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THE MIRAGE TOOLBOX: AN INTEGRATED ASSESSMENT TOOL FOR TEMPORARY STREAMS

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ABSTRACT

The assessment of the ecological status of water bodies, as requires by the European Water Framework Directive, can raise a number of problems when applied to temporary streams. These problems are because of the particular physical, chemical and biological conditions resulting from the recurrent cessation of flow or even the complete drying of the stream beds. In such non-permanent water bodies, the reference quality standards developed for permanent streams may only be applicable under certain circumstances or may not be applicable at all. Work conducted within the collaborative EU-funded project Mediterranean Intermittent River ManAGEment (MIRAGE) has addressed most of these difficulties and has used diverse approaches to solve them. These approaches have been brought together in the so-called MIRAGE Toolbox. This toolbox consists of a series of methodologies that are designed to be used in a sequential manner to allow the establishment of the ecological and chemical status of temporary streams and to relate these findings to the hydrological status of the streams. The toolbox is intended to serve the following purposes: (i) the determination of the hydrological regime of the stream; (ii) the design of adequate schedules for biological and chemical sampling according to the aquatic state of the stream; (iii) the fulfillment of criteria for designing reference condition stations; (iv) the analysis of hydrological modifications of the stream regime (with the definition of the hydrological status); and (v) the development of new methods to measure the ecological status (including structural and functional methods) and chemical status when the stream's hydrological conditions are far from those in permanent streams. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: temporary streams; aquatic state; MIRAGE; hydrological status; ecological status

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INTRODUCTION

Temporary rivers comprise approximately one half of the global river network and are predicted to expand further because of climate change and increased water abstraction for human use (Carlisle *et al*., 2010). These systems are characterized by the recurrent onset and cessation of flow or even the complete drying of stream bed segments; these complex hydrological dynamics strongly influence biotic communities as well as nutrient and organic matter processing (Lake, 2000, 2007; Larned *et al*., 2010; Datry *et al*., 2014). From an ecosystem perspective, temporary rivers form a complex spatial and temporal mosaic of lotic, lentic, and terrestrial habitats (Boulton and Suter, 1986; Williams, 2006). They harbour unique and diverse aquatic, amphibious and terrestrial biotic assemblages, and they store, process, and transport energy and matter (Lake, 2011). However, the current paradigms in river science and management have emerged from and have been developed for permanent rivers. The principles of biodiversity conservation, integrated water resource management and water

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quality control ignore the reality that major parts of the global river network are temporary (Gasith and Resh, 1999; Larned *et al*., 2010).

Temporary rivers remain generally neglected in water legislation and regulations such as the European Water Framework Directive (EU-WFD; European Communities, 2000) or the US Federal Water Pollution Control Act (commonly referred to as the Clean Water Act), posing a great challenge to water managers who are, therefore, compelled to apply permanent river management principles when making decisions. The hydrological variability of temporary rivers needs adaptive management strategies, especially in the context of climate change. The ecological status (ES) assessment of temporary rivers constitutes one of the missed challenges within the context of the EU-WFD (Nikolaidis *et al*., 2013). In summary, temporary rivers need to be fully recognized and integrated into river science, management and monitoring (Datry *et al*., 2014).

The Mediterranean Intermittent River ManAGEment (MIRAGE) project is concerned with the development of tools suitable for the sound management of temporary streams. Emphasis is placed on achieving a good chemical and ES, as required by the EU-WFD. One of MIRAGE's major aims is to support the general application of the EU-WFD in Mediterranean river basins. To do so, it provides appropriate guidelines for the assessment of temporary streams, a type of watercourse of major and increasing importance in the Mediterranean region (Meehl *et al*., 2007). The members of the MIRAGE team have developed a variety of tools applicable to various aspects related to the intermittent nature (i.e. hydrology, ecology and chemistry) of temporary streams [e.g. Dieter *et al*., 2011; García-Roger *et al*., 2011; Kirkby *et al*., 2011; Gallart *et al*., 2012; De Girolamo *et al*., 2013a, 2013b (submitted)]. The main focus of the MIRAGE Toolbox is to help professionals addressing the management of temporary streams from an interdisciplinary perspective by covering a wide range of the conditions that a temporary stream may experience. The principal objective of the MIRAGE Toolbox is to integrate complex hydrological conditions with the ecological and chemical indicators to establish EU-WFD compliant ES and chemical status (CHS). Here, we introduce a comprehensive approach for assessing the environmental quality of temporary streams based on the concept that the occurrence of periods without flow or even without water is the principal factor controlling physicochemical and biological processes in these streams. For practical reasons, this approach takes the form of a collection of tools that are new or adapted from procedures currently applied to permanent streams.

This paper provides a thorough overview of the methodologies that make up the MIRAGE Toolbox, to show the user sequence and the linkage between each focused method that have been presented independently in several papers (Table I) describing scientific experiments and results in detail.

TOOLS IN THE TOOLBOX

Rationale

The MIRAGE Toolbox is a sequential arrangement of tools covering hydrological [temporary stream regime (TSR)-Tool, hydrological status (HS)-Tool, and aquatic state (AS)-Tool)], ecological [reference condition (RC)-Tool, biological assessment (BioAS)-Tool, and ES-Tool] and chemical [physicochemical status (PCHS-Tool) and CHS-Tool] aspects of the assessment of temporary streams, (Figures 1 and 2). We synthesize, in a series of figures, the content and the way in which each tool has to be used (Figure 2). The aim is not to describe each of the tools in detail (such descriptions are provided by the papers listed in Table I) but rather to describe the overall process and the sequence in which the tools are to be used (Figure 2).

Temporary stream regime (TSR-Tool)

The first question to address is whether the stream is temporary and, if so, to what extent. This question is answered with the so-called TSR-Tool, which is described in detail in Gallart *et al*. (2012) and synthesized in Figure 3. To overcome the frequent lack or scarcity of hydrologic data from temporary streams, the TSR-Tool uses only data on the presence–absence of flow at a monthly scale, preferably from at least a 10-year monitoring period. If hydrological data are not available, then the TSR-Tool proposes the use of rainfall–run-off modelling or interviews with the inhabitants. The data obtained are used to calculate two metrics that synthesize the two main hydrological parameters relevant to the characterization of temporary streams: flow permanence and predictability of the dry season (Gallart *et al*., 2012). These specific metrics proposed in the TSR-Tool are as follows: (i) the long-term annual relative number of months with flow (M_f), as a measurement of flow permanence, and (ii) the 6-month dry-season predictability (Sd_6), a measurement of the seasonality of drying. Sd_6 is computed as follows:

$$Sd_6 = 1\left(\sum_1^6 Fd_i / \sum_1^6 Fd_j\right) \quad (1)$$

where Fd_i represents the multiannual frequencies of zero-flow months for the six contiguous wetter months in the year, and Fd_j represents the multiannual frequencies of zero-flow months for the remaining six drier months in the year. According to Gallart *et al*. (2012), the Sd_6 metric is dimensionless, with a value of 0 if no-flow conditions occur equally throughout the year, and a value of 1 if all of the no-flow conditions occur in the same 6-month period every year. If the regime is fully permanent, this metric cannot be computed, so the value of 1 may be used to indicate full predictability.

