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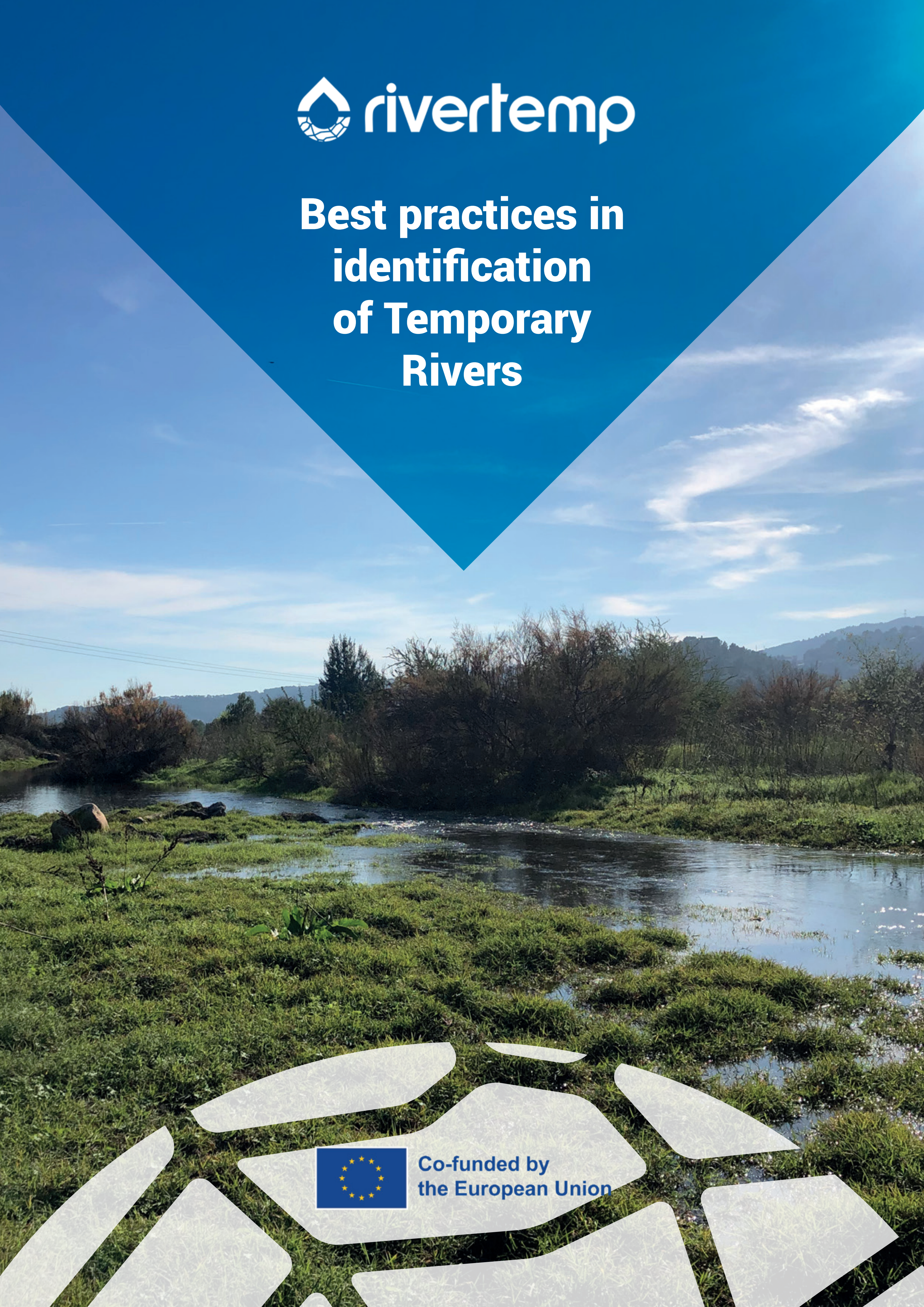
Best practices in identification of Temporary Rivers



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1. Introduction

1.1 Definitions of non-perennial rivers

Non-perennial rivers (NPRs) are defined as watercourses that may dry up for some period of time within the year (European Parlament - Water Frame Directive 2000/60/CE, 2000). It is important to clarify that NPRs are all rivers in which some data demonstrate the absence of water along the riverbed (Figure 1).

Figure 1. An example of the potential variations observed in the same portion of a temporary river within the same year: A) ponding (16-12-2022). B) dry (16-04-2023). Photos by I. Brichetto, Palancia river, Valencian Community (Spain).

The definition includes a wide range of different intermittencies: from the river with episodic water presence to quasi-perennial rivers (Magand et al., 2020). These rivers were usually located in regions with a semi-arid or arid climate, where the dry season is longer each year than in other regions (Shanafield et al., 2021). However, this phenomenon occurs wherever in the world, and it has

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been demonstrated that NPRs are ubiquitous (Allen et al., 2020; Messager et al., 2021).

Beside their ubiquity, the NPRs had and still have difficulties being recognized and classified in national legislation as a group of rivers with specific characteristics and needs (Fritz et al., 2017). In Europe, the Water Framework Directive (WFD) was adopted in 2000 to establish a new framework for the protection and sustainable management of water resources. Its purpose is to classify the ecological quality of surface water bodies and achieve "good ecological status" for all inland and coastal waters within the EU, defining for all surface water bodies a reference condition that represents the undisturbed condition (Magand et al., 2020). Only some countries in the Mediterranean region integrate the WFD with national implementations that introduce the concept and some classifications for the rivers in which may occur drying events. In 2008, Spain and Italy, respectively with ORDEN ARM/2656/2008" (Figure 2) and "Decreto Ministeriale 16 giugno 2008, n. 131" (D.M. 131/2008, Figure 3), defined a possible classification of the different temporariness.

Perennial	Water courses have natural flow regime conditions flow during the whole year.
Temporary or seasonal	Water courses where natural flow regime conditions present a marked seasonality, showing reduced flow or dry riverbed in summer, and flow is present during an average period of 300 days in a year.
Intermittent or strongly seasonal	Water courses where natural flow regime conditions present a high temporality, and flow is present during an average period between 100 and 300 days in a year.
Ephemeral	Water courses that in natural flow regime conditions only flow sporadically, mainly in storm episodes, during an average period less than 100 days in a year.

Figure 2. Classification of the different river temporariness types in the WFD (ORDEN ARM/2656/2008) (for the implementation of WFD 2000/60/CE). The no-flow days' data for an undisturbed regime are obtained with the help of a rainfall-runoff model.

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Stream type	Description
Temporary	Watercourse that can dry out completely and/or at some stretches
• Intermittent	Water is present more than 8 months a year. It may dry out in some river stretches and/or several times a year
• Ephemeral	Water is present <8 months a year. Disconnected pools may remain
• Episodic	Water only present after heavy rains, once every 5 years

Figure 3. The table in figure shows the temporary rivers classification defined in the Italian D.M. 131/2008 (for the implementation of WFD 2000/60/CE).

To maintain consistency with the normative definitions and facilitate comparability of assessment methods and ecological status classes between Member States, a two-phase Intercalibration Exercise was conducted to ensure alignment of class boundaries. The Intercalibration Exercise was executed by five Geographical Intercalibration Groups (GIGs), one for each of the five regions that share similar water body types across Europe (Fritz et al., 2017). The Mediterranean GIG, comprising Bulgaria, Cyprus, France, Greece, Italy, Portugal, Slovenia and Spain, introduced a classification, called RM5 for non-perennial rivers known as *Temporary streams*, where all kinds of possible NPRs were included (Fritz et al., 2017; Magand et al. 2020). These three examples highlight the lack of consistency in formulating clear and concise terminological frameworks, despite the term "temporary" being used in all cases. Specifically, in the case of D.M. 131/2008 and Mediterranean GIG, the term "temporary" is used as a broad category encompassing all rivers that are not classified as perennial. Over the years, without an official and universal classification, the scientific literature has differentiated epithets to refer to a wide range of river intermittency. Possible terms indicating NPRs can be “arid”, “discontinuous”, “dry”, “ephemeral”, “episodic”, “intermittent”, “interrupted”, “irregular”, “non-perennial”, “non-permanent”, “seasonal”, and “temporary” (Busch et al. 2020).

Due to the lack of homogeneity in terminology, it was essential to define universal and commonly accepted definitions for these rivers and their different types of intermittencies. Busch et al. (2020) proposed a review of the

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most used epithets for different kinds of non-perennial rivers to define universal and general definitions:

- *Non-perennial*: any lotic, freshwater system that periodically ceases to flow and/or is dry at some point in time and/or space.

- *Intermittent*: a non-perennial river or stream with a considerable connection to the groundwater table, having variable cycles of wetting and flow cessation, and with a flow that is sustained longer than a single storm event. These waterways are hydrologically gaining most of the time when considering long term flow patterns.

- *Ephemeral*: a type of non-perennial river or stream without a considerable groundwater connection that flows for a short period of time, typically only after precipitation events. These waterways are hydrologically losing most of the time when considering long term flow patterns.

This endeavour aims to clarify the literature by pointing out the different types of rivers that can be encountered. However, it should be noted that alternative terms are still commonly used instead of *non-perennial*; this is reflected, for example, in the definitions used in some significant European projects on this topic.

On one hand, the MIRAGE (Mediterranean Intermittent River manAGEment) was an EU-funded project from 2009 to 2011 to develop and codify methods and tools to assess the ecological quality requested by WFD also for *temporary rivers* (see section 2.1). *Deliverable 8.1* indicated the dichotomy *temporary/permanent* as the terminology employed to distinguish between rivers that may or may not experience periodic drying.

