***
		***Rapid***
		***Riffle***
		***Step***
		***Glide***
		***Pool***

Figure 8 – Main morphological units of mountain mobile bed streams (modified from *Halwas & Church, 2002*).

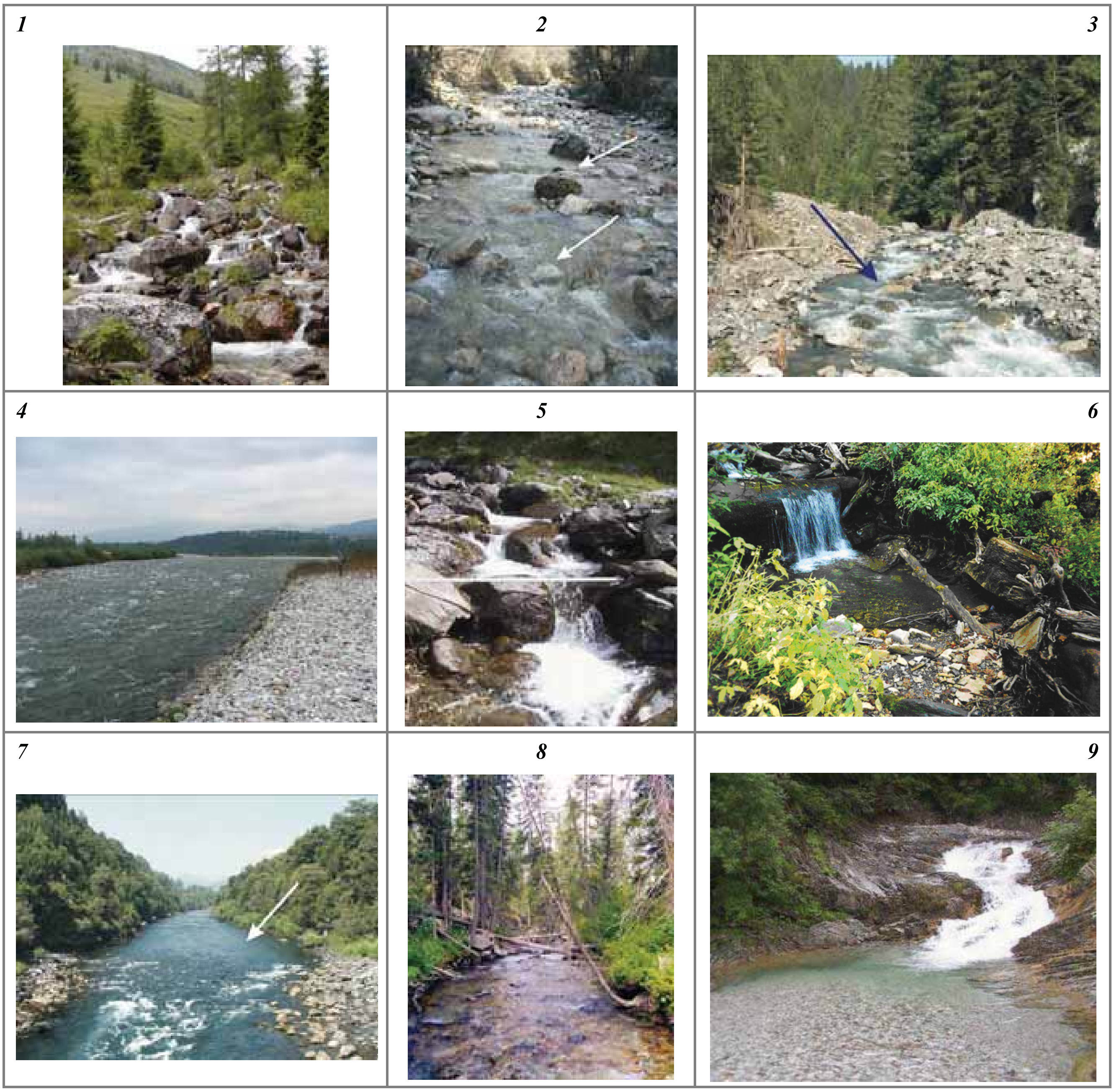


Figure 9 – Morphological units in mobile bed stream channels. (1) *Cascade*; (2), (3) *rapids* (some transverse ribs are indicated by the arrow); (4) *riffle*; (5) series of *steps* alternated with *pools*; (6) *log step*; (7) *glide* (indicated by arrow); (8) *glide*; (9) *pool* downstream a bedrock *cascade*.

Morphologies at reach scale

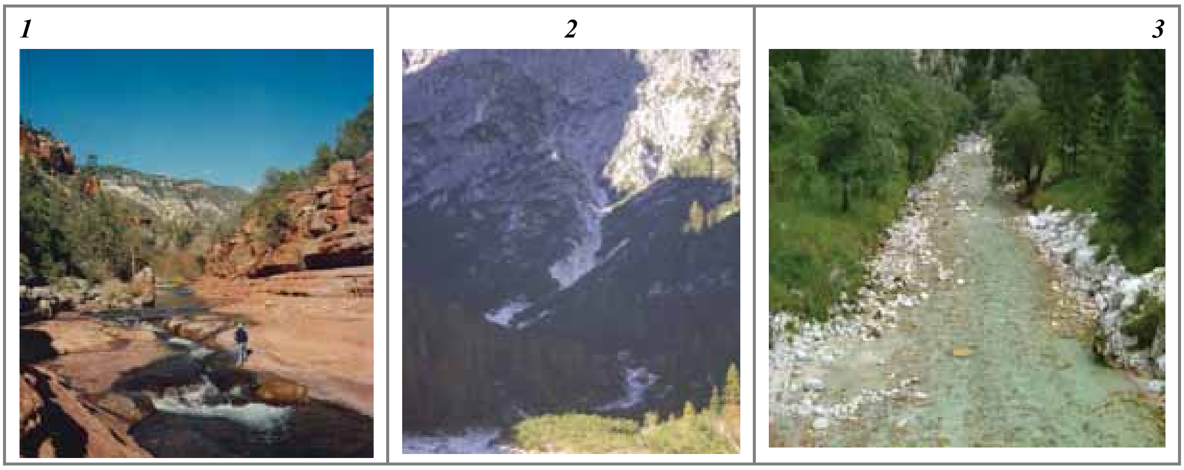


Figure 10 – First morphological classification of streams at reach scale. (1) Bedrock channel; (2) colluvial channel; (3) alluvial (mobile bed) channel.

Table 1 – Typical morphological units included in the bed configurations at reach scale.

REACH SCALE	**UNITS**
1. Cascade	Cascades, steps, pools
2. Plane bed	Rapids, glides
3. Riffle pool	Riffles, pools
4. Dune ripples	Dune, ripples

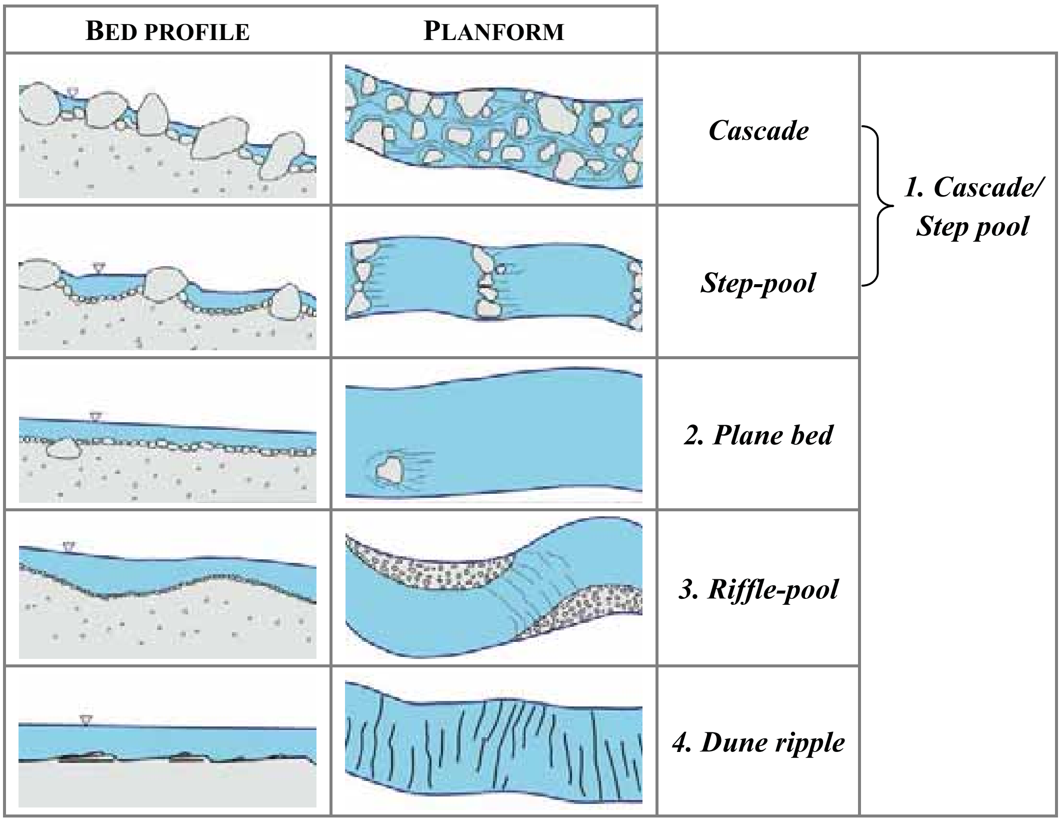


Figure 11 – Bed configurations at reach scale in alluvial (mobile bed) stream channels (modified from *Montgomery & Buffington, 1997*).

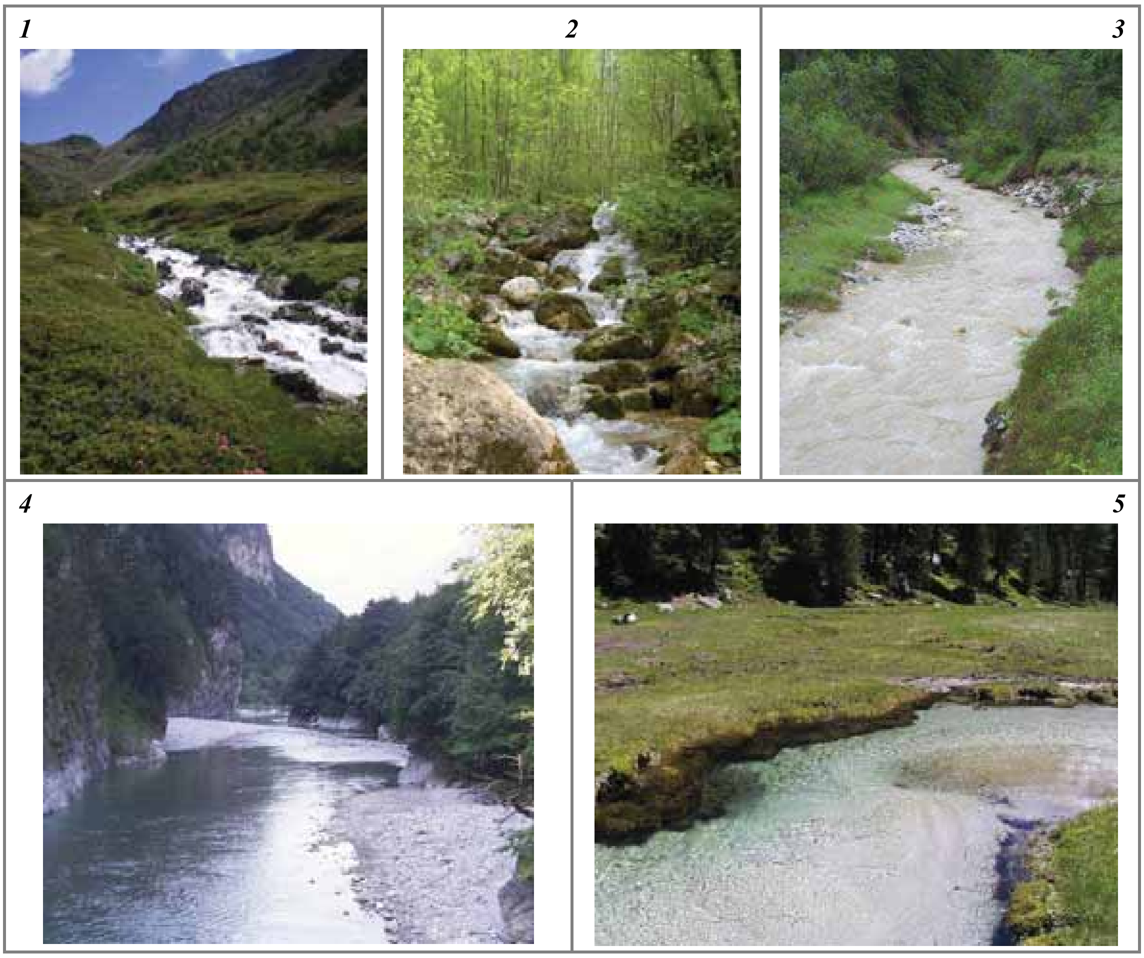


Figure 12 – Bed configurations at reach scale in mobile bed streams. (1) *Cascade*; (2) *step pool*; (3) *plane bed*; (4) *riffle-pool*; (5) *dune-ripple*.

4. FINAL SEGMENTATION

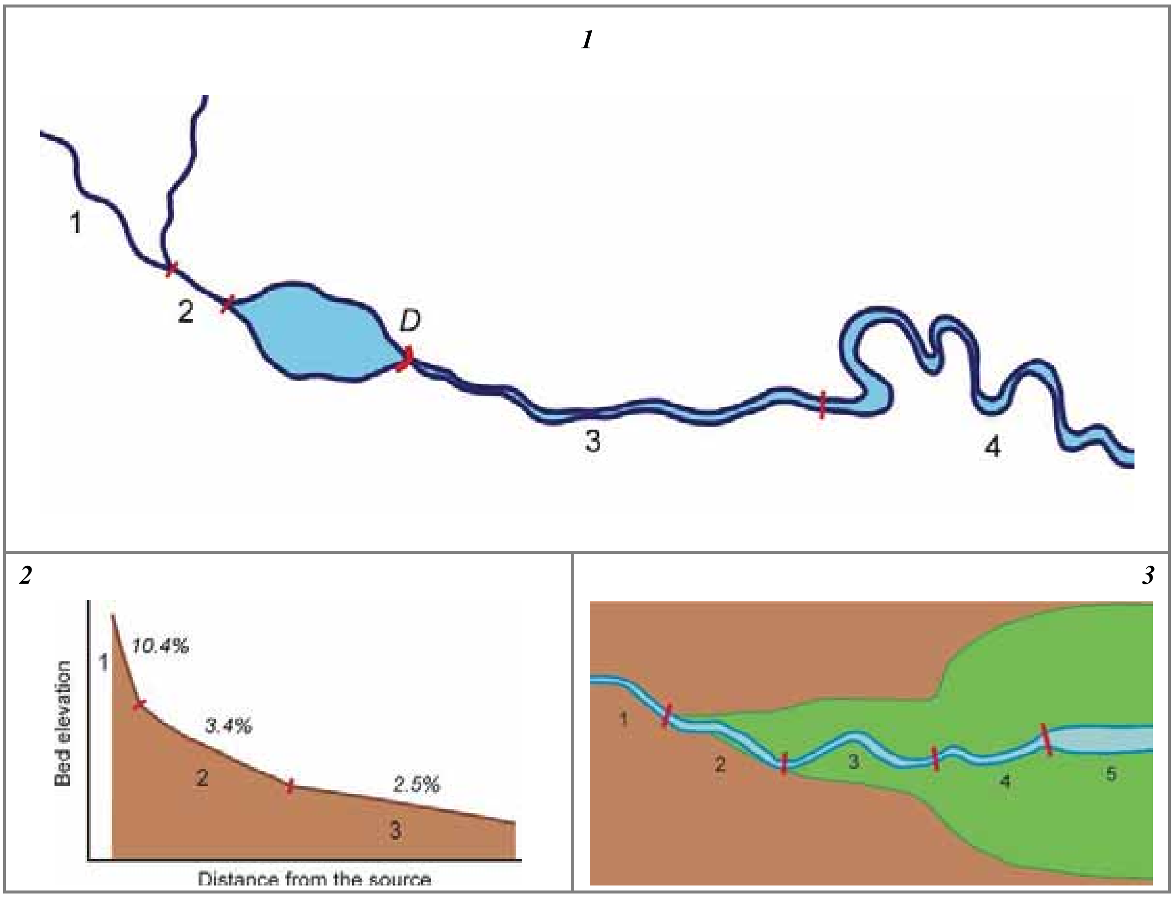


Figure 13 – Examples of discontinuities accounted for the final segmentation in reaches. (1) Hydrological discontinuity due to a relevant tributary (reaches 1 and 2); dam (D) (reaches 2 and 3: note that the reservoir is not considered as a river reach). The passage from reach 3 to 4 is instead due to a change in channel morphology (from sinuous to meandering: see previous step). (2) Discontinuity in bed slope (confined reaches). (3) Other discontinuities that can be used for river segmentation: the passage from reach 3 to the following reach is not motivated by a change in morphology (sinuous channel) but by a change in plain width and confinement index (from 3 to 4), and by a significant change in channel width (from 4 to 5).

5. SUMMARY

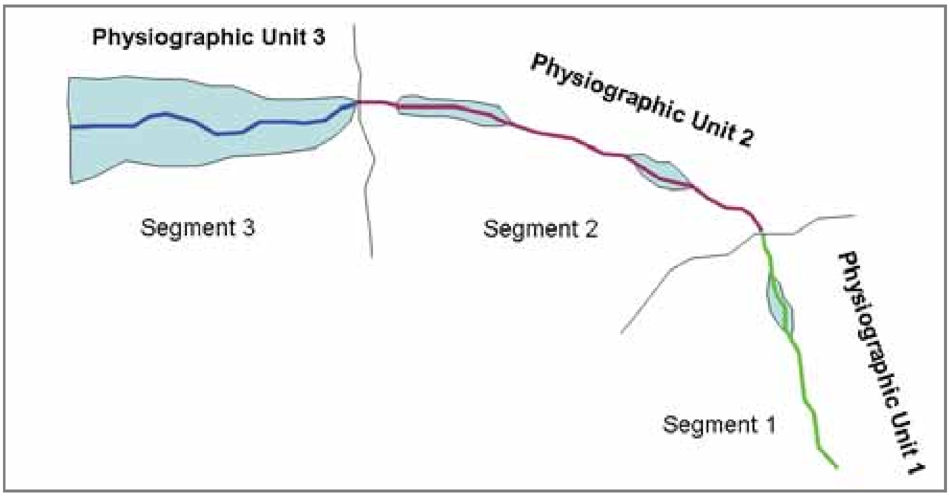


Figure 14 – Summary of the segmentation. STEP 1: for each physiographic unit, at least one segment is defined.

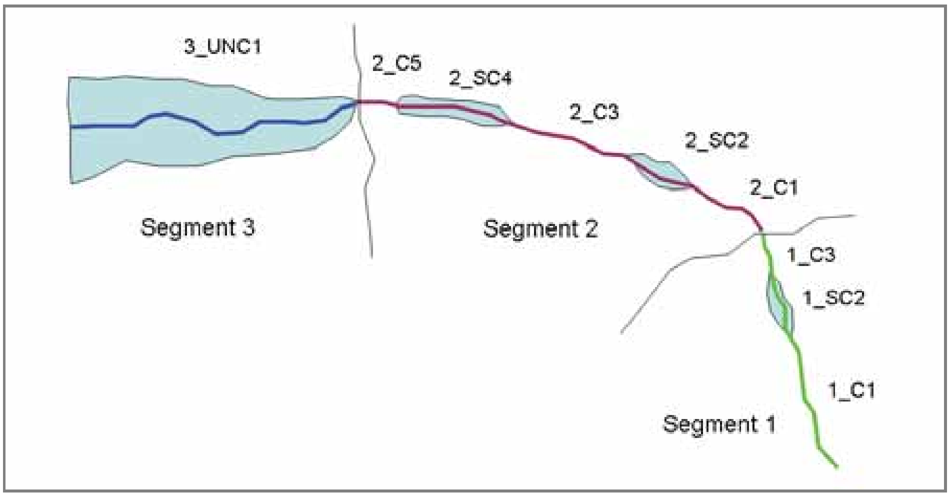


Figure 15 – Summary of the segmentation. STEP 2: a first division of the segments is carried out based on confinement classes (C: confined, SC: semiconfined, UNC: unconfined).

