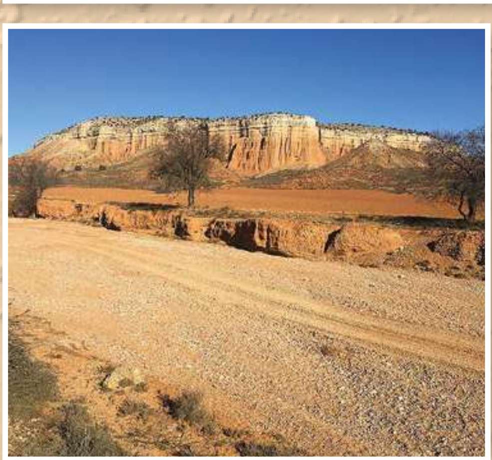
Alfredo Ollero • Carmelo Conesa-García • María Rosario Vidal-Abarca (eds.)

A GUIDE TO GOOD PRACTICES FOR THE MANAGEMENT AND RESTORATION OF MEDITERRANEAN EPHEMERAL STREAMS: RESILIENCE AND ADAPTATION TO CLIMATE CHANGE



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Justification and aims

This book has come out of nothing, a blank page, because the restoration and management of ephemeral streams in the Mediterranean is practically non-existent. These fluvial systems are not guided by good practices, but rather the opposite is the case: they are subjected to important impacts, to very frequent situations of neglect and generalised malpractice.

Therefore, this is a necessary and urgent book, because human action on ephemeral streams largely consists of bad practices; and because human perception about these watercourses is loaded with a negative edge, prejudice, a frequent desire to occupy them, an almost total lack of respect and even a false sense of security.

In recent years the authors have checked the ephemeral streams in the basins of the Ebro and the Murcia region within the framework of the CCAMICEM project. These are streams that are representative of the whole of the Mediterranean and share what is stated in the previous paragraph. Taking as a starting-point the characterisation and evaluation studies carried out, we have acquired a diagnosis of the main problems and experience to be able to provide some management and recovery measures and solutions. Added to the current situation of deterioration, there are the effects of climate change, which are very evident in this fluvial typology and, in some regards, more intense and serious than in permanent and temporary rivers.

The objectives of this study are: i) to establish the basis on which the management and recovery of ephemeral streams should and can be developed, according to their characteristics and conditioning factors, including the perspective of climate change; ii) to publicise the value of these watercourses and the need for their functional and environmental improvement; and iii) to provide a simple and practical guide to serve as support for specific initiatives and procedures to be set up and developed by the appropriate government administrations.

To sum up, the priority measure, as a first step to being able to recover ephemeral streams, is to improve understanding of them, publicise them and raise awareness about them. This is the meaning and direction of this brief catalogue of good practices, which constitutes, above all, technical and informative material which can explain the importance of these streams, the effect on them of global change and local human disturbances, and the possibilities of adaptation and recovery.

1
Fundamentals

Alfredo Ollero,
Carmelo Conesa-García and
María Rosario Vidal-Abarca

1.1. What is stream restoration?

The main objective of restoring rivers, gullies and ephemeral streams is to preserve and improve their natural function, so they can be handed down to future generations in a good condition, given their high value as patrimony. We have altered and degraded our fluvial systems to such an extent that their restoration is the great scientific challenge of the 21st century and should become a powerful line of research (Ollero, 2015).

In basic terms, restoration involves re-establishing the processes of a natural system, returning its structure, function, territory and dynamics. Authentic restoration is, therefore, passive recovery or self-recovery, simply consisting of eliminating impacts to allow the natural system to recover by itself. Thus, on our way to the future, there has been a development from a previous phase when it was believed that technology could dominate or control the natural system until the current phase in which, in some regards, it is now possible to work with the natural system rather than against it. It is now necessary to take a further step to achieve an effective restoration of natural systems: to let the system do the work.

Therefore, authentic restoration could be defined as a path of self-recovery of the processes, structure, functions, territory, dynamics and resilience of a natural system, starting with the elimination of the impacts that degrade it and doing so over a prolonged period of time, until a natural and self-sustainable functioning is achieved (Ollero, 2015). This definition can be applied perfectly to any fluvial system.

A restored fluvial system will have recovered:

- Its natural processes and all interactions between its elements and other systems,
- Its structure, in other words, all its components and flows in all their complexity and diversity,
- Its functions as part of the Earth system (transport, regulation, habitat, etc.),
- Its territory, that is to say, its own continual space that it should occupy in order to develop all its processes and functions,
- Its natural dynamics over time,

- Its resilience or strengths for dealing with future impacts, its capacity for self-regulation and self-recovery
- And, therefore, all the goods and services that it provides to society.

In short, the restoration process should achieve naturalness, functionality, dynamism, complexity, diversity and resistance for the natural system.

As a result of these considerations, restoration should be passive and fundamentally geomorphological. But an active recovery can also be carried out, with specific actions which help accelerate or guide the work of the river. A fluvial system will have recovered when it once again has enough resources to continue its development, maintaining itself structurally and functionally, interacting with adjoining systems and with the capacity to recover within the normal limits of environmental stress and alteration.

Basically, stream restoration is necessary and urgent in itself, but it is also a very useful tool in land management, in environmental planning and for mitigating of risks of flooding. In the future it will undoubtedly lead to better conserved watercourses, functioning efficiently, in harmony with human activities that are better suited to the river and, consequently, they will be less vulnerable. Stream recovery provides resilience to both the river and society, it will strengthen their interactions and give coherence to a relationship between fluvial territory and society which is so often lacking in current times.

1.2. How do ephemeral streams work?

Non-perennial rivers and streams make up at least 50% of the world's fluvial network and this percentage is much higher in many Mediterranean basins (Skoulikidis et al., 2017; Calle, 2018; Messager et al., 2021). For that reason, they are not a hydrological or geomorphological anomaly, but rather an important reality in southern Europe. These watercourses do not only present characteristics common to rivers with a continuous flow, from a hydraulic, geomorphological and ecological point of view, but they also share environmental problems associated with the extraction of aggregates (Rinaldi et al., 2005; Sanchis et al., 2017; Calle et al., 2017), the construction of dams, ripraps or breakwaters (Ollero, 2015), among others.

But, in addition, ephemeral streams are markedly different in some key aspects. They can be defined as fluvial systems (in their entirety or on some of their reaches) in which only surface water circulates in a sporadic or passing way, in most cases because they are disconnected from the aquifer, so that they only carry direct discharge in response to precipitation events (Levick et al., 2008). This temporary nature is reflected in the very origin of the term ephemeral, which comes from the Greek word *ephémeros* (that which only lasts for one day). Scientific literature refers to non-perennial rivers in many ways –intermittent, temporary, semipermanent, seasonal, ephemeral, etc.– and recently the acronym IRES *(intermittent rivers and ephemeral streams)*, has started to be used in order to define rivers which temporarily flow and stop flowing and/or completely dry up at some point or right along the channel (Datry et al., 2017). This discontinuous nature defines them and at the same time makes it difficult to classify them and, therefore, safely deal with their management and conservation (Vidal-Abarca et al., 2020). The space-temporal variability of their discharge means that the very river, or even a reach of the river, can be identified as intermittent or ephemeral depending on the moment and place of the observation (Segura et al., 2021).

In brief, unlike perennial rivers, IRES do not have baseflow, which means that when the direct flow ceases, they become dry. This is especially marked in ephemeral streams in arid and semi-arid zones (*semi-arid ephemeral streams* –SAES-). The absence or shortage of baseflow could be due to climatic (aridity, as occurs in the SAES), lithological (karst), structural (disconnection with the aquifer) or even anthropogenic causes (Datry et al., 2017). The combination of all these factors makes it very complicated to make classifications because the reduction or disappearance of surface flow changes from the headwaters to the river mouth and between flood events. Thus, it is common to find permanent or temporary flows at the headwaters (connected to local aquifers) which disappear from the surface downstream (disconnected from the aquifer and with transmission losses).

Flows in these streams tend to be *flash floods*. They generate very heightened hydrographs, with a very steep upward curve, very high peak discharges and very short delay times. They can change from a discharge of 0 to hundreds or thousands of m^3/s in minutes or hours, which results in sudden and frequent flooding (Camarasa, 2021). They run also, on many occasions, along channels with steep slopes and a high sediment load, transported spasmodically due to strong fluctuations in discharge. We can predominantly find coarse sediment (sand, gravel, pebbles, blocks), from where we derive the Arabic toponym *ramla* (sandy or stony ground). The sediment moves along channels with a braided pattern composed of multiple secondary channels and alluvial bars (middle and lower stream reaches) or in a single channel (headwaters). The bedload is transported in the narrowest cross-sections and is deposited forming bars where the channel widens. Occasionally bed armouring can be seen.

Hydromorphological functioning is the key motor in all fluvial dynamics, and it is even more so in these kinds of streams marked by the absence or shortage of flow. The sediment load transported by a stream is adjusted to the discharge, and morphological channel adjustments depend on the sediment budgets relating erosion and deposition rates. The nature of this balance could be established by considering the geomorphological effectiveness of hydrological events on different time scales. The morphological adjustments in these kinds of systems are mainly controlled by the magnitude and frequency of hydrological events. The main events that are pro-

Figura 1. An ephemeral channel reach with a sandy bed, Arroyo Grande (Villamanta, Madrid)

duced in Mediterranean ephemeral channels (large floods) are the least frequent, but the most effective in terms of total sediment transport and morphological channel change (Baker, 1977; Conesa-García, 2005; López-Bermúdez et al., 2002). Less dramatic events, which are more repetitive, cause local readjustments as part of the overall changes due to larger floods. The bankfull and flood discharges construct and model these channels, throughout the eastern half of the Iberian Peninsula, from Navarra to Andalucía, creating an extensive network, with an interesting gradation in relation to aridity conditions, as well as considerable morphological variety.

Ecological functioning in these channels is mainly governed by the biogeochemical processes that occur in dry sediments, so that its functional dynamic seems more like that of a terrestrial ecosystem than an aquatic one. The accumulation of sediment, the presence of terrestrial plants and leaf deposits in riparian zones create the perfect framework for the colonisation and development of biotic communities adapted to soil (Arce et al., 2019), generating zones of high microbial activity, which, among other processes, facilitate the decomposition of organic material (Sánchez-Montoya et al., 2019) and the recycling of nutrients. Ephemeral streams, also play an important role in both the overall carbon cycle (Von Schiller et al., 2019; Marcé et al., 2019; Keller et al., 2020) and the nitrogen cycle (Gómez et al., 2012; Arce et al., 2014, 2015; Merbt et al., 2016).

In the ephemeral streams inhabits a rich and abundant diversity of organisms (from microorganisms to vertebrates, both vegetable and animal), but mainly of a terrestrial origin (Steward et al., 2011, 2017; Sánchez-Montoya et al., 2016; 2017; Martínez-Yoshino et al., 2021). When the humidity on the bed of these streams is greater than on the hillsides, it is possible to find an abundant and rich vegetation community of helophytes, bushes and even trees, which act to retain sediment and generate small habitats for the settlement of other species (Jacobson et al., 1999; 2000a; b). In addition, the presence of vegetation along the channel could be the start of the formation of alluvial bars and islands with important geomorphological implications (Tooth and Nanson, 1999, 2000). These accumulations of organic materials are redistributed by sporadic flash-floods increasing environmental heterogeneity and the availability of resources (Vidal-Abarca et al., 2000). In fact, ephemeral streams provide a food source for many species of animals, they are places for mating and function as corridors for their dispersal (Seveg et al., 2003; Jopp and Reuter, 2005; Sánchez-Montoya et al., 2019). Moreover, some vertebrates that live in these ecosystems fulfil important ecological functions, such as being landscape engineers, agents for seed dispersal and recyclers of nutrients (Leggett et al., 2004; Sánchez et al., 2017).

1.3. Antecedents and difficulties in the management of ephemeral streams

Ephemeral streams in the Mediterranean pose many difficulties that can become the reason for restoration programs. These problems come from the severity of the geomorphological impacts affecting them, their sudden and sporadic nature –happening sometimes in an unpredictable way–, the fact that they are not taken into account in the hydrological management and planning framework, the difficulties in determining the correct geomorphological recovery, the way they are perceived negatively by society and their distancing from the programmes of conventional conservationist policies (Ollero et al., 2019).

These streams, which are so common in the Mediterranean region, have been sidelined from fluvial restoration and rehabilitation programmes. In Spain, as in Italy, we can confirm that until the present, there have been no examples of restoration in ephemeral channels. And their management is limited and deficient. In the bibliographical reviews there have only been a few one-off cases of restoration in California (Kondolf et al., 2013). Apart from the “forgotten” technical-administration of these channels, a lack of social awareness and appreciation is also very notable, above all taking into account that local impacts could be important, while the results of global change could lead to even more severe effects on these streams. We are, basically, faced with very sensitive but also undervalued fluvial systems (Ollero et al., 2019), which have been overlooked in current recovery initiatives.

Historically, one of the administrative types of problems has been the difficulty to catalogue these kinds of fluvial systems (Gallart et al., 2017). The problem resides in the fact that the criteria used in Spain to characterize rivers, even at a legal level, are exclusively hydrological. The Instruction for Hydrological Planning (IPH), approved by Order ARM 2656/2008, defines ephemeral streams as "fluvial systems in which, in a natural regime, surface water only flows sporadically, in storm episodes, during a mean period of less than 100 days a year". In the United States an ephemeral stream is defined as carrying water in less than 10% of the days of the year (Sutfin et al., 2014).

In any case, the limits between ephemeral, intermittent, generally temporary and perennial rivers are not clear and are still open to debate (Busch et al., 2020): the presence or absence of flow has considerable space-time variability, to such an extent that the same reach can change its state in different conditions, according to the characteristics of the rain and storms. And although many criteria can be applied, what is truly undeniable is that all of them are fluvial systems, that present complex hydrological, geomorphological and ecological processes, all playing a transcendental role on the land. Therefore, the main difference with ephemeral streams is in some way artificial. That is to say, it is not because they are ephemeral, but because of the fact that the classification system has disincentivised their study, very rarely do they have gauging systems, and in many cases, they receive less attention and appreciation from the government and society.

In spite of the need to understand their hydrogeomorphological functioning and their undeniable role in Mediterranean society, there is no census or mapping of these ephemeral streams in the Iberian Peninsula and, as they lack a permanent flow, so very few are classified as water masses in river basin districts.

In the Iberian Mediterranean area several doctoral theses and studies have been published (Thornes, 1976; Mateu, 1982; Conesa-García, 1990; Segura, 1990; Camarasa, 1992), which are becoming fundamental references in fluvial geomorphology in semi-arid zones. However, we could say that there is still a certain lack of knowledge about them and an even greater lack of management, without forgetting the hundreds of population nuclei and kilometres of transport links that are directly at risk from these watercourses (Domenech et al., 2008; García Lorenzo, 2010; Noguera et al., 2014). In the Ebro basin some studies have recently been developed about significant cases related to extreme events and only in these cases (4 in the whole of the basin) have AHIS stations been recently installed and cartography carried out on flood zones of the SNCZI.

Fortunately, however, at a scientific level, understanding and interest about these ephemeral channels is increasing and there has been an extensive production of both ecological studies (public-funded projects, as GUADALMED, MIRAGE, LIFyE + TRivers, among others) and geomorphological ones, most notably those about ephemeral streams developed in recent years by the Confederación Hidrográfica del Júcar (Segura and Sanchis, 2013; Segura, 2017; Sanchis et al., 2017, 2019; Calle, 2018). Most of these studies also attempt to advance knowledge of recent environmental changes and their perspectives of recovery.

There is also currently considerable interest on the part of the Spanish Hydrological Authority to carry out hydromorphological studies and assessment of ephemeral streams, after detecting clear deficiencies in the application of Directive (2000/60/CE) for providing a framework for water policy in these fluvial systems. Spain and Italy have taken the lead in producing scientific and technical proposals for the specific application of the principles of the Directive for Mediterranean ephemeral channels (MEC), although without much success until now; perhaps because they focus on hydrological aspects, leaving aside the morphological ones. Meanwhile, the Spanish Ministry for Ecological Transition has developed and initiated the application of a protocol to characterise hydromorphologically and evaluate water masses of fluvial category, that has a special assessment system for ephemeral streams, but which has not yet been officially published.

Table 1

Basic difficulties foreseen in the fluvial restoration of ephemeral channels (Ollero et al., 2019)

Type of problem	Problems and causes that make restoration difficult	Grade of difficulty
Physical	Enormous length and diversity of the fluvial ephemeral network in the Iberian Peninsula.	High
Scientific	Uncatalogued ephemeral network, not mapped or quantified.	High
Management	Ephemeral fluvial network mainly outside the planning framework (very few water masses of an ephemeral nature).	High
Management	Lack of control in the localisation of human pressures generating severe geomorphological impacts: there is no inventory of extractions, road-stream crossings, fords, etc.	High
Social	The negative social perception of ephemeral streams (dry, with sediment and "weeds", contempt for gravel, the dumping of rubble and rubbish).	High
Social	A false sense of security and limited historical memory of flooding events, leading to a lack of prudence and prevention.	High
Management	Inappropriate land uses in channels, service and police zones, including canalisation, construction and covering over of urban reaches, planting vegetation to stabilize the bed, etc.	High
Management	Emergency post-flood work in a systematic way for extracting sediment from the bed and its accumulation on the banks: economic cost without problems being resolved.	High
Management	Water abstraction and consumption of underground flows which is uncontrolled and unregulated.	Medium
Management	Problems with the official and practical definition of ephemeral and temporary streams in general.	Medium

Management	Very limited number of gauging and control stations along ephemeral channels.	Medium
Social	Lack of monitoring and reporting of actions and impacts on these channels.	Medium
Management	Extremely low level of representation of ephemeral channels by protection figures such as the “natural fluvial reserves” in Spain.	Medium

2

The current deterioration of ephemeral streams

Alfredo Ollero, María Luisa Suárez, María Rosario Vidal-Abarca, Carmelo Conesa-García, Yilena Hermoso, Sergio Sanmartín, Ana Sáenz de Olazagoitia, Francesca Segura-Beltrán and Carles Sanchis-Ibor

2.1. Pressures and impacts

The pressures come from land use and human intervention that, in either an individual or synergic way, have effects on the functioning of the basins and channels. These human pressures thus generate impacts on the fluvial network: alterations in its hydromorphological and ecological function, a deterioration in its hydromorphological, physical-chemical and biological naturalness, and consequently, a loss of geodiversity, biodiversity and natural patrimony, a deterioration in the health of the natural system and collateral effects on other ecosystems and on human society itself.

Ephemeral streams share pressures and impacts with permanent or temporary watercourses. The differences occur in the intensity with which they manifest themselves and in their consequences. Generally, the hydrogeomorphological impacts are more intense and extended in ephemeral streams, while those related to water quality or biodiversity tend to be of less relevance than in perennial rivers.

There is a notable difficulty in identifying impacts based on observed changes and attributing them to specific causes, as occurs in all fluvial systems, making this a considerable challenge in scientific research which attempts, in every concrete case, to answer the following questions: To what degree can a process or change detected in a fluvial course be due to natural dynamics, global changes or local impacts? What is the relative weight of each one of these factors? What is the trend of the process or change, how might it evolve? How can the process be corrected or mitigated if it has an anthropic origin, how can we restore fluvial functions and provide resilience to the system?

Part of the difficulty with these questions is the dilemma of identifying climate change and its effects on ephemeral streams. Climate change or global change?

2.2. Hydrogeomorphological and ecological deterioration

Ephemeral streams are usually quite undervalued by the human population and they are subjected to all kinds of anthropogenic impacts. In fact, the almost permanent absence of water raises the intensity and quantity of aggressions they are exposed to. In ephemeral streams we can detect both the main impacts affecting aquatic ecosystems (for example, wastewater spills, rubbish, the extraction of underground water, canalisation, check dams,…) and terrestrial ecosystems (mining, dumping, pollution, …). This situation means that they are one of the most mistreated ecosystems on the planet (Vidal-Abarca et al., 2020).

Hydrogeomorphological deterioration is especially relevant in these channels due to their very nature and due to the anthropic uses acted out on them directly and indirectly. In accordance with Gregory (2006) and Segura et al. (2021) this deterioration could be the result of four groups of conditions: of the bed, of the drainage network, of reaches of the channel and on specific points (table 2).

Table 2

Effects on ephemeral channels: human causes and hydrogeomorphological responses. Adapted from Gregory (2006) and Segura et al. (2021)

Causes	Possible responses		
	Conditions: flow (H) sediment (S)	In the channel	
		Local adjustments	Overall adjustments
One-off effect/ cross-section			
Construction of reservoirs	H– S–	Erosion downstream, incision	Possible reduction in channel capacity, incision
Weirs, channel mouths	H– S–	Erosion downstream, incision	Incision
Culverts, return flows	H+	Invasion of vegetation reducing geomorphological dynamics	Conversion into perennial rivers
Bridges	H+	Scouring at the foot of the bridge piers	Transmission of downcutting processes downstream
Concrete-lined channels	H+	Erosion downstream	not applicable
Fords and road-stream crossings	H- S-	Retention of sediments upstream, bed erosion downstream	Breakage of continuity, incision

Effect on a channel reach			
Bank protection works: revetment and construction of dykes	S- H+		There could be effects downstream
Canalisation – concrete lining of banks and stabilisation – constriction of channels and dredging – straightening of channels and artificial chute cutoffs – changes in the hydraulic radius (widening, deepening)	 H+ S- H+ S- H+ H+ S-	Alteration to the bed slope and hydraulic geometry, drainage channel capacity and geomorphological processes	Increase in flow velocity downstream. knickpoint erosion could recede upstream. Channel widening could lead to sediment deposition downstream
Longitudinal paths and tracks and tyre tracks on the channel	H+ S-	Compaction of sediment, destruction of bedforms; they can encourage short cuts in secondary channels	Effects upstream and downstream, channel simplification, bed incision
Elimination (“cleaning”) of vegetation in the channel	S+	Erosion of the affected reach, destruction of channel planform features	
Removal of riparian vegetation	S+	Erosion of channel and sides	
Grazing	S+	Erosion of channel and sides	
Removal of sediment, dredging, actions to widen drainage section and extraction of aggregates	S-	Local changes, conversion of convex cross-sections into concave ones	Progressive erosion downstream and regressive upstream, associated with downcutting processses
Dumping of sediment, mining remains and other solid waste	S+	Possible local deposition	Bed aggradation upstream and/or downstream
Invasion of exotic vegetable species	S-	Stabilisation of the banks and bed	Reduction in the transference of sediment downstream
Reforestation	S-	It could reduce the dimensions of the channel	Possible modification, depending on the type of forest
Planting and cultivation in the channel	S-	Reduction in geomorphological activity, sediment stabilisation	Channel simplification and bed incision
False restoration with grey infrastructure	H- S-	It depends on the characteristics of the channel designed	It depends on the characteristics of the channel designed

Conduits buried in the channel, either transverse or parallel (collectors, pipelines, pipes)	S-	Need to maintain control of the channel	Stabilisation of the reach, sometimes channel narrowing
Filling the sides of the channel with rubble and one-off dumping of rubbish and rubble on the bed	H+ S+	Channel narrowing, alteration in geomorphological processes	Instability, arrival to the channel of unnatural materials
Construction of buildings and structures next to the channel	S+	Channel affected locally by the deposition of sediment	
Effects on the drainage network			
Agricultural drainage	H+	Possible effects where the water arrives	
Networks of irrigation channels	H-	Possible changes where the discharge is withdrawn	
Culverts	H+	Vertical bed accretion upstream by inlet plugging and scour pool downstream	It could increase flood peaks downstream
Effects on the basin			
Increase in temperature	H- S-	Decrease in channel flow capacity due to increased vegetation cover	Decrease in channel flow capacity due to increased vegetation cover
Decrease in precipitation	H- S-	Reduction in the hydraulic capacity of the channel due to a lack of flow	Reduction in the hydraulic capacity of the channel due to a lack of flow
Hydrometeorological events of greater intensity	H+ S+	Compensation of the previous effects	Compensation of the previous effects
Deforestation	H+ S+		Upstream formation of gullies and knickpoint erosion. Downstream there could be changes in the channels and an increase in capacity, depending on the availability of sediment
Reforestation	H- S- (but there could be reaches with increases)	Possible reduction in the hydraulic capacity of the channel	Possible effects, but it depends on the type of forest
Grazing	H+ S+	Local effects due to bank erosion	Bed aggradation

Fires	H+ S+	Diverse morphological channel adjustments	Bed aggradation
Agriculture, ploughing	H+ S+	Effects in the confluences	Bed aggradation
Land uses, soil conservation measures. Construction of terraces	H- S-	Possible decrease in hydraulic channel capacity	Possible effects, but it depends on the management of the drainage network
Abandonment of soil conservation measures. Destruction of terraces	H+ S+	Efects of the confluences	Bed aggradation
Urbanisation	H+ S-	Erosion around road-crossing drainage culverts	The culvert system increases the drainage network
Effects on zone at risk of flooding			
Check dams	H+	More flooding when there is breakage	
Occupation of palaeochannels and valleys	H+	More flooding in urban zones	
Conversion of channels into public thoroughfares	H+	More flooding in urban zones	
Anthropic occupation of the floodplain	H+	Reduction in the fluvial space, alteration in flows	Simplification of the planform, channel narrowing, bed incision

In table 3 the main human activities affecting ephemeral streams are recorded from an ecosystemic perspective. The table is based on the studies of Gómez et al. (2005) and Vidal-Abarca et al. (2020) and the field experience of the authors in the Iberian southeast. Although the table includes a qualitative assessment of the intensity of the impact on the biological communities and the ecological processes of ephemeral streams, it should be taken into account that any human activity affects the habitat in one way or another, as well as the biological communities that live there. From this perspective, the main impacts that affect ephemeral streams can be classified according to their effects on: i) surface / underground water; ii) the channel bed; iii) biological communities and iv) the landscape.

Table 3
Main human activities having an impact on the biological communities and resources of ephemeral streams. Adapted from Gómez et al. (2005) and Vidal-Abarca et al. (2020).

Human actions	Impact	Intensity of impact
On surface / underground water		
Use of floods for crops	– It could alter temporality of the discharge	Traditional activity with low impact
Salt extraction (hypersaline ephemeral streams)	– Drying of the channel	Very high
Bathing in saline and muddy waters	– It could affect the distribution of sediment	Medium
Derivation of water for irrigation	– It affects the temporality of the discharge	High
Construction of dams	– A physical barrier for organisms – Alteration of the structure and distribution of the vegetation in the channel and the riparian area – Alteration in the entry of nutrients	Very high
Construction of little dams to retain sediments	– Change in the flow dynamics and sediment transport – Alteration in the entry of nutrients	High
Transfer of water from other basins	– Change in the composition of the communities of organisms – Introduction of exotic and/or invasive species	Very high
Extraction of underground water	– Overexploitation of underground waters	High
Extraction of subsurface water	– It could alter the spatial distribution of water in the channel – Disappearance of hyporheos and effect on hyporheic fauna	Medium
On the stream channel		
Rainfed crops	– Morphological channel adjustments – Elimination of habitats and biological communities	High
Extraction of gravel and sand	– Changes in bedforms and sediment load – Elimination of habitats and biological communities	High

Liquid effluents	– Groundwater and surface water pollution	High
Dumping of rubble and rubbish	– Groundwater and surface water pollution	High
Entry of pesticides / herbicides	– Groundwater and surface water pollution	High
Road construction	– Overall morphological channel adjustments – Impossibility of recharging aquifers – Elimination of habitats and biological communities	Very high
Canalisation of the channel	– Removal of riparian vegetation	High
Urbanization	– Partial or total elimination of the channel – Impossibility of recharging the aquifer – Acoustic pollution – Visual impact	Very high
On biological communities		
Removal of vegetation	– Extraction of rare and/or endemic vegetable species	Very high
Harvesting of plants and animals (e.g. snails)	– It can affect the abundance patterns in some of the vegetal and animal species	Traditional activity with low impact
Grazing	– Alterations in terrestrial plant communities – Compaction of bed sediments due to trampling	High
Hunting	– Death of protected species	Very high
Burning of vegetation	– Removal of vegetation	High
On the landscape		
Hiking	– Changes in structure and compaction of the sediment – Damage to vegetation	Low
Trekking	– Changes in structure and compaction of the sediment – damage to vegetation	Medium
Motocross and 4x4 vehicles	– Acoustic pollution – Changes in structure and compaction of the sediment – Alteration in habitats and organisms	High
Camping areas	– Alteration /disappearance of riversides	Very high
Environmental education activities	– It could affect vegetation in the bed and the riparian area	Activity with low impact

2.3. Causes and examples of deterioration

In this section, we have classified the main impacts detected on ephemeral channels into 16 groups studied by the authors of this guide, both in the framework of the CCAMICEM project and in other previous ones, presenting specific visual examples.

