Education in categorization and identification of temporary rivers to fight climate change

Training materials

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Università degli Studi di Salerno
ingenio CSIC-UPV
femxa
DRAXIS Environmental Technologies
ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ TECHNICAL UNIVERSITY OF CRETE

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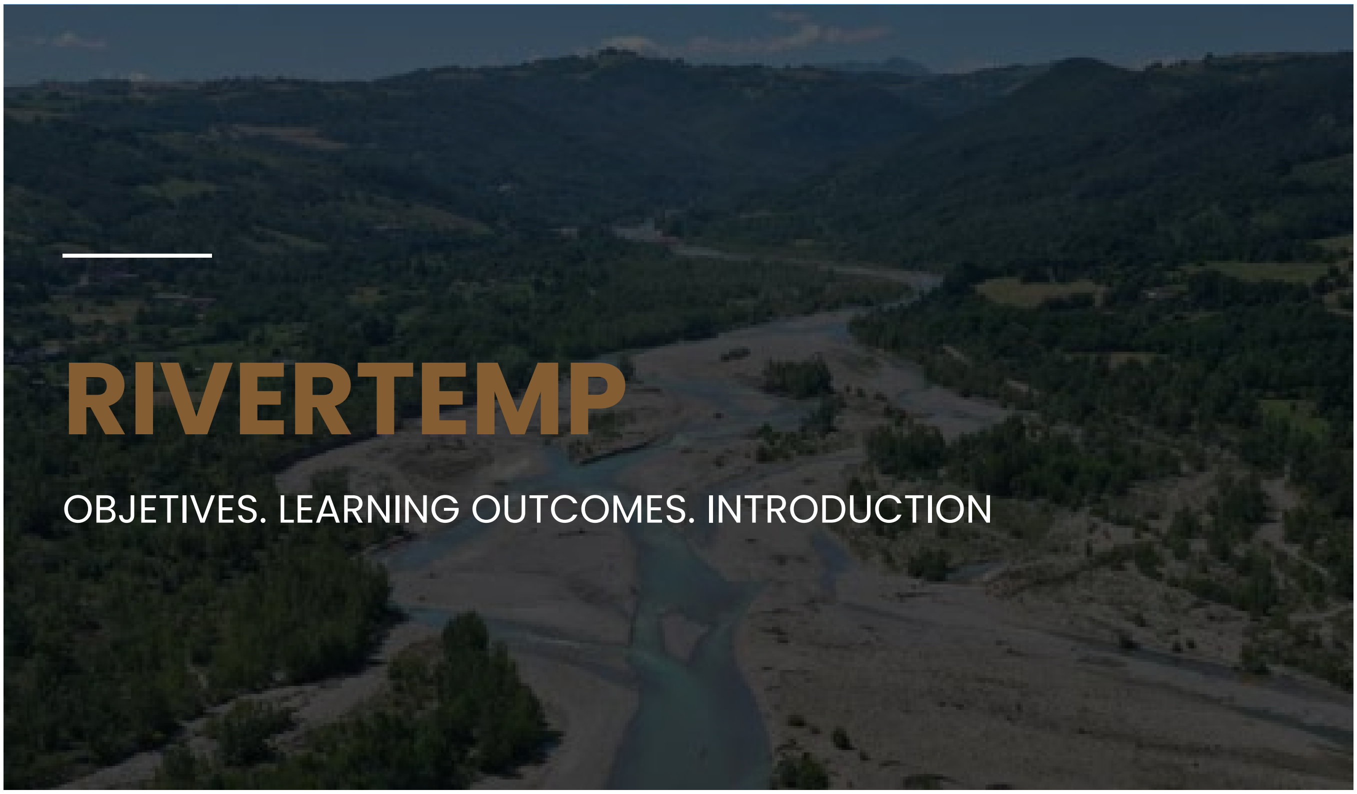
MODULE 1: Introduction to temporary rivers and flow intermittency_v2_ES

This module will introduce you to temporary rivers. Together with the definition, you will see basic concepts of flow intermittency, temporary rivers diffusion and spatio-temporal variability. You will start to discover how to classify rivers based on flow intermittency and finally understand the challenges that these rivers represent for river science.

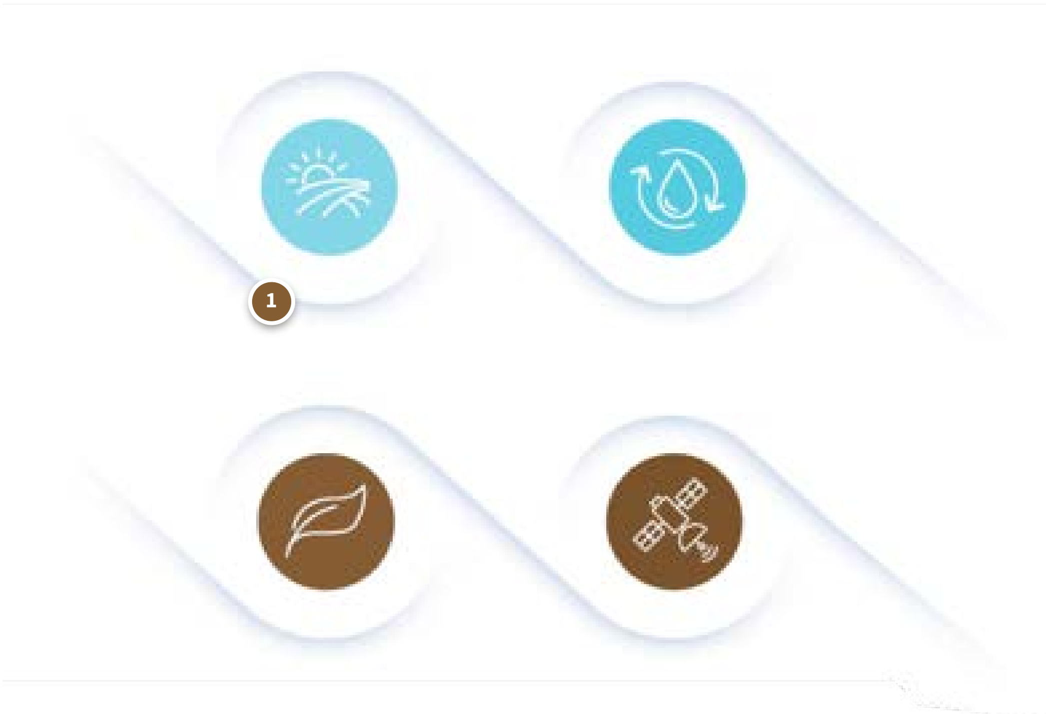
LET'S GET STARTED!

Objectives & Learning Outcomes



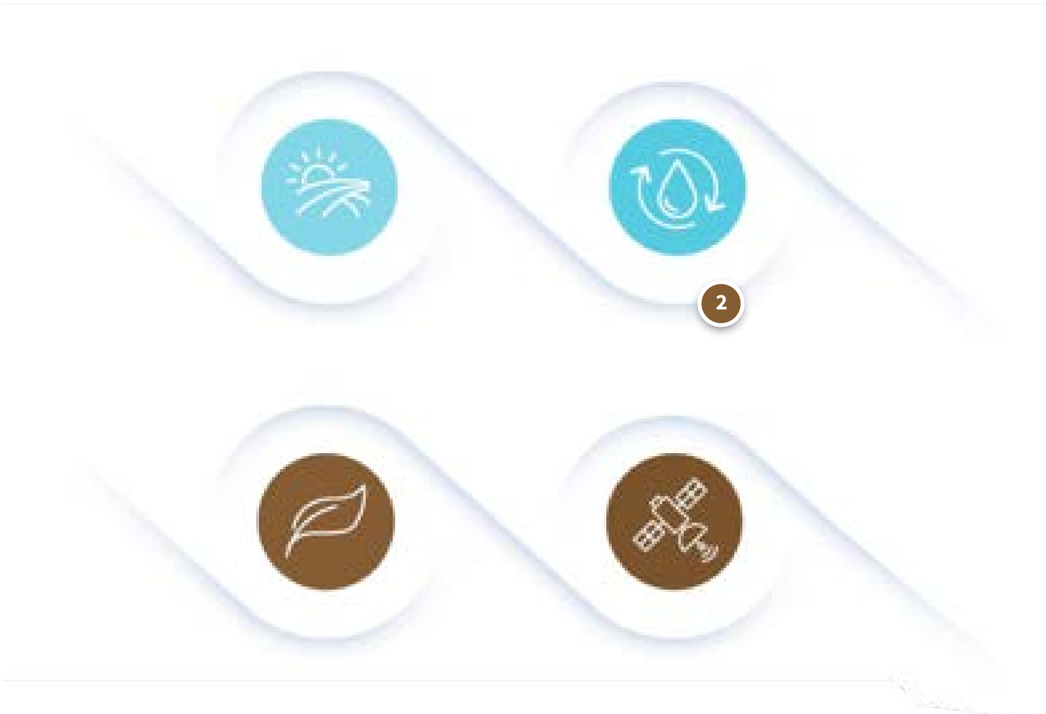
The **4 Objectives and Learning Outcomes** of this module 1 are the following:

Click on the buttons to view the information.



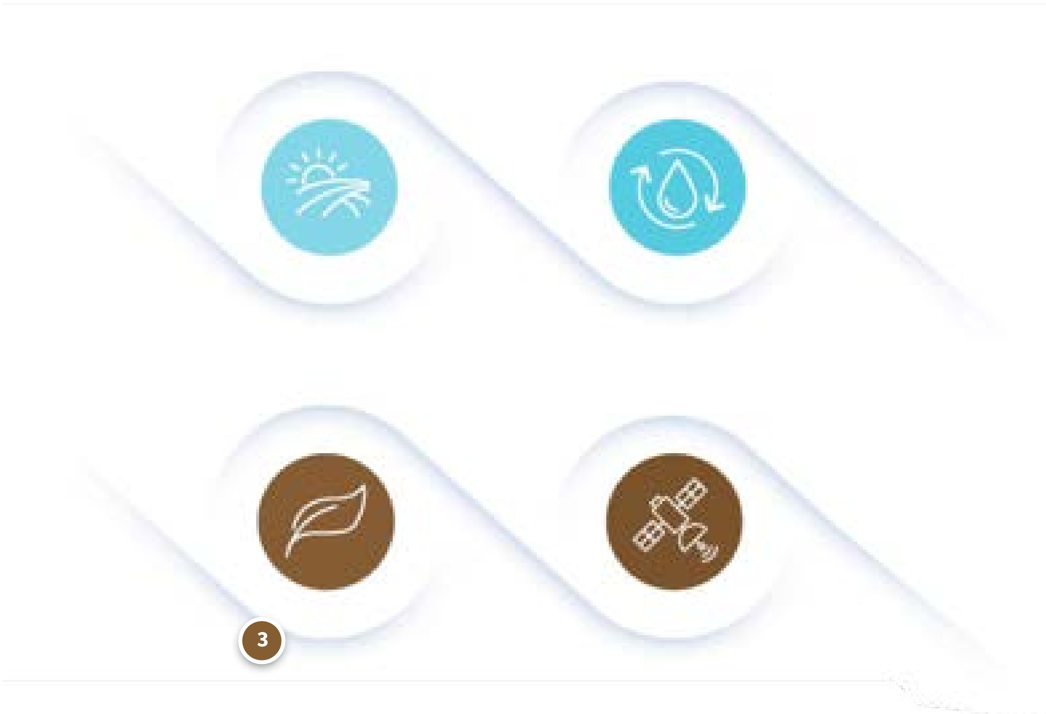
1

Redefinition of the **river concept**, including basic principles of flow intermittency.



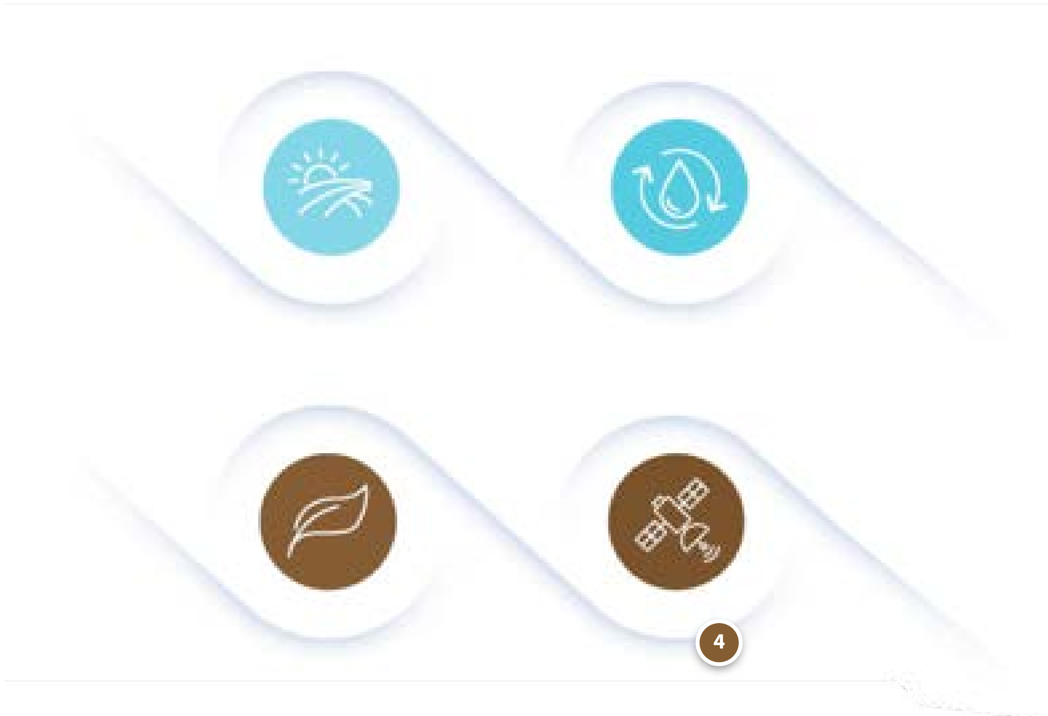
2

Prevalence and spatio-temporal variability of Temporary Rivers (**TRs**).



3

Recognition and classification of **TRs hydrological conditions**.



4

Introduction to the **satellite images** as monitoring instruments.

CONTINUE

Introduction

What do you know about temporary rivers?

Before starting, the following questionnaire will introduce you to the topics of the course using five simple multiple-

Pay attention, you may begin to doubt your basic knowledge choice questions.

about rivers.

CONTINUE

Click on the image to enlarge it

Look carefully at each of these photographs.

In which of the following photos do you recognize a river?

Select the options that you consider correct:
(multiple-choice possibility)

- [ ] Photo 1
- [ ] Photo 2
- [ ] Photo 3
- [ ] Photo 4
- [ ] Photo 5
- [ ] Photo 6

SUBMIT

NEXT QUESTION

Select the options that you consider correct:

In which climate zone are TRs present?

- All climates
- Tropical climate
- Temperate climate
- Continental climate
- Polar climate

SUBMIT

NEXT QUESTION

Select the options that you consider correct:

Recent hydrological studies estimate that temporary rivers represent...

- ○ from 5% to 15 % of global river network
- ○ from 20% to 30% of global river network
- ○ from 30% to 45 % of global river network
- ○ from 50% to 60 % of global river network

SUBMIT

NEXT QUESTION

Select the options that you consider correct:

The intermittencies of a temporary river result in lower river ecosystem quality and poor ecosystem services it can provide.

- True
- False

SUBMIT

NEXT QUESTION

Select the options that you consider correct:

The challenge of the new generation of water managers is to shift all the temporary rivers to perennial conditions.

- True

False

SUBMIT

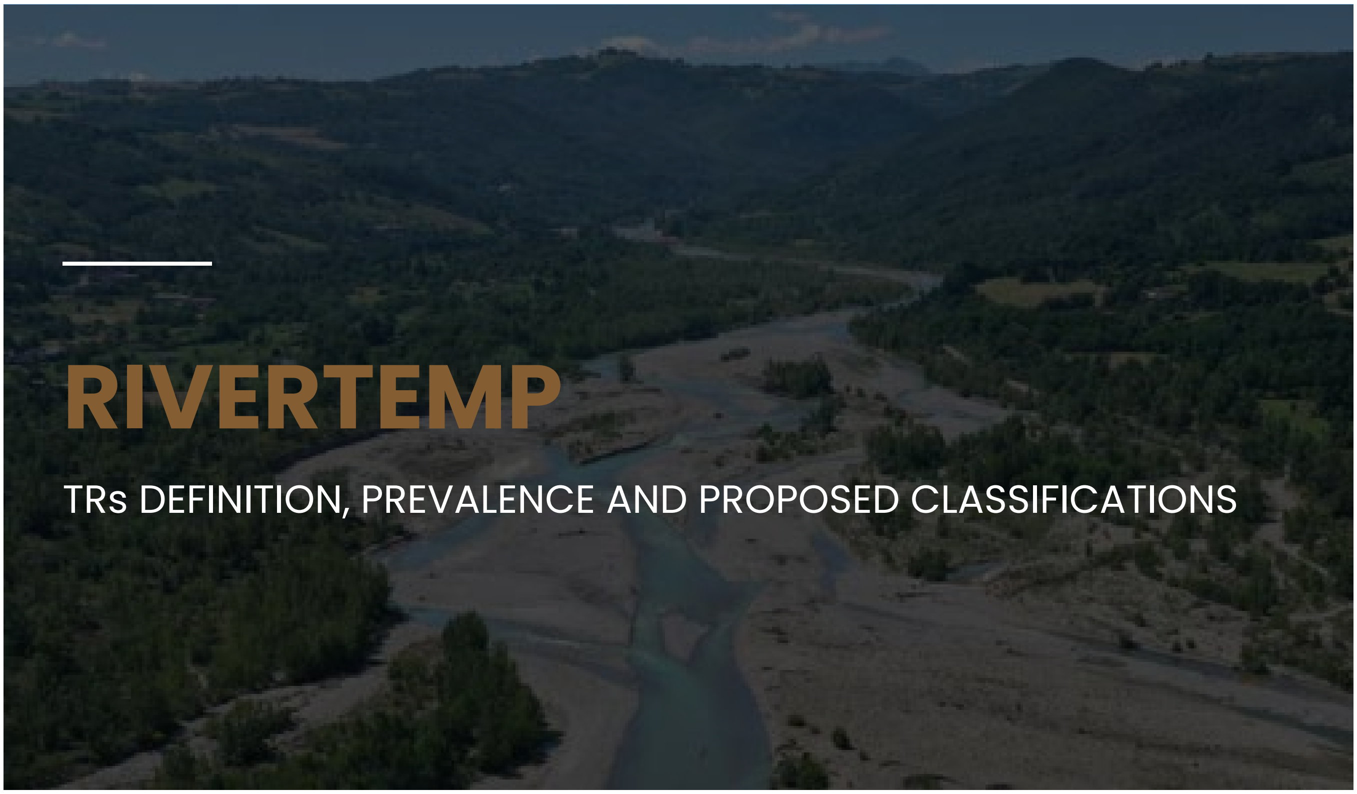
CONTINUE

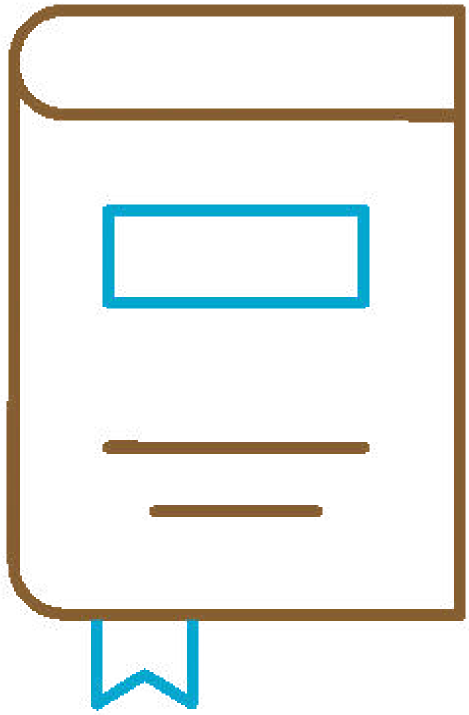
The module is divided into two parts:

1. TRs definition, prevalence and proposed classifications.
2. Importance of TRs for society and monitoring methodologies.