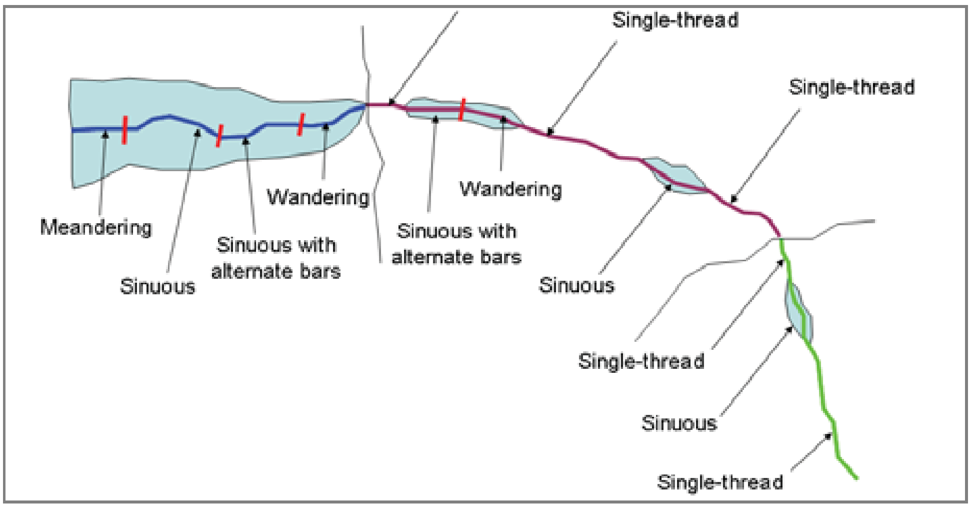


Figure 16 – Summary of the segmentation. STEP 3: channel morphologies are classified.

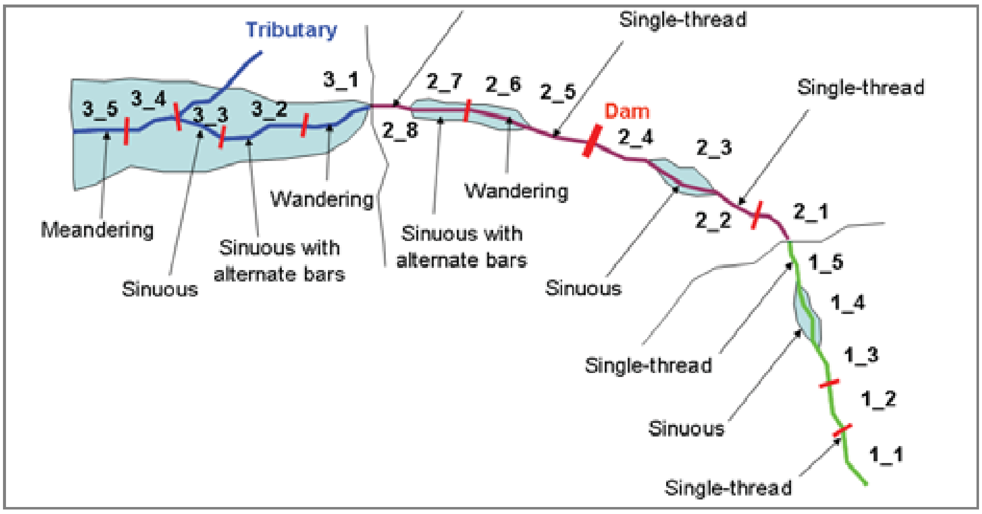


Figure 17 – Summary of the segmentation. STEP 4: the segmentation is concluded by accounting for other discontinuities (in the example: bed slope for the confined reaches, dam, and tributary).

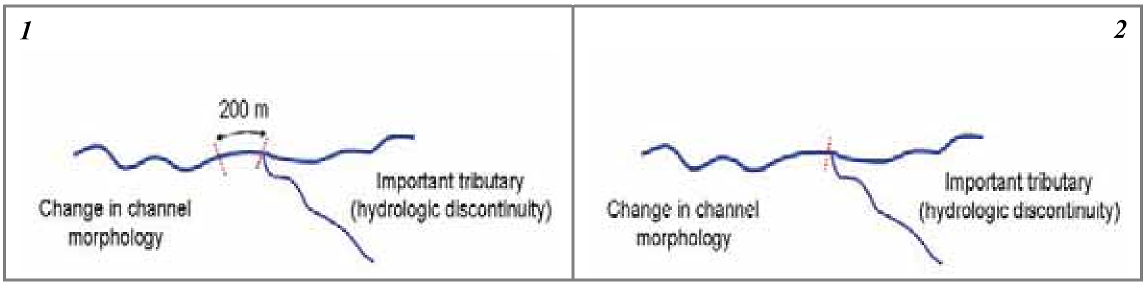


Figure 18 – In the cases in which a rigid application of the segmentation criteria would cause an excessive fragmentation, a criterion of predominance should be adopted. (1) A hydrological discontinuity exists (tributary) but, 200 m downstream, the channel changes its morphology (from sinuous to meandering), therefore a rigid application of the previous criteria would cause the definition of a reach 200 m long. (2) To avoid this, the hydrological discontinuity (tributary) is assumed as the main criterion, therefore the 200 m downstream are included in the downstream reach with a meandering morphology.

Geomorphological Functionality

1. CONTINUITY

F1: Longitudinal continuity in sediment and wood flux

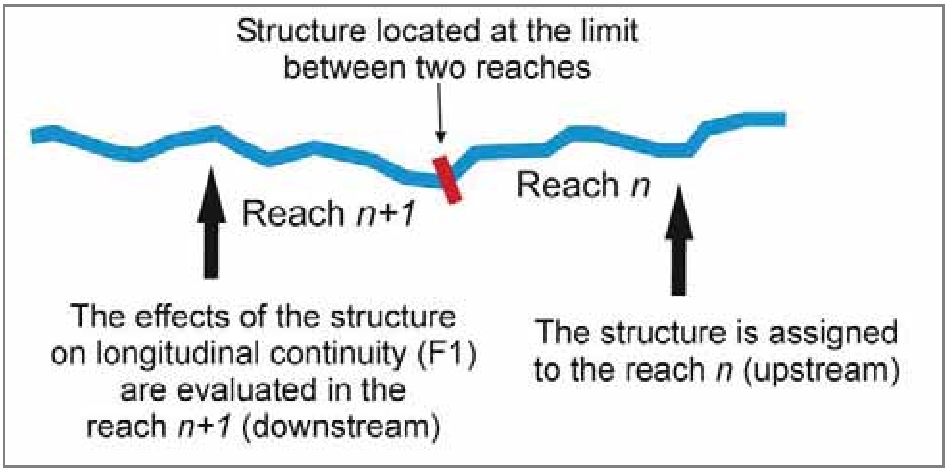


Figure 19 – Longitudinal continuity in sediment and wood flux. Rule of assignation of a transversal structure located at the limit between two reaches and its effects on longitudinal continuity.

Confined channels

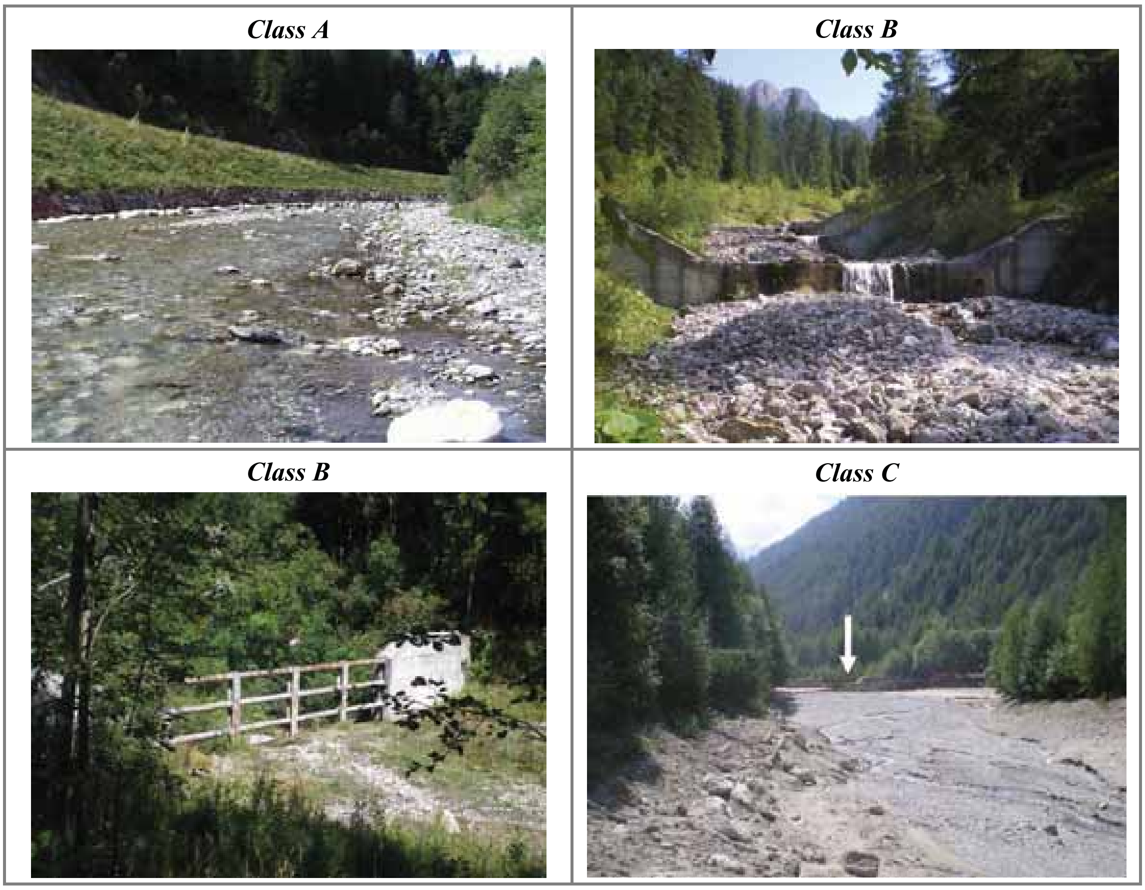


Figure 20 – Longitudinal continuity in sediment and wood flux. *Class A*: absence of discontinuities. *Class B*: up on the right, filled consolidation check dams; low on the left, open check dam. *Class C*: a check dam (arrow) with total interception represents a complete alteration of longitudinal continuity in the reach downstream from the check dam.

Semiconfined and unconfined channels

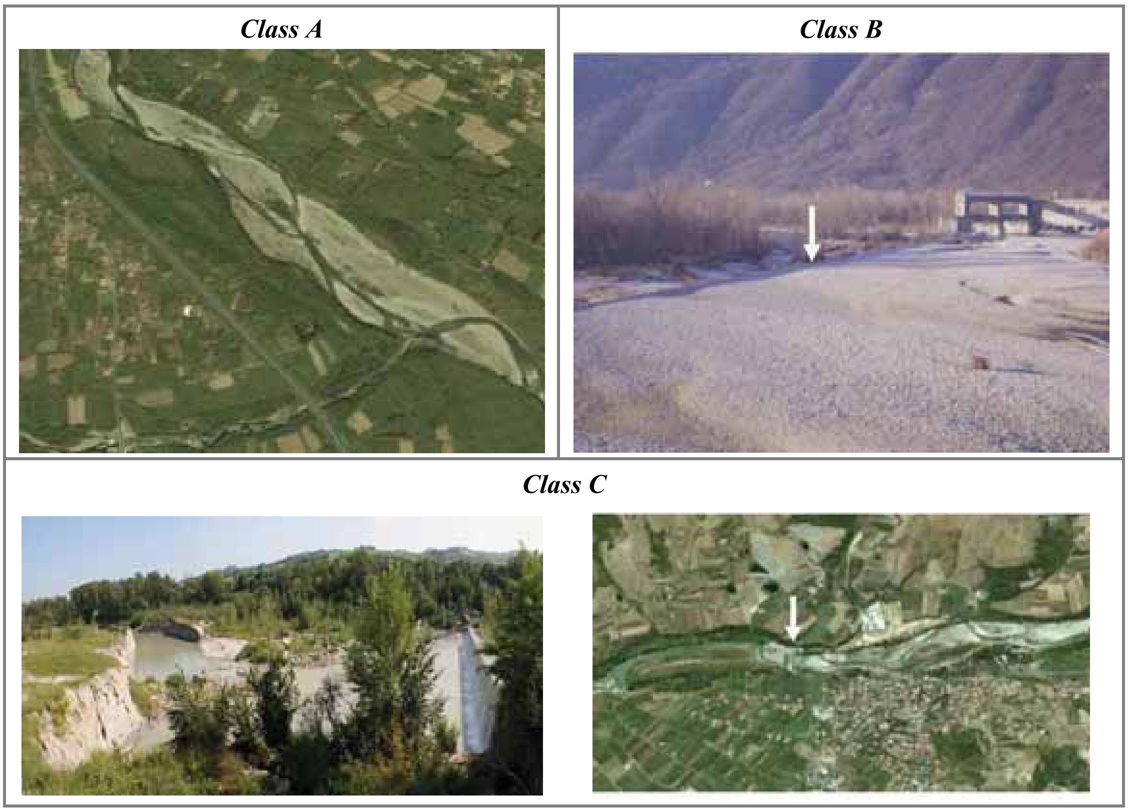


Figure 21 – Longitudinal continuity in sediment and wood flux. *Class A*: absence of discontinuities. *Class B*: filled check dam (arrow) altering the normal flux of sediment but without causing total interception and a discontinuity of forms (bars are equally existing either upstream and downstream). *Class C*: the presence of a weir or check dam with total sediment interception results in a significant alteration of the reach immediately downstream (the river flows from right to left).

F2: Presence of a modern floodplain

Relationships with other surfaces

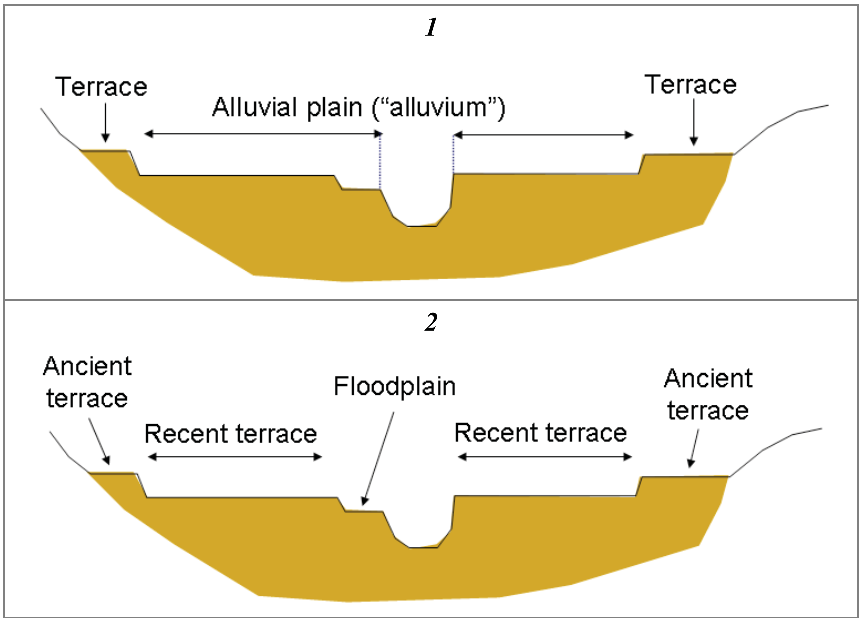


Figure 22 – Distinction between alluvial plain and floodplain. (1) Terminology commonly used on geological maps; (2) terminology adopted here (the alluvial plain can include both floodplain and "recent" terraces, which are previous portions of a floodplain abandoned due to incision during the last 100÷150 years).

Figure 23 – Differences between floodplain and "recent" terrace. (1) and (2) Examples of modern floodplain (note the very limited differences in elevation with channel bars); 3: "recent" terrace generated by a bed incision of about 2÷3 m; 4: "recent" terrace generated by an intense incision (> 3 m).

Interactions with other indicators

With reference to the schematic diagram (*Figure 24*), some cases are reported as follows, highlighting the interactions with other indicators (bed incision, changes in channel width, vegetation in the fluvial corridor). Note that the assignation to one of the three *Classes* (*A*, *B* or *C*) depends on the lateral and longitudinal extension of the floodplain.

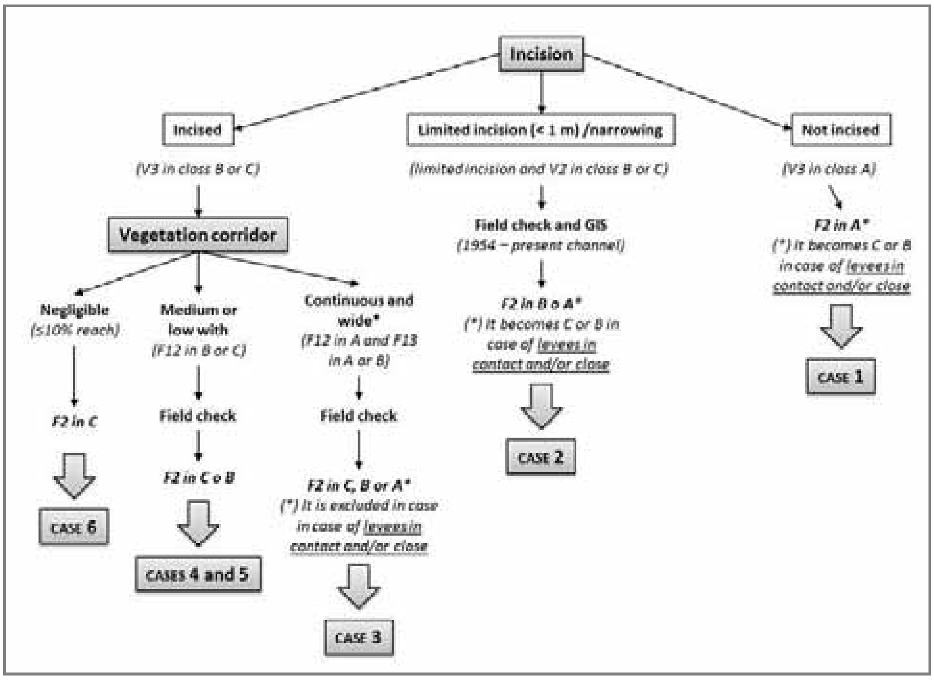


Figure 24 – Sketch of interactions among different indicators to support the classification of *F2*.

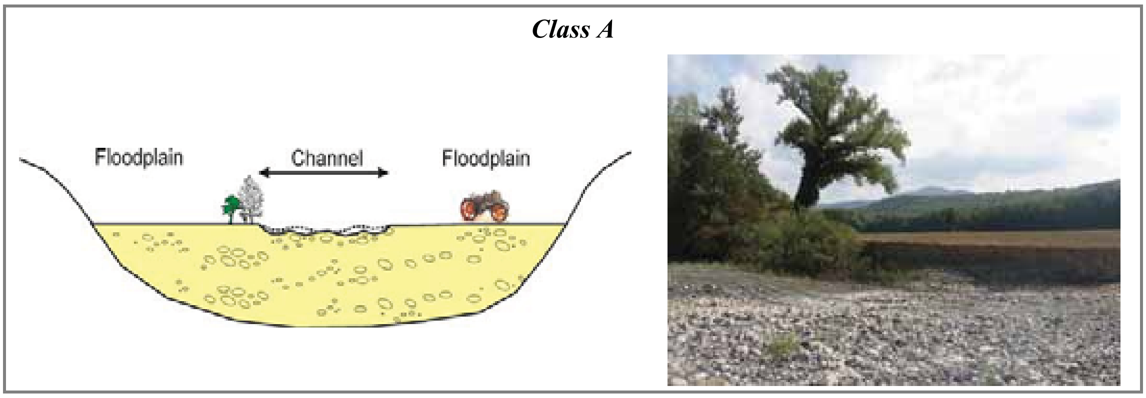


Figure 25 – CASE 1: the channel is not incised (*V3* in *Class A*), therefore the adjacent plain coincides with a modern floodplain (*Class A*).

Class B

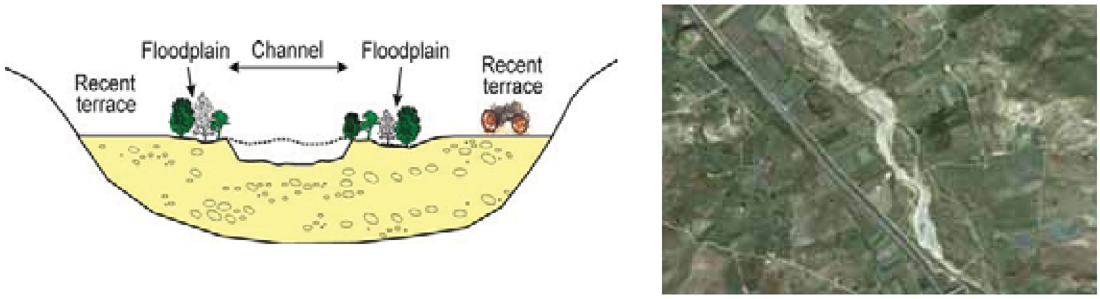


Figure 26 – CASE 2: the channel is slightly incised and narrowed compared to 1954. Vegetation in the fluvial corridor is quite wide (*F12* in *Class B*) and mostly coincides with the channel of 1954. The field assessment enables verification that the vegetation corridor coincides with the modern floodplain, resulting therefore in *Class B*.