Fords and other road-stream crossings

Fords have an extensive impact on the whole of the ephemeral fluvial network. There are different types: simple unelevated crossings, concrete platforms, concrete elevations or earth over pipes or small frames, reinforced fords in the part facing downstream given the jump they have produced, etc. Fords usually cause an accumulation of alluvium upstream and local erosion with scour pools downstream, that is to say, an authentic damming effect that alters geomorphological function, the processes and forms, as well as preventing other eco-environmental processes.
Bridges alter the channel to a lesser degree, depending on the type of design and other technical characteristics. Small pedestrian paths or crossings also generate affections.


Two photos (**figures 2 and 3**) of a ford crossing the Rambla de Aguarón (Zaragoza). It is the most precarious typology, very frequent and has a notable local impact on the geomorphological channel features, although it does not have a damming effect as in the following case.

Figure 4. This ford in the Rambla de Cariñena (Zaragoza) clearly shows the retention of alluvium upstream (right) and an erosive escarpment at the foot of the obstacle (left) with a damming effect, which had to be reinforced as shown in the following photos.

The same ford in the photo above was subjected to strong downward scour (**figure 5**, left) during flooding in March 2015 and was reinforced, as can be seen in **figure 6** (right) taken from the riverside.

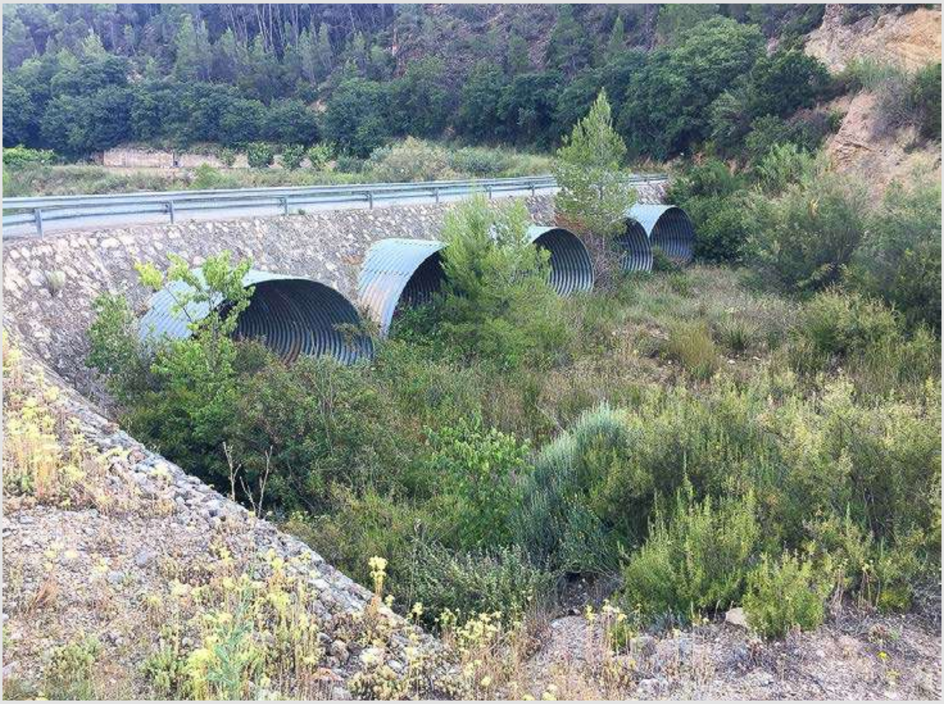


Figure 7. A more powerful ford, with a road passing over the Barranco del Agua in Jalance (Valencia). The culvert pipes are larger than normal, but even so it is impossible to drain all the water in extreme floods. This structure does not only notably alter the ephemeral stream, it also constitutes a critical hazard point of overflow and high risk.

Figures 8 and 9. Culvert pipe of the ford at la Virgen de Lagunas in the Rambla de Cariñena, pulled away by the flood in March 2018. It was the only pipe for the ford in spite of the dimensions of the channel. The ford was destroyed as observed on the right.

Figure 10. Bridge and road-crossing drainage culverts in the Rambla de Valdemorado in Cariñena (Zaragoza). **Figure 11.** The crossing of a simple path can modify the local base level and alter the longitudinal profile of an ephemeral stream (Sierra de Armantes, Zaragoza).

Figures 12 and 13. Left (fig. 12): Bridge-ford provided with culverts and a concrete ramp downstream in the Rambla de La Murta (Murcia). On the right (fig. 13) a close-up of a bridge-ford in the upstream section.


Figures 14 and 15. Bed scouring and removal of the footings of piers supporting the bridge on the AP-7 motorway in the Rambla de las Moreras (Mazarrón, Murcia).


Figure 16. A ford without inferior drainage in the Rambla de la Torre (Perín, Cartagena). **Figure 17**. Road crossing over the channel connecting the ramblas de los Dolores and Benipila (Cartagena) saved by a reinforced concrete pontoon structure.


Figure 18. At the intersection of the Rambla de los Pinares and the D14 road (Águilas, Murcia) the culverts present a drainage capacity much lower than is necessary and are often useless because of obstruction. **Figure 19.** Rambla de la Anchura (Murcia) with local bed scour at the foot of the cement floor.

Longitudinal paths in the channel, compaction due to the passing of vehicles

Another very extensive impact, given that their very ephemeral nature encourages people to use them as communication links. Their morphosedimentary units are destroyed, the bed is compacted, discontinuity and fragmentation are generated and, what is more, this practice leads to a clear exposure to flash floods.

Figures 20 and 21. Tracks and compaction in the Barranco de Tudela (Bardenas, Navarra) and in the Barranco L'Areny (Peralta de la Sal, Huesca).

Figure 22. The longitudinal track in the Barranco Reajo (Arnedillo, La Rioja) restricts the lateral natural evolution of the channel. Figure 23. The track in the image on the right goes along the Rambla de Valcodo (Fuentes de Jiloca, Zaragoza) for several kilometres.

Figures 24 and 25. Tracks along the Talave and Chirivel ramblas in Albacete and Murcia respectively.

Channels converted into roads and streets

As a special form of occupation of these ephemeral channels, there are many examples of how they integrate as streets in an urban setting, and to a lesser degree, how they are occupied by a road. In both cases they involve the total destruction of the channel as such and create a very serious situation of risk.

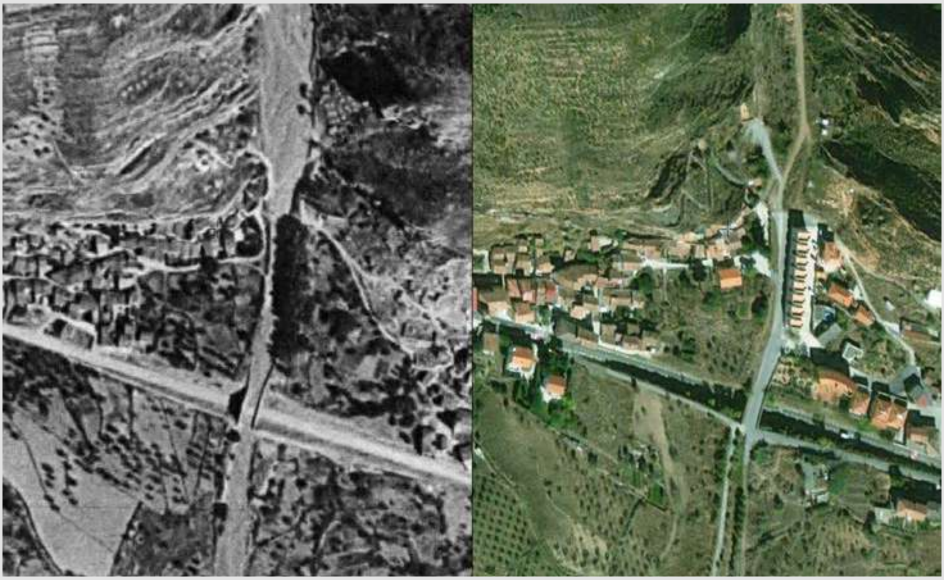
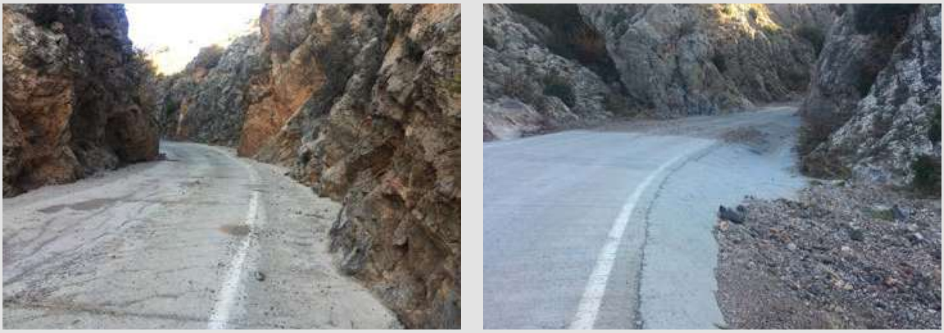


Figure 26. The Barranco Cirijuelo crosses over a bridge, the LR-115 road, before reaching the River Cidacos in Santa Eulalia (La Rioja). In image 1956 (left) the gully channel can be seen to narrow as it passes over the bridge, and in the current photo (right) it can be observed how it has been converted into a street.

Figure 27. The N-332 road occupies the Rambla del Charco (Cartagena) and has been raised leaving the channel as a small ditch. Figure 28. The Barranco de la Porquerola is partially occupied by an access road in the housing estate in Montroig del Camp (Tarragona).



Figures 29 and 30. Two photos of the road joining Corbatón and Alpeñés (Teruel) invading and traveling along the Rambla de Corbatón for one kilometer. In the two images below (**figures 31 and 32**) we can observe the consequences of flood in August 2020, which destroyed this road.

Weirs and reservoirs

These are rare in ephemeral streams. They involve the same hydromorphological and ecological problems as in perennial streams, generating the breakage of longitudinal connectivity for the bedload and for certain populations of living organisms. The effects of downstream incision are very marked.

Figure 33. Weir in the Rambla de Librilla (Murcia). **Figure 34**. View from the reservoir and dam of the Rambla del Moro (Cieza, Murcia).

Figure 35. Weir that takes water from the Rambla de Torrealvilla (Lorca, Murcia).

Check dams

In numerous ephemeral channels check dams were constructed in the 20th century to retain sediment, breaking the longitudinal channel profile. In many cases these were accompanied by other actions of reforestation and the fight against soil erosion. They have had a very limited effect on reducing torrential flooding, but have caused considerable sediment deficits downstream.

Figure 36. Sedimen retention by a check dam in the Barranco de La Recueja (Alcalá de Júcar, Albacete). **Figure 37**. Semi destroyed gabion check dam in the Rambla de la Pimienta (Manchones, Zaragoza).

Figure 38. Local scouring and bed armouring downstream of a check dam in the Rambla de Zarzadilla (Murcia). **Figure 39**. Another example accompanied by the plantation of poplars in the Rambla del Boquerón (Murcia) (right).

Figure 40. Another example in the Rambla de la Rogativa (Nerpio, Albacete).

Alluvium extraction, dredging, cleaning, widening of the drainage section and sediment movement

This group of practices is very extensive and has many types and dimensions. The common effect is the geomorphological destruction of the channel and total contempt for three of its natural elements: alluvium, woody sediment and colonising vegetation, popularly referred to in a derogatory way as “weed”. The aim of these actions is, in theory, to provide to the channel greater drainage capacity or croos-section area, which is only achieved temporarily, often only until the arrival of the next flood. Above all, they are actions that respond to continued unjustified demands, which the local authorities give into in the end. In this way, they are applied in a periodic way as a placebo effect, without clear objectives, no clear project or environmental evaluation or control.

Figure 41. Opening of a drainage cross-section to protect a road in Antequera (Málaga). **Figure 42**. On the right, results of dredging in the River Cidacos (Arnedo, La Rioja). On many occasions, like in this case, the gravel is not extracted, but rather it accumulates on the channel sides, with the lateral deposits becoming larger and producing the destruction of bed forms and banks.

Figures 43 and **44**. Removilisation of sediment in the Rambla de Alpartir (Zaragoza) and in the Villahermosa River (Castelló).

Figures 45 and **46**. Dredging and removal of sediment from the Rambla de las Moreras (Mazarrón, Murcia) in its final reach, affected by incision.

Occupation of the channel and elimination of the fluvial territory

These are also very diverse, because of isolated structures and buildings, and more extensive urbanisation processes. The results are the partial or total physical disappearance of the channel, or its burial on occasions and the generation of a situation of considerable risk, given that the floodwaters will search for the old channels and will look for a way out of them or even look for more dangerous alternatives.

Figure 47. Mouth reach of the Barranc de la Rompuda under the urban district of Orpesa (Castelló). **Figure 48**. Gauging station of the River Seco (Oliete, Teruel) partially invading the natural channel.

Figure 49. Barranco de la Noguera, Alcalá de Júcar (Albacete).

Figures 50 and **51**. Two photos of occupation and use of the channel in the Rambla de Espinardo (Murcia).

Rubble, rubbish, solid waste

These have a visual impact and can affect the ecosystemic quality and participate in geomorphological processes, as well as form obstacles and accumulations in the flooding process.


Figures 52 and **53**. Rambla de Alpartir and Rambla de Valcodo (Zaragoza).


Figures 54 and **55**. Two photos of the Rambla Celada (Murcia).


Figures 56 and **57**. The Rambla de Ceacejo next to Bullas (Murcia) and Rambla Salada de Lorca (Murcia).

Defences, channelling, canalisation and channel revetments

With different levels of intensity, many ephemeral channels have these grey structures, especially in urban and semi-urban districts. Their aims are defensive, given that they attempt to prevent erosion and overflowing, but they are not always efficient, they increase velocity and redirect problems downstream. They have different kinds of typology, as shown in the following images.

Figures 58 and **59**. Canalisation of the Rambla de Caminreal (Teruel) and the Barbadiel Stream in La Milla del Río (León).

Figure 60. Canalisation of the Barranco de las Casas in la Puebla de Alfindén (Zaragoza) whose reform in 2014 reduced the channel flow capacity by at least half. **Figure 61.** Canalisation of the Riera de l'Alforja (Tarragona).

Figures 62 and **63**. Channelling with ripraps and gabions in the Rambla de Alfocea (Zaragoza) and with walls in the Rambla de Sant Josep in La Vall d'Uixó (Castelló).

Figure 64. Stone riprap protecting the bridge pillars at the highway crossing on the Rambla de las Balsas (Longares, Zaragoza). **Figure 65**. Removal of defences in an incised channel reach in the Rambla de las Moreras (Mazarrón, Murcia).

Figures 66 and **67**. Two photos of channelling and masonry lining of the bed in the Rambla Mullidar (Liétor, Albacete).

Figures 68 and **69**. Río Guadalentín in Lorca (Murcia) and the Rambla Honda in Ayna (Albacete).

Figures 70 and **71**. Reach in Rambla de Albudeite canalised with mansory walls and concrete lined bed (Murcia) and section of the River Campanillas (Málaga) channeled by longitudinal dikes of loose stone.

Buried conduits or conduits parallel to the channel, culverts, collectors and irrigation canals

These are common in semiurban spaces and can be a danger on occasions, and in other cases they can involve reinforcements and structures that lead to greater effects on the channel.

Figure 72. On occasions we find elements as dangerous as a hose crossing the channel (arroyo Reajo, Arnedillo, La Rioja). **Figure 73**. Collector in construction in Murcia (photo by Nacho García, La Verdad de Murcia).

Modifications to the dishcharge, extractions, dumping and spills, drainage and return flows

Hydrological modification in ephemeral streams is less important and less frequent, generally, than in perennial streams. However, different examples can be found, mainly with extra amounts of water because of dumping or spills and return flows. In many cases, certain ephemeral channel reaches have a permanent discharge after these hydrological "gains". The consequences are very negative for the fluvial ecosystem, which completely changes, increasing its colonisation, especially with helophyte and invasive plants.

Figures 74 and **75**. The Rambla del Pozuelo (Murcia) colonised by reeds, and the canalised Rambla de Ortigosa (Ontur, Albacete), colonised by helophytes.

Figures 76 and 77. Spill into the Rambla de Ortigosa (Ontur, Albacete) and the same watercourse converted into a collector of irrigation waste water (right).

Figure 78. The Rambla del Judío (Cieza, Murcia). **Figure 79**. The spill from the water treatment plant upstream of the population of Cariñena leaves a permanent surface flow in a stream-reach of the same name.

Channel rectification, channel-bend shortening

Anthropic changes are very uncommon along ephemeral channels, except in those simple examples which come about from canalisation. But there are some examples, most notably those that have been produced unconsciously in channels used as paths, in which short cuts have been made, in such a way that the fluvial course has made use of these short cuts when there are floodwaters.

Figure 80. Lower reach of la Yasa Agustina stream (Aldeanueva de Ebro, La Rioja) with a rectification to the channel so that it can pass over the Lodosa Canal.

Figure 81. The frequent passing of vehicles has caused two channel-bend shortenings in the Rambla de la Alhóndiga (Terrer, Zaragoza).

Figure 82. Channel reach transformed into a crop field with different rectifications and structures (Barranco de Balsones, Nigüella, Zaragoza).

Plantations and crops in the channel

In some ephemeral channels, crops have been introduced taking advantage of the proximity of the phreatic zone and in spite of the stony nature of the substrate. This is more common in "valley" type channels, with a predominance of fine materials, apparently disconnected from the river network, but subject to sediment contributions in large occasional floods. Less frequent and more difficult to justify are some cases in which plantations and reforestation take place within the channel. The objective seems to be to stabilise the bed, although the effect could be negative in later extreme events, as well as generating processes of channel narrowing, simplification, and bed incision and other geomorphological effects downstream.


In La Rioja in recent years there have been several plantations on ephemeral and temporary streams: in **figure 83** the Jubera River in Ventas Blancas, on the right (**figure 84**) the Linares River in Igea, below on the left (**figure 85**) the Leza River in Murillo and on the right **(figure 86**) the Reajo Stream (Arnedillo).




Figure 87. The Rambla de Vertiente de Guardiola (Murcia) cultivated and with reeds. **Figure 88**. Terracing in the Rambla de Librilla (Murcia).

Figure 89. Upper-middle reach of la Yasa Agustina stream (Autol, La Rioja) with plantations in the channel, increasing active bed incision.

Figure 90. Islands stabilised by plantations in the Barranco de la Nava (Aguilar del Río Alhama, La Rioja).

Figures 91 and **92**. Olive trees in the Rambla Coronadas (left) and Rambla Ibarzo (right) in Mesones de Isuela (Zaragoza).

Grazing

In many ephemeral channels we have observed hoof prints from the passing of ovine and caprine cattle, that take advantage of the plants which have colonised the channel. The impacts reported are trampling and alterations in the vegetation communities.

Grazing in the Barranco de Tudela (Bardenas, Navarra) (**figure 93**) and in the Rambla de Valdelentisco (Mazarrón, Murcia) (**figure 94**).

Invasion of reeds

In the whole of the Mediterranean region of the Iberian Peninsula there has been an invasion of reeds *(Arundo donax)* in all kinds of channels in permanent and ephemeral streams. In some channels there is complete colonisation of the bed, preventing the movement of alluvium and taking over the space of autochthonous species.

Figures 95 and **96**. Invasion of reeds in the Rambla de Vall d'Uixó (Castelló) and in the Barranco Salado de Muel (Zaragoza).

Figure 97. The treatment process for the elimination of reeds consists of covering them with black plastic material for at least 10 months. Figure 98. In an incomprehensible way, some planting of reeds with defensive aims takes place on the sides of ephemeral streams, as in this case in the Rambla de Cariñena (Zaragoza).

Other actions and land uses

In addition to what has already been said, there are many other human actions that are responsible for global change in the basins of ephemeral streams (an alteration and elimination of the vegetation cover, abandonment and change of land uses, deforestation, reforestation, fires, urbanisation, etc.) and these modify the channels, as well as other local actions (raising of channel banks, harvesting, hunting, recreational activities, etc.), that have more direct effects to a greater or lesser degree.

Figure 99. Numerous ephemeral streams are becoming extinct in the territory, although they could recover their flow in extreme rainfall events. In this case it is difficult to view the watercourse in the crop field (Épila, Zaragoza).

3

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 σ > 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:

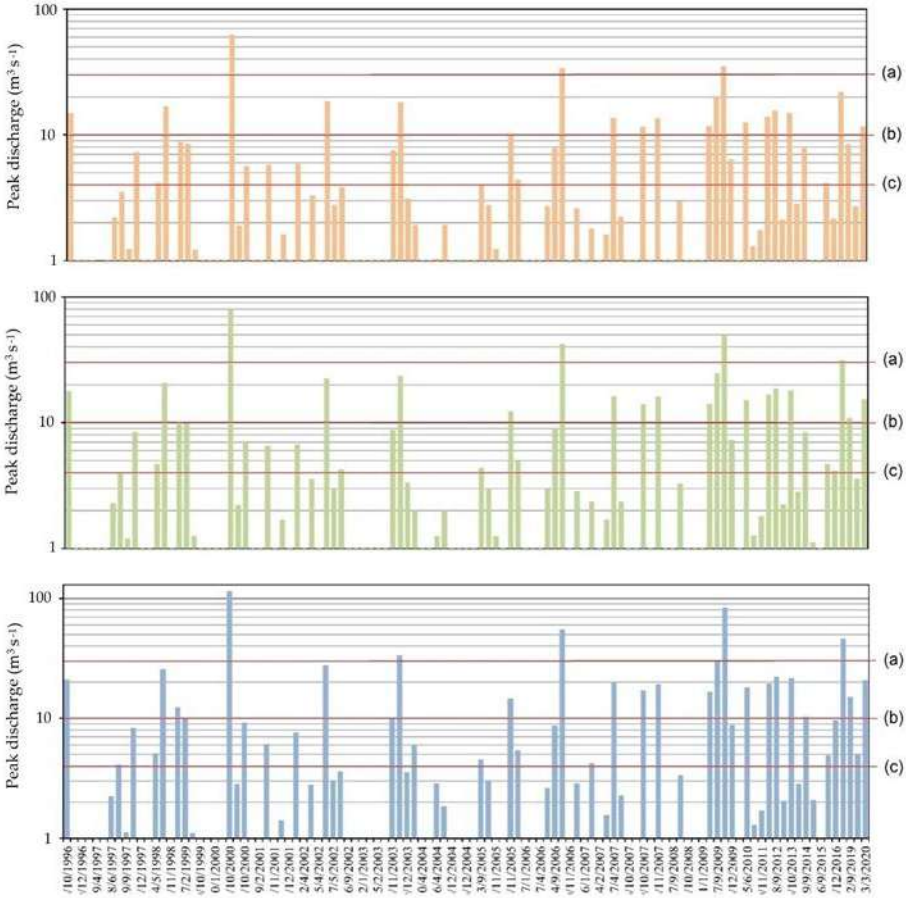

Figure 101. Thresholds of discharge peaks associated with different classes of morphological adjustments during the events simulated using GeoWEPP for upper, middle and lower reaches of the Rambla de la Azohía (period 1996-2020). (a) overall morphological changes, affecting the bankfull channel and active 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="4">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="2" 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="2">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></td><td>Continual defences in both banks (canalisation)</td><td>-6</td><td colspan="2">-3</td></tr>
<tr><td></td><td>Discontinuous defences or on one bank</td><td>-4</td><td colspan="2">-2</td></tr>
<tr><td></td><td>Defences away from the minor channel</td><td>-2</td><td colspan="2">-1</td></tr>
<tr><td colspan="3" 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 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

<table>
<tr><td colspan="3">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.</td><td>5</td></tr>
<tr><td>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.</td><td>If they are in more than 25% of the surface of the current corridor</td><td colspan="2">If they are in less than 25% of the surface of the current corridor</td></tr>
<tr><td>If the alterations are substantial ones</td><td>-3</td><td colspan="2">-2</td></tr>
<tr><td>If the alterations are minor</td><td>-2</td><td colspan="2">-1</td></tr>
<tr><td rowspan="2">The naturality of the vegetation has been altered by invasive species or reforestation</td><td colspan="2">if the alterations are significant</td><td>-2</td></tr>
<tr><td colspan="2">If the alterations are minor</td><td>-1</td></tr>
</table>

(Aerial photograph, identification in the field)

Assessment of the riparian quality

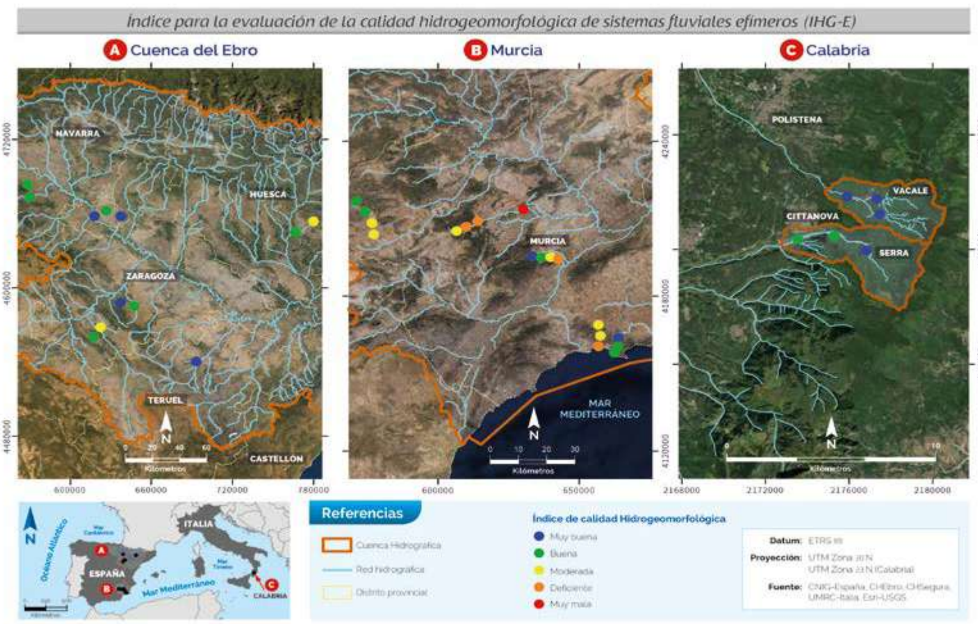

Figure 103. Application of the IHG-E index to the ephemeral streams studied in the CCAMICEM project.

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)

FIELD SHEET FOR THE CALCULATION OF THE RDI					
Nº:	Name:			Date:	
Location:				Hour:	
UTM-X:		UTM-Y:		Altitude (m):	
Photos					
ANTHROPOGENIC PRESSURES/IMPACTS					
	Presence	Value		Presence	Value
Channelling		10	Channel drainage		5
Surfaced road		10	Extraction of groundwater		4
Check dam height > 5m		10	Wells in the channel		4
Gravel pits		9	Dried trees		4
Crops in the channel		9	Check dam height < 5m		3
Cattle (waste)		9	Solid organic waste		2
External water entry		8	Rubble		2
Liquid effluents		8	Pesticides/herbicides		2
Burning of vegetation		7	Harvesting vegetation		1
Tracks on the bed		6	Snail harvesting		1
Motorbike raceways		6	Hunting (waste)		1
Car raceways		6	Σ Impact value		
			II = (Σ Impact value)/50		

RECOVERY CAPACITY								
Connectivity channel-hillslope (%)	>75	50-75	25-50	<25	Left bank		Right bank	
Application value	1,00	0,75	0,50	0,25	C_{lb}		C_{rb}	
Natural land use (%)	>75	50-75	25-50	<25	Left bank		Right bank	
Application value	1,00	0,75	0,50	0,25	N_{lb}		N_{rb}	
			[(Clb * Nlb) + (Crb * Nrb)]/2				RC	

CALCULATION OF THE INDEX	
RDI = 1 + II - RC	

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.