CONTINUE

TRs definition





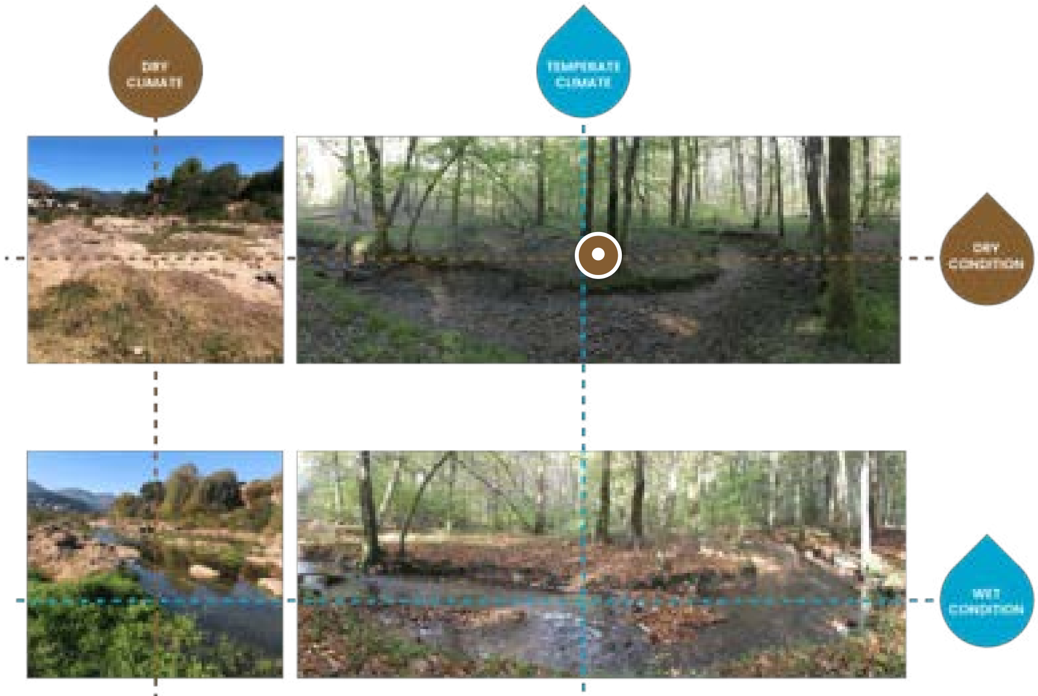
Definition:

Temporary Rivers (**TRs**), or non-perennial rivers, are ubiquitous water courses characterised by the occurrence of **non-flowing periods,** represented by dry stream beds or discontinuous water presence for some period within the year:

Click on the buttons to view the information.


DRY CLIMATE
TEMPERATE CLIMATE
DRY CONDITION
WET CONDITION

(click to enlarge)



(click to enlarge)

(click to enlarge)

(click to enlarge)

Temporary rivers during their dry and wet condition, for dry - Palancia River, Valencian Community, Spain (photo credits Isabelle Brichetto) - and temperate - Clauge River, Jura, France (Datry et al., 2017) - climates

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Datry, T., Singer, G., Sauquet, E., Capdevilla, D. J., Von Schiller, D., Subbington, R., ... & Zoppini, A. (2017). Science and management of intermittent rivers and ephemeral streams (SMIRES). Research Ideas and Outcomes, 3, 23-p.

What does this mean?

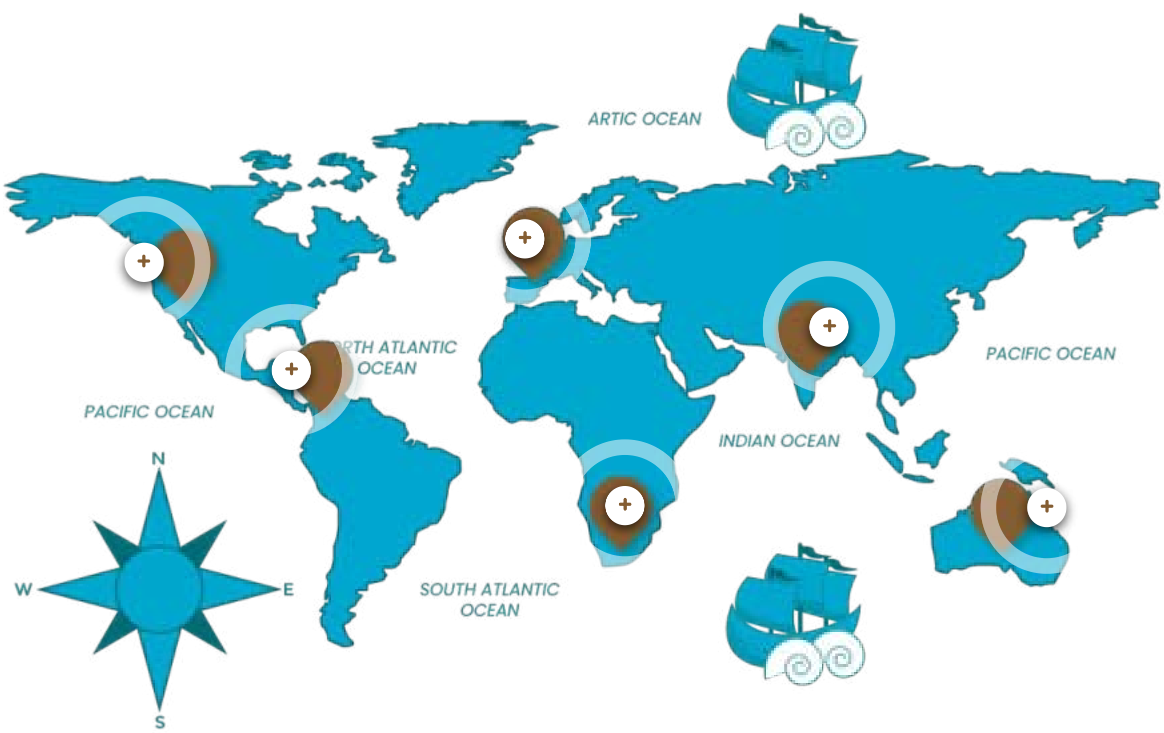
This means that **TRs** are rivers which experience the absence of water flux (flow cessation) along the riverbed **at least one day per year**.

This definition includes a **wide range of intermittencies:**

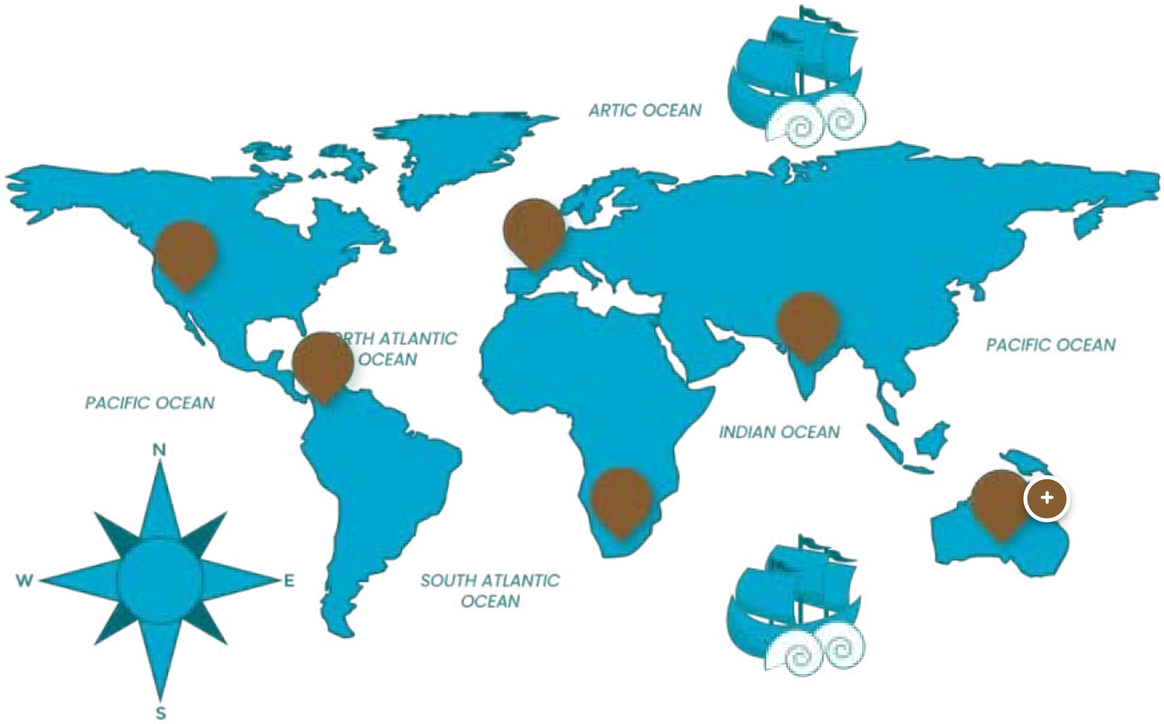
1. Quasi-perennial water courses.
2. Rivers with episodic water presence.
3. Stagnant water courses in which water can be often found just in ponds or wetlands.

Historically, TRs have been **associated with regions with a semi-arid or arid climate**, where climatic, hydrological, or geomorphological conditions contribute to river drying. However, the drying phenomenon on rivers is occurring **in all climatic zones in the world.**

Click on the buttons to view the information.



California (USA)


ARTIC OCEAN
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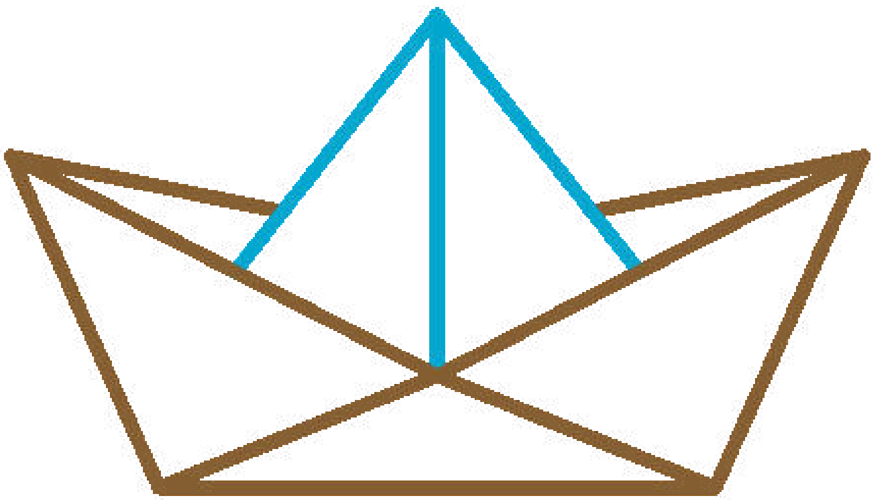
Europe

South Africa

Colombia

Examples of temporary rivers distributed among all the globe

CONTINUE



High variability

TRs are characterized by high variability in both space and time, experiencing dry and wet periods with heterogeneities along river reaches.

Did you know... ?

They are common and ubiquitous, representing **more than 50% of the global river network**.
Due to the combination and continuous succession of terrestrial and aquatic ecosystems, **the biodiversity of TRs can be extremely high.**

These water courses provide a variety of benefits and ecosystem services to our society, such as:

1. The provision of water and timber materials.
2. The provision of aquatic and terrestrial habitats.
3. The regulation of the biogeochemical cycles of nitrogen, phosphorus and carbon.
4. The provision of ecological corridors for wild and herded animals.

In addition to provision of the mentioned ecosystem services, **the drying and rehumidification processes of rivers** influence:

The biodiversity

The ecosystem functioning

However, suffering from negative perceptions and being historically overlooked by hydrologists, **TRs are deteriorating at alarming rates,** with difficulties in being recognized in the legislation as a **group of rivers with specific characteristics and needs.**

In recent years, without an official and universal taxonomy, the scientific literature has differentiated epithets to refer to TRs and flow intermittency.

1. Arid
2. Discontinuous

3 Dry

4 Ephemeral

5 Intermittent

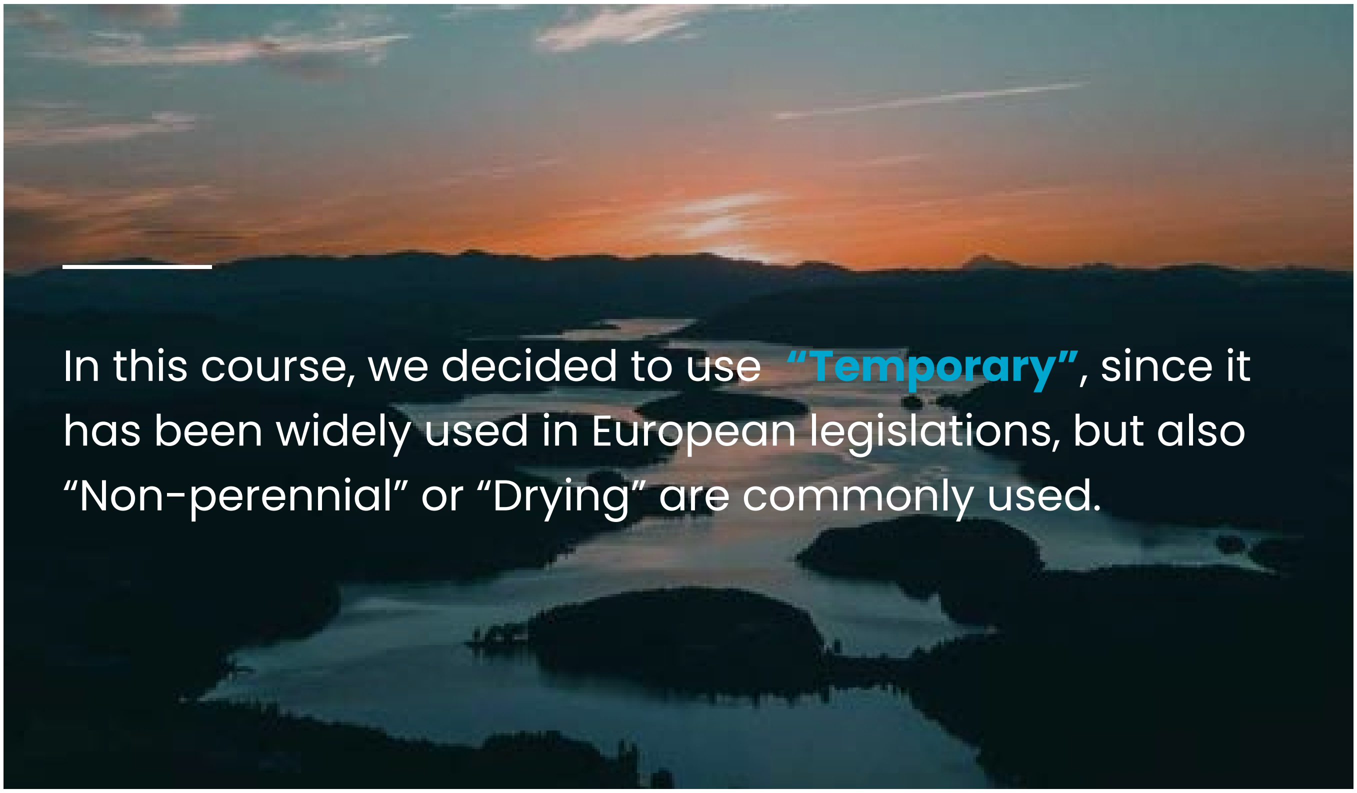
6 Interrupted

7 Irregular

8 Non-permanent

9 Seasonal

10 Episodic



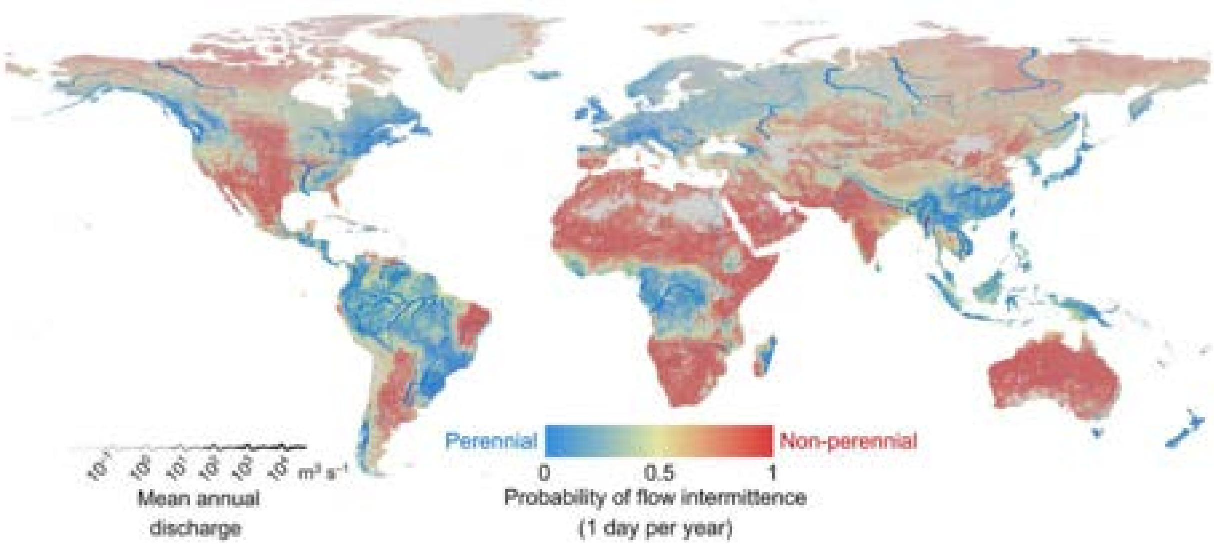
In this course, we decided to use **“Temporary”**, since it has been widely used in European legislations, but also “Non-perennial” or “Drying” are commonly used.

CONTINUE

Global prevalence of temporary rivers

Recent hydrological analyses of Messager et al. (2021), trying to quantify the **global presence of non-perennial rivers around the world,** conclude that the condition of flow intermittency is the rule on earth and not the exception, defining river intermittency as flow cessation for at least one day per year on average.

Click on the image to enlarge it



Global distribution of temporary rivers. Intermittence is defined as flow cessation for at least one day per year on average (**Data from Messager et al., 2021**)

Messager, M. L., Lehner, B., Cockburn, C., Lamouroux, N., Pella, H., Snelder, T., ... & Datry, T. (2021). Global prevalence of non-perennial rivers and streams. Nature, 594(7863), 391-397.

Let's look at the **Mean Annual Flow** (**MAF**) variable, that is obtained by dividing the sum of all the individual daily flows by the number of daily flows recorded for the year:

MAF > 0,1

If we consider rivers with MAF > 0.1 m^3/s, the estimates report a percentage of TRs around **41%**,

MAF < 0,1

But if also low-order rivers (with MAF below 0.1 m^3/s) are included, the percentage rises over **50%** with a conservative estimation.

IMPORTANT

These results pose a **very important question** for our general perception of rivers, since **the most common condition is the flow intermittency** or cessation, whereas **a perennial flowing condition is less common on Earth**.

Is the classification between **perennial rivers and temporary rivers** fixed?

Please note that the separation between perennial and non-perennial rivers is not stable over time. Different factors can influence a significant shift from one condition to another, enhancing flow intermittencies in various parts of the world. These factors are mainly:

1. Local climate
2. Rainfall events
3. Climate change
4. Anthropogenic pressures, such as changes in water withdrawals

(**Acuña et al., 2017**)

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Acuña, V., Hunter, M., & Ruhí, A. (2017). Managing temporary streams and rivers as unique rather than second-class ecosystems. Biological Conservation, 211, 12-19.

South West Europe

In southwestern Europe, land cover changes and increased water demands by irrigation are the main drivers of streamflow reduction.