Class B

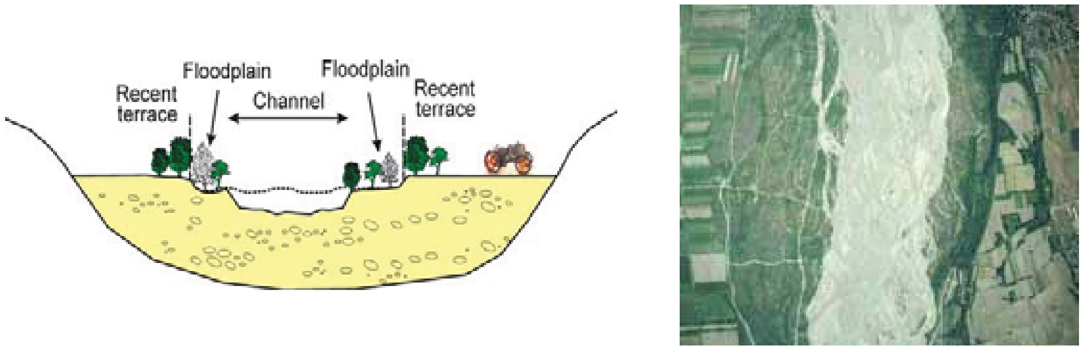


Figure 27 – CASE 3: the channel is moderately incised and slightly narrowed compared to 1954. Vegetation corridor is continuous and wide (*F12* and *F13* in *Class A*). Field assessment enables verification that the vegetation corridor also includes portions of "recent" terraces, therefore the floodplain is not sufficiently wide (*Class B*).

Class B

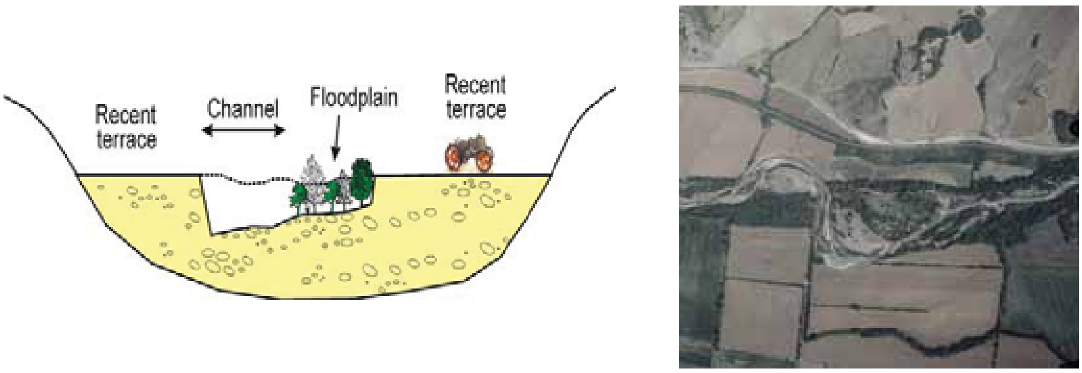


Figure 28 – CASE 4: the channel is incised and the vegetation corridor has a medium width (*F12* in *Class B*). Field assessment enables verification that most of the vegetations corridor corresponds to a modern floodplain formed after incision as consequence of lateral mobility (*Class B*).

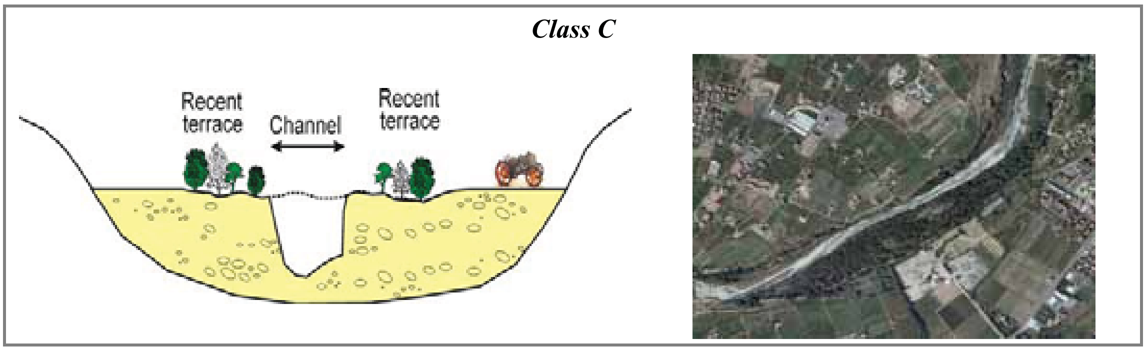


Figure 29 – CASE 5: the channel is heavily incised (> 6 m) and narrowed, and the vegetation corridor has a medium width (*F12* in *Class B*). Field assessment enables verification that the vegetation in this case occupies portions of the 1954 channel disconnected by the present channel ("recent" terraces) (*Class C*).

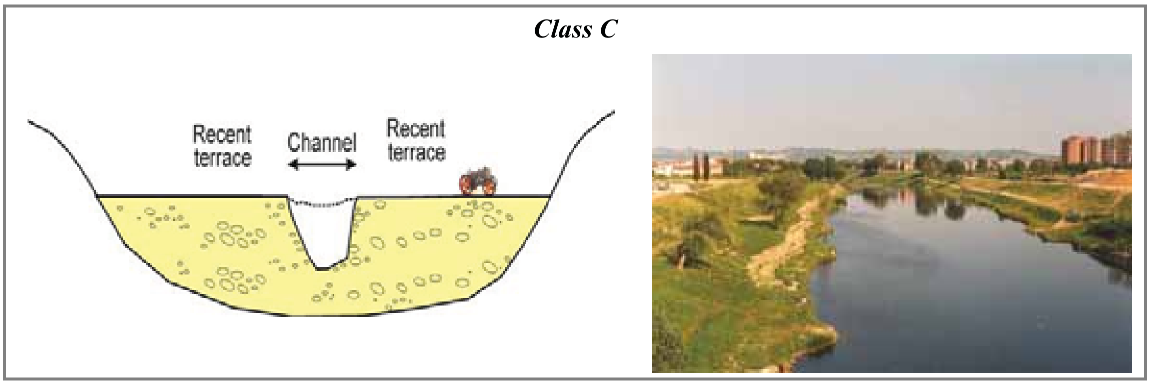


Figure 30 – CASE 6: the channel is heavily incised (> 6 m) and vegetation corridor that could be a post-incision floodplain is absent (*F12* in *Class C*), therefore the reach is necessarily in *Class C*.

F3: Hillslopes – river corridor connectivity

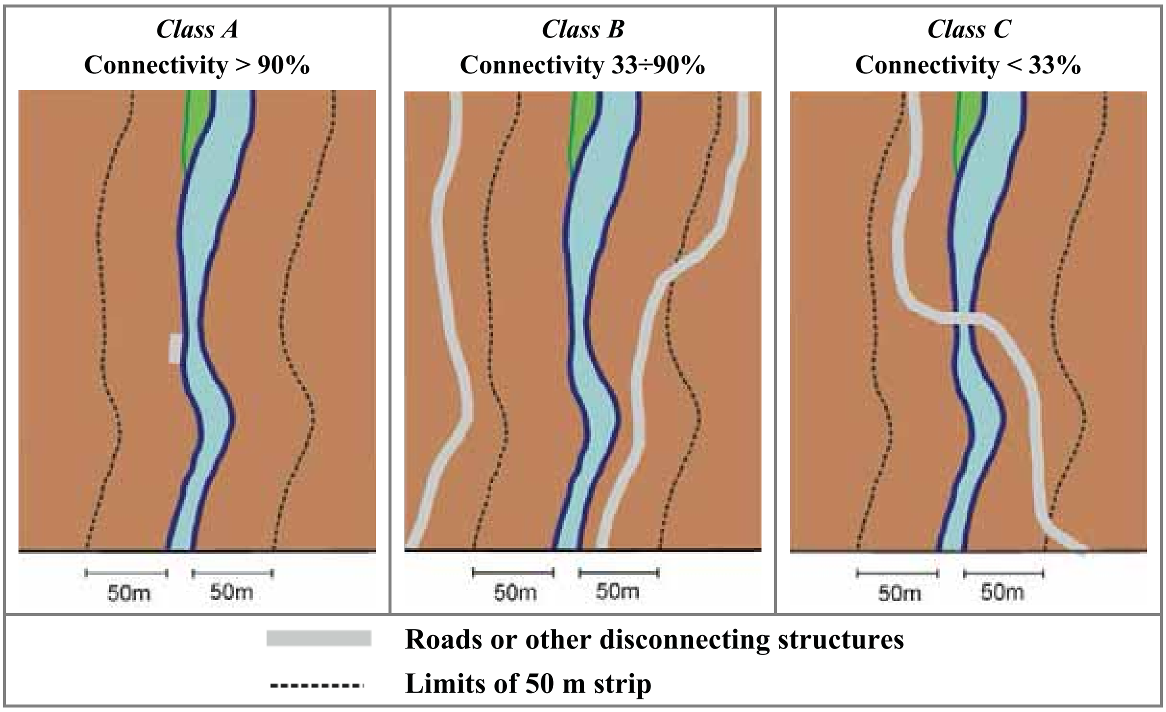


Figure 31 – Connectivity between hillslopes and fluvial corridor. *Classes* as a function of the link between stream and adjacent hillslopes for a strip 50 m wide on both sides.

F4: Processes of bank retreat

Figure 32 – Processes of bank retreat. *Class A*: frequent retreating banks, particularly along the outer side of bends (red arrows, photo on the left). *Class B*: this class includes reaches with bank erosion observed only locally. *Class C*: absence of eroding banks due to bank protections and/or absent channel dynamics.

Class C

Figure 32 (continued) – Processes of bank retreat. *Class C* (last row): widespread unstable banks with mass movements due to an excessive bank height related to bed incision.

F5: Presence of a potentially erodible corridor

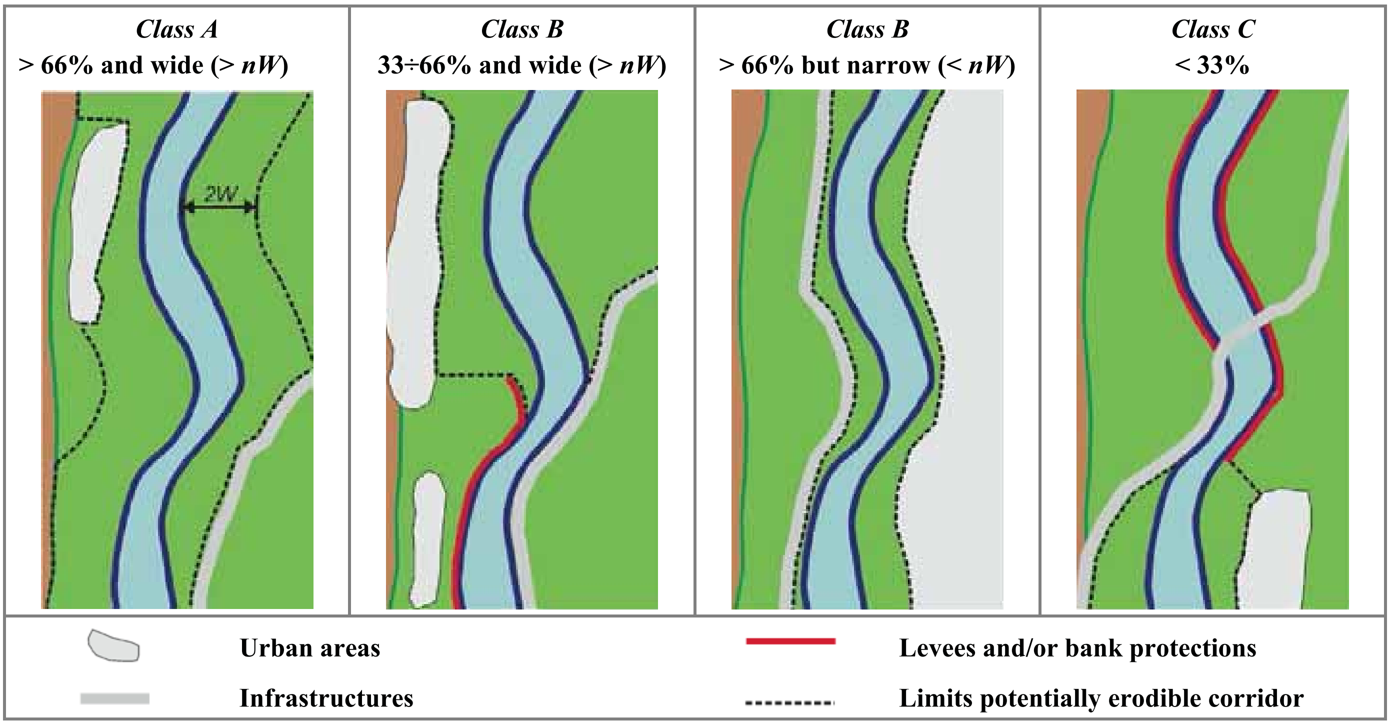


Figure 33 – Potentially erodible corridor. *Class A*: notwithstanding the constructed area and the road, a continuous and sufficiently wide erodible corridor exists. *Class B*: the erodible corridor is wide (mean width in the reach > *nW*) but with medium longitudinal continuity (33÷66%) (second figure from left), or it is continuous (> 66%) but not sufficiently wide (mean width < *nW*) (third figure from left). *Class C*: a potentially erodible corridor (of any width) exists only for < 33% of the reach.

2. MORPHOLOGY

F6: Bed configuration – valley slope

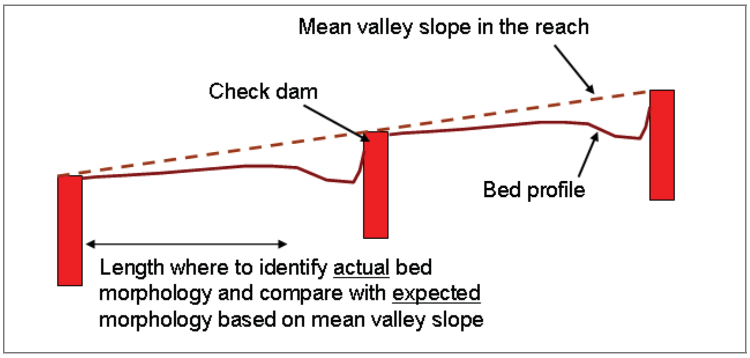


Figure 34 – Bed configuration and valley slope. Rule for the measurement of the mean valley slope of the reach in the presence of structures (check dams) and to identify the length of analysis of bed morphology.

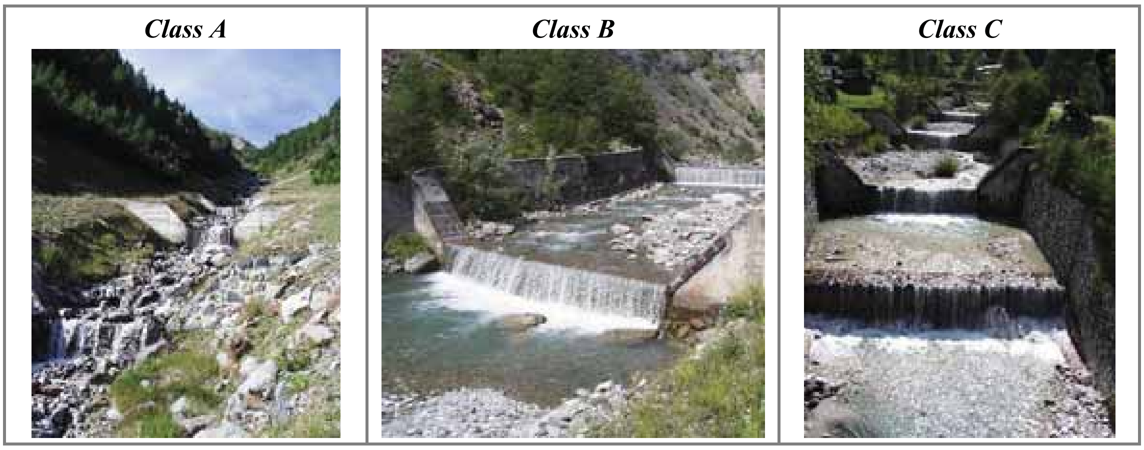


Figure 35 – Bed configuration and valley slope. *Class A*: consolidation check dams that do not alter the expected bed configuration based on valley slope (step pool in both cases). *Class B*: the consolidation check dams determine a bed configuration (plane bed) different from the expected one (cascade / step pool). *Class C*: complete alteration of bed configuration, due to distance between transversal structures being too close, not allowing the creation of natural bed forms (except the scour pool downstream from the structures).

F7: Forms and processes typical of the channel pattern

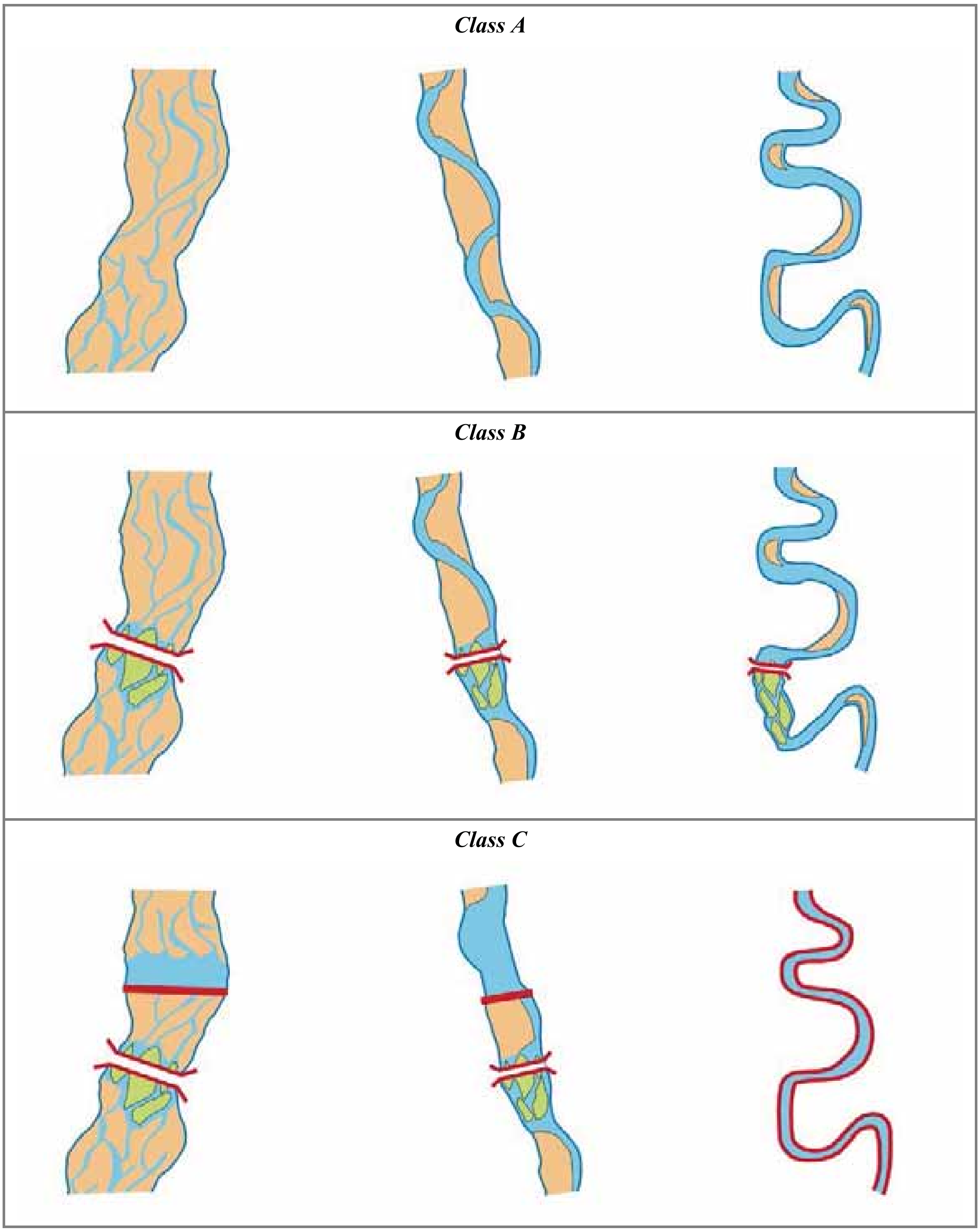


Figure 36 – Forms and processes typical of the channel pattern: examples for multi-thread, transitional, and single-thread channels. *Class A*: absence of alterations. *Class B*: a bridge can alter the morphological pattern (< 33% of the reach) by the formation of islands. *Class C*: in case of a braided or transitional channel, a bridge and a check dam can produce significant alterations in the reach (> 33%). Notwithstanding these alterations, the reach maintains a prevalence of forms such as to be classified as braided or sinuous with alternate bars, respectively. In the case of a single-thread channel, bank protections cause a loss of the typical forms and processes for that typology (bars, bank erosion, etc.), although the conservation of a meandering planimetric pattern.