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Table I. Tools of the MIRAGE Toolbox, related documents from the MIRAGE project and peer-reviewed scientific journals where each tool is defined and used

Tool	Documents in MIRAGE	Papers produced by MIRAGE project	National guidance documents or standards
TSR-Tool (temporary stream regime)	Deliverable 3.3	Gallart *et al*., 2012	Italy: DM Ambiente 131-2008 Spain: MARM 2008
RC-Tool (reference conditions)	Deliverable 4.2	Sánchez-Montoya *et al*., 2009, 2012a.	CEDEX, 2004 (Spanish guidance) CNR-IRSA, 2008a, 2008b (Italian guidance)
HS-Tool (hydrological status)	Deliverable 3.3 and 3.5	Cazemier *et al*., 2011; Vernooij *et al*., 2011; De Girolamo *et al*., 2011, 2013a, 2013b (submitted)	Italy: DM Ambiente 260–2010 Italy: ISPRA, 2011
MUHC protocol		Cazemier *et al*., 2011; Vernooij *et al*., 2011; Querner *et al*., 2011	
AS-Tool (aquatic states)	Deliverable 3.4	De Girolamo *et al*., 2011; Gallart *et al*., 2012	
BioAS-Tool (biological assessment)			
ES-Tool (ecological status)	Deliverable 4.1	Sánchez-Montoya *et al*., 2011	HIBIM (Spain)
Sampling strategy	Deliverable 4.1	García-Roger *et al*., 2011 Buffagni *et al*., 2008	CHE, 2013 (Spain) STAR_ICMi (Italy: CNR-IRSA, 2007; DM Ambiente 56–2009)
Eurheic and oligorheic states	Deliverable 4.1	García-Roger *et al*., 2011	HIBIM, CHE, 2013 STAR_ICMi (Italy: DM Ambiente 260–2010) HES method (Greece) (Artemiadou and Lazaridou, 2005)
Arheic state	Deliverable 4.2 Deliverable 4.3	Steward *et al*., 2011	Non-existent
Functional measures	Deliverable 4.3	Dieter *et al*., 2011	Non-existent
PCHS-Tool (physicochemical status)		De Girolamo *et al*., 2012; Sánchez-Montoya *et al*., 2012b	NCS metric in Greece Italy: DM Ambiente 260-2010
CHS-Tool (chemical status)	Deliverable 7.3	Ademollo *et al*., 2011; David *et al*., 2012; Chahinian *et al*., 2013	WFD-CIS Guidance no. 25 on sediment and biota monitoring (European Commission, 2010)

National standard protocols where tools may be used are also indicated in the table.

Plotting the coordinates of M_f and Sd_6 in the TSR plot (Figure 3) allows the comparison between diverse regimes as well as the analysis of regime changes as a result of human activity. The plot is also designed to help classify the stream regime into one of the following regime types: (i) permanent (P); (ii) intermittent with pools in the no-flow period (I-P); (iii) intermittent with dry channel in the no-flow period (I-D); and 4(iv episodic-ephemeral (E). According to this figure, M_f should be close to 1 for a stream to be classified as permanent. To be classified as an intermittent stream with permanent pools (even in the dry season), a range of M_f values was proposed based on the degree of predictability ($M_f \geq 0.6$ if the stream is highly predictable, but $M_f \geq 0.85$ if predictability is low). This dependence is also valid for intermittent streams with dry channels in the summer ($0.3 \leq M_f \leq 0.6$ in predictable streams but higher values in unpredictable streams). Lastly, ephemeral–episodic streams are those without water for most of the time; hence, low values of M_f are expected. Practical examples of the use of the TSR-Tool may be found in Gallart *et al*. (2012) and De Girolamo *et al*. (2013a and b) (Table I).

Reference conditions (RC-Tool)

The RC concept is defined as the condition in the absence of human disturbance that is used to describe the standard, or

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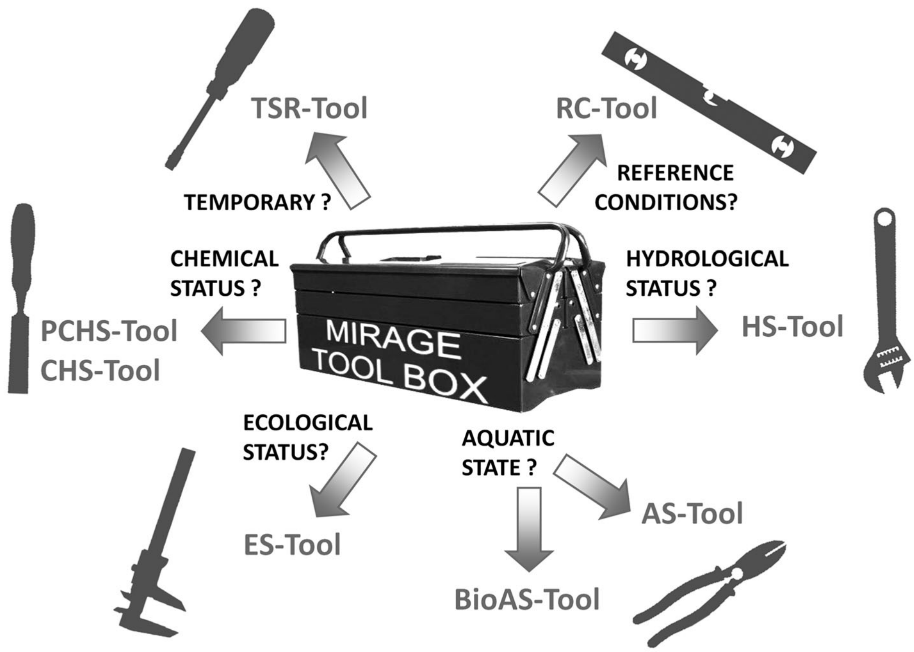

Figure 1. Schematic representation of the MIRAGE Toolbox and the tools that it contains. TSR: temporary stream regime; RC: reference conditions; HS: hydrological status. AS: aquatic states; BioAS: biological assessment of aquatic states; ES: ecological status; PCHS: physicochemical status.

benchmark, against which the current condition of a stream is compared (Stoddard *et al*., 2006). The method for determining if a site is in RC is an important issue because the same metric cannot be used as both of the following: (i) the criterion to establish the RC and (ii) the criterion to validate if a site is in the RC (Stoddard *et al*., 2006). The RC should be linked to transverse information such as stream typology. Moreover, reference sites should present the full range of conditions expected to occur naturally within a given stream type (Barbour *et al*., 1996; Reynoldson and Wright, 2000; Stoddard *et al*., 2006; Pardo *et al*., 2012). The selection of criteria for establishing RC in temporary streams is a complicated task because the river may dry out completely or only a few pools may remain during several months of the year (Sánchez-Montoya *et al*., 2012a).

The RC protocol evaluates a total of 37 attributes (Figure 4) in a stream. The protocol incorporates various aspects (i.e. diffuse sources of pollution and land uses, morphological alteration, presence/absence of invasive species, hydrological condition and others) at two different spatial scales (from the basin scale to the reach or segment; Sánchez-Montoya *et al*., 2012a). This protocol is a combination of criteria previously developed in the context of Mediterranean streams in Spain by Bonada *et al*. (2004), Munné and Prat (2009) and Sánchez-Montoya *et al*. (2009) and recently intercalibrated for several Mediterranean countries (Feio *et al*., 2013a). After this *a priori* selection, site validation must be applied to confirm and improve the selection of reference sites (Barbour *et al*., 1996). This is so because certain types of disturbances may be difficult to detect with the commonly used screening methods (Hering *et al*., 2006). There can be a particular need for the validation of a preliminary selection of reference sites in European rivers because these rivers are typically affected by multiple pressures, such as organic pollution or flow regulation (Hering *et al*., 2006). In this context, we propose three additional validation criteria (Figure 4). These criteria are all related to nutrient conditions (refer to Sánchez-Montoya *et al*., 2012b for details).

