En : **A guide to good practices for the management and restoration of mediterranean ephemeral streams: resilience and adaptation to climate change** : 51-76 (2021) https://doi.org/10.6018/editum.2912 (c) Universidad de Murcia bajo una licencia Atribución (cc-by)

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Indicators of resilience, evaluation and criteria for management and restoration

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3.1. Indicators of geomorphic and ecological resilience in ephemeral streams

By resilience we understand the capacity of a system to absorb possible alterations and reorganise itself, while undergoing changes to essentially maintain the same function, structure, identity and feedback (Walker et al. 2004). A threshold of geomorphological stability can be surpassed in an ephemeral channel when faced with changes which are intrinsic to itself or external variables (Schumm, 1979). Normally, this type of resilience is accompanied by resistance or difficulty that ephemeral streams face when the geomorphic equilibrium state is altered due to natural processes or human activities (Thoms et al. 2018). Generally, all types of equilibrium referred to fluvial geomorphological systems can be applied to intermittent rivers and ephemeral streams (IRES), taking into account the peculiarities of their function, which is irregular and discreet over time, through specific hydrological events of different magnitudes: 1) a static equilibrium, when an equilibrium of trends results in a static state, a state without changes; 2) a stable equilibrium, characterised by the tendency of a system to move towards a condition of previous equilibrium, that is to say, to recover after having been altered by external factors; 3) an unstable equilibrium, where a small alteration leads to a greater change and, generally, to the achievement of a new stable equilibrium; 4) a metastable equilibrium, when the system remains relatively stable over a long period of time, in spite of experiencing slight alterations that tend to modify it; 5) an equilibrium in a stationary state, in which the properties of the system are invariable in a given time scale, but could oscillate around a middle state due to the presence of variables that interact with themselves; 6) a dynamic equilibrium, considered as a state of energy distribution which is reached rapidly in response to a changing energetic equilibrium (Leopold and Langbein, 1962). In this case, the fluctuations produced within a range of situations of equilibrium, related to the condition of a constantly changing system, could have a trajectory of non-repeated states over time (Thorn and Welford, 1994).

The morphology of IRES, and particularly in the ephemeral streams specific to semi-arid areas (SAES), reflects the influence of very diverse variables operating at multiple scales (Schumm, 1998). In similar topological and lithological conditions, the most important of these is the predominant climate regime, clearly affecting vegetation cover and types of types of soil, and especially the magnitude and variability of peak discharges. These variables intervene in a combined way, determining other variables directly involved in the formation of the channel itself: the supply and transportation of sediment, the texture of the bed and banks, and the balance between erosion and deposition. All of these interact at different spatio-temporal scales, continually affecting the channel pattern, the cross-section shape and geometry, the processes of incision and vertical bed accretion, the slope and equilibrium profile and the morphological dynamics of the bed. To the degree that these scales and variables participate in the very dynamics of these systems, they can also be used as geomorphic indicators of the capacity of resistance and recovery to a previous situation of equilibrium.

Geomorphological sensitivity and resistance

Ephemeral streams are particularly sensitive to direct human alterations (for example, the construction of check dams, ripraps, breakwaters, canalisation, etc.) (Surian and Rinaldi, 2003; Conesa-García and Pérez-Cutillas, 2014; Dufour et al., 2015), but they present an extraordinary variability in their resistance to gradual or progressive environmental change (for example, the progressive change in the climate or vegetation cover). Calle et al. (2017) and Sanchis-Ibor et al. (2017) confirmed in their respective studies of the Rambla de la Viuda and the Palancia River that both ephemeral streams had a high geomorphological sensitivity to the immediate effects of aggregate extractions on the sediment load in large floods, a considerable resistance in previous conditions of greater stability and a somewhat slower later recovery. Mediterranean ephemeral streams have been subjected to action for more than two thousand years that have changed their level of adjustment, depending on the magnitude of the intervention, the pre-existing characteristics and the rhythm of occurrence of extreme hydrological events.

SAES are responsible for their own hydraulic efficiency when they pass over alluvial land, where they have shapes of an open and shallow channel, from the trough type channels to wide shallow cross-sections, that end up disappearing in the plain. In these settings, resistance comes from the combined effect of variables such as channel planform and geometry, bed material grain-size, and density and type of vegetation covering the main channel and active floodplain (Fryirs and Brierley, 2013). On the other hand, the sensibility of the channel in the reach under consideration reflects the ease with which it can carry out an adjustment (in other words, the way in which the reach tends to adjust its shape in order to resist the change) and the proximity of the conditions of a critical threshold:

sensitivity = adjustment capacity + proximity to the critical threshold

In general, watercourses are usually quite sensitive to alterations and can easily adapt to them as part of their natural adaptation capacity, but they are geomorphic systems with a propensity to undergo drastic changes if they surpass important thresholds (for example, extreme flood events). Their recovery rarely reflects an ordered, progressive and systematic process. The components of this type of system adjust themselves in different ways and at different rates, so that individual reaches experience transitions between different states at different points in time (Fryirs and Brierley, 2013). Nevertheless, when there is an approximation to this critical threshold it happens in a slow and progressive way (for example, a trajectory immersed in a process of climate change) the most resistant channel reaches of SAES, in particular those of gravel beds, demonstrate a more resilient behaviour, being able to respond to changes through adjustments that operate as mechanisms of negative feedback. In this scenario, stability is maintained in the mid to long term due to the self-regulatory nature of the system, which tends to absorb a large part of any external impacts.

Indicators of geomorphological resistance

Equilibrium profile

The changes in discharge (Qw) downstream affect the curvature of the longitudinal profile of the channel. The equation of Wolman and Leopold (1960) for the condition of equilibrium of a bankfull channel establishes that increases in Qw contribute to concave profiles (Leopold and Maddock, 1953; Sinha and Parker, 1996), while the reduction in Qw downstream contribute to the convexity of the channel profile. In this sense, ephemeral streams typically show a notorious reduction in Qw along their trajectory (Martín-Vide et al., 1999; Bull, 2007), often associated with a rectilinear profile (Powell et al., 2012; Ferrer-Boix. 2016) or slightly convex one (Heede, 2004). The decrease in discharge downstream in these types of watercourses is often related to high rates of permeability that occur on their granular beds, especially of sand and gravel. The result Is a constant slope in most of the profile.

Equilibrium slope

We understand equilibrium slope in an IRES to mean that which balances the liquid and solid discharges attributed to flood events occurring during a given period. The slope could also be considered as the variable that is able to reestablish a lost equilibrium (Martín Vide, 1997). Processes of regressive or progressive erosion, provoked by direct actions on the bed, tend to reduce the slope if a fixed or stable base level is maintained downstream, until the initial slope of the bed is achieved and the previous state of equilibrium is reached again (as observed in figure 100). This is the case of bed lowering caused by extractions of aggregates in the Rambla de Béjar, which involved a readjustment of the slope downstream and dismantled the footings of the pillars of the A7 highway bridge at its crossing with the stream. In contrast, an increase in deposition under the same circumstances could increase the bed slope in the affected reaches.