F8: Presence of typical fluvial forms in the alluvial plain

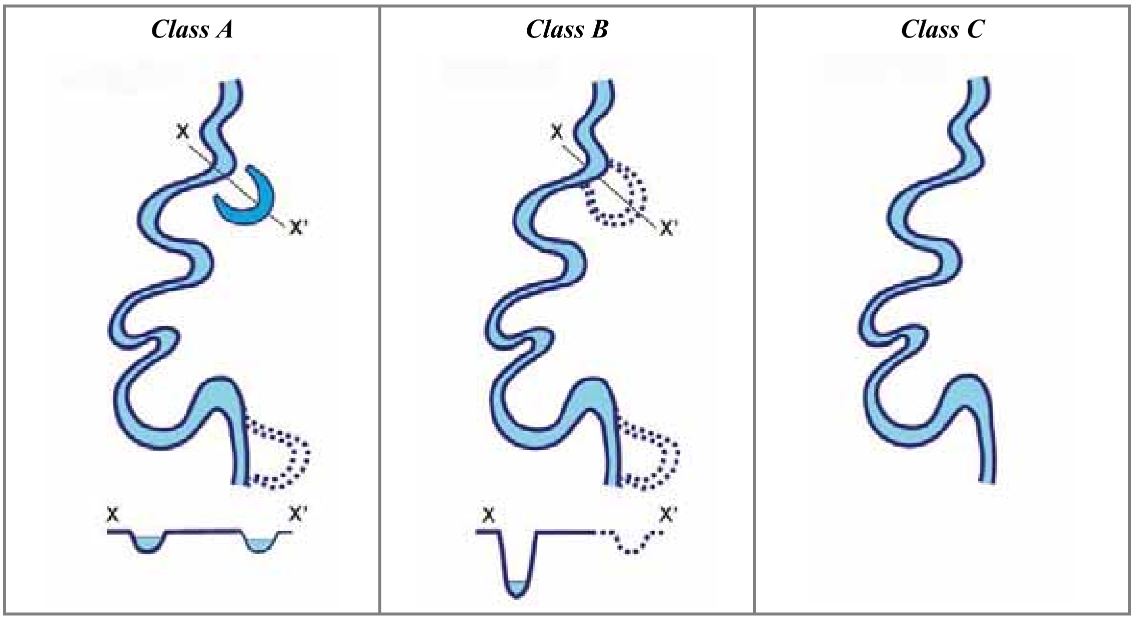


Figure 37 – Presence of typical fluvial forms in the alluvial plain. *Class A*: presence of natural fluvial forms (e.g. abandoned meander, oxbow lake). *Class B*: traces of fluvial forms, now disconnected by the channel due to incision, but with possible reactivation. *Class C*: complete absence of fluvial forms in the alluvial plain.

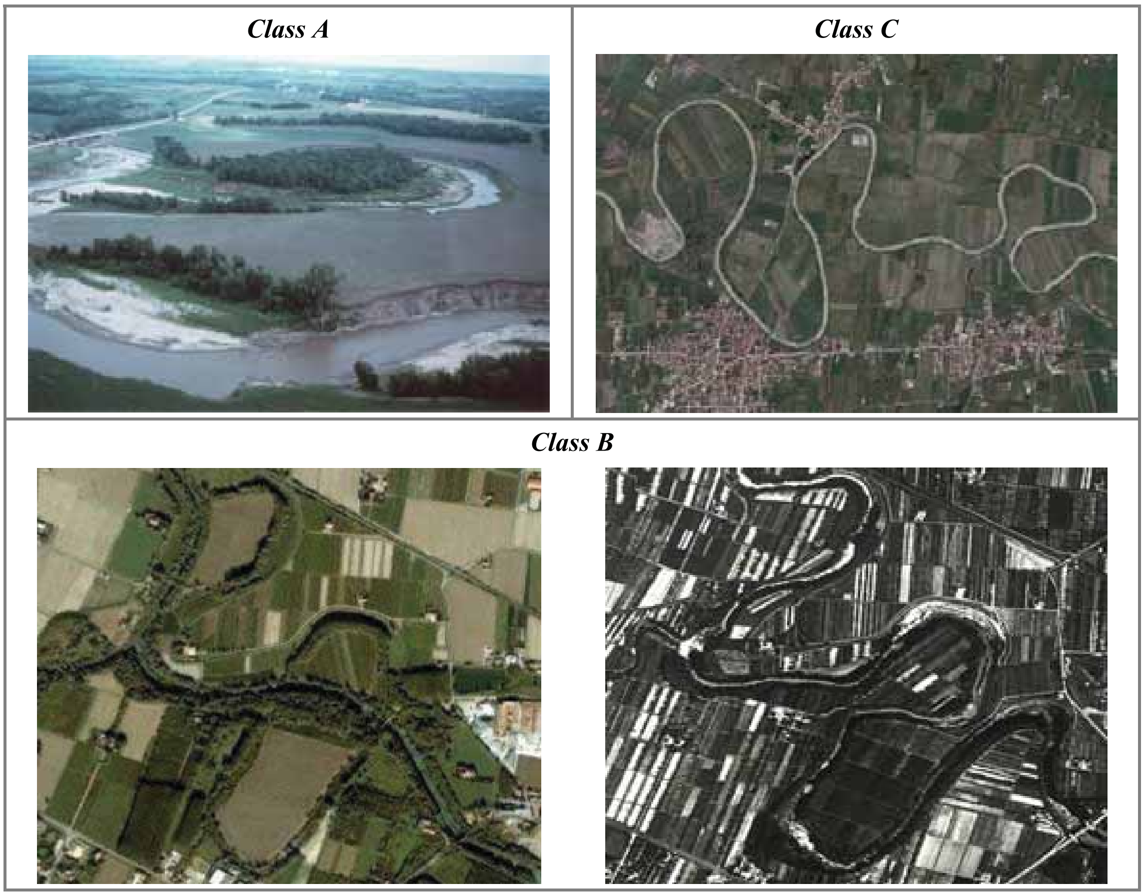


Figure 38 – Presence of typical fluvial forms in the alluvial plain. *Class A*: meandering river with a recent cut-off. *Class C*: meandering river with complete absence of forms in the plain. *Class B*: traces of abandoned meanders exits (photo on the left), disconnected from the channel because of bed incision. The observation of the aerial photos of the 1950's (photo on right) enables verification that these forms have been abandoned during the last decades.

F9: Variability of the cross-section

Confined channels

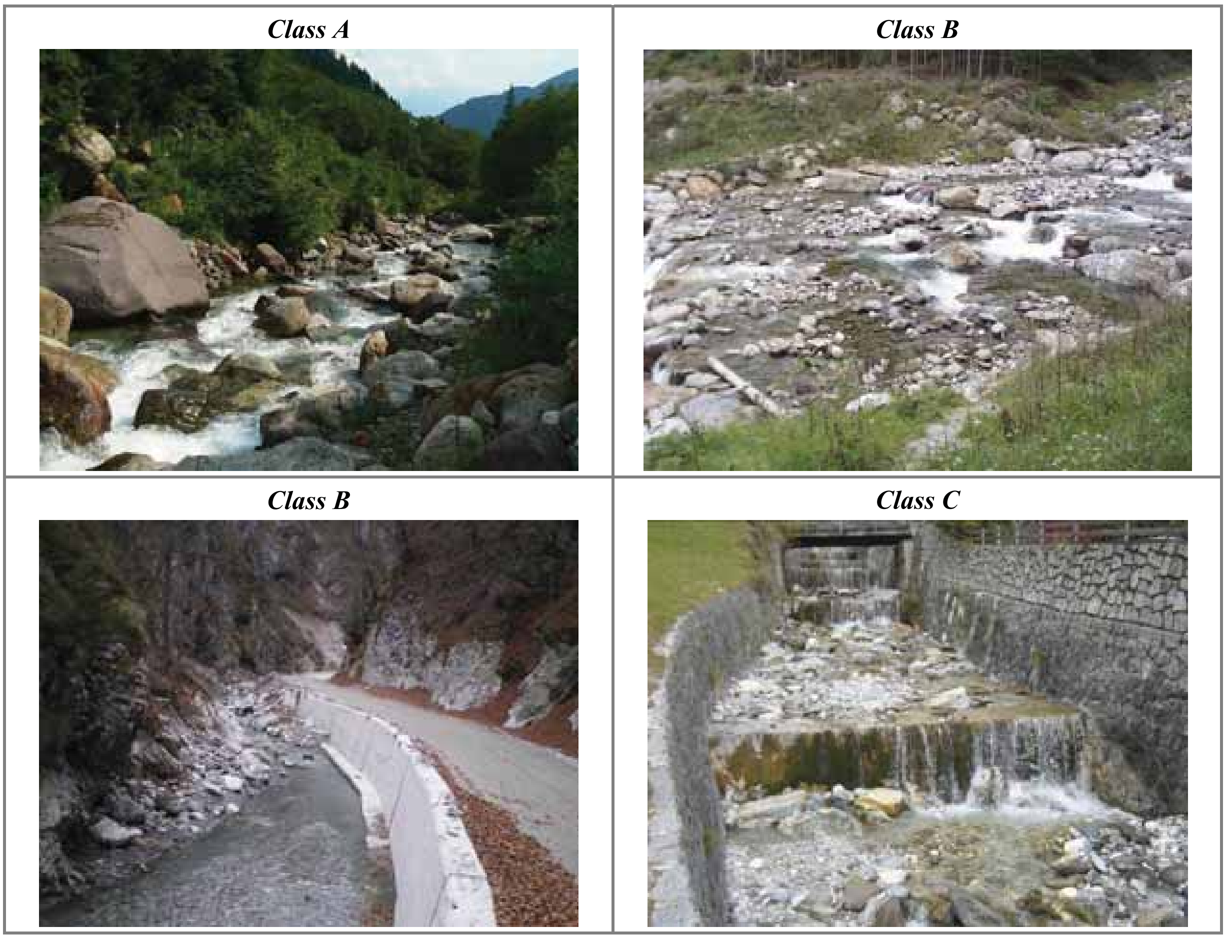


Figure 39 – Variability of the cross-section in confined channels. *Class A*: absence of alterations of the natural heterogeneity in the cross-section. *Class B* (photo top right): alterations for a limited portion of the reach. *Class B* (photo bottom left): alterations on a substantial portion of the reach (> 66%) but only on one side (bank wall). *Class C*: complete alteration of the natural heterogeneity in the cross-section due to bank walls on both sides.

Semiconfined and unconfined channels

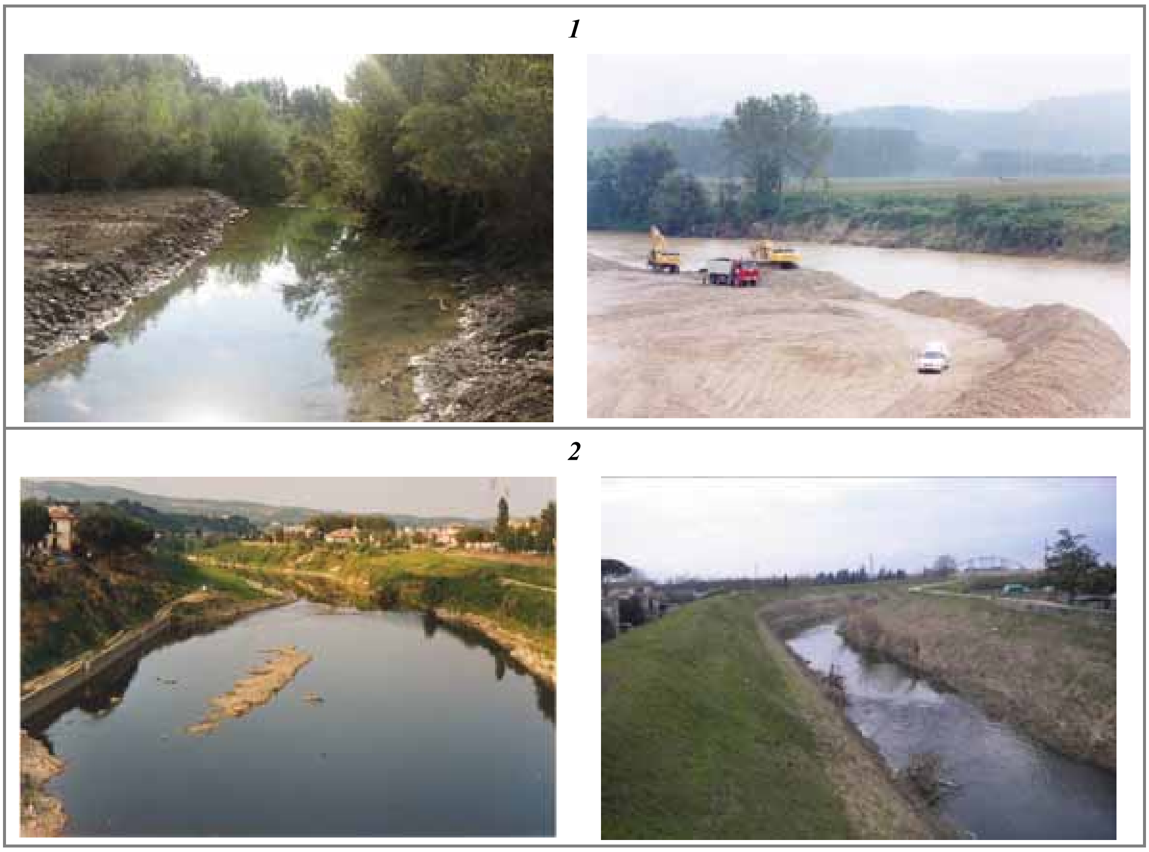


Figure 40 – Alteration of cross-section variability in semi- and unconfined channels. (1) Cases of partial homogenization of the cross-section due to interventions. (2) Cross-section homogeneity extended for long reaches due to excessive artificiality.

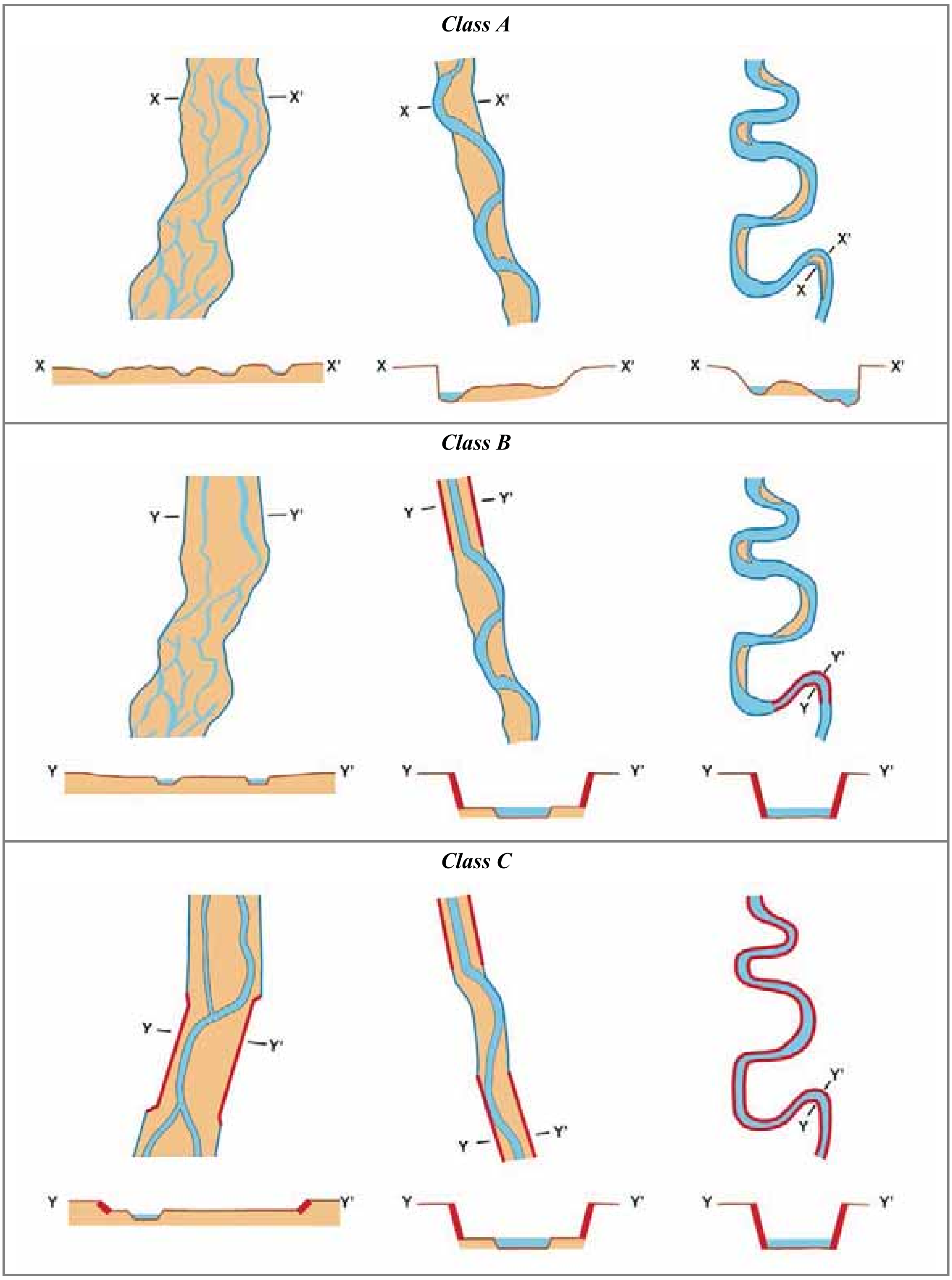


Figure 41 – Variability of the cross-section in semi- and unconfined channels: examples for multi-thread, transitional, and single-thread channels. *Class A*: absence of alterations. *Class B*: alterations for a portion < 33% of the reach length. *Class C*: alterations for a portion > 33% of the reach length.

F10: Structure of the channel bed

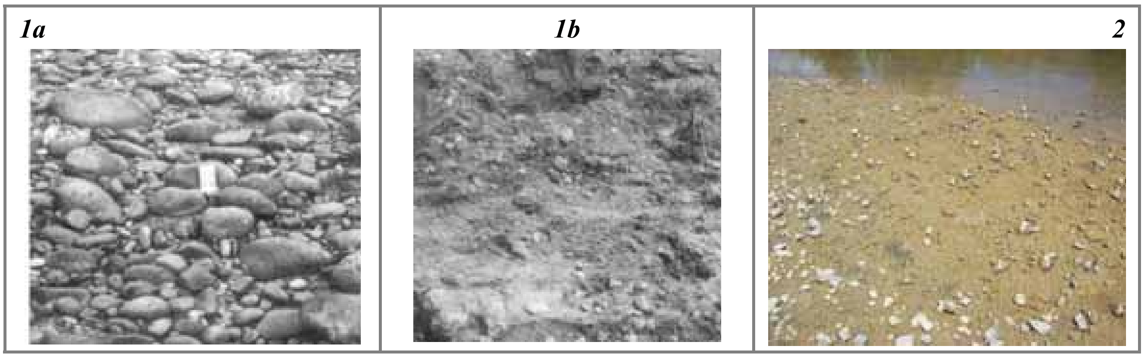


Figure 42 – Alterations of the substrate. (1) Armouring (*a*: superficial layer; *b*: sub-layer). (2) Clogging.

Confined channels

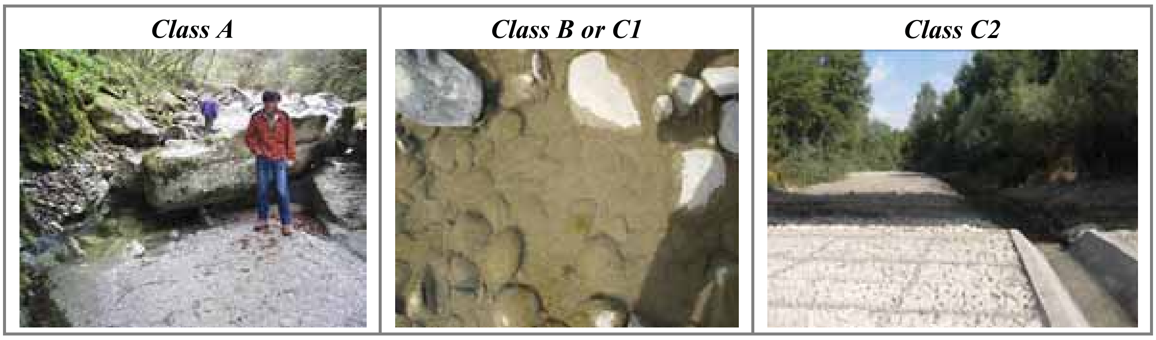


Figure 43 – Alteration of substrate in confined channels. *Class A*: natural heterogeneity of substrate in a confined channel. *Class B* or *C1*: presence of clogging (the assignation to *Class B* or *C1* will depend on its extension in the site). *Class C2*: complete alteration of substrate because of widespread bed revetments.

<u>*Semiconfined and unconfined channels*</u>

Figure 44 – Alterations of substrate in semi- and unconfined channels. *Class A*: natural sediment heterogeneity in an unconfined channel. *Class B* or *C1*: presence of armouring (photo on left) or clogging (photo on right) (assignation to *Class B* or *C1* will depend on the extension of armouring and/or clogging along the site). *Class C2*: bedrock outcroppings due to bed incision (photo on left) or completely altered substrate because of bed revetment (photo on right).

F11: Presence of in-channel large wood

Class A

Class C

Figure 45 – Presence of large wood. *Class A*: natural presence of large wood in a steep confined channel with limited width and (cascade, first row on left), and in a wider and less steep confined channel with (plane bed morphology, center); natural absence of riparian vegetation and large wood because the reach is above the tree-line (right); natural presence of large wood in unconfined channels (photos in central row). *Class C*: examples of channels with absence of large wood because of recent interventions of removal (photos in the lower row).