Hydrological status (HS-Tool)

Temporariness in rivers occurs not only because of specific climatic and geologic conditions but is also because of human actions. River flow may decrease because of direct abstraction or because of transmission losses induced by lowering of the groundwater level. Conversely, a naturally temporary stream may exhibit permanent flow because of waste water effluents or reservoir releases. It is important to determine whether the stream is hydrologically modified compared with streams in RCs because this modified status has direct consequences for biological communities (Belmar *et al*., 2012). The disruption of the natural magnitude or timing of stream flows is usually known as hydrologic alteration, and several methods are available for its assessment (e.g. IAH, The Nature Conservancy, 2009). Here, the HS-Tool is proposed to determine the HS (Figure 5), considering not

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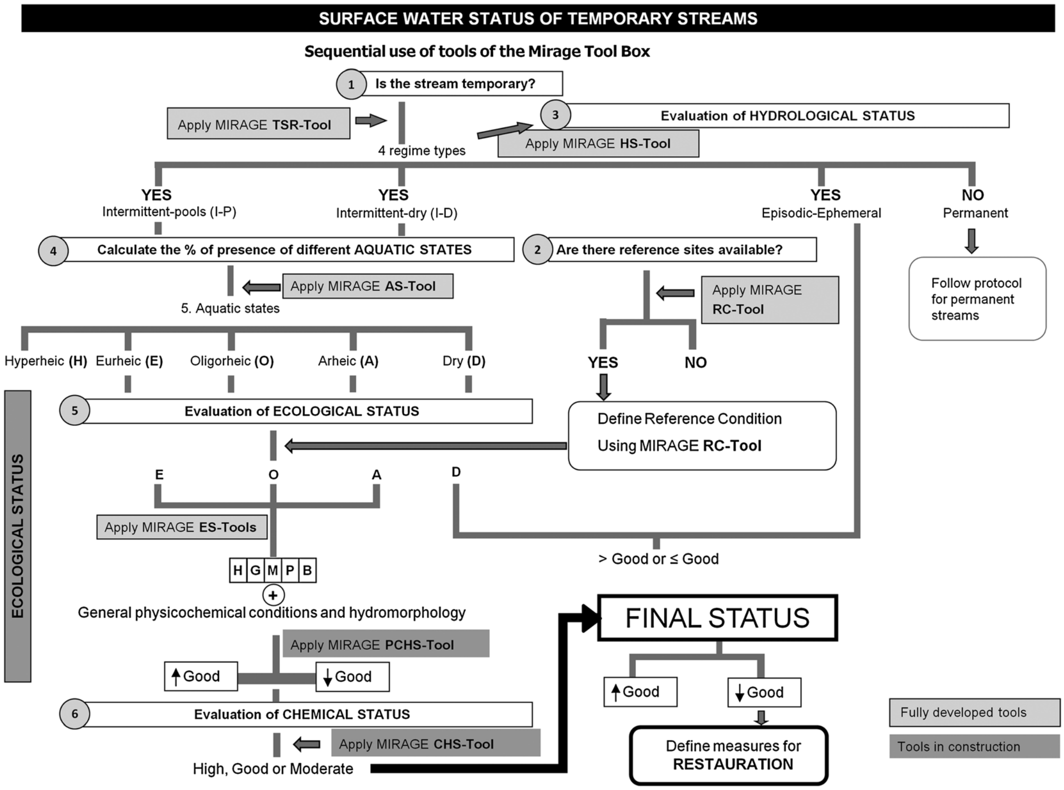

Figure 2. Flowchart showing the sequential use of the tools from the MIRAGE Toolbox. Acronyms for tools as in Figure 1. Codes for aquatic states as follows: H: hyperrheic, E: eurheic, O: oligorheic, A: arheic; D: dry (hyporheic and edaphic states). Codes for ecological status: H: very good; G: good; M: moderate; P: poor; B: bad.

the magnitude of stream flows but the duration and timing of the periods without flow or the occurrence of the diverse ASs (refer to the next section for their definition).

The assessment of the alteration of the hydrologic regime requires that two of the three following data sets are available: (i) the recorded/gauged flow; (ii) the natural flows; and/or (iii) the water releases and net abstractions (excluding flows returned to the system after use). A first approach, consistent with the other tools, is based on the comparison between the regime at the studied reach and the regime in a reach in RC as a surrogate of the natural regime. The two regime metrics (M_f and Sd_6) described in the preceding texts are compared, assuming that both reference and studied sites belong to the same river type. Note that if RC sites are not available for any reason, we propose here alternative modelling approaches to simulate flow and to estimate the temporary regime metrics.

The regime of the stream is determined by searching the coordinates of the two metrics in the TSR plot (plot of M_f and Sd_6, as shown in Figure 3). The Euclidean distance between the RC site and the study site is then measured and compared with the annual variability of the metrics. If a transition to a regime type different from the RC site has occurred, it can then be concluded that the study stream is hydrologically altered. If no RC sites are available for the comparison, we suggest simulating the natural or altered stream flow of the study site by means of available, suitable hydrological models (e.g. Soil and Water Assessment Tool and SIMulation of GROundwater). The steps for this process are included in the Modelling Ungauged Hydrological Conditions (MUHC) protocol, developed within the MIRAGE project (Figure 6). At least 5 years of river flow are simulated by the model using hydrological parameters from similar or neighbouring subbasins and/or expert judgement. This procedure has been applied in the Candelaro Basin (De Girolamo *et al.*, 2013a) and in the Evrotas Basin (Greece) (Cazemier *et al.*, 2011; Querner *et al.*, 2011; Tzoraki *et al.*, 2013).

Aquatic states (AS-Tool)

Aquatic states are defined as the transient assemblages of the aquatic habitats occurring in a stream reach in a wet–dry cycle. According to Gallart *et al.* (2012), six ASs exist in temporary streams: *hyperrheic* (H), *eurheic* (E), *oligorheic* (O), *arheic* (A), *hyporheic* and *edaphic* (Figure 7). A stream is in *hyperrheic* state when water discharge is unusually high (flood), inducing major erosion of bed sediments and biota. The *eurheic* state implies that the river is flowing,