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On the other hand, The DRYvER (Securing biodiversity, functional integrity and ecosystem services in DRYing riVER networks) is an ongoing European project, started in 2020, where a team of multidisciplinary experts from 11 countries in Europe, South America, China, and the USA delve the climate change impacts on biodiversity, ecosystem functions, and ecosystem services of *temporary rivers* (see section 2.2). Nevertheless, the terminology used in *Deliverable 1.1*, on the website and in the apps refers to *drying river networks (DRNs)*.

In this Deliverable 3.1, belonging to the project RIVERTEMP, the term *temporary rivers* (TRs) is utilized to refer to *non-perennial rivers* (NPRs). This choice has been driven by the widespread usage of the term in national legislation throughout Europe and in the Mediterranean region.

1.2 Classification of hydrological regimes and conditions

To understand and assess the possible shifting of a TR from one hydrological regime to another, it is fundamental to define and classify the possible hydrological regimes that describe the wide range of temporariness that TRs can present. During the year, several perspectives and methods were used to distinguish and classify operatively different regimes.

One of the first approaches has been based on counting the number of no-flow days per year with the help of a rainfall-runoff model, an example is the Spanish classification provided in the implementation of the WFD (Figure 2). It is a simple and easy model but less capable to describe the hydrologic variability that the temporary reach of a river can present and, thus, less useful to determine the ecological condition (Magand et al., 2020).

From the biological perspective, different hydrological and ecological concepts were identified to classify possible hydrological regimes and conditions in TRs (Boulton, 2003; Fritz et al. 2006). Gallart et al. (2017) proposed a simplified classification (Figure 4) based on three different *aquatic phases*

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(*flow*, *pools*, and *dry*) that were the same operational metrics used in the French project Onde (https://onde.eaufrance.fr/), called *low flow levels* (Magand et al., 2020). The *flow* (or *flowing*) condition is characterized by the presence of a continuous surface flow in the river channel. The *pools* (or *ponding*) condition regroups the possible condition in which there is surface water in the river channel but only in disconnected pools or ponds. A *dry* river implies the absence of surface water even if a hyporheic life is possible.

Figure 4. Overview of the three different hydrologic conditions that can occur in TRs: a) flowing b) ponding and c) dry. Photos by C. Cavallo, Sciarapotamo river, Salerno (IT).

Even if the metric *flow-pools-dry*, or *flowing-ponding-dry*, emerged as the most consistent for the description of the possible condition in TRs, terminology to refer to these conditions still lacks homogeneity. The *hydrologic* (or *hydrological*) *conditions* epithet seems to be the most diffused definition of generically alluding to the flow-pools-dry classification. It is used both in literature (Magand et al., 2020) and European official reports and project about TRs. For example, DRYvER uses this terminology in the crowdsourcing app (Tutorial for the DRYRivERS web application) (see Section 2.2). Therefore, within the context of this Deliverable of the RIVERTEMP project, we refer to *hydrologic conditions* to indicate the flowing-ponding-dry condition of the riverbed.

Based on these hydrologic conditions, the scientific literature has proposed different approaches to defining threshold values for the flow and pool permanence or considering the seasonality of these occurrences to classify the possible hydrologic regimes for TRs (Gallart et al., 2017; De Girolamo et al., 2015). However, due to the inherent subjectivity in determining these

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boundary values, a universally applicable method that can be employed across most of the hydrologic network remains elusive.

1.3 Definitions for natural and artificial intermittence

To safeguard the TRs, it is important to have consciousness of the causes that determine the intermittency, not only the type of its intermittency. Despite the attention on TRs is arising in multiple research fields, the main focus of research still mainly remains on perennial rivers. In TRs, the alternation between flowing and not flowing conditions is a characteristic of the natural hydrological regime, also known as natural flow intermittence (NFI). However, a human-induced alteration of hydrological regime can also cause an anthropogenic flow intermittence (AFI) (Datry et al., 2023).

It is not always easy to assess the difference between natural and anthropic drivers which determines the intermittency of a river, especially when the result is a decrease in flow discharge (Skoulikidis et al., 2017). On the opposite, when TRs become perennials due to an unnatural increase in flow discharge, it is easier to establish a cause-and-effect linkage attributed to anthropogenic drivers, like dams, Wastewater Treatment Plants (WWTPs) or urban, civil and industrial discharges (Hassan & Egozi, 2001). In that case, the increased baseflow (anti-drought) can give rise to notable ecological implications, like the change in the composition of native biotic communities (Poff & Zimmerman, 2010).

1.4 Global prevalence of temporary rivers

Messager et al. (2021) quantified that along the global river network with a MAF (mean annual flow) > 0.01 m^3/s, the length in which water ceases to flow

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at least one day per year goes between 51% (conservative approach) to 60%. Moreover, the phenomenon of shifting from a permanent to a temporal flow regime would enhance in future scenarios due to anthropogenic pressures, such as climate change, changes in land use and increasing water withdrawals (Döll & Schmied, 2012; Pumo et al., 2016). In the last 50 years, many of the biggest and most famous rivers, such as the Nile, Yellow, Indus, and Colorado, which used to run continuously, have started to have stretches where water ceases to flow (Datry et al., 2014). All this evidence demonstrates how nowadays the TRs are the rule rather than the exception.

1.5 The lack of social perception and legal recognition

Despite the burgeoning literature on the theme in the last years, there is a lack of consciousness by the population on the importance of the TRs for the river network (Cottet et al., 2023; Llanos-Paez & Acuña, 2022), their role in groundwater regulation, their contribution to local and regional biodiversity and biogeochemical integrity (Magand et al., 2020). This determines a subordination in the attention given to the protection of these systems compared to perennial rivers in national legislations and policies, indicating a general lag in recognition (Magand et al., 2020; Messager et al., 2021).

Llanos-Paez & Acuña (2022) showed how the social perception of a river's importance is closely related to the permanence of flow, highlighting that sociocultural difficulties still exist in considering a dry riverbed as a full-fledged river. Moreover, fishers are important stakeholders that address the politics of river restoration and preservation more to perennial reaches where biota species are generally more present (Cottet et al., 2023). Furthermore, especially in arid and semi-arid regions, there is a widespread presence of ephemeral streams that are usually dry but could have periodically tragic floods. Thus, in this region, people tend to immediately reconnect TRs to the

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dangers of flooding rather than a water resource that must be protected. Indeed, in EU-Med region, they are still used as parking lots or waste disposal sites (Figure 5) (Skoulikidis et al., 2017).

Figure 5. Example of waste disposal sites in temporary river channel. Photo by I. Brichetto, the Carraixet river, Valencian Community (2023).

All these cultural biases on TRs determine legislation that still lags in updating the management and protection of TRs (Acuña et al., 2014; Messager et al., 2021). These rivers can be subjected to the same regulations as perennial rivers (e.g., the Water Framework Directive in the EU, the Water Act in the U.S.) or, in some cases, they may be excluded from the legislation (Cottet et al., 2023). For example, even if Spanish and Italian implementations of WFD defines TRs (see Figure 2 and 3), an essential portion of the intermittent river network is excluded by ecological assessments programs since the definition include only streams with a catchment area > 10 km2 (Italy), a catchment area > 10 km2 and a mean annual flow higher than 0.1 m3/s (Spain) (Fritz et al., 2017). Furthermore, in the United States (Marshall et al., 2018) and France (e.g., the

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decree Giraud 2019), there is a gradual removal of TRs from maps and national stream definitions, resulting in the loss of their official status as water courses (Cottet et al., 2023). The implications of TRs' neglect from the normative determine the exclusion from systematic analysis on the ecological status and case-by-case management where restrictions on human activities are usually defined if they could likely affect downstream water bodies (Acuña et al., 2014).

1.6 How to assess flow intermittency

The high spatial and temporal variability of the hydrological conditions defines pivotal obstacles to studying TR intermittency. To have clear patterns of river intermittency is fundamental to know the hydrologic conditions that rivers can experienced along with the frequency, duration, and seasonality of these changes in flow condition. Furthermore, it is possible to understand the evolution of intermittency over time and the alteration of the natural flow regime only by comparing real-time data with a long-term dataset that can be used as an RC (Reference Condition) of the river (Magand et al., 2020).

Over the years, several methods and approaches have been developed to characterize the hydrologic regime and the flow intermittency of TRs:

- **Field surveys.** Field surveys are one of the best solutions for acquiring real-time data on the metrics of the flow regime and can assess with high accuracy which hydrologic condition is present on time (Magand et al., 2020). The main obstacles are the limited possibilities to replicate the campaigns. Citizen science and crowdsourcing could be viable solutions when the temporary stretches are easy to reach.

- **Gauging stations.** Gauging stations are one of the best solutions to obtain long-term data and evaluate the possible evolution of flow discharge over the years. The main disadvantages are the rare presence of gauging stations in intermittent stretches and their problem of measuring small flows or the presence/absence of water during the ponding phase (Oueslati et al., 2015).

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- **Logger sensors.** Another method to obtain real-time and medium-term data are field loggers that can measure water temperature, electrical conductivity, or both of them (Chapin et al., 2014). These instruments may detect the movement of wetting and drying fronts (Bhamjee & Lindsay, 2011) but could have difficulties in distinguishing between flowing and standing water. In addition, the drawback is the possibility of instruments being swept away or buried during floods or their integrity being compromised by vandalism (Magand et al., 2020).

- **Hydrological modelling.** Actual hydrologic models are still biased in predicting the variability of flow discharge in TRs. They overestimate zero-flow events and still lack predicting the spatial variability of hydrologic conditions (Datry et al., 2012; Gallart et al., 2017). Moreover, several limits are also in modelling the surface-groundwater interaction without information on the moisture condition of the riverbed during no-flow days (Ye et al., 1997). The improvement of hydrological models is an important aspect that must still gain to allow the application on TRs (Magand et al., 2020).