3. VEGETATION IN THE FLUVIAL CORRIDOR

Figure 46 – Vegetation in the fluvial corridor. (1) Presence of vegetation connected with the channel in a semiconfined reach; (2) absence of vegetation (right) or vegetation disconnected by the stream channel because of the presence of walls.

<u>F12: Width of functional vegetation in the fluvial corridor</u>

<u>Confined channels</u>

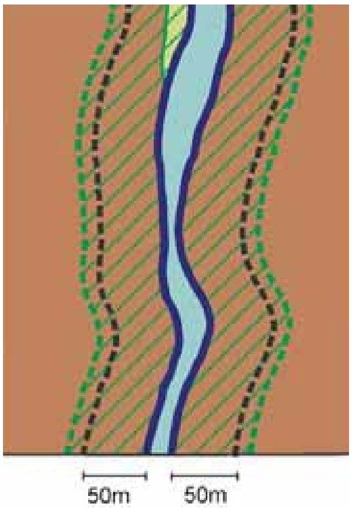
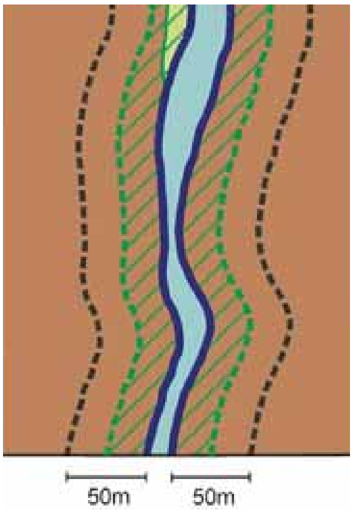
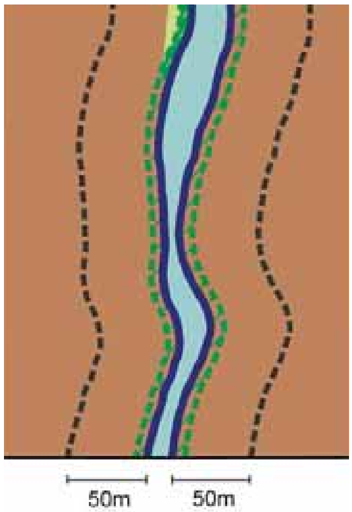
Class A **Vegetation width > 90% of the 50m strip**	***Class B*** **Vegetation width 33÷90% of the 50m strip**	***Class C*** **Vegetation width < 33% of the 50m strip**
		

Figure 47 – Width of functional vegetation in confined channels. *Class A*: the vegetation corridor occupies > 90% of the plain and adjacent hillslopes (for a strip of 50 m for each side, represented by the dotted black line). *Class B*: the vegetation corridor is between 33 and 90%. *Class C*: the vegetation corridor is extremely limited (< 33%).

Semiconfined and unconfined channels

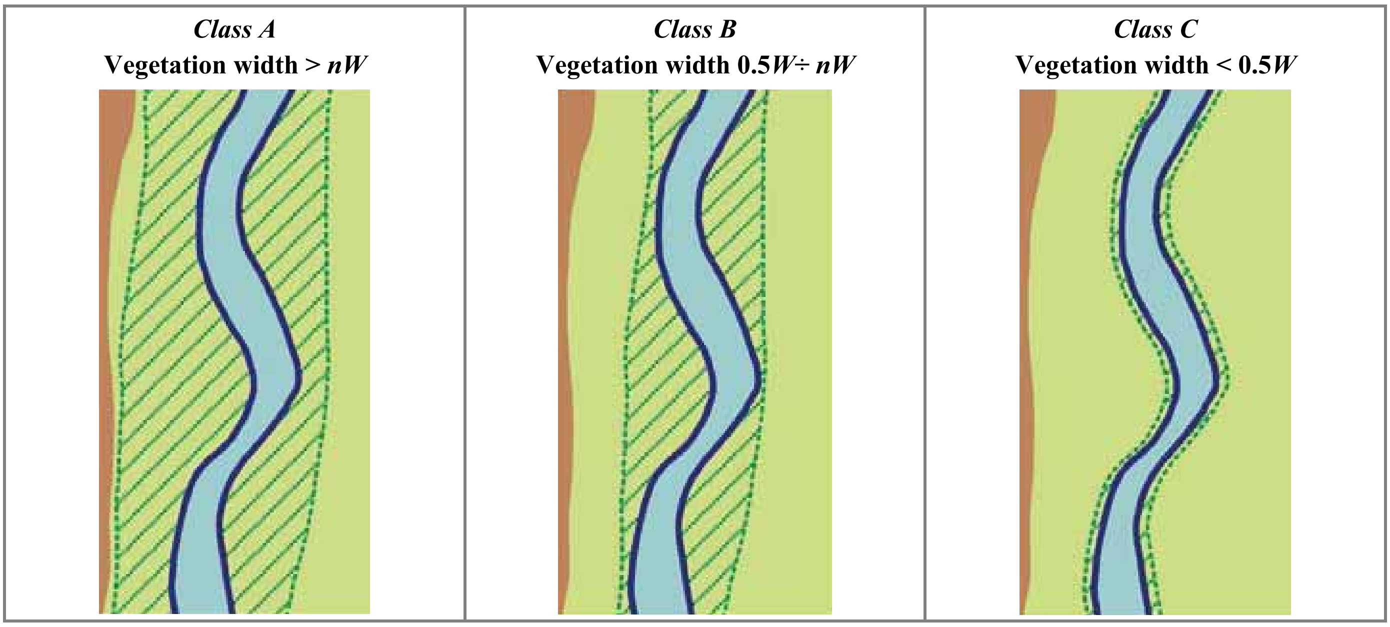


Figure 48 – Width of fluvial corridor in semi- and unconfined channels. *Class A*: the vegetation corridor is sufficiently wide, having a width > nW (W: mean channel width); *Class B*: the vegetation corridor has a medium width, being included between $0.5W$ and nW; *Class C*: the vegetation corridor is extremely narrow, having a width < $0.5W$.

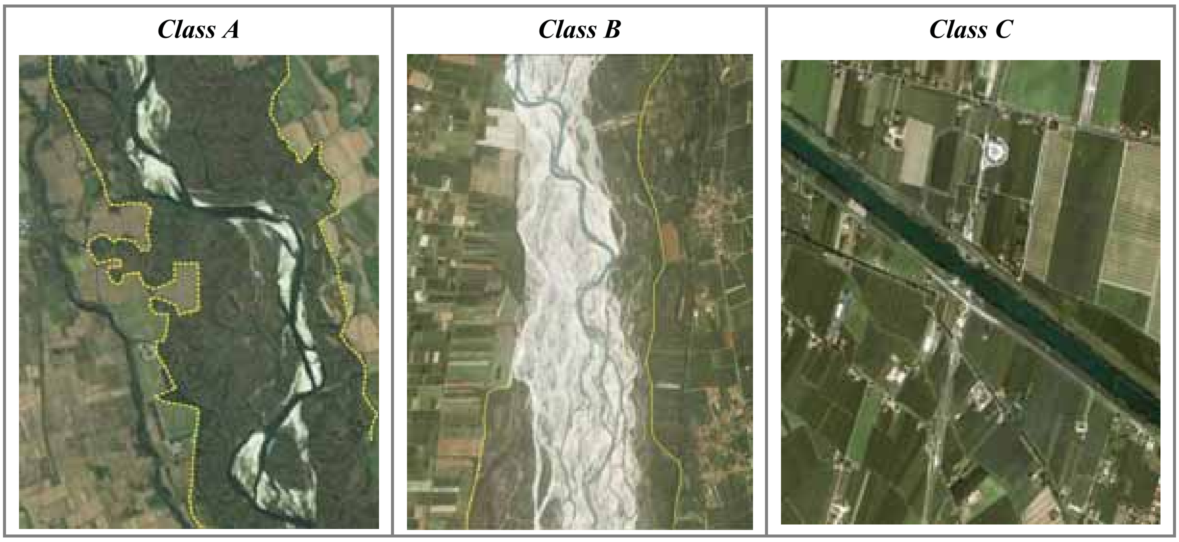


Figure 49 – Width of functional vegetation in semiconfined and unconfined channels. *Class A*: the vegetation corridor is very wide compared to the channel width. *Class B*: the vegetation corridor has a medium width. *Class C*: the vegetation corridor is almost absent.

F13: Linear extension of functional vegetation along the banks

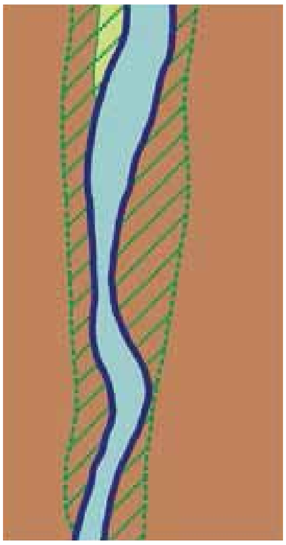
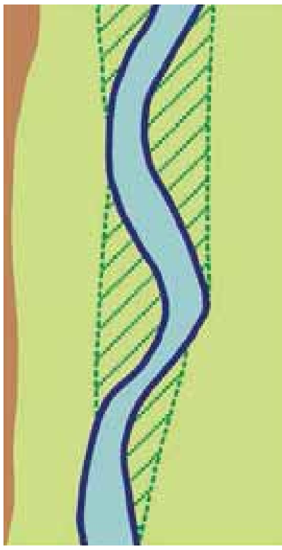
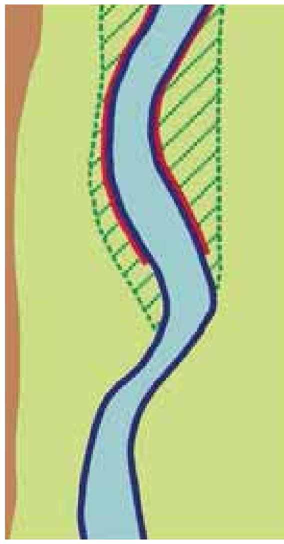
Class A **Vegetation linear extension > 90%**	***Class B*** **Vegetation linear extension 33÷90%**	***Class C*** **Vegetation linear extension < 33%**
		 **Levees and/or bank protections**

Figure 50 – Linear extension of the vegetation corridor. *Class A*: the linear extension is very high (> 90% of the total length of both banks). *Class B*: the linear extension is lower than 90% but higher than 33%. *Class C*: although a vegetation corridor exists for about half of the reach, most of it is disconnected because of the existence of artificial levees and/or bank protections.

Artificiality

1. UPSTREAM ALTERATION OF LONGITUDINAL CONTINUITY

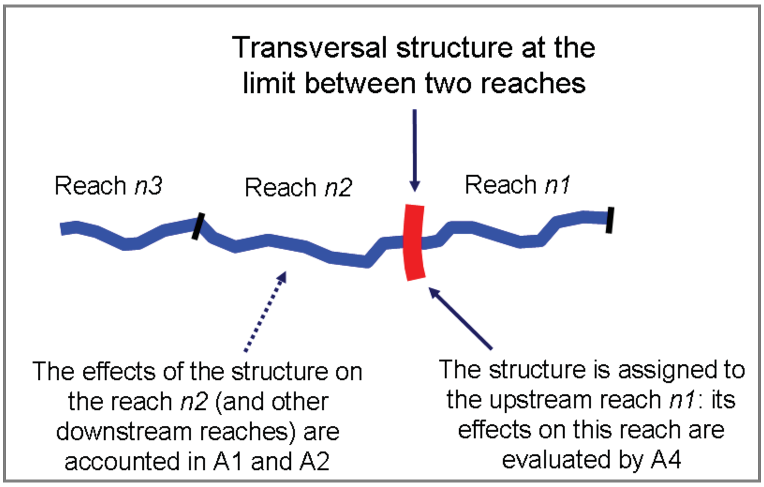


Figure 51 – Rule of assignation of a transversal structure coinciding with the limit between two reaches and its effects on the alteration of sediment and water discharges.

A1: Upstream alteration of discharges

Figure 52 – Alteration of discharges. Typical alteration structures. (1) Dam; (2) spillway.

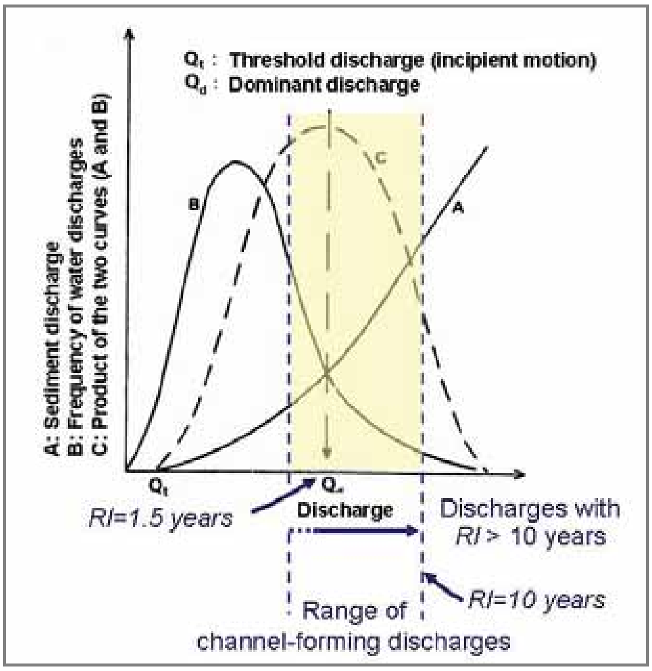


Figure 53 – Range of channel-forming discharges, including the discharges with return interval of up to 10 years. $Q_{1.5}$ (discharge with a return interval of 1.5 years) is the value conventionally assumed as the most representative of channel-forming discharges.

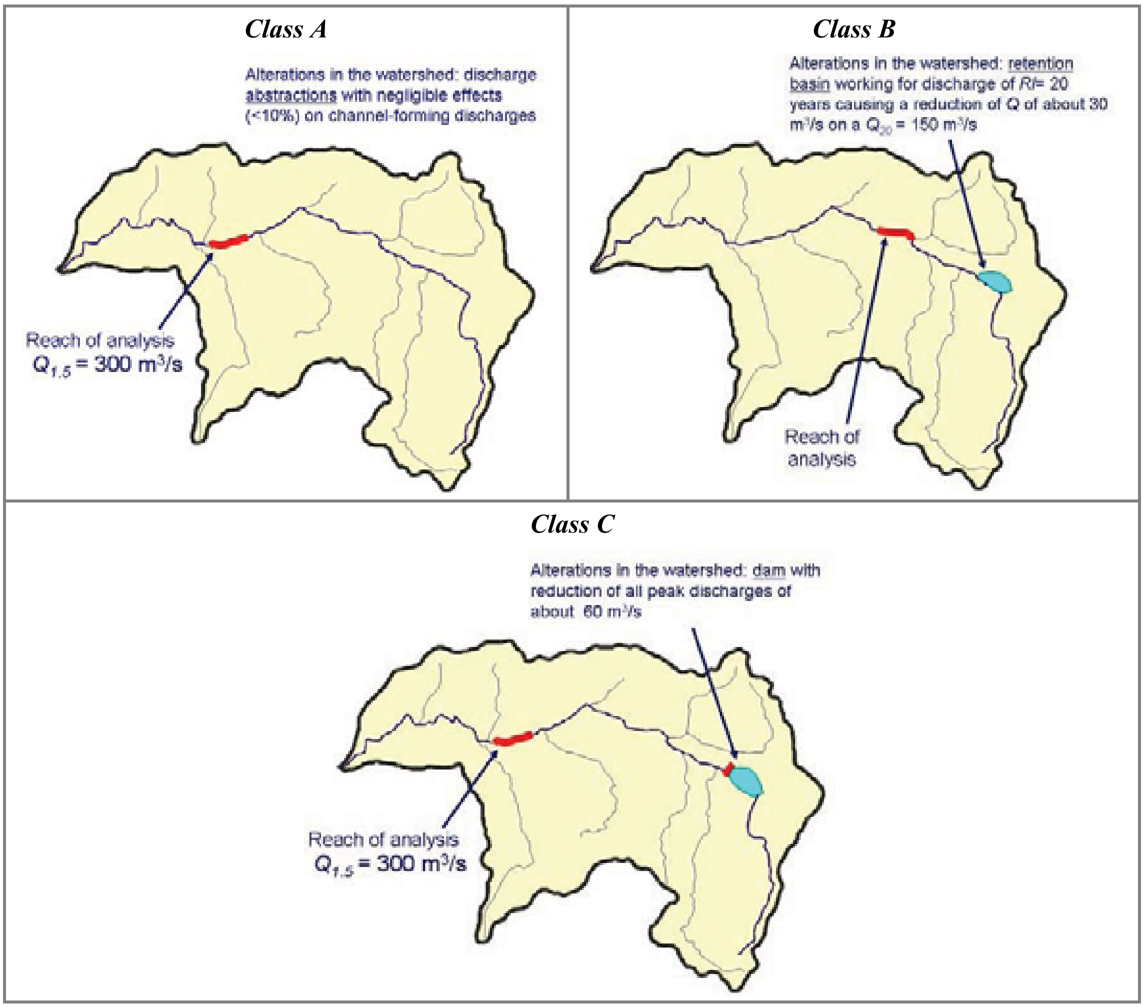


Figure 54 – Upstream alteration of discharges. *Class A*: negligible alteration; *Class B*: alteration of high discharges (with *RI* > 10 years) but not of channel-forming discharges; *Class C*: alteration of channel-forming discharges.

A2: Upstream alteration of sediment discharges

Structures in mountain areas

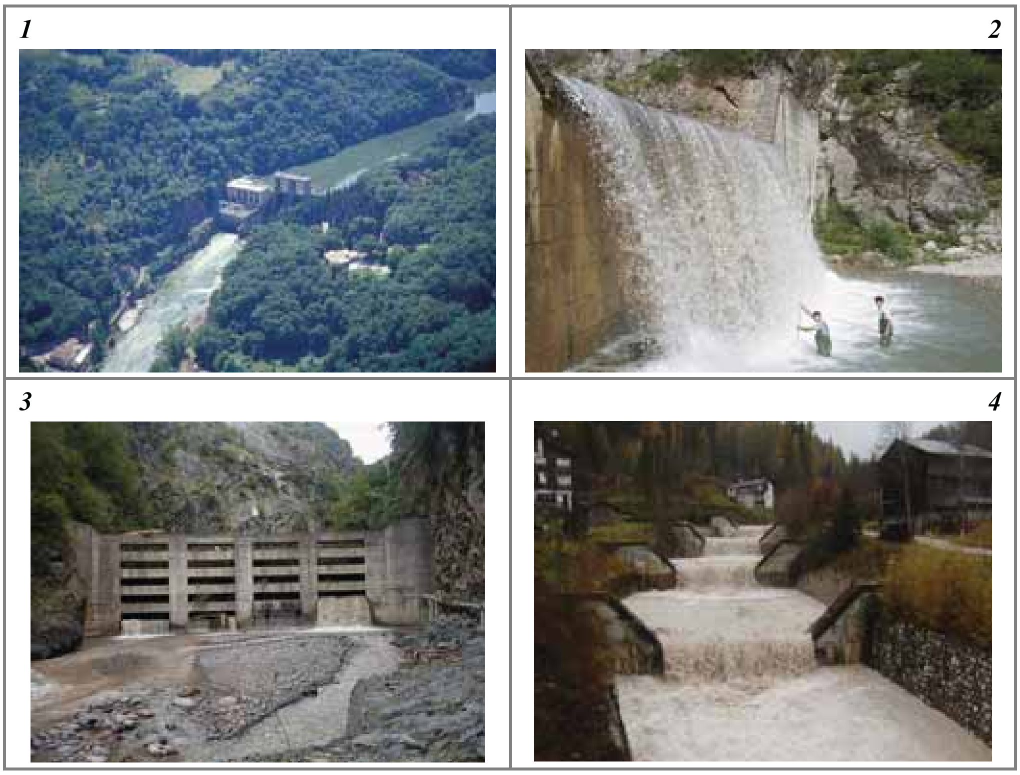


Figure 55 – Transversal structures of alteration of sediment discharges in mountain areas. (1) Dam; (2) retention check dam; (3) open check dam; (4) sequence of stepped consolidation check dams.

Structures in hilly – lowland areas

Figure 56 – Transversal structures of alteration of sediment discharges in hilly and lowland areas. (1) Consolidation check dam; (2) abstraction weir; (3) not filled abstraction weir; (4) filled abstraction weir.