In the last 50 years, some of the world's biggest rivers, such as **Nile, Yellow, Indus, and Colorado,** that historically were flowing continuously, have started to experience flow cessation and dry riverbeds in some portions of the river.

This generated a transition from permanent waterways to temporary watercourses. Furthermore, climate change, with increased evaporation and decreased precipitation, will directly affect the hydrological cycle, increasing the events in which water will cease to flow.

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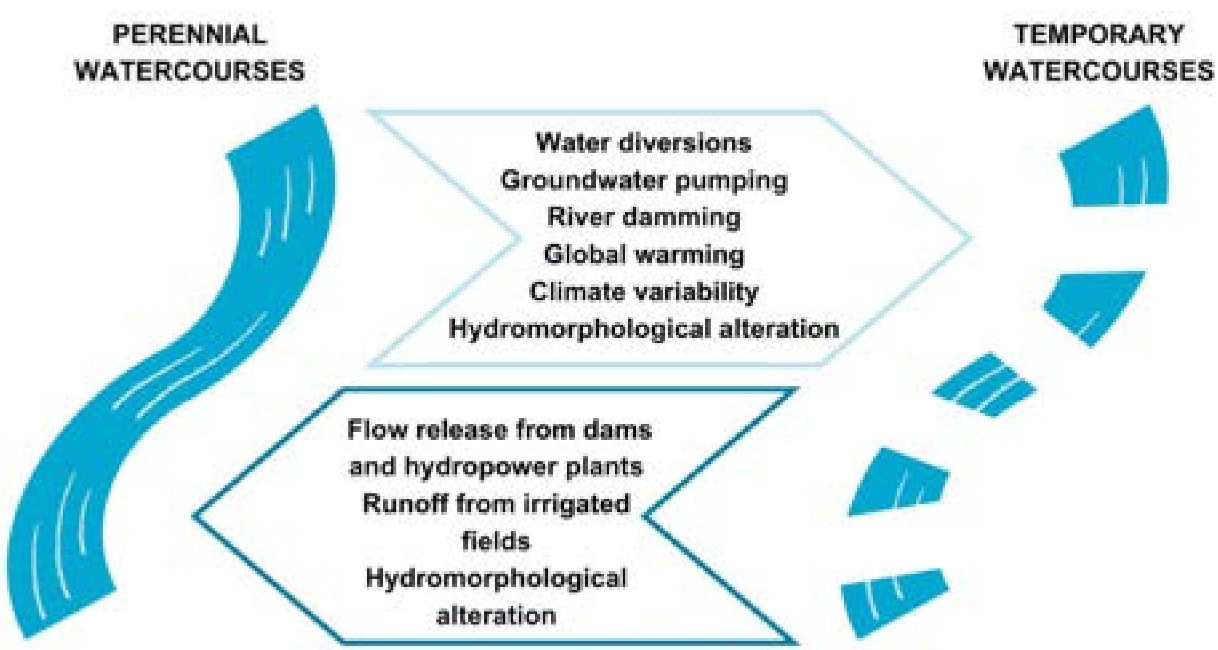
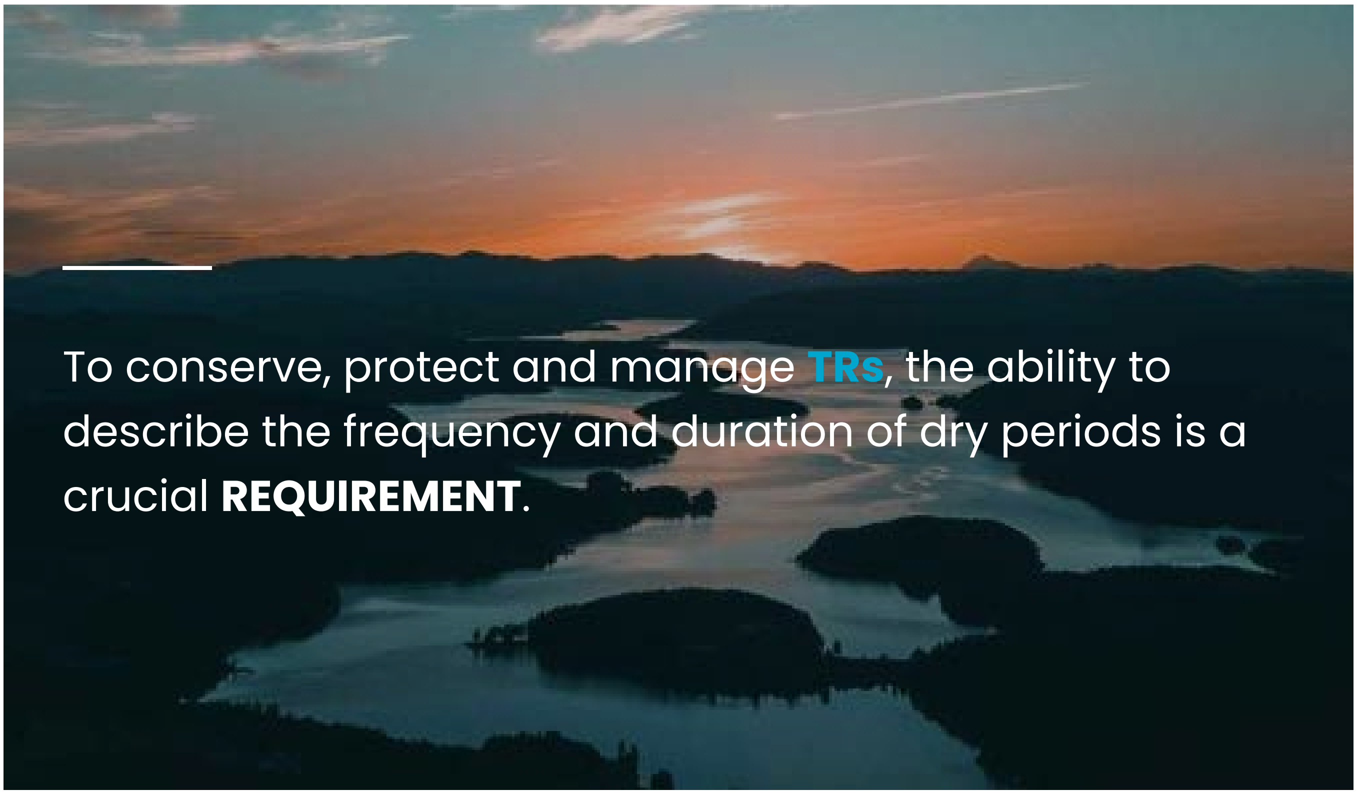


Drivers of transition from perennial to temporary and from temporary to perennial flow regimes

CONTINUE

TRs classification based on flow intermittency



Intensity of flow intermittency

The description of flow intermittency can provide important information to understand when and for how long surface water is present in a river, as well as to evaluate the presence of aquatic habitat for animals and plants.

Scale to look

By analysing TRs, the scale to look at is typically the reach scale, being the river reach a portion of the river along which similar hydrological and morphological conditions exist. This scale usually ranges in 0.1-10 km.

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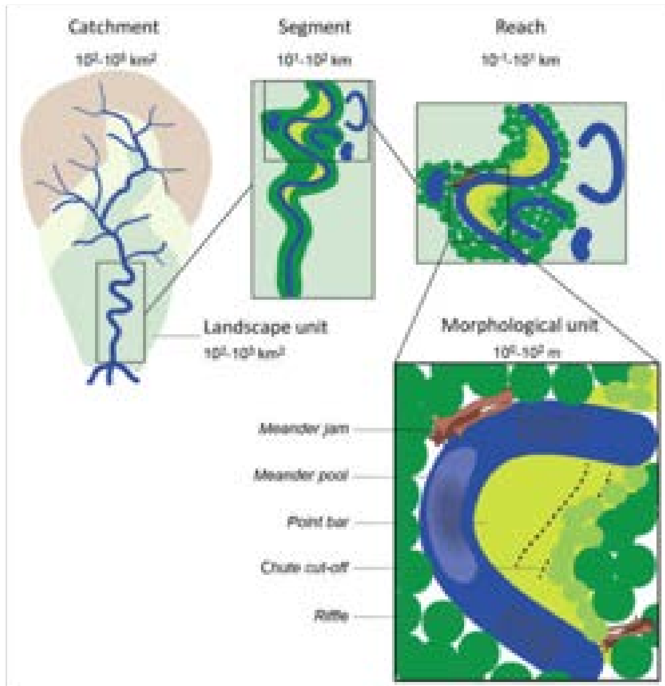

Hierarchical structure of river systems, from catchment to morphological unit ([**Rinaldi et al., 2016. Translated.**])

Rinaldi, M., Belletti, B., Comiti, F., Nardi, L., Mao, L., Bussettini, M. (2016): Sistema di rilevamento e classificazione delle Unità Morfologiche dei corsi d'acqua (SUM). Versione aggiornata 2016. ISPRA – Manuali e Linee Guida 132/2016. Roma, gennaio 2016.

What is the **reach scale** for?

The reach scale is selected to assess the frequency and duration of dry periods in temporary rivers.

From a geomorphological point of view, a river reach (same channel morphology and hydrological characteristics) has an homogeneous response to flow cessation.

Therefore, flow intermittency should be defined considering this spatial scale.

However, the presence of surface water is not only driven by river morphological characteristics, because it can vary depending on:

1. The hydraulic conductivity of the river sediment.
2. The local elevation of the water table.
3. The evapotranspiration rate due to air temperature and solar radiation.

IMPORTANT

Therefore, we suggest clearly **defining an appropriate spatial scale and describing the method used** for river segmentation, before starting to classify hydrological conditions in selected river reaches.

It is important to state that the classification of the hydrological condition **should be related to the water presence inside the active channel,** i.e. the portion of the river corridor defined by a break in bank slope that is also typically the edge of permanent vegetation.

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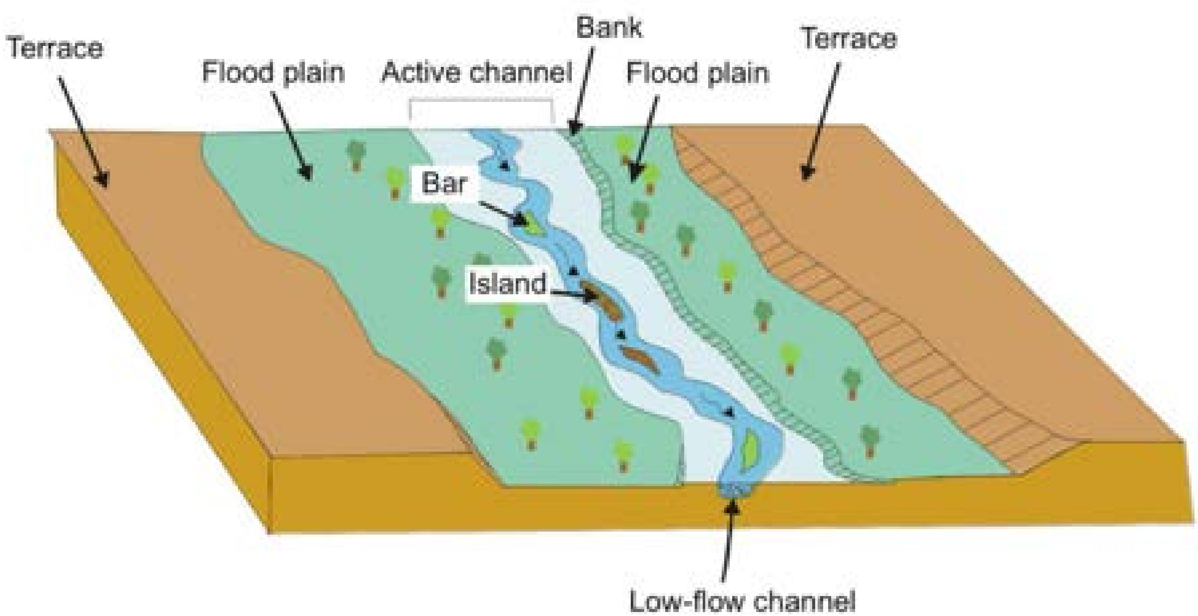


Components of river morphology. The active channel can be defined as the portion of the river corridor bounded by river banks and permanent vegetation. In the active channel, morphological dynamics is more effective and sediments are actively transported and deposited (**Università di Napoli. Translated.**)

Università di Napoli. Traslated. https://www.docenti.unina.it/webdocenti-be/allegati/materiale-didattico/397494

CONTINUE

Hydrological and ecological perspective

Click on the START > button to view the information and click on the images to enlarge it.

Sciarapotamo river, Salerno (IT) under the 3 hydrological conditions F) flowing, P) ponding, and D) dry.

From an hydrological and ecological perspective, one of the most diffused approaches to estimate the frequency and duration of dry periods is based on the distinction of three different hydrological conditions.

Flowing condition (F)

Visible continuous flow of water along the analysed river reach.
The flowing condition is easily detectable since there is a continuous surface flow in the river channel.

Ponding condition (P)

Discontinuous water presence; surface water is located in isolated ponds, pools or portions of the low-flow channel.

The ponding condition is more ambiguous, because it regroups intermediate states in which surface water is present along the river channel, forming isolated ponds, pools or submerged portions of the low-flow channel. This condition is typically stable when there is a significant connection with the groundwater or when hyporheic fluxes connect the riverbed and the water table.

Dry condition (D)

Absence of surface water, with dry riverbed.

The dry condition implies the absence of surface water inducing a dry riverbed, and it is generally due to the complete disconnection of the river with the groundwater.

References:

(Cavallo et al., 2022)

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

Based on the temporal permanence of the three hydrological conditions **(F, P, D),** different hydrologic regimes can be identified in **TRs**.

However, due to the inherent subjectivity in determining the **boundary values** among hydrological conditions, a universally applicable method remains elusive.

Different classifications of TRs flow intermittency have been proposed in the scientific literature, but there is no statistical robustness nor coordination among **EU countries**.

CONTINUE

The Water Framework Directive (WFD, European Commission, 2000)

is the major legal instrument to protect river ecosystems in the European Union, with the aim to achieve a Good Ecological Status in all water bodies. It states that, in order to evaluate the ecological status, reference conditions for each type of water body must be defined in advance.

European Commission

The EU Water Framework Directive

Water supports life. It is a crucial resource for humanity, generating and sustaining economic and social prosperity. It is also at the core of natural ecosystems and climate regulation.

The EU Water Framework Directive (WFD), adopted in 2000, takes a pioneering approach to protecting water based on natural geographical formations: river basins. It sets out a precise timetable, with 2015 as the deadline for getting all European waters into good condition.

Europe's water is under pressure. Economic activities, population growth and urbanisation are increasing pressures on freshwater throughout Europe.

Unless stronger action is taken, 47% of EU surface waters will not have good ecological status by 2015.

About 25% of groundwaters have poor chemical status due to human activities. The chemical status of 40% of surface waters is unknown, showing that monitoring is inadequate in many Member States.

The 2012 Blueprint to Safeguard Europe's Water Resources identifies obstacles to better water management, offers concrete solutions and sets the EU's water policy agenda for years to come.

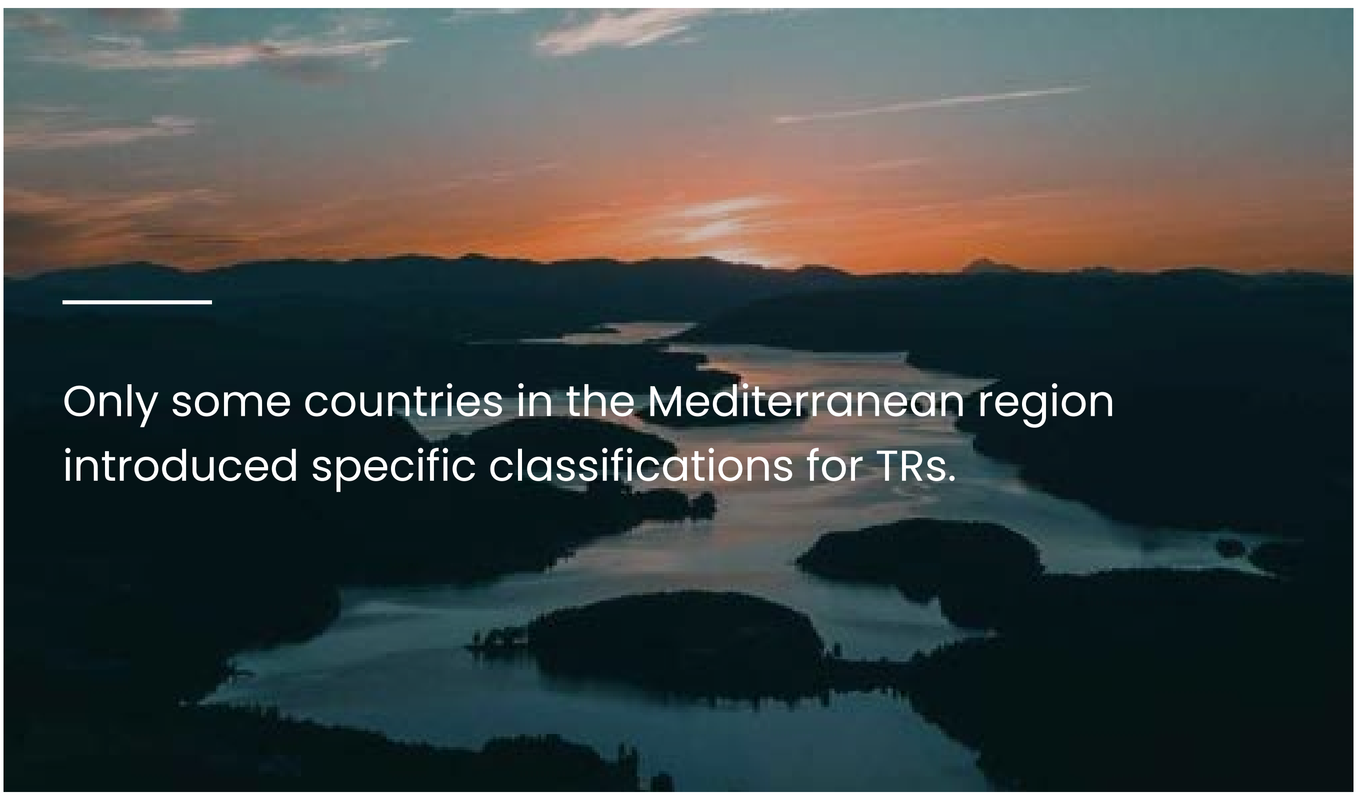
The WFD is complemented by other, more specific, EU laws:

- The Environmental Quality Standards Directive (2008)
- The Marine Strategy Framework Directive (2008)
- The Floods Directive (2007)
- The Groundwater Directive (2006)
- The Bathing Water Directive (2006)
- The Drinking Water Directive (1998)
- The Urban Wastewater Directive (1991)
- The Nitrates Directive (1991)

Environment

There are strong limitations to the implementation of **WFD in TRs,** starting from the definition of **reference conditions**.

It is therefore necessary to **monitor and model flow intermittencies,** retrieving the **frequency, duration and seasonality** of each hydrological condition.



Click cards to flip

Italy, with "D.M. 131/2008" of Ministero dell'Ambiente e della Tutela del Territorio e del Mare - MATTM, 2008)

Reference: *MATTM. (2008). Ministero dell'Ambiente e della Tutela del Territorio*

Spain, with "ORDEN ARM/2656/2008" of Instrucción de Planificación Hidrológica - IPH, 2008).

Reference: *IPH. (2008). Orden ARM/2656/2008, de 10 de septiembre, por la que se aprueba la instruccion de*

This two countries developed national legislations for temporary rivers classification.

Click on the buttons to view the information.

Thresholds

For example:

The average number in a year of days or months with no-flow.

Non-perennial river categories

Temporary, intermittent, ephemeral and episodic categories.

In parallel with national legislations, different European research projects worked for classifying temporary rivers based on flow intermittency. Examples of these research projects are:

Click on the buttons to view the information.