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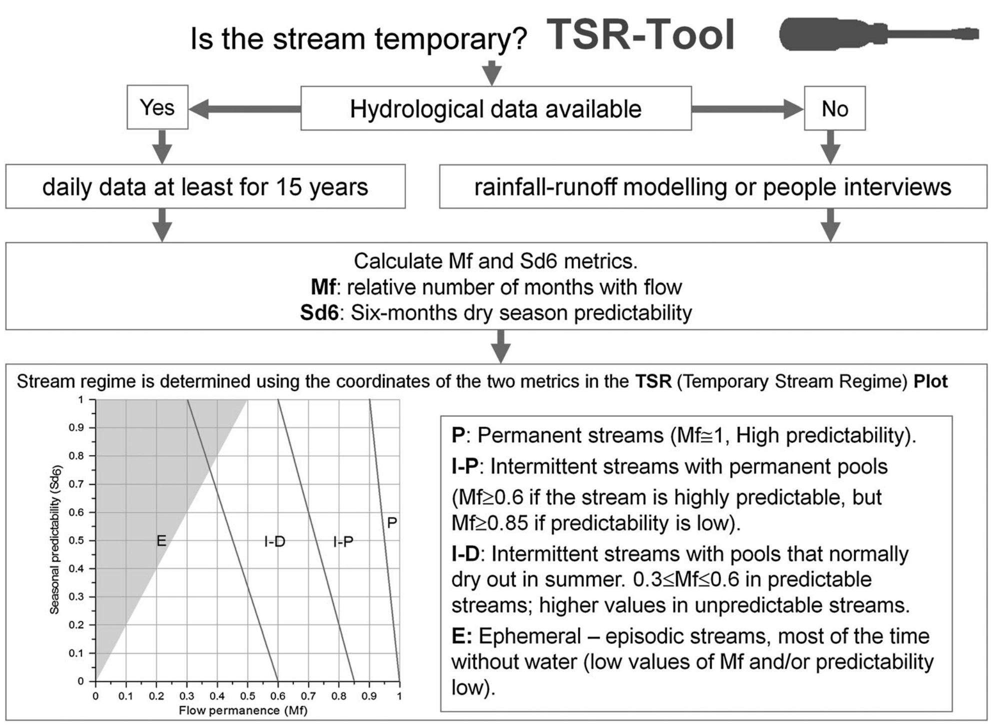

Figure 3. TSR-Tool. Flowchart showing the steps used to determine whether the river is temporary. P: permanent; I-P: intermittent with pools; I-D: Intermittent dry; E: ephemeral. Refer to Gallart *et al*. (2012) for details.

and the river mesohabitats (e.g. riffles and pools) are present and fully connected. The *oligorheic* state occurs when pools are the dominant mesohabitat, but they are still connected by a surface flow. The *arheic* state implies that pools are present but totally disconnected by any surface flow. The *dry bed* state (D) implies that no surface water is available in the mainstream section with (*hyporheic* state) or without (*edaphic* state) saturation of the alluvium. A detailed description of the ASs and their relationship to previous studies (e.g. Boulton *et al*., 1998; Boulton, 2003) is provided in Gallart *et al*. (2012).

Although the TSR-Tool provides a quantitative classification system for measuring the degree of temporariness, the AS-Tool provides a more qualitative but nevertheless illustrative analysis of the river regime. The AS-Tool has the following three main purposes: (i) to describe the temporal occurrence of the ASs throughout the year in the long term; (ii) to select the expected best date for sampling the aquatic biota in temporary streams for their ES assessment; and (iii) to analyse the recent history of the ASs during the weeks prior to the sampling that may affect biological communities.

Beyond the lack of active aquatic species in dry river beds (D), other strong constraints also affect the aquatic species when the stream is in flood (H) or only disconnected pools remain (A). Stream biodiversity is usually low after floods; consequently, quality metrics will be low. In contrast, the stream biological communities may change to a greater or lesser extent in the *arheic* state depending on the time elapsed since the moment of pool disconnection (Buffagni *et al*., 2010). Note that environmental conditions (both biotic and abiotic) may be very different between pools (e.g. differing in size and exposure) and within the same pool during the drying phase. This will most likely lead not only to a decrease of taxa richness but also to a replacement of its resident community. For these reasons, the assessment of the ES in temporary streams using aquatic biota should preferably be performed when the stream is in the *eurheic* or *Oligorheic* state (refer to the succeeding texts, the ES-Tool section). This recommendation is important for further steps within the sequential use of the MIRAGE Toolbox because the ES assessment of streams is primarily based on the sampling of the biotic community inhabiting the system. Knowledge of the different mesohabitats present in a stream and their temporal occurrence is thus crucial for an adequate analysis of the ES of temporary streams (García-Roger *et al*., 2011; Gallart *et al*., 2012).

As there is usually no information on the temporal occurrence of ASs, it is necessary to use flow records (or simulations) to obtain statistics. A critical issue at this step is the selection of threshold flow values that distinguish between the occurrences of the different ASs. To correctly identify

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Is the stream in Reference Conditions? **RC-Tool**

Apply the Reference Conditions Protocol (Evaluate 37 attributes for each site)

- Reference criteria: 37 criteria

Spatial Scale	Type of pressure	Criteria	Threshold
BASIN SCALE	Land uses	1. Urban and industrial land use	<0.4%
		2. Superficial mining land use	<0.4%
		3. Landfill site	<0.4%
		4. Intensive irrigated farming (vineyards, orchards and rice).	<1%
		5. Intensive farming (cereal other irrigated fruit trees, etc)	<10%
		6. Dry land farming	<30%
		7. Forestry, tree plantations (non native)	< 30%
		8. Natural areas	>70%
		9. Burnt vegetation	< 7%
RIVER SEGMENT	Morphological alteration	10. Representative diversity of substrate materials appropriate for the type	yes
		11. Artificial bank structures along the river segment	<10%
		12. River profiles along the river segment	<20%
		13. Minimal length to dams and weirs	≥10 km
	Invasive species	14. Non indigenous species (animals or plants) recently introduced, not known to present a risk of being invasive	<3
		15. Alien species (animals or plants) in stage of active colonisation, which are quantitatively predominant	Inexistent o 1
	Hydrological condition	16. Dams which significantly modify the natural hydrological flow regime (flow regulation) located upstream	Inexistent
		17. No effect of inter-basin water transfer	
		18. Near natural level of groundwater (aquifer not affected by over-exploitation).	
	Land uses in floodplain occupation: 100 m.	19. Urban and industrial land uses	<0.4%
		20. Extractive activities (sand and gravel extraction)	<10%
		21. Intensive irrigated farming (vineyards and orchards)	Inexistent
		22. Intensive farming	<10%
		23. Dry land farming	<20%
		24. Fast-growth riparian forestry, tree plantations (non native species)	<20%
		25. Natural areas	>80%
	Land uses in riparian corridors occupation: 30 m.	26. Urban and industrial land uses	<0.2%
		27. Extractive activities	<5%
		28. Intensive irrigated farming (vineyards and orchards)	Inexistent
		29. Intensive farming	Inexistent
		30. Dry land farming	<10%
		31. Forestry, tree plantations (non native species)	<10%
		32. Burnt vegetation (to create fresh pastures)	Inexistent
		33. Natural areas	>90%
		34. Cattle breeding or farming	Inexistent
		35. Rubbish and effluent (liquids and solids) dumping	Inexistent
		36. Use as roads	Inexistent
		37. Recreational use (parking places and parks)	Inexistent

- Validation criteria: 3 criteria

Spatial scale	Criteria	Threshold (High-Good)
site	N-NH4+ (mg/l)	≤0.031
	N-NO3- (mg/l)	≤0.480
	P-PO4- (mg/l)	≤0.041

37 reference
+ 3 validation

REFERENCE SITES

Figure 4. RC-Tool. Flowchart showing the steps to obtain a model for reference sonditions situation: (S) thematic geographical and cartographic information systems; (E) measured data using aerial photos and maps; (C) data measured or observed in the field and/or laboratory; (T) data from technical reports. Refer to Sánchez-Montoya *et al*. (2012a) for details.

these thresholds, both field observations on the ASs and synchronous discharge measurements are needed (Gallart *et al*., 2012). Once the discharge thresholds between ASs are defined, it is possible to compute their long-term monthly frequencies using flow records. These frequencies can be plotted on the AS frequency graph, with the frequencies accumulating from drier to wetter states for every month (Figure 7). This graph may then be used to schedule the best period of the year for sampling the biota, that is, the period when the opportunity to find well-developed aquatic communities is the greatest.