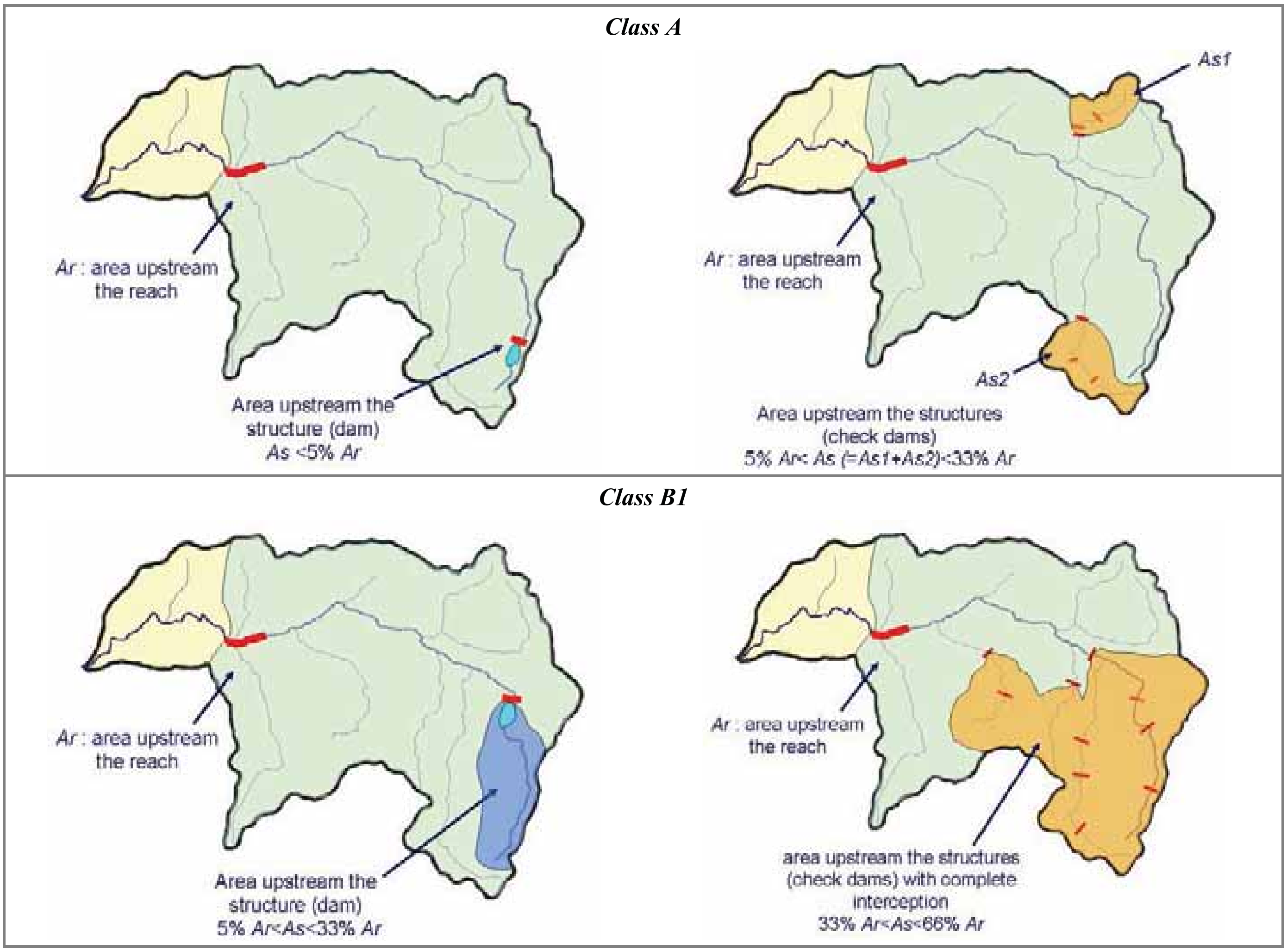


Figure 57 – Upstream alteration of sediment discharges. *Class A*: dam with a negligible drainage area (< 5% of the area upstream from the reach, *Ar*) (left); the total area of portions of the watershed with check dams is < 33% of the area upstream from the reach (right). *Class B1*: dam with a drainage area between 5% and 33% of the area upstream from the reach (left); the total area of portions of the watershed with check dams is between 33% and 66% of the area upstream from the reach (it applies in the case of reaches in hilly or lowland areas) (right).

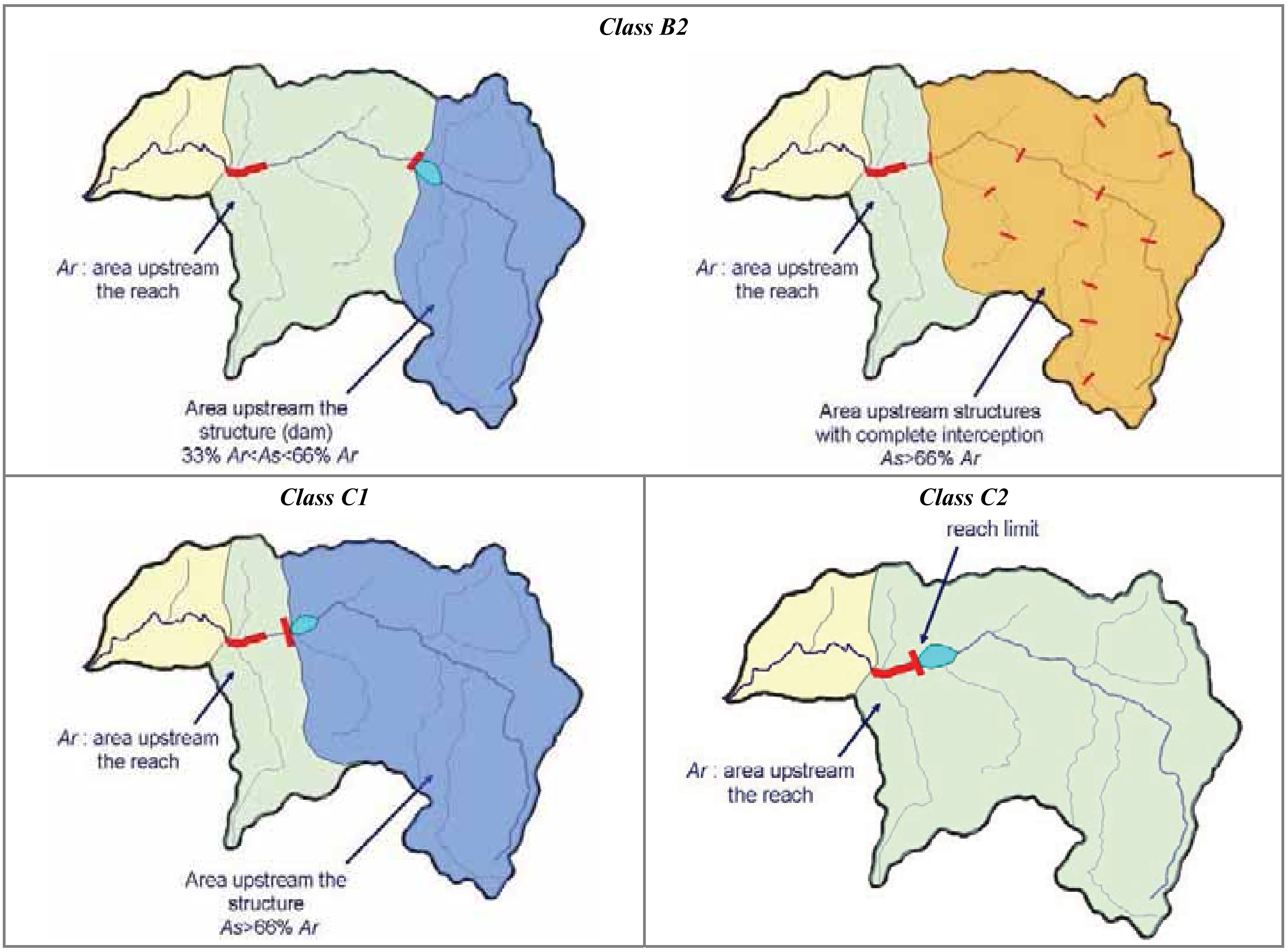


Figure 57 (continued) – Upstream alteration of sediment discharges. *Class B2*: dam with a drainage area between 33% and 66% of the area upstream from the reach (left); the total area of portions of the watershed with check dams is > 66% of the area upstream from the reach (it applies in the case of reaches in hilly or lowland areas) (right). *Class C1*: dam with a drainage area > 66% of the area upstream from the reach (left). *Class C2*: dam at the upstream limit of the reach (right).

2. ALTERATION OF LONGITUDINAL CONTINUITY IN THE REACH

A3: Alteration of discharges in the reach

Figure 58 – Other structures (besides those defined for *A1*) that can cause an alteration of discharges within a reach. (1) Retention basins; (2) discharge abstraction.

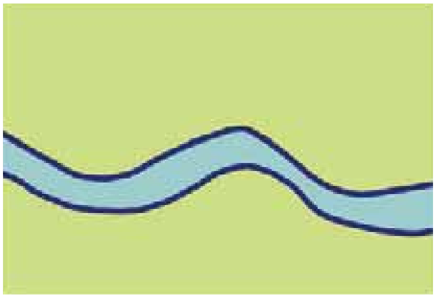
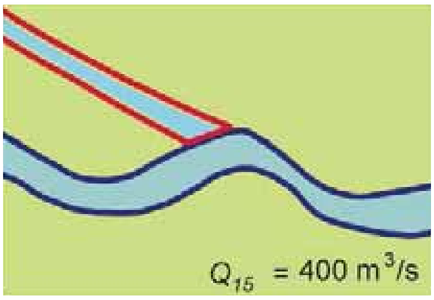
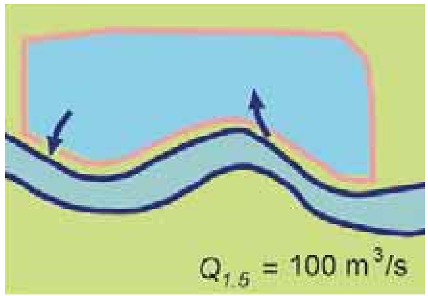
Class A	*Class B*	*Class C*
		
No alteration	**Spillway working only for peak discharges with *RI* > 15 years and causing reduction in *Q* of about 50 m^3/s**	**Retention basin working for all peak discharges (*RI* > 1 year) and causing a reduction in *Q* of about 15 m^3/s**

Figure 59 – Alteration of discharges in the reach. *Class A*: absence of alteration. *Class B*: alteration of discharges with *RI* > 10 years. *Class C*: alteration of channel-forming discharges.

A4: Alteration of sediment transport in the reach

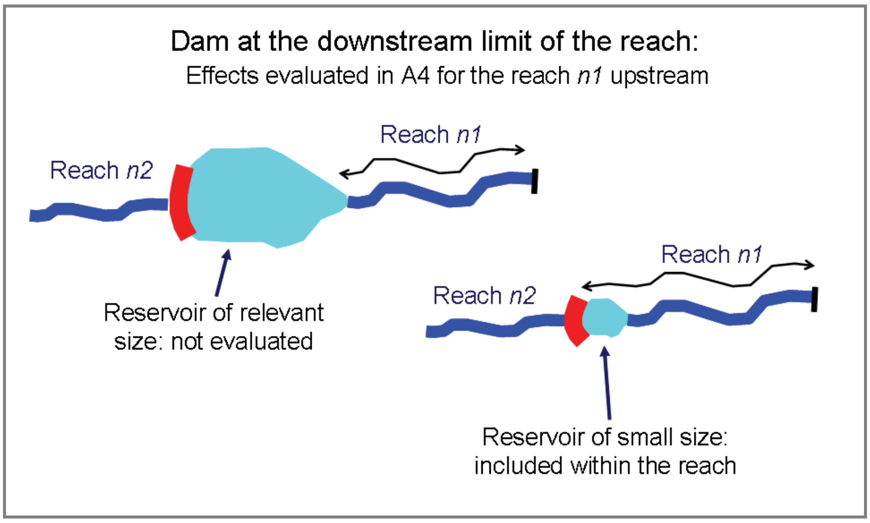


Figure 60 – Rule of evaluation of the effects of a dam and reservoir at the downstream limit of the reach.

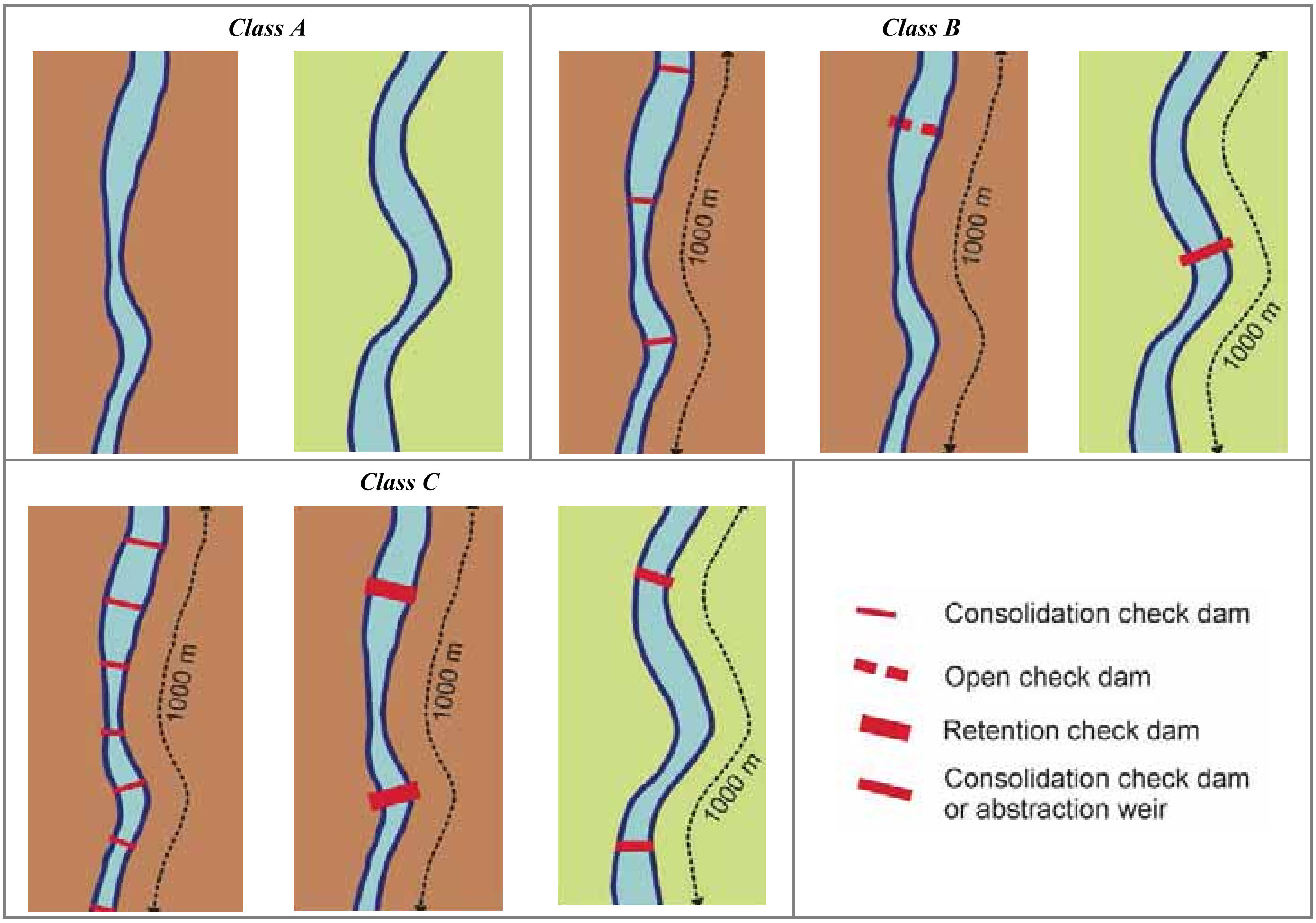


Figure 61 – Alteration of sediment transport. *Class A*: absence of alteration. *Class B* in mountain areas: consolidation check dams in limited number (≤ 1 every 200 m); or open check dams. *Class B* in lowland areas: consolidation check dams or abstraction weirs in limited number (≤ 1 every 1000 m). *Class C* in mountain areas: frequent consolidation check dams (> 1 every 200 m) or one or more retention check dams. *Class C* in lowland areas: frequent consolidation check dams and/or abstraction weirs (> 1 every 1000 m).

Figure 62 – Cases with very high density of transversal structures (> 1 every 100 m in mountain areas): an additional score of 12 is applied.

A5: Crossing structures

Figure 63 – Crossing structures. (1) Bridge with interference on fluvial dynamics; (2) crossing structure unrelated to the fluvial corridor; (3) ford with culverts; (4) culvert.

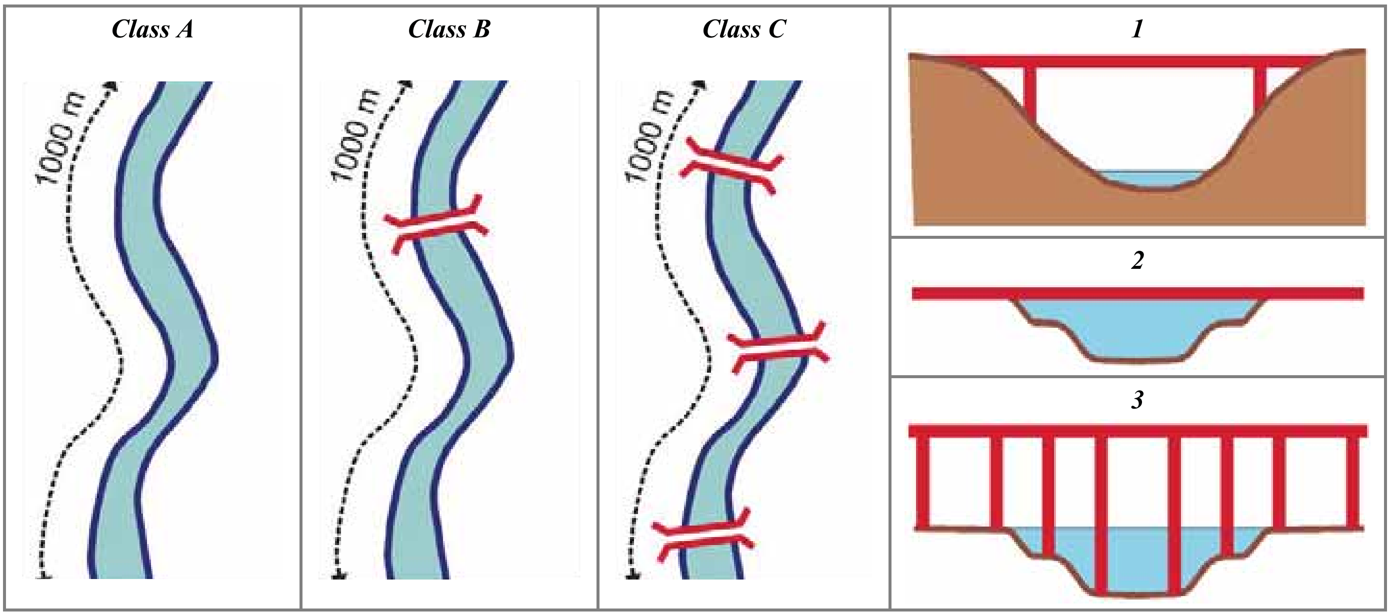


Figure 64 – Crossing structures. *Class A*: absence of structures. *Class B*: crossing structures in limited number (≤1 every 1000 m). *Class C*: frequent crossing structures (>1 every 1000 m). On the right: interference of bridges with the fluvial corridor. (1) Bridge completely unrelated (viaduct crossing a valley at relevant height); (2) bridge with no piers but which may interfere with high discharges; (3) bridge very high but with piers interfering with fluvial dynamics processes.

3. ALTERATION OF LATERAL CONTINUITY

A6: Bank protections

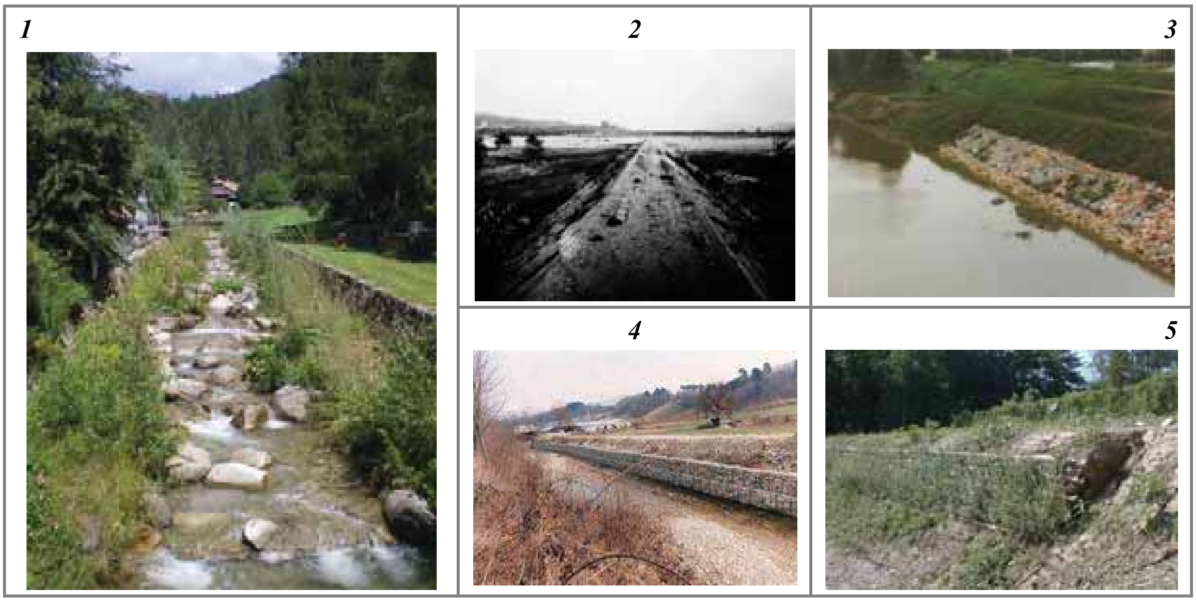


Figure 65 – Bank protections. (1) Bank walls (2) groyne; (3) rip raps; (4) gabions; (5) bioengineering bank stabilization.