4

Good practices for the management and restoration of ephemeral streams

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Askoa Ibisate, J. Horacio García, Carmelo Conesa-García,
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4.1. A proposal for good practices related to geomorphological dynamics

Segura (2014) and Segura and Sanchis (2015) warned us that in most projects geomorphological restoration is not addressed in all its complexity and there is frequently a lack of understanding of the hydrosedimentary dynamics in fluvial systems, even more so in the case of ephemeral ones. Other problems that they indicated were i) the difficulty in making historical images compatible as a reference when the dynamics are so intense and complex, ii) the impossibility of managing the sedimentary deficit by the hydrographic administration, unless the extraction of aggregates is prohibited definitively, and iii) the fact that restoration actions do not consider signs of recovery and the capacity of resilience of the channels, so there is no recognition that the cheapest and most effective strategy in ephemeral streams would be facilitating self-regeneration, because of their great energy. Currently, they are perceived from a similar perspective, given that there have hardly been any advances made in this area.

Taking into account that the geomorphic resilience of these channels is high in many cases, it is necessary to assess whether the elimination of the impacts –especially the direct ones, that is to say those carried out on the channel itself– could be enough to generate effective repercussions, counting on the fundamental recovery work acted out by floods (Segura, 2014; Calle et al., 2017). However, we should be aware that the low frequency of geomorphic impact floods could slow down response times. Thus, it is essential to extend research projects to be able to monitor changes, given that it is likely that in some cases active rehabilitation measures should be considered to speed up the work of the stream (Horacio, 2015).

GOOD PRACTICE 1 REMOVAL OF CHECK DAMS, BARRIERS AND TRANSVERSE OBSTACLES

Figure 104. Tracks that have a barrier effect and invade the channel in the Barranco de la Mata (Jubera, La Rioja)

OBJECTIVES	• To recover the natural function and continuity of the fluvial system. • To recover hydrogeomorphological processes of the channel and bed. • To reduce the anthropic presence on the channel and riparian corridor, recovering the function and naturalness of the watercourse as a natural corridor. • Improve the longitudinal continuity of the riparian corridor. • Recovering floodplain functionality.
ACTIONS	• Making obstacles permeable so that they do not prevent the circulation of water and sediment. • Knocking down obstacles to allow trapped sediment to pass. • Educate about the importance and natural functioning of solid discharge and raise awareness about how this type of obstacle negatively affects the bed. • Create access for fisch if there are fish populations in the ephemeral stream.

AGENT	The State, through Hydrographic Confederations.
CONDITIONING FACTORS	• Insufficient budgets for these kinds of actions. A significant economic investment is required. • Construction management and careful handling of the machinery so as not to alter the morphology of the channel. • Natural regeneration of areas affected by machinery. • Problems of accessibility to isolated territories. • Possible pollution of sediments trapped in reservoirs.
TIME, TREND, PROGNOSIS	A positive effect of this good practice would be a rapid naturalisation of the channel, especially if there are flow events with the capacity to mobilise sediments. With these processes, the longitudinal profile previously altered by these obstacles is reconstructed. The effects of this good practice are always positive, taking the stream one or several flow events to naturally regenerate its dynamics.

GOOD PRACTICE 2 — REMOVAL OF FORDS AND OTHER ROAD-STREAM CROSSINGS

Figure 105. Bridge of the C32 over the Río Foix (Cubelles, Barcelona). The location of the pillars in the active channel could have been avoided.

OBJECTIVES	• Locally recover natural flows of liquid and solid discharge. • Recover the longitudinal continuity of the channel and riparian corridor, also preventing access to the fords. • Recover natural hydrogeomorphological processes in the channel and especially in the bed. • Eliminate or reduce anthropogenic impacts by recovering the functionality and naturalness of the stream as a natural corridor. • Reduce risks, due to the vulnerability of these structures, which have often caused human losses due to their use during flooding.
ACTION	• Reduce the number of fords, reserving the minimum number of crossings possible. Study alternatives for cases with accessibility problems. • Construction of bridges as an alternative to fords, in places where the impact of the riparian corridor is minimal, thus reducing impacts on the functional quality of the system. • Take away access points from the fords that have been eliminated and modify those that remain operational to reduce damage in the riparian area.
AGENT	Hydrographic Confederations (PHD) and in some cases road services
CONDITIONING FACTORS	• Insufficient budgets for this type of action. • Careful handling of machinery so as not to alter the morphology of the channel. • Nature restoration in the areas affected by machinery. • As the number of fords is reduced, there may be an increase in infrastructure parallel to the channel in order to reach the nearest crossing. • Awareness of the population about the importance of carrying out a greater journey to reach a crossing.
TIME, TREND, PROGNOSIS	This good practice would have to be of carried out immediately and its positive effects would be noticed in the following flood event, quickly making the bed more natural thanks to the movement and entrainment of bedload accumulated in the old fords. A state plan that provides generalised action in order to provide environmental improvement and risk reduction would be very appropriate.

GOOD PRACTICE 3	REMOVAL OF INTERNAL PATHS AND CLOSURE OF ACCESS POINTS

Figure 106. Channel of the Río Foix (Cubelles, Barcelona)

OBJECTIVES	• Avoid the processes of geomorphic disturbance in the channel (e.g. compaction, waterproofing, ...) and effects on the quality of the riparian space because of the passing of vehicles and their access points. • Recover hydromorphological processes of flood and mobility of the solid discharge by restricting the compaction of the alluvial bed. • Eliminate or reduce anthropogenic influences by recovering the functionality and naturalness of the stream as a natural corridor. • Reduce or eliminate discontinuities in the habitats and in the distribution of species. • Reduce risk, taking into account the vulnerability of these precarious paths.

ACTION	• Closure of the access points to the channel by means of sign posting, plant or anthropogenic barriers, placement of dead wood, large stones, etc. at some specific places. • Generate new infrastructure, which will satisfy the needs provided by internal paths, placing them outside the channel and as far as possible from the fluvial system, preventing them from following a path parallel to it and which might affect the floodplain, connectivity of the riparian space and the cross-sectional naturalness. When infrastructure cannot be installed outside the floodplain, avoid the use of impermeable infrastructures in order to minimize their impact on to the hydrogeomorphological processes of overflow and flooding. • Provide sediment in the channels where extraction has taken place to facilitate vehicle mobility. • Educate about the importance and natural functioning of the solid discharge and raise awareness about the negative effects of vehicles crossing the channel.
AGENT	Hydrographic Cnfederations with the support of local administrations and the possible participation of volunteers.
CONDITIONING FACTORS	• Impossibility of locating the path outside the channel due to orographic conditions. • Presence of private properties on the channel banks. • Pressure from farmers and land owners because of the loss of surface area on the adjoining land where the new path could be located. • Insufficient budgets for the construction of new infrastructure.
TIME, TREND, PROGNOSIS	This good practice would have to be carried out immediately, despite the possible impediments when affecting private property. Its effects are positive, depending on the size of the path, affected area or level of sediment compaction. They would be noticed in the first reconstructive flood of the channel and could be fully recovered with a few flood events. This good practice should be linked to the correct land use planning in the flood space if the new path is located in this space when there is no other alternative. In turn, the route of the path could delimit the floodplain, in order to restrict the presence of incompatible land uses in this area, thus minimizing risk.

GOOD PRACTICE 4 | PROHIBITION OF DREDGING, REMOTION OR ALLUVIUM EXTRACTION

Figure 107. Bed gravel extraction in the Desedan Torrente (Longarone, Italy)

OBJECTIVES	• Reduce sediment deficits that cause this type of action, recovering transport and the sedimentation processes downstream. • Prevent alteration of bedforms and banks caused by the entry of machinery and by the actions themselves, which destroy the channel and its geomorphic units. • Allow the stream to reconstruct its longitudinal morphological equilibrium. • Recover the ecological processes and living beings in the benthic and hyporheic zones.
ACTION	• Promulgate regulations at state level for prohibiting dredging and the extraction of aggregates that include sanctioning procedures. Also prohibit the movement and dumping of dredged sediments in any channel.

	• Replace and enhance the location of this type of action on high terraces, outside the current active channel. • Provide sediment in channels where the dredging and extraction actions have been of such magnitude that the stream presents a notable sediment deficit and is unable to recover in the short / medium term, and in reaches where the balance has been broken even if the extractions have only been occasional.
AGENT	The State through the Hydrographic Confederations. It should involve extraction companies being obliged to change their location and working way.
CONDITIONING FACTORS	• Pressure from extractive companies to continue executing these actions. • An increase in clandestine extractions of aggregates can be foreseen if the extraction is limited to the upper terraces.
TIME, TREND, PROGNOSIS	This good practice would have to be carried out immediately, since its positive effects would already be noticed in the following extraordinary flood. Depending on the magnitude of extraction, complete recovery could take several flood events.

GOOD PRACTICE 5 — RECOVERY OF AREAS AFFECTED BY EXTRACTIONS AND THE PROVISION OF SEDIMENTS IN DEFICIT REACHES

Figure 108. Natural alluvial bedforms in the Rambla de la Viuda (Costur, Castelló)

OBJECTIVES	• Recover functionality in flooding processes. • Naturalise the mobility and transport of the solid discharge along the channel • Avoid bed incision, headwater erosion, bank instability and the risk of removing structure footings. • Recover the natural processes and forms in this type of stream. • Reduce risk by preventing possible counterproductive processes in flooding situations.
ACTION	• Provide sediment and distribute it properly in the channels where extractions have been undertaken. It is necessary for there to be construction management with geomorphological knowledge and the use of machinery that only generates minimal impacts. If contributions of fluvial sediments from other foreign areas are made to the channel, it is necessary to respect and not damage the existing alluvial forms in that reach. It is necessary to take into account characteristics such as the grain-size, roundness index, and lithological nature of the provided sediment, which have to be in accordance with those of the sediment present in the reach, where it is going to be introduced. Whenever possible, sediments from the river itself will be used, taken from a nearby point, extracted for example from a fluvial terrace. • Have sediment banks in each sub-basin to be able to carry out this type of action. • Sediment inputs trapped in reservoirs. Program periodic drainage of dam beds in order to facilitate the mobility and continuity of the solid discharge fed by the sediments retained in them. • Occasionally it may be appropriate to provide dead wood. • Combine this practice with the removal or permeabilization of transverse and lateral obstacles, since these cause a disconnection between the bed and banks, and prevent the arrival of new sediment to the channel. • Revegetate the riparian corridors using autochthonous species that have been affected by extraction. • Raise awareness among the local population about the value and functions of the bedload and involvement in voluntary activities.
AGENT	• Hydrographical Confederations. • Private sector: the extraction companies themselves can collaborate. • Local volunteers.

CONDITIONING FACTORS	• Very limited budget availability for this type of action. • Cost of sediment transport. • Pressure exerted by extraction companies so that extraction can continue in channels. • Possible pollution of sediment trapped in reservoirs.
TIME, TREND, PROGNOSIS	This good practice should be implemented immediately, and its action should be directly related to the previous good practice. The positive effects would be felt in the following large flood; however, they will vary depending on the magnitude of the extraction and the effectiveness of the subsequent recovery.

GOOD PRACTICE 6 PROHIBITION OF POST-FLOOD ACTIONS

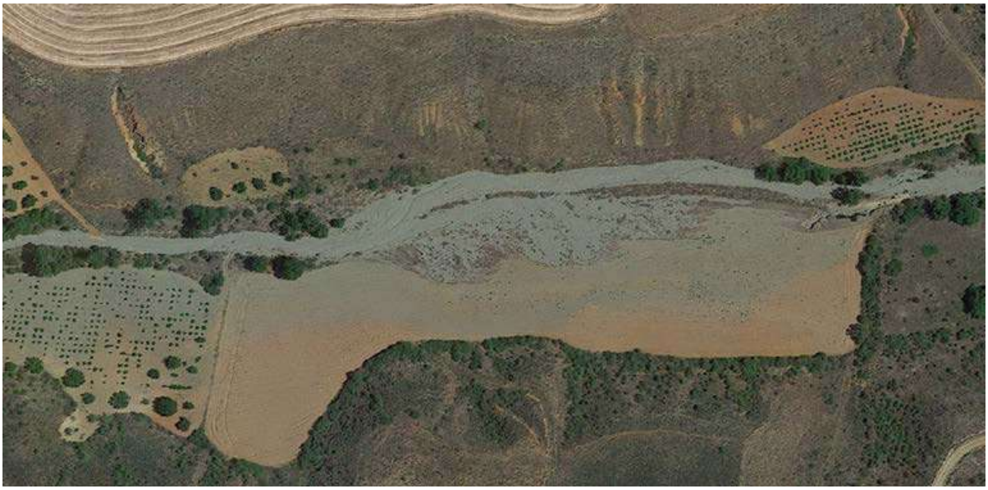


Figure 109. Overflow caused by a flood in the Gully of La Parra (San Martín del Río, Teruel). The channel needs and seeks more space, since which was occupied by farmland. We must not act against these natural processes. Unfortunately, when they are registered, the channel is usually redirected and undergoes overall morphological changes.

OBJECTIVES	• Prevent disturbance in bedforms and banks caused by the entry of machinery and by actions that destroy the channel and its morphology. • To appreciate the regenerative role of floods, as builders of a wide variety of geomorphic units and habitats.

	• Prevent the common false sense of security that leads to irresponsible and reckless actions downstream. • Educate about the natural functioning of the stream and about the futility and impact of actions that seek to increase the drainage cross-section area temporarily and without justification.
ACTIONS	• Enact a statewide prohibition law that includes sanctioning procedures for clandestine actions. • Reassign to good practices the budgets allocated to these negative traditional actions.
AGENT	Hydrographic Confederations as environmental guarantors of fluvial channels.
CONDITIONING FACTORS	• Powerful social inertia, reflected in continuous demands supported by political and economic interests, which only attribute negative effects to floods and falsely assign to sediment and vegetation a disturbing role on the flow. • Low budgets for this type of action. • Pressure from extraction companies to continue carrying out these actions. • Existence of transverse obstacles in the channel that can present problems during floods and for which alternative actions must be sought.
TIME, TREND, PROGNOSIS	This good practice would have to be carried out immediately and its positive effects would be felt in the first reconstructive flood of the channel. Associated with an adequate management of the land uses in flood-prone areas and with environmental education, post-flooding action should be totally suppressed in the short term and eliminated from people's imagination.

GOOD PRACTICE 7 RESIZING AND PERMEABILISING BRIDGES, FORDS AND ROAD-STREAM CROSSINGS

Figure 110. The flood in the Rambla de Cariñena, as a result of the storm Gloria episode (January 2020), destroyed the ford of the Virgen de Lagunas, rendering the only existing pipe under it useless. Apparently, this ford is illegal and it is the local owners who rebuild it after each flood.

OBJECTIVES	• Recover the fluvial continuity and the functionality of floods. • Naturalise sediment mobility and the transport of liquid and solid discharge. • Reduce the vulnerability of these structures and thus reduce risk.
ACTION	• Replace precarious fords drained by small culverts or pipes with higher fords and drainage pontoons. • Replace fords with bridges with as few support points as possible on the bed. • Make bridges permeable in the lateral areas of the channel (riparian corridor, floodplain). • Make roads permeable when they cross the flood plain.

AGENT	• The State through the Hydrographical Confederations. • The competent road services in each case. • The private sector can also participate.
CONDITIONING FACTORS	• Resizing and permeabilization are complex tasks which require a project and a significant economic investment, and sometimes also require an environmental assessment procedure. • Convergence of different administrations.
TIME, TREND, PROGNOSIS	The effects of this good practice are always positive, although depending on the infrastructure to be resized or made permeable, and the actions and rehabilitation works carried out, the ephemeral stream may take one or several flood events to renaturalise its operation. The risk reduction is evident once the work has been concluded.

GOOD PRACTICE 8 DIVERTING STRUCTURES, COLLECTORS AND DRAINS, AND MOVING THEM AWAY FROM THE CHANNEL

Figure 111. Pipes and collectors lead to a further narrowing of the Río Seco channel (Hoz de la Vieja, Teruel)

OBJECTIVES	• Reduce anthropogenic pressures on the fluvial system by avoiding the interaction of these structures with hydromorphological functioning. • Reduce risks by reducing exposure to these structures. • Enable decanalisation of the channel, which was sometimes channelled to protect these structures, and, therefore, the fluvial dynamics.
ACTION	• Move all types of structures (gas pipelines, oil pipelines, power lines, collectors, wastewater discharge pipes, irrigation canals, culverts, etc.) away from the channel and its banks. • Eliminate defense structures that protect channel banks.
AGENT	The owners and managers of each of the structures
CONDITIONING FACTORS	• Integration in urban planning and land management. • Significant economic cost of the actions.
TIME, TREND, PROGNOSIS	Very necessary and urgent action that should be promoted by the State through legislation and regulations. Its effects would be immediate in reducing risk and would be slower and more gradual in achieving the naturalisation of fluvial functioning.

GOOD PRACTICE 9 DECANALISATION

Figure 112. The Rambla de Albuñol (Granada)

OBJECTIVES	• Not protecting banks and allowing erosion to affect them, as this can be a key (sometimes unique) contribution to sediment transport in the channel. • Therefore, recover erosion, transport and deposition processes in the system and dynamize the stream, returning planform freedom to the channel so this can move laterally. • Increase the width of the drainage cross-section. • Reduce flow velocity at the flood stage. • Eliminate hard lateral structures that prevent the nesting of bird species and the development of natural vegetation. • Reduce risks due to a false sense of security and do not transfer the hazard to downstream reaches.
ACTION	• Decanalise the channel planform by removing lateral structures. • Unearth and discover the channel, preventing its narrowing and the hazard from the flow at the flood phase, caused by increased energy. • If necessary, revegetate the riparian corridors with native species that have been affected by canalisation. • Educate about the importance and natural functioning of ephemeral streams and raise awareness about how channelling negatively affects the bed.
AGENT	Hydrographic Confederations and sometimes the local administration.
CONDITIONING FACTORS	• Attention to lateral subsurface flows. • Existence of budgets for this type of action. • Careful handling of machinery so as not to alter the morphology of the channel. • Opposition of private property owners of the channel's side lands.
TIME, TREND, PROGNOSIS	This good practice would have to be carried out immediately and its positive effects would be felt in the first reconstructive flood of the channel. This action should improve the stream dynamics and should be linked to the correct management of land uses in the floodplain.

GOOD PRACTICE 10	NATURALISATION OF THE CHANNEL AND RECONSTRUCTION OF CHANNEL PLANFORMS AND ALLUVIAL BEDFORMS

Figure 113. Action of urbanisation and "fluvial park" in the Barranco Valvadera (Bergasa, La Rioja), which has altered its original morphology. We must try to avoid these actions and restore natural geomorphic units.

OBJECTIVES	• Recovery of natural geomorphological processes, fluvial dynamics and ecological processes. • Recover ancient fluvial planforms and channel patterns, which may have been altered by human action. • Return the natural patrimony and geodiversity. • Prevent linear bed incision and downcutting processes caused by the canalisation, artificial neck cutoffs and simplifications of fluvial planforms that have generated an increase in the bed slope.
ACTION	• Reconnections to reopen old channel routes, through the movement and removal of sediments. • Cancellation of artificial meander cutoffs (chute and neck cutoffs) and anthropogenic rectifications of the planform.

AGENT	Hydrographic Confederations as environmental guarantors of fluvial channels. They can be integrated into the National River Restoration Strategy.
CONDITIONING FACTORS	• Insufficient budgets for this type of action. • When making a reconnection between the old channel and the current one they could be at different heights. This difference in the local base level of both channels can be reduced or suppressed with sediments from the streams themselves if possible.
TIME, TREND, PROGNOSIS	In ephemeral streams it is necessary to wait in the medium term and after several flood events for the consolidation of recovery processes. It is very important to monitor the actions in case they do not have a positive outcome, so it is essential to follow the principles of adaptive management.

GOOD PRACTICE 11 ELIMINATION OF PLANTATIONS AND CROPS WITHIN THE ACTIVE CHANNEL

Figure 114. Planting within the channel of the Barranco de La Nava (Aguilar de Río Alhama, La Rioja)

OBJECTIVES	• Reactivate sediment mobilisation, flood flows and geomorphological processes. • Return the necessary space to the ephemeral stream to develop its fluvial dynamics in a natural way. • Recover the active channel and riparian corridor. • Naturalise ecological processes.

	• Reduce risk by eliminating exposure to these elements and avoid increasing the hazard they generate in some fluvial sectors.
ACTION	• In the event of possible invasions by private property, expropriate the land, as it is within the Public Hydraulic Domain (PHD) defined by the Water Law and regulated by Royal Decree 9/2008. • Removal of possible longitudinal or transverse obstacles linked to the protection or consolidation of these plantations and crops. • Eliminate plantations and crops.
AGENT	Hydrographic Confederations and regional services for the protection of the natural environment.
CONDITIONING FACTORS	• Pressure from companies and individuals which for decades have been occupying the grounds of the PHD. • Insufficient budgets for expropriating the land. • It can be an unpopular measure for the local population. • Sometimes it is the local or regional administrations that have carried out these actions.
TIME, TREND, PROGNOSIS	Although a long bureaucratic process is necessary for carrying out this good practice, it should be brought about immediately and the watercourse by itself would be capable of recovering from the impacts generated. Its positive effects would soon manifest themselves after a few flood events, provided that they have enough magnitude to move sediment. This good practice can be very effective in fluvial reaches in plains, which can reach very high levels of naturalness.

4.2. A proposal for good practices for ecological functioning

This block of good practices focuses on the recovery of naturalness using an ecosystem approach. The measures in the previous block constitute the basis for achieving good fluvial functioning, and involve the reconstruction of the habitats, but sometimes it is necessary and urgent to act directly on the species, either promoting appropriate ones, or eliminating the invasive ones.

In most cases it is advisable to combine several of these good practices, as well as associate them with those of the previous block. The success of the recovery project will be based on this integration of measures which should always be adapted to the local situation and, as far as possible, implemented with minimal intervention, and with most work concentrated on the fluvial system.

GOOD PRACTICE 12 — REMOVAL OF REEDS (*Arundo donax*)

Figure 115. Example in a permanent river (River Segura in Molina de Segura, Murcia) of treatment for the elimination of reeds on both channel banks.

OBJECTIVES	• Control of monospecific reed formations *(Arundo donax)* and the progressive reduction of their presence. • Increase in the diversity of habitats and, consequently, of plant and animal species (biodiversity). • Increase in pollinisers and therefore in pollination. • Increase drainage capacity during floods.
ACTION	• Delimit the area of the ephemeral stream where action needs to be taken. • There are several effective methods for reed removal (chemical, physical, mechanical and promotion of competition) with different levels of effectiveness and damage to other plant and animal species (Deltoro et al., 2021). The one that seems most effective at present is to cover the stands of the reeds with a black plastic material, once they have been cut, for at least 10 months.

AGENT	Due they are spaces of hydraulic public domain, the powers of action correspond to the Hydrographic Confederations.
CONDITIONING FACTORS	• The use of one or other method of reed removal depends on the characteristics of the reed field. • It is always advisable to use methods that do not harm other species.
TIME, TREND, PROGNOSIS	The time of action for the removal of the reeds depends on the method used. In any case, several years must elapse (>3 years) for the results to be acceptable. Bear in mind that it is an invasive species, whose eradication requires a lot of effort and money.

GOOD PRACTICE 13 PROTECTION MEASURES FOR AUTOCHTHONOUS SPECIES

Figure 116. The Rambla de Alarba (Morata de Jiloca, Zaragoza)

OBJECTIVES	• Maintain the natural biodiversity of the ephemeral stream and its environment. • Contribute to reduce sediment movement and transport.

	• Increase capacity to capture carbon. • Increase the ability to regulate the local climate by cooling in summer.
ACTION	• Limit grazing. • Limit the passing of all kinds of vehicles in the channel. • Establish and apply public protection figures.
AGENT	It can be approached from the biodiversity protection services of the Autonomous Communities. It also has significant potential to be integrated into local initiatives and voluntary activities.
CONDITIONING FACTORS	• Grazing, common in these streams, is usually a serious inconvenience for the maintenance and protection of these autochthonous species. • Activities such as trekking, moto-cross or all-terrain vehicles deeply damage the native vegetation. • Similarly, environmental education becomes a key argument to inform the general public about the need to maintain these species.
TIME, TREND, PROGNOSIS	It depends, on the one hand, on the effectiveness of the channel use limitations and, on the other, on the degree of awareness of the public visiting these places.

GOOD PRACTICE 14 MEASURES FOR PREVENTING THE COLONISATION OF INVASIVE SPECIES

Figure 117. Río Foix (Cubelles, Barcelona), with different non-native species on its banks.

OBJECTIVES	• Maintain the natural biodiversity of the stream and its surroundings. • Facilitate sediment mobility.
ACTIONS	• Protection of autochthonous species. • Maintenance of the sediment seed banks in the ephemeral stream. • Limit the introduction of invasive species to the watercourses by the local or visiting population. • Environmental education to raise awareness about the most common invasive species and warn of the dangers of the introduction of invasive species.
AGENT	Conservation associations have an important role to play in informing the public about the most dangerous species and the negative effects of their introduction.
CONDITIONING FACTORS	It is necessary to implement different synergistic actions, such as those indicated, to achieve the objective, so it is essential to have a well-defined action plan in the medium term.
TIME, TREND, PROGNOSIS	The alteration of the natural environmental conditions of these streams facilitates the settlement of many invasive species, whose management is especially complicated due to the cryptic and stochastic nature of the invasion process. Only by maintaining the good condition of these channels will it be possible to minimise the impact caused by these species.

GOOD PRACTICE 15 CREATION OF HABITATS

Figure 118. Río Huecha (Bulbuente, Zaragoza)

OBJECTIVES	• Maintain the natural biodiversity of the ephemeral channel and its surroundings. • Maintain the natural hydrodynamics of the stream. • Activate the different biogeochemical processes.
ACTIONS	All actions aimed at the maintenance and conservation of native natural vegetation, as well as all processes that facilitate natural hydromorphological dynamics, are key in the genesis of habitats for organisms. In extreme cases of degradation, it is necessary to create new habitats, which favour the reinstallation of processes and forms, soil formation and colonisation.
AGENT	Passive restoration can be adopted, in which the ephemeral stream performs the work of habitat generation. But sometimes, the damage is so severe that it is necessary to carry out an active process of creation. It would correspond, in principle, to the Hydrographic Confederations, where a works management team with competence in river geomorphology is fundamental.
CONDITIONING FACTORS	The creation of habitats depends almost exclusively on maintaining the natural conditions of the channel; that is, freedom for the water and solid load to move, which is deposited creating bars and other morphosedimentary units of varied texture, on which basic organic matter accumulates for the colonisation of different plant and animal species. Having natural floods is a guarantee of success.
TIME, TREND, PROGNOSIS	The amount and diversity of biogeochemical processes (e.g. the decomposition of organic matter, release of nutrients, nitrogen control, etc.), which characterise the ephemeral channels, occur over the different habitats generated. Thus, the creation and diversification of habitats is a guarantee of the proper functioning of these streams.

GOOD PRACTICE 16 REVEGETATION

Figure 119. Bad practice of revegetation in a dry channel reach of the Arba de Luesia (Rivas, Zaragoza) altered by recovery work of the drainage cross-section. The aligned stakes narrow the channel.

OBJECTIVES	• Recreate the autochthonous vegetation of the place as much as possible. • Increase biodiversity. • Control sediment movements and generate sand bars and other bedforms in the channels. • Generate new habitats for species.
ACTION	• Let the seed banks act, the one which exists in the bed sediment, and the one transported by the flood waters (passive revegetation). • Use of plant cuttings or planting in exceptional cases to speed up the processes (active revegetation).
AGENT	Hydrographic Confederations in the Hydraulic Public Domain, both allowing the watercourse to work and taking action if necessary.

CONDITIONING FACTORS	Excessive grazing and activities such as trekking, moto-cross or off-road vehicles, and even hiking, can delay the revegetation process.
TIME, TREND, PROGNOSIS	Ecological succession in passive revegetation processes is not usually slow, but depends on the entry of seeds through floods or the amount and diversity of the seeds accumulated in the bed sediments. Passive revegetation is the best guarantee to recover autochthonous vegetation.