Equilibrium bed

An ephemeral stream bed could be considered to be in equilibrium when, after a flood event, it maintains its same elevation, regardless of the magnitude of the discharge and sediment transport. In such an equilibrium, several variables take part, among which Lane (1955) highlights the unit water discharge, the unit solid dis-

Figure 100. Regressive erosion produced by a change in the local base level in the Rambla Salada, tributary of the River Segura on its right side. The unevenness of the bed will tend to smooth over as the erosion goes up in the upstream direction until a baseline equilibrium is achieved, the point in time when the bed will recover stability and have a new equilibrium slope.

charge, the longitudinal bed slope and the predominant sediment grain-size. Any change affecting one or various of these variables in a specific event will involve the alteration of the pre-existing equilibrium, making a compensatory effect necessary in posterior events. When the liquid discharge and the bedload are not in equilibrium in a specific event, an IRES can experience a deficit in the bedload sediment transport or, alternatively, an excess. In the first case, the transitory erosion is not normally compensated for by deposition and this will lead to bed incision processes. In the second case, the flow has overfeeding or excess sediment and there is vertical bed accretion. Such an equilibrium also depends on the channel slope and the size of the particles transported. The positive or negative equilibrium between solid and liquid discharge can be balanced during various events by an adaptation of the longitudinal bed slope and the sediment grain-size. In this way, it is very frequent to observe that the upper reaches of ephemeral streams, having a greater slope, have beds with a thicker texture, and vice versa, the lower reaches have a lower slope with finer material.

Relationship between DMR and stream competence

Dimensionless morphological ratios (DMR) of the channel could be another indicator of resilience in SAES if they are related to the balance between stream power and critical energy at the event scale. Normally, they have been applied in classification systems in watercourses and fluvial recovery projects, but they also reflect the trend for morphological adjustments within the temporal scale. Depending on these ratios and the current dynamics of SAES, it can be determined whether the observed trend could be stopped, and even reversed, or, alternatively, a continued effort is made to find a new equilibrium.

Ephemeral streams have extraordinary dynamics that are strongly conditioned by changes in climate, vegetation cover and human impacts. The variability in dimensionless morphological ratios (DMR) can be used as an appropriate geomorphic indicator of this dynamism on different scales, both temporal and spatial. It is commonly assumed that the changes in the ratios of width-depth (WDR) and incision (IR) often correspond to human interventions. However, in some cases, the entrenchment ratio (ER) reflects a disconnection between the previous alluvial plain and human settlement, which involves an adjustment process in the long term.

Width-to-depth ratio (WDR) of the channel. This ratio, obtained by dividing the bankfull width by the average depth, usually reflects flow magnitudes and the sediment load over time (WSDNR, 2004; Rosgen, 1996). Therefore, in our case, it is a useful indicator for expressing the flow-competence and transport capacity during peak discharges responsible for the current active channel shape. In these studies, the WDR has also been considered as a function of the dominant sediment texture on the channel perimeter (Schumm, 1960; Richards, 1982) and the boundary conditions (geological constraints, sloped valley, bed substrate and riparian vegetation) that controls the shape of a specific section (Charlton, 2008). Under such conditions, the WDR is adjusted by the balance between erosion and sediment within the channel, causing vertical accretion deposits or degradation and displacement of banks (Simon and Castro, 2003).

Entrenchment Ratio (ER). This indicator, or ratio between the flood prone width and the bankfull width, represents in the case of IRES the vertical containment of the main channel and the capacity of its active floodplain to laminate overflow discharges. According to Rosgen (1997), during flooding, highly entrenched stretches can contain all the flow within the channel itself and there is no spill onto the floodplain. In moderately entrenched reaches, occasionally high water levels can cover most of the flood prone area, while stream stretches that have limited or no entrenchment connect their floodplain directly to bankfull flows. SAES, and in particular ephemeral gravel-bed streams near the coastline, usually present representative reaches of three modalities: (1) entrenched at the headwaters, often on alluvial fans; (2) moderate entrenchment in the middle reach, with a trough shaped channel and a flat bed; and (3) a non-entrenched reach of overspill next to the mouth of the channel. The ER values can be attributed to many factors, including climatic variations, local tectonic subsidence affecting the base level and human impacts (Bull, 1997), with the immediate effect of an increase in erosion provoked by an increase in discharge and hydraulic radius in cross-sections with materials of low mechanical resistance to erosion.

Incision ratio (IR). The IR, defined as the relationship between the height of the lowest bank and the maximum bankfull depth (Rosgen, 1996), is a more sensitive geomorphic indicator of bed degradation than the entrenchment ratio. As the floodplain is wider in relation to the bankfull width, a larger incision and formative-discharge is required to produce significant changes in the ER. Any change in ER generally involves substantial changes in IR and will be subject to flood peaks with longer return times (≥ 50-year floods). An incision rate of nearly 1 indicates bed stability during the last phases of channel formation. Alternatively, IR values greater than 1 reflect recent processes in lowering or degradation of the bed, which could be relevant ($1.5 < IR < 2$) and very intense ($IR > 2$).

The DMR combined with the reach-based stream power balance approach at the event scale could provide more useful information for determining the resilience and level of morphological adjustment in SAES. Conesa-García et al. (2019) adopted these criteria in the Alto Mula (the Segura Basin) to identify reaches with different degrees of resistance and sensitivity. These authors calculated the mean excess energy of the flow (ε) as the mean stream power (ω) minus the critical energy (ω_c), associated to the slope and the size of particles on the bed (Parker et al., 2011). Specifically, they confirmed that the lowest morphological adjustments occurred during events of low energy (values ε below 30 W m^{-2}) in moderately cross-sections affected by incipient or null entrenchment and moderate WDR along bend reaches (BS), and in very incised and entrenched cross-sections with moderate to high WDR along the straight channel reaches (SS). However, straight or not very sinuous reaches, of a granular bed, with slight entrenchment, but subjected to strong incision, were more sensitive in similar conditions of energy, and experienced the most significant changes in flash floods during which the ε threshold of 250 W m^{-2} was exceeded.

In addition, consideration of the "relative bed stability" (RBS) Index as a criterion of stability, made it possible to observe in this case two ω patterns with very different statistics for stable and unstable beds, independent of the degree of incision: (1) a pattern of unstable granular beds (RBS < 1) which have a median ω at around 150 W m^{-2}, with $\sigma > 50$ W m^{-2}; and (2) a relatively stable bed pattern, whose medians ω and σ decrease as the stability degree increases. In addition, they could confirm patterns related to the magnitude of the 35-300 W m^{-2} range, depending on the incision ratios. In the less incised stretches, but with more unstable bedforms, the median ω within this range was much lower than that estimated under conditions of greater morphological stability (Conesa-García et al., 2019).