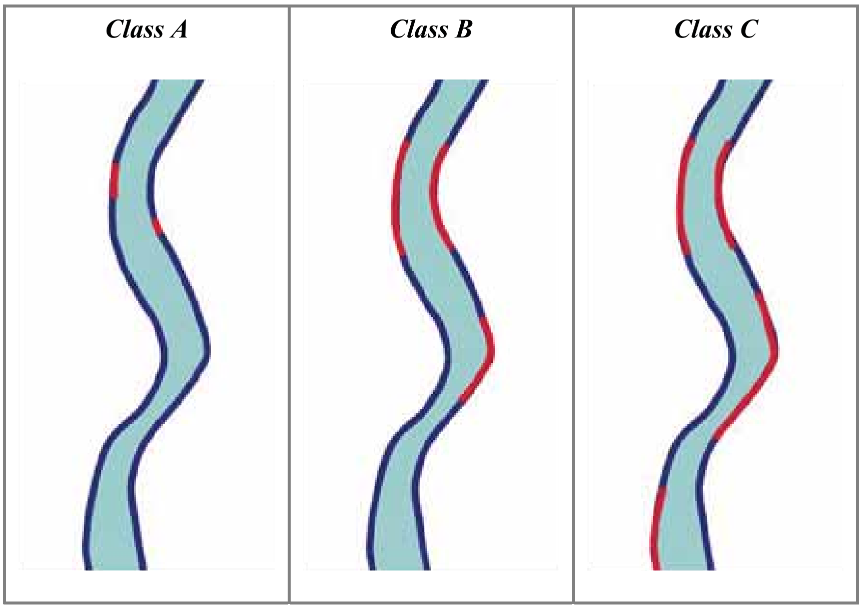


Figure 66 – Bank protections. *Class A*: localized protections (red lines); in the example the structures are 4% of the total length of the two banks. *Class B*: significant presence of bank protections (≤ 33%); in the example they are about 30% of the total length of the two banks. *Class C*: relevant presence of bank protections (> 33%); in the example they occupy about 50% of the total length of the two banks.

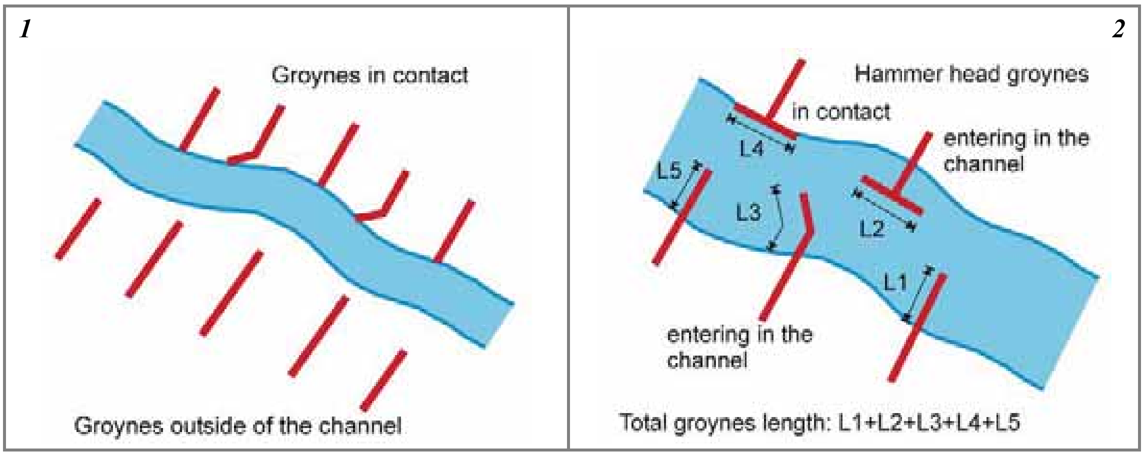


Figure 67 – Case of groynes. (1) Groynes outside of the channel are not considered (instead, they are accounted for in the indicator *F5*); in the case of straight groynes in contact with the channel boundary, the width of the groyne head is usually negligible. (2) In the case of groynes entering in the channel, the greater size between protruding length and head width is considered (the latter is generally the prevailing size in the case of hammer head groynes). Note that hammer head groynes in contact (as opposed to straight or bayonet groynes) are considered.

A7: Artificial levees

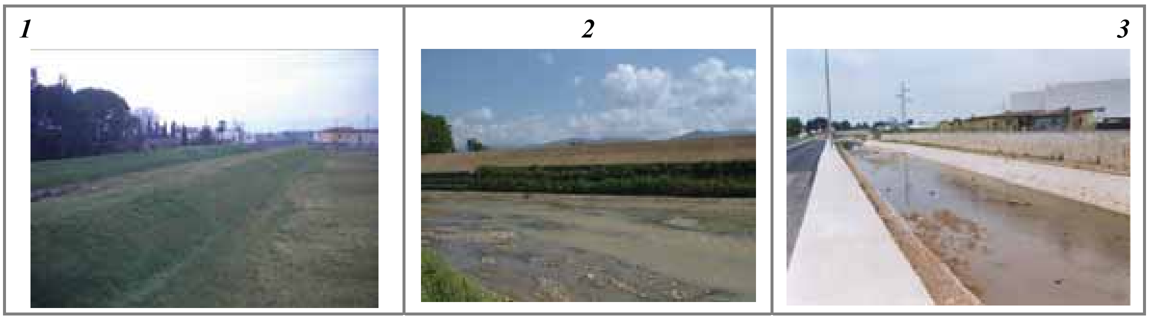


Figure 68 – Artificial levees. (1) Earth levees; (2) levee in contact with the channel; (3) bank walls with function of levees.

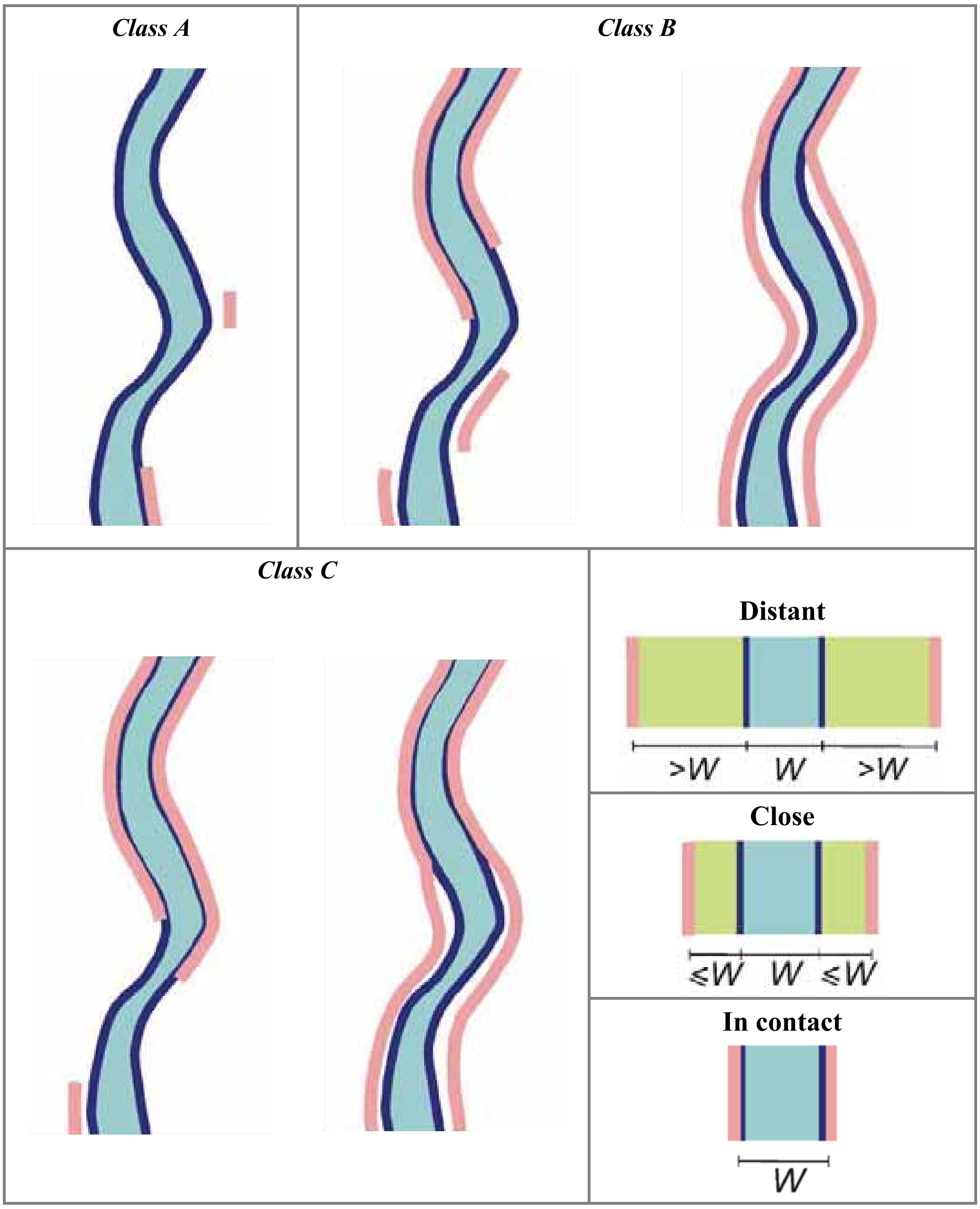


Figure 69 – Artificial levees. *Class A*: localized levees in contact or close (< 10%). *Class B*: the total sum of levees in contact and close is < 90%, with those in contact between 33% and 50% (left), or the total sum of levees in contact and close is > 90% but those in contact are < 33% (right). *Class C*: levees in contact are > 50% of the reach (left), or those in contact are between 33% and 50% but the total sum of levees in contact and close is > 90% (right). Bottom right: definition of distant, close and in contact levees.

Figure 70 – Cases of bank protections plus levees in contact occurring for most of the reach (> 80%), for which a score of 12 is added.

4. ALTERATION OF CHANNEL MORPHOLOGY AND/OR SUBSTRATE

A8: Artificial changes of river course

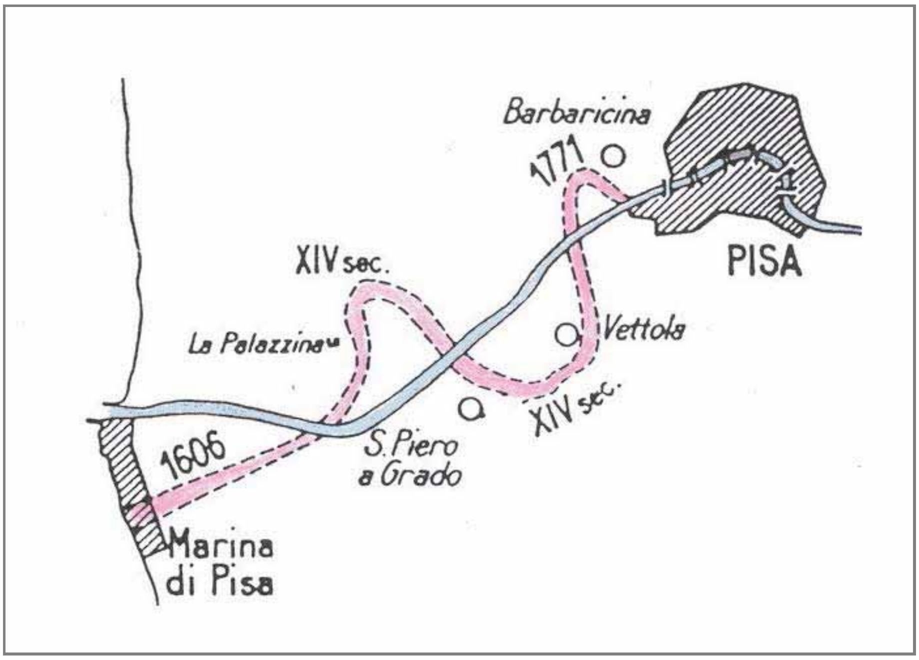


Figure 71 – Artificial changes of river course. Example of well known artificial changes (meander cut-offs, change of position of river mouth) occurring in historical times.

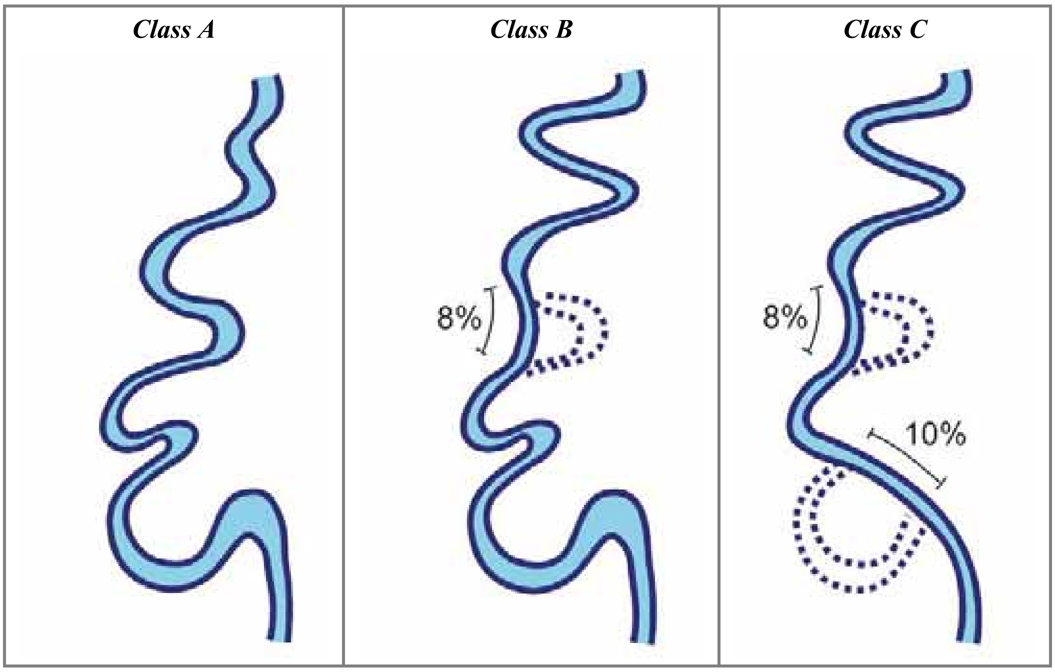


Figure 72 – Artificial changes of river course. *Class A*: absence of artificial changes. *Class B*: artificial changes for a length < 10% of the reach. *Class C*: artificial changes for a length > 10% of the reach.

A9: Other grade control structures

Class A

Class B

Class B

Class C1

Class C2

Figure 73 – Other grade control structures and revetments. *Class A*: total absence of other grade control structures or revetments. *Class B*: presence of sills (first row on right) or mass ramps (second row on left) with low density. *Class C1*: various sills and partial bed revetment. *Class C2*: total bed revetment with impermeable systems. If such revetments occur along most of the reach (> 80%), <u>an additional score of 12</u> is assigned.

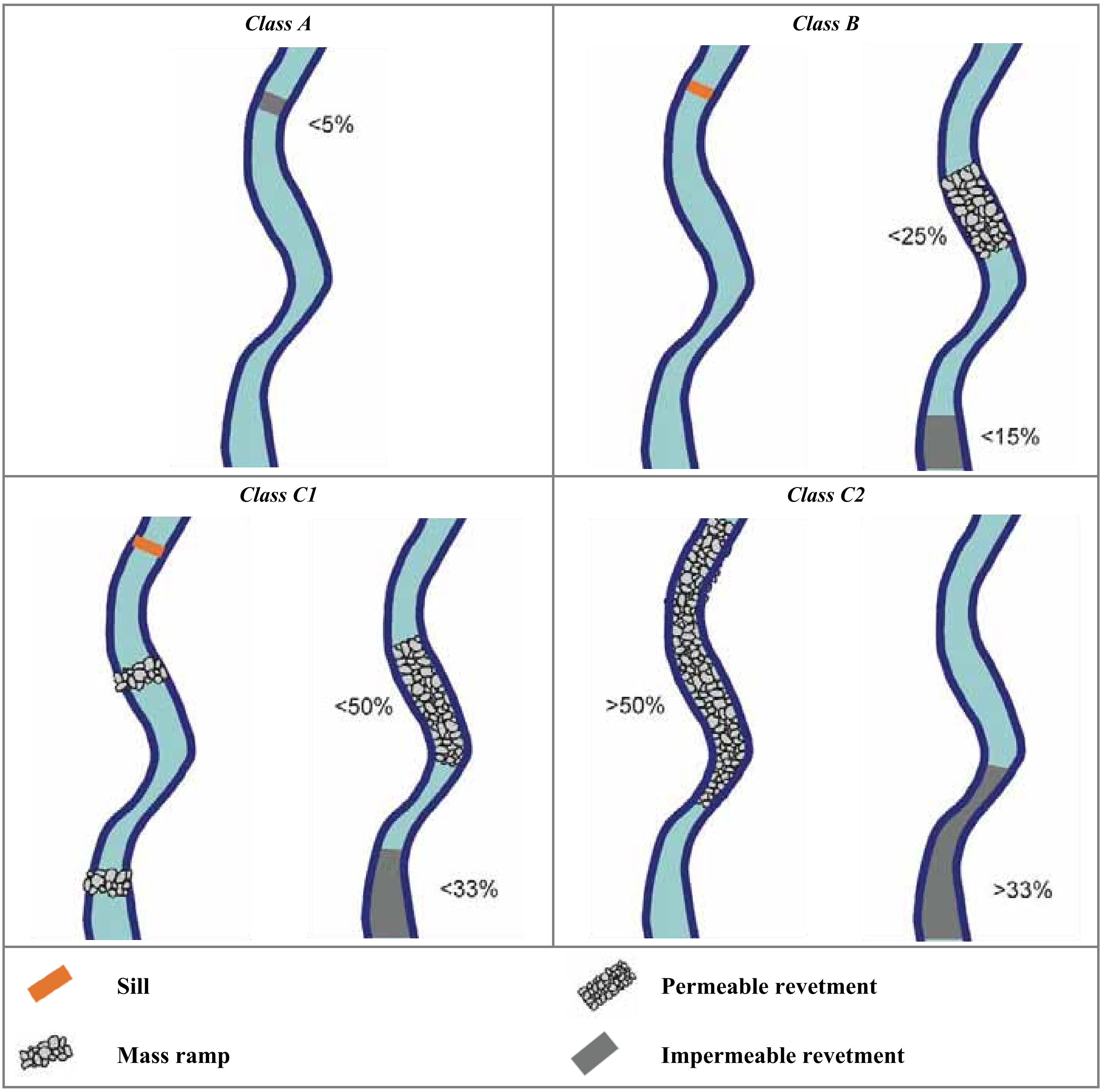


Figure 74 – Other grade control structures and/or revetments. *Class A*: absence of other structures and localized revetments (<5%). *Class B*: grade control structures (sills, ramps) with a density ≤ 1 every *n* (*n* = 200 m in mountain areas, *n* = 1000 m in hilly and lowland areas), or permeable revetments with length ≤ 25% of the reach and/or impermeable revetments with length ≤ 15% of the reach. *Class C1*: grade control structures (sills, ramps) with a density > 1 every *n*, or permeable revetments with a length ≤ 50% of the reach and/or impermeable revetments ≤ 33% of the reach. *Class C2*: permeable revetments > 50% of the reach and/or impermeable revetments > 33% of the reach.

5. INTERVENTIONS OF MAINTENANCE AND REMOVAL

A10: Sediment removal

Figure 75 – Sediment removal. (1) and (2) Recent and present activity; (3) and (4) indirect indicators of intense past activity are the presence of mining sites. Assignation to *Class B* or *C* depends on the extension of the activity (localized or widespread), in the case of confined channels, and on the intensity of the mining activity either in the past and in recent times, in the case of semi- and unconfined channels.

A11: Wood removal

Figure 76 – Wood removal. *Class A*: absence of interventions of wood removal. *Class B*: partial removal, including removal by private citizens. *Class C*: removal interventions by public agencies.