- **Remote sensing.** Remote sensing has defined significant opportunities for monitoring the conditions of the TRs. The airborne surveys allow the execution of rapid and extended surveys on intermittent reaches, even if the riverbed is complicated to reach personally (Gao et al., 2021). The satellite images can return periodical, sometimes with a revisit time shorter than a week, multispectral image of the entire river network, through which is possible to monitor constantly the evolution of the aquatic phases (Cavallo et al., 2021a, 2022a). The main drawback of the satellite image is the spatial resolution, which hinders the application for narrow rivers and streams (Costigan et al., 2017). In section 2.3 a more detailed description of this technique is presented.

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2. Best practices in identification of Temporary Rivers

At the global scale, TRs still suffer from being overlooked by hydrologists and water managers (Llanos-Paez & Acuña, 2022) and, consequently, they did not develop sufficient science-based methods for managing these unique aquatic and terrestrial ecosystems. The RIVERTEMP project aims to implement tools and resources to fight climate change and its impact on temporary rivers and to support and develop green and digital capabilities in the higher education sector on this specific topic. The project involves strategic partnerships between higher educational institutions (Politecnico di Torino (IT), Università degli Studi di Salerno (IT), Universitat Politecnica de Valencia (ES) and Polytechneio Kritis (GR)), small and medium-sized enterprises (DRAXIS ENVIRONMENTAL S.A. (GR)) and vocational education and training providers (FEMXA FORMACIÓN S.L.U. (ES)). Synergies with other initiatives like the DRYvER project are seeking to create a comprehensive database of TRs. The RIVERTEMP project aims to develop innovative IT tool, GIS-based repository, e-learning platform and MOOC (Massive Open Online Course), and the related training material for crowd-mapping TRs. It highlights the role of higher education in promoting responsible water management and aims to fill the gaps in water education. The project will produce open educational resources and engage in dissemination and exploitation activities.

In the following chapter, we collected a summary of a few best practices to identify and classify TRs, using duration and frequency (or permanence) of flowing, ponding and dry conditions. The following review considers the EU projects MIRAGE and DRYvER and the use of satellite image processing for the identification and classification of TRs. In addition, we mentioned the GIS-based repositories for the management and use of open-source databases.

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2.1 The MIRAGE project

In the context of the publication of the European Commission's Blueprint to Safeguard Europe's Waters, the MIRAGE-proposed framework for the characterization of the eco-hydrological dynamics and the systematic description of the measured impact for temporary rivers could bring considerable added value to the EU revision of all relevant water policies. The project recommended additions to WFD articles including an explicit definition of TRs, adaptation of environmental objectives to their peculiarities and establishment of a proper method to determine the initial status and specific actions in River Basin Management Plans (Nikolaidis et al., 2013).

The MIRAGE projected developed a Toolbox to bring together all the approaches that adapt the reference quality standards developed for permanent streams, in non-temporary water bodies (Prat et al., 2014). The 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 MIRAGE 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 fulfilment 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.

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

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[physicochemical status (PCHS-Tool) and CHS-Tool] aspects of the assessment of temporary streams, (Figures 6).

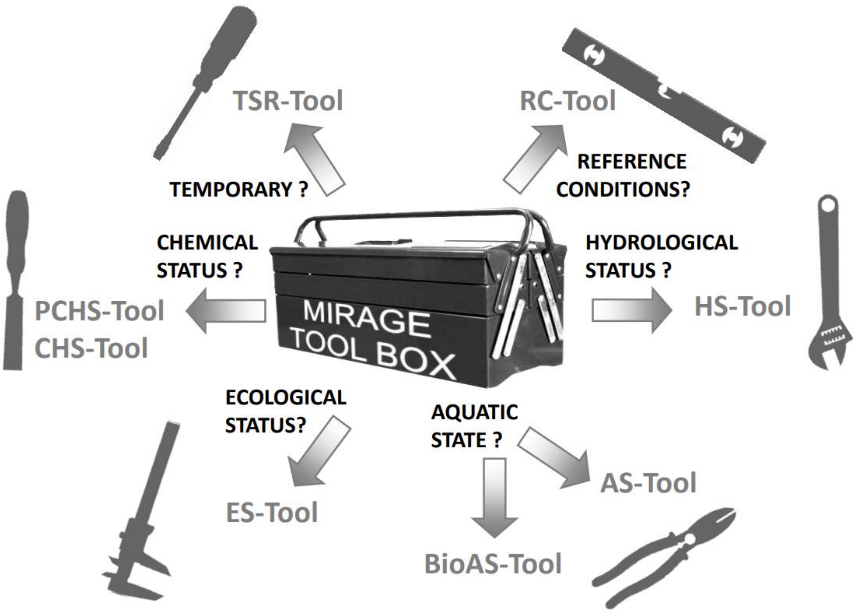

Figure 6. Schematic representation of the MIRAGE Toolbox and the tools that it contains (Prat et al., 2014).

The following image (Figure 7) resumes the overall process in which each tool – aforementioned - must be used sequentially. A more detailed description of the MIRAGE Toolbox can be found in Prat et al. (2014).

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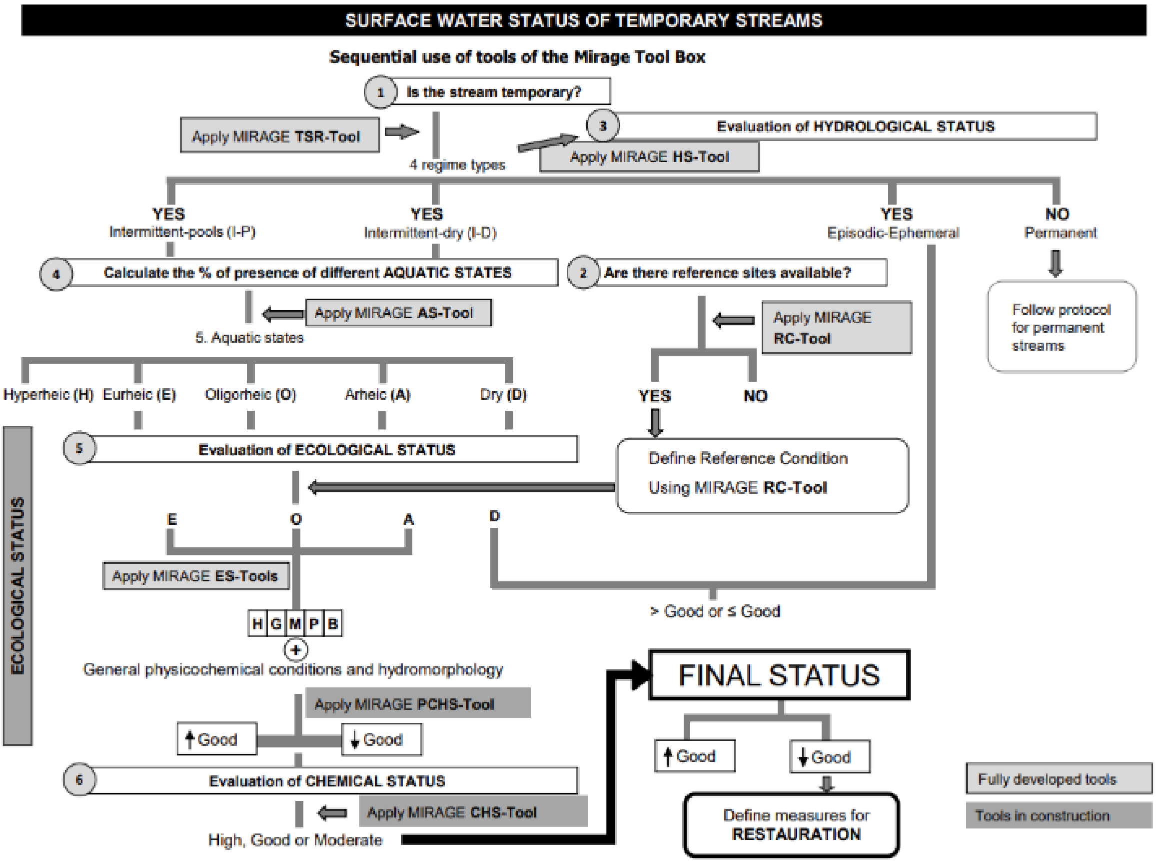

Figure 7. Flowchart showing the sequential use of the tools from the MIRAGE Toolbox (Prat et al., 2014).

2.1.1 Temporary stream regime – Tool

The Temporary stream regime – Tool (TSR-Tool) allows to assume if a river is temporary and its temporary regime (Gallart et al., 2012) using two metrics: the long-term annual relative number of months with flow (Mf) and the 6-month dry-season predictability (Sd6) (Table 1). Must be used data on the presence-absence of flow at a monthly scale with a period of monitoring of at least 10 years to calculate these two parameters; if there is no data, a rainfall-runoff

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model or inhabitants' interviews can be used to obtain the temporary series. Figure 8 resumes in a flowchart the TSR – Tool steps.