The capacity of an ephemeral stream reach to absorb (to resist and recover) alterations is related to geomorphological thresholds in discrete flooding events over time. Changes in a channel occur when the thresholds related to the stream power and the flow or sediment regime are exceeded (Schumm 1979). The morphology of a given reach is susceptible to change (therefore, sensitive to change) when it is near to the critical geomorphic threshold imposed by a disturbance (Brewer and Lewin 1998; Schumm, 1969, 1979). In such a situation, the resistance to change is low and there is an adjustment in the channel in accordance with the magnitude of the alteration. The recovery can be slow or rapid, through adaptation of the different morphological units that make up the channel (Fryirs and Brierley, 2013) and the colonisation and development of vegetation (Dollar et al. 2007). The stream power threshold for stability in the lower ephemeral reach of the Alto Mula differed from that suggested by other researchers for perennial gravel-bed watercourses. In particular, in the cross-sections with a more stable bed (RBS < 1) and bankfull discharge, the minimum value ω required for the degradation of the bed exceeded 80 W m^{-2}.

Under conditions of greater flow competence (1 < RBS < 2), this value ranged from 33 W m^{-2} in moderately incised stream reaches (1< IR < 2) to 42 W m^{-2} in highly incised ones (IR > 2). The threshold of 300 W m^{-2}, suggested by Magilligan (1992) for major morphological adjustments with erosion, was exceeded in 16% of cases, although around a third of this percentage was produced in sections with a very stable bed. These stable beds are generally characterised by local outcrops of rocky substrate or are composed of pebbles and thick blocks that are only moved in large flash floods. In these cases, it was observed that there was a clear influence of bed erosion on the stability of the channel, in agreement with the behaviour of ephemeral channels with an alternating alluvial granular bed and cohesive substrate (Wittenberg et al., 2007; Conesa-García et al., 2007). These results seem to confirm the existence of current morphological changes (a deceleration in scour processes associated with bed armouring and channel widening) different from those developed in an earlier stage that were responsible for the deep incision and entrenchment (Conesa-García et al., 2020a). Such results were consistent with those obtained when relating the mean stream power (ω) vs. critical energy of resistance (ωc) (ω/ωc) and the mean power gradient (∂ω/∂s) for different ranges of DMR in each class of reach. The cross-sections with moderate incision values and W/D, and insignificant or null entrenchment, along the bend sub-reaches, were frequently the object of bankfull discharge with a low to moderate capacity to transport sediment, which produced bed stability and minor morphological adjustments. The highest values of energetic balance showed greater dispersion and corresponded to cross-sections which were less entrenched and prone to channel widening. Similar results were obtained by Yochum et al. (2017) on finding a greater morphological response and adjustment in unconfined channels in accordance with the increase in unit stream power (ω).

Stream power thresholds and morphological adjustments

In particular, the spatial and temporal morphological variability in SAES, as a function of the variations in the energy of floodwaters, has only been studied to a limited degree (Levick et al., 2008; Ortega et al., 2014). Sutfin et al. (2014) proposed a non-metric multidimensional ordering scale, based on geometric and hydraulic variables: a relationship between width-to-depth ratio (W/D), gradient of the sheet of water (S), stream power (Ω) and shear stress (τ). Other authors relate morphological adjustments in these types of ephemeral channels with systematic changes in mean stream power (ω) / resisting power (ω_c) (ω/ω_c) (Bull, 1997) and, therefore, in transport efficiency, associated with the mean stream power gradient (∂ω/∂s) and excess energy (Conesa-García et al., 2020a). Recently, in the framework of the CCAMICEM project, Conesa-García et al. (2020b, 2021) have proposed a methodological approach to assess, on the scale of events, the relationships between sediment budgets and stream power during flood events along an ephemeral gravel-bed channel (the Rambla de la Azohía, Murcia), combining High Resolution Digital Models (VHRDTM), provided by SfM-MVS and TLS, and a hydrodynamic 1D model calibrated using field data. The following are the most notable results:

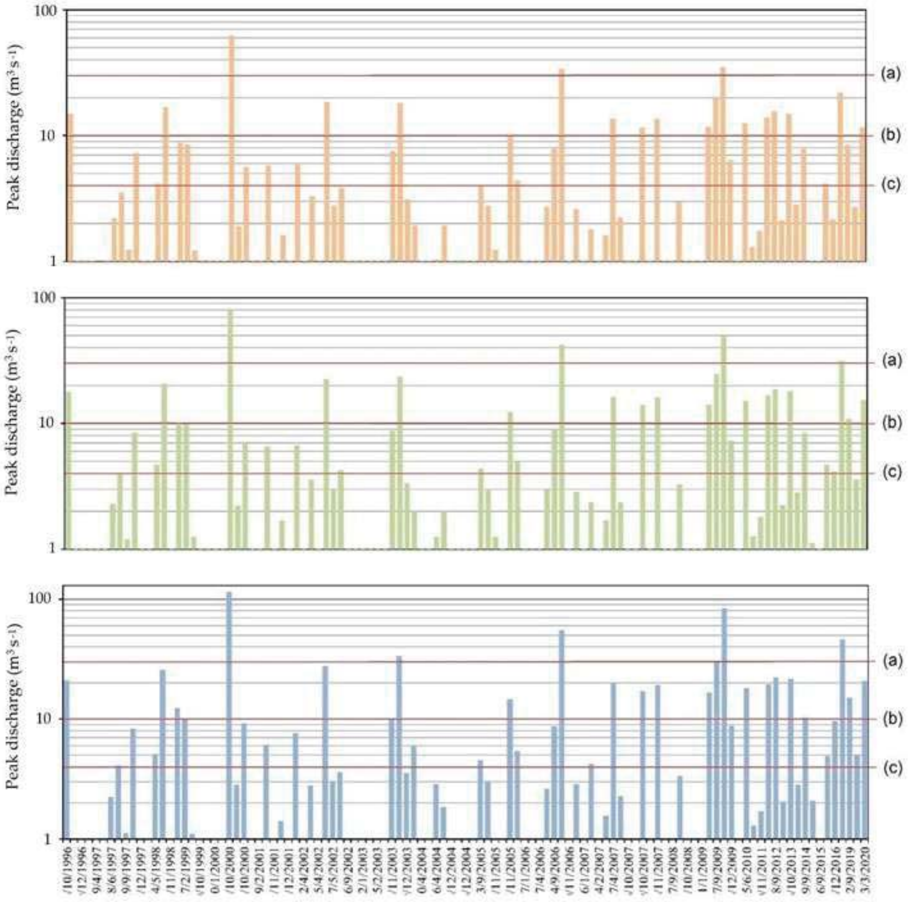

Figure 101. Thresholds of discharge peaks associated with different classes of morphological adjustments during the events simulated using GeoWEPP for upper, middle and lower reaches of the Rambla de la Azohía (period 1996-2020). (a) overall morphological changes, affecting the bankfull channel and active flood bed); (b) moderate changes (local scour holes, vertical bed accretion, and basal bank undercut); (c) minor adjustments limited to surface bed washing due to selective transport and small variations in active bed forms. From CCAMICEM Project (2018-2021).