MIRAGE —

Implemented by European Commission, MIRAGE proposed a methodology to integrate hydrological, ecological and physicochemical aspects for the implementation of the WFD in Mediterranean temporary streams (https://cordis.europa.eu/project/id/211732)


MIRAGE
Grant agreement ID: 211732
Project closed
Start date
1 January 2009
End date
31 December 2011

LIFE + TRivers —

LIFE + TRivers provided a software (TREHS) to evaluate temporary river regimes as a first step for their ecological status assessment (http://www.lifetrivers.eu/)

SMIRES —

SMIRES established a multidisciplinary network of scientists and experts from 32 countries to consolidate and expand knowledge on TRs and translate it into science-based sustainable management (https://www.smires.eu/)

These research projects have recently provided new insights for understanding the eco-hydrological functioning of TRs freshwater ecosystems. However, there are difficulties in establishing general TR typologies (or hydrotypes), and more intense cooperation between Member States of the European Union is currently needed

(European Commission, 2022).

IMPORTANT

Within the existing classifications, in this course, we propose to use the one published by the **Spanish Environmental Ministry** (MITERD Guide, 2021), as it is based on the temporal occurrence of TR hydrological conditions.

CONTINUE

MITERD Guide, 2021

(Ministerio para la Transición Ecológica y el Reto Demográfico)

Click on the button to download the document.

guia-para-evaluacion-del-estado-aguas-superficiales-y-subterraneas_tcm30-514230.pdf

PDF

9.4 MB

Click on the image to enlarge it

The Spanish classification distinguishes **TRs categories** based on **three metrics (M)** concerning:

Management Temporary River Categories (MTRCs)	% Flow Permanence (Mf)	% Pool Permanence (Mp)	% Dry Permanence (Md)
Perennial or Quasi-perennial	99 < Mf ≤ 100	0 ≤ Mp < 1	0 ≤ Md < 1
	82 < Mf ≤ 99	0 ≤ Mp ≤ 18	0 ≤ Md ≤ 18
Intermittent-fluent	27 < Mf ≤ 82	0 ≤ Mp ≤ 73	0 ≤ Md ≤ 73
Intermittent-stagnant	0 < Mf ≤ 27	40 ≤ Mp ≤ 100	0 ≤ Md ≤ 60
Ephemeral	0 < Mf ≤ 27	0 ≤ Mp ≤ 40	33 ≤ Md ≤ 100

(click on the image to enlarge it)

Criteria to define the four hydrotypes, or "management temporary river categories" (MTRCs): quasi-perennial, intermittent-fluent, intermittent-stagnant and ephemeral, proposed in Spain based on the flow permanence (Mf), pool (or ponding) permanence (Mp), and dry river permanence (Md) (**Munné et al., 2021**)

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Munné, A., Bonada, N., Cid, N., Gallart, F., Solà, C., Bardina, M., ... Prat, N. (2021). A proposal to classify and assess ecological status in Mediterranean temporary Rivers: Research insights to solve management needs. Water, 13(6), 767.

Mf

Temporal permanence of **flowing** conditions

Mp

Temporal permanence of **ponding** conditions

Md

Temporal permanence of **dry** conditions

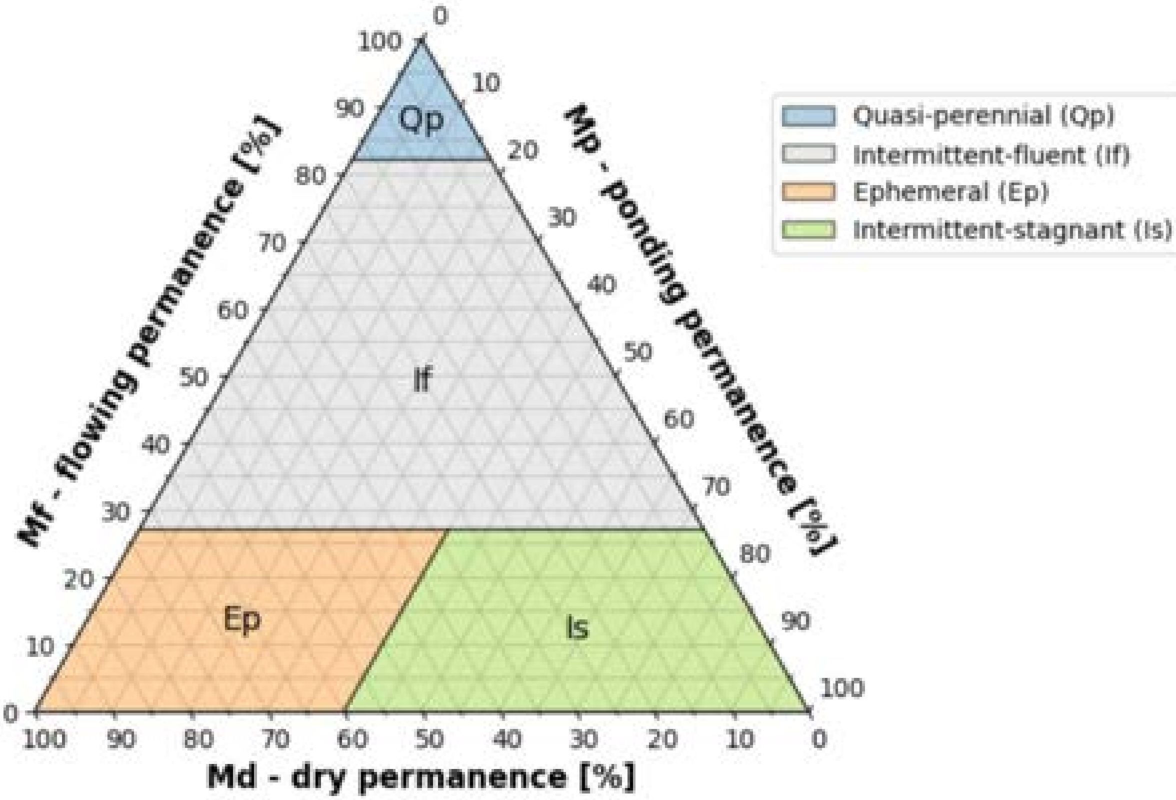
The combination of the three metrics (**Mf**, **Mp**, **Md**) is used to classify **TRs** into **four groups**, named **hydrotypes**.
In particular, the hydrotypes identified by **MITERD** (Ministerio para la Transición Ecológica y el Reto Demográfico) are:

1. Perennial or quasi-perennial
2. Intermittent-fluent
3. Intermittent-stagnant
4. Ephemeral

Click on the image to enlarge it

Ternary plot

The metrics **Mf, Mp and Md** can also be plotted in a **ternary plot** used for visually classifying temporary rivers in hydrotypes.



Ternary plot to graphically define the temporary rivers hydrotypes: quasi-perennial, intermittent-fluent, intermittent-stagnant, and ephemeral. The classification is based on three metrics: flow permanence (Mf), ponding permanence (Mp) and dry permanence (Md) (**Munné et al., 2021. Adapted**)

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Munné, A., Bonada, N., Cid, N., Gallart, F., Solà, C., Bardina, M., ... Prat, N. (2021). A proposal to classify and assess ecological status in Mediterranean temporary Rivers: Research insights to solve management needs. Water, 13(6), 767.

This ternary plot has been proposed by Munné et al. (2021) and it is an adaptation of the TREHS classification described in Gallart et al. (2017).

Definition:

From now on, the term **hydrotype** is used to distinguish the four different categories of temporary rivers (perennial or quasi-perennial, intermittent-fluent, intermittent-stagnant and ephemeral).

This classification should be rolled out in **Spain** for the River Basin Management Plans in the third cycle (2022–2027) of the European Water Framework Directive.

Additional information will be available in the coming years to better investigate this classification **(Munné et al., 2021).**

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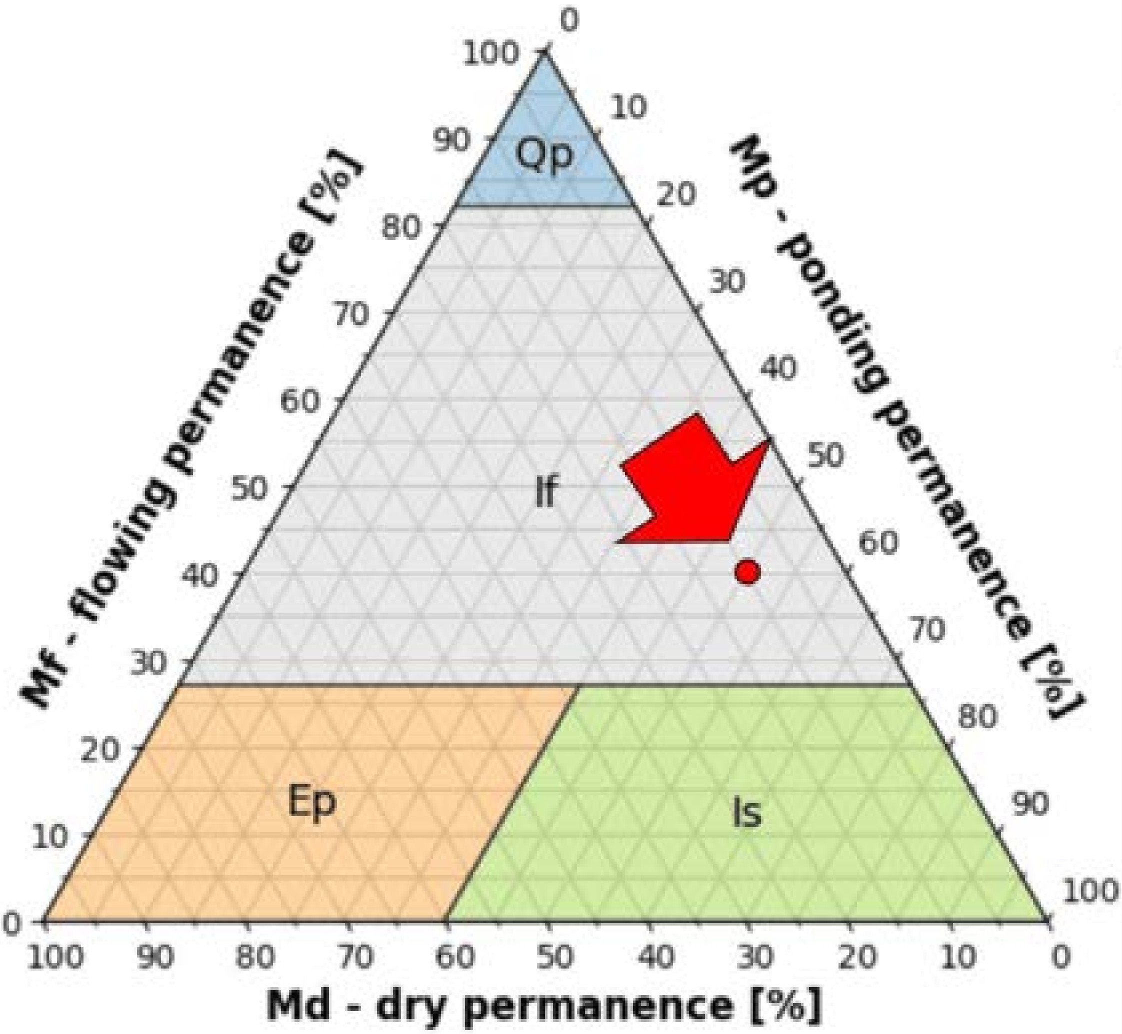
Munné, A., Bonada, N., Cid, N., Gallart, F., Solà, C., Bardina, M., ... Prat, N. (2021). A proposal to classify and assess ecological status in Mediterranean temporary Rivers: Research insights to solve management needs. Water, 13(6), 767.

Click on the image to enlarge it

A point in the ternary plot

Note that, for every river reach, the relative values of **Mf, Mp and Md** can vary depending on the year. However, once Mf, Mp and Md are calculated for a specific period of time, the classification of the river reach can be represented as **a point in the ternary plot.**



In this example, Mf=40%, Mp=50%, Md=10%

Obviously, always Mf + Mp + Md = 100%

CONTINUE

How to monitor water presence and hydrological conditions

The pivotal obstacles to study and classify TR hydrological regimes are:

Mf

The high spatial and temporal variability of the **flowing** permanence

Mp

The high spatial and temporal variability of the **ponding** permanence

Md

The high spatial and temporal variability of the **dry** permanence

To deal with this spatio-temporal variability, a common approach consists to firstly segment the river in homogeneous hydro-morphological river reaches **(sensu, Rinaldi et al., 2013),** and then, to estimate Mf, Mp, and Md at a yearly scale or for an entire period of interest.

Rinaldi, M., Surian, N., Comiti, F., & Bussettini, M. (2013). A method for the assessment and analysis of the hydromorphological condition of Italian streams: The Morphological Quality Index (MQI). Geomorphology, 180, 96-108.

See Module 3, for details

Monitoring flow intermittency at the **scale of the homogeneous reach** is a fundamental starting point to describe the **frequency**, **duration**, and **timing** of each hydrological condition along the year.

Furthermore, for every investigated reach, it is necessary to understand the **evolution of intermittency over time**, or the possible alteration of the flow regime due to current or future water use.

CONTINUE

Methods and approaches to observe and monitor the hydrological conditions

Click on the START button to view the information.

Several methods and approaches are currently available to observe and monitor the hydrological conditions frequencies in TRs. Available approaches can be grouped in 5 categories as follows:

Field surveys

Field surveys are one of the most common solutions for acquiring data on the TR flow conditions. Data collected in the field can have high accuracy and reliability. Therefore, this approach is often limited by the lack of replicability and the costs of field data collection campaigns. To reduce costs and extend coverage, in recent years mobile phone apps have been developed using citizen science and crowdsourcing as data sources

Example: DRYvER App (https://www.dryver.eu/app)

Streamflow gauging stations

Streamflow gauging stations are widely used to obtain instantaneous flow rate in rivers and long-term data series.

When the streamflow time series is available, it allows to evaluate the evolution of flow discharge over the years and the frequency and duration of zero-flow periods.

However, streamflow gauging stations only measure the surface flow in one point or river section and are rarely present along TRs. Thus, this technique reveals serious issues in distinguishing the zero-flows events into dry and ponding phases.

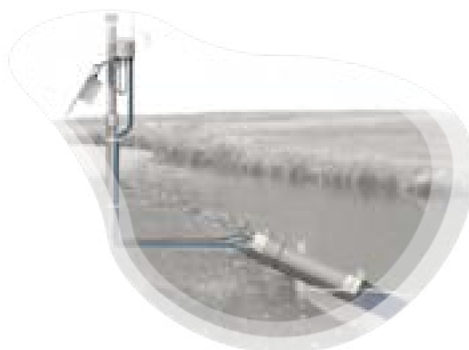
It has been observed in many cases that the real cessation of surface flow occurs for some discharge threshold above 0 in the flow record, while lower discharges eventually correspond to the ponding or dry conditions.

It is still not clear how the threshold between flowing and non-flowing events is stable over the year and between years, as well as if there is the possibility to establish a flow rate threshold in time series to distinguish between ponding and dry conditions (**Oueslati et al., 2015**).

References: *Oueslati, O., De Girolamo, A. M., Abouabdillah, A., Kjeldsen, T. R., & Lo Porto, A. (2015).*

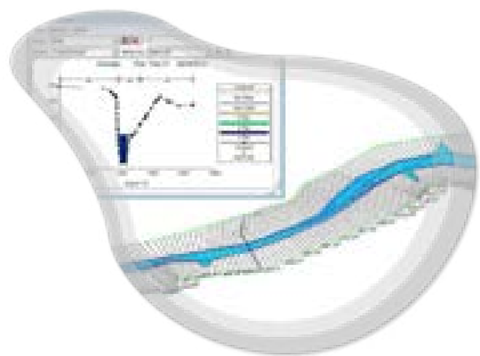
Classifying the flow regimes of Mediterranean streams using multivariate analysis. Hydrological Processes, 29(22), 4666-4682.

Data loggers



Another method to obtain real-time data and time series of water presence is using data loggers measuring water table level, water temperature and/or electrical conductivity.
These instruments may detect the movement of wetting and drying fronts but could have difficulties in distinguishing between flowing and standing water. In addition, the drawbacks are their punctual measurements and the possibility of instruments being swept away or buried during floods or their integrity being compromised by vandalism.

Hydrological modeling

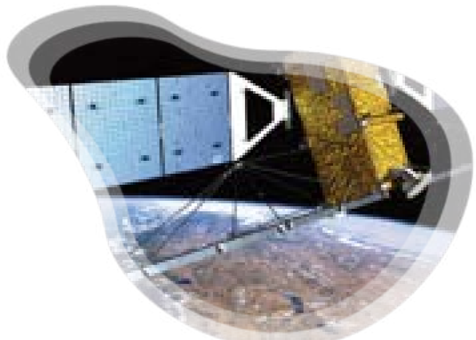


Hydrological models are useful tools when able to predict flow occurrence in rivers. This approach, which allows for estimating the streamflow rate in every river section, has a large history in river science. However, important limitations can be generated by the data availability and by the physical representation of the surface-groundwater interaction, soil moisture conditions, grain size and hydraulic conductivity of the riverbed sediment during zero-flow events.

Most common approaches can still be biased in predicting the zero-flow events at the river reach scale, due to the complexity of the physical processes behind the flow occurrence in rivers.

Hydrological modeling can overestimate or underestimate zero-flow events with a large variability of uncertainty depending on the study case. They require gauging stations for model calibration as well as a high amount of data (surface-groundwater interaction, riverbed composition, etc.) for model construction.

Remote sensing



Remote sensing has recently demonstrated significant potential for monitoring hydrological conditions in TRs. Currently, both airborne surveys and satellite images may allow the execution of rapid and extended estimation of flow condition in TRs.
Satellite images are collected worldwide and can have a revisit time, on the same river reach, shorter than a week.
Multispectral sensors offer the possibility to better distinguish water from sediment and vegetation and, therefore, to intensively monitor the evolution of hydrological conditions.
The main drawbacks of the satellite images application on temporary rivers are related to the limited spatial resolution (down to 10 m of Sentinel-2 mission, for the freely available satellite data, which hinders its application in narrow rivers and streams) that induces to a qualitative evaluation of the water presence along the river channel, the cloud coverage, since an important share of available images is unusable, and the presence of dense vegetation cover in riverbeds that may masks the river channel.

Satellite images and remote sensing

Because of global coverage and short revisit time, in this course we refer to the use of satellite images and remote sensing to estimate the relative frequencies of flowing, ponding, dry conditions. In particular, the Sentinel-2 dataset is suggested, due to its free and open access characteristics and for its spatial resolution, reaching up to 10 m on the ground.

Sentinel-2

The Sentinel-2 mission comprises two twin satellites equipped with a Multispectral Sensor (MSI), which acquires a total of 13 bands, with a spatial resolution ranging from 10 to 60 m depending on the band. The presence of the two satellites allows for capturing the same area every 5 days (or more frequently for overlapping acquisitions). This time interval represents an appropriate observation timing, since in TRs the hydrological condition can change and shift from one to another in less than a week (see Module 2 for details).

Click on the button to open the website.

About Copernicus Sentinel-2...

If you want to discover more about these 2 satellites.

INFOGRAFHIC

CONTINUE

To finish this first module, in the following videos you will be able to discover how this satellite works. You just have to press the Play button.

Come on!

Click on the button to watch the videos.

1

Earth from Space: special edition

2

Moving ahead with Sentinel-2

CONTINUE

References

Bibliographic references

In the development of any academic course, bibliographic references play a crucial role by providing the necessary theoretical and practical support for the material taught.

References not only strengthen the credibility of the study materials but also allow students to explore the topics covered more deeply, gaining

This set of references has been carefully selected to provide a solid foundation of knowledge, encompassing a variety of a deeper understanding of key concepts and discovering new perspectives.

sources, including books, academic articles, recent research, and digital resources.

We hope these references will be a valuable tool for learning, fostering a comprehensive and critical understanding of the topics addressed in this course.