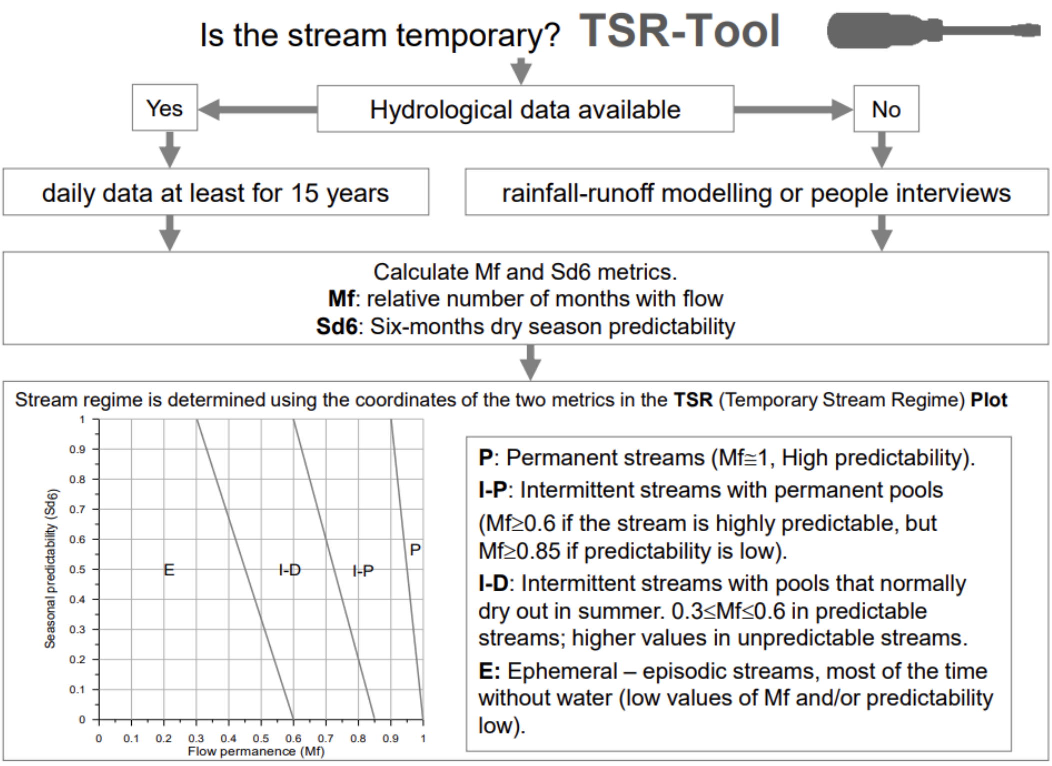

Figure 8. TSR-Tool. Flowchart showing the steps used to determine whether the river is temporary (Prat et al., 2014).

Evaluated the two metrics, they were used to plot in the TSR Plot the point corresponding to the river case. Depending on the area in which the point will be, it is possible to classify the hydrologic regime. In Figure 8, it is possible to see four different hydrologic regimes: permanent (P), intermittent with pools in the no-flow period (I-P), intermittent with a dry channel in the no-flow period (I-D) and episodic-ephemeral (E).

2.1.2 Reference conditions – Tool

Due to the approach defined in the WFD, assuming and monitoring the current condition of a river is fundamental to the comparison with reference conditions (RC). RC is defined as a natural condition without anthropogenic

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pressures and it is used as a standard to evaluate the current status (Stoddard et al., 2006). To select the right RC for temporary rivers, a list of 37 attributes is used (Figure 9) based on previous criteria used in Spain by Bonada et al. (2004), Munné and Prat (2009) and Sánchez-Montoya et al. (2009).

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

- Validation criteria: 3 criteria

Spatial Scale	*Criteria*	*Threshold (High-Good)*
Site	N-NH_4^+ (mg/l)	≤0.031
	N-NO_3^- (mg/l)	≤0.480
	P-PO_4^- (mg/l)	≤0.041

37 reference
+ 3 validation

REFERENCE SITES

Figure 9. RC-Tool. Flowchart showing the steps to obtain a model for reference conditions situation (Prat et al., 2014).

A validation of this selection is mandatory to confirm the RC chosen. The method must be different from the previous one and, thus, the three criteria, related to nutrient conditions, listed in the second column in Figure 9 are used (Sánchez-Montoya et al., 2012).

2.1.3 Hydrologic Status- Tool

Anthropogenic pressures could affect the temporariness of rivers modifying their hydrologic status (or regime). The Hydrologic Status – Tool (HS – Tool) allows to determine the HS of a river by evaluating the duration and timing of

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the occurrences of the different aquatic statuses (ASs) or no-flow periods. Defined the RC with the RC – Tool and evaluated the two metrics Mf and Sd_6, the two points were plotted in the TSR-Plot. The Euclidean distance between the two points, representing the RC site and study area, is compared with the annual variability of the metrics to evaluate the possible shifting from one hydrological regime to another. The protocol of these steps is shown in Figure 10.

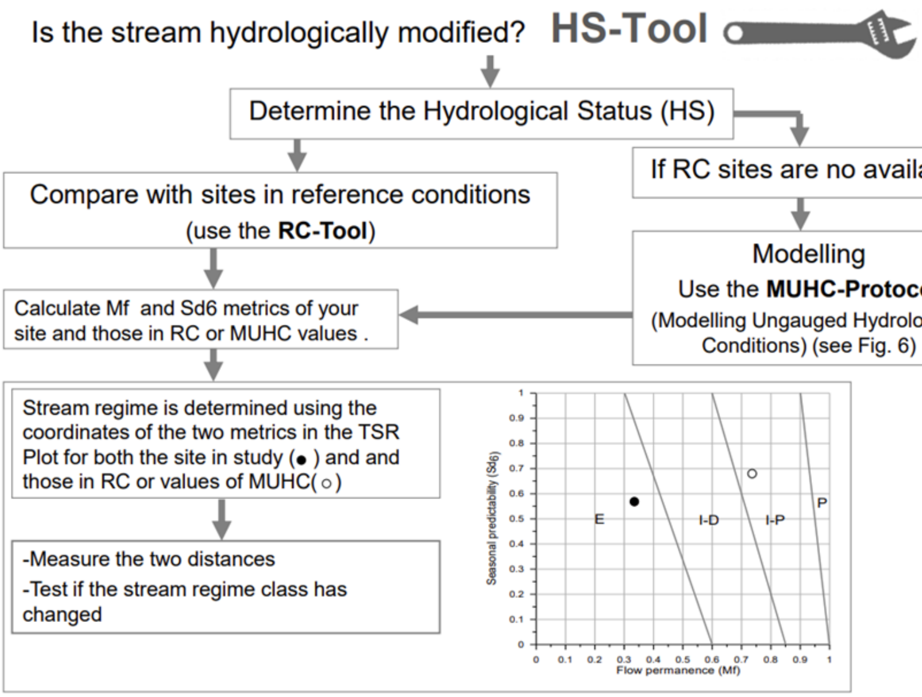

Figure 10. HS-Tool. Flowchart showing the steps used to determine the hydrological status based on the availability or non-availability of RC (Prat et al., 2014).

If there are no sites that can be used as RC, the MIRAGE project developed the Modelling Ungauged Hydrological Conditions (MUHC) protocol (Figure 11) to simulate at least 5 years of the natural and the altered flow using hydrological models to obtain the two points on TRS – Plot to compare with the annual

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variability of the metrics (e.g. Soil and Water Assessment Tool and SIMulation of GROundwater).

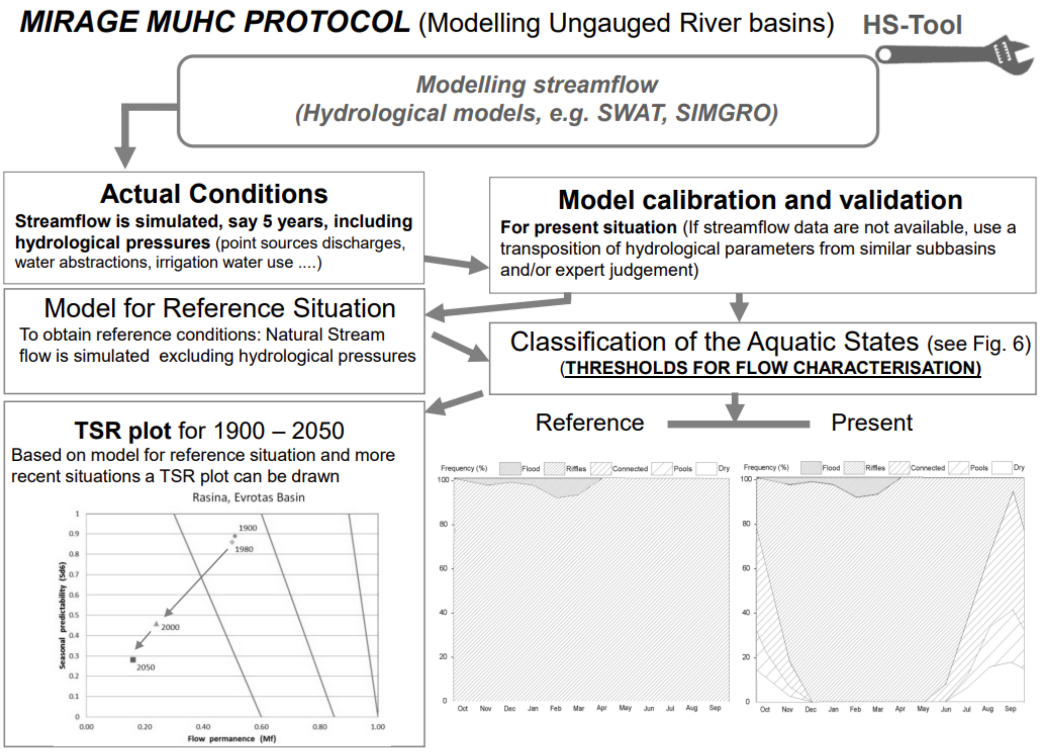

Figure 11. Flowchart showing the steps used to perform the MUHC protocol to establish the hydrological status if no gauging stations are in the studied basins (Prat et al., 2014).

2.1.4 Aquatic States- Tool

According to Gallart et al. (2012), there are six aquatic states: Hyperrheic (H), Eurheic (E), Oligorheic (O), Arheic (A), hyporheic and edaphic. The AS – Tool adds qualitative information on the river regime description and is propaedeutic for the Ecologic status – tool. The AS – Tool (Figure 12) allows for determining the best date for aquatic biota samplings, typically during the Eurheic or Oligorheic state. If no information is available on the occurrence of ASs, it is possible to use flow records (or simulation). To determine the threshold flow values that assess the passage from one AS to another,

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synchronous field observations and flow measurements are mandatory (Gallart et al., 2012).