Major events, with discharge peaks greater than 30 m^3 s^{-1}, registered the highest values of stream power ($\omega > 300$ Wm^{-2}) (figure 101) and a considerable spatial variability both in the mean power gradient ($\sigma > 6$ Wm^{-2}/m) and in the excess energy ($\sigma > 80$ Wm^{-2}). These flows mobilised a large bedload, causing notable transitory erosion and general vertical accretion. It was specifically found that the discharges that exceed the bankfull level tend to produce increased vertical accretion (0.20 to 0.35 m for a discharge peak of 31 $m^3 s^{-1}$), after having mobilised a large quantity of bed material upstream. During this process considerable variations occurred in the stream power gradient ($-15 < \partial\omega/\partial s < 15$ Wm^{-2}/m) and a high mean excess energy (mean ratios $\omega/\omega_c > 2$ for the same event). In contrast, the values of ω from 35 to 150 Wm^{-2} were associated with the elimination of bank deposits and moderate changes in active bars (figure 101). The degradation of the bed dominated especially in the lateral zones, due to bank breaking and the displacement of intermediate gravel bars. However, moderate peak discharge (10-20 $m^3 s^{-1}$), in the sub-bankfull stages, mainly produced processes of surface washing, selective transport, and local scouring, affecting active low bars.

Morphosedimentary dynamics as an indicator of geomorphic resilience

The grade of maintenance and recovery of a channel pattern can be approached as an indicator of resilience at the basin scale (Fryirs and Brierley, 2013). However, in the reaches, the changes in disposition, interconnection and composition of bed forms (for example bars, riffles, pools and runs) and changes in bed material texture in response to alterations in the fluvial system tend to be more related to initial grain-size distribution of sediment, spatial-temporal variations in bedload and morphological channel features (Thorp et al., 2006; Poole 2010; Elosegi and Sabater 2013; Conesa-García et al., 2020b). On both scales, bed forms and substrate nature, the concept of resilience takes on greater ecomorphological importance and applicability. In this way, several authors have recognised that these settings represent a critical physical habitat for biota and riparian ecosystems (Fuller et al., 2019), at the same time as influencing, in an integral and decisive way, the global response of the channel to alterations within a dynamic equilibrium (Fryirs and Brierley, 2013). The differential behaviour of these bed forms, which in turn are highly changeable in ephemeral channels, involves a mixed resilience, capable of “absorbing” much of the disturbance without a substantial change in the general shape of the channel.

Depending on their activity and rhythm of adjustment within ephemeral channels, very different types of bed can coexist, from active bars, without vegetation, which are extremely changeable, to zones of cohesive rocky substrate and high stabilized alluvial bars. The bars submerged sporadically by water flows of moderate and high magnitude are usually colonised by characteristic plant associations, with a predominance of bushes and shrubs, reflecting such hydrological conditions and the nature of the granular materials on which they settle. The combination of erosive and deposition processes, which encourage, cushion or prevent their development determine the potential response of each morphosedimentary unit in particular. Under these criteria, we can infer relationships of magnitude-frequency of the formation and re-elaboration of such units. The density and type of vegetation observed on each geoform unit class will make it possible to detect its degree of sensitivity/resilience compared to alterations in the hydrological regime or changes in the mean stream power in extreme events. The studies are becoming increasingly common (Calle et al., 2017; Conesa-García et al. 2020b; Ibisate et al., 2021, among many others), analysing these types of relationships between bed forms, vegetation and adjustment capacity (sensitivity to withstand alterations: connection of some bars with others, vertical or lateral accretion of these due to an increase in deposition; or partial re-elaboration, disintegration and destruction of a geomorphological unit because of erosion).

Most SAES flow in alluvial formations (glacis, fans and floodplains) with a partially confined trajectory that can locally affect its adjustment capacity. The presence of rocky substrate in certain reaches limits the lateral and vertical adjustment of the channel. However, the most common in arid and semi-arid areas is the presence of granular beds with high armouring rates and banks composed of unconsolidated detrital material, which, depending on the bed slope, forms wide and shallow channels which are not very sinuous (Schumm, 1961; Scott, 2006) (figure 102). This bed armouring is generally due to a high supply of sediment of all sizes, the rapid recession of flash flood hydrographs and prolonged periods without runoff (Reid and Laronne, 1995). Little or no vegetation cover on the banks can also contribute to the widening of the channel in long reaches of SAES (Reid and Frostick, 1997).

Figure 102. Lower reach of the Rambla de las Moreras with a gravel and pebble bed, high bedload and lateral erosion. An ephemeral stream on the coast of Murcia with a considerable source of coarse sediment in metamorphic terrain at the headwaters.

The distribution of geomorphological units is very much affected by the local slope of the bed. In upper reaches, at the headwaters (for example, entrenched in alluvial fans), the floodwaters have a high stream power and the slope plays an important role determining the degree of adjustment and resistance in the bed forms, according to their proximity to the recovery threshold of the previous longitudinal profile. These are usually straight or not very sinuous channels, narrow and relatively deep, where the processes of vertical incision predominate over lateral erosion. These conditions limit the capacity of the channel to adjust laterally so that the range of bed forms is also very limited.

In lower reaches, however, with hardly any slope, not confined laterally, and therefore normally subjected to sporadic low energy flows, they have a greater lateral development being sensitive to lateral adjustments and variations in the shape and degree of connection of the deposits. In these cases, the low energy conditions facilitate the dissipation of floodwater and bed accretion, through the succession of deposits with fining-upward sedimentary sequences. These channel reaches, moderately resistant, have the capacity for localized adjustment. The vegetation cover tends to colonise more easily and increases its resistance to change, above all in the most stable bars. The middle reaches, characterised by greater mobilisation of the sediment load and more frequent variations in the height of the bed, are prone to vertical, lateral and overall adjustments, and are therefore very sensitive.

Indicators of ecological resilience

Ephemeral streams include a wide variety of ecosystems ranging from those with narrow channels on rocky surfaces and steep slopes to those with very wide channels on sandy or gravel beds and low slope. The configuration of this complex typology is marked by the topographical, geological and climatic setting in which they develop. In this way, ephemeral streams with narrow channels and rocky outcrops are located in mountainous areas mainly composed of hard substrate, while wider channels are developed in flat zones on softer and more erodible materials. All of them have in common the absence of flow during practically the entire duration of the annual hydrological cycle (Vidal-Abarca et al., 2020), although it is the events of sporadic water floods that, finally, configure their morphology.