GOOD PRACTICE 17 ELIMINATION OF RUBBISH AND DUMPING IN CHANNELS AND BANKS

Figure 120. Garbage and waste in the Ruisseau des Lavandières in Caunes-Minervois (France)

OBJECTIVES	• Eliminate anthropogenic elements of the ephemeral fluvial system, contributing to their naturalisation. • Improve habitats and increase biodiversity.
ACTION	• Frequent periodic campaigns to clean the entire ephemeral stream network of rubbish, waste and dumping.

	• Awareness campaigns to try to educate the population about the inappropriateness and negative consequences of using the channels as garbage dumps and landfills.
AGENT	Hydrographic Confederations and volunteers from associations and educational centres.
CONDITIONING FACTORS	• Social inertia from a deeply rooted ancestral contempt for these dry courses. • Absence of cataloguing and legal recognition of many of these channels.
TIME, TREND, PROGNOSIS	This good practice can have an important and immediate social impact, so that campaigns can be quickly organized at a local level promoted by associations and educational centres. The benefits can be immediate.

4.3. A proposal for good practices in managing the fluvial territory

Fluvial management, including restoration measures, implies and requires the existence of a territory. The fluvial system has a spatial component, it occupies a place on the earth's surface, which must be respected and which is the setting where it functions and recovers. Land management is a work in progress marked by conflicts, interests, lack of coordination, irresponsibility, breaches, inertia and complex economic and environmental dynamics throughout the geographical space; made even more complicated in rivers and further still in ephemeral streams.

The good practices of this block, which are very difficult to apply, could achieve a new scenario for the area occupied by fluvial zones. With more natural basins and channels, it is possible for ephemeral streams to establish themselves in their space and adjacent land uses can be managed for the maintenance of that space and to guarantee natural fluvial function.

GOOD PRACTICE 18 NATURALISATION OF THE BASIN

Figure 121. The Rambla Celumbres (Cinctorres, Castelló)

OBJECTIVES	• Make the fluvial system more natural. • Recover erosion, transport and sedimentation processes. • Increase biodiversity in the basin and channels.
ACTION	• Reduce land uses that involve water and sediment consumption. • Reduce uses that make the zone more impermeable, such as urbanisation processes and the consumption of space. • Increase the surface area of protected natural spaces to guarantee natural sources of water, sediment and species.
AGENT	All bodies and institutions involved in land management and environmental protection. It is also necessary for the collaboration of environmental organizations and citizens in general, to take the lead in changes in consumption habits.
CONDITIONING FACTORS	It is a very complex process integrated into land management and adequate and sustainable land use planning. The difficulty and slowness of many planning and legal processes and the obstacles established by the economic powers, interested in maintaining the current situation of overconsumption, are widespread conditions that are very difficult to overcome.

TIME, TREND, PROGNOSIS	It is essential to start these types of actions at the basin scale now in order to achieve long-term results. It will take several decades for changes to become effective and results meaningful.

GOOD PRACTICE 19 — RETURNING THE WATERCOURSE ITS NATURAL SPACE AND GENERATING A FLUVIAL TERRITORY

Figure 122. The Rambla Cervera (Sant Mateu, Castelló), with internal protective ripraps that cut through and restrict the channel active space.

OBJECTIVES	• Achieving continuous erodible, floodable, wide and non-developable river spaces (which do not have to be public spaces, they must only maintain some conditions such as the prohibition of extraction or building). • Geomorphological freedom and regeneration processes, increasing the mobilisation and transport of solid discharge, as well as activity on erodible banks.

	• Recovery of the functionality of riparian corridors and floodplains, allowing overflow and managing to naturalise the function of the watercourse. • Lamination of flood waters in a natural way, cushioning the peak flows by the overflow itself within the fluvial territory. In this way, downstream risk can be reduced by avoiding and limiting the installation of defense structures.
ACTION	• Removal of longitudinal dikes (levees) or setback of embankments, to achieve the mobility of the channel and the free dynamics of fluvial processes. • Widen the river territory upstream and near population centers to reduce the frequency of overflows. • Establish expropriations, acquisitions, barter or compensatory measures for territories and private plots within the river territory, offering the possibility of maintaining their activities, but respecting flood processes. • Promote changes in land use, prioritising its adaptation to river functioning. • Provide the fluvial space achieved with a nominal and legal consideration as a Fluvial Territory in accordance with National Strategy for River Restoration.
AGENT	Hydrographic Confederations and regional councils for spatial planning and land management, through coordinated plans and programs that are implemented in reference fluvial reaches.
CONDITIONING FACTORS	• Ownership conflicts. • River spaces occupied by crops, buildings, communication links by road and rails or other infrastructure. • Heterogeneity in ownership arrangements and the circumstances of each section. • Applicability in extensive ephemeral streams with flood plains, and much less feasible and effective in others with a very small width. • Need for budgets for this type of action, which can be important if expropriations or purchases are the chosen action option.
TIME TREND, PROGNOSIS	This action will achieve its medium-term objectives and must be linked to the correct land use planning in the flood-prone area. The fluvial territory must be seen as a solution based on nature in the face of existing environmental problems, protecting the dynamics of the ephemeral stream and minimising risks, and thus recovering part of its territory.

GOOD PRACTICE 20 RETURNING PUBLIC PROPERTY TO THE FLUVIAL TERRITORY

Figure 123. Andarax River (Santa Fe de Mondújar, Almería)

OBJECTIVES	• Recover the Hydraulic Public Domain in channels affected by private occupations. • Recover naturalness in the fluvial function according to the lines indicated by the objectives of the previous good practice (nº 18). • Minimize risks associated with flooding and erosion by reducing exposure and vulnerability. • Improve the planning of land use in the fluvial space and control over it.
ACTION	• Cadastral reviews throughout the ephemeral stream network. • Delimit and demarcate the Hydraulic Public Domain (HPD), defined by the Water Law and regulated by Royal Decree 9/2008, throughout the ephemeral stream network. • In the reaches where it is possible, consolidate the continuous band of the fluvial territory. • Expropriate land within the Hydraulic Public Domain, and remove defences and channeling works that restrict its function. • Raise awareness and educate about the importance of the figures of the HPD and the Fluvial Territory, not only to improve the hydrogeomorphological and ecological naturalness of the river system, but also as instruments that provide effective and adaptable land planning and management in order to control activities in this space, with the consequent reduction in risks.

AGENT	The State through the Hydrographic Confederations and with the support of the judiciary making existing laws effective.
CONDITIONING FACTORS	• Ownership conflicts. • Pressure from companies, individuals and owners of the affected territories within the HPD and the Fluvial Territory. • Lack of knowledge and lack of social awareness about the HPD and the Fluvial Territory.
TIME, TREND, PROGNOSIS	This good practice would have to be immediately implemented, although expropriation processes are complex and lengthy, so their positive effects could take time to be noticed.

GOOD PRACTICE 21 — FLUVIAL TERRITORY IN URBAN REACHES: GREATER WIDTH, DEURBANISATION, CHANGING LAND USES

Figure 124. Barranco Valera in Herce (La Rioja)

OBJECTIVES	• Recover the functionality and fluvial naturalness also in urban areas, freeing up spaces for the watercourse, removing obstacles and making the channel and the floodplain permeable.

	• Reduce urban exposure and vulnerability to flood hazards. • Reduce and prevent "bottleneck" situations generated in many channels by their passage through an urban space and with it their negative effects on the affected specific reach and other reaches involved. • Raise awareness among the urban population about the values and functioning of ephemeral streams regardless of their specific dimensions and previous local perception.
ACTIONS	• Recover land to free up the fluvial zone by generating an erodible and flood-prone space as wide and continuous as possible. • Plan the urban space adapting the urban regulations to the fluvial space and make land gains along the course non-developable. • Change uses and structures so that in the urban space there is a wide and continuous lateral zone which expands the channel. • Eliminate landfills and dumping in the fluvial territory, which is very frequent in urban and peri-urban areas. • Promote and execute the deurbanisation (decanalisation of the channel, removal of constructions and roads, distancing and diversion of infrastructure, etc.) of surfaces of the fluvial territory for its better adaptation to fluvial function. • Replace urban uses and structures with open spaces such as orchards and naturalised parks. • Encourage citizen movements that work along these lines.
AGENT	All the competent administrations in matters of land management and urban planning. It should be supported by a large-scale state plan that would coordinate and guide action at every local level.
CONDITIONING FACTORS	• Urban areas are considered to be well-established both socially and legally, which makes it very difficult and expensive to take action on them. Many situations are inherited and irreversible and urban planning regulations themselves prevent their modification. • Conflicts with owners and with urban managers that protect regulated public use. • Fluvial spaces occupied by buildings, communication links or other infrastructure. • Perception and social consideration of urban structures as a positive and inevitable progress and a broad rejection of deurbanization initiatives • Insufficient budgets for this type of action.

TIME, TREND, PROGNOSIS	This good practice is complex in its implementation and will probably require action in phases, especially in large population centres. The expected effects will also be progressive. It has to be linked to the correct land use planning in the flood plain. The fluvial territory should be seen as a solution based on nature, effective risk management, social acceptance and a priority in municipal management.

4.4. A proposal for good practices in hydrological, environmental and risk management

This block focuses on management and is above all a call to administrations to accept responsibility for considering and valuing the ephemeral fluvial network, for monitoring its correct hydrological functioning, for its permanent environmental evaluation and for the legal and effective protection of these watercourses. For all this, sensitivity, awareness and willingness to act are all necessary.

GOOD PRACTICE 22	CATALOGUING AND FORMALIZING ALL OF THE EPHEMERAL CHANNELS IN THE FLUVIAL NETWORK

Figure 125. Barranco del Cilluelo (Fuendejalón, Zaragoza)

OBJECTIVES	• Identify the different ephemeral fluvial systems to be able to manage them and find specific and effective solutions. • Assess the importance and representativeness of the ephemeral fluvial network in the context of the overall drainage network.
ACTIONS	• Integrate the entire ephemeral stream network as bodies of water into the management mechanisms of hydrographical districts. • Have a complete and updated cartography of the ephemeral fluvial network.
AGENT	The State through Hydrographic Confederations.
CONDITIONING FACTORS	• Sometimes there are difficulties of definition due to variations in flow regime and diversity in channel geometry and planform. • There are streams with only a few ephemeral reaches, which makes it difficult to catalogue them. • It is necessary to overcome inertia due to ignorance and underappreciation both in society and in government administrations.
TIME, TREND, PROGNOSIS	This good practice is an indispensable starting point. To reverse the current situation it is necessary to improve knowledge, and that knowledge starts with identification as a first step, of both specific cases and the whole ephemeral drainage network. It is a simple action, which can be carried out through a research project, but will then require a willingness to make it effective and will lay the foundations for other measures.

GOOD PRACTICE 23	INCREASING THE GAUGING STATIONS AND CONTROL POINTS OF THE AHIS SYSTEM IN THE EPHEMERAL FLUVIAL NETWORK

Figure 126. One of the very few gauging stations in the ephemeral network of the Ebro basin, that of the Seco River in Oliete (Teruel), built after the flash flood of 2013, which caused a fatality.

OBJECTIVES	• Improve the knowledge of ephemeral streams and give them greater visibility. • Detection, quantification and classification of peak discharges and floods in ephemeral streams. • Improve the prediction of extreme events and reduce risk.
ACTION	• Creation, updating and improvement of a georeferenced database of all ephemeral streams. • Provide AHIS network stations to all ephemeral streams where it is possible.

AGENT	The State through Hydrographic Confederations. It could be subject to funding from European funds.
CONDITIONING FACTORS	• Lack of budgets for this type of action. • Large dimensions of the ephemeral fluvial network.
TIME, TREND, PROGNOSIS	It is a fundamental and good practice, but it involves a considerable cost and will have to be considered as we move forward gradually over time. It would be of great interest to have this infrastructure throughout southern Europe.

GOOD PRACTICE 24 HYDROLOGICAL NATURALISATION, GEOMORPHIC AND FUNCTIONAL DISCHARGES

Figure 127. Ephemeral channel reach of the Isuela River (Huesca) with denatured discharge due to hydrological regime regulation from the Arguis reservoir.

OBJECTIVES	• Deregulate these streams, since the intense regulation is a cause of environmental degradation and completely modifies the natural discharge regime. • Recover the processes of erosion, transport and sedimentation of ephemeral fluvial systems.

	• If regulation is maintained, recover the frequency of floods in order to activate the functional processes of the fluvial system. • Control populations of living beings. • Cleaning and decontamination of the channel.
ACTIONS	• Elimination or regulation of anthropogenic detractions and derivations of the discharge. • In reservoirs, consider the possibility of releasing water to generate geomorphic and functional floods when it is recommended. • Naturalise by controlling spills from Wastewater Treatment Plants (WWTPs). • Control irrigation collectors and other external spills, which make the discharge less natural. If possible, divert them to perennial streams or rivers.
AGENT	Hydrological Confederations and users of regulation and exploitation systems.
CONDITIONING FACTORS	• Conflict over water uses. • Ownership conflicts. • Low capacity of reservoirs in ephemeral streams. • Difficulties in having water when it is needed.
TIME, TREND, PROGNOSIS	Hydrological naturalisation can be achieved in the medium and long term if agreements are reached about water use. Situations are often very complex and local constraints prevent global action. The generation of geomorphic and functional discharge, which is very necessary in most fluvial systems, is of little effectiveness in ephemeral streams, which are already naturally subjected to a limited number of hydrogeomorphic events. It can only be considered in exceptional cases in streams affected by the construction of reservoirs.

GOOD PRACTICE 25 ASSESSING THE ECOLOGICAL STATUS OF THE ENTIRE EPHEMERAL STREAM NETWORK

Figure 128. The Rambla Huechaseca (Pozuelo, Zaragoza)

OBJECTIVES	• Improve knowledge of ephemeral streams. • Improve the state of ephemeral streams. • Raise awareness about the environmental status of ephemeral streams and make this type of fluvial systems known to the population.
ACTION	• Integrate ephemeral streams into the bodies of water assessed with the aim of achieving a good ecological status (Directive 2000/60/EC). • Amend the ecological status assessment procedure of Directive 2000/60/EC for bodies of water from ephemeral streams, basing it mainly on hydromorphological indicators.
AGENT	• Hydrographic Confederations. • Volunteers. • The private sector can also participate. • Working groups of the European Commission, which should insist on the need to evaluate ephemeral streams.

CONDITIONING FACTORS	• Lack of budgets for this type of action. • Large dimensions of the ephemeral fluvial network in the Mediterranean area. • Need for geomorphological and ecological training for the people who develop the evaluation.
TIME, TREND, PROGNOSIS	It is a good practice of great interest, which should be implemented urgently taking into account the state of many ephemeral streams. Diagnosis is the first step to solve the problems and be able to proceed to the environmental recovery of these courses.

GOOD PRACTICE 26 — CONTROLLING AND CLOSING OF GROUNDWATER ABSTRACTION POINTS IN EPHEMERAL CHANNELS

Figure 129. “The Pozuelo Geyser”. This artesian well was drilled in the 1970s on the bed of the Rambla Huechaseca (Pozuelo, Zaragoza) and causes the water to outflow with a constant discharge and temperature.

OBJECTIVES	• Protect ephemeral streams and their environmental quality. • Maintain or recover natural hydrological functioning and the volumes of water in the channel and in the phreatic zone.
ACTION	• Compile a complete record of wells and their location in the context of the ephemeral stream network and their associated aquifers. • Restrict well construction. • Sanctions and rules in favour of the closure of groundwater abstraction points near these ephemeral fluvial systems.
AGENT	Hydrographic Confederations.
CONDITIONING FACTORS	• Existence of many illegal wells and clandestine water extraction. • Associated economic activities and private interests in water. • Deficiencies in hydrological planning. • Absence of sanctions and widespread systematic judicial non-compliance.
TIME, TREND, PROGNOSIS	This good practice will be very complex to bring in, requiring a long time. The effects on the fluvial dynamics will not be immediate, but will take time. It should be considered in the long term and associated with changes in land use, consumption habits and the process of adaptation to climate change.

GOOD PRACTICE 27	PROTECTING EPHEMERAL STREAMS OF A HIGH ENVIRONMENTAL VALUE AND QUALITY

Figure 130. One of the headwaters of the Rambla Barrachina in la Muela de Teruel (Teruel).

OBJECTIVES	• Maintain and improve the hydrogeomorphological and ecological status of these ephemeral streams. • Use the media to promote and disseminate environmental information related to ephemeral streams. • Complete networks of protected fluvial spaces with all existing ephemeral channel typologies. • Enhance the value of the ephemeral streams as a whole as well as their unique reaches of greatest value and quality.
ACTION	• Create and implement specific protection figures for ephemeral streams. • Multiply the number of ephemeral streams protected as fluvial nature reserves. • Provide to protected watercourses management plans and environmental education proposals.
AGENT	Ministry of Ecological Transition

CONDITIONING FACTORS	• Lack of budgets for this type of action. • Low social interest for these streams.
TIME, TREND, PROGNOSIS	This good practice, in addition to involving a figure of protection for the reach in question, would be fundamental for improving the promotion of these types of channels among the local population, and could even energize the territory. It is urgent that we protect ephemeral streams because this will produce positive environmental and social effects and will function as an example so we can go on developing initiatives in all basins.

GOOD PRACTICE 28 FLUVIAL AGENTS FOR CONTROLLING, MONITORING AND PROTECTION

Figure 131. Hydrographic Confederation of the Júcar River.

OBJECTIVES	• Protect ephemeral channels by preventing impacts from taking place. • Monitor compliance with the rules and check the result of the good practices that are being executed in the fluvial systems.

	• Report to the authorities and sanction bad environmental practices in ephemeral streams. • Create the green jobs that are necessary and compatible with the change of environmental mentality that must be implemented in society.
ACTION	• Creation of the figure of "Fluvial Agent". • Enact a statewide prohibition law that includes sanctioning procedures for the main impacts on ephemeral streams. • Associate the work of fluvial agents with the implementation of good conservation and monitoring practices.
AGENT	The Ministry of Ecological Transition through Basin Organisationss and Water Agencies.
CONDITIONING FACTORS	• A significant permanent budget allocation is needed in view of the size of the fluvial network and the need for a large group of agents. • Possible negative social perception if it is considered as a new environmental measure in conflict with certain economic interests.
TIME, TREND, PROGNOSIS	This good practice should be a priority in the framework of post-pandemic recovery funds and in the context of environmental change and adaptation to climate change. It would be a starting point that could guarantee the effectiveness of the remaining good practices and also help bring about the necessary change in social mentality about ephemeral streams.

GOOD PRACTICE 29 IMPROVING BUILDING CONDITIONS IN FLOOD ZONES

Figure 132. Barranco de Gran Tarajal (Fuerteventura).

OBJECTIVES	• Reduce vulnerability and thus risk in ephemeral streams, in cases in which exposure cannot be reduced (deurbanisation). • Educate the population about risk and raise awareness about the need to change consumption habits and location.
ACTION	• Close basement floors in flood zones. • Permeabilise the floors at ground level to facilitate the passage of water and raise all equipment • Raise homes, shops and services to non-floodable floors, preferably in pilot-supported structures. • Have temporary barriers and portable containment and retention elements, as well as floodgates and watertight doors. • Transfer of public services and common buildings to non-flood prone areas. • Prohibit new construction in flood zones. • Establish emergency systems and evacuation plans for each urban centre.
AGENT	This action should be the subject of a state plan led by the ministries of housing and ecological transition.
CONDITIONING FACTORS	• Need for large budgets. • Social inertia and a false sense of security in the riverside population.
TIME, TREND, PROGNOSIS	This good practice should be subject to a legal procedure that allows it to be carried out rapidly. Its effectiveness will be immediate and will make it possible to considerably reduce vulnerability. The problem is widespread, since many population centres are crossed by, or directly built, on ephemeral streams.

4.5. A proposal for good practices for evaluation, knowledge and awareness

This block proposes good practices which are fundamental for the achievement of all the previous ones, and especially those concerned with management. The involvement of society is sought here and is to be based on education and awareness, which must encourage both the continuous denunciation of bad practices and collective work on the definition, implementation and monitoring of good actions.

GOOD PRACTICE 30 — GLOBAL ENVIRONMENTAL EDUCATION, A CHANGE OF MENTALITY AND AWARENESS CAMPAIGNS ABOUT EPHEMERAL STREAMS

Figure 133. School environmental awareness activities.

OBJECTIVES	• Improve knowledge about ephemeral streams and their geomorphological function and fluvial ecology. • Inform and raise awareness about the impacts and problems of ephemeral streams and their environmental value. • Contribute to a profound change of mentality in relation to the territory and the environment, as a fundamental basis to be able to address river recovery and in the context of adaptation to climate change. • Change societal habits by moving towards processes of productive degrowth and sustainability.
ACTION	• Develop information and awareness campaigns and activities about fluvial functioning in educational centres and for broad sectors of society. • Develop a specific and urgent awareness campaign about ephemeral streams.

	• Establish social awareness and specific environmental education programs, including content in the school's curriculum. • Promote the creation of associations that are working for the necessary change of mentality. • Finance initiatives that change consumption habits and favour degrowth and sustainability. • Awareness-raising actions aimed especially at the riverside populations which are potentially vulnerable to floods in these types of streams.
AGENT	Initiatives must be led by civil society and formal education and financed by the ministries of education and universities and ecological transition.
CONDITIONING FACTORS	• Widespread ignorance of the population that has a negative impact on rivers. • Lack of respect and social and administrative attention towards ephemeral streams. • Limited traditional participation in the initiatives that are undertaken along these lines. • Economic, social and political inertia that hinders changes in mentality and in forms of consumption. • Need for budgets to implement the proposed actions.
TIME, TREND, PROGNOSIS	Decades ago, society changed its mentality towards issues such as adaptation of the environment and the unsustainable consumption of fluvial resources. Now we have to go the opposite way, which could also take decades. This good practice should be constantly publicised and made permanent over time, as it forms the basis for any fluvial recovery project. A specific awareness campaign on ephemeral streams is needed very urgently, in the short term, in order to lay the foundations for the implementation of all the other good practices.

GOOD PRACTICE 31 | STUDYING AND DENUNCIATION OF NEGATIVE ACTIONS

Figure 134. Ford built in a particularly active channel reach on the Rambla de Valdelentisco, next to Isla Plana (Cartagena). During the floods, a large bedload (sand and gravel) passes through this road-stream crossing, with the consequent danger that it represents for vehicle access.

OBJECTIVES	• Prevent the proliferation of bad practices, negative action and false restoration in ephemeral channels. • Better understand the dynamics of ephemeral streams and their response to certain human interventions. • Raise awareness among the population about bad and good practices in ephemeral streams. • Modify the generalized negative social perception of ephemeral streams and the generalized positive social perception of many negative actions. • Recover from negative actions present in the ephemeral channels.

ACTION	• Identify and locate all possible bad practices and negative actions throughout the ephemeral fluvial network. • Officially report through legal procedures and through public communication all these bad practices, including false restorations. • Continuously insist through the media on the values and natural functioning of ephemeral streams and constantly and forcefully warn about bad practices that harm them. • Creation of green employment with figures such as "fluvial agents", who can facilitate control and protection of these types of watercourses and has the main role in making formal complaints to the authorities of bad actions. • Awareness and sensitization campaigns in order to teach how to detect negative actions in ephemeral streams. • Creation of a simple portal for complaints, so that anyone can quickly report negative actions, and that the competent administration can detect and expedite hypothetical restorations.
AGENT	Groups and management bodies, such as the Iberian Centre for River Restoration (CIREF), the environment agencies or departments of the different public administrations and environmental associations. It can also be developed from individual scientific-technical voluntary work.
CONDITIONING FACTORS	• Need for budgets for this type of action. • Ignorance and lack of awareness about these types of fluvial systems, both socially and in the judicial field itself, which causes abandonment and neglect and proliferation of negative actions. • The often enormous extent of the ephemeral stream network, which make it very difficult to reach all of it in order to identify and report bad practices.
TIME, TREND, PROGNOSIS	Many restoration actions and good practices that are efficiently applied will have started from the identification and official reporting to the authorities of anthropogenic impacts, so this previous work is necessary and urgent and should be extended in the territory covering the entire ephemeral network.

GOOD PRACTICE 32 PARTICIPATION AND VOLUNTEERING

Figura 135. Field campaign with fluvial geomorphology students.

OBJECTIVES	• Involve the population in the defence and recovery of fluvial systems and natural spaces. • Awareness-raising and environmental education about ephemeral channels. • Speeding up the execution of stream restoration actions and good practices. • Detection of environmental problems, conflicts and difficulties that may arise in restoration processes.
ACTIONS	• Creation of local campaigns to reverse negative actions. • Development of scientific studies and promotional publications to inform and prevent new actions and / or negative impacts. • Courses and technical meetings to encourage participation and environmental volunteering in fluvial issues and to train participants. • Design a participation and volunteering protocol for each action and good practice.

AGENT	It can be managed and coordinated from the hydrographic confederations with support in educational, scientific and social centres.
CONDITIONING FACTORS	• Generally low social appreciation of ephemeral streams. • Limited experience and extension of these types of environmental practices in the territory. • Insufficient budgets to finance these actions. • Complexity of ephemeral streams and many of the recovery initiatives and good practices that can be carried out.
TIME, TREND, PROGNOSIS	Participation and voluntary actions must be present in all phases of fluvial recovery, starting with the approach, debate about and prior planning of the measures and including the follow-up after the actions.

GOOD PRACTICE 33 MONITORING AND FOLLOW-UP


Figures 136 and 137. The Rambla de Cariñena (Zaragoza) and Río Seco de Sarsamarcuello (Huesca).

OBJECTIVES	• Recognize over time the processes and effects derived from the recovery actions implemented in ephemeral streams, checking their effectiveness and proceeding, if necessary, to changes of action within the framework of adaptive management. • Have a scientific network of information and studies on ephemeral streams.
ACTION	• Process monitoring at observation and sampling points to check changes.

	• Application of geomorphological and ecological monitoring protocols for the recovery and function processes of the fluvial system. • Periodical applications of diagnostic indices. • Implementation and maintenance of multidisciplinary scientific-technical teams that carry out monitoring and follow-up, and technical training to develop these practices. • Possibility of involving volunteers in some actions.
AGENT	Hydrographic confederations, universities and research centres
CONDITIONING FACTORS	• Insufficient budgets for this type of action. • Complexity of ephemeral streams and recovery initiatives, so there is a need for different monitoring and follow-up programs adapted to specific conditions.
TIME, TREND, PROGNOSIS	It is an essential and good practice, which guarantees all the others and contributes to the success of all of them. It must be carried out before any other action is taken and last for at least five years.

5

Good practices for adapting to climate change in ephemeral streams

Carmelo Conesa-García, Pedro Pérez-Cutillas, Alberto Martínez-Salvador, María Luisa Suárez, María Rosario Vidal-Abarca, Francisco Alonso-Sarría and Alfredo Ollero

5.1. The perception of climate change and its impacts on ephemeral streams

River systems in general and ephemeral streams in particular are excellent indicators of climate change, so that the impacts of climate change can be clearly perceived in their channels.

The semi-arid ephemeral streams (SAES) have a much more important hydrological and geomorphological impact than has been recognized thus far. Much of the water and sediment loads that feed the floods in many rivers come from ephemeral streams. This lack of understanding about their functionning and contribution to more hierarchical permanent river systems is also accompanied by very little information on the impacts of climate change on their dynamics and morphology. Understanding of these types of impacts by society in general, and by land management institutions and bodies in particular, is almost non-existent. It can even be said that the scientific literature on the subject is much less extensive than in the case of continuous watercourses. The number of studies on morphological adjustments to river systems associated with climate change has been increasing considerably since the middle of the last century (Schumm and Lichty, 1963; Schumm, 1968). However, the vast majority of them refer to climate change impacts on rivers rather than on seasonal, intermittent or sporadic watercourses. Particularly abundant are the perception and evaluation studies of recent natural and anthropogenic impacts on the morphology of European rivers. The generalised perception in these cases for the last century and a half is of a tendency to bed incision, followed by a narrowing of the channel and bank stability (Liébault and Piégay, 2002; Rinaldi, 2003; Surian and Cisotto, 2007; Zawiejska and Wyzga, 2010; Skarpich et al., 2013; Conesa-García et al., 2021).

In general, there is some consensus that any fluvial system, whether perennial or ephemeral, can tend towards a new (non-stationary) state driven by climate change over relatively long timescales (from decades to centuries). (Schumm, 1977; Knox, 1984; Bull, 1991; Brierley and Fryirs, 2005). In any case, the impacts of current climate change on SAES appear to be greater than on perennial river systems (Chin and Gregory, 2001; Lowe and Likens, 2005), but despite they are still not very well-known and are perceived as having less importance among environmental management agents.