It is occasionally difficult (if not impossible) to establish the ASs from hydrological parameters because of a lack of data. In these cases, the possibility of using biotic

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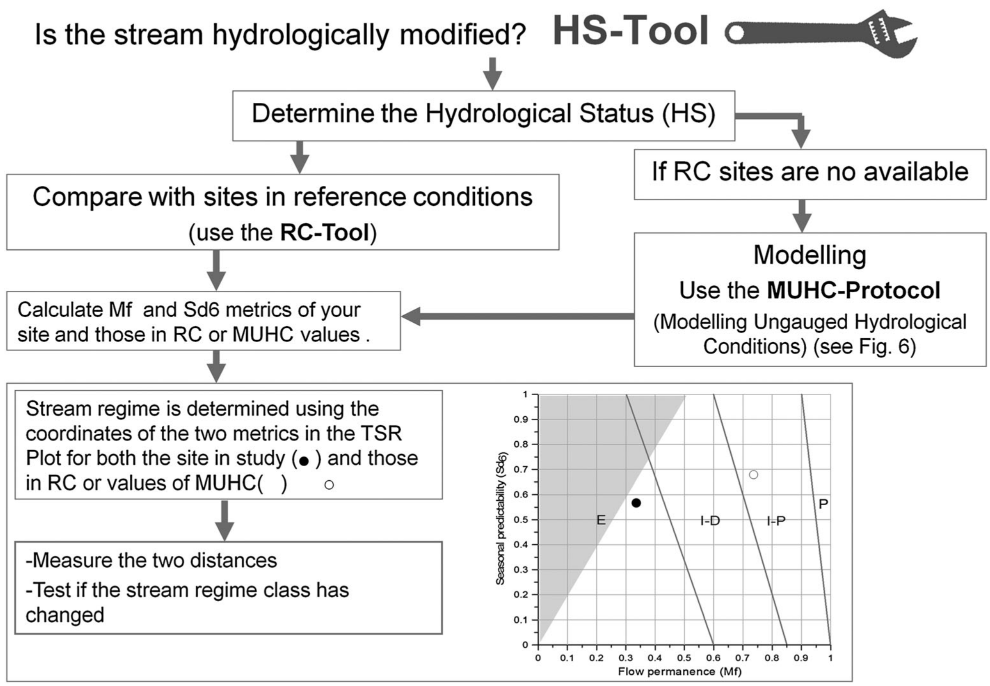

Figure 5. HS-Tool. Flowchart showing the steps used to determine the hydrological status based on the availability or non-availability of RC. Codes as in Figure 3. Refer to Querner *et al*. (2011) and De Girolamo *et al*. (2013a, 2013b) for details.

assemblages (i.e. macroinvertebrates) to define the ASs is being explored by the development of a new tool called the BioAS-Tool. Many observations of macroinvertebrates in streams and rivers are recorded without any indication of the hydrology. As it is necessary to know the AS to determine the ES in a sampling moment, the BioAS-Tool will allow managers to establish the ASs from samples collected in the past.

Ecological status (ES-Tool)

The main objective of the ES-Tool is to specify the ES of temporary streams in terms of five quality classes as required by the EU-WFD (Figure 2). Note that the ES assessment requires previous analyses of the hydrological regime using the TSR-Tool and AS-Tool and the determination of the AS at the sampling date. These conditions are especially critical because the only valid methods available to date to determine the ES are only applicable when the stream has been in the *eurheic* and *oligorheic* state for a sufficiently long period. Guidance for an adequate sampling method for aquatic macroinvertebrates in temporary streams, which has been developed within the framework of the MIRAGE project, can be found in García-Roger *et al*. (2011).

The ES of a stream can be determined from data on the aquatic macroinvertebrate communities through the use of metrics such as richness and diversity at the taxonomic level of family. Alternatively, more sophisticated multimetric indexes developed in the last years are available for this purpose (Hering *et al*., 2006; Munné and Prat, 2009). Several biological metrics have been used for stream quality monitoring in the MIRAGE project, such as the number of family taxa, the number of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa and two multimetric indexes, the STAR Intercalibration Common Metric Index (STAR_ICMi) and the Index Multimètric Mediterrani quanTitatiu index (García-Roger *et al*., 2011). Interestingly, the STAR_ICMi has been used to calibrate the indexes that we have used in our streams (Buffagni *et al*., 2006). For more information on how these metrics respond to the changes in the transition from lotic to lentic conditions in temporary streams, refer to Buffagni *et al*. (2009), Rose *et al*. (2008) and Munné and Prat (2011). Feio *et al*. (2013b) have recently investigated the definition of limits separating quality classes in Mediterranean streams.

Is there any way to establish the ES of a dry stream? Although temporary streams are often dry, the structure and function of dry stream beds have rarely been explored (Wishart, 2000; Steward *et al*., 2012). To fill this gap, the MIRAGE project has investigated a new methodology using terrestrial invertebrates to assess the ES when the stream channel is devoid of surface water (D state). It is based on the sampling of terrestrial invertebrates (Figure 8) and

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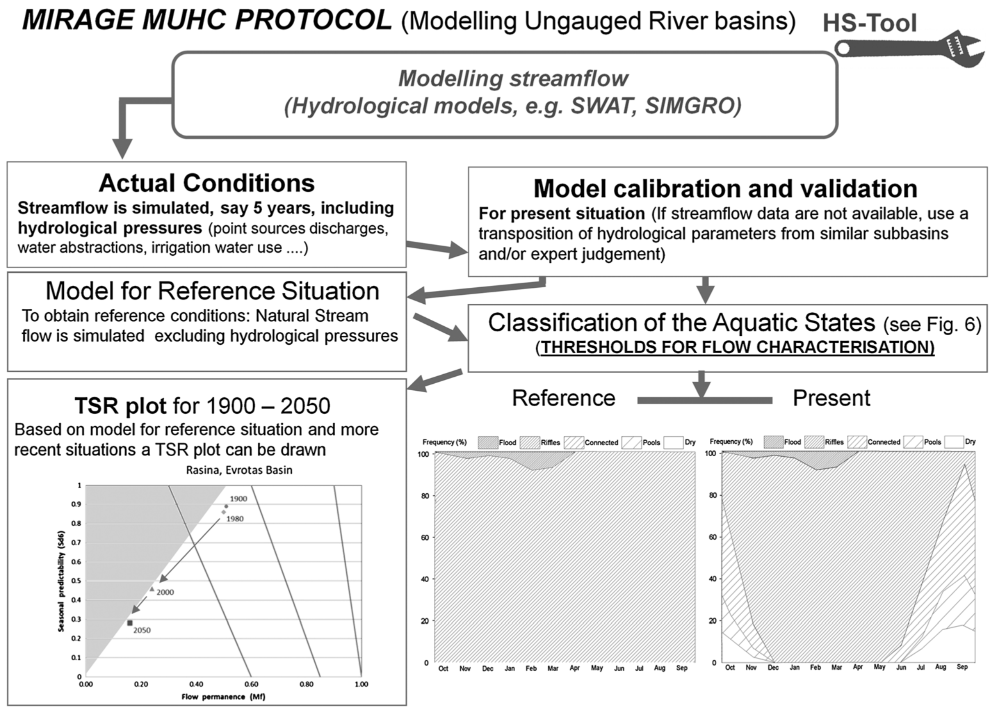

Figure 6. Flowchart showing the steps used to perform the MUHC protocol to establish the hydrological status if no gauging stations are located in the studied basins. Refer to Querner *et al*. (2011) and De Girolamo *et al*. (2013a, 2013b) for details.

implies that a distinctive community of terrestrial invertebrates is present during the dry phase (Steward *et al*., 2011; Table I). Note that this methodology is especially interesting for episodic/ephemeral streams, where standard aquatic macroinvertebrate-based methods are not applicable (Corti and Datry, 2012). Currently, however, no standardized method is available. During the MIRAGE project, substantial advances have been made in defining sampling procedures, but the use of the macroinvertebrate data collected with these samples to establish the ES is still a research topic. The major issues are the lack of adequate guides to classify the animals and the need to establish associations between the taxa present and the environmental pressures.