Amazon river - Brazil, Photo credits: NASA. https://www.nasa.gov/image-article/amazon-river/

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Nile river - South Sudan, Photo credits: Britannica. https://www.britannica.com/place/Nile-River/Physiography

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Palancia river - Spain, Photo credits: Isabelle Brichetto.

Po river - Italy, Photo credits: Gabriele Pileri.
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Sangone creek - Italy, Photo credits: Massimo Pinca.
https://www.reuters.com/news/picture/idUSRTS8WTIV/

Università di Napoli. Traslated
https://www.docenti.unina.it/webdocenti-be/allegati/materiale-didattico/397494

CONTINUE

Quiz

It is time to test what you have learned!

Please select the best response for each question based on your understanding of TRs.

You must answer all the questions correctly to continue with the course.

Question

01/03

What are Temporary Rivers (TRs)?

- ○ Rivers that activate only after a storm event.
- ○ Water courses with the occurrence of non-flowing periods.
- ○ Abandoned rivers not significant for biodiversity and ecosystem services.

Question

02/03

What is the global diffusion of TRs?

- ○ There are no studies about their prevalence.
- ○ They represent about 30% of the world's river network.
- ○ They represent about half of the world's river network.

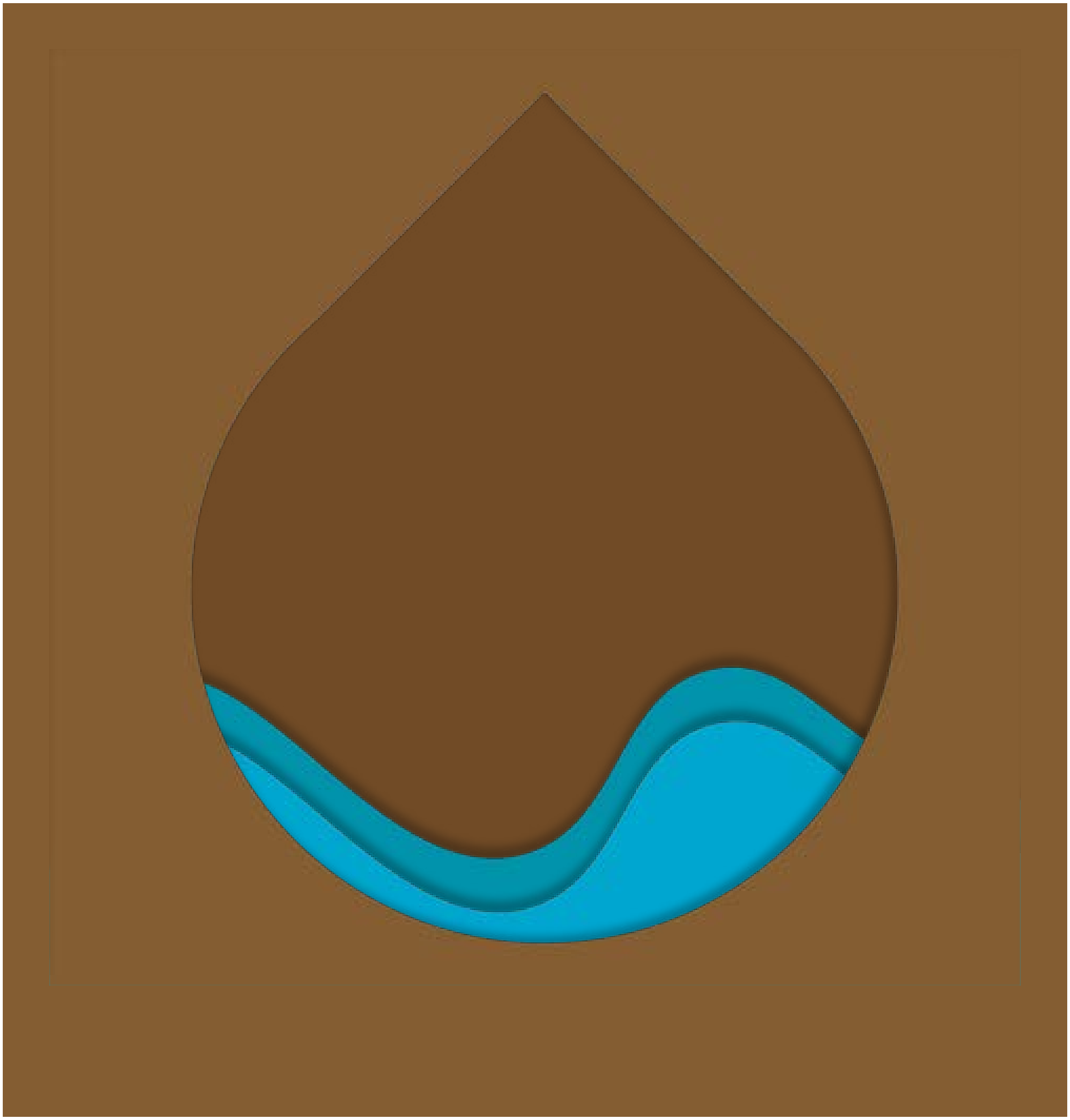
Question

03/03

What is the upcoming monitoring instrument for studying TRs?

- ○ Streamflow gauging stations, for their diffusion on temporary river reaches.
- ○ Data logger, for their ability to discriminate the ponding from the dry hydrological condition.
- ○ Remote sensing and satellite, for their global observation and good resolution at reach scale.

Closure



Congratulations!

You have **completed** this module.

Congratulations for your achievement! By successfully completing the first module, you have extended your concept of ‘rivers’, assessing that even the water courses where water ceases to flow have to be considered as ‘river’.

The high variability that characterised TRs both in space and time, together with their diffusion and importance for biodiversity at the global scale are the other take-home messages of this module. Well done! At this point, you are ready to discover how to study, monitor and model TRs, using innovative techniques.

Let’s move to module 2!

MODULE 2: Working with satellite images_v2_ES

In this module, you will learn how to work with satellite images. You will get an overview of satellite data characteristics and potentialities. In addition, you will be able to access Sentinel-2 multispectral data and to extract information from them.

You will explore the potentialities of the Sentinel-2 for the identification of water presence in temporary rivers and test your knowledge with a practical activity.

LET'S GET STARTED!

Passive and active remote sensing

Electromagnetic spectrum of sensors mounted on satellites

Passive vs Active sensors

3. SATELLITE IMAGES

What is the format of satellite images?

Sentinel-2 mission

What is the spatial resolution of the images extracted from Sentinel-2 data?

From which source can images of Sentinel-2 be viewed or downloaded?

4. VISUALIZATION OF THE IMAGES

How do we see images with cloud cover?

How are the digital images we observe every day generated?

RGB image

5. SPECTRAL SIGNATURES

Spectral signatures of different land covers in literature

How to construct the spectral signature of land covers?

Spectral signatures of different land covers in temporary rivers extracted from Sentinel-2

6. SIMULATION ACTIVITY

What is the best combination of false-color bands?

What is the optimal band combination you have identified?

Comparison among RGB images and FCI

7. REFERENCES

References

8. CLOSURE

Closure

Objectives & Learning Outcomes

The **6 Objectives and Learning Outcomes** of this module are the following:

Click on the buttons to view the information.

Acquire basic concepts of remote sensing

Understand the differences between remote sensing sensors

View the characteristics of Sentinel-2 images

Find satellite data-source

Learn how to distinguish water from sediments and vegetation patches in multispectral images

Identify the best band triplet for enhancing the visibility of water in river

CONTINUE

Introduction

Why are satellite images useful in monitoring **temporary rivers?**

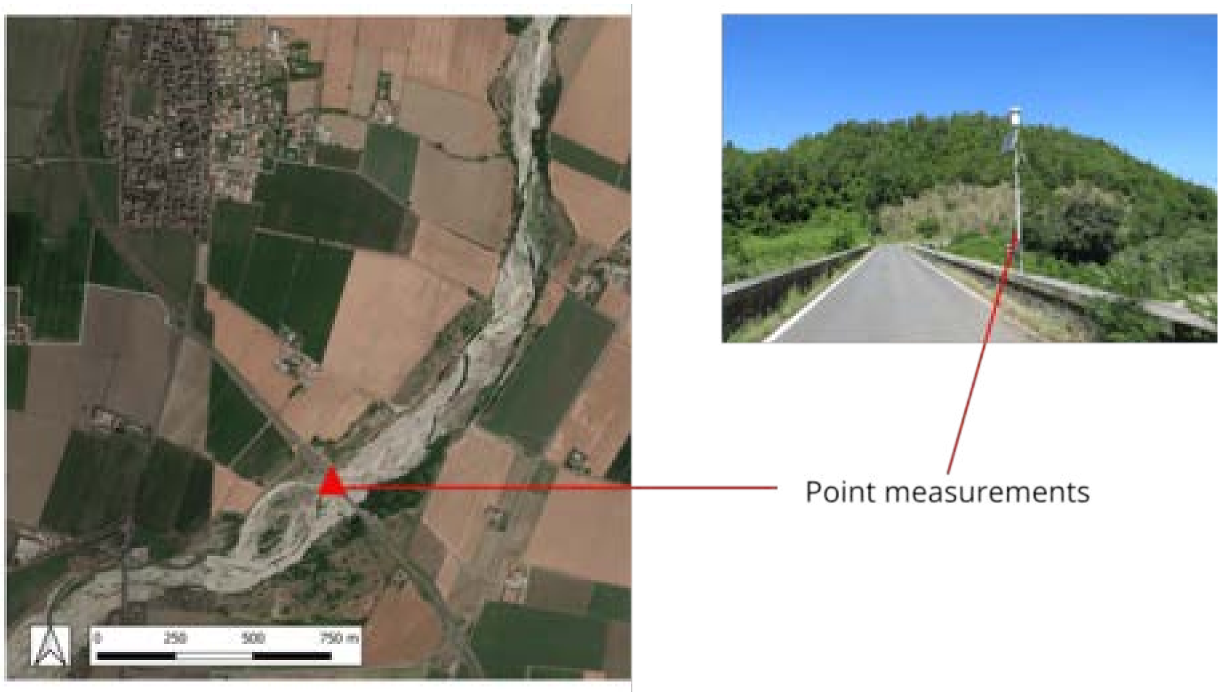
As illustrated in the previous module (**Module 1**), temporary rivers exhibit considerable spatial and temporal fluctuations in the presence of water. Reaches with continuous water flow may have spatially adjacent reaches completely dry or with isolated ponds of water.

Such spatial variation is difficult to be detected by conventional measuring instruments.

Measurements at a single point are not representative of what occurs along the entire fluvial reach, nor along the entire river.

With the data collected by **Sentinel-2 satellites**, which are medium-resolution multispectral instruments, it is possible to **identify the spatial distribution of the three hydrological conditions** (F, P, D) along temporary rivers.

Click on the image to enlarge it



Traditional gauging station. Image credits Carmela Cavallo

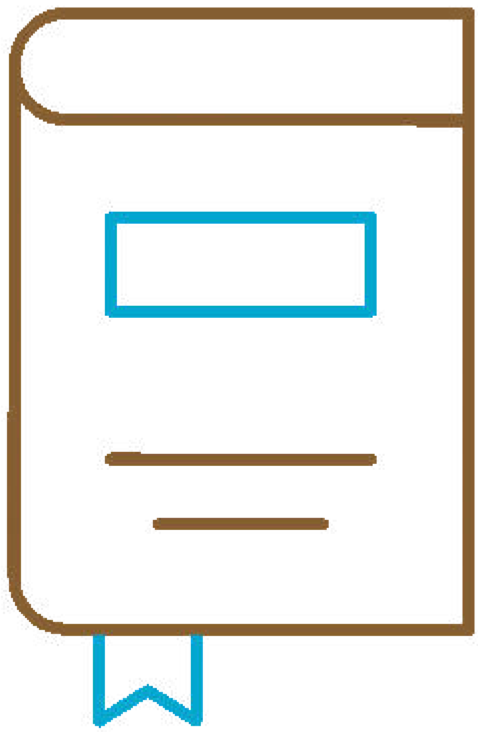
CONTINUE

Introduce the concept of remote sensing

In order to better understand the topics that will be presented in this and subsequent modules, it is necessary to introduce the concept of **remote sensing** and to briefly recall the characteristics of the most widely used sensors in satellite applications.

Definition:

Remote sensing is a technical-scientific discipline that allows to identify, measure and analyse the qualitative and quantitative characteristics of a specific object placed at a distance, based on the measurements of the electromagnetic energy that is emitted, reflected or diffused by the surface under examination.



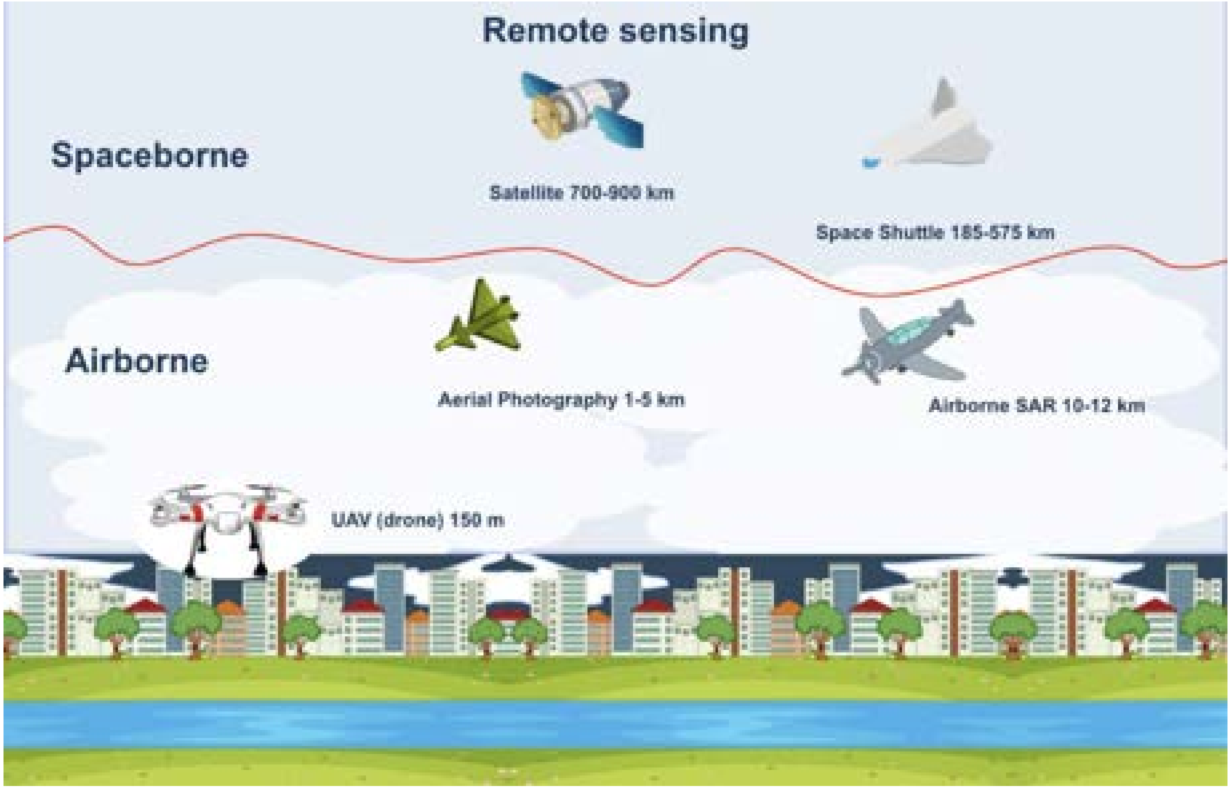
The data are aquired by **sensors** mounted on various platforms, such as drones, airplanes and satellites.

How does it work?

Sensors **detect the electromagnetic energy** coming from a scene and convert the received signal into information.

A significant advantage of satellite remote sensing, compared with the use of other platforms, is the possibility to monitor wide areas, potentially covering the entire globe, with various spatial and temporal resolutions.

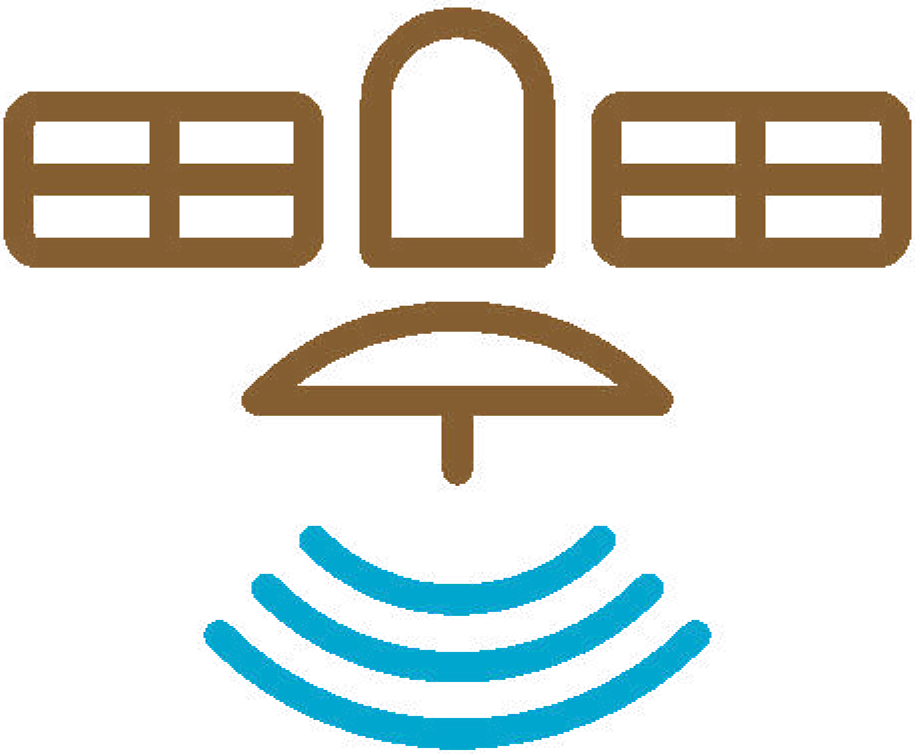
Click on the image to enlarge it



Distance from the earth surface of the different remote sensing platforms. Image credits Carmela Cavallo

CONTINUE

Passive and active remote sensing



Depending on the functioning and the target of satellite acquisition, it is possible to distinguish two main types of sensors used for the measurement of electromagnetic radiation:

PASSIVE SENSORS

Passive sensors, such as the one mounted on the Sentinel-2 satellites, detect the natural energy that is emitted or reflected by the observed object.

ACTIVE SENSORS

In active remote sensing, instead, the sensor itself produces the radiation to illuminate the scene and then records the return signal. Synthetic Aperture Radar (**SAR**) is the most

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.

commonly used active sensor. They function by sending a beam of radiation to a target surface, collecting the signal sent back after the interaction and, therefore, modification of the beam with the scene.

Reference: Radiation source of Passive remote sensors. Image credits Carmela Cavallo

Reference: Radiation source of Active remote sensors. Image credits Carmela Cavallo

CONTINUE

Electromagnetic spectrum of sensors mounted on satellites

PASSIVE SENSORS

Passive Sensors receive signals from different spectral channels centered on particular wavelengths of the electromagnetic spectrum.

The following wavelength regions are usally considered:

1. The visible (VIS, 0.4 µm - 0.75 µm).
2. The infrared (IR, 0.7 µm - 1 mm).
3. The thermal infrared (10.6 µm - 12.51 µm).