Currently, a worldwide framework has been initiated that aims to analyze the biological communities that live in these ecosystems and their capacity for resistance and / or resilience (Steward et al., 2011; 2017; Sánchez-Montoya et al., 2016; 2017; 2019), what are the ecological processes that govern them (Merbt et al., 2016; Arce et al., 2019; Marcé et al., 2019; Von Schiller et al., 2019; Keller et al., 2020) and how much and how they contribute to human well-being (Nicolás et al., 2021). The level of knowledge on these aspects is still very incipient, however, it is possible to make some interesting considerations, with a future perspective. In general terms, species inhabiting ephemeral streams should be resistant or resilient to sporadic flood, and especially to hard environmental conditions imposed by this habitat (high levels of sunshine, high fluctuation in environmental temperature; lack of water and humidity, etc.).

Not all ephemeral stream contains a relatively stable vegetation community. In fact, only those that conserve a certain degree of humidity and stability on the bed are capable of maintaining a community of vegetation, but always of terrestrial origin. In a recent study on plant communities of ephemeral streams in southeastern Spain (Martinez-Yoshino et al., 2021) the biological traits of these plants were studied. The results showed that the vegetation able to live in these ecosystems had a clearly xerophilic profile, with the dominant presence of perennial taxa, of a small size, mainly phanerophytes and camephytes, with leaves of a soft texture, small flowers with light colours (yellow and white), grouped into inflorescences and small fruits with brown colours; with simple roots, without physical defences on the leaves and stems, using anemochories as the main mechanism for dispersion. All of those traits make it possible for their survival (resilience) in these stressful environments.

Given the special capacities for adaptation of the plants that colonise ephemeral streams, the impacts and alterations that they undergo have more to do with human activities (for example, the extraction of gravel or sand from the bed; canalisation of the streams, etc.) than with hydrological alterations (frequency and magnitude of discharge peaks). In this regard, Stubbington et al. (2019) demonstrated that plants on dry channels respond to, among other factors, sediment composition and geomorphological impacts. So, their resilience capacity depends more on the configuration and stability of the ephemeral channels than on their own biological and physiological traits, already selected due to the typical environmental conditions of these streams.

3.2. Diagnostics

In ephemeral channels, we are witnessing, with great harshness, a generalised problem that comes from the negative social perception of dry rivers, because of the mere fact that they do not carry any visible water and are considered as potentially dangerous due to the unpredictability of flooding (Llasat et al., 2008). This perception, which is very widespread in society in spite of the abundance and autochthonous character of these types of channels, has yet to be investigated at a psychological and sociological level, and has not been contrasted or quantified scientifically using methods such as surveys, but it is evident for many experts and the issue has been debated in many forums, meetings and congresses. Attention has been drawn to this matter ever since the allegation of contempt for gravel (Ollero et al., 2011b) and in studies promoting a change in mentality towards geomorphology in order to be able to deal with fluvial restoration (Horacio, 2015; Ollero, 2015).

Another problem, which can generally be extended to most types of fluvial courses in these settings, comes from the disturbance and modifications caused by human interventions. Measures for management, for example, public works in the channel or regulation of the discharge, cause direct effects such as narrowing, loss of mobility or the substitution of riverside species (Sanchis et al., 2019). To these we should add indirect changes, associated with alterations in the land uses of the basin, and their influence on sediment yield and runoff, generating new environmental conditions to which the fluvial system will try to adapt (Conesa-García et al., 2007).

The effects of climate and global change on the morphology of Mediterranean ephemeral channels (MEC) look like they will adopt, in some regions, similar patterns to those recorded in recent decades in gravel-bed rivers that descend from European mountain ranges and have been studied in more detail. Human intervention has accelerated synergic processes of incision, narrowing and vegetation colonisation, which have considerably modified the morphology and ecology of many channels (Ollero, 2011; Martîn Vide et al., 2010; Segura and Sanchis, 2013). A lot of these disturbances need to be monitored regionally to be better understood and so that specific measures for MEC can be proposed.

Nevertheless, the low flow frequency in ephemeral streams has other specific implications, which can distinguish them from perennial ones. In ephemeral streams, temporary variability in discharge peaks and hydrological connectivity within the channel and in its network, account for difficulties in absorbing the impacts and providing rapid responses. For that reason, episodes of flash flooding capable of providing a hydrological and sedimentary connection to the whole network are very important. It is after these episodes when great changes are observed, responding to impacts that took place in previous years or decades. As a consequence, the responses to the changes could differ in space and time, taking longer in ephemeral streams than in perennial rivers (Segura, 2014).

The diagnosis of the environmental state or situation of ephemeral streams can be carried out using indices that bring together different hydromorphological and ecological indicators. In a simplified way these indices, based on an increasingly complex reality, provide a score that serves to assess the dimensions of the problems and that is able to compare the specific cases with each other. There are numerous indices for the evaluation or diagnosis of fluvial channels, in all countries, although there are few that can be applied to ephemeral streams. Two specific indices for these channels, the IHG-E and IAR, have been designed and applied by the authors of this guide.

The IHG-E Index

The IHG hydromorphological index (Ollero et al., 2007, 2009, 2011a) has been used in several studies in the Iberian Peninsula and America (Ollero et al., 2021a). In recent years, work has been carried out on a version of the index adapted for ephemeral streams (IHG-E), having been applied to the basin of the Júcar (Ballarín and Mora, 2018) and in the present context of the CCAMICEM project (Sanmartín, 2019; Prados, 2020; Ollero et al., 2021b). It is not yet a definitive index, but as part of the improvement process the results are being checked and combined with other indicators such as geomorphic resilience (Sanchis et al., 2017; Segura and Sanchis, 2018; Calle, 2018), hydromorphological indicators from the sampling procedure and follow-up of the IDRAIM and SUM systems, and the MQI index (Rinaldi et al., 2016). In this way, the estimated IHG-E for reaches, and its interaction with the rest of the indicators, could be essential when it is time to assess the recovery capacity of the channels and their reaches and the resulting diagnosis will constitute the basis for defining measures to be taken.

The IHG-E index is designed into three blocks of indicators: (1) the functional quality of the system (table 4); (2) channel quality (table 5); and (3) quality of the riparian space (table 6). When it is applied, we obtain a general result for the hydrogeomorphological quality and we also obtain a result for each one of the blocks analysed. These blocks do not have the same weight in the final result of the index. They are weighted according to the importance assigned to each one of these blocks for assessing ephemeral stream function. Each one of the blocks analysed is divided into three indicators, which are also weighted according to their importance. Each one of the parameters of analysis (indicators) has a maximum score that is achieved when none of the impacts affecting this parameter are detected in the assessment of a reach. The application of the index consists of taking away the reduction in points, detected by the sheet template previously established, for each impact from the maximum score in each parameter. The score for each block is found by adding together the three parameters in each one and the final score for hydromorphological quality is calculated by adding up the scores in the three blocks.