A12: Vegetation management

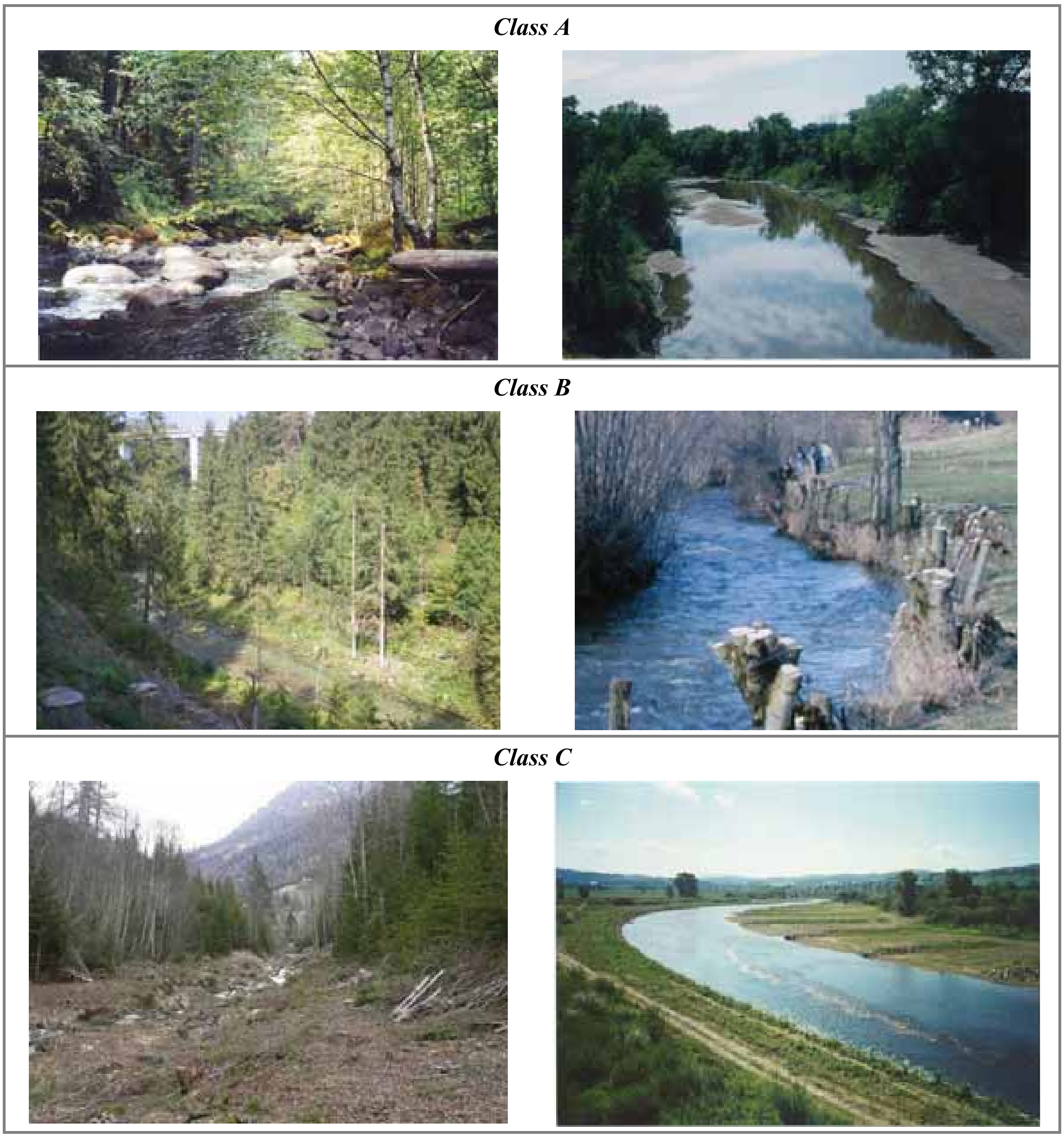


***Figure** 77* – Vegetation management. *Class A*: absence of vegetation cutting interventions. *Class B*: interventions of selective cutting. *Class C*: interventions of total vegetation cutting.

Channel Changes

V1: Changes in channel pattern

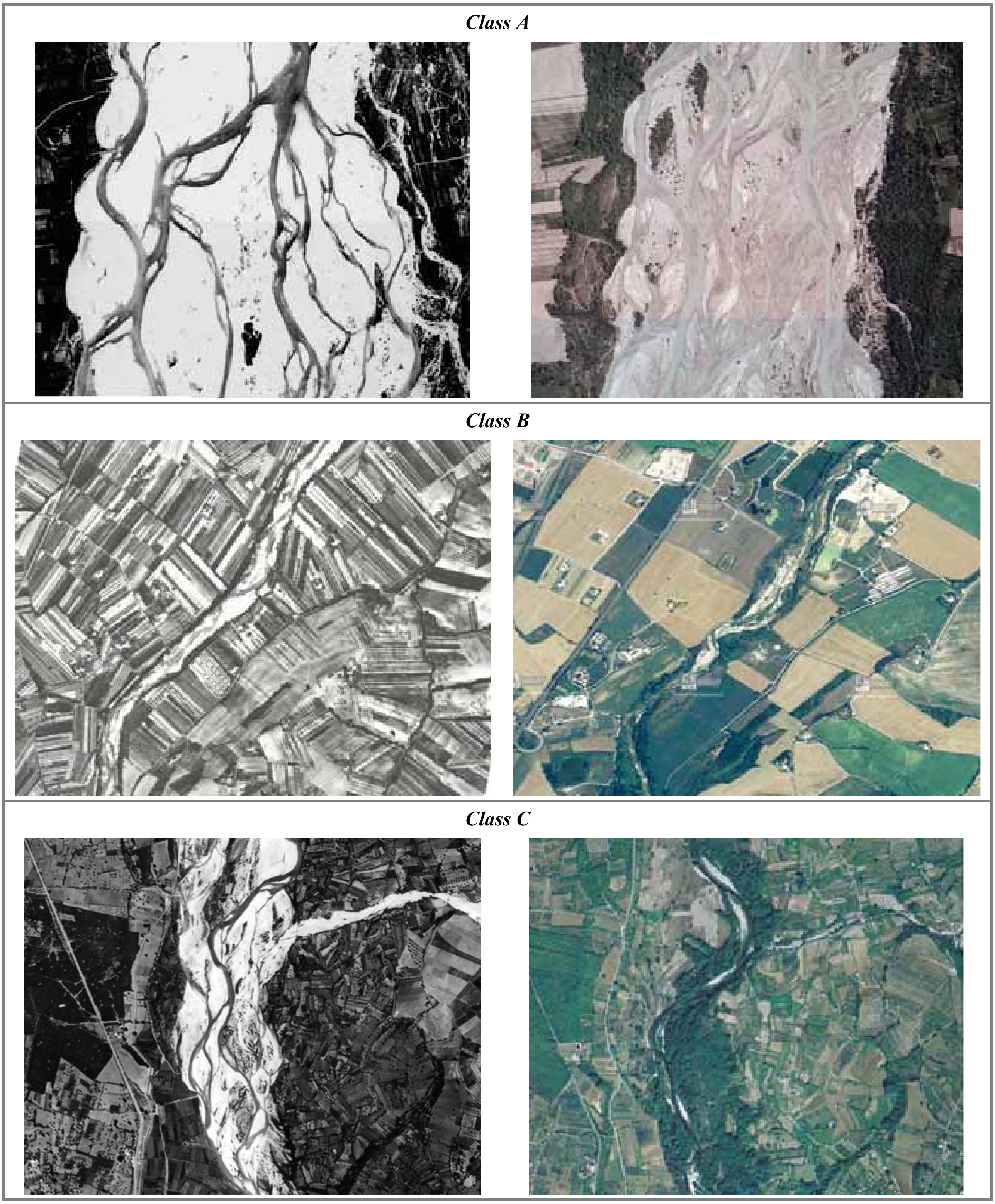


Figure 78 – Changes in channel pattern (on the left the aerial photo dated 1954, on the right the present situation). *Class A*: the channel maintains a prevailing wandering pattern, although channel narrowing occurred. *Class B*: change from wandering to sinuous. *Class C*: change from braided to sinuous.

V2: Changes in channel width

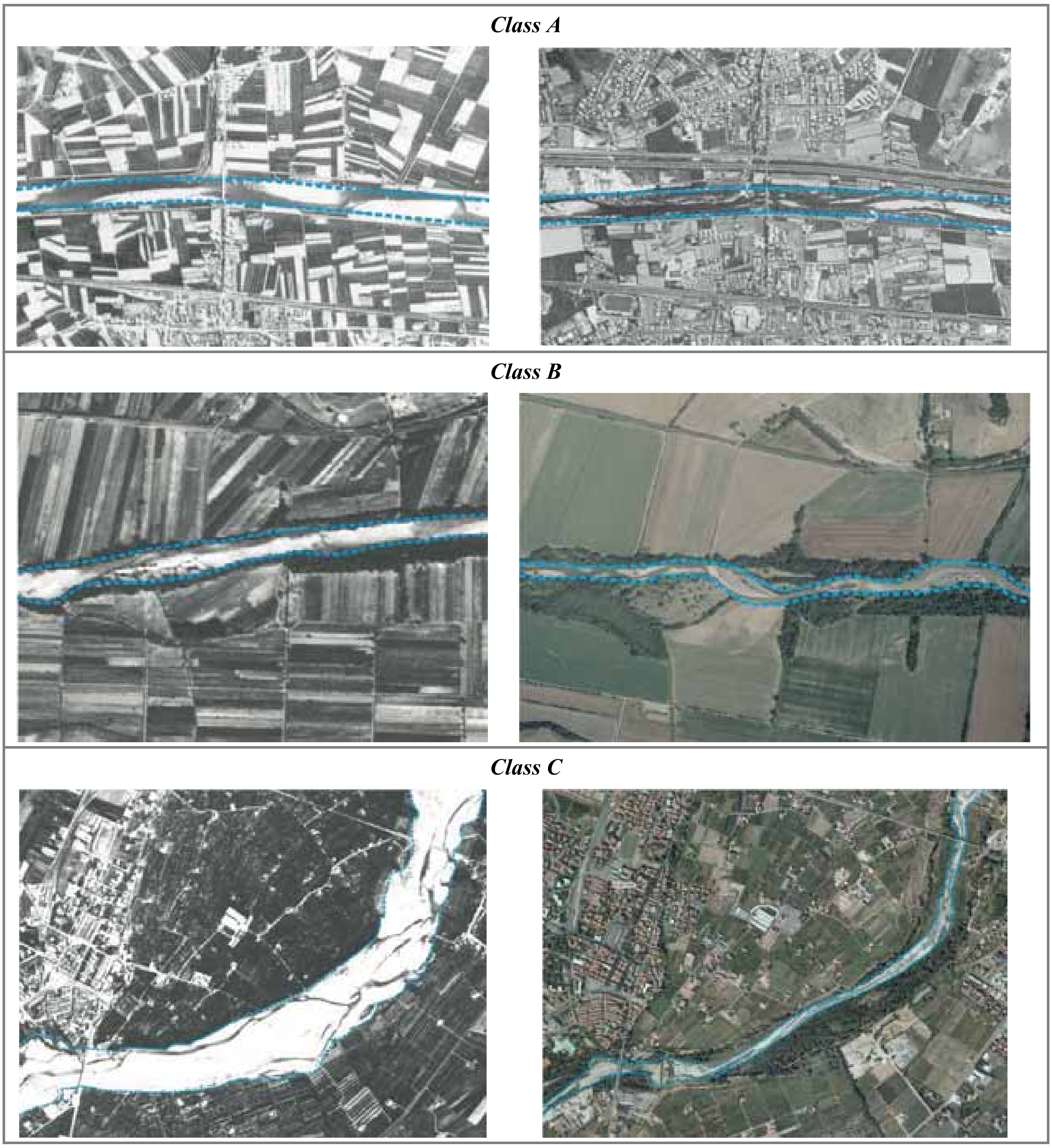


Figure 79 – Changes in channel width (on the left the aerial photo dated 1954, on the right the present situation). *Class A*: very limited channel narrowing (< 15%). *Class B*: channel narrowing from 15% to 35% of channel width in 1954. *Class C*: very intense channel narrowing (> 35%).

V3: Bed-level changes

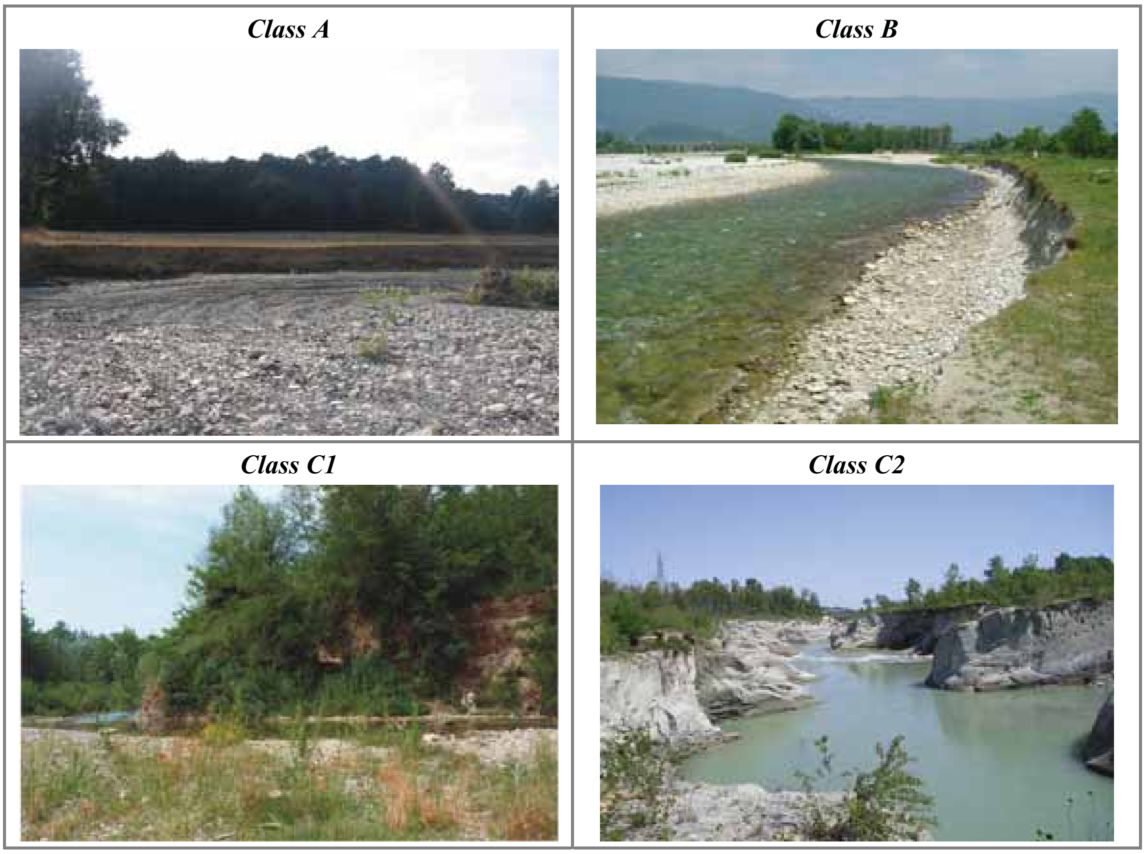


Figure 80 – Bed-level changes. *Class A*: negligible incision (< 0.5 m). *Class B*: incision from limited to moderate (from 0.5 to 3 m). *Class C1*: intense incision (> 3 m). *Class C2*: very intense incision (> 6 m) causing the complete erosion of the alluvial deposits.

Field evidence

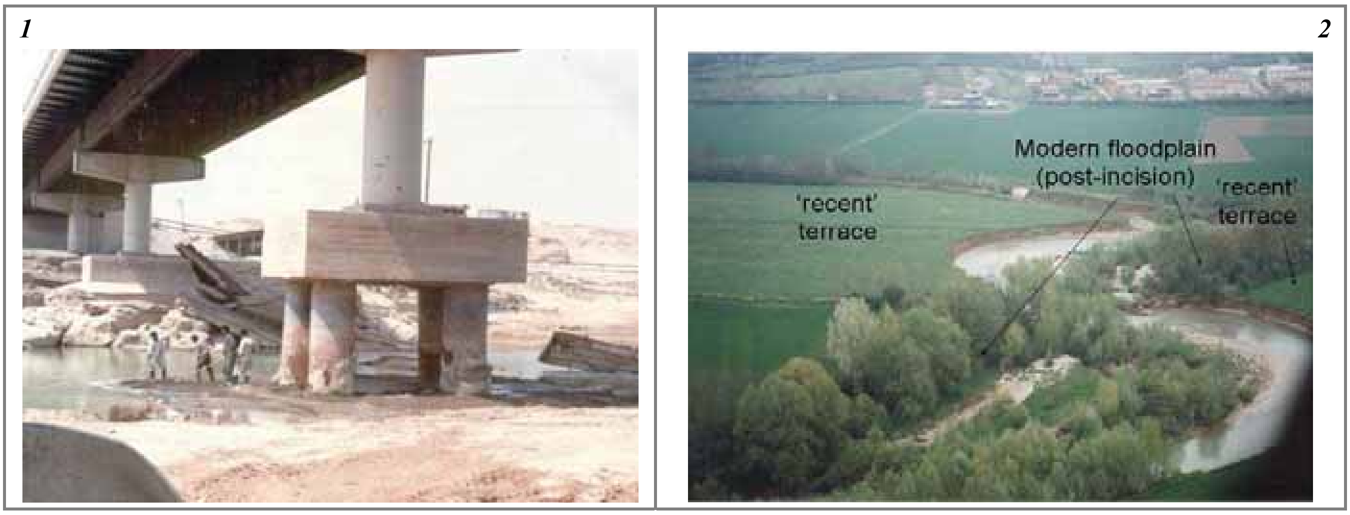


Figure 81 – Field evidence of incision. (1) Exposed bridge piers. (2) Differences in level between modern (post – incision) floodplain and "recent" terrace (the latter corresponding to the pre – incision floodplain).

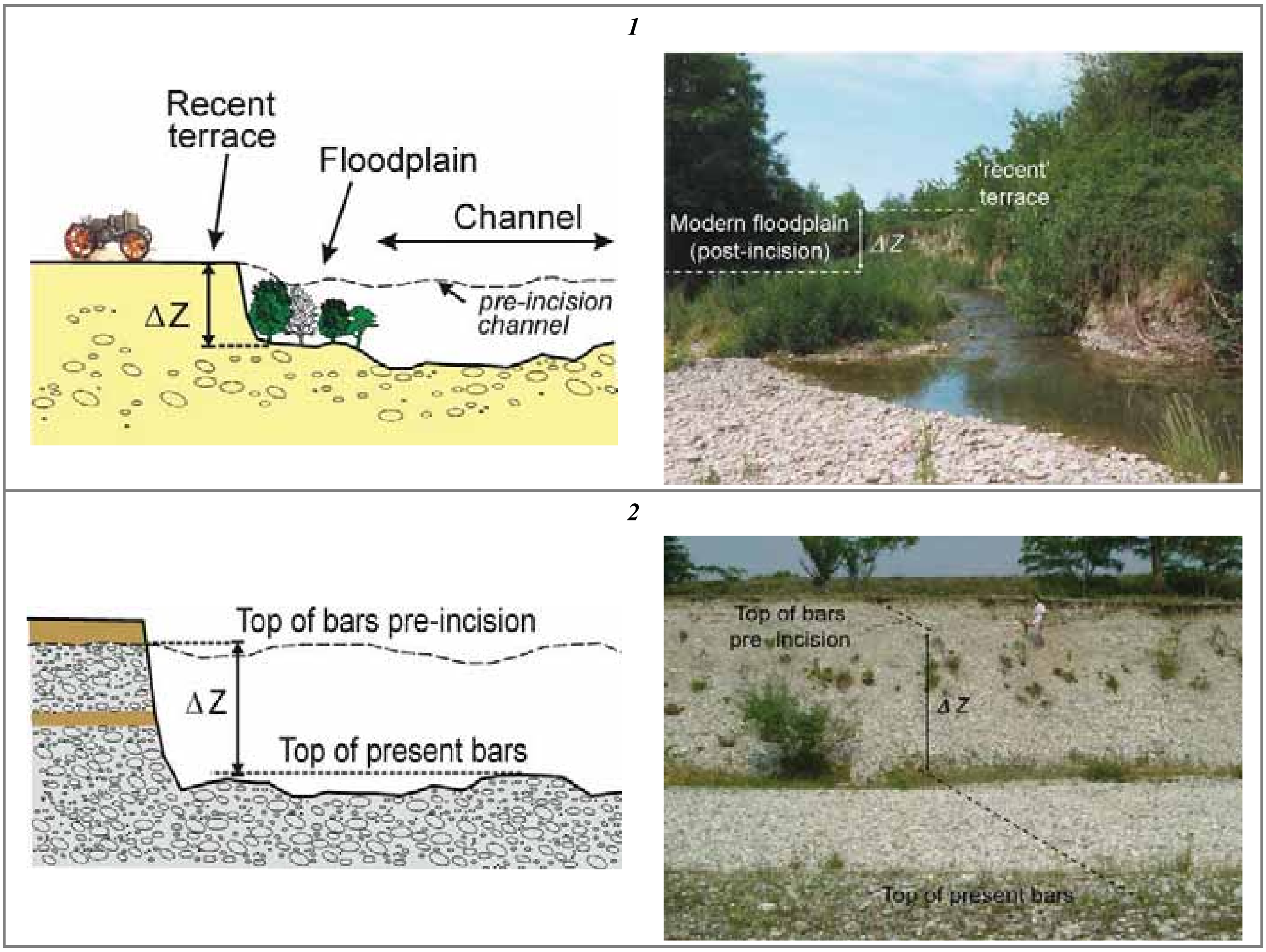


Figure 82 – Estimation of the amount of incision based on differences in elevation among surfaces. (1) Measurement of difference in elevation (ΔZ) between modern floodplain and recent terrace (pre- incision floodplain); (2) measurement of difference in elevation between the top of gravel on an eroding bank (corresponding to the top of bars before incision) and top of present channel bars.