A wide range of studies are emerging that address the changing morphology of alluvial rivers in cold and humid temperate environments in response to future climate change projections using simulations and prediction models (hydrodynamic, morphodynamical and cellular ones, among others) (Boyer et al., 2010; Verhaar et al., 2011). However, very little has been written on this subject regarding ephemeral channels. To know the response of these systems to new climate scenarios, information on future discharge is needed, which can be obtained from hydrological models applied to the simulated data in these scenarios (Dankers and Feyen, 2008). The lack of paleohydrological data and the use of different temporal resolutions of alluvial records in semi-arid ephemeral streams (SAES) make it even more difficult to attempt to generalise the response of these types of systems to climate change (Macklin et al., 2012). There are hardly any studies available on the impacts of long-term climate variability on flood frequency, based on the analysis of instrumental records and paleofloods (Benito et al., 2020). This is the main problem for morphodynamic modelling in SAES, since, together with field data on the bed roughness and texture and hydraulic geometry, real measurements of solid and liquid discharge are required to be able to calibrate and assess the simulated discharge. Despite the attempts made in many of these ephemeral channels (for example, the Rambla de Algeciras, the Rambla del Albujón, etc.), it has been difficult to obtain representative gauging series, due to the continuous failure and destruction of the registration instruments during the floods. More recently, the installation of water level sensors (levelogger type, calibrated from atmospheric pressure data, electromagnetic or ultrasonic sensors, etc.) by various agencies and bodies (e.g. Hydrographic Confederations, CEDEX) has substantially improved the direct collection of real-time flow data; but even so, there are still limited historical records (Bishop et al., 2008) and it continues to be difficult to generate complete long series. Only when it has been possible to calibrate hydrological models, have scientists been able to use future climate projections, based on regional climate models (RCM) representing these types of settings or global climatic models (GCM) and scenarios of gas emissions, whose simulated information (temperature, precipitation) is transferred to these models in order to obtain future discharge data and predictions of possible increases in flood magnitude.

5.2. Reaction of ephemeral streams to the impact of climate change

Ephemeral streams in semi-arid regions (SAES) are especially sensitive to climate change (Peirce, 2012), but are also easily altered by anthropogenic disturbances in the basin or channel. The difficulty with distinguishing between effects attributed to climate variations and human activities has forced many authors to analyse the hydrological and morphological changes of the SAES as a result of the interaction of both factors (Lane, 1955; Schumm and Parker, 1973; Brady et al., 2001; Simon and Rinaldi, 2006; Norman et al., 2008, 2017; Leopold et al., 2012; Dean et al., 2016). The vegetation of ephemeral ecosystems is usually resistant to natural water losses and the harsh environmental conditions imposed by climate change. The establishment of shrubs and bushes in some bedforms and banks is a sign of stability in the face of erosion. These are normally on slightly sloping banks, alluvial terraces and high inactive bars. Some influence of riparian woody vegetation has also been found in ephemeral braided channel reaches, where it is unlikely that a variation in water and sediment inputs due to climate change will produce significant morphological adjustments capable of replacing all existing alluvial forms and remove vegetation from the most stable bars (Hupp and Osterkamp, 1996; Merrit and Wohl, 2003; Shaw and Cooper, 2008). During floods these types of channels experience local erosion and deposition, and they can be more resistant than those that are steeper and entrenched in foothills and alluvial fans. In the latter, the most powerful flooding can cause a global restructuration of the channel and riparian habitat (Suftin et al., 2014). However, some human practices, such as vehicle traffic, military exercise manoeuvres or direct interventions on the channel (ripraps, breakwaters, or aggregate extraction) (Calle et al., 2017), are able to cause a greater and faster impact on braided ephemeral channels than on the cohesive and mixed substrate (alternating between the alluvial and rocky bed).

Climate change is being led in semi-arid regions by increasingly frequent extreme weather events, to which SAES show very different geomorphic responses (Naylor et al., 2016). Faced with similar climatic conditions, channels with cohesive banks resist increases in shear stress and stream power more than those with poorly compacted detritic banks. But the same reach of SAES can also respond differently depending on its state at the radiative forcing stage.

Even apparently sensitive SAES, such as those that run through soft materials (e.g. marls, silts), can experience negative and positive feedback, capable of partially absorbing the impacts of rapid climate change, when they transport a large bedload of coarse material. This is the case in many ephemeral streams in the south east of the Peninsula, which have their source area of sediment in metamorphic steep lands (mycaschists, slates and quartzites) and/or limestone-dolomitic and calcarenitic terrains, subjected to strong weathering, while their lower reach crosses through neogenic-quaternary formations of soft sediments (e.g. The Rambla Librilla, Algeciras, Salada or Moreras). Similar geomorphic impacts and responses have been described by Lane et al. (2016) in ephemeral systems in other semi-arid environments. Generally, when faced with most extreme floods, SAES show a rapid geomorphic response and inertia time (or relaxation, in terms of Phillips and van Dyke, 2016) over a relatively long time (on a scale of decades or centuries). For example, high bar-islands of coarse sediment (gravels, pebbles and blocks), generated by large flash floods, can remain for quite some time without significant changes and can even reach great stability. Such morphological adjustments sometimes involve a change in the equilibrium threshold of the system (Fruergaard and Kroon, 2016). When events of moderate and low magnitude occur on a recurring basis, SAES usually have shorter relaxation and feedback times that absorb minor alterations well (e.g. local incision and deposition).

SAES are very changeable streams, where phases of vertical sedimentary accretion alternate with phases of bed incision. Equilibrium conditions often last a short time, as they are often interrupted by dominant erosion or deposition processes, fed by feedback mechanisms, which cause local base-level variations. Examples of disequilibrium promoted by changes in the base-level are channel entrenchment that causes a lowering of its bed or the formation of alluvial fans that raise this level (Bull, 1997). The effects of climate change on vegetation cover in the headwater areas of these ephemeral streams have an important geomorphological impact on their middle and lower reaches (Bedford et al., 2011). The hillslopes, subjected to the conditions of extreme weather scenarios (for example, RCP 8.5), can provide a much higher sediment load during floods than in current events of similar magnitude. Under such circumstances, these SAES show great sensitivity and instability (Bull, 1997) and acquire a new dynamic state, dominated by vertical accretion and bed armouring to the detriment of incision and entrenchment processes.

SAES are dynamic geomorphic systems with an intermittent and variable response associated with events of different magnitudes, whose frequency can change over different time scales (Vita-Finzi, 2012). Large floods are the main factor governing short- and long-term sediment flows (Coolthard and Macklin, 2001, Lotsari, 2015). A higher frequency of these events, above the effective transport load at bankfull stage, will produce a faster and more substantial modification in the most sensitive ephemeral channels.

Since ephemeral systems owe their operation to the occurrence of heavy rainfall, any change in precipitation patterns, and in particular the frequency-duration-intensity curve, in the short and long term, will be reflected in the discharge regime (Brookes, 2009), and therefore, also in the rhythm of morphological channel adjustments. There is a general consensus about the change of trend in the regime and frequency of heavy rains. The main finding from the analysis of this trend in Spain during the last two centuries is an increase in the frequency of high-intensity rainfall events (especially on the Mediterranean coast) and a relatively stable accumulated precipitation per event or an even somewhat decreasing one depending on the case (González Herrero and Bech, 2017; Camarasa, 2021).

Most climate models predict severe changes in semi-arid Mediterranean regions, including increasing warming and dryness, intensifying droughts, increased rainfall variability, and more frequent torrential rainfall (Stein et al., 2011). These changes will alter the patterns of colonisation and the development of vegetation and create new patterns of sporadic flow in ephemeral channels: longer periods without runoff combined with periods of smaller floods, relatively spaced out over time, and a greater probability of extreme events associated with especially intense rains (Betancourt, 2007). A temporary climate change can significantly influence vegetation, surface runoff, weathering and erosion processes in semi-arid Mediterranean basins, and in turn affect the morphological dynamics of ephemeral streams very directly. Over long periods, sediment discharge during floods becomes an independent variable, which conditions the average balance between the net fluxes of erosion and deposition. A significant change in the hydrological regime, associated with sudden variations in the transport of water and sediments will imply overall morphological adjustments in these types of systems. A decrease in average annual rainfall, combined with the occurrence of heavy rainfall, affecting the headwaters of these SAES, would imply an increase in extreme peak discharge and bedload (in terms of volume and grain-size), which would tend to configure a wider and shallower channel, of an "oued" type. This trend is clear in headwaters composed of strongly fissured crystalline or metamorphic materials, subjected to intense thermoclasty processes, from which alluvial channels are developed that function as a dominant source of coarse sediments (e.g. the Rambla de Valdelentisco, Azohía, Moreras, Pastrana, Ramonete, Andarax, ...). On the other hand, when most of the basin, including the headwaters, are composed of soft or non-cohesive materials (marls, gypsum, sands, fragile calcarenites, ...), incision and entrenchment prevail over the processes of bed aggradation, leading to the deepening and narrowing of the channel (e.g. the Rambla de Salada, Chícamo, Santomera, Algeciras, ...).

There is a correlation between the variables involved in the equilibrium of the channel bed (simplified to four in the Lane's balance analogy -Lane, 1955-: unit liquid discharge, q_w; unit solid discharge, q_s; slope, S; and sediment grain-size, D) and the main variables that define the channel morphology (width-to-depth ratio of the channel, sinuosity, and meander length and amplitude). Faced with climate change, SAES can adjust their channel according to two primary premises based on the combination of both types of variables (Table 9):

Table 9

Hypothetical changes in water and sediment discharge and expected morphological adjustments in ephemeral channels due to global atmospheric warming.*

PS	PSF	q_w	q_{OV}	q_s	D	S	w	d	w/d	λ	Si
Sub-humid	Drier	–	+	+	+	+	+	–	+	+/–	+
Semi-arid	More humid	+	–	+	+/–	+/–	+/–	+	–	+	–
	Drier	–	++	++	++	+	+	–	+	+/–	–

PS = Present situation; PFS = Possible future situation; q_w = average unit discharge of floods; q_{ov} = unit peak discharge in larger floods (bankfull and overflow); q_s = unit sediment discharge; D = characteristic sediment grain-size on the bed (median); S = channel slope; w = bankfull channel width; d = bankfull channel depth; w/d = width/ depth ratio; λ = meander length (wave length); Si = sinuosity index.

*Drawn up from the considerations and criteria of Lane (1955), Schumm and Parker (1973), Verhoog (1987), Brady et al. (2001) and Norman et al. (2008, 2016).

From table 9 it can be inferred that for semi-arid areas current global warming may mean a decrease in average discharge and a considerable increase in peak discharge in extreme floods and in the unit sediment load (figure 138). In response to such changes, SAES tend to self-regulate through widening of the channel, vertical bed accretion, loss of depth, with the consequent increase in the width/depth ratio, increase in the characteristic grain-size of the bed materials and surface hydraulic transmissivity, and decreasing sinuosity.

A study carried out by CEDEX (2012) in the Segura Basin foresees an 11% reduction in its natural water inputs in a moderate climate change scenario and significantly lower inputs for more extreme radiative forcings (RCP 6.0 and RCP 8.5 scenarios) in 2050. Such changes will most likely have a clear impact on the composition and density of vegetation on hillslopes and channel banks, which will affect sediment yield and transport during high water flows.

The same approach has been applied to IRES (e.g. the Upper Mula) and SAES (e.g. the Rambla de la Azohía) in the region of Murcia from emission estimates (SRES) from the Fifth Evaluation Report (IPCC, 2013b). In the basin of the Upper Mula, the average discharges will experience a significant decrease in water inputs. According to projections, in the most extreme scenario (RCP 8.5), there would be a decrease in discharge of around 42.8% for the period 2041-2070, this decrease being more pronounced for the period 2071-2100 (52.4%). Rainfall would be about 27.9% lower by the end of the 2071-2100 period in the most extreme scenario (Martínez-Salvador et al., 2021). If the potential impact of climate change is assessed by comparing the set of future periods (2019-2040, 2041-2070 and 2071-2100) with that of the reference, in the first period under the RCP 4.5 and RCP 8.5 scenarios, water inputs would be re-

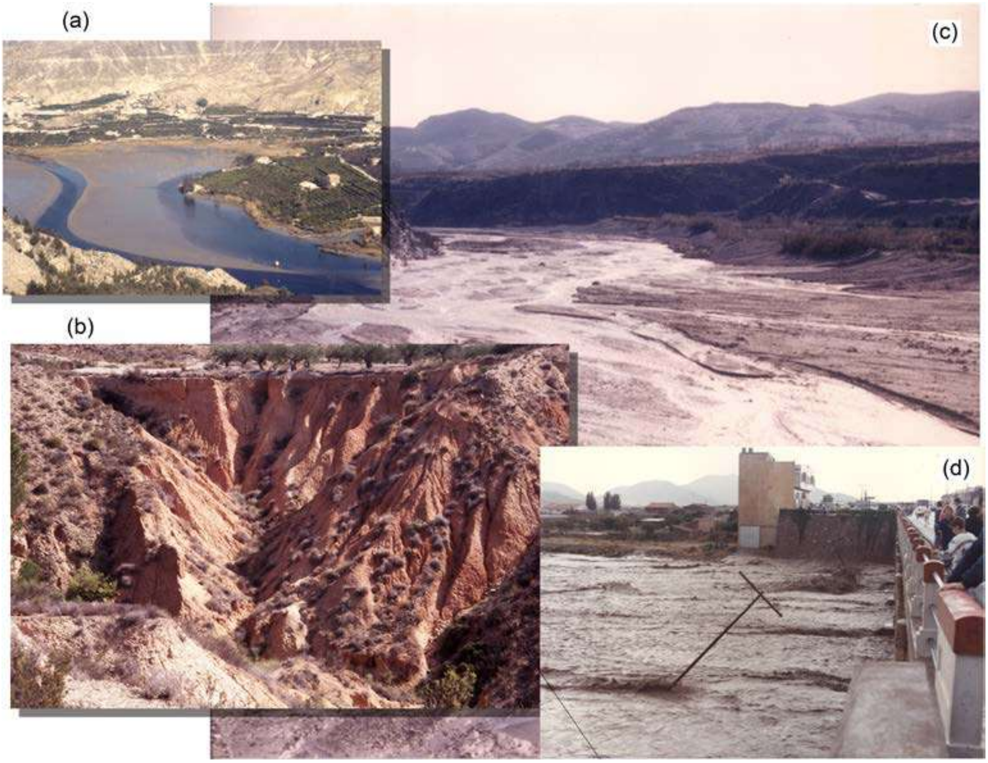
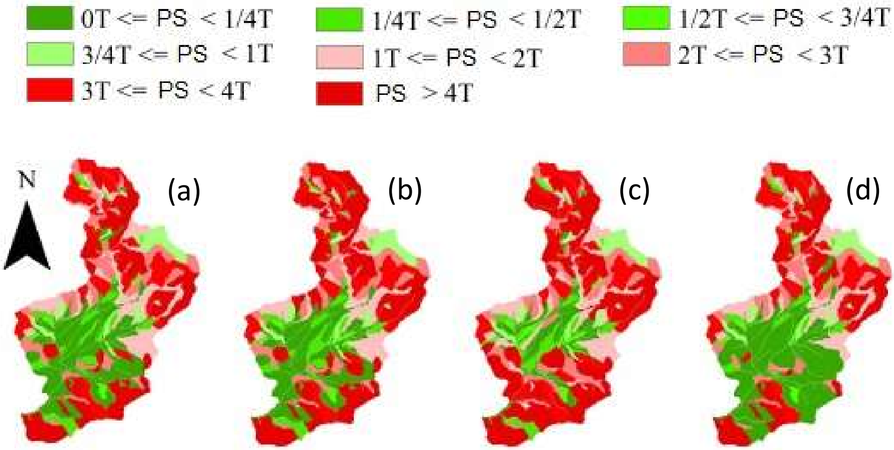


Figure 138. Examples of fragile environmental conditions in semi-arid Mediterranean basins that can be aggravated by an increase in erosion and sediment production associated with climate change: (a) the Blanca Reservoir partially filled by sediment contributions from bare hillslopes, gullies (b) and adjacent tributaries; (c) and (d) flash flood of November 1989 in the Rambla de Nogalte (Lorca), during which a large load of solids was transported (> 20% of the total discharge).

duced by around 0.85 Hm^3/year and 1.23 Hm^3/year respectively. In the period 2041-2070, contributions would continue to decrease by around 1.39 Hm^3/year for RCP 4.5 and 1.99 Hm^3/year for the RCP 8.5 scenario. According to the most unfavourable models, these reductions could reach 2.43 Hm^3/year (RCP 8.5) for the period 2071-2100 (Martínez-Salvador et al., 2021).

In the Rambla de la Azohía the effects of climate change will cause an increase in peak flows and suspended sediment loads for events projected under different future scenarios with precipitation magnitudes similar to the current ones (figure 139). Depending on the climate change scenario, peak discharges will increase between 9% (RCP 4.5) and 13% (RCP 8.5) on average, while suspended load will do so by around 12% (RCP 4.5) and 35% (RCP 8.5) (Alonso-Sarría et al, 2021) (figure 139). This increase is mainly caused by the loss of the coverage of the low scrub, which in part



Q	Qsim	Qsim	Qsim
45.5	48.9 (+7.35%)	51,8 (+13.7%)	41 (-9.95%)
PS	PSsim	PSsim	PSsim
12889	14760 (+14.5%)	18206 (+41.2%)	10265 (-20.3%)

Figure 139. Discharge (Q) (m^3/s) and sediment yield (ton) (PS) simulated using GeoWEPP for current reference scenarios (a), RCP 4.5 (b), RCP 8.5 (c) and resilience (d) in the Rambla de la Azohía Basin. Source: Alonso-Sarría et al. (2021). T = annual replacement rate of a soil type to maintain sustainable land use (1T = 11.2 t ha^{-1} $year^{-1}$, threshold above which the rate of erosion may be considered intolerable).

would be degraded due to the extreme aridification projected by the end of the 21st century, and the significant increase in the area of bare soil. A scenario of resilience, developed to mitigate the severe effects of scenarios RCP 4.5 and RCP 8.5, and an attempt to recover the previous equilibrium, through the introduction or re-establishment of plant species adapted to conditions of extreme aridity (e.g. esparto or albardin), would mean an average reduction in peak discharge and suspended load of 7% and 14%, respectively (Alonso-Sarría et al., 2021).

To better understand the extent of the impacts of climate change on SAES, it is necessary to have more information about the historical morphological adjustments of these type of ephemeral channels in response to the climatic variations in recent decades and centuries. This is undoubtedly a very complicated task due to the small number of ephemeral systems that have not been affected by human activity and the lack of interest in the analysis of their geomorphological evolution in general. Most of the studies conducted on recent morphological changes in SAES have not been able to discern between effects due to climate change and those induced by direct human action, both being addressed in an integrated way (Simon and Rinaldi, 2006; Thornes, 2009; Delong et al., 2012; Leopold et al., 2012; Villarreal et al., 2014; Norman and Niraula, 2016). It also seems clear, and this has been confirmed by various authors (e.g. Liébault and Piégay, 2002; Dufaur et al., 2015), that anthropogenic impacts on these systems are more visible and pronounced in the short term than those caused by climate change. When a SAES has reached a fragile and unstable equilibrium due to climate change in a progressive regime in the medium and long term, slight direct human interference is enough to exceed the threshold of the previous state and rapidly alter its morphodynamic features.

5.3. Initiatives and proposals for adapting to climate change

The management and restoration of ephemeral streams are very complex actions that must take into account multiple and varied aspects, such as existing and potential ecological values and benefits, economic interests and human protection against floods. This complexity is even more noticeable with the incorporation of the effects of current climate change. Among the most common drivers of the SEAS adaptation proposals to new climate scenarios, its geomorphological dynamics plays a relevant role. It should be noted that the importance of hydromorphological aspects, and especially those related to the transport of water and sediments, has already been highlighted by numerous authors in fluvial restoration programs (Brierley and Fryirs, 2005; Hebersack and Piégay, 2008; Surian et al., 2011) and is recognized in current legislation (the European Commission, 2000). However, the attention paid to the geomorphological and systemic functioning of ephemeral streams is still very limited and lacklustre. In the US there is no unanimous agreement on their definition and classification, frequently being included in the group of IRES. In ten of its States (21%) they are not regulated or, in the best case, the regulation affects a very small number of them (Zollitsch and Christie, 2014). To improve the scientific information available about ephemeral streams, various actions and initiatives have been proposed: 1) the creation of a database of projects linked to existing ones such as FAME; 2) an improvement in the flow of communication, information and participation of the different social groups involved; 3) the study of under-researched aspects, such as the adaptation of methodologies for the evaluation of environmental discharges (EED) to the case of SAES; 4) recognition and analysis of the ecogeomorphological vulnerability of these types of channels; and 5) assessment and evaluation of the ecosystemic services provided by ephemeral streams in general.

The current trend and projections for different future climate scenarios in the semi-arid Mediterranean regions show an overall decrease in precipitation and runoff, and a significant increase in the frequency of particularly heavy rainfall and large floods. Most likely, the aridification of these areas will lead to an important change in the hydrological regime of ephemeral streams, in which the long dry stages, combined with moderate to low magnitude events, and extreme floods will be more frequent, thus shortening their return periods (Conesa-García et al., 2021). Extraordinarily intense flooding events can be decisive for breaking the current morphological equilibrium of SAES, given that they will be responsible for very high rates of bedload transport and deposition, which will often lead to processes of vertical bed accretion and channel bank erosion. Steeper fall limbs and shorter hydrograph lag times in flash floods will indicate deposition of large volumes of coarse material, most likely leading to increased bed armouring rates. Examples of these processes, which will become more recurrent with climate change, are quite common in ephemeral gravel-bed channels (Hooke, 2019; Conesa-García et al., 2020). Such hydrological and morphological changes will significantly alter the ecological conditions in these channels, and particularly in their banks. The reduction in the recharging of subsurface aquifers (Meixner et al., 2016) and the impoverishment of the riparian vegetation (Stromberg et al., 2015) will be clear symptoms of this. In this regard, the restoration of SAES could include proactive measures, such as recovery of the riparian vegetation and actions that ensure the occurrence of environmental floods (Palmer et al., 2009), through the preservation of shelters (e.g. pools) in the upper and middle reaches, and the decrease in volumes of water and sediment retained and abstracted in headwater areas (e.g. by check dams) (Lake et al., 2017).

The restoration of SAES is predicted to take a long time because this is determined by the sporadic nature of floods, which are often unpredictable and of a very short duration, and quite spread out over time. The long periods required to achieve the objectives of adaptation to climate change pose serious financial problems, to which we should add the limited interest shown until now by Water Management Administrations. Mediterranean ephemeral channels (MEC) are, on the other hand, unique ecosystems, traditionally subjected to strong human pressures, and water management agents do not have enough information about their dynamics and response in the short and medium term. This lack of knowledge is even greater when we attempt to manage adaptation to the combined effects of this pressure and to climate change.

Good management and restoration practices for ephemeral streams in relation to climate change

The good practices in fluvial management and restoration that can slow down or correct the effects of climate change in ephemeral streams are mainly those that lead to stopping or inverting processes derived from it, that are altering the morphological and ecological equilibrium of such systems. In the process of adapting to climate change it is also fundamental to count on ephemeral channels that are efficient for coping with possible extreme flow events of great magnitude, and to have autochthonous vegetable species that can exercise their biomorphological functions in an appropriate way.

Among the good practices presented in Chapter 4, the following can be highlighted (Table 10) for their usefulness for adaptation to climate change and the reduction of its effects.

Table 10

Good practices in ephemeral streams with special application to adaptation to climate change

Good practice	Effects on adaptation to climate change
A. Naturalisation of the basin	– Control of erosion processes in headwater areas that cause vertical bed accretion in ephemeral streams and reduce their drainage capacity in the face of catastrophic floods. – A decrease in surface runoff and consequently the most harmful effects of floods. – Increased infiltration capacity for recharging the subalveal aquifer.
B. Naturalisation of the channel bed through the elimination of transverse barriers, fords and internal paths.	– Improve the longitudinal continuity of ephemeral channels recovering their functionality and naturalness as natural corridors. – Recover the hydromorphological processes of this type of channel during floods, such as the mobility of bed material, general transitory erosion and bedload transport by removing transverse barriers (check dams, concrete sleepers, etc.) and reducing the compaction of the bed, thus restoring its texture and natural granular structure. – Prevent geomorphological alteration processes in the channel bed due to the effects of deposition and erosion caused upstream and downstream of check dams respectively; prevent compaction and impermeabilisation of the bed because of passing vehicles, and avoid possible effects on the ecological quality of the riparian space.
	– Reduce or prevent discontinuities in the habitats of the channel and in the distribution of species. – Reduce situations of risk given the vulnerability associated with the following elements: poor anchoring of dykes and check dams, locations or designs that are inappropriate for the lithological and topographical conditions of the corrected reaches, construction of fords in relatively narrow and deep channels, and the poor condition of tracks crossing the streams.

C. Naturalisation of the banks of the channel through the removal of ripraps and coated walls	– Take away the protection on the sides of the channel (e.g. ripraps and lining walls) and allow erosion on the banks and talus, as these constitute a substantial source of sediment along the ephemeral streams. – Recover erosion processes, transport and sedimentation which affect the overall system (channel and flood plain) and reestablish natural fluvial dynamics, giving back to the main channel its capacity to migrate freely. – Increase the average width of the drainage cross-section. – Reduce the flow velocity during flooding. – Replace hard structures (works, masonry walls, cement, concrete), which prevent the nesting of bird species and the development of natural vegetation. – Decrease risks ascribable to a false sense of security. – No transferring of hazard to reaches located downstream.
D. Promote action to cushion the effects of climate change on the hydraulic regime of ephemeral streams	– Promote stream bed hydraulic conductivity and transmissivity. – Maintain the equilibrium channel profile (straight or slightly concave). – Reduce the longitudinal bed slope along reaches in headwaters. – Increase bed roughness, channel geometry and riparian vegetation. – Prevent situations of overflow and flooding due to extreme hydrological events, which will be more frequent with climate change.
E. Actions aimed at reestablishing the natural transport of sediment	– Recover continuity in transport, particularly of bedload. – Ensure hydromorphological connectivity between different channel reaches during the floods. – Reestablish the ephemeral stream's own natural morphosedimentary dynamics. – Prevent significant local variations in the bed sediment texture
F. Adaptation of drainage and communication structures to climate change	– Improve the capacity of drainage infrastructure (culverts, pontoons and bridges) to drain the waters of large floods (which are becoming more frequent with climate change). – Readapt their design and dimensions to wider channels.
	– Adopt drainage systems and road structures to minimise their effects on the channels, especially local bed scouring and the bank erosion. – Reduce or eliminate the hazard associated with road-stream crossings in high-risk points, dismantling or moving these infrastructures to other more stable and less dangerous reaches.

G. Give back the stream its natural space and generate a fluvial territory	– Increase the hydraulic channel capacity to drain predictable flood waters in accordance with IPCC forecasts. – Laminate large floods. – Facilitate both water and sediment transport during floods, which will increase according to climate change predictions.
H. Expand the fluvial zone in urban reaches and deurbanize the areas necessary to laminate the floods	– Increase the capacity of these channels to be able to handle floods. – Reduce or minimise risks coming from floods in urban centres and in the local population. – Laminate the flood waters naturally, reducing peak discharge, using the overflow itself within the fluvial space.
I. Protect ephemeral streams of high environmental value and quality	– Incorporate a significant number of non-impacted ephemeral streams to the network of fluvial reserves, which will serve as witnesses to the natural behaviours of these ecosystems in the face of climate change.
J. Monitoring and follow-up	Follow-up and supervision of pilot ephemeral streams to analyse the effectiveness or difficulty of recovery processes and, when necessary, design rectification projects.