Example:

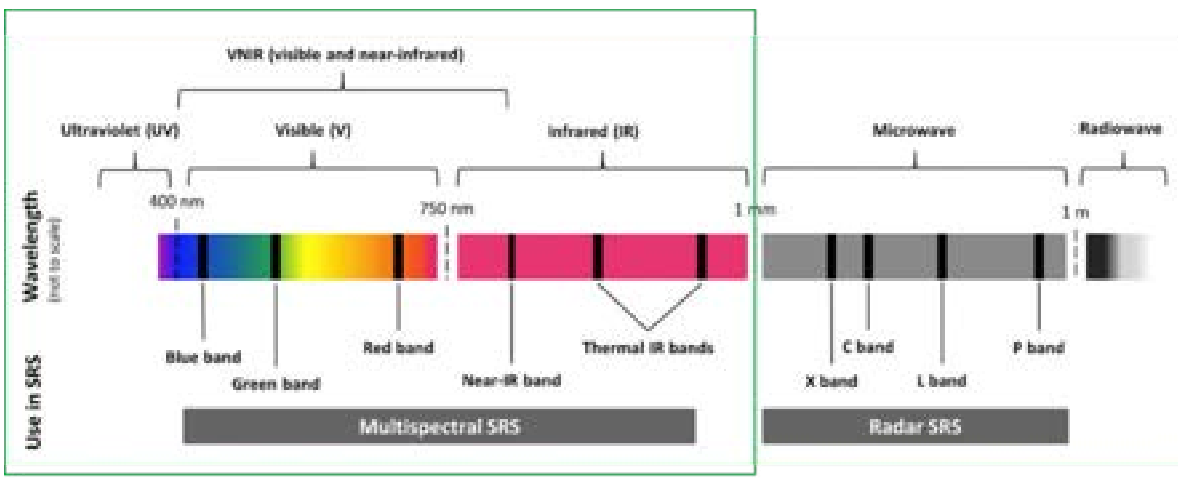
Some examples of sensors that use this type of detection are:

- Panchromatic sensor (using a single band).
- Multispectral sensor (using about 10 bands).
- Hyperspectral sensor (using about 100 bands).

Thus, multispectral and hyperspectral images are composed by multiple layers of bands or channels, each one capturing information within a specific range of wavelengths across the electromagnetic spectrum.

Image: Electromagnetic spectrum and range of wavelengths used by Passive sensors (SRS, Pettorelli et al., 2018)

Reference: *Pettorelli, N., Schulte to Bühne, H., Shapiro, A. C., & Glover-Kapfer, P. (2018). Satellite Remote Sensing for Conservation. WWF Conservation Technology Series 1(4). WWF.*



Passive Multispectral images

ACTIVE SENSORS

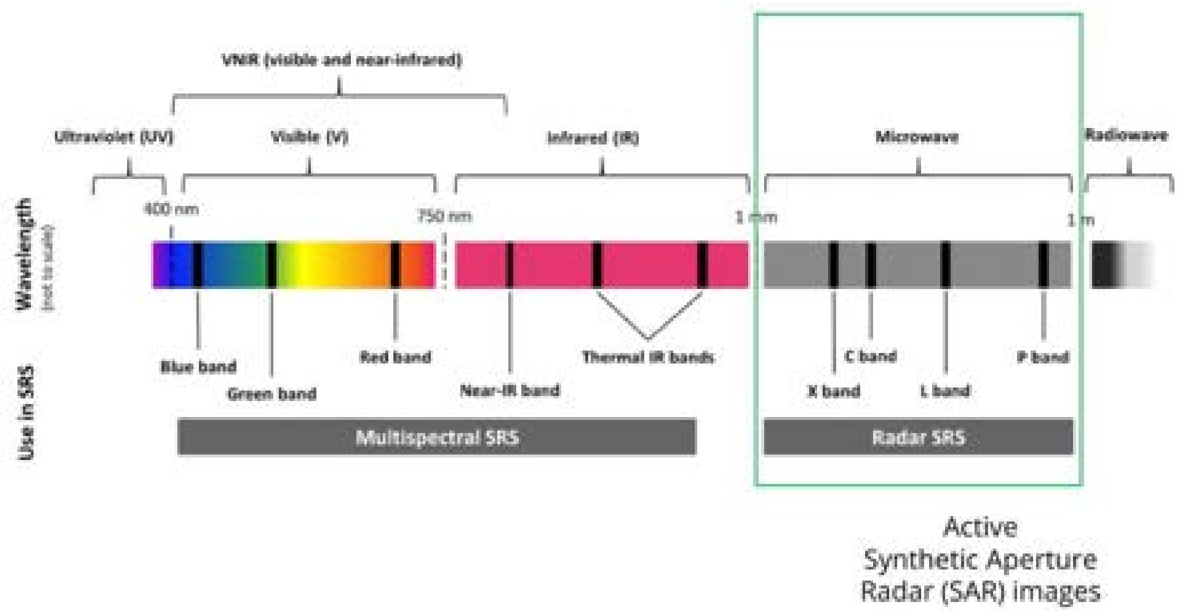
Active sensors, such as radar, operate in the **microwave part of the electromagnetic spectrum (1 mm-10 cm)**.

Synthetic Aperture Radar (SAR) images do not consist of 'bands' like multispectral images but are made up of a single scene discretized into pixels, where each pixel contains information on the amplitude (intensity of the reflected signal) and phase (distance of the sensor from the target) of the radar signal.

Amplitude data are used to monitor changes in land cover classes over time, while the phase is the most important information for interferometric applications and for deriving ground displacements through specific algorithms (e.g. monitoring slow landslides).

Image: Electromagnetic spectrum and range of wavelengths used by Active sensors (SRS, Pettorelli et al., 2018)

Reference: *Pettorelli, N., Schulte to Bühne, H., Shapiro, A. C., & Glover-Kapfer, P. (2018). Satellite Remote Sensing for Conservation. WWF Conservation Technology Series 1(4). WWF.*



CONTINUE

Passive vs Active sensors

Can you imagine what the main drawbacks of each of these sensors might be?

Click on the buttons to view the information.

Passive vs Active sensors

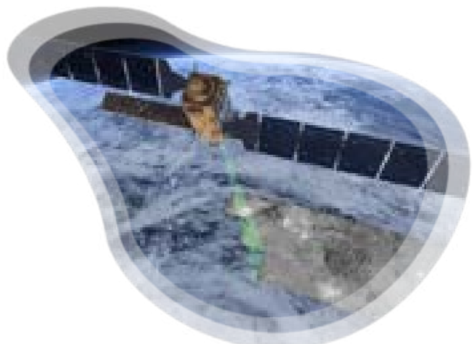
PASSIVE SENSORS

The main drawback of passive sensors is the **inability to observe the Earth's surface in the presence of clouds**.

Consequently, long periods without observations may occur in areas with frequent precipitation, such as the equatorial ones.

However, in most cases, such optical data do not require long and complicated pre-processing steps and are easier to use.

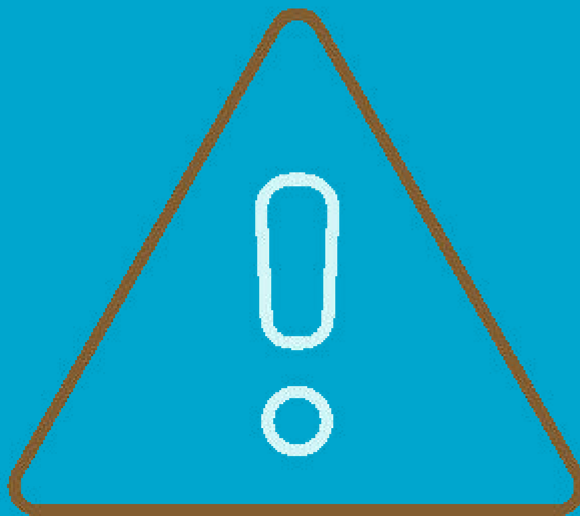
ACTIVE SENSORS



Instead, the data from active remote sensing (e.g. SAR data) have the advantage of operating at wavelengths not hindered by cloud cover.

Furthermore, active sensors can acquire data both at day and night. These peculiarities allow higher frequencies of observation of evolutionary dynamics.

So... Do active sensors have no weaknesses ?



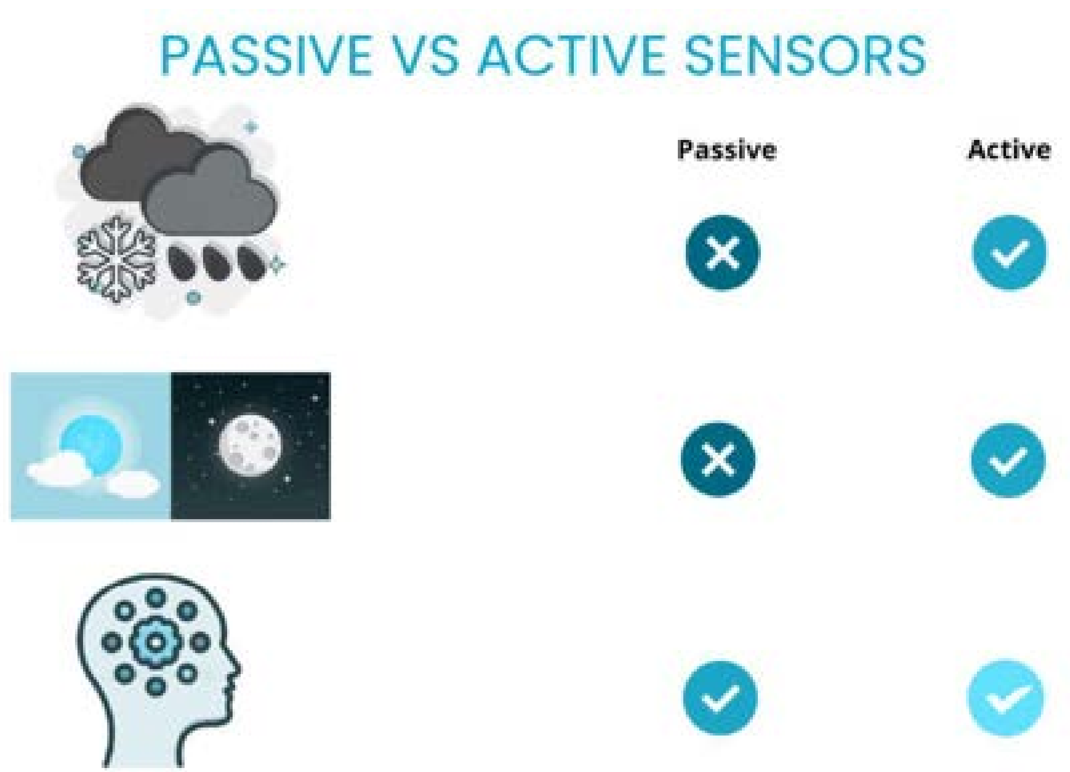
IMPORTANT

The weaknesses of SAR data are represented by the **complexity of the data** and, consequently, by the operating difficulties for non-expert users.

In addition, SAR data **can be affected by geometric errors**, which mainly occur in mountainous areas making the images unreadable.

In summary...

Click on the image to enlarge it



Main differences between Passive and Active remote sensors. Image credits Carmela Cavallo

The discussion on SAR imagery is much more complex and **this course aims to provide only basic concepts of remote sensing**, going through the distinction of the two different types of sensors.

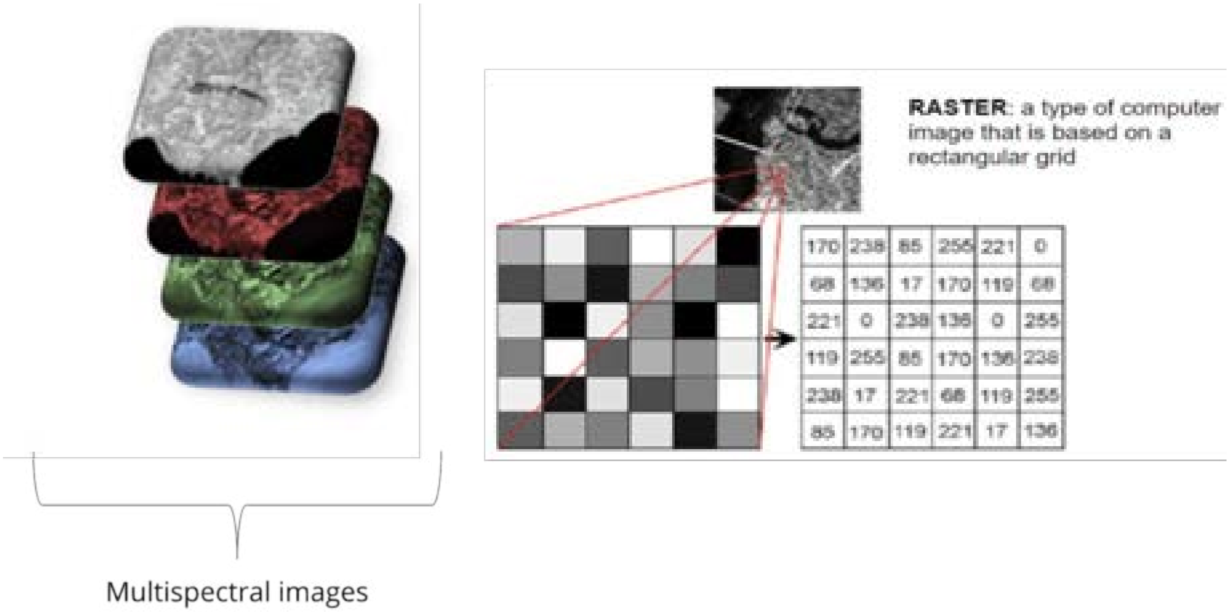
Following a concise overview of the primary distinctions between active and passive sensors, **our focus will now be exclusively on the multispectral data from the Sentinel-2 mission**.

CONTINUE

What is the format of satellite images?

Every band acquired by a passive sensor is then divided into discrete units called pixels. A satellite image can be represented by a raster file, in formats like GeoTIFF or other specific formats of remote sensing processing software.

Click on the image to enlarge it



The format of satellite images (Yeung, n.d. Adapted.)

i

Yeung, S. (n.d.). Tutorial 1: Introduction to computer vision. Stanford AI Lab. https://ai.stanford.edu/~syyeung/cvweb/tutorial1.html

CONTINUE

Sentinel-2 mission

The **Sentinel-2 (S2) mission** is part of the Copernicus Earth Observation program led by the European Commission and operated by the European Space Agency (ESA).

The S2 mission boasts global coverage, capturing every image with a swath width of 290 km.

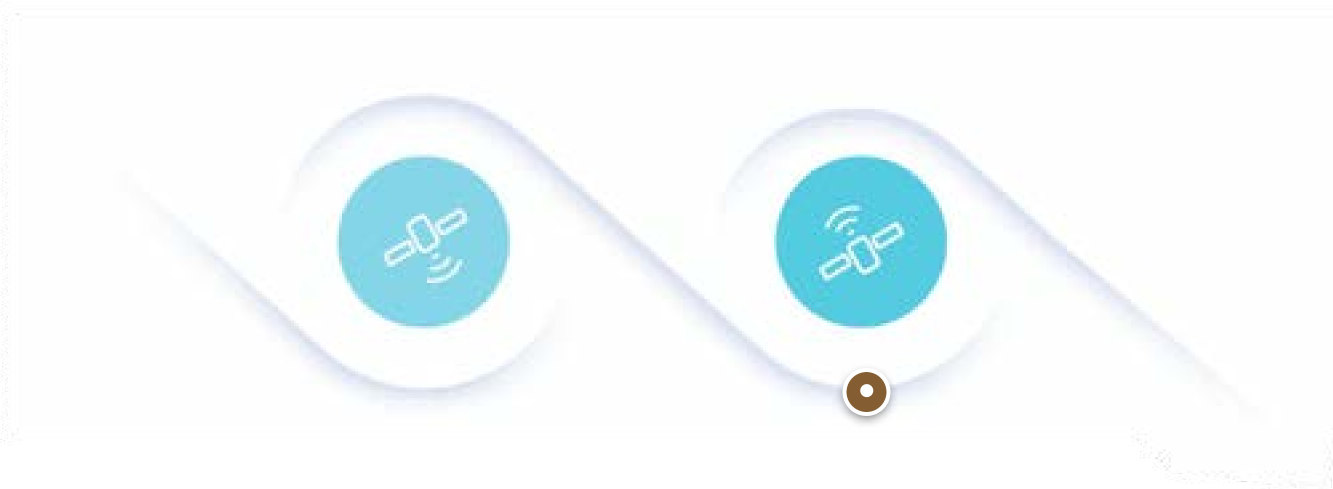
Photo of the Sentinel-2A spacecraft in the thermal vacuum chamber testing at IAGB's facilities (Image credits ESA, IABG, 2015)

This mission involves a constellation of two polar-orbiting satellites positioned in tandem within the same orbit:

Click on the buttons to view the information.

Sentinel-2A

The first satellite, Sentinel-2A, launched on 23rd June 2015 provides images with a revisit time of approximately 10 days.



Sentinel-2B

Since the launch of the second satellite, Sentinel-2B, on 7th March 2017, the overall revisit time has halved, becoming 5 days at the equator and even less at mid-latitudes, due to the overlapping of satellite tiles.

To ensure the long-term continuity of the mission, **Sentinel-2C** has already been launched, and **Sentinel-2D** is planned to follow. These satellites will replace Sentinel-2A and 2B as they reach the end of their operational lifespans, sustaining the mission's crucial role in environmental monitoring, agricultural planning, and disaster management.

CONTINUE

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).

The **MSI** provides **13 spectral bands** into **VIS**, **NIR** and **SWIR** (Short-Wave InfraRed), with a spatial resolution of:

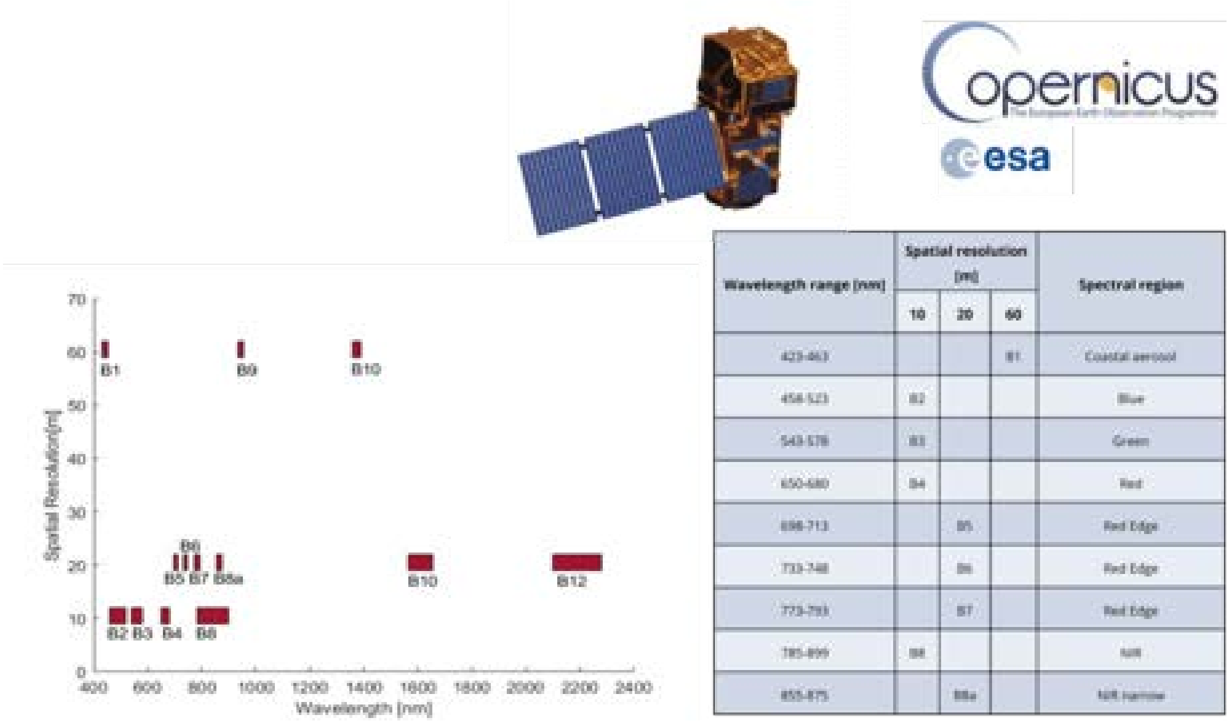
1. 10 m for four bands.
2. 20 m for six bands.
3. 60 m for three bands.