The ES of streams and rivers has traditionally been assessed using structural measurements such as the biological metrics indicated in the preceding texts. However, a more complete assessment of the ES should include functional metrics (Figure 8). The importance of using functional indicators has been stressed recently by Palmer and Febria (2012). An important advantage of functional metrics is that most of them can be applied in all AS that a temporary stream may experience during the year. The functional metric that has been most thoroughly evaluated by members of the MIRAGE project is leaf litter decomposition (Gessner and Chauvet, 2002; Datry *et al*., 2011). The sampling methodology, which implies the deployment and tracking of leaf litter bags, has been described by Dieter *et al*. (2011), who performed a pilot study monitoring five catchments of the MIRAGE project. However, although considerable advances have recently been made, no standardized method defining water quality indices and boundary layers for ES assessment using these tools is yet available (Woodward *et al*., 2012). Other functional measures whose evaluation has started only recently in the MIRAGE project include biofilm activity, nutrient uptake and ecosystem metabolism (Timoner *et al*., 2012)

Physicochemical status (PCHS-Tool)

This tool was designed to determine the PCHS of temporary streams. This information is necessary to establish their ES (Figures 2 and 9). Physicochemical variables are considered in the EU-WFD as support elements for the determination of the ES (WFD Directive Annex V). As indicated by the EU-WFD, eight items are considered to be of major importance. These items are the thermal, oxygenation and salinity conditions, the acidification status and the concentrations of nutrients. The reference threshold values for physicochemical parameters, proposed specifically for temporary streams, are established and discussed in Sánchez-Montoya *et al*. (2012b) and summarized in Figure 9. In terms of the classification of the stream's nutrient status, a biologically based nutrient classification system has been developed both

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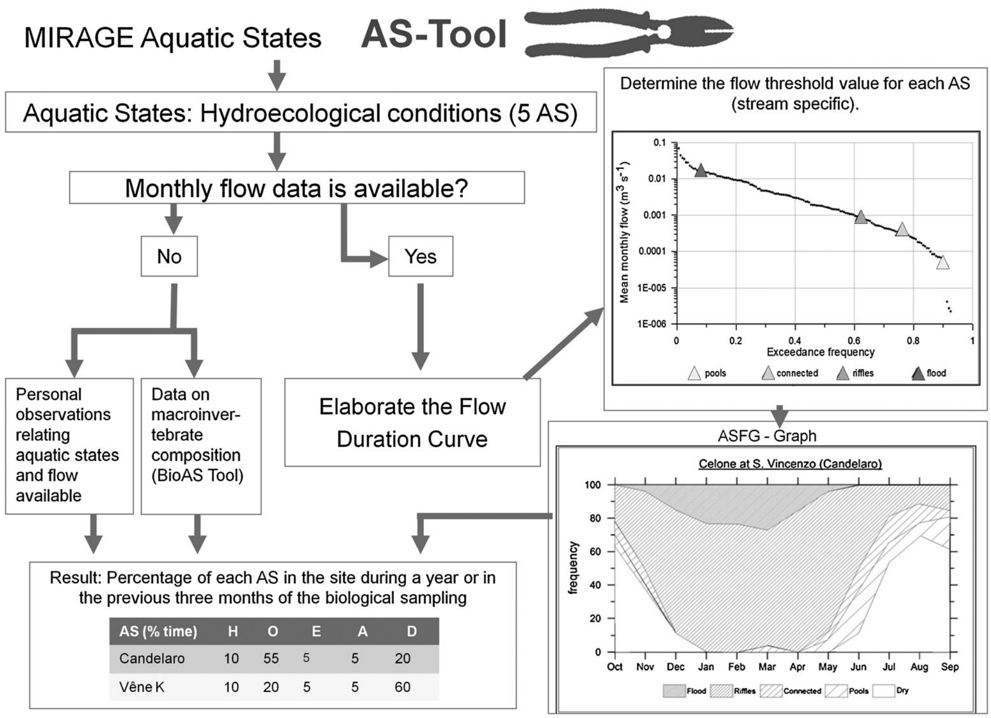

Figure 7. AS-Tool. Flowchart showing the steps to determine the aquatic states of the streams H: hyperrheic, E: eurheic, O: oligorheic, A: arheic; D: dry (hyporheic and edaphic states). Refer to Gallart *et al.* (2012) for details.

for permanent and temporary streams (Skoulikidis *et al.*, 2006). This system may serve as a guide for the PCHS classification of temporary streams.

The PCHS-Tool is not separated from the other tools in the MIRAGE Toolbox but has been developed in view of the spatial and temporal variability of the physicochemical conditions of the waters of temporary streams through the different ASs (Figure 9). We also consider that the *eurheic* and *oligorheic* AS are the best states for the application of the PCHS-Tool, as they show a lower spatial variability of

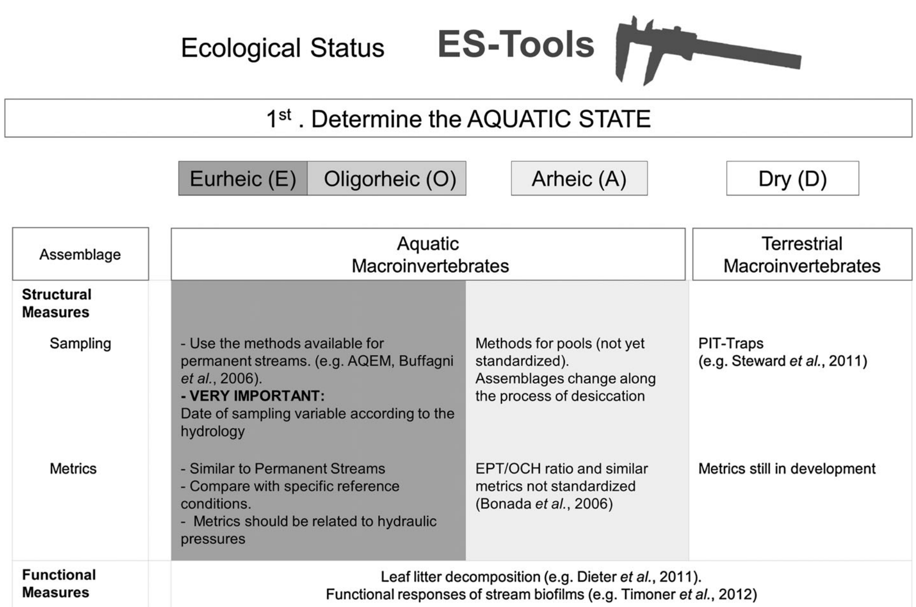

Figure 8. ES-Tool. We indicate the tools already available and the work achieved in the MIRAGE project. Structural indicators are well known and have been treated extensively in several papers. For application in Mediterranean streams, refer to Munné and Prat, 2009, 2011.