Table 4

Assessment of the functional quality of the system

Naturality of the water discharge ☐

The circulating water discharge responds to natural dynamics in terms of volume, seasonal regime and extreme processes, and therefore, the fluvial system perfectly fulfills its hydrological transport function		10
Upstream, or in the sector itself there are human actions (reservoirs, diversions, dumping, spills, disruptions, wells, flow returns, water transfer, urbanisation, fires, repopulation, etc.) that modify the quantity of discharge and/or its temporal distribution	If there are notable changes in the discharge, so that the natural seasonal regime is reversed, or a permanent discharge of anthropic origin circulates along the channel	-10
	If there are marked changes in the quantity and temporariness of the discharge	-8
	If there are variations in the quantity of discharge but modifications in the seasonal regime are not very marked	-6
	If there are some variations in the quantity of discharge but the seasonal flow regime is remained	-4
	If there are slight modifications in the quantity of discharge	-2

(Catalogue of actions, hydrological data, monitoring and field-testing)

Naturality of solid discharge ☐

Solid discharge does not present any retention of anthropic origin and the fluvial system mobilises and transports the sediment naturally.		20
In the headwaters and in the upper reaches of the main fluvial system there are check dams with the capacity to retain sediment	If more than 75% of the drainage basin until the reference channel reach has sediment retention	-3
	If between 25% and 75% of the watershed area until the reference reach has sediment retention	-2
	If there are check dams that retain sediment, even if they affect less than 25% of the watershed until the study section	-1
In the tributaries draining directly into the reach there are check dams or elements with the capacity to retain sediment	important	-2
	occasional	-1
In the valley watershed along the study reach there are anthropogenic elements or alterations that retain sediment or affect its mobility or connection with the channel	important	-2
	occasional	-1
In the channel within the sector there are one or more dams with the capacity to retain sediment		-3
In the channel within the reach there are obstacles (fords, structures, clogged weirs, waste,…) with the capacity to retain sediment	If there are several obstacles	-2
	If there is a single obstacle	-1
In the reach there are extractions of aggregates or dredging that reduce the availability of sediment and alter its mobility	Important and frequent	-6
	Occasional	-3
In the reference reach there is compacted sediment or sediment removed because of vehicles passing or other anthropogenic factors, or the sediment there consists of rubble or unnatural elements	important	-2
	occasional	-1

(Catalogue of actions, cartography, aerial photograph, field survey)

Functionality during flooding ☐

<table>
<tr><td colspan="5">The channel and flood-prone areas can perform its functions of energy dissipation during the flood, laminating peak-flows due to overflow and sediment deposition, without anthropogenic restrictions</td><td>15</td></tr>
<tr><td colspan="3" rowspan="3">There are actions in the channel reach (dredging, extractions,…) or anthropic elements (fords, check dams, obstacles,…) within the minor channel, which alter the processes and flood flows</td><td colspan="2">In more than 20% of the length of the reach</td><td>-3</td></tr>
<tr><td colspan="2">In between 5% and 20% of the length of the reach</td><td>-2</td></tr>
<tr><td colspan="2">In less than 5% of the length of the reach</td><td>-1</td></tr>
<tr><td colspan="3">The flood-prone area has longitudinal defences restricting the natural functions of lamination, deposition and energy dissipation.</td><td>In more than 20% of the reach length</td><td colspan="2">In less than 20% of the reach length</td></tr>
<tr><td rowspan="3"></td><td colspan="2">Continual defences in both banks (canalisation)</td><td>-6</td><td colspan="2">-3</td></tr>
<tr><td colspan="2">Discontinuous defences or on one bank</td><td>-4</td><td colspan="2">-2</td></tr>
<tr><td colspan="2">Defences away from the minor channel</td><td>-2</td><td colspan="2">-1</td></tr>
<tr><td colspan="4" rowspan="2">The flood-prone area outside the channel has land uses (urban, industrial), or obstacles (defences, road infrastructures, buildings, irrigation canals…), affecting the hydrogeomorphological processes of overflow and flooding and flood water flows</td><td>Abundant</td><td>-4</td></tr>
<tr><td>Occasional</td><td>-2</td></tr>
<tr><td colspan="2" rowspan="2">The flood-prone area presents land uses that reduce its natural functionality</td><td colspan="3">If raised, or impermeable land is greater than 10% of its surface</td><td>-2</td></tr>
<tr><td colspan="3">If there is raised or impermeable land but it is no more than 10% of its surface</td><td>-1</td></tr>
</table>

(Catalogue of actions, cartography, aerial photograph, field survey)

Assessment of the functional quality of the system ☐

Table 5

Channel quality assessment

Naturality of the channel shape ☐

The channel planform remains unaltered and its morphology presents features and dimensions in accordance with the characteristics of the basin and valley and with the natural function of the system		5
Artificial changes and direct or indirect anthropogenic modifications (changes resulting from activity upstream) have been registered in the channel planform	In more than 10% of the reach length	In less than 10% of the reach length
If there have been drastic changes (diversions, artificial meander cutoffs,…)	-5	-3
If minor changes have been registered (setting back of banks, small rectifications,…)	-4	-2
If there were old prior changes that the fluvial system has partially naturalised	-2	-1

(Catalogue of actions, cartography, aerial photograph, monitoring and field-testing)

Longitudinal and vertical naturality ☐

The channel is natural and continuous and its longitudinal and vertical hydrogeomorphological processes are functional and natural		15
In the channel there are structures that break the longitudinal continuity and alter the morphology of the channel bed	If there is at least one check dam of more than 10 m in height	-3
	If there are several weirs less than 10 m high	-2
	If there is only one weir less than 10 m high	-1
There are fords and road-stream crossings consisting of tracks and paths that alter the longitudinal continuity of the channel	More than 1 for every 2 km of channel	-6
	Less than 1 for every 2 km of channel	-2
There are bridges or other minor obstacles that alter the longitudinal continuity of the channel	More than 1 for every 2 km of channel	-2
	Less than 1 for every 2 km of channel	-1
Bed topography and sediment structure show signs of alteration due to dredging, extraction, bed lining, the passing of vehicles, …	In more than 20% of the length of the reach	-4
	between 5 and 20% of the length of the reach	-2
	Occasionally	-1

(Catalogue of actions, cartography, aerial photograph, field survey)

Transverse naturalness ☐

The channel is natural and can move laterally, given that the morphology of its natural banks is consistent with the hydromorphological processes of erosion and sedimentation		10
The channel has been subjected to complete canalisation or there are non-continuous defences on the banks or infrastructure (buildings, roads and highways, irrigation canals, …) attached to the banks	In more than 50% of the length of the reach	-6
	between 20% and 50% of the length of the reach	-4
	Between 5 and 20% of the length of the reach	-2
	Occasionally	-1
The channel banks have unnatural elements, rubble or interventions affecting their natural morphology	notable	-2
	slight	-1
In the reach there are symptoms of the lateral dynamics being limited or there is no equilibrium between erosion and deposition on the banks, possibly being the effect of human actions upstream	notable	-2
	slight	-1

(Catalogue of actions, cartography, aerial photograph, field survey)