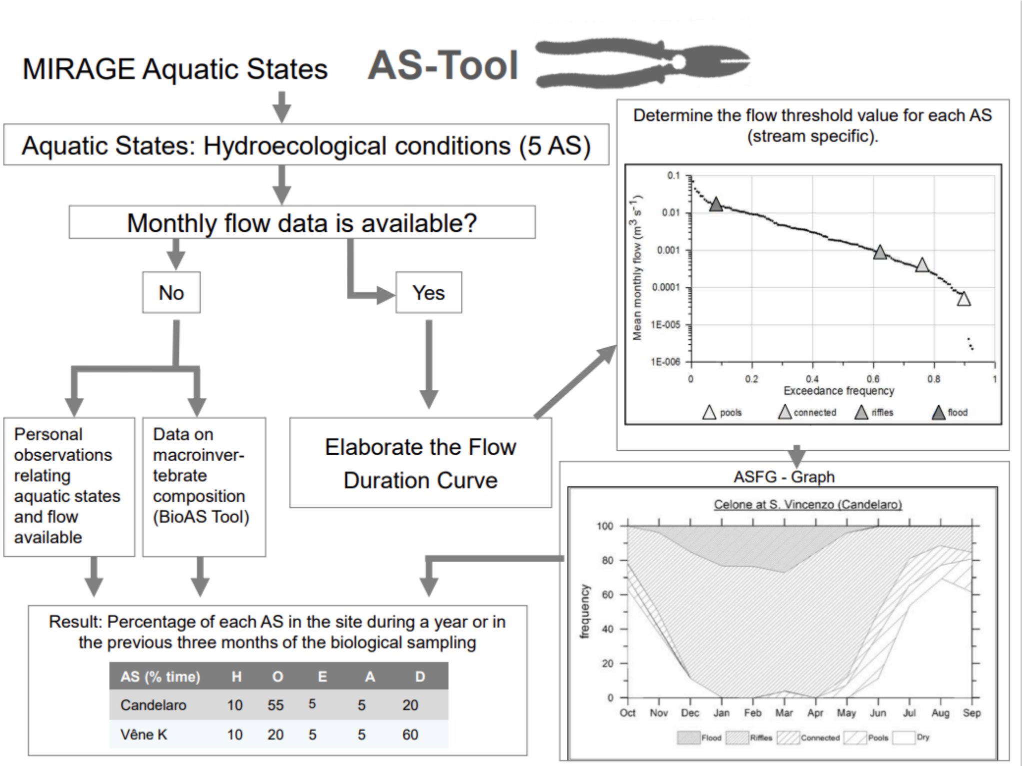

Figure 12. AS-Tool. Flowchart showing the steps to determine the aquatic states of the streams (Prat et al., 2014).

A new tool, BioAS – Tool, was developed to allow managers to define the ASs from samples of macroinvertebrates collected in the past. This tool is able to assess the connectivity of flow using some biological traits (i.e. the proportion of filter feeders, organisms feeding on detritus b1 mm, temporarily attached to the substrate, fliers, with a mean body size between 1 and 2 cm, feeding on dead animals ≥ 1 mm, with diapause and adult (imago) aquatic stages) and the shifting in abundance from macroinvertebrate families dominating in flowing conditions (i.e. Hydropsychidae, Simuliidae, and Heptageniidae) to the ones that spreads in disconnected pools (i.e. Hydropsychidae, Simuliidae, and Heptageniidae) (Cid et al., 2016).

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2.1.5 Ecological Status - Tool

Ecological Status – Tool (ES – Tool) must evaluate the ecological status of temporary rivers based on the five quality classes required by the WFD (i.e. High, Good, Moderate, Poor, Bad). To apply this tool, the TSR and AS – Tools are mandatory. The determination of the ES is based on the aquatic macroinvertebrate communities' studies. The MIRAGE project used several biological metrics such as the number of family taxa, the number of Ephemeriotera, Plecoptera and Trichoptera (EPT) taxa and two multimetric indexes, the STAR Intercalibration Common Metric Index (STAR_ICMi) and the Index Multimetric Mediterrani quanTitatiu index (García-Roger et al., 2011). For dry conditions, when aquatic biota is impossible to investigate, the MIRAGE project developed a methodology using terrestrial invertebrates to determine ES (Steward et al., 2011). A more complete method is given by the combination of biological metrics with functional metrics, which can be applied in all ASs. In the MIRAGE project, the most functional metric used is leaf litter decomposition (Gessner & Chauvet, 2002; Datry et al., 2011).

In Figure 13 there is a flowchart that resumes the ES – Tool. To have more detail on the sampling technique for aquatic macroinvertebrates developed within the MIRAGE project, is recommended to read García-Roger et al. (2011).

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Ecological Status **ES-Tools**

1st . Determine the AQUATIC STATE			
	Eurheic (E) / Oligorheic (O)	Arheic (A)	Dry (D)
Assemblage	Aquatic Macroinvertebrates		Terrestrial Macroinvertebrates
Structural Measures			
Sampling	- Use the methods available for permanent streams. (e.g. AQEM, Buffagni *et al.*, 2006). - **VERY IMPORTANT:** Date of sampling variable according to the hydrology	Methods for pools (not yet standardized). Assemblages change along the process of desiccation	PIT-Traps (e.g. Steward *et al.*, 2012)
Metrics	- Similar to Permanent Streams - Compare with specific reference conditions. - Metrics should be related to hydraulic pressures	EPT/OCH ratio and similar metrics not standardized (Bonada *et al.*, 2006)	Metrics still in development
Functional Measures	Leaf litter decomposition (e.g. Dieter *et al.*, 2011)		
Ecosystem measurements	Benthic metabolism (e.g. Von Schiller *et al.*, 2012)		

Figure 13. ES-Tool Description of different indexes or functional indexes used for determining the ecological status for different Ass (Prat et al., 2014).

2.1.6 Physicochemical status-Tool

This tool is used to determine the Physicochemical (PCH) variables established in WFD 2000/60/EU: thermal conditions, oxygen, salinity, acidification status and the concentrations of nutrients. Threshold values for good conditions for temporary rivers (Figure 14) are proposed in Sánchez-Montoya et al. (2012). Also, for the PCHS - Tool, the Eurheic and Oligorheic are the best conditions to apply this method. For dry conditions, the PCHS - Tool cannot be used.

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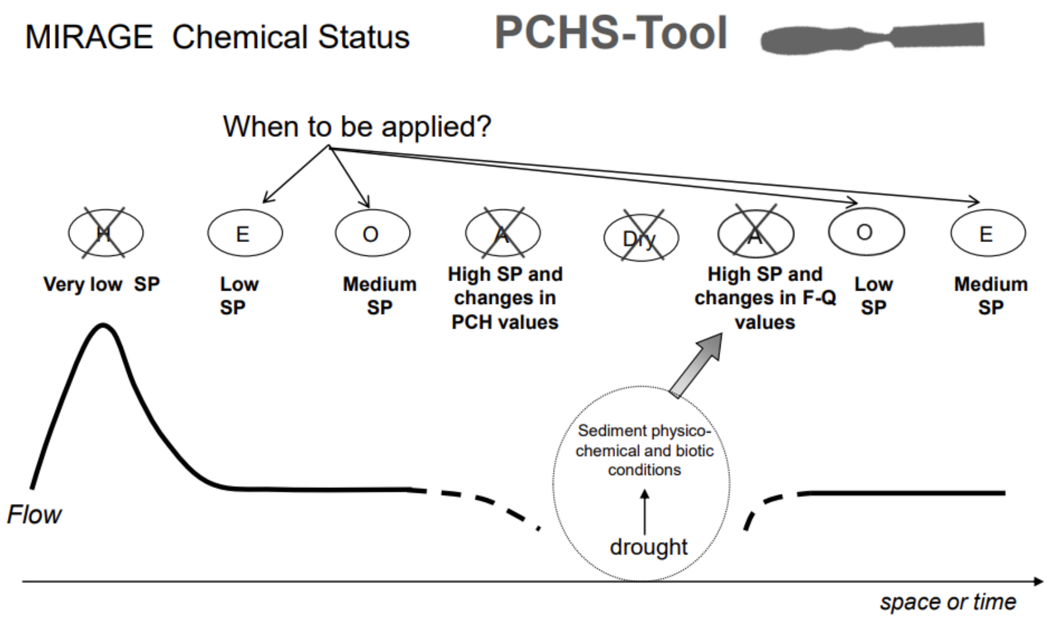

General parameters	Reference Value	High-Good
Oxygen saturation (%)	97.0	91.0-103.2
Dissolved Oxygen (mg/l)	9.9	8.1-10.8
Conductivity (µS/cm)	337	443
pH	8.0	8.3

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 14. 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 (Prat et al., 2014).

2.1.7 Chemical status-Tool

The Mirage project develops a specific guideline for monitoring hazardous substances in temporary rivers, due to the limitation of adapting those included in WFD 2000/60/EC that may not always be suitable for temporary rivers (Figure 15).

If it is an I-P river, during Eurheic and Oligorheic states, it is possible to use the approach for water bodies (EC, 2010). Moreover, the method must include the sampling of the solid phase.

During dry phases of I-P rivers or for I-D and E rivers, it is fundamental to study the sediments where may be found hazardous substances. Due to the high spatial variability that marks temporary rivers, it is compulsory that each mesohabitat is sampled, even if there is more than one in the same cross-

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section. The sediment must be sampled at least once per year, in particular it is recommended before the dry periods, when the river channel is in an Oligorheic state and low current velocities.