CONTINUE

In detail:

1. 10 m for the visible and the NIR bands: 2, 3, 4, 8.
2. 20 m for the Red-Edge (RE), NIR and SWIR bands: 5, 6, 7, 8a, 11, 12.
3. 60 m for the atmospheric bands: 1, 9, 10.

Click on the image to enlarge it



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

Multispectral bands of Sentinel-2. Image credits Carmela Cavallo

CONTINUE

What is the spatial resolution of the images extracted from Sentinel-2 data?

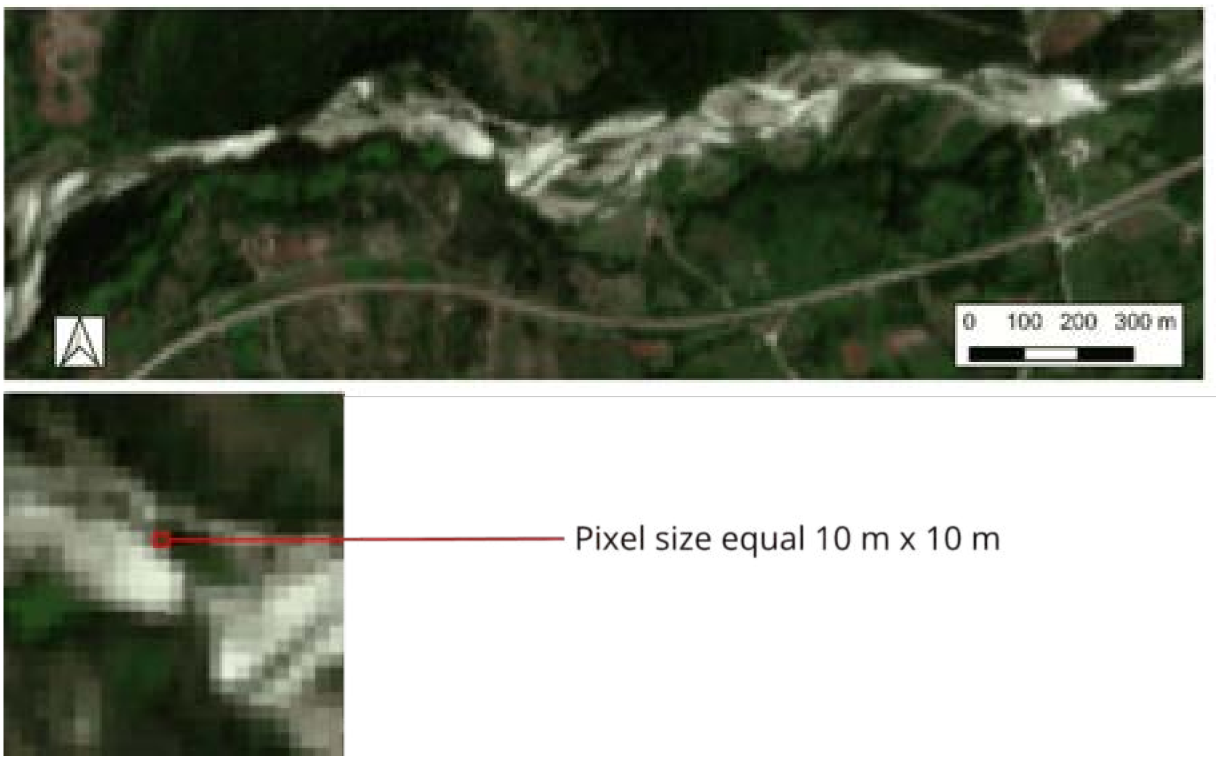
Resampled to a different spatial resolution

The bands of the Sentinel-2 satellite can be resampled to a different spatial resolution. This procedure, integrated into the image processing tool, involves transforming the pixel grid of the original image in order to adapt it to the new desired resolution. This procedure may include interpolation of pixel values or the use of more sophisticated algorithms to best preserve the image characteristics.

Harmonise the bands

In general, the resampling of the Sentinel-2 bands is necessary to harmonise the bands at 20 and 60 meters with the others acquired at 10 meters. This operation is essential for combining the different bands and generating new integrated images.

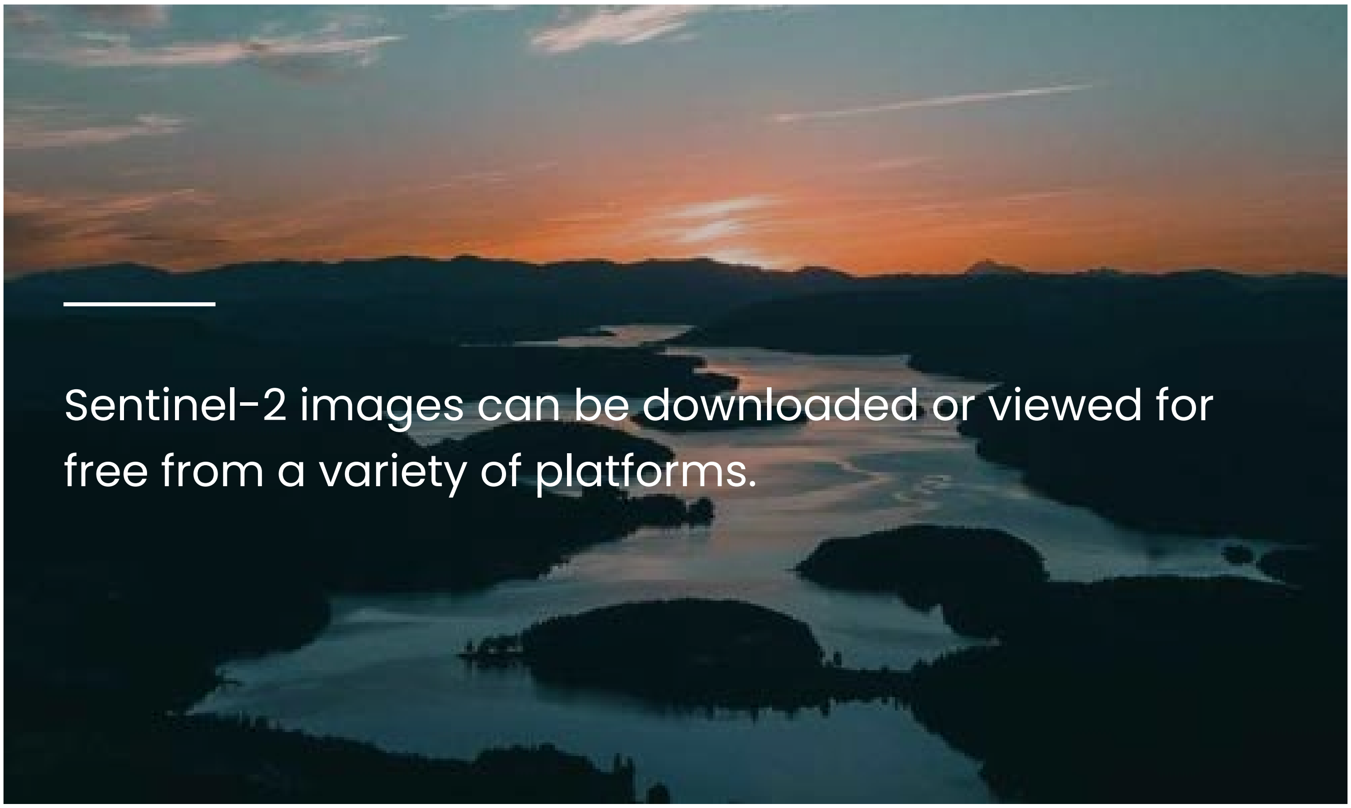
Click on the image to enlarge it



Spatial resolution of Sentinel-2. Image credits Carmela Cavallo

CONTINUE

From which source can images of Sentinel-2 be viewed or downloaded?



Did you know...?

As part of the Rivertemp project, a tool was created to visualize two different combinations of Sentinel-2 bands, as it will be described in **Module 4**.

These are some of the available platforms for visualising and/or downloading Sentinel-2 images:

Click on the links to visit the websites

Google Earth Engine (GEE)

https://earthengine.google.com/

Copernicus Browser

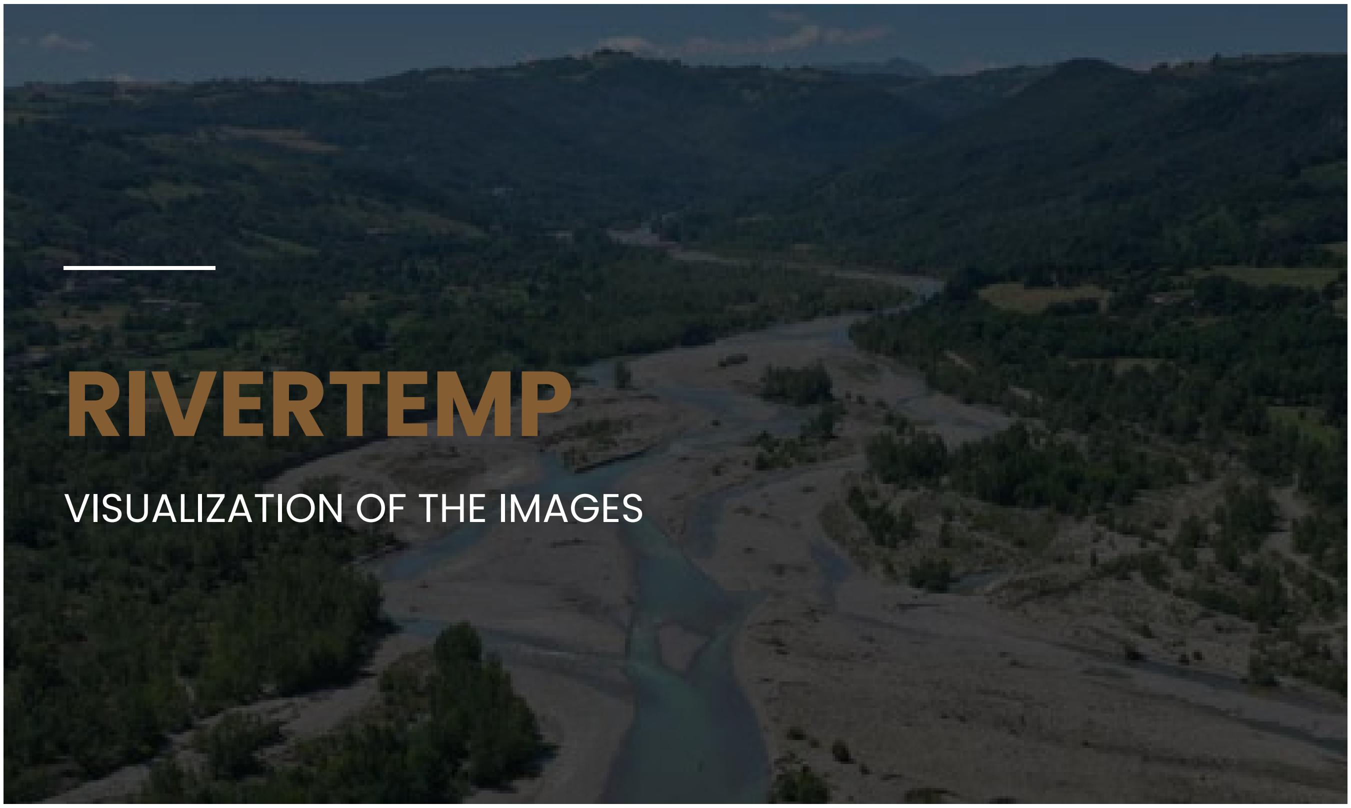
https://dataspace.copernicus.eu/browser/

RIVERTEMP Temporary River Classifier

https://classifier.rivertemp.eu/

CONTINUE

How do we see images with cloud cover?

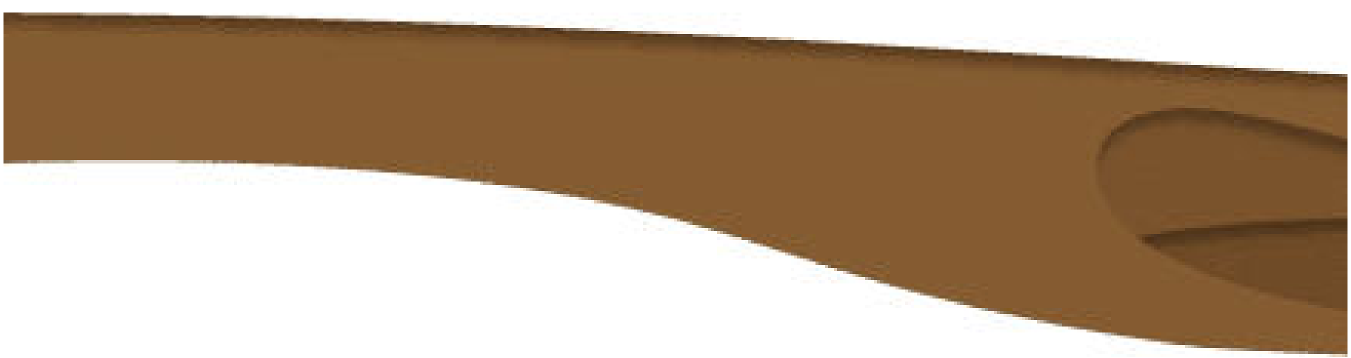


Remember

As previously highlighted, a significant limitation of passive sensors is their incapacity to observe the Earth's surface in the presence of clouds, leading to an elongated acquisition time interval between useful observations.

Clouds and **cloud shadows** can cover the **entire image** or only a **portion of it**.

Best practices involve **excluding images affected by clouds or shadows** along the river reach.



How can this exclusion be accomplished?

This exclusion can be accomplished through:

Quantitative criterion

Such as filtering out

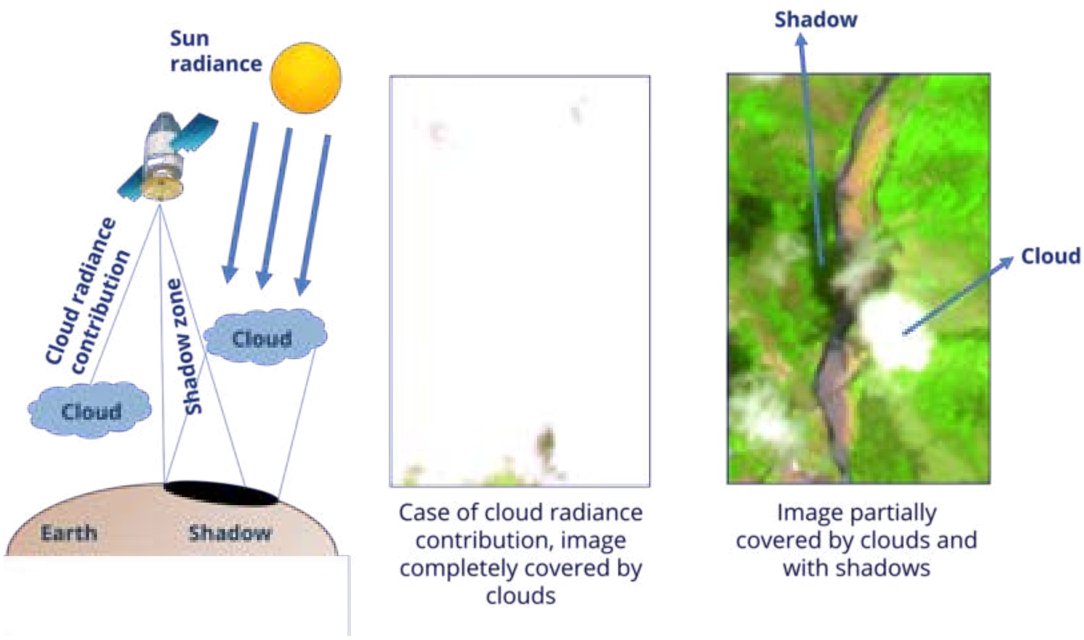
Qualitative analysis

Based on visual

images with a coverage percentage exceeding a specified threshold	identification.

Guidelines on how to select images with partial cloud cover will be provided in Module 4.

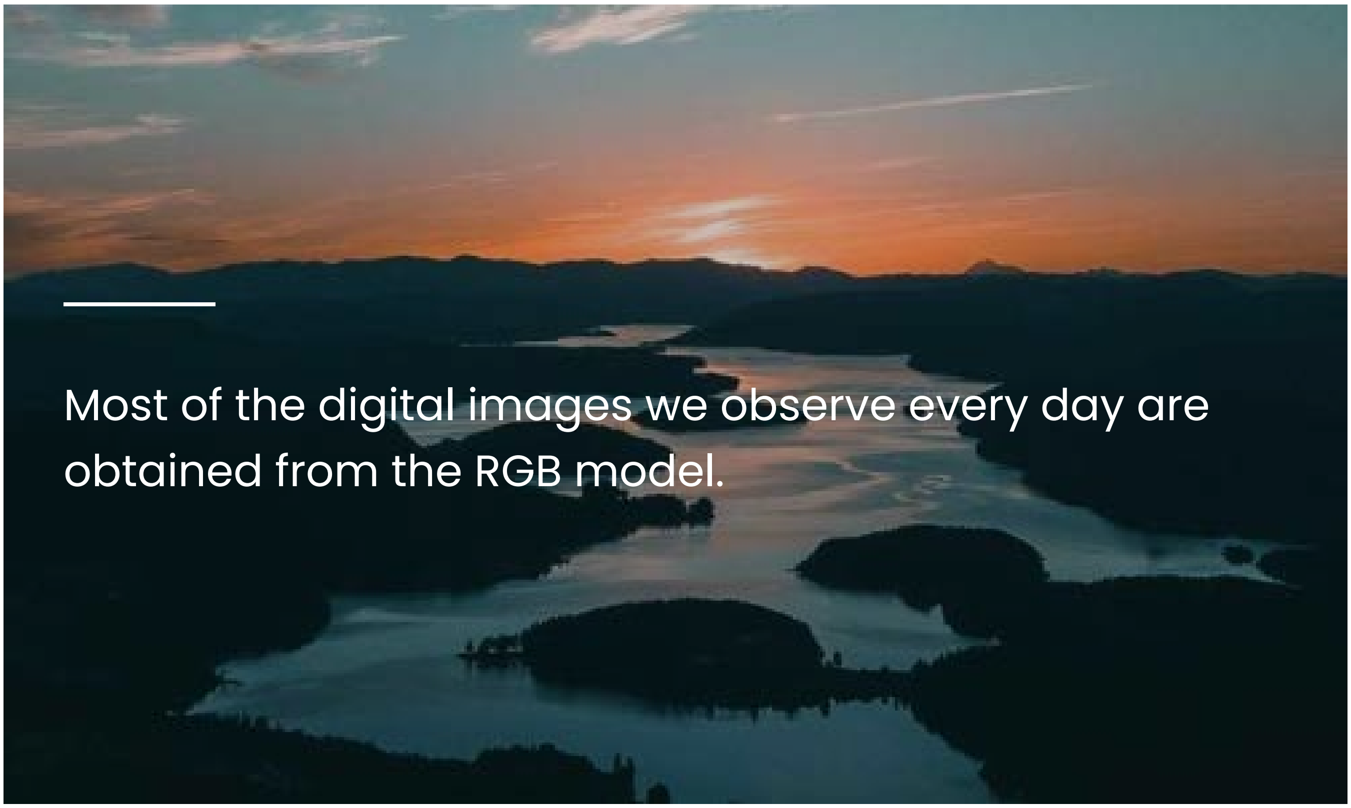
Click on the image to enlarge it



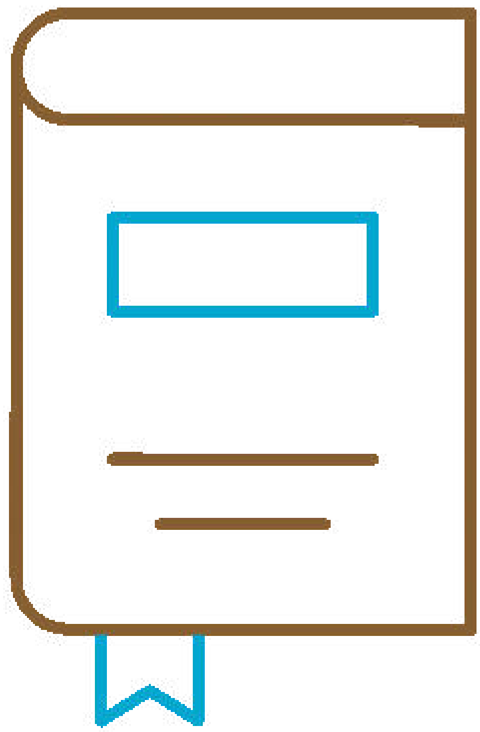
Images affected by cloud cover and cloud shadows. Image credits Carmela Cavallo

CONTINUE

How are the digital images we observe every day generated?