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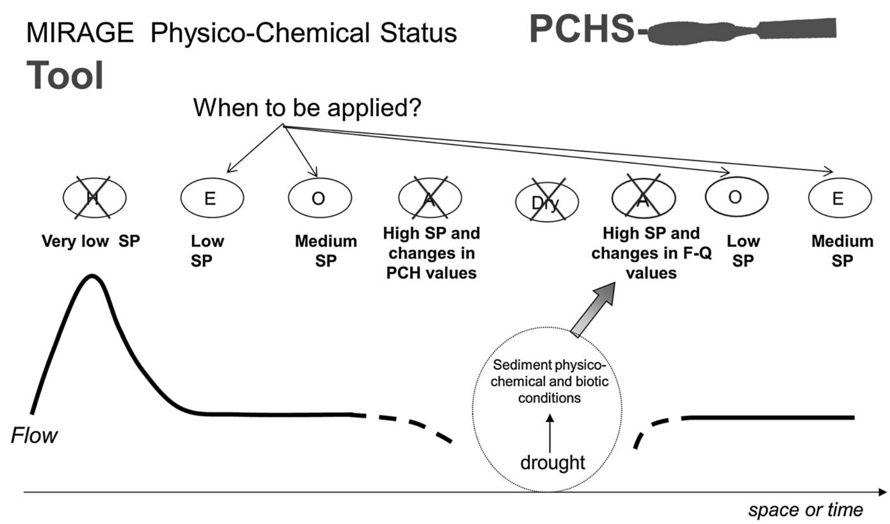

General parameters	Reference Value	High-Good
Oxygen saturation (%)	97.0	91.0-103.2
Dissolved Oxygen (mg/l)	9.9	8.1-10.8
Conductivity (μS/cm)	337	443
pH	8.0	8.3

General parameters	Reference Value	High-Good
Phosphate (mg/l)	0.027	0.041
Nitrate (mg/l)	0.232	0.480
Nitrite (mg/l)	0.019	0.041
Ammonium (mg/l)	0.023	0.031

Figure 9. PCHS-Tool. Time scale of application of the PCHS-Tool in relation to the transition of AS in the natural hydrological cycle of temporary streams. Acronyms for aquatic states as in Figure 7. SP means spatial variability in physical conditions and solute concentrations. Refer to Sánchez-Montoya *et al*. (2012b) for details.

physicochemical conditions. The *arheic* state usually shows a high spatial variability of physicochemical conditions even at the reach scale (Gómez *et al*., 2009). It has been observed that as surface water flow decreases, the heterogeneity of local stream-channel environmental conditions (e.g. water residence time, biological community structure, sediment–water interactions, and redox conditions) increases (Dahm *et al*., 2003; Lewis *et al*., 2007; Lillebo *et al*., 2007; Von Schiller *et al*., 2011). In contrast, under the high flood conditions of the *hyperrheic* state (i.e. during or just after a flood event), physicochemical conditions are highly influenced by the features of the rainfall event (e.g. the amount of rainfall and the intensity of the event) and the conditions of the basin (Vidal-Abarca *et al*., 2004; Tzoraki *et al*., 2007; Von Schiller *et al*., 2011; De Girolamo *et al*., 2012). Because of the absence of surface water, the PCHS-Tool cannot be applied during hyporheic–edaphic (dry) states, although it has been demonstrated that these ASs influence several of the physicochemical conditions after rewetting (Gómez *et al*., 2012).

Chemical status (CHS-Tool)

The monitoring obligations for priority substances established by Directive 2000/60/EC (European Communities, 2000) are never feasible for the particular characteristics of temporary rivers, and a specific guideline for monitoring hazardous substances has been developed during the MIRAGE project (CHS-Tool; Figure 10). First, the planning of monitoring should incorporate considerations of the TSR-Tool and the AS frequency graphs. During normal flow conditions (eurheic and oligorheic states), the monitoring in the case of I-P rivers should follow the recommendations for water bodies (European Commission, 2010). Water monitoring frequencies should be selected to address the variability in concentrations resulting from both natural and anthropogenic conditions. When there is a potential concentration peak because of the flow onset and release of pollutants from sediment (Ademollo *et al*., 2011), an increased monitoring frequency is required. Besides, it is also important to sample solid phase matter with a time-integrating system to check the compliance with maximum allowable concentrations Environmental Quality Standard established in Directives 2008/105/EC (European Communities, 2008) and 2013/39/EU (European Union, 2013).

During the dry phase of I-P rivers and in the case of I-D and E rivers, it is advisable to analyse fluvial sediments, which have been demonstrated to be a reservoir for lipophilic hazardous substances. The quality of sediments is also related to the ES and has particularly important effects on the reproductive cycles of aquatic organisms (Archaimbault *et al*., 2010). As verified in the MIRAGE project, the spatial heterogeneity of temporary rivers can be very high if several hydrological conditions and habitats are simultaneously present in transects: riffle, run, pool and dry sites. It is important to sample each condition. Sediment can be sampled

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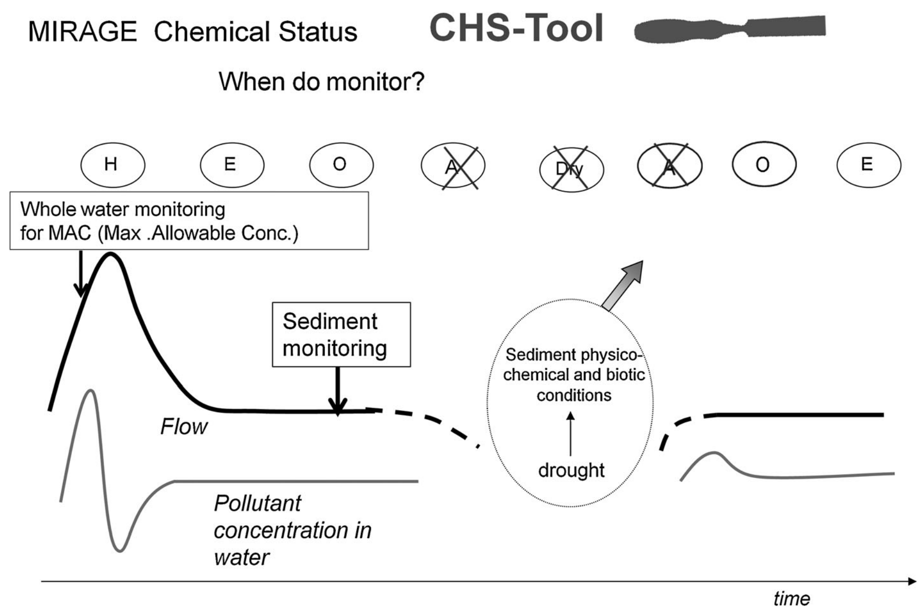

Figure 10. CHS-Tool. Time scale of application of the CHS-Tool in temporary rivers for the various types of measurements to be made according to the WFD-CIS Guidance 25 (European Union, 2010), acronyms for aquatic states as in Figure 7.

once per year (i.e. minimum requirement of the EU-WFD), but care should be taken to the sample at the end of the winter or at the beginning of the spring prior to the dry period, preferably in the *oligorheic* AS, and in a period with low current velocities.