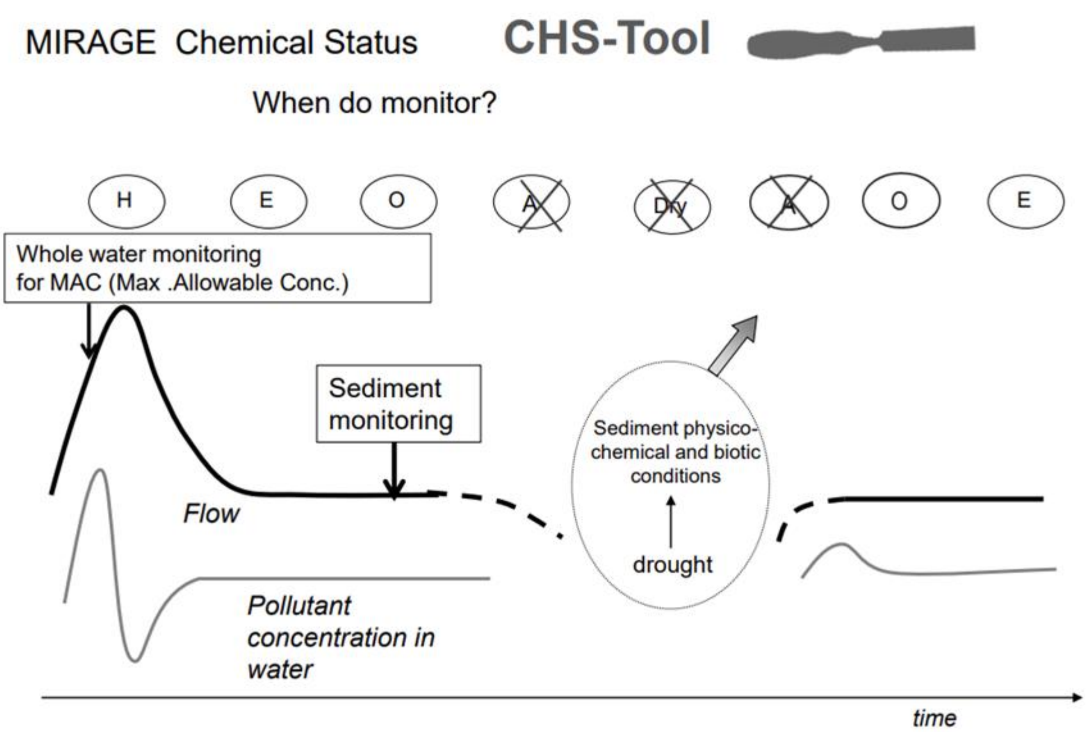

Figure 15. CHS- Tool for the monitoring of hazardous substances in temporary river developed during MIRAGE project (Prat et al., 2014).

2.2 The DRYvER Project

The Paris Agreement (2015) achieved one of its most crucial aims by recognizing the significance of protecting biodiversity and maintaining the functional integrity of ecosystems in the face of climate change and its impacts. As a result, the conservation of river networks has become more of a priority than ever, given their ecological value in providing key ecosystem services (Thorp et al., 2010). The arising attention on TRs by researchers and institutions is crucial due to the lack of knowledge on the effects that climate change will have on these kinds of rivers and their ecosystem services and functions (Datry et al., 2021).

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Thus, the Horizon 2020 project brought together a multidisciplinary team of experts from 11 countries across Europe, South America, China, and the USA to investigate and mitigate these environmental challenges. Their collaborative effort led to the start of the DRYvER project (Securing biodiversity, functional integrity, and ecosystem services in DRYing riVER networks, or temporary rivers).

Datry et al. (2021) explicate how the primary objective of this project is to investigate nine TRs in drying river networks (DRNs) across a broad geographical extent covering Europe and the Community of Latin American and Caribbean States (CELAC) to understand the direct and indirect correlation between climate change and the alteration of biodiversity, ecosystem functions, and ecosystem services in these 9 rivers. Figure 16 illustrates the geographical locations of the nine rivers (6 in Europe and 3 in CELAC) selected as case studies for the DRYvER project.

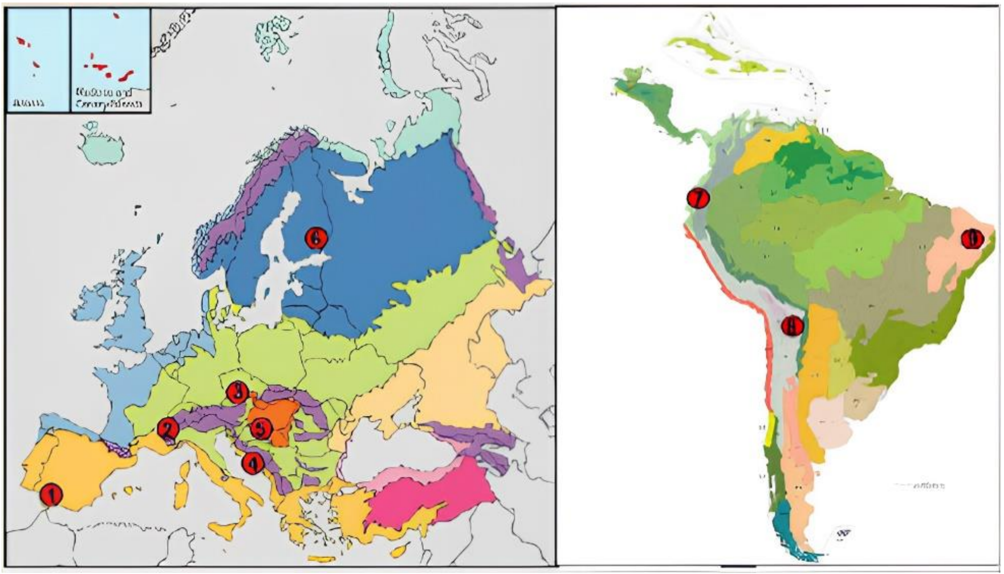

Figure 16. Locations of the nine rivers across Europe and South America taken as case studies for the DRYvER project (Datry et al., 2021). The red points highlight: 1) the Genal network in Andalucía (Spain, Mediterranean ecoregion). 2) The Albarine network in Southern Jura (France, Alpine ecoregion). 3) The Velička network in Morava (Czech Republic, Continental ecoregion). 4) The Krka network in the Dinaric Karst (Croatia, Balkanic ecoregion). 5) The Bükkösdi-víz network, in the Mecsek (Hungary, Pannonia ecoregion. 6) The Vantaanjoki network, Helsinki-Uusimaa Region (Finland, Boreal ecoregion). 7) The Cube network, in the Andean-Choco region (Ecuador, Pacific Lowlands). 8) The Rio Chico network in the Sucre region (Bolivia, Central High Andes ecoregion). 9) The Jaguaribe network, in the Northeast Semiarid region (Brazil, Caatinga ecoregion).

In addition, the DRYvER project strives to develop a worldwide applicable meta-system framework (Cid et al., 2021) and knowledge-based strategies, guidelines, and tools to include adaptive management of TRs in the actual policies to mitigate and adapt to climate change (Datry et al., 2021). The project has already produced a substantial number of papers, reports and documents that are accessible on the website (https://www.dryver.eu/results/). The DRYvER project will endeavours also create an extensive open-source dataset for monitoring the hydrologic conditions of TRs.

Considering the limits of gauging stations for monitoring zero-flow conditions and pools, field surveys are still one of the best methods to evaluate the real-time condition of TRs (Magand et al., 2020). The need for a large amount of field surveys promotes citizen science projects and crowdsourcing as possibilities to enlarge the collection of field data and to raise public awareness on environmental issues (Conrad & Hilchey, 2011; Johnson et al., 2014). Following this approach, one of the main outputs of this project is an open-source application DRYRivERS, a classic crowdsourcing app that allows every citizen to collect information about the drying events of TRs.

This application exists in two different versions:

- The mobile application was developed to allow offline data recording on the field in a user-friendly way. It is available on Google Play (https://play.google.com/store/apps/details?id=com.dryrivers&pli=1) and App Store (https://apps.apple.com/us/app/dryrivers/id1593273058).

  The web application (https://www.dryver.eu/app) is a real-time map of all recorded data. The users here can add new spots and records, or they can edit their previously recorded data.

To record a hydrologic condition of a river portion with the DRYRivERS app, users can follow these easy steps:

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- Add the location of the spot (can be used on the phone GPS or can be found at an existing point on the map).
- Take a photo showing the river's condition.
- Assess the hydrologic condition in the river channel between flowing water, disconnected pools or dry riverbed.
- After they record the data, the information must be saved and uploaded.

The app can record all the data as soon as the mobile phone will be connected again to the internet (Wi-Fi or mobile internet), thus, it is possible to record the river portion even where there is no network coverage.
For more detailed information, this link https://youtu.be/TZL4Rx_PxrY provides a tutorial video for the DRYRivERS app or it is possible to follow the instructions within the document "Tutorial for the DRYRivERS web application" provided by DRYvERS. Below there is a short tutorial resume that explains the essential steps to start and exploit the app as a simple user.

2.2.1 Mobile App Tutorial

The Mobile App serves as an operational tool for individuals to document and record the hydrologic conditions of TRs. A tutorial summary is provided below:

Figure 17. Login or Sign-up (source: https://www.dryver.eu/citizen-science/how-does-it-work).

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- Starting the app, the section in Figure 17 is displayed. To log in to your existing account on the app, enter your email address and password, and click on the LOGIN button. If you are a new user, click on the SIGN-UP button on the app's starting screen. This step will take you to the Registration page, where you can enter the necessary information. Once you have completed the registration process, click on the SIGN-UP button to finish. If you would like to select your preferred language, click on the Please select preferred language link.

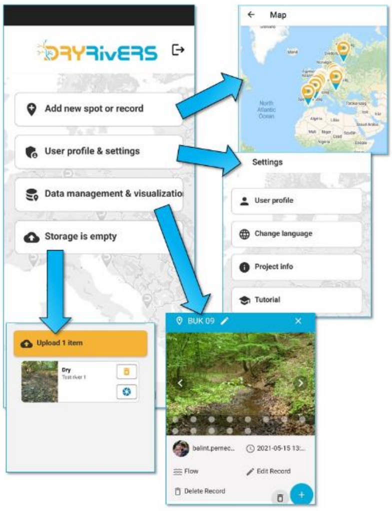

Figure 18. Starting screen options (source: https://www.dryver.eu/citizen-science/how-does-it-work).