Most of the indicators or driving factors of the "good ecological status" of MEC refer to the continuity/connectivity of geoecological processes (CCEs), the flood regime (FR) and the river productivity model (RPM). The first two types of factors have special relevance during flooding, although the second, in particular, is subject to the uncertainty of CCG projections for CPR scenarios with higher radiative forcing (RCP6.0 and RCP8.5). The RPM, however, can extend to the post-flood stage. The adaptation of these systems to more arid conditions, dominated by global geoecological adjustments associated with increasingly extreme hydrological events, requires an integrated management of the basin. The adoption of integrative measures is required, aimed at the naturalisation of the basin and its ephemeral channels (see table 10). Perhaps in the most sensitive semi-arid Mediterranean basins, where SAES have intensive human occupation and the different Administrations have promoted structural actions to defend against floods, there is a greater risk of exceeding the current dynamic equilibrium threshold. In such cases, an intensification of torrential rain events and an increase in the frequency of peak discharges above bankfull flow, associated with climate change, can profoundly alter the hydromorphological processes of the channel. Again, proactive actions seem to be the best option here to cushion these types of effects. Among the numerous proposals for prevention or proactive action, the most notable are related to: (1) the integrated planning of structural and biotechnical measures; (2) an increase in the infiltration capacity of soils (through reforestation, terraces and other soil conservation practices); (3) the naturalisation of basins and ephemeral channels; (4) the joint use of surface and groundwater; and (5) the recovery of traditional irrigation systems in marginal drylands (e.g. the diversion of flood waters using “boqueras” (stone mouths that are made in the channel to irrigate the adjacent lands), from elevation levels that ensure environmental discharge.

1) Forest hydrological correction projects carried out in these basins must incorporate studies of sustainable optimisation of the functions of the check dams, according to their effectiveness and ability to minimize possible negative impacts (bed incision, textural changes in the sediment, immobilisation of bed material, bed armouring at the foot of the check dam, the formation of pools promoting progressive erosion downstream, ...). Conesa-García et al. (2007) found an uneven behaviour and degree of effectiveness in the check dams installed in semi-arid Mediterranean basins with similar slopes, but with different lithological characteristics and distributions of hydrological soil groups. Check dams demonstrated greater effectiveness for erosion control in the headwaters of basins with a predominance of marls and gullies (e.g. the Rambla del Cárcavo, Cieza) and as aquifer recharge systems in sub-basins of metamorphic land (e.g. the Rambla de Torrecilla, Lorca). However, in the lower headwater reaches they were less efficient and even caused unwanted alterations in the channel (debris avalanche due to rupture of the check dams, over-excavation and incision downstream causing new narrower and deeper bankfull channels, pools at the foot of the structures, bed armouring due to surface washing processes, erosion furrows and spill lobes, etc.) (figures 140 and 141).

In highly erodible slopes, various authors have suggested, as an alternative to restoration and adaptive management to climate change, the installation of sustainable erosion control structures which blend in with the natural dynamics of SAES (Conesa García and Lenzi, 2013; Tosline, 2016; Norman et al. 2017): gabion and dry-stone check dams, and low elevation loose rock block dams, reinforced by biotechnical and bioengineering treatments on adjacent talus and banks. A properly planned system of such structures (which optimise their design, height and location) can have less drastic and more beneficial hydromorphological and ecological effects in many ephemeral channels, especially when the check dams are completely filled with sediment: these reduce the velocity, shear stress and energy of the flood waters, thereby also reducing overall net erosion, favoring runoff water infiltration, buffering against the downstream flood wave, retaining coarse sediment with a rapid recovery of the bedload, facilitating plant colonisation in sedimentary wedges and increasing the stability of hillslopes in gully areas.

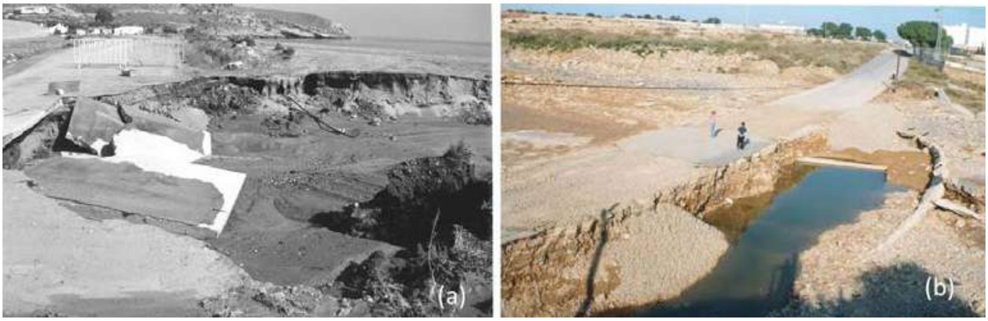
2) The naturalisation of the basin and plant recolonisation. There is a broad consensus that the best way for ephemeral streams to recover their natural morphodynamics and minimize the hydromorphological and ecological effects associated with climate change is to address forest rehabilitation and restoration activities (and vegetation cover in general) in headwaters and along areas of fluvial influence (for example, riparian sectors) (Descheemaeker et al., 2006; Nyssen et al., 2008; Frankl et al.,

Figures 140 and 141. Masonry check dams installed in the basin of the Rambla del Cárcavo in the lower (a) and middle reach (b) (Cieza), responsible for heavy surface washing, silcrete formation and bed erosion downstream.

2013; Demissie, 2016). One very effective adaptive proposal could be to increase the vegetation area, especially the forest area, and recolonise the most arid lands of the watershed with xerophilous species, which resist long periods of drought, increase infiltration and stop soil erosion (thyme, the association of rosemary, heather and other xerophilous scrubs, such as dwarf palm and buckthorn -Rhamnus lycioides-, herbaceous plants and grasses such as esparto, albardine or *brachypodium retusum*, cacti, shrubs such as broom or Nerium oleander, ...).

3) The naturalisation of the channel, eliminating road crossings and fords (figures 142 and 143), canalisation (figure 144), linning walls and ripraps for protection of banks, and transverse barriers; all of these are drastic and ineffective structural measures and do not show much respect to the natural hydrological and geomorphological functioning of gullies and *ramblas*.

4) The integrated use of surface and groundwater in ephemeral river systems is another proactive measure (table 11), that can contribute to the adaptation of their ecosystems to climate change if done in a rational and sustainable way. Within the framework of the *Scientific Workshop on the provision of environmental flows in Mediterranean ephemeral rivers,* held in Madrid in 2004, this strategy was considered crucial for achieving an adequate management of these ecosystems, being catalogued by several representatives of the Geological and Mining Institute of Spain (IGME) as a Good Management Practice (GMP) (IUCN-CMC, 2004). The assessment of changes in surface runoff rates, as a result of new climate scenarios in semi-arid basins, may serve to find out to what extent their total renewable water resources will vary, but it is not enough to support sustainable water management in these types of ecosystems. It will be necessary to take into account the impact of climate change on runoff patterns at the event scale, in terms of its effects on the flood regime and on the interconnectivity of surface and subsurface flows.



Figures 142 and 143. Examples of the destruction of fords by flooding in the Ramblas of Ramonete (Lorca) and Benipila (Cartagena). Very dangerous and vulnerable crossings, often causing hydrogeomorphological disturbances in many Mediterranean ephemeral channels.

5) Recovery of traditional irrigation practices utilising flood waters that exceed the established ecological discharge for each SAES (figure 145).

6) Raising awareness among politicians and local stakeholders about conservation actions and the sustainable management of ephemeral streams.

Figure 144. Ephemeral streams near Águilas (Murcia) with protective linning walls for greenhouses (a, b and c) located in the floodplain (even in the active channel), with narrowed channel reaches (a and b), promoting vertical bed accretion processes (d, e and f).

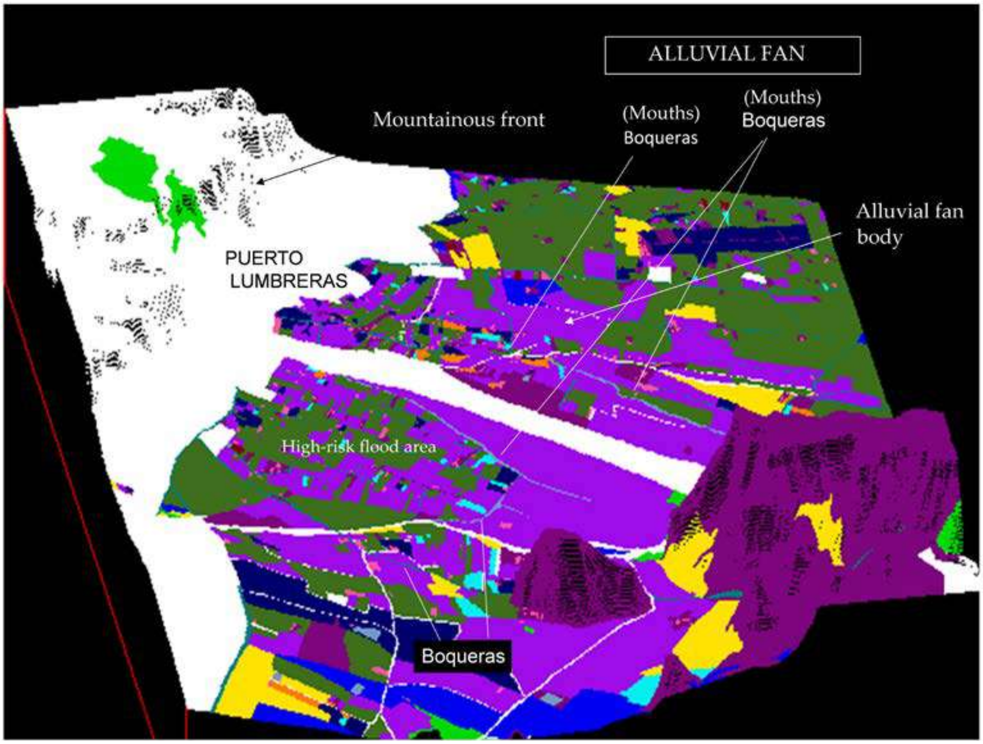


Figure 145. Example of the derivation of flood waters through the use of mouths (locally called "*boqueras*") after water drafts that ensure environmental discharge and recovery of traditional irrigation systems in dry lands. System for utilising flood waters through *boqueras* in the Rambla de Nogalte (Province of Murcia). It was traditionally a flood lamination system which formed a network of mouths and canals for distribution and irrigation in wide surfaces of the alluvial fan through which the main ephemeral stream runs.

Table 11

Areas of action and aspects connected to geomorphological management – ecological adaptations of ephemeral channels to climate change.

Areas of proactive action	Aspects involved in the adaptive management of ephemeral streams to climate change
Surface runoff regime	– Regime of the floods (volume, frequency, duration, peak discharges, ...). – Timescale effects (short, medium and long term). – Spatial scale effects (overall river system, main channel, reference reach, drainage network, ...). – Effects associated with future climate scenarios. – Behaviour and dynamics of the pools during the flooding. – Critical flow thresholds affecting the processes of regeneration and conservation of the vegetation cover in the channel.
Interaction of surface and sub-surface waters	– Changes in the infiltration capacity of bed materials (permeability). – Balance of water losses due to hydraulic transmissivity (especially in ephemeral gravel-bed streams). – Space-time variations in bed material texture. – Duration of flooding events and recharge times. – Effectiveness of transverse structures and other measures of action on the channel (e.g. biotechnical or bio-engineering) for the recharge of aquifers.
Geoecological aspects	– Hydraulic geometry in ordinary and extraordinary floods. – Characteristic morphosedimentary units (types, features and distribution). – Net and total sediment fluxes. – Nutrient dynamics. – Permeability of the bed.
Climatic conditions	– Change in rainfall regime. – Decrease in average annual rainfall and increase in the frequency of especially heavy rainfall. – Implications arising from increased temperature and evapotranspiration. – Increase in thermal anomalies (more intense and lasting heat waves).
Other environmental conditions of the slope area (present and potentially adaptive)	– Land use policies, management practices and cultivation techniques. – Hydrological soil response. – Soil erodibility (geotechnical properties). – Slope energy.

	– Density and structure of the current vegetation cover and its foreseeable evolution, according to modalities of adaptation to different climate change scenarios. – Sustainable agricultural planning (adaptability of agricultural and irrigated areas, sustainable exploitation of water resources in line with forecasts of greater climatic aridity).
Flood flows and hydromorphological effects	– Magnitude and frequency of floods as being primarily responsible for morphological changes and erosion/sedimentation balance in MEC and SAES. Major events cause overall morphological adjustments and mobilise all the material from the bed. The moderate and smaller ones (sub-bankfull discharges) redistribute the sediment, even causing local or general incision. – Flood hazard and mitigation, adaptation and protection strategies.
Status of the quality of flood waters	– Degree of turbidity (suspended sediment load) of the flood waters. – Nutrient fluxes. – Influence of the spills to the channels. Ephemeral streams are more vulnerable because they have less water to dilute pollutants (during large floods they can be displaced in high concentrations quickly, reaching the sea in the case of coastal streams).
Riparian vegetation	– Habitat conditions (bank profile, texture and structure of deposits and rocks on the banks, degree of submersion of vegetation during floods with different depth and frequency ...). – Longitudinal source of nutrients, with losses in spatial continuity, which can be increased under more arid conditions simulated by moderate and extreme radiative forcings.
Human action on ephemeral channels and their flood zones	Actions and policies of environmental sensitivity and sustainable management / restoration practices, aimed at cushioning the impacts of climate change, addressing, as a proactive measure, the following problems: – Alterations in the hydrological and hydraulic regime, whose effects will be aggravated by climate change (e.g. those produced by inappropriate dams and diversions of surface waters, or by extractions of groundwater and subsurface water, which cause sudden ruptures in the natural dynamics of ephemeral streams). – Invasion of the functional space of the flood waters with the consequent loss of their laminating capacity. – Human interference in the natural dynamics of erosion, transport and sedimentation processes (erosion control structures and sediment retention). – Increase in the degree of vulnerability and fragility of ephemeral fluvial ecosystems during increasingly prolonged periods of drought and more frequent extreme floods (flash flood type).

	– Harmful environmental effects related to excessive economic and demographic development (waste discharges, aquifer pollution, etc.)

Table drawn up from the technical reports of the IUCN-CMC (2004) and Magand (coord., 2020) and results of the RIFLUTME (2011-2013) and CCAMICEM (2018-2021) projects..

Regulatory framework and initiatives at European level

There are different European directives and international initiatives on environmental protection and sustainability of water resources, which include among their objectives the protection and management of IRES. However, within this regulatory framework, very little mention is made of ephemeral runoff systems, and there are hardly any specific guidelines that promote the evaluation of their ecological and hydromorphological quality.

The Water Framework Directive, Directive 2000/60/EC of the European Parliament and Council of 23 October 2000, establishes a framework for action for the European Community in the field of water planning and management. This Directive calls on Member States (MS) to assess and improve the ecological status of IRES, but this possibility is not contemplated for SAES. The fragility of the IRES has recently been recognized in the wake of emerging global changes caused by climate change. (Magand, coord., 2020). The particular regime of temporary rivers, their extensive presence in the EU and future climate change scenarios make it advisable to adapt current biomonitoring methods and develop new instruments to promote an effective and reliable assessment of their ecological status.

The Floods Directive, Directive 2007/60/EC of the European Parliament and Council of 23 October, urges member states to identify areas at risk of flooding, to draw up the corresponding flood hazard maps and to develop flood hazard management plans based on the prevention, protection and programming of action strategies. These areas include the SAES, which play a very noticeable role in the generation of large floods within hydrological areas of the Mediterranean. The sporadic and unpredictable operation of the SAES, the dry state of their channels for long periods and lack of knowledge about the limits of lamination of its flood waters usually mean that the population very much underestimates their dangerousness. This lack of perception is often accompanied by an intense and inadequate human occupation of the space required by the SAES for their natural self-management, which leads to high-risk situations. Given this problem, it is therefore advisable to delimit and protect the functional space of these systems in their global dimension, trying to respect the width of the channel and the floodplain that is necessary to absorb the effects of more intense and frequent floods foreseen due to climate change. Where the road inter-

Figure 146. Local road crossing the Rambla de la Azohía (municipality of Cartagena). The culvert-type drainage system, located in this and in so many other road crossings with gravel-bed streams, will have to adapt to the increase in bedload expected for future scenarios of climate change.

sects with streams, for example, the channel must be wide enough to evacuate flood water, and road and drainage infrastructures will have to adapt to the new hydrological conditions (Conesa-García et al., 2013, 2014, 2017) (figure 146). In many of these flood-prone hotspots, existing infrastructure does not improve the resilience of the affected sections, and it will be necessary to readapt their design and dimensions, or, in the most vulnerable cases, dismantle them and move them to other more stable and less dangerous sections.

The European Strategies on Adaptation to Climate Change (EEACC) is another important initiative to improve the resilience of the European territory in general, and of IRES and SAES in particular, in the face of the increasing risk of flooding. These are adaptation strategies and plans based on three transversal priorities: (1) integrating adaptation into **macro budgetary policy; (2)** nature-based solutions for adaptation; and (3) local adaptation **measures.** Climate change is expected to significantly modify the hydrological cycle in watercourses (permanent, seasonal and ephemeral), especially in Mediterranean and semi-arid basins, where current global-scale models foresee significant changes in precipitation and temperature patterns (an increased temporal rainfall variability and an increased frequency of extreme weather events, such as supra-seasonal floods and droughts) (Hisdal et al., 2001; Döll and Zhang, 2010; Schneider et al., 2013). Regime changes between intermittent and ephemeral regimes have a strong impact on habitat conditions for biota, with a particular impact on their ecosystemic services. This is a problem that is estimated to affect more than 6% of the world's land area by 2050, mainly in semi-arid regions (Magand, coord., 2020). Strategies proposed by the European Commission include facilitating LIFE funding to improve capacity and accelerate adaptation measures in Europe (2014-2020). In particular, it will promote adaptation in vulnerable areas (transboundary flood management, sustainable water management and combating desertification in drought-prone areas) and promote measures to raise awareness about adaptation.

Conclusions

Ephemeral streams are widely represented in the Mediterranean river networks of southern Europe. Their enhancement, conservation and restoration constitute one of the most relevant environmental challenges of the twenty-first century. But the possibilities of achieving restoration actions for ephemeral channels are currently very scarce in the Mediterranean region. Probably the only area of support will be the initiative of specific people from scientific or technical fields and at a local level, since at a social and general management level there is an overwhelming absence of interest, lack of specific figures, budgets and many practical difficulties.

The underestimation of the value and role played by ephemeral streams extends to researchers and managers as well. Little research effort has been given over to knowing and informing about the natural values and contributions of these ecosystems to human well-being. Only recently have some methods appeared to be able to monitor and evaluate the ecological quality of these ecosystems, which are necessary to promote laws and develop policies for their conservation and the mitigation of the impacts they suffer.

In addition, even more markedly than other fluvial systems, ephemeral streams must base their recovery on the functionality and naturalness of geomorphological processes. This study guide has highlighted this problem, has laid some foundations and proposed measures as lines of action that should be followed.

Ephemeral streams are excellent indicators of climate and global change. The widespread processes of narrowing, simplification and incision that the entire river network undergoes are also clearly manifested in these fluvial systems. But also in semi-arid regions, there are symptoms of climate change: for example, the intensification of the processes of physical weathering and production of coarse sediments on increasingly arid slopes, and bed armouring processes, associated with an increase in the bedload, in these types of channels, which will tend to widen through lateral erosion (African wadi type channels). Good river management and restoration practices can slow down and correct these effects. In adapting to climate change, it is essential to have efficient channels in the face of possible extreme weather events of great magnitude, as well as native plant species that adequately exercise their biogeomorphological functions.

It would be key and necessary to achieve a first restoration action from national and regional administration to serve as an example of a demonstration and especially provide a source of social awareness about the value of these watercourses, their problems and their functionality in nature and on the land.

From a scientific point of view, different research projects coexist that are not isolated, but collaborate and transfer knowledge and experience with each other. It is necessary to maintain scientific discussion between the different projects in order to establish a systematic and homogeneous base and then be able to compare the results and join forces when making more robust proposals. The current decade, in a complex environmental context in which adaptation to climate change is already of the utmost urgency, is a key period for laying these foundations and consolidating a scientific, technical and social path that definitively values ephemeral streams, preserving those that are in good condition, reducing pressures and impacts, recovering the deteriorated ones, involving public administrations in their care and sustainable management, and continuously monitoring their operation and evolution in terms of climate and environmental changes.

Glossary

Alluvial. Refers to environments dominated by detrital material transported and deposited by river dynamics (alluvium). An alluvial river is one that flows through sediments that are constantly eroded and deposited by the river itself. The channel pattern in this type of river does not reflect significant lithological controls due to rocky outcrops, so its morphology depends on the balance between its erosive capacity and the resistance of the alluvial bed and banks.

Bankfull discharge. Discharge corresponding to the main channel filled, therefore, that which is prior to the threshold of overflow on the floodplain. It is closely related to geomorphic discharge, that is, having the maximum capacity to transport solid load and modify banks and the channel bed. It is also known as "formative or dominant discharge".

Base flow. This is the technical name for the dry weather flow in a stream or river. River base flow results from ground water seeping into riverbanks or the riverbed. The flow may be significant enough to allow the stream to flow year round (i.e., perennial or permanent stream). Without base flow recharge from ground water to streams and rivers, many would not carry a flow of water except during storms. Streams that flow only periodically in response to rainstorms or seasonal snowmelt events are known as ephemeral or intermittent streams.

Breakwaters. A protective structure of stone or concrete which are used to manage the forces of the flow upon the channel banks. In rivers and streams, they are usually designed to protect their banks from erosion and modify the channel geometry, promoting incision in the central part and deposition on the lateral sides.

Canalisation / decanalisation. A rigid structure that transforms the natural channel into a canal with a uniform section. Decanalisation is the process of removing the rigid structure so that the river recovers its erosive-sedimentary dynamics.

Channel. A morphological unit in charge of transporting the liquid and solid discharge of the river system. Its dimensions are designed to fulfill this function with maximum efficiency. Topographically it has clear boundaries defined by different width-to-depth ratios. It can take very different patterns and planforms (straight, sinuous, meandering, braided, single or multiple, etc.). According to their dimensions and water level, two types of channels are commonly differentiated: a minor channel, through which low waters flow, and the main channel, which is capable of draining high waters without overflowing.

Channelling. Type of action on the fluvial channel aimed at maintaining the watercourse within limits in a more or less rigid way. Its objective is the protection of the surrounding lands susceptible to flooding. In most cases, the channel bed remains natural and the banks stabilised.

Check dam. A dam transverse to the flow, used for sediment retention. During the twentieth century it was a very common structure, especially as a measure of accompaniment to the actions of reforestation and in the fight against erosion. Its effectiveness in reducing torrentiality in floods has been very low, but, nevertheless, they have generated significant sedimentary deficits downstream.

Discharge (liquid and solid). Liquid discharge (Q) (m^3/s) is the volume of water carried by a river in a particular place and time. It is a product of the velocity (m/s) multiplied by the cross-sectional flow area (m^2). The total volume of water contributed by a river in a given period of time is called a contribution. Solid discharge (Q_s) (m^3/s) refers to the amount of sediment that a river carries in a specific place and time, while unit solid discharge (q_s) (m^2/s) is defined as the volume of solid material passing a channel cross-section per unit of time (s) and width (m).

Flash flood. The sporadic and sudden surface flow produced in ephemeral streams or channels which usually have a dry bed; it can reach a significant peak discharge, overflow its main channel and cause flooding in adjacent areas. It is often characterized by a hydrograph of very short duration and base time, with especially fast rising and falling phases, which can generate energetic flows during strong and intense storms.

Flooding. Phenomenon whereby the flow over tops the main channel boundaries (above bankfull discharge) spreading over the floodplain. This is a totally necessary hydrological process in which large environmental changes occur that subject the system to a dynamic equilibrium. The increase in stream power associated with a flood causes the resistance thresholds to be exceeded. The transport of gravels and pebbles in the main channel is joined by the deposition of large amounts of fine sediment in the floodplain, and, consequently, geomorphic activity increases and overall morphological adjustments occur that affect the entire fluvial system.

Deurbanisation. A process by which urban instalations and activities are removed, which often implies the gradual elimination of obstacles (anthropogenic elements), that currently offer no use. Its presence affects the ecological quality of the river to different degrees.

Drainage. Evacuation of the discharge through the channel or structures enabled for it at road-stream crossings. It depends on the dimensions and hydraulic characteristics of the passage cross-section, such as width, depth, slope or roughness. Since the river is a self-built element to transport the liquid and solid flow with maximum efficiency, its drainage section is perfectly designed to fulfill this task. The high stream power expenditure during floods can mean changes in channel geometry; however, it is the river itself that is readjusted to remain efficient in the evacuation of water and sediment. On the contrary, the so-called "river sediment cleanups", based on the false myth that the natural accumulation of sediments harms the river and increases overflows, involves an aggressive modification in the drainage cross-section and a breakdown of the river's equilibrium.

Dredging. Action of removal of sediments from the riverbed in order to increase its depth and drainage capacity. It is one of the most widespread actions in so-called "river cleaning", being totally inefficient for the purposes that are proposed and with a high cost for the taxpayer.

Fluvial territory. Space belonging to the river, including the channel, riparian corridor and the floodplain, either totally or partially. It is a geomorphological and ecologically active band, of maximum efficiency and complexity as a natural system. It is, in short, a space to be reclaimed, although it usually clashes with socio-economic interests, since it must be wide, continuous, floodable, erodible, not defended and not building land.

Ford. Area of a channel enabled for the passage of people and vehicles (usually agricultural). They are usually firm-bottomed, flat and shallow. Many ford crossings are passage ways using rock or concrete, generally set at or near bed level to maintain natural flow velocities. Natural stream "cross overs" or riffles are often selected as fords.

Geomorphic. Everything related to the (geo)processes and (geo)forms that generate a landscape. The term derives from geomorphology, a science responsible for studying the processes of erosion, transport and sedimentation that occur on the earth's surface, as well as the forms derived from such processes. In fluvial studies, geomorphic aspects are studied as a part of general morphology (channel planform and longitudinal profile) and local morphology, which includes geometry of the channel (width, depth, width-depth ratio, bankfull dimensions ...), bedforms (riffles, runs, pools ...), in relation to hydraulic characteristics (hydraulic radius, water slope, bed roughness ...), and sediment properties (texture, mainly grain-size distribution, and sedimentary structure).

Improvement. A type of action focused on the environmental recovery of some aspect of the river, but not on its whole recovery as a system. An example of improvement can be the creation of fish passages to encourage crossing of the river, thereby optimising the mobility of the fish fauna on its longitudinal route.

IRES (Intermittent Rivers and Ephemeral Streams). A type of fluvial system characterized by flow intermittency patterns and unique ecological conditions. They abound especially in arid, semi-arid and Mediterranean regions, but are also present in humid areas, together draining more than half of the Earth's surface. Their ecology and ecosystem services are little known, which shows a general lack of appreciation and undervaluation by society.

Maintenance. Measures and actions aimed at preserving in certain conditions what has been done by some type of previous action on the river. Many of the maintenance actions are related to those known as "emergency works", that is, actions applied immediately after a flood and that, in general, are done with some haste to repair damaged infrastructures and defences or increase (temporarily) the drainage section.

Management. A theoretical framework that establishes the guidelines that a process must adopt to achieve the previously defined objectives. It is, therefore, any initiative or project with the capacity to intervene in the river. Even granting a "non-use" use (conservation) is applying a type of management. As a society we have the ability to decide how we want our rivers to be and that is management, regardless of whether or not this management involves intervention. A restoration plan or a proposal of improvement measures are examples of management.

Meander cutoff. A geomorphological process that involves a change of route of the channel. It is a rapid process that occurs when the flow seeks a shorter path with a greater slope downstream. The cutoff usually occurs in the narrowest part of the meander lobes, leaving the rest of the bend disconnected, so that a new type of fluvial habitat is formed. The steeper drop in bed slope causes the flow gradually to abandon the meander which will silt up with sediment from deposition. This type of natural process leaves an imprint of considerable revitalization of bank erosion while the river reaches the equilibrium of its new sinuous route. Artificial meander cutoff is also carried out for anthropogenic reasons, usually to gain space for other uses (e.g., livestock, agricultural, industrial) or as a protective measure.

Monitoring. A systematic process of collecting and analysing data from a natural system to monitor a process and justify decision-making in management. Monitoring should be carried out from the beginning of the program and continue throughout the implementation period, as well as after it is over. Ideally, monitoring should also be carried out before the execution of a project to know the characteristics of the system prior to the application of measures.

Naturalisation. A type of river recovery based on a partial improvement of the river. It is based on the elimination or reduction to the minimum level possible of anthropogenic pressures that deteriorate the good ecological status of the river. As human activities and associated infrastructures lose prominence to the detriment of the river, these will be naturalised. Currently, along the same lines, the term *rewilding* is gaining prominence.