Channel quality assessment ☐

Table 6

Assessment of the riparian quality

Longitudinal continuity ☐

The riparian corridor is continuous along the functional reach and on both banks of the minor channel, provided that the geomorphological framework of the valley allows this	5	
The longitudinal continuity of the natural riversides could be interrupted either because of permanent land use (urbanisation, industrial units, farms, gravel pits, buildings, roads, bridges, defences, irrigation cannals, …) or because of surfaces with temporary land use (poplar trees, crops, arable land, tracks, …).	If more than 30% of the discontinuities are permanent	If less than 30% of the discontinuities are permanent
If the riverside zone is completely eliminated	-5	
If there is a bank with the riparian corridor that is completely eliminated and the other partially eliminated	-4	-3
If there is a bank on the riparian corridor that is completely eliminated and the other more or less natural	-3	-2
If the riparian corridor on both banks is partially eliminated	-2	-1

(Cartography of land use, aerial photograph, monitoring and field-testing)

Width of the corridor ☐

The riparian corridor conserves all of its potential width, so that it perfectly fulfills its role in the hydromorphological system.		5
The width of the riparian corridor has been reduced due to human occupation	If its current mean width is less than 20% of its potential width	-5
	If its current mean width is between 20% and 40% of its potential width	-4
	If its current mean width is between 40% and 60% of its potential width	-3
	If its current mean width is between 60% and 80% of its potential width	-2
	If its current mean width is greater than 80% of its potential width	-1

(Current and old aerial photographs (comparison), field survey)

Structure and naturality ☐

In the riparian corridor a natural structure typical in these environments is conserved alongside the naturality of the species and all its transverse complexity and diversity, without there being any internal anthropogenic obstacles separating or disconnecting the different habitats making up the corridor.		5
There are anthropogenic pressures and elements in the riparian corridor (grazing, clearings, felling, fires, exploitation of the aquifer, rubbish, roads, defences, irrigation canals, tracks, paths,…) affecting its transverse structure and connectivity.	If they are in more than 25% of the surface of the current corridor	If they are in less than 25% of the surface of the current corridor
If the alterations are substantial ones	-3	-2
If the alterations are minor	-2	-1
The naturality of the vegetation has been altered by invasive species or reforestation	if the alterations are significant	-2
	If the alterations are minor	-1

(Aerial photograph, identification in the field)

Assessment of the riparian quality ☐

Figure 103. Application of the IHG-E index to the ephemeral streams studied in the CCAMICEM project.

The RDI index

The "*Ramblas*" Disturbance Index (RDI) ("rambla" is a local term used to name ephemeral streams) (Suárez and Vidal-Abarca, 2008) was designed to assess the state of conservation of Mediterranean ephemeral streams as a response to the total absence of criteria, by the Water Framework Directive 2000/60/EC, to establish the environmental state of these ecosystems. This index is being used in different basins in Spain, such as those of the Júcar and Segura rivers, to establish the level of disturbances caused by anthropogenic impacts on these channels. Futhermore, the RDI has been tested in dry streams in the Peninsula of Baja California (México), demonstrating its utility for any type of ephemeral channel (Suárez et al., 2010).

The RDI combines the presence of pressures/impacts in the reach studied with the capacity of recovery of the ecosystem with the level of connectivity and the naturality of the adjacent ecosystem. The multiple and varied human impacts detected in the "*ramblas*" range from effects produced by very large dams to those that are caused by activities with low impact, such as the harvest of perennial sempre-vivas, or snails. Regarding the land use and connectivity of the channel with the hillslope, both channel banks can be quantified visually and semi-quantitively (%), independently. The connectivity assesses the continuity that exists between the hillslope and the channel, while land uses are evaluated according to the percentage of occupation of the agricultural, urban, industrial and natural use which includes forest masses, weeds and grasslands typical of the Mediterranean semi-arid environment. Tables 7 and 8 show the protocol for the application and calculation of the RDI and the field sheet.

Table 7

Protocol for the application and calculation of the Rambla Disturbance Index (RDI)

Steps to follow	Observations
Select a reach 100 m in length in the ephemeral stream, far from the access point to the channel if possible.	The bridges and paths used for access to the stream should be avoided due to, at these points, there can are disturbances that can alter the value of the parameters to be measured.
The field sheet includes two sections, each one with a different objective, which should be completed independently.	The field sheets include a header that identifies the stream, the location sampled and photos.
Useful considerations for filling in the field sheet for semi-arid Mediterranean ephemeral streams	
1-Anthropogenic impacts	
On impacts detected in the ephemeral rivers. This involves analysing both the quantity and intensity of the impact.	The value of the impact is an indicator of the intensity of the pressure and is related to its reversibility. Thus, a value of 1 indicates that the impact is easily reversible and 10, that it is totally irreversible.

2- Capacity for recovery	
This section takes into account two aspects. On the one hand, the connectivity between the channel and the hillslope on both sides of the stream is calculated (%). Secondly, the land uses on both riversides is semi-quantified independently.	Work is carried out on both sides of the 100 m of channel reach selected.

CALCULATION AND QUALITY CLASSES FROM THE RDI

RDI = 1 + II – RC Range of variation: 0-2

(II) is the impact index: **II = (Σ Impact Value)/50** Range of variation: 0-11

It is the sum of the values of the impacts detected divided by 50. A value of 50 has been established as the maximum possible score of the impact, taking into account that the maximum value detected in the whole of the ephemeral streams where it has been applied was 40 and offering a margin for greater impacts in other channels

RC is the recovery capacity of the system: **RC = ((Clb * Nlb) + (Crb * Nrb))/2**
where Clb is the connectivity of the left bank; Crb is the connectivity of the right bank; Nlb is the naturalness of the left bank; Nrb is the naturalness of the right bank Range of variation: 0-1

It is the average of connectivity and naturality of the ecosystem in both banks

Connectivity (%) Natural land use (%)	Application value
>75	1.00
50-75	0.75
25-50	0.50
< 25	0.25

QUALITY CLASSES FROM THE RDI

Quality classes	State of conservation	RDI value
I	VERY GOOD	< 0.4
II	GOOD	0.4 – 0.9
III	< GOOD	> 0.8

Table 8

Field sheet for the calculation of the Rambla Disturbance Index (RDI)