- The Starting screen (Figure 18) offers four options. You can add a new spot or record by clicking on the namesake button. To access your user profile and adjust your preferences, click on the User Profile & Settings menu (Figure 18). You can upload recorded spots/records from your device's storage by selecting the Upload Items button (Figure 18). To manage and edit your spots and records, you can go to the Data Management & Visualization menu (Figure 18). To sign out of the app, click on the Exit icon next to the DRYRivERS app logo.

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Figure 19. Adding a new spot (source: https://www.dryver.eu/citizen-science/how-does-it-work).

- Clicking the Add new spot or Record button on the Starting screen will redirect you to the Map screen (Figure 19). From there, you have two options for locating the spot you wish to record: either by using the GPS icon to find your current position or manually scrolling and zooming on the map. Your current location is indicated by a black crosshair. There are three methods for adding a new spot or record: A) GPS method: Tap the GPS icon to determine your current location, then tap the Add new icon. This will add a new spot at your current position (this option is possible only when the GPS accuracy is under 200m). B) Map-based method: Navigate to the desired location on the map by scrolling and zooming. Tap the map to place a marker, which will appear with a blue outline. Then tap the Add new icon. B) Adding a record to an existing spot: Select a marker on the map by tapping it, which will be outlined in black. Tap the Add new icon to add a new record to the selected spot.

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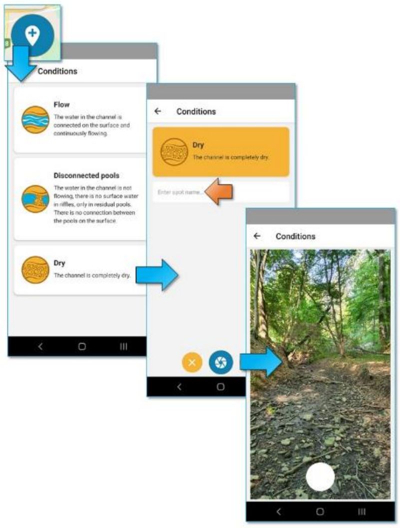

Figure 20. Conditions screen (source: https://www.dryver.eu/citizen-science/how-does-it-work).

- Upon selecting the Add New icon on the Map screen, you will be redirected to the Conditions screen (Figure 20). Here, you are required to choose the most appropriate condition option (Flow / Pools / Dry) that accurately describes the hydrological status of the site. If you are adding a new spot, you have the option to enter a name for it (Figure 20). Subsequently, it is strongly recommended to capture multiple photographs (at least one) of the current conditions by clicking the Photo icon and then pressing the Shutter button (Figure 20).

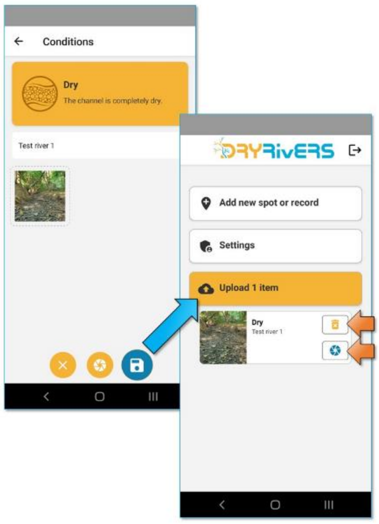

Figure 21. Uploading item (source: https://www.dryver.eu/citizen-science/how-does-it-work).

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- Once you have completed all the necessary steps, you can save your record by selecting the Save icon (Figure 21). Following that, you will be directed back to the Starting screen, where you have the option to either add another spot or record or upload your saved items by clicking the Upload items button (Figure 21). If desired, you can add additional photos to the already saved items by selecting the shutter icon. Conversely, if you no longer wish to upload certain saved items, you can delete them using the trash bin icon.

2.3 Remote sensing

Remote sensing is a technical-scientific discipline that allows identifying, measuring, and analyzing the qualitative and quantitative characteristics of a specific object placed at a distance, based on electromagnetic energy measurements, emitted, reflected or diffused by the surface under examination. The data acquisition takes place thanks to remote sensors mounted on platforms, such as drones, airplanes and satellites that allow to detect the electromagnetic energy coming from a scene and to convert it into information. A significant advantage of satellite remote sensing, compared to other remote platforms, is the possibility of monitoring wide areas with various spatial and temporal resolutions. Moreover, some satellite archives provide time series longer than 40 years (e.g., Landsat). The wide use of satellite data is also encouraged by the free distribution policy adopted by some space agencies (e.g., the Copernicus program of the European Space Agency), as well as research and education programmers set up by private companies (e.g., Planet, Esri).

Satellite platforms are equipped with sensors that measure the electromagnetic radiation reflected or emitted by a given object or surface. Based on the functionality of the sensor, two main types of remote sensing

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are distinguished: active remote sensing and passive remote sensing. In active remote sensing, the sensor produces electromagnetic radiation to illuminate the scene and records the return signal. The most common active sensor is, for example, Synthetic Aperture Radar (SAR), which sends a beam of radiation, and records the return signal after it has interacted, and has therefore been modified, from the investigated surface. By contrast, passive remote sensing makes use of passive sensors that detect the natural energy emitted or reflected by the observed object, and it is the most widely used technology for monitoring the earth's surface (Wulder et al., 2019). In passive remote sensing systems, the most common source of energy is the sun which irradiates the earth's surface with a continuous range of electromagnetic radiation. Sensors of this type generally measure in different spectral channels centered on certain wavelengths of the electromagnetic spectrum. Typically, they range from the visible (0.4 µm - 0.7 µm) to the infrared (0.7 µm - 1 mm). The main drawback of passive sensors is the inability of observing the Earth's surface in the presence of clouds; consequently, long periods without observation may occur in areas with frequent precipitation. On the other hand, in most cases, data acquired by passive sensors do not require long and complicated pre-processing steps. They are frequently corrected radiometrically and geometrically by various space agencies and can be directly exploited by a user. Furthermore, by associating the blue, green and red bands with the corresponding channels (respectively blue, green and red) a natural color image (True Color) can be obtained, through an additive color synthesis operation, which can be easily interpreted even by non-experts.

The development of new technologies in the field of Earth observation has contributed to the launch of several increasingly powerful and sophisticated satellite missions into space. A variety of satellite missions have followed one another over the years, among them Landsat, MODIS (Moderate Resolution Imaging Spectroradiometer) and the more recent Sentinel-2 mission. The choice of the satellite data to be used, in a specific monitoring application, depends on many factors, such as the object size (e.g., the length and width of the target), the spatial resolution required, the physical properties of the

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objects to be observed, the duration of the observation period and the frequency with which changes need to be tracked (Legleiter and Fonstad, 2012; Brierley and Fryirs, 2013; Gilvear and Bryant, 2016). In general, spatial, temporal and spectral resolutions are in opposition to each other, data with coarse spatial resolution are available with high temporal resolution, and vice versa. Therefore, the choice of the most suitable satellite remote sensed datasets is challenging due to inevitable trade-offs between spatial resolution and revisit time.

The use of satellite data for monitoring TRs has so far been limited by two main factors: the spatial resolution of the satellite images and the availability of images at affordable costs. High spatial and temporal resolutions are required for monitoring TRs. Very high-resolution images (space resolution of the order of 0.5 m) are available for commercial use but their use for continuous monitoring in long time intervals is limited by the high costs of the products. Among freely distributed multispectral images with systematic global coverage, the Sentinel-2 mission provides the highest spatial resolution and revisiting frequency.

The Sentinel-2 mission is part of the Copernicus Earth Observation program led by the European Commission and operated by the European Space Agency (ESA). The Sentinel-2 mission comprises a constellation of two polar-orbiting satellites placed in the same orbit. The first satellite, Sentinel-2A, launched on 23rd June 2015 provides images with a revisit time of approximately 10 days at the equator. Since the launch of the second satellite, Sentinel-2B, on 7th March 2017, the overall revisit time has become around 5 days at the equator and 2-3 days at mid-latitudes. Both satellites are equipped with an opto-electronic Multispectral Instrument (MSI), which has provided moderate-resolution imagery since June 2015 (Sentinel-2A) and March 2017 (Sentinel-2B). MSI acquires thirteen spectral bands (see Table 2) in the visible (bands 1-2-3-4), red-edge (bands 5-6-7), near-infrared (NIR, bands 8-8a), shortwave infrared (SWIR, bands 9-10-11-12). The spatial resolution is 10 m for bands 2,3,4 and 8; 60 m for bands 1,9 and 10 and 20 m for the other ones.

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Table 1. Spectral coverage of the Sentinel-2 satellite data.

Wavelength range [nm]	Spatial resolution [m]			Spectral region
	10	20	60	
423-463			B1	Coastal aerosol
458-523	B2			Blue
543-578	B3			Green
650-680	B4			Red
698-713		B5		Red Edge
733-748		B6		Red Edge
773-793		B7		Red Edge
785-899	B8			NIR
855-875		B8a		NIR narrow
925-965			B9	Water - Vapour
1350-1410			B10	SWIR - Cirrus
1565-1655		B11		SWIR
2100-2280		B12		SWIR

Thanks to the excellent compromise between spatial and temporal resolution and the possibility to download the data easily and free-of-charge, the multispectral data from the Sentinel-2 satellite mission are the most appropriate for monitoring TRs.