Rapid flow-level rise. Abundant and intense rains, combined or not with melting snow waters, can produce a significant and sudden increase in the discharge and raise the water level beyond the banfull stage, flooding the land surrounding the main channel. The flow-level rise always occurs from a base flow. When river levels rise quickly, for example in response to a storm, hydraulic radius, water velocity, shear stress and stream power also increase in a short time.

Restoration. It refers to all those actions aimed at recovering the natural and self-sustaining dynamics of a system starting with the elimination of the pressures and impacts that afflict and degrade it. It is a long-term process in time and difficult to achieve in its entirety.

Regime. Behavior of the average monthly discharge of a river throughout the year. It is mainly regulated by the precipitation regime, but also by the temperature, the physiography of the basin (especially the slopes), the different soil types and the presence of aquifers, vegetation and human activity. The extreme stages of the fluvial regime correspond to floods and minimum discharges (dry bed in ephemeral streams), while the module represents a constant average discharge for the whole year.

Rehabilitation. Set of restorative measures aimed at improving the fluvial dynamics, but without being able to achieve total recovery of the river.

Resilience. Capacity of the river system to absorb disturbances and maintain or recover its structural and functional characteristics, thus being able to return to the situation prior to the disturbance once it ceases.

Revegetation. Measures aimed at restoring the vegetation cover of a sector whose native formations have become degraded.

Riprap. A permanent, erosion-resistant ground cover of large, loose, angular stone. Its main purpose is to protect slopes, streambanks, channels, or areas subject to erosion due to concentrated runoff. Frequently ripraps of rocks or other materials are used to shore up an embankment, reinforce the base of erodible channel banks, and ultimately deter or prevent erosion in rivers, including ephemeral streams.

Risk. Possibility that a territory and the society that inhabits it might be affected by a phenomenon of sporadic occurrence. It is an anthropogenic concept, since there is no risk without human presence. In mathematical terms it can be expressed as the multiplication of natural hazard by exposure and vulnerability.

SAES (Semi-Arid Ephemeral Streams). As part of IRES, SAES are the specific class of ephemeral streams typical in semi-arid environments. This guide focuses especially on SAES. Bear in mind that, for example, there are ephemeral high mountain streams, such as some torrents, which are not SAES, because they do not have a semi-arid climate.

SBN (Solutions based on nature). A theoretical approach that uses the principles of nature to respond to challenges for society such as climate change, disaster risk or food security. Based on planning and conservation principles, it involves the integration of humans and the environment to achieve development in balance with the ecosystems and the services they provide.

Weir. A barrier built to raise the water level of the river in order to derive part of the discharge for some specific use (e.g., irrigating, hydroelectric production). The size of these transverse structures is usually smaller than dams and reservoirs.

References

Alonso-Sarría, F., Vidal-Abarca, M.R., Martínez-Salvador, A., Conesa-García, C., Suárez, M.L., Pérez-Cutillas, P., Gomáriz-Castillo, F.J. (2021) Effects of vegetation as an ecosystem service on the changes in runoff and sediment yield in a Mediterranean semi-arid basin, *EGU General Assembly 2021*, Göttingen, Germany.

Arce, M.I., Sánchez-Montoya, M.M., Vidal-Abarca, M.R., Suárez, M.L., Gómez, R. (2014) Implications of flow intermittency on sediment nitrogen availability and processing rates in a Mediterranean head water stream. *Aquatic Sciences*, 76: 173-186.

Arce, M.I., Sánchez-Montoya, M.M., Gómez, R. (2015) Nitrogen processing following experimental sediment rewetting in isolated pools in an agricultural stream of a semiarid region. *Ecological Engineering*, 77: 233-241.

Arce, M.I., Mendoza-Lera, C., Almagro, M., Catalan, N., Romani, A.M., Marti, E., Gomez, R., Bernal, S., Foulquier, A., Mutz, M., Marcé, R., Zoppini, A., Gionchetta, G., Weigelhofer, G., del Campo, R., Robinson, C.T., Gilmer, A., Rulik, M., Von Schiller, D. (2019) A conceptual framework for understanding the biogeochemistry of dry riverbeds through the lens of soil science. *Earth-Science Reviews*, 188: 441-453.

Baker, V.R. (1977) Stream–channel response to floods, with examples from central Texas. *Geological Society of America Bulletin,* 88(8): 1057–1071.

Ballarín, D., Mora, D. (2018) *Evaluación del estado hidrogeomorfológico en los rîos efímeros de la CHJ.* Confederación Hidrográfica del Júcar.

Bedford, D., Macias, M., Miller, D.M., Newlander, A., Perkins, K.S., Sandquist, D.R., Schwinning, S. (2011) Ecohydrologic function and disturbance of desert ephemeral stream channels. *American Geophysical Union, Fall Meeting 2011*, abstract #B24C-07.

Benito, G., Sanchez Moya, Y., Medialdea, A., Barriendos, M., Calle, M., Rico, M., Sopeña, A., Machado, M.J. (2020) Extreme floods in small mediterranean catchments: long-term response to climate variability and change. *Water*, 12, 1008; doi:10.3390/w12041008.

Betancourt, J. (2007) Climate variability and change in the Southwest. In *Proceedings from the Southwest Region Threatened, Endangered, and At-Risk Species Workshop,* 22-25 October 2007, Tucson, Arizona. Prepared for the Legacy Resource Management Program, Strategic Environmental Research and Development Program, and Environmental Security Technology Certification Program by HydroGeo-Logic, Inc., Reston, Virginia.

Bishop, K., Buffam, I., Erlandsson, M., Folster, J., Laudon, H., Seibert, J., Temnerud, T. (2008) Aqua Incognita: the unknown headwaters. *Hydrological Processes*, 22: 1239-1242.

Boyer, C., Verhaar, P.M., Roy, A.G., et al. (2010) Impacts of environmental changes on the hydrology and sedimentary processes at the confluence of St. Lawrence tributaries: Potential effects on fluvial ecosystems. *Hydrobiologia,* 647(1): 163–183.

Brady, L.M., Gray, F., Wissler, C., Guertin, D.P. (2001) Spatial variability of sediment erosion processes using GIS analysis within watersheds in a historically mined region, Patagonia Mountains, Arizona. *U.S. Geol. Surv. Open File* Rep.:01–267 (Retrieved from). http://geopubs.wr.usgs.gov/open-file/of01-267/.

Brewer, P.A., Lewin J. (1998) Planform cyclicity in an unstable reach: complex fluvial response to environmental change. *Earth Surface Processes and Landforms*, 23: 989-1008.

Brierley, G.J., Fryirs K.A. (2005) *Geomorphology and River Management. Applications of the River Styles Framework*. Blackwell Publishing, Oxford.

Brooks, R.T. (2009) Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems of the forests of the northeastern United States. *Climatic Change,* 95: 469–483.

Bull, W.B. (1991) *Geomorphic Responses to Climatic Change*. Caldwell, NJ, Blackburn Press.

Bull, W.B. (1997) Discontinuous ephemeral streams: *Geomorphology,* 19: 227–276.

Bull, W. B. (2007) *Tectonic geomorphology of mountains: a new approach to paleoseismology*. Blackwell, Oxford.

Busch, M.H., Costigan, K.H., Fritz, K.M., Datry, T., Krabbenhoft, C.A., Hammond, J.C., Zimmer, M., Olden, J.D., Burrows, R.M., Dodds, W.K., Boersma, K.S., Shanafield, M., Kampf, S.K., Mims, M.C., Bogan, M.T., Ward, A.S., Pérez Rocha, M., Godsey, S., Allen, G.H., Blaszczak, J.R., Jones, C.N., Allen, D.C. (2020) What's in a name? Patterns, trends, and suggestions for defining non–perennial rivers and streams. *Water,* 12, doi:10.3390/w12071980

Calle, M. (2018) *Morphosedimentary dynamics of ephemeral rivers affected by gravel mining: GIS mapping and geomorphic change detection.* PhD Thesis, Universidad Complutense de Madrid.

Calle, M., Alho, P., Benito, G. (2017) Channel dynamics and geomorphic resilience in an ephemeral mediterranean river affected by gravel mining. *Geomorphology,* 285: 333-346.

Camarasa, A.M. (1992) *Génesis de crecidas en pequeñas cuencas semiáridas: Barranc del Carraixet y Rambla de Poyo.* Universitat de València.

Camarasa, A.M. (2021) Flash–flooding of ephemeral streams in the context of climate change. *Cuadernos de Investigación Geográfica,* 47, doi 10.18172/cig.4838

CCAMICEM (2018-2021) Proyecto coordinado *"Respuesta morfológica y sistémica al cambio climático en cauces efímeros mediterráneos: dinámica, resiliencia y propuestas de actuación"*. Referencia CGL2017-84625-C2-1-R, Proyecto financiado por FEDER, Ministerio de Ciencia, Innovación y Universidades, Agencia estatal de Investigación (AEI). Programa Estatal de Investigación, Desarrollo e Innovación Orientada a los Retos de la Sociedad.

CEDEX (2012) Estudio de los impactos del cambio climático en los recursos hídricos y las Masas de Agua. Efecto del cambio climático en los recursos hídricos disponibles en los sistemas de explotación. Disponible en http://www.magrama.gob.es/es/agua/temas/planificacionhidrologica/ImpactoCCSistemasExplotacion_tcm7-310164.pdf

Charlton, R. (2008) *Fundamentals of fluvial geomorphology.* Routledge, New York.

Chin, A., Gregory, K.J. (2001) Urbanization and adjustment of ephemeral stream channels. *Annals of the Association of American Geographers*, 91 (4): 595–608.

Conesa-García, C. (1990) *El Campo de Cartagena: clima e hidrología de un medio semiárido.* Ayuntamiento de Murcia.

Conesa-García, C. (2005) Les 'ramblas' du Sud-Est espagnol: systèmes hydromorphologiques en milieu méditérranéen sec. *Zeitschrift für Geomorphologie,* 49(2): 205-224.

Conesa-García, C., López Bermúdez, F., García Lorenzo, R. (2007) Bed stability variations after check dam construction in torrential channels (South-East Spain). *Earth Surface Processes and Landforms,* 32: 2165-2184.

Conesa-García, C., García Lorenzo, R. (2009) Bed texture changes caused by check dams on ephemeral channels in mediterranean semiarid environments. *Zeitschrift für Geomorphologie,* 52(4): 437-461.

Conesa-García, C., García-Lorenzo, R. (2013) Evaluating the effectiveness of road-crossing drainage culverts *in ephemeral streams*. *Hydrological Processes*, 27(12): 1781-1796. Doi: 10.1002/hyp.9335.

Conesa-García, C., Lenzi, M.A. (Eds., 2013) *Check Dams, Morphological Adjustments and Erosion Control in Torrential Streams*. Collection 'Environmental Science, Engineering and Technology'. Nova Science Publishers, New York, 339 pp.

Conesa-García, C., García Lorenzo, R. (2014) Flood hazard assessment for bridge crossings over ephemeral channels: a case study of the Murcia coast (SE Spain). *Cuadernos de Investigación Geográfica,* 40(1): 119-146.

Conesa-García, C., Pérez-Cutillas, P. (2014) Alteraciones geomorfológicas recientes en los sistemas fluviales mediterráneos de la Península Ibérica. Síntomas y problemas de incisión de los cauces. *Revista de Geografía Norte Grande,* 59: 25-44.

Conesa-García, C., García Lorenzo, R., Pérez-Cutillas, P. (2017) Flood hazards at ford stream crossings on ephemeral channels (south-east coast of Spain). *Hydrological Processes,* 31: 731-749.

Conesa-García, C., Pérez-Cutillas, P., García-Lorenzo, R., Eekhout, J., Gómez-Gutiérrez, A., Millares, A., Martínez-Salvador, A. (2020a) Dimensionless morphological ratios versus stream power variations at bankfull stage in an ephemeral channel. *Geomorphology,* 361, doi: 10.1016/j.geomorph.2020.1071.

Conesa-García, C., Puig-Mengual, C., Riquelme, A., Tomás, R., Martínez-Capel, F., García-Lorenzo, R., Pastor, J.L., Pérez-Cutillas, P., Cano González, M. (2020b) Combining SfM photogrammetry and terrestrial laser scanning to assess event-scale sediment budgets along a gravel-bed ephemeral stream. Remote Sensing, 12. 3624. Doi 10.3390/rs12213624.

Conesa-García, C., Martínez-Salvador, A., Martínez-Capel, F., PuigMengual, C., Pérez-Cutillas, P., Zema, D.A., Bombino, G. (2021) GeoWEPP model, high-resolution 3D models and groundbased survey to detect sedimentation changes and morphological adjustments in an ephemeral stream, EGU General Assembly 2021, Göttingen.

Conesa-García, C., Riquelme, A., Puig-Mengual, C., Martínez-Capel, F., Tomás, R., García-Lorenzo, R., Cano González, M., Pérez-Cutillas, P., Pastor, J.L. (2021) Relationships between changes in stream power, flow competence and bed elevation along a gravel-bed ephemeral stream monitored from high-resolution 3D models. *34 th International Geographical Congress,* 16 -20 August 2021, Istanbul.

Coulthard, T.J., Macklin, M.G. (2001) How sensitive are river systems to climate and land-use changes? A model-based evaluation. *Journal of Quaternary Science,* 16(4): 347–351.

Dankers, R., Feyen, L. (2008) Climate change impact on flood hazard in Europe: An assessment based on high- resolution climate simulations. *Journal of Geophysical Research*, 113(D19): D19105.

Datry, T., Singer, G., Sauquet, E., Jordá-Capdevilla, D., Von Schiller, D., Subbington, R., Magand, C., Pařil, P., Miliša, M., Acuña, V., Alves, M., Augeard, B., Brunke, M., Cid, N., Csabai, Z., England, J., Froebrich, J., Koundouri, P., Lamouroux, N., Martî, E., Morais, M., Munné, A., Mutz, M., Pesic, V., Previšić, A., Reynaud, A., Robinson, C., Sadler, J., Skoulikidis, N., Terrier, B., Tockner, K., Vesely, D., Zoppini, A. (2017) Science and management of intermittent rivers and ephemeral streams (SMIRES). *Research Ideas and Outcomes,* 3: e21774. doi 10.3897/rio.3.e21774.

Dean, D.J., Topping, D.J., Schmidt, J.C., Griffiths, R.E., Sabol, T.A. (2016) Sediment supply versus local hydraulic controls on sediment transport and storage in a river with large sediment loads. *J. Geophys. Res. Earth Surf.* (Retrieved from). http://onlinelibrary.wiley.com/ doi/10.1002/2015JF003436/full.

DeLong, S.B., Prentice, C.S., Hilley, G.E., Ebert, Y. (2012) Multitemporal ALSM change detection, sediment delivery, and process mapping at an active earthflow. *Earth Surface Processes and Landf*prms, 37(3): 262–272.

Deltoro, V., Jiménez, J., Vilán, X.M. (2012) *Bases para el manejo y control de Arundo donax L. (caña común).* Conselleria d'Infraestructures, Territori i Medi Ambient. Generalitat Valenciana. Valencia.

Demissie, B. (2016) Ephemeral stream dynamics, land cover changes and climate variability in the marginal grabens of the northern Ethiopian Rift Valley. *Afrika Focus*, 29(2): 93-100

Descheemaeker K, Nyssen J, Poesen J, Raes D, Mitiku H, Muys B, Deckers S. (2006) Runoff on slopes with restoring vegetation: A case study from the Tigray highlands, Ethiopia. *Journal of Hydrology.* 331: 219-241.

Döll, P., Zhang, J. (2010) Impact of climate change on freshwater ecosystems: a globalscale analysis of ecologically relevant river flow alterations. Hydrology and Earth System Sciences, 14, 783–799.

Dollar E.S.J., James, C.S., Rogers, K.H., Thoms, M.C. (2007) A framework 592 for interdisciplinary understanding of rivers as ecosystems. *Geomorphology*, 89: 147-162.

Domenech, S., Ollero, A., Sánchez Fabre, M. (2008) Núcleos de población en riesgo de inundación fluvial en Aragón: diagnóstico y evaluación para la ordenación del territorio. *Geographicalia,* 54: 17-44.

Dufour, S., Piégay, H. (2009) From the myth of a lost paradise to targeted river restoration: forget natural references and focus on human benefits. *River Research and Applications,* 25: 568-581.

Dufour, S., Rinaldi, M., Piégay, H., Michalon, A. (2015) How do river dynamics and human influences affect the landscape pattern of fluvial corridors? Lessons from the 743 Magra River, Central-Norther Italy. *Landscape and Urban Planning,* 134: 107–118.

Elosegi, A, Sabater, S. (2013) Effects of hydromorphological impacts on river ecosystem functioning: a review and suggestions for assessing ecological impacts. *Hydrobiologia,* 712: 129-143.

European Commission (2000) *Directive 2000/60 EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. Official Journal L 327, 22/12/2000, 73 pp.

Ferrer-Boix, C., Chartrand, S.M., Hassan, M.A., Martín-Vide, J.P., Parker, G. (2016) On how spatial variations of channel width influence river profile curvature. *Geophysical Research Letters,* 43: 6313–6323.

Frankl, A., Poesen. J., Mitiku, H., Deckers J., Nyssen, J. (2013) Quantifying longterm changes in gully networks and volumes in dryland environments: The case of Northern Ethiopia. Geomorphology, 201: 254-263.

Fruergaard, M., Kroon, A. (2016) Morphological response of a barrier island system on a catastrophic event: the AD 1634 North Sea storm. *Earth Surface Processes and Landforms*, 41: 420–426.

Fryirs, K.A., Brierley, G.J. (2013) *Geomorphic analysis of river systems: an approach to reading the landscape.* Wiley-Blackwell, Chichester.

Fuller, I.C., Gilvear, D.J., Thoms, M.C., Death, R.G. (2019) Framing resilience for river geomorphology: reinventing the wheel? *River Research and Applications,* 35(2): 91-106.

Gallart, F., Cid, N., Latron, J., Llorens, P., Bonada, N., Jeuffroy, J., Jiménez-Argudo, S.M., Vega, R.M., Solà, C., Soria, M., Bardina, M., Hernández-Casahuga, A.J., Fidalgo, A., Estrela, T., Munné, A., Prat, N. (2017) TREHS: An open-access software tool for investigating and evaluating temporary river regimes as a first step for their ecological status assessment. *Science of The Total Environment,* 607-608: 519-540.

García Lorenzo, R. (2010) *Peligrosidad de las aguas de avenidas en los cruces de carreteras con ramblas. Estudio aplicado a la franja costera meridional de la región de Murcia.* PhD Thesis, Universidad de Murcia.

Gómez, R., Arce, M.I., Sánchez, J.J., Sánchez-Montoya, M.M. (2012) The effects of drying on sediment nitrogen content in a Mediterranean intermittent stream: A microcosms study. *Hydrobiologia*, 679: 43-59.

González-Herrero, S., Bech, J. (2017) Extreme point rainfall temporal scaling: a long term (1805-2014) regional and seasonal analysis in Spain. *International Journal of Climatology,* 37(15): 5068-5079.

Gregory, K.J. (2006) The human role in changing river channels. *Geomorphology,* 79: 172-191.

Guzmán, M.E. (2015) *Metodología para estimar el espacio de libertad fluvial en cauces efímeros.* Tesis doctoral. E.T.S. Montes, Universidad Politénica de Madrid.

Habersack, H., Piégay, H. (2008) *River restoration in the Alps and their surroundings: past experience and future challenges.* In: Habersack H., Piégay H. & Rinaldi M. (eds.), "Gravel-bed Rivers VI -From Process Understanding to River Restoration, Developments in Earth Surface Processes", Elsevier, 703-738.

Heede, B.H. (2004) Dynamics of selected mountain streams in the Western United States of America. In Slaymaker, O. (ed) *Geomorphology: Critical Concepts in Geography. Volume I: Fluvial Geomorphology*, 299–315, Routledge, London.

Hisdal, H., Stahl, K., Tallaksen, L.M. and Demuth, S. (2001) Have streamflow droughts in Europe become more severe or frequent? *International Journal of Climatology,* 21: 317-333.

Holling, C.S. (Ed., 1978) *Adaptive environmental assessment and management.* Wiley.

Hooke, J.M. (2016) Morphological impacts of flow events of varying magnitude on ephemeral channels in a semiarid region. *Geomorphology,* 252: 128-143.

Hooke, J.M. (2019) Extreme sediment fluxes in a dryland flash flood. *Scientific Reports* **9,** 1686. https://doi.org/ 10.1038 /s41598-019-38537-3.

Horacio J. (2015) Reflexiones y enfoques en la conservación y restauración de rîos: georrestauración y pensamiento fluvial. *Biblio 3W Revista Bibliográfica de Geografia y Ciencias Sociales,* XX (1142).

Hupp, C.R., Osterkamp,W.R. (1996) Riparian vegetation and fluvial geomorphic processes. *Geomorphology,* 14: 277–295.

Ibisate, A., Ollero, O., García, J.H., Ortiz Martínez de Lahidalga, J., Sáenz de Olazagoitia, A., Hermoso, Y., Conesa-García, C., Gómez-Gutiérrez, A. (2021) Geomorphological evolution of ephemeral rivers through historical and UAVs images. *EGU General Assembly 2021,* Göttingen, Germany.

IPCC (2013): *Cambio Climático 2013. Bases físicas. Resumen para responsables de políticas, Resumen técnico y Preguntas frecuentes.* Informe del Grupo de trabajo I del IPCC. Disponible en: http://www.ipcc.ch/pdf/assessmentreport/ar5/wg1/WG1AR5_SummaryVolu me_FINAL_SPA NISH.pdf.

IUCN-CMC (2004) Scientific workshop on the provision of environmental flows in Mediterranean ephemeral rivers. Madrid, 18 September 2004, draft v2.0. Report author: Alcácer, C., IUCN —Centre for Mediterranean Cooperation. Madrid, 22 pp.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L., Cherry, D.S. (1999) Transport, retention and ecological significance of woody debris within a large ephemeral river. *Journal of the North American Benthological Society*, 18: 429-444.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L., Cherry, D.S. (2000a) Hydrologic influences on soil properties along ephemeral rivers in the Namib Desert. *Journal of Arid Environments*, 45: 21-34.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L., Cherry, D.S. (2000b) Variation in material transport and water chemistry along a large ephemeral river in the Namib Desert. *Freshwater Biology*, 44: 481-491.

Jopp, F., Reuter, H. (2005) Dispersal of carabid beetles: Emergence of distribution patterns. *Ecological Modeling*, 186: 389-405.

Keller, P.S., Catalán, N., von Schiller, D., Grossart, H.P., Koschorreck, M., Obrador, B., Frassl, M.A., Karakaya, N., Barros, N., Howitt, J.A., Mendoza-Lera, C., Pastor, A., Flaim, G., Aben, R., Riis, T., Arce, M. I., Onandia, G., Paranaíb, J.R., Linkhorst, A., del Campo, R., Amado, A.M., Cauvy-Fraunié, S., Brothers, S., Condon, J., Mendonça, R.F., Reverey, F., Rõõm, E.I., Datry, T., Roland, F., Laas, A., Oberteg U., Park, J.H., Wang, H., Kosten, S., Gómez, R., Feijoó, C., Elosegi, A., Sánchez-Montoya, M.M., Finlayson, C.M., Melita, M., Oliveira Junior E.S., Muniz, C.C., Gómez-Gener, L., Leigh, C., Zhang, Q., Marcé R. (2020) Global CO_2 emissions from dry inland waters share common drivers across ecosystems. *Nature Communications*, 11: 1-8.

Knox, J.C. (1984) Fluvial responses to small scale climate changes. In Costa, J.E., Fleisher, P.J. (Eds.) *Developments and Applications of Geomorphology*, 318-342, Berlin, Springer-Verlag.

Kondolf, G.M., Podolak, K., Grantham, T.H. (2013) Restoring mediterranean-climate rivers. *Hydrobiologia,* 719: 527-545.

Ladson, A.R. (2003) *Assessing the health of ephemeral rivers. Review of geomorphic and hydrologic indicators.* Cooperative Research Centre for Catchment Hydrology & Monash University.

Lake, P.S., Bond, N., Reich, P. (2017) Restoration ecology of intermittent rivers and ephemeral streams. In Datry, T., Bonada, N., Boulton, A. (Eds) *Intermittent rivers and ephemeral streams. Ecology and management,* 509-533, Elsevier.

Lane, E.W. (1955) Design of stable channels. *Transactions of the American Society of Civil Engineers,* Paper No. 2776, 1234– 1279.

Lane, E.W. (1955) The importance of fluvial morphology in hydraulic engineering. *Proceedings American Society of Civil Engineers,* 81, Paper No. 745 (Retrieved from http://agris.fao.org/agris-search/search.do?recordID=US201400000288).

Lane, S.N., Bakker, M., Gabbud, C., Micheletti, N., Saugy, J.N. (2016) Sediment export, transient landscape response and catchment-scale connectivity following rapid climate warming and Alpine glacier recession. *Geomorphology*, 277: 210-227.

Lea, D.M., Legleiter, C.J. (2016) Mapping spatial patterns of stream power and channel change along a gravel-bed river in northern Yellowstone. *Geomorphology,* 252: 66–79.

Leggett, K.E.A., Fennessy, J., Schneider, S. (2004) A study of animal movement in the Hoanib River catchment, northwestern Namibia. *African Zoology*, 39: 1-11.

Leopold, L.B., Maddock, T. (1953) *The hydraulic geometry of stream channel and some physiographic implications.* Prof. Pap. 252, U.S. Geol. Surv., Washington D. C.

Leopold, L.B., Langbein, W.B. (1962) *The concept of entropy in landscape evolution.* U. S. Geol. Survey. Prof. Paper 500-A, 20 pp.

Leopold, L.B., Wolman, M.G., Miller, J.P. (2012) *Fluvial Processes in Geomorphology.* Courier Corporation.

Levick, L.R., Goodrich, D.C., Hernández, M., Fonseca, J., Semmens, D.J., Stromberg, J., Tluczek, M., Leidy, R.A., Scianni, M., Guertin, D.P., Kepner, W.G. (2008) *The ecological and hydrological significance of ephemeral and intermittent streams in the arid and semi-arid American Southwest.* U.S. Washington: Environmental Protection Agency and USDA/ARS Southwest Watershed Research Center.

Liébault, F., Piégay, H. (2002) Causes of 20th century channel narrowing in mountain and piedmont rivers of southeastern France. *Earth Surface Processes and Landforms*, 27: 425-444.

Llasat, M.C., López, L., Barnolas, M., Llasat-Botija, M. (2008) Flash-floods in Catalonia: the social perception in a context of changing vulnerability. *Advances in Geosciences,* 17: 63-70.

López Bermúdez, F., Conesa-García, C., Alonso, F. (2002) Floods: magnitude and frequency in ephemeral streams of the spanish mediterranean region. In Bull, L., Kirkby, M. (ed) *Dryland rivers,* 329-350, Wiley.

Lotsari, E., Thorndycraft, V., Alho, P. (2015) Prospects and challenges of simulating river channel response to future climate change, *Progress in Physical Geography*, doi: 10.1177/0309133315578944.

Lowe, W.H., Likens, G.E. (2005) Moving headwater streams to the head of the class. *Bioscience,* 55: 196–197.

Macklin, M.G., Lewin, J., Woodward, J.C. (2012) The fluvial record of climate change. *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, 370, No. 1966, River history, pp. 2143-2172.

Magand, C. (coord., 2020) *Intermittent rivers and ephemeral streams: what water managers need to know.* SMIRES project. Technical report – Cost ACT.

Magilligan, F.J. (1992) Thresholds and the spatial variability of flood power during extreme floods. *Geomorphology,* 5: 373–390.

Manrique, A., Nájera, A., Escartín, C., Moreno, C., Martínez Bravo, E., Espejo, F., Sánchez Martínez, F.J., Aparicio, M., Cordero, S., González, S. (2017) *Guía para la reducción de la vulnerabilidad de los edificios frente a las inundaciones.* Consorcio de Compensación de Seguros, Madrid.

Marcé, R., Obrador, B., Gómez-Gener, L., Catalán, N., Koschorreck, M., Arce, M.I., Singere, G., von Schiller, D. (2019) Emissions from dry inland waters are a blind spot in the global carbon cycle. *Earth-Science Reviews*, 188: 240-248.