<table>
<tr><th colspan="9">FIELD SHEET FOR THE CALCULATION OF THE RDI</th></tr>
<tr><td>Nº:</td><td colspan="6">Name:</td><td colspan="2">Date:</td></tr>
<tr><td colspan="7">Location:</td><td colspan="2">Hour:</td></tr>
<tr><td colspan="3">UTM-X:</td><td colspan="4">UTM-Y:</td><td colspan="2">Altitude (m):</td></tr>
<tr><td colspan="9">Photos</td></tr>
<tr><th colspan="9">ANTHROPOGENIC PRESSURES/IMPACTS</th></tr>
<tr><td colspan="2"></td><td>Presence</td><td>Value</td><td colspan="3"></td><td>Presence</td><td>Value</td></tr>
<tr><td colspan="2">Channelling</td><td></td><td>10</td><td colspan="3">Channel drainage</td><td></td><td>5</td></tr>
<tr><td colspan="2">Surfaced road</td><td></td><td>10</td><td colspan="3">Extraction of groundwater</td><td></td><td>4</td></tr>
<tr><td colspan="2">Check dam height > 5m</td><td></td><td>10</td><td colspan="3">Wells in the channel</td><td></td><td>4</td></tr>
<tr><td colspan="2">Gravel pits</td><td></td><td>9</td><td colspan="3">Dried trees</td><td></td><td>4</td></tr>
<tr><td colspan="2">Crops in the channel</td><td></td><td>9</td><td colspan="3">Check dam height < 5m</td><td></td><td>3</td></tr>
<tr><td colspan="2">Cattle (waste)</td><td></td><td>9</td><td colspan="3">Solid organic waste</td><td></td><td>2</td></tr>
<tr><td colspan="2">External water entry</td><td></td><td>8</td><td colspan="3">Rubble</td><td></td><td>2</td></tr>
<tr><td colspan="2">Liquid effluents</td><td></td><td>8</td><td colspan="3">Pesticides/herbicides</td><td></td><td>2</td></tr>
<tr><td colspan="2">Burning of vegetation</td><td></td><td>7</td><td colspan="3">Harvesting vegetation</td><td></td><td>1</td></tr>
<tr><td colspan="2">Tracks on the bed</td><td></td><td>6</td><td colspan="3">Snail harvesting</td><td></td><td>1</td></tr>
<tr><td colspan="2">Motorbike raceways</td><td></td><td>6</td><td colspan="3">Hunting (waste)</td><td></td><td>1</td></tr>
<tr><td colspan="2">Car raceways</td><td></td><td>6</td><td colspan="4">Σ Impact value</td><td></td></tr>
<tr><td colspan="2"></td><td></td><td></td><td colspan="4">II = (Σ Impact value)/50</td><td></td></tr>
<tr><th colspan="9">RECOVERY CAPACITY</th></tr>
<tr><td>Connectivity channel-hillslope (%)</td><td>>75</td><td>50-75</td><td>25-50</td><td><25</td><td colspan="2">Left bank</td><td colspan="2">Right bank</td></tr>
<tr><td>Application value</td><td>1,00</td><td>0,75</td><td>0,50</td><td>0,25</td><td>C_{lb}</td><td></td><td>C_{rb}</td><td></td></tr>
<tr><td>Natural land use (%)</td><td>>75</td><td>50-75</td><td>25-50</td><td><25</td><td colspan="2">Left bank</td><td colspan="2">Right bank</td></tr>
<tr><td>Application value</td><td>1,00</td><td>0,75</td><td>0,50</td><td>0,25</td><td>N_{lb}</td><td></td><td>N_{rb}</td><td></td></tr>
<tr><td colspan="3"></td><td colspan="4">[(Clb * Nlb) + (Crb * Nrb)]/2</td><td>RC</td><td></td></tr>
<tr><th colspan="9">CALCULATION OF THE INDEX</th></tr>
<tr><td colspan="8">RDI = 1 + II - RC</td><td></td></tr>
</table>

3.3. Principles, criteria and conditions for restoration and a new way of managing ephemeral streams

The lack of antecedents in the restoration of ephemeral streams and their geomorphological relevance for their function affect the action to be taken and lead to the first key principle: adaptive management. This concept was defined by Holling (Ed., 1978) as learning while action is taken, improving the management system while it is applied, not depending on a previous detailed plan, but rather progressively adapting to the natural processes based on follow-up, and always with a view to preserving environmental values. This adaptive management is therefore associated with sustainability in its widest sense, as well as agreements with land agencies and multidisciplinary scientific monitoring, which is all undergoing permanent change and modulating decision making.

Another inseparable principle is integrated environmental management, so that fluvial restoration, risk management and land planning should be combined, and feedback about them shared. In the ephemeral streams this principle is fundamental and poses a great challenge for our age, given that these fluvial systems are hardly or never considered in land management and planning, even though they are protagonists during extreme hydrological events and serious risk situations. For this reason, restoration projects and processes must be efficient at dealing with these shortcomings, as well as looking for the recovery of natural systems.

As we can deduce from the characteristics and function of these fluvial systems, as set out in previous sections, the restoration of ephemeral streams has to be fundamentally geomorphological and aimed at recovering functionality together with hydromorphological and ecosystemic values. And preferably, the restoration should be passive, where all or most of the work can be carried out by the watercourse once the impacts have been eliminated or controlled. These criteria should guide our proposals a priori, although the adaptation process itself could lead to opting for more or less occasional active possibilities, and to ecological interventions that are not supported so much by geomorphology.

In order to manage and recover these ephemeral streams it is necessary to take into account several conditioning factors. Firstly, hydrological and sedimentary connectivity (longitudinal, lateral, vertical and temporal) presents considerable fluctuations (Camarasa and Segura, 2001), and therefore, absorption of the impacts and responses are slower than in perennial rivers. As these dry channels depend solely on floodwaters, until they adapt to the new environmental conditions, the transitory states can last a very long time. It can take a long time before geomorphic flood waters can reconstruct the channel, which is why active recovery operations not taking into account these circumstances can be counterproductive (Segura et al., 2021).

In addition, reference models cannot be used (for example, the situation in the aerial photograph in 1956, proposed by the ENRR) for the restoration of ephemeral streams. These streams take a long time to absorb impacts and it is very difficult to establish at which temporary phase they are in at a given moment, given that effects differ in time and space. Consequently, it is essential to analyse and determine the whole historical trajectory to understand the evolution of these factors, that determine the current state (Dufour and Piégay, 2009). In light of the fact that these factors fluctuate much more then in perennial rivers, it becomes clearer for the need to analyse the trajectories as the first step before proposing restoration plans.

Working on the historical trajectory of rivers allows us to analyse their capacity for resilience. Some studies carried out on Mediterranean ephemeral streams suggest that these watercourses have a great capacity for self-regeneration, given that they possess high amounts of energy. The design of specific indicators of spontaneous recovery makes it possible to check the regenerating power of floodwaters and the importance of extreme hydrological events on the evolution of channels. Therefore, it is necessary to continue advancing along these lines, with the aim of having instruments of diagnosis and restoration criteria based on the real functioning of ephemeral streams (Sanchis et al., 2017, Calle et al., 2017).

In the same sense as previously stated, we continue to believe that, in principle, priority should be given to passive restoration rather than an active one. Therefore, it is important to prioritise the elimination of direct impacts on indirect ones, allowing the fluvial system to self-regenerate. This also involves prioritising local action on specific reaches, rather than carrying out large scale projects on the basin. Nevertheless, depending on the trajectory of each watercourse, in the cases in which no signs of self-regeneration are detected, active recovery may be necessary.

This synthesis of principles, criteria and conditioning factors, should all be taken into account before considering a restoration project or any good practice to apply to a specific scenario. Therefore, these have been taken into account in order to define the 33 good practices for ephemeral streams set out in the following chapter.