Satellite images acquired by passive sensors have been widely exploited to map water surfaces along perennial rivers due to the high availability of data, as well as the appropriate spatial and temporal resolutions (Piégay et al., 2020). Some authors have developed supervised or unsupervised classification methods to generate water or land cover maps. Baki and Gan (2012) implemented an unsupervised neural network to extract land cover classes (water, sediment and vegetation) from Landsat images for monitoring the bank erosion/accretion and island dynamics of the Jamuna River for three decades (1973–2003). Carbonneau et al. (2020) used a supervised classification method to extract land cover classes (water, vegetation and sediment) and delimit active channels from Sentinel-2 images on four Italian rivers: the Po River, the Sesia River, the Paglia River, and the Bonamico River.

Although several techniques have been developed for the extraction of water surfaces from multispectral sensors to date, there is still no universal classification method that works for all case studies, and the extraction of land cover from multispectral satellite images is an ever-changing topic (Huang et al., 2018; Talukdar et al., 2020).

A simple and widely used way to extract water surfaces or land cover classes is to use multispectral indices (Petropoulos and Kalaitzidis, 2012). The trend of the spectral reflectance curves of an object or surface provides useful information in the derivation of multispectral indices. In fact, indices represent a combination of two or more spectral bands for which a surface takes on characteristics that make it distinguishable from others.

The spectral signature of "clear" water (suspended solids <10 mg/l) peaks in the green wavelength band (0.50-0.56 μm) and decreases with increasing wavelength, reaching near-zero reflectance in the near-infrared (NIR) region (0.75-1.4 μm). The reflectance spectrum of turbid water exhibits higher values than moderate-turbid water in the visible and near-infrared regions and approaches zero at longer wavelengths (Malinowski et al., 2015; Cavallo, 2022b). This is due to the concentration and size of solutes, sediments and organic matter, the presence of which increases the reflection in the near-infrared band. The spectral response of vegetation varies, as for water, with the wavelength, and depends on multiple factors, such as the type of vegetation, density, state of growth and moisture content. In the visible, the reflected energy values are correlated to the presence of pigments, such as chlorophyll.

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For photosynthesis, vegetation absorbs the visible blue and red radiation and reflects the green one. In the near-infrared lengths (0.7-1.35 μm), the spectral signature is influenced by the structure of the leaf, while in the short-wave infrared (1.35- 2.70 μm) by the water content. Healthy vegetation tends to show greater reflectance in the near-infrared wavelengths (Bannari et al., 1995). For soils, in the same way, the reflectance varies according to their chemical and physical composition. The most important factors are the moisture content, the organic substance content, the texture and the structure (Ou et al., 2022). The reflectance of the soil increases with the wavelength and decreases proportionally to the moisture content in correspondence with the water absorption peaks (e.g., 1.4, 1.9, 2.7 μm, see Figure 22). Typically, the water of wetlands, lakes and rivers contains solid particles and could appear not "clear". In general, in environments such as lakes, turbidity in the surface layers is low, and the water in most cases has a spectral signature similar to "clear" water (suspended solids <10 mg/l). Whereas in rivers, due to solid transport, turbidity may be greater, and the spectral signature may appear similar to turbid water. Furthermore, in the case of shallow water, the spectral signature can be influenced by the type and color of the background material (e.g., sediment or aquatic vegetation).

From the analysis of spectral signatures, the most common multispectral indices used to extract water, vegetation and bare soil surfaces were derived. For example, McFeeters (1996) proposed the Normalised Difference Water Index (NDWI) derived from the green and NIR bands.

$$NDWI = \frac{\rho_{green} - \rho_{NIR}}{\rho_{green} + \rho_{NIR}}$$

Later, Xu (2006) found that the shortwave infrared (SWIR) band is able to reflect some subtle characteristics of water, so he replaced the near-infrared (NIR) band in NDWI with the SWIR band and proposed the MNDWI (Modify Normalised Difference Water Index).

$$MNDWI = \frac{\rho_{green} - \rho_{SWIR}}{\rho_{green} + \rho_{SWIR}}$$

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From the spectra presented in Figure 22, it can be argued that areas covered with "clear" water will be characterized by positive values of NDWI. On the contrary, it is expected that the surfaces covered by turbid waters will manifest almost null values of NDWI. In contrast, both clean and turbid water will be characterized by positive values of MNDWI.

The Normalised Difference Vegetation Index (NDVI, Curran, 1983) was developed to detect vegetated surfaces but also to extract water surfaces. Based on the reflectance characteristics of water (see Figure 22), the NDWI and MNDWI values for water are generally greater than zero, while the NDVI values are less than zero.

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$

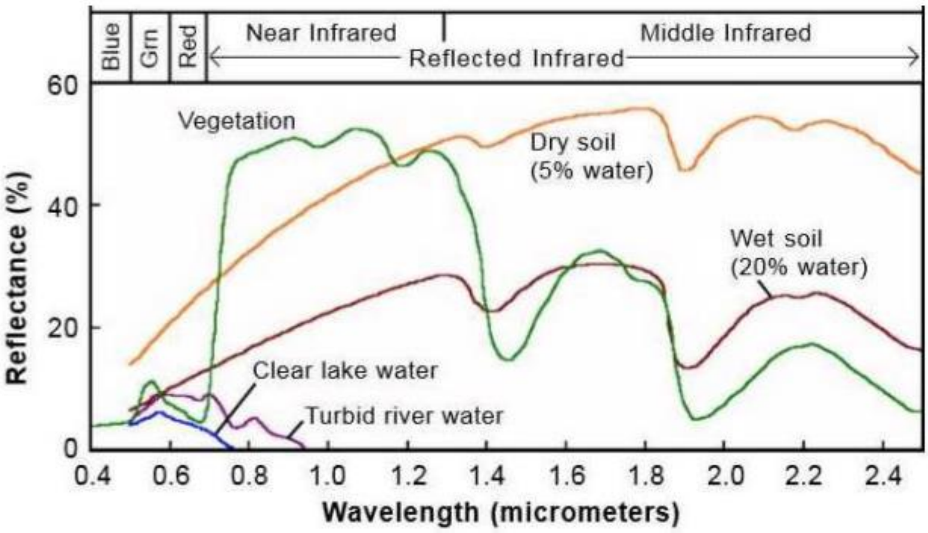

Figure 22. Spectral reflectance of clear lake water (suspended solids <10 mg/l), turbid river water, vegetation, dry soil and wet soil, (source: Pft [ErM E x 100 - Agricultural Meteorology - Progressive Gardening]).

Several authors have used multispectral indices and a threshold method to extract the wet channel from satellite images and study the morphological evolutions of river channels. For example, Cavallo et al. (2021b) extracted the wet channel of the Italian Po River from Landsat-4/5, Landsat-8 and Sentinel-2 datasets using a threshold method based on the MNDWI index for analyzing its morphological changes from 1986 to 2021. Kryniecka and Magnuszewski (2021) exploited a threshold method based on the Sentinel Water Mask (SWM)

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and Automated Water Extraction Index no shadow ($AWEI_{nsh}$) to extract water surfaces from six Sentinel-2 multispectral images to study alternate sandbars movement on the Vistula River in Poland. Jiang et al. (2014) developed an automated water surface extraction method exploiting four multispectral water indices (NDWI, MNDWI, $AWEI_{nsh}$ and Automated Water Extraction Index with shadow, $AWEI_{sh}$) for the wet channel mapping of six different rivers in the north and north-western China.

Although remote sensing has found a wide implementation for water extraction in perennial rivers, only recently some authors have begun to explore the potential of satellite data in monitoring the presence of water along TRs. For example, Seaton et al. (2020) examined the utility of various multispectral indices derived from Sentinel-2 and Landsat-8 satellite imagery for identifying and mapping water surface areas along three TRs located in the Western Cape of South Africa. The authors observed that the NDWI and $AWEI_{nsh}$ by Wang et al. (2018) lend themselves better to extract the water surface. Maswanganye et al. (2022) explored the use of multi-source remotely sensed data to monitor the spatial distribution of pools and pool dynamics along three TRs. The authors extracted water surfaces using three multispectral indices, including NDWI, MNDWI and NDVI, and a supervised random forest (RF) classification method from Sentinel-2 multispectral images. The RF is a machine learning algorithm that used a nonparametric method to resolve classification and regression problems. It is based on Classification And Regression Trees algorithm (CART) and overcomes its drawbacks by employing a multitude (a “forest”) of decision trees to make powerful predictions, less prone to overfitting problems. They also extracted water surfaces from the Sentinel-1 SAR data with a threshold classification method. The results of their work suggest that MNDWI and NDWI identified pools better than other methods in both the rivers studied.

Further and more recent studies exploited satellite datasets to estimate the flow intermittency of TRs. In particular, Wang and Vivoni (2022) developed a new approach to establish the presence of surface flow in a TR of Arizona (USA)

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by exploiting the commercial CubeSat (Planet) imagery. An index, based on the NIR band, was proposed in order to determine the flow condition in different reaches of the Hassayampa River at a daily scale during three years of observation. The temporal evolution of this index showed a high degree of convergence with the observed flow data recorded by a gauging station located in the surveyed river reach. Finally, Cavallo et al. (2022a) used multispectral Sentinel-2 images to detect and monitor changes in water surface presence along three Mediterranean TRs located in southern Italy. By evaluating the reflectance signature of water, sediment and vegetation covers, and with the help of ground truth data and high-resolution images, it emerged that the false colour image with SWIR, NIR, and RED's Sentinel-2 bands allows water surfaces to be clearly distinguished from the other components of the river corridor. The false-color composite images permit to perform a supervised classification of the surveyed river reaches in terms of three hydrologic conditions during six years of observation: "Flowing" (F), "Ponding" (P) and "Dry" (D). The obtained dataset allowed to train locally calibrated Random Forest (RF) models. Such models were used to solve a classification problem by filing the temporal gaps between satellite images and predicting the occurrence of one of the three hydrologic conditions (F/P/D) on a daily scale by using local meteo-hydrological data.

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