Martín Vide, J.P. (1997) *Ingeniería Fluvial.* Politext, Àrea d'Enginyeria Civil, Edicions UPC, Barcelona, 209 pp.

Martin-Vide, J.P., Ninerola, D., Bateman, A., Navarro, A., Velasco, E. (1999) Runoff and sediment transport in a torrential ephemeral stream of the Mediterranean coast. *Journal of Hydrology,* 225: 118–129.

Martín Vide, J.P., Ferrer-Boix, C., Ollero, A. (2010) Incision due to gravel mining: modeling a case study from the Gállego River, Spain. *Geomorphology,* 117: 261-271.

Martínez-Salvador, A., Millares, A., Eekhout, J.P.C., Conesa-García, C. (2021) Assessment of streamflow from EURO-CORDEX Regional Climate Simulations in semi-arid catchments using the SWAT model. *Sustainability*, 13(13), 7120; doi 10.3390/su13137120.

Martínez-Yoshino, N., Suárez, M.L., Vidal-Abarca, M.R. (2021) Delimitando los rasgos biológicos de la vegetación de los ríos secos: el caso de las ramblas de la cuenca del Segura (SE de España). *Anales de Biología*, 43: 11-25.

Mateu, J.F. (1982) *El norte del País Valenciano: geomorfología litoral y prelitoral.* Universitat de València.

Meixner, T., Manning, A.H., Stonestrom, D.A., Allen, D.M., Ajami, H., Blasch, K.W., et al. (2016) Implications of projected climate change for groundwater recharge in the western United States. *Journal of Hydrology,* 534: 124–138.

Merritt, D.M., Wohl, E.E. (2003) Downstream hydraulic geometry and channel adjustment during a flood along an ephemeral, arid-region drainage. *Geomorphology,* 52: 165–180.

Merbt, S.N., Proia, L., Prosser, J.I., Marti, E., Casamayor, E.O., von Schiller, D. (2016) Stream drying drives microbial ammonia oxidation and first-flush nitrate export. *Ecology*, 97: 2192–2198.

Messager, M.L., Lehner, B., Cockburn, C., Lamouroux, N., Pella, H., Snelder, T., Tockner, K., Trautmann, T., Watt, C., Datry, T. (2021) Global prevalence of non-perennial rivers and streams. *Nature,* 594, doi 10.1038/s41586-021-03565-5

Naylor, L.A., Spencer, T., Lane, S.N., Darby, S.E., Magilligan, F.J., Macklin, M.G., Möller, I. (2017) Stormy geomorphology: geomorphic contributions in an age of climate extremes. *Earth Surface Processes and Landforms*, 42: 166-190.

Nicolas, N., Suárez, M.L., Vidal-Abarca, M.R. (2021) Contributions of dry rivers to human well-being: a global review for future research. *Ecosystem services,* 50: 101307. doi 10.1016/j.ecoser.2021.101307

Noguera, I., Duarte, P., Ollero, A. (2014) Caracterización hidrogeomorfológica y evaluación del riesgo en un curso efimero mediterráneo: el rîo Seco (Aragón, España). *Revista de Investigación para el Desarrollo Sustentable INDES,* 2(2): 9-19.

Norman, L.M., Brinkerhoff, F., Gwilliam, E., Guertin, D.P., Callegary, J., Goodrich, D.C., Gray, F. (2016) Hydrologic response of streams restored with check dams in the Chiricahua Mountains, Arizona: Hydrology of streams with check dams installed. *River Research and Appl*ications, 32(4): 519–527.

Norman, L.M., Niraula, R. (2016) Model analysis of check dam impacts on long-term sediment and water budgets in Southeast Arizona, USA. *Ecohydrology and Hydrobiology,* 16(3): 125–137.

Norman, L.M., Sankey, J.B., Dean, D., Caster, J., DeLong, S., DeLong, W., Pelletier, J.D. (2017) Quantifying geomorphic change at ephemeral stream restoration sites using a coupled-model approach. *Geomorphology,* 283: 1-16.

Norton, J.B., Bowannie Jr., F., Peynetsa, P., Quandelacy, W., Siebert, S.F. (2002) Native American methods for conservation and restoration of semiarid ephemeral streams. *Journal of Soil and Water Conservation,* 57(5): 250-258.

NRCS - Natural Resources Conservation Service (2007) *Stream Restoration Design (National Engineering Handbook 654),* Chapter 11: Rosgen Geomorphic Channel Design. United States Department of Agriculture, USDA, 11–76.

Nyssen, J., Poesen. J., Descheemaeker, K., Nigussie, H., Mitiku, H., Moeyersons, J., Frankl, A., Govers, G., Munro, N., Deckers, J. (2008) Effects of region-wide soil and water conservation in semi-arid areas: The case of northern Ethiopia. Z. Geomorph. N.F. 52(3): 291-315.

Ollero, A. (2011) Los cauces fluviales como indicadores de cambio global: propuesta metodológica. *Zubía,* monográfico 23: 189-202.

Ollero, A. (2015) *Guía metodológica sobre buenas prácticas en restauración fluvial (manual para gestores).* Zaragoza: Contrato de Río del Matarraña.

Ollero, A., Ballarín, D., Díaz Bea, E., Mora, D., Sánchez Fabre, M., Acín, V., Echeverría, M.T., Granado, D., Ibisate, A., Sánchez Gil, L., Sánchez Gil, N. (2007) Un índice hidrogeomorfológico (IHG) para la evaluación del estado ecológico de sistemas fluviales. *Geographicalia,* 52: 113-141.

Ollero, A., Ballarín, D., Mora, D. (2009) *Aplicación del índice hidrogeomorfológico IHG en la cuenca del Ebro. Guía metodológica.* Confederación Hidrográfica del Ebro, 93 p., Zaragoza.

Ollero, A., Ibisate, A., Gonzalo, L.E., Acín, V., Ballarín, D., Díaz, E., Domenech, S., Gimeno, M., Granado, D., Horacio, J., Mora, D., Sánchez Fabre, M. (2011a) The IHG index for hydromorphological quality assessment of rivers and streams: updated version. *Limnetica,* 30(2): 255-262.

Ollero, A., Ibisate, A., Acín, V., Díaz, E., Granado, D., Horacio, J. (2011b) Innovación y libertad fluvial. *Ponencia al VI Congreso Ibérico sobre Gestión y Planificación del Agua,* Fundación Nueva Cultura del Agua.

Ollero, A., Ibisate, A., Horacio, J., Conesa-García, C., Álvarez, Y., Segura, F., Sanchis, C., Ballarín, D., Calle, M., Sánchez Fabre, M. (2019) Diagnóstico y posibilidades de restauración en cursos de agua efímeros mediterráneos. *Actas del III Congreso Ibérico de Restauración Fluvial Restaurarríos 2019,* 481-487, CIREF y CH Segura, Murcia.

Ollero, A., Ballarín, D., García, J.H., Ibisate, A., Mora, D., Sánchez Fabre, M. (2021a) Diagnóstico fluvial, impactos en cauces y cambio global: aplicaciones del índice hidrogeomorfológico IHG. *Geographicalia*, 73: 295-316.

Ollero, A., Ballarín, D., García, J.H., Hermoso, Y., Ibisate, A., Pirchi, V.N., Prados, R., Sanmartín, S. (2021b) Hydromorphological assessment and potential restoration in ephemeral Mediterranean streams: application of the IHG-E index in the Ebro basin, Murcia (Spain) and Calabria (Italy). *Ecological Indicators* (in press).

Ortega, J.A., Razola, L., Garzón, G. (2014) Recent human impacts and change in dynamics and morphology of ephemeral rivers. *Natural Hazards and Earth System Sciences,* 14: 713-730.

Palmer, M.A., Lettenmaier, D.P., Poff, N.L., Postel, S.L., Richter, B., Warner, R. (2009) Climate change and river ecosystems: protection and adaptation options. *Environmental Management,* 44: 1053–1068.

Parker, C., Clifford, N.F., Thorne, C.R. (2011) Understanding the influence of slope on the threshold of coarse grain motion: revisiting critical stream power. *Geomorphology,* 126: 51–65.

Peirce, S.E.K. (2012) *Characterization of ephemeral streams using electrical resistance sensors in a Southern Ontario watershed*, PhD Thesis, University of Guelph, Ontario, Canada.

Phillips, J.D., Van Dyke, C. (2016) Principles of geomorphic disturbance and recovery in response to storms. *Earth Surface Processes and Landforms,* 41: 971–979.

Poole, G.C. (2010) Stream hydrogeomorphology as a physical science basis for advances in stream ecology. *Journal of the North American Benthological Society,* 29: 12-25.

Powell, D.M., Laronne, J.B., Reid, I., Barzilai R. (2012) The bed morphology of upland single-thread channels in semi-arid environments: Evidence of repeating bedforms and their wider implications for gravel-bed rivers, *Earth Surface Processes and Landforms,* 37: 741–753.

Prados, R. (2020) *Evaluación hidromorfológica de cursos efímeros mediterráneos y propuestas de restauración.* Trabajo Fin de Master en Ordenación Territorial y Medioambiental, Universidad de Zaragoza.

Reid, I., Frostick, L.E. (1997) Channel form, flows and sediments in deserts. In Thomas, D.S.G. (ed) *Arid zone geomorphology: process, form and change in drylands,* 205-229, Wiley: Chichester.

Reid, I., Laronne, J.B. (1995) Bed load sediment transport in an ephemeral stream and a comparison with seasonal and perennial counterparts. *Water Resources Research,* 31: 773-781.

Richards, K.S. (1982) *Rivers: form and process in alluvial channels.* Methuen, London, pp. 361.

RIFLUTME (2006-2008) Proyecto "*Procesos de riesgos con origen natural asociados a sistemas fluviales de régimen torrencial mediterráneo*". Referencia 02955/PI/05, Fundación SENECA.

Rinaldi, M. (2003) Recent channel adjustments in alluvial rivers of Tuscany, Central Italy. *Earth Surface Processes and Landforms,* 28: 587-608.

Rinaldi, M., Wyżga, B., Surian, N. (2005) Sediment mining in alluvial channels: physical effects and management perspectives. *River Research and Applications,* 21(7) 805-828.

Rinaldi, M., Surian, N., Comiti, F., Bussettini, M., Lastoria, B., Nardi, L. (2016) *IDRAIM. Sistema di valutazione idormorfologica, analisi e monitoraggio dei corsi d'acqua. Versione aggiornata 2016.* Istituto Superiore per la Protezione e la Ricerca Ambientale.

Rosgen, D.L. (1996) *Applied river morphology.* Wild-land Hydrology, Pagosa Springs, Colorado.

Rosgen, D.L. (1997) A geomorphological approach to restoration of incised rivers, In Wang, S.S.Y., Langendoen, E.J., Shields, F.D. (Eds) *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision.* The University of Mississippi, Oxford.

Sampietro, M.M., Peña, J.L. (2016) Geomorphological dynamic changes during the Holocene through ephemeral stream analyses from Northwest Argentina. *Catena,* 147: 663-677.

Sánchez Escolano, L.M., Toro, F.J. (2020) Las ramblas del Sureste español como medio de vida: una aproximación al caso almeriense. *Cuadernos de Geografía de la Universidad de Valencia,* 105: 75-96.

Sánchez-Montoya, M.M., von Schiller, D., Ruhí, S.P.G., Proia, L., Miñano, J., Vidal-Abarca, M.R., Suárez, M.L., Tockner, K. (2016) Responses of ground-dwelling arthropods to surface flow drying in channels and adjacent habitats along Mediterranean streams. *Ecohydrology*, 9: 1376-1387.

Sánchez-Montoya, M.M., Moleón, M., Sánchez-Zapata, J.A., Escoriza, D. (2017) The biota of intermittent and ephemeral rivers: Amphibians, reptiles, birds and mammals. In Datry, T., Bonada, N., Boulton, A. (eds.) *Intermittent Rivers and Ephemeral Streams, Ecology and Management*, 299–322. Academic Press: London.

Sánchez-Montoya, M.M., Guerrero-Brotons, M., Miñano, J., Gómez, R. (2019) Effects of debris piles and pools along dry riverbeds on nutrients, microbial activity, and ground-dwelling arthropods: A Namibian ephemeral river case. *Journal of Arid Environments*, 175: 104082.

Sanchis, C., Segura, F., Almonacid, J. (2017) Channel forms recovery in an ephemeral river after gravel mining (Palancia River, Eastern Spain). *Catena,* 158: 357-370.

Sanchis, C., Segura, F., Navarro, A. (2019) Channel forms and vegetation adjustment to damming in a Mediterranean gravel-bed river (Serpis River, Spain). *River Research and Applications,* 35(1): 37-47.

Sanmartín, S. (2019) *Caracterización y evaluación hidromorfológica de cursos efímeros en la cuenca del Ebro.* Trabajo Fin de Grado en Geografía y Ordenación del Territorio, Universidad de Zaragoza.

Schneider, C., Laizé, C.L.R., Acreman, M.C. and Flörke, M. (2013) How will climate change modify river flow regimes in Europe? *Hydrology and Earth System Sciences,* 17: 325–339.

Schumm, S.A. (1960) *The shape of alluvial channels in relation to sediment type.* US Geological Survey professional paper 352B, 17–30.

Schumm, S.A. (1961) *Effect of sediment characteristics on erosion and deposition in ephemeral stream channels*: U.S. Geological Survey, Professional Paper 352-C, p. 31-70.

Schumm, S.A. (1968) *River adjustment to altered hydrologic regimen: Murrumbidgee River and paleochannels, Australia.* United States Geological Survey, *Professional Paper* 598.

Schumm, S.A. (1969) River metamorphosis. *Journal of the Hydraulics Division of the American Society of Civil Engineers,* 95: 255–273.

Schumm, S.A. (1977) *The fluvial system.* New York, Wiley-Interscience.

Schumm, S.A. (1979) Geomorphic thresholds: the concept 762 and its applications. *Transactions of the Institute of British Geographers,* 4: 485-515.

Schumm, S.A. (1998) *To Interpret the Earth: Ten ways to be wrong.* Cambridge University Press.

Schumm, S.A., Lichty, R.W. (1963) *Channel widening and floodplain construction along Cimarron River in Southwestern Kansas.* United States Geological Survey, *Professional Paper* 352-D.

Schumm, S.A., Parker, R.S. (1973) Implications of complex response of drainage systems for Quaternary alluvial stratigraphy. *Nat. Phys. Sci.* 243 (128): 99–100. http://dx.doi.org/10.1038/physci243099a0.

Scott, S.H. (2006) *Predicting sediment transport dynamics in ephemeral channels: a review of literature.* Army Engineer Waterways Experiment Station. Vicksburg, MS. Coastal Hydraulics Lab. Report Number: ERDC/CHL-CHETN-VII-6. 8 p.

Seely, M., Henderson, J., Heyns, P., Jacobson, P., Nakale, T., Nantanga, K., Schachtschneider, K. (2003) Ephemeral and endoreic river systems: relevance and management challenges. *Transboundary rivers, sovereignty and development: hydropolitical drivers in the Okavango River Basin,* 187-212, African Water Issues Research Unit and Green Cross International.

Segev, O., Ziv, M., Lubin, Y. (2003) The male mating system in a desert widow spider. *The Journal of Arachnology*, 31: 379-393.

Segura, F. (1990) *Las ramblas valencianas: algunos aspectos de hidrología, geomorfología y sedimentología.* Universitat de València.

Segura, F. (2004) Ramblas y barrancos: los ríos de piedras. *Mètode,* Universitat de València.

Segura, F. (2014) Sobre la restauració fluvial i la complexitat dels rius efímers: algunes consideracions critiques. *Cuadernos de Geografía Universidad de Valencia,* 95/96: 101-147.

Segura, F. (2017) *Canvis ambientals i antròpics recents en els sistemes fluvials mediterranis: crònica d'una destrucció anunciada.* Discurs de recepció com a membre numerària de la Secció de Filosofia i Ciències Socials, Institut d'Estudis Catalans.

Segura, F, Sanchis, C. (2013) Assessment of channel changes in a Mediterranean ephemeral stream since the early twentieth century. The Rambla de Cervera, Eastern Spain. *Geomorphology,* 201: 199-214.

Segura, F., Sanchis, C. (2015) Restauración geomorfológica, cambios ambientales, imagen de referencia e imagen objetivo en rîos efimeros: reflexiones crîticas. *II Congreso Ibérico de Restauración Fluvial Restauraríos,* Pamplona, 2015.

Segura, F., Sanchis, C. (2018) Estrechamiento de cauces y cambio de patrón en cursos fluviales mediterráneos como consecuencia del cambio global en las últimas décadas: indicadores geomorfológicos. In Garcia, C., Gómez-Pujol, C., Morán-Tejeda, E., Batalla, R.J. (ed) *Geomorfología del Antropoceno. Efectos del cambio global sobre los procesos geomorfológicos,* 393–397, Universitat de les Illes Balears.

Segura, F., Sanchis, C., Ollero, A. (2021) Restauración en ramblas y ríos semipermanentes. *Soluciones ante los impactos climáticos en ríos y costas,* CONAMA.

Shaw, J.R., Cooper, D.J. (2008) Linkages among watersheds, stream reaches, and riparian vegetation in dryland ephemeral stream networks. *Journal of Hydrology,* 350: 68–82.

Simon, A., Castro, J. (2003) Measurement and analysis of alluvial channel form. In Kondolf, G.M., Piegay, H. (Eds) Tools in fluvial geomorphology, 291-322, Wiley.

Simon, A., Rinaldi, M. (2006) Disturbance, stream incision, and channel evolution: the roles of excess transport capacity and boundary materials in controlling channel response. *Geomorphology,* 79(3–4): 361–383.

Sinha, S. K., Parker, G. (1996) Causes of concavity in longitudinal profiles in rivers. *Water Resources Research,* 32(5): 1417–1428.

Škarpich, V., Hradecký, J., Dušek, R. (2013) Complex transformation of the geomorphic regime of channels in the forefield of the Moravskoslezské Beskydy Mts.: case study of the Morávka river (Czech Republic). *Catena,* 111: 25–40.

Skoulikidis, N.T., Sabater, S., Datry, T., Morais, M.M., Buffagni, A., Dörflinger, G., Zogaris, S., Sánchez Montoya, M.M., Bonada, N., Kalogianni, E., Rosado, J., Vardakas, L., De Girolamo, A.M., Tockner, K. (2016) Non-perennial Mediterranean rivers in Europe: status, pressures, and challenges for research and management. *Science of the Total Environment,* 577: 1-18.

Stein, E.D., Vyverberg, K., Kondolf, G.M., Janes, K. (2011) Episodic stream channels: imperatives for assessment and environmental planning in California. *Proceedings of a Special Technical Workshop, November 8-10, 2010*, Final Technical Report, 2011.

Steward, A.L., Marshall, J.C., Sheldon, F., Harch, B., Choy, S., Bunn, S.E., Tockner, K. (2011) Terrestrial invertebrates of dry river beds are not simply subsets of riparian assemblages. *Aquatic Sciences*, 73: 551-566.

Steward, A.L., Langhans, S.D., Corti, R., Datry, T. (2017) The biota of intermittent rivers and ephemeral streams: Terrestrial and semiaquatic invertebrates. In Datry, T., Bonada, N., Boulton, A. (eds.) *Intermittent Rivers and Ephemeral Streams, Ecology and Management*, 245-271. Academic Press: London.

Stromberg, J.C., Gallo, E.L., Lohse, K.A., Meixner, T., Moody, E.K, Sabo, J.L., Setaro, D.L. (2015) *Structure and function of ephemeral streams in the arid and semi-arid Southwest and implications for conservation and management.* Final Report, SERDP Project RC-1726. Arizona State University, Tempe.

Stubbington, R., Chadd, R., Cid, N., Csabai, Z., Miliša, M., Morais, M., Munné, A., Pařil, P., Pešić, V., Tziortzis, I., Verdonschot, R.C.M., Datry, T. (2018) Biomonitoring of intermittent rivers and ephemeral streams in Europe: current practice and priorities to enhance ecological status assessments. *Science of the Total Environment*, 618: 1096-1113.

Stubbington, R., Paillex, A., England, J., Barthès, A., Bouchez, A., Rimet, F., Sánchez-Montoya, M.M., Westwood, C.G., Datry, T. (2019) A comparison of biotic groups as dry phase indicators of ecological quality in intermittent rivers and ephemeral streams. *Ecological Indicators,* 97: 165–174. https://doi.org/10.1016/j.ecolind.2018.09.061

Suárez, M.L., Vidal-Abarca, M.R. (2008) Índice para valorar el estado de conservación de las ramblas mediterráneas (Indice de Alteración de Ramblas = IAR). *Tecnología del Agua,* 293: 67-78.

Suárez, M.L., Vidal-Abarca, M.R., Navarro, I., Gómez Cerezo, R., López Bermúdez, F. (2010) Los Arroyos de Baja California Sur (México): caracterización ambiental y aplicación de un índice de estado de alteración (IAR). *Cuaternario y Geomorfología,* 24(1-2): 63-77.

Surian, N., Rinaldi, M. (2003) Morphological response to river engineering and management in alluvial channels in Italy. *Geomorphology,* 50(4): 307-326.

Surian, N., Cisotto, A. (2007) Channel adjustments, bedload transport and sediment sources in a gravel-bed river, Brenta River, Italy. *Earth Surface Processes and Landforms,* 32: 1641-1656.

Surian, N., Rinaldi, M., Pellegrini, L. (2011) Channel adjustments and implications for river management and restoration. *Geografia Fisica e Dinamica Quaternaria,* 34: 145-152.

Sutfin, N.A., Shaw, J., Wohl, E., Cooper, D. (2014) A geomorphic classification of ephemeral channels in a mountainous, arid region, southwestern Arizona, USA. *Geomorphology,* 221: 164-175.

Thoms, M.C., Piégay, H., Parsons, M. (2018) What do you mean, 'resilient geomorphic systems'?. *Geomorphology,* 305: 8-19.

Thorn, C.E., Welford, M.R. (1994) The Equilibrium Concept in Geomorphology. *Annals of the Association of American Geographers*, 84: 666-696.

Thornes, J.B. (1976) *Semi-arid erosional systems: case studies from Spain.* London School of Economics and Political Science.

Thorp, J.H., Thoms, M.C., Delong, M.D. (2006) The riverine ecosystem synthesis: Biocomplexity in river networks across space and time. *River Research and Applications,* 22: 123-147.

Tooth, S., Nanson, G.C. (1999) Anabranching rivers on the Northern Plains of arid central Australia. *Geomorphology*, 29: 211-233.

Tooth, S., Nanson, G.C. (2000) The role of vegetation in the formation of anabranching channels in an ephemeral river, Northern Plains, arid central Australia. *Hydrological Processes*, 14: 3099-3117.

Tosline, D. (2016) *Instalación de estructuras de control de la erosión en un paisaje como alternativa de tratamiento de restauración y gestión adaptativa de cuencas hidrográficas para el cambio climático.* Research and Development Office Science and Technology Program Final Report ST-2016-720. U.S. Department of the Interior, Bureau of Reclamation, Research and Development Office, Denver, 53 pp.

Verhaar, P.M., Biron, P.M., Ferguson, R.I., Hoey, T.B. (2011) Implications of climate change in the twenty-first century for simulated magnitude and frequency of bed-material transport in tributaries of the Saint-Lawrence River. *Hydrological Processes* 25(10): 1558–1573.

Vidal-Abarca, M.R., Gómez, R., Sánchez Montoya, M.M., Arce, M.I., Nicolás, N., Suárez, M.L. (2020) Defining dry rivers as the most extreme type of non-perennial fluvial ecosystems. *Sustainability,* 12, 7202; doi:10.3390/su12177202.

Villarreal, M.L., Webb, R.H., Norman, L.M., Psillas, J.L., Rosenberg, A.S., Carmichael, S., Sparks, P.E. (2014) Modelling landscape-scale erosion potential related to vehicle disturbances along the U.S.-Mexico border. *Land Degradation and Development,* 27(4): 1106-1121.

Vita-Finzi, C. (2012) River history. *Philosophical Transactions of the Royal Society* A, 370(1966): 2029–2039.

Von Schiller, D., Datry, T., Corti, R., Foulquier, A., Tockner, K., Marcé, R., García-Baquero, G., Odriozola, I., Obrador, B., Elosegi, A., Mendoza-Lera, C., Gessner, M.O., Stubbington, R., Albariño, R., Allen, D.C., Altermatt, F., Arce, M.I., Arnon, S., Banas, D., Banegas, A., Beller, E., Blanchette, M.L., Blanco, J.F., Blessing, J., Boëchat, I.G., Boersma, K.S., Bogan, M.T., Bonada, N., Bond, N.R., Brintup, A., Bruder, A., Burrows, R.M., Cancellario, T., Carlson, S.M., Cauvy-Fraunié, S., Cid, N., Danger, M. de Freitas, B., Dehedin, A., De Girolamo, A.M., Del Campo, R., Díaz-Villanueva, V., Duerdoth, C.P., Dyer, F., Faye, E., Febria, C., Figueroa, R., Four, B., Gafny, S., Gómez, R., Gómez-Gener, L., Graça, M.A.S., Guareschi, S., Gücker, B., Hoppeler, F., Hwan, J.L., Kubheka, S., Laini, A., Langhans, S.D., Leigh, C., Little, C.J., Lorenz, S., Marshall, J., Martín, E.J., McIntosh, A., Meyer, E.I., Miliša, M., Mlambo, M.C., Moleón, M., Morais, M., Negus, P., Niyogi, D., Papatheodoulou, A., Pardo, I., Pařil, P., Pešić, V., Piscart, C., Polášek, M., Rodríguez Lozano, P., Rolls, R.J., Sánchez Montoya, M.M., Savić, A., Shumilova, O., Steward, A., Taleb, A., Uzan, A., Van der Vorste, R., Waltham, N., Woelfle-Erskine, C., Zak, D., Zarfl, C., Zoppini, A. (2019) Sediment respiration pulses in intermittent rivers and ephemeral streams. *Global Biogeochemical Cycles*, 33: 1251-1263.

Walker, B., Holling, C.S., Carpenter, S., Kinzig, A. (2004) Resilience, adaptability and transformability in social-ecological systems. *Ecology and society*, 9.

Wittenberg, L., Laronne, J.B., Newson, M.D. (2007) Bed clusters in humid perennial and Mediterranean ephemeral gravel-bed streams: The effect of clast size and bed material sorting. *Journal of Hydrology*, 334, 312–318.

Wolman, M.G., Leopold L.B. (1960) Magnitude and frequency of forces in geomorphic processes, *J. Geol.*, *68*, 54–74.

Yochum, S.E., Sholtes, J.S., Julian, A., Scott, J.A., Bledsoe, B.P. (2017) Stream power framework for predicting geomorphic change: The 2013 Colorado Front Range flood. *Geomorphology*, 292: 178-192.

Zawiejska, J., Wyżga, B. (2010) Twentieth-century channel change on the Dunajec River, southern Poland: patterns, causes and controls. *Geomorphology,* 117: 234-246.

Zollitsch, B., Christie, J. (2014) *Report on State Definitions, Jurisdiction and Mitigation Requirements in State Programs for Ephemeral, Intermittent and Perennial Streams in the United States*. The Association of State Wetland Managers, Funding Support Provided by U.S. Environmental Protection Agency. The McKnight Foundation.

Ephemeral channels (*ramblas* or dry channels - except in sudden occasional flash floods) are prevalent in the Mediterranean, where they make up most of the fluvial network. They are fundamental natural systems in the hydrological cycle for transporting water, sediment and nutrients, and, therefore, are excellent indicators of climate and global change. Their promotion, the recognition of their role, their hydromorphological values and ecosystemic services are all absolutely essential for understanding their level of resilience and contribution to adapting to climate change. And it is urgent for us to work on their management, recovery and conservation, because overall they are subjected to strong pressures and are being greatly damaged.

This guide warns the reader about the multiple impacts these channels are subjected to, it informs us about their important Mediterranean heritage, which is so underestimated and ignored; and it proposes 33 good practices for their management and recovery. It is a book that can offer ideas to the people responsible for managing them, but is aimed at the whole of society, because the challenge is very complex: we have to recover ephemeral channels by improving understanding and raising awareness. And we must act quickly, because it is already late and until now practically nothing has been done to respect, protect and recover these vital fluvial systems on our land. This is our challenge.

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