DISCUSSION

The variation in hydrological conditions in temporary streams leads to time-varying aquatic mesohabitat conditions (i.e. ASs) that play a key role in determining the streams' biological communities (Boulton, 1989, 2003; Arscott *et al*., 2010; García-Roger *et al*., 2011) and ecosystem functioning (Fisher *et al*., 1998; Acuña *et al*., 2005; San Giorgio *et al*., 2007; von Schiller *et al*., 2008; Corti *et al*., 2011; Dieter *et al*., 2011; Datry *et al*., 2014). This effect is so important that temporary streams can be considered a distinct class of ecosystem rather than simply hydrologically challenged permanent streams (Larned *et al*., 2010). These particularities of temporary streams directly demand specific tools and metrics for their management because the traditional perception that a healthy stream must flow all year round is not applicable to temporary streams (Steward *et al*., 2012).

The MIRAGE Toolbox allows an integrated assessment of temporary streams and can be applied to the wide range of existing temporary stream types, as it provides the following: (i) an accurate classification system for the degree of intermittency of temporary streams relevant for biological communities and (ii) an adequate procedure for defining sampling schedules (for biological and chemical samples) according to the AS of the stream. These schedules are not based on the time of the year (spring versus summer sampling times, as commonly used in practice) but according to the AS of the stream. As indicated by Munné and Prat (2011), the antecedent hydrological conditions may change the values of the biological quality metrics. Therefore, it is crucial to know the antecedent ASs before sampling because taxa composition may be very different before, during and after a dry period. For this reason, the timing of sampling can strongly influence the outcome of further analyses. Hence, the characterization of the different ASs that a temporary stream undergoes based on long-term or simulated flow data and the calculation of the M_f and Sd_6 metrics are crucial in defining the moment at which biological and water samples should be taken.

The use of the MIRAGE Toolbox is comparable with that of a Swiss utility knife. For each specific tool, it offers a number of alternative approaches to accomplish the desired purpose. For instance, the TSR-Tool and HS-Tool can be used to determine whether the study stream is temporary and whether the stream hydrological regime has been altered by human activities. Thus, users can benefit from reported long-term hydrological data if available or, alternatively, use data obtained from modelling. The MIRAGE Toolbox also provides a link to the software needed to implement the modelling in each case (Vernooij *et al*., 2011). Another example of the extensive functionality of the toolbox is the broad array of metrics that can be used for the ES-Tool. As stated in the preceding texts, not only community descriptors using various aquatic organisms (e.g. diatoms,

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macroinvertebrates, and fishes) but also terrestrial assemblages and functional indicators (e.g. leaf processing; Dieter *et al*., 2011) can be used.

According to Datry *et al*. (2014), temporary river ecology is still in its infancy despite several recent advances and revisions on the topic (e.g. Larned *et al*., 2010; Sabater and Tockner, 2010). This general lack of knowledge limits our ability to provide clear management advice for temporary rivers. The MIRAGE Toolbox aims to address several of these limitations by providing an array of tools to be applied in a sequential manner to define the ES of temporary streams. Nevertheless, several bottlenecks remain, and further research is necessary to improve the performance of the MIRAGE Toolbox for managing temporary streams.

One of the most critical steps of the procedure is the selection of the threshold flow values that demarcate the occurrence of the diverse ASs (AS-Tool). As stated in the preceding texts, this selection should preferably be performed based on the shape of the flow duration curve (i.e. the distribution function of flow discharges; Figure 7). To identify these thresholds correctly, field observations on the ASs synchronous with discharge measurements are needed for each stream. However, in the absence of such observations, thresholds can be estimated only provisionally by incorporating the width and regularity of the stream bed reach near the gauging station (Gallart *et al*., 2012). This approach based on the qualitative aspects of hydrology, instead of those based more specifically on the measurements of flow (Riegels *et al*., 2011), tries to overcome the usual scarcity or lack of data in temporary streams and facilitate the use of other sources of information, including data from maps, field observations or the experience of people living in the area.

A similar problem arises in relation to the characterization of the stream regime. As described in the preceding texts (TSR-Tool), the stream regime is operationally determined from the combination of two metrics: M_f and Sd_6, as shown in Figure 3 (TSR plot). Although proven useful in the pilot study sites of the MIRAGE project (Gallart *et al*., 2012), the boundaries between the regime types are still tentative. These boundaries will be refined as more sites are analysed, improving our ability to categorize and score the range of values observed against valid references. Additionally, the longitudinal heterogeneity along the river of the TSR plot must be considered. How to address this internal heterogeneity is a topic for further research.

The assessment of temporary streams can be achieved with the tools described before if hydrological data are available (e.g. from gauging stations) or inferred from models. Nevertheless, these two alternatives may not be a panacea. Installing gauging stations on temporary streams may represent an economic investment that is not always feasible. In contrast, mathematical models require long-term environmental data series to be parameterized, but such data series are not always available. As a result, in those cases where the hydrological data are missing, we do not yet have a proper tool for establishing the TSR and subsequently the ES. The MIRAGE team is aware of this problem and is currently developing a tool (BioAs-Tool) based on the hydrological preferences of indicator organisms to relate their relative abundances under different flow conditions at the reach scale (Mérigoux *et al*., 2009). It has been demonstrated that metrics such as EPT (the sum of the number of EPT taxa) and Odonata, Coleoptera and Heteroptera (OCH; the sum of the number of OCH taxa) respond to the seasonal changes in flow variation in Mediterranean temporary streams (Bonada *et al*., 2006). Other approaches based on the biological traits of organisms inhabiting temporary streams in the Mediterranean region have also proven useful (Bonada *et al*., 2007; García-Roger *et al*., 2013). Following this idea, the objective of the BioAs-Tool is to develop a methodology that enables us to determine the AS of temporary streams when biological sampling was made using the macroinvertebrate community as a proxy.

The MIRAGE Toolbox can be further enhanced and expanded in future versions, especially after the development of standardized protocols and biological indexes including functional measurements, such as organic matter breakdown, and sampling of terrestrial invertebrate assemblages during the dry AS. Organic matter breakdown links the characteristics of riparian vegetation with the activity of both aquatic invertebrates and microbial organisms, whereas the structure of terrestrial invertebrate assemblages colonizing the dry stream bed may be influenced by anthropogenic disturbances in the dry channel (Steward *et al*., 2011). Organic matter decomposition is one of the ecosystem processes that best meet the requirements of good indicators and, thus, offers the highest potential as an indicator of the functional aspects of river ecosystem health (Young *et al*., 2008; Woodward *et al*. 2012). However, further research on the influence of interacting stressors on organic matter decomposition responses is needed. In this sense, results from the MIRAGE project have indicated the importance of preconditioning during intermittent flow on organic matter processing rates in temporary streams (Dieter *et al*., 2011). Lastly, functional indicators should be seen as complementary to traditional (structural) monitoring tools. Measurement of both structural and functional aspects provides a more complete picture of ecosystem health than either aspect alone (Young *et al*., 2008). Despite the efforts devoted to functionality recently (Datry *et al*., 2014), we are still far from an effective integration of the structural and functional aspects to be used for the measure of the ES in temporary streams. The MIRAGE Toolbox is another step in this direction, offering an increased emphasis on the hydrological constraints that affect the derivation of ES.

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