Most of the digital images we observe every day are obtained from the RGB model.



Definition:

The **RGB model** is the easiest model that can be implemented for the construction of colored images, due to the physiology of the human eye and the technologies employed.

In an **RGB-based digital image,** each pixel is represented by **three color components:**

R

RED

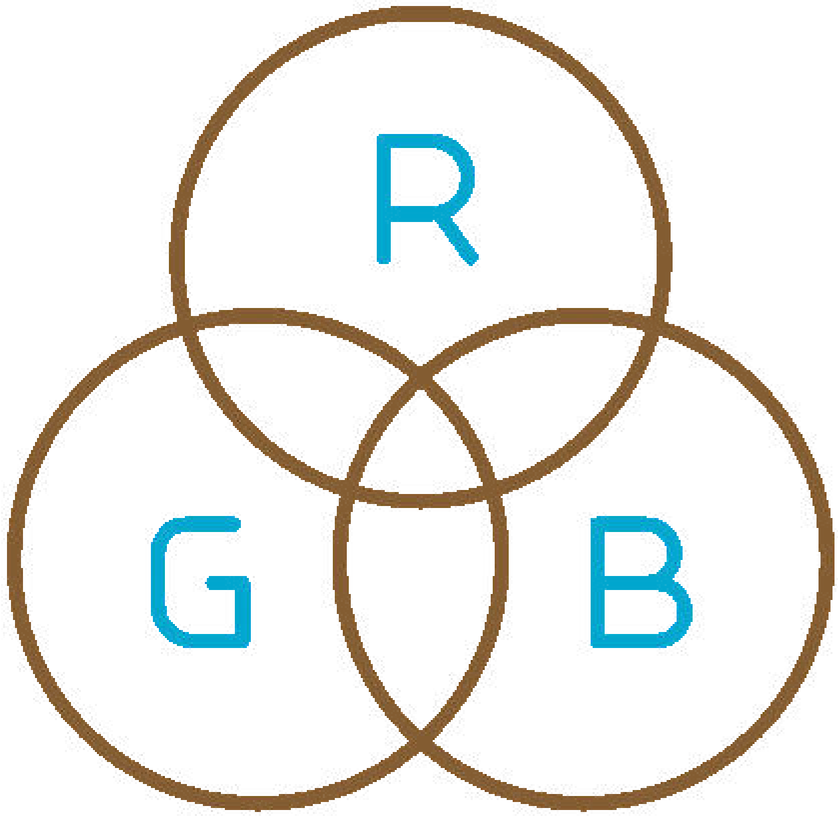
G

GREEN

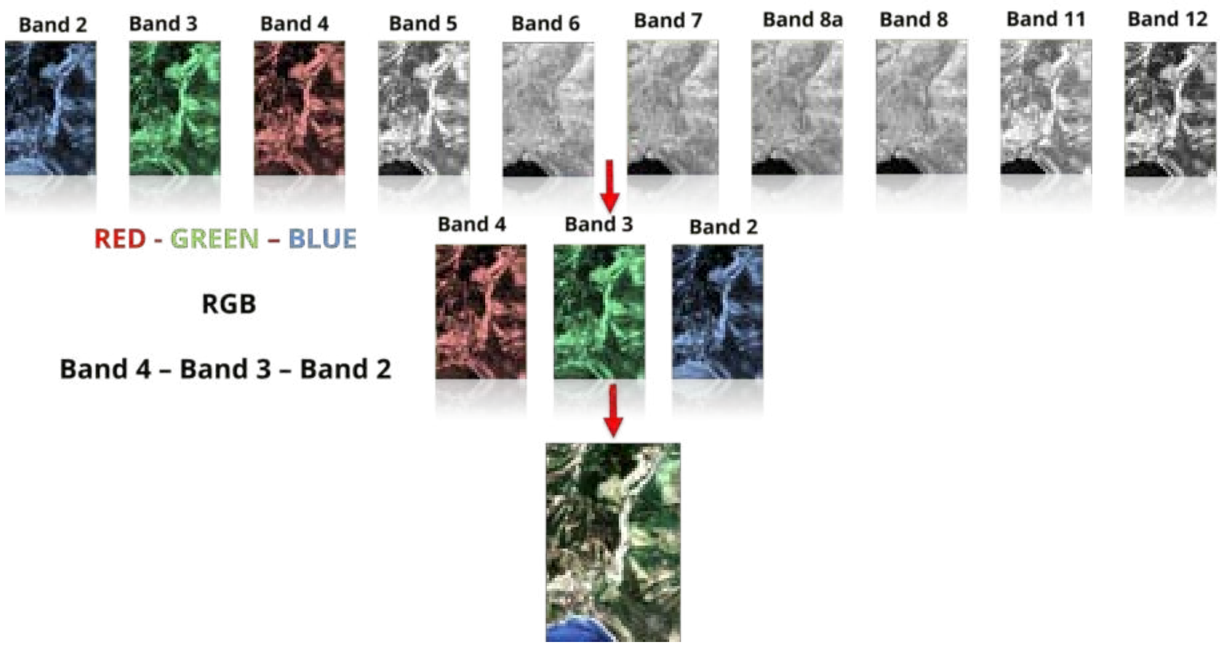
B

BLUE

Each component **can vary in intensity** from 0 to 255, where 0 represents the absence of color and 255 represents the maximum intensity of that color.



Clik on the image to enlarge it



Red-Green and Blue (RGB) image generation. Image credits Carmela Cavallo

CONTINUE

RGB image

Look closely at the following image:

Click on the image to enlarge it

RGB of Google Earth Pro

RGB of Sentinel-2

Comparison between RGB of Google Earth Pro - spatial resolution < 1m, and RGB extracted by Sentinel-2 - spatial resolution 10 m (Cavallo et al., 2022)

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

Are you able to see the river?

In the image it is possible to observe a comparison between the RGB image

In this color combination (True-Color Image, TCI), the flowing water is not easily distinguishable from the other components of provided by Google Earth Pro and the RGB image generated using Sentinel-2 bands.

the river channel, such as vegetation and sediments.

IMPORTANT

Since RGB images do not adequately allow to differentiate between land cover classes, it is more convenient to create **False-Color Images (FCIs)**, selecting another band triplet, in order to enhance the distinction among channel components.

CONTINUE

Spectral signatures of different land covers in literature

In order to identify a better combination of bands that allows distinguishing various macro hydro-morphological units (wet channel, sand bars, vegetated bars), the spectral signatures of land cover classes have been analysed.

Before proceeding with the extraction of spectral signatures, let's try to understand what is meant by the term "spectral signature".

Different types of surfaces have different reflectivity behaviours and, thus, spectra. Remote sensing images typically feature surfaces such as:

1. Water.
2. Vegetation.
3. Bare sediments.
4. Urbanised areas.

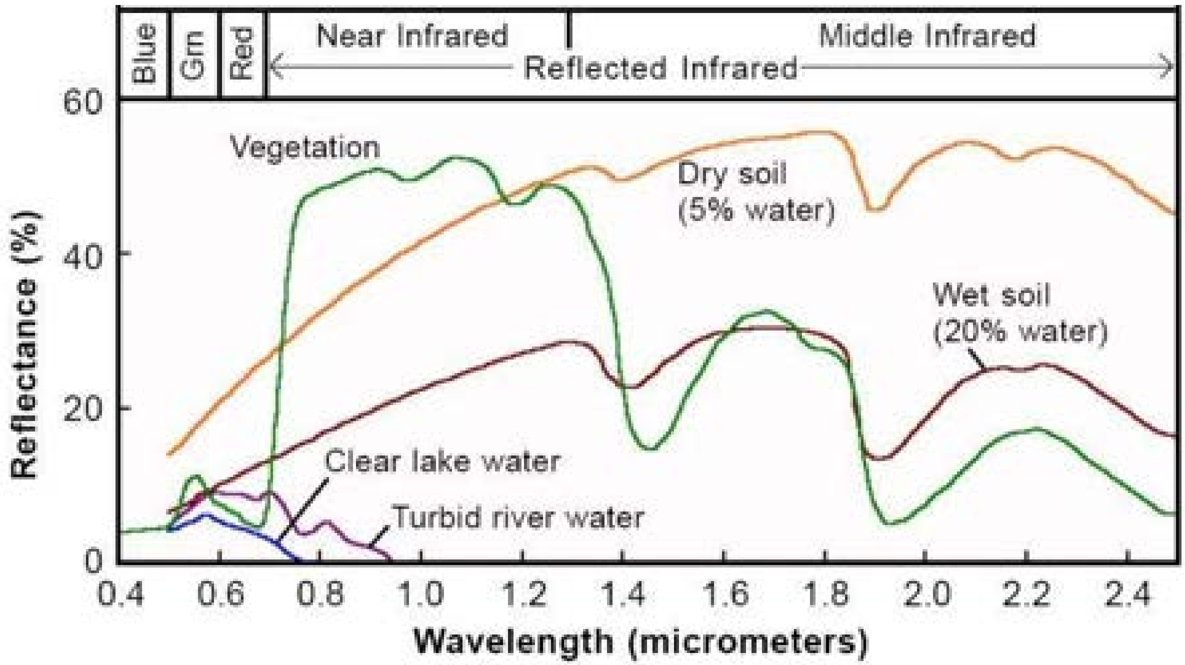
What accounts for this difference?

This difference is due to the fact that the reflected and emitted quantity of electromagnetic

energy differs as the incident wavelength and the land or object characteristics vary.

Click on the image to enlarge it

Considering the variation of the energy reflected by an object with the particular wavelength of such reflection, and iterating it through a range of wavelengths, the "**spectral signature**" of the object is obtained, meaning its spectral behaviour.



Spectral signatures of water, soil and vegetation (Smith, 2012)

Smith, R. B. (2012). Introduction to hyperspectral imaging. Microimages. Inc, 5-6.
https://www.microimages.com/documentation/html/Tutorials/hyprspec.htm

The land covers commonly present in fluvial environments are:

1. Areas covered by water.
2. Vegetated areas (eventually distinguishing grass and bushes cover).
3. Bare sediments.

IMPORTANT

The chemical, physical and structural composition of land covers can vary considerably, influencing the spectral responses.

CONTINUE

The spectral signature of water depends on its **chemical and physical characteristics:**

Click cards to flip

Reflectance spectrum peaks in the green wavelength band (0.50–0.56 μm) and decreases against increasing wavelengths, reaching a reflectance close to

The turbid water reflectance spectrum exhibits higher values than clear water in the visible and near-infrared region and approaches zero at longer wavelengths.

Why?

This is due to the concentration and size of solutes, sediments and organic matter, whose presence reinforces the reflection in the near-infrared band.

Typically, the water of wetlands, lakes and rivers contains solid particles and could appear not clear.

Click cards to flip

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)

In **rivers**, due to solid transport, turbidity may be greater, and the spectral signature may appear similar to turbid water

In the case of shallow water, the turbidity of the surface layer can be particularly high.

Furthermore, in the case of shallow transparent water, the spectral signature can be influenced by the type and color of the background material.

The spectral response of vegetation varies, as for water, with the wavelength, and depends on multiple factors, such as:

1. The type of vegetation.
2. The density.
3. The state of growth.
4. The moisture content.

Click on the tabs to view the information.

VISIBLE LENGHT

NEAR INFRARED LENGTHS

In the **visible**, the reflected energy values are correlated to the presence of pigments, such as chlorophyll.

For the purposes of photosynthesis, vegetation absorbs the visible blue and red radiation and reflects the green one.

VISIBLE LENGHT

NEAR INFRARED LENGTHS

In the **near-infrared lengths** (0.75-1.35 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.

CONTINUE

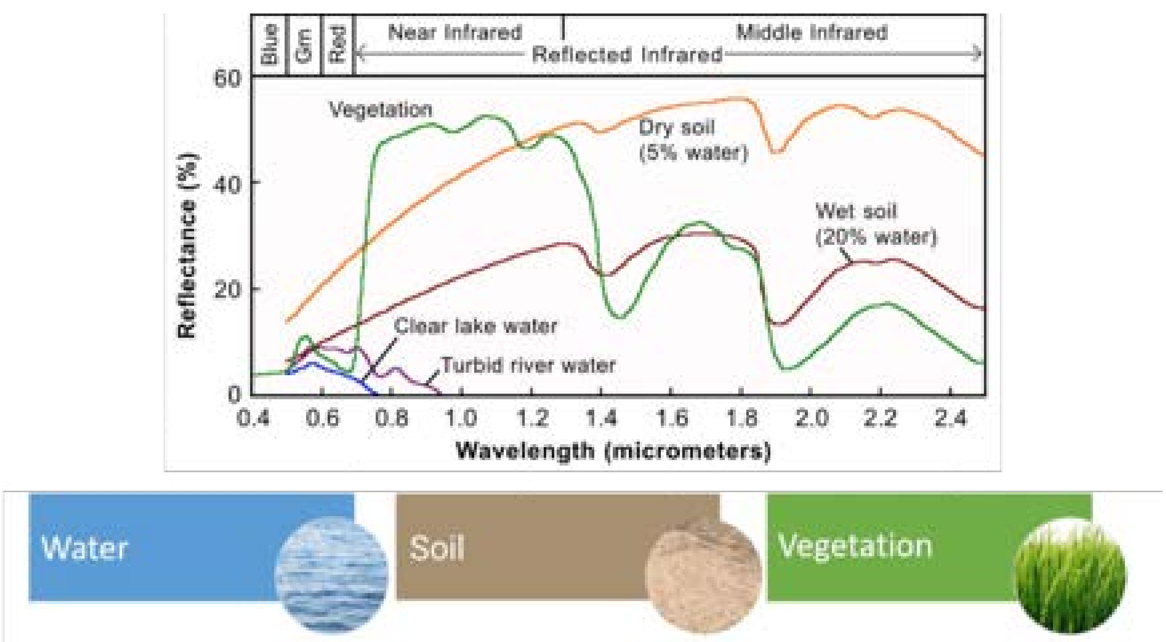
For **sediments**, in the same way, the reflectance varies according to their chemical and physical composition. The most important factors are:

1. The moisture content.
2. The organic substance content.
3. The texture.
4. The structure.

The reflectance of the sediments 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).

The reflectance of a moist ground is lower than that of a dry ground.

Click on the image to enlarge it



Spectral signatures of water, soil and vegetation (Smith, 2012)

Smith, R. B. (2012). Introduction to hyperspectral imaging. Microimages. Inc, 5-6.
https://www.microimages.com/documentation/html/Tutorials/hyprspec.htm

CONTINUE

How to construct the spectral signature of land covers?

The differences in the spectral signatures

In order to better distinguish between the various macro hydro-morphological units (wet channel, sand bars, vegetated bars), the differences in the spectral signatures have to be investigated and exploited.

Polygons on GIS software

Starting from the Very-High Resolution (VHR) images provided by Google Earth Pro and UAV (such as drones), as well as from geotagged pictures, for each identified land cover class several polygons were drawn on GIS software.

The four classes

The four classes have been:

1. Water.
2. Bare sediments.
3. Grass.
4. Bushes.

Overlap to Sentinel-2 images

Once obtained, the georeferenced polygons per each class have been overlapped to Sentinel-2 images in order to retrieve the spectral signature of the land cover as received by the satellite.

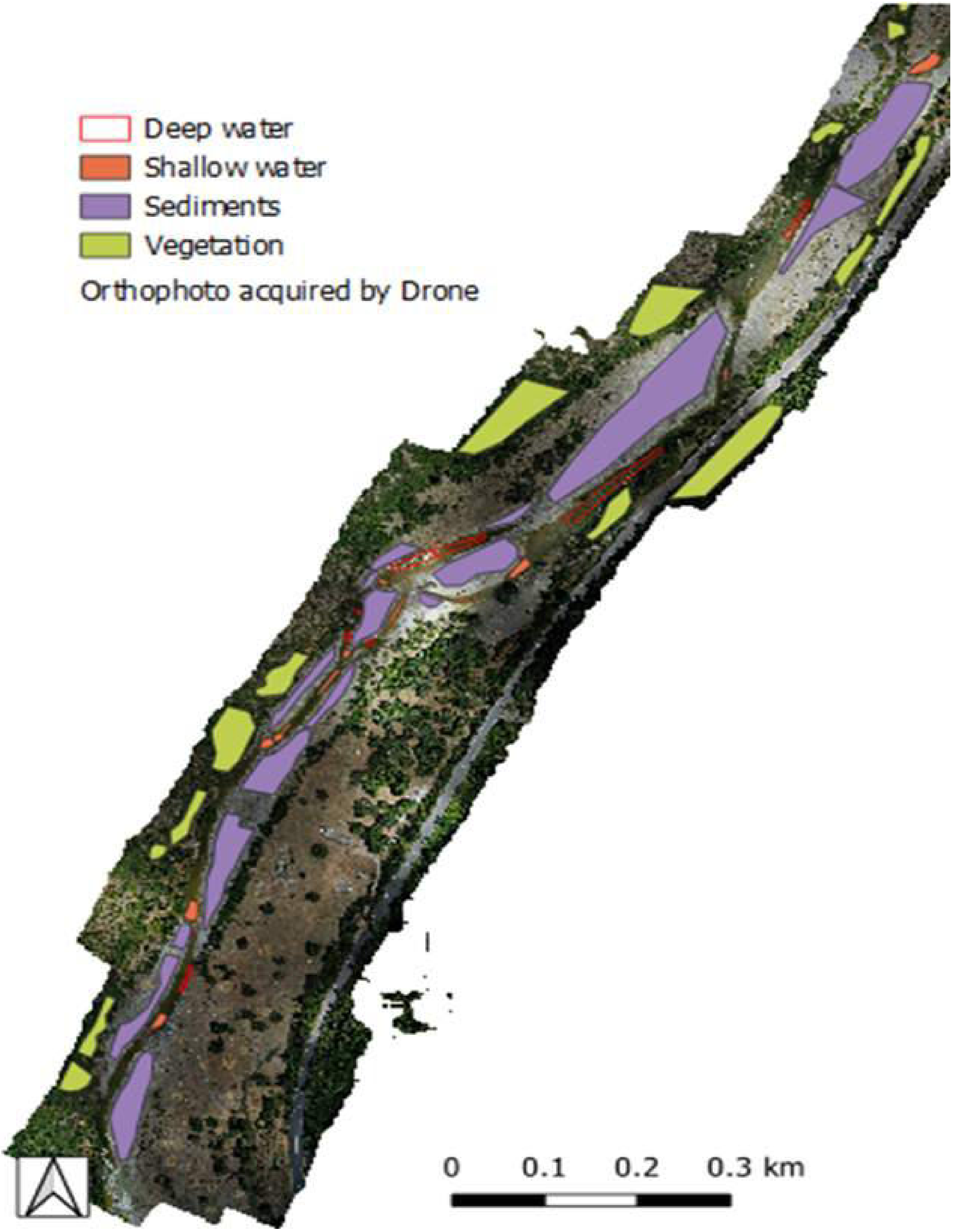
Plot the expectral signatures

For each cover class, the spectral signatures across the S2 bands were plotted using the pixels contained in the respective polygons.

Exception to S2 bands

All the S2 bands were used, except for the atmospheric bands B1, B9 and B10.

Click on the image to enlarge it



Deep water
Shallow water
Sediments
Vegetation
Orthophoto acquired by Drone
0
0.1
0.2
0.3 km

Image credits Carmela Cavallo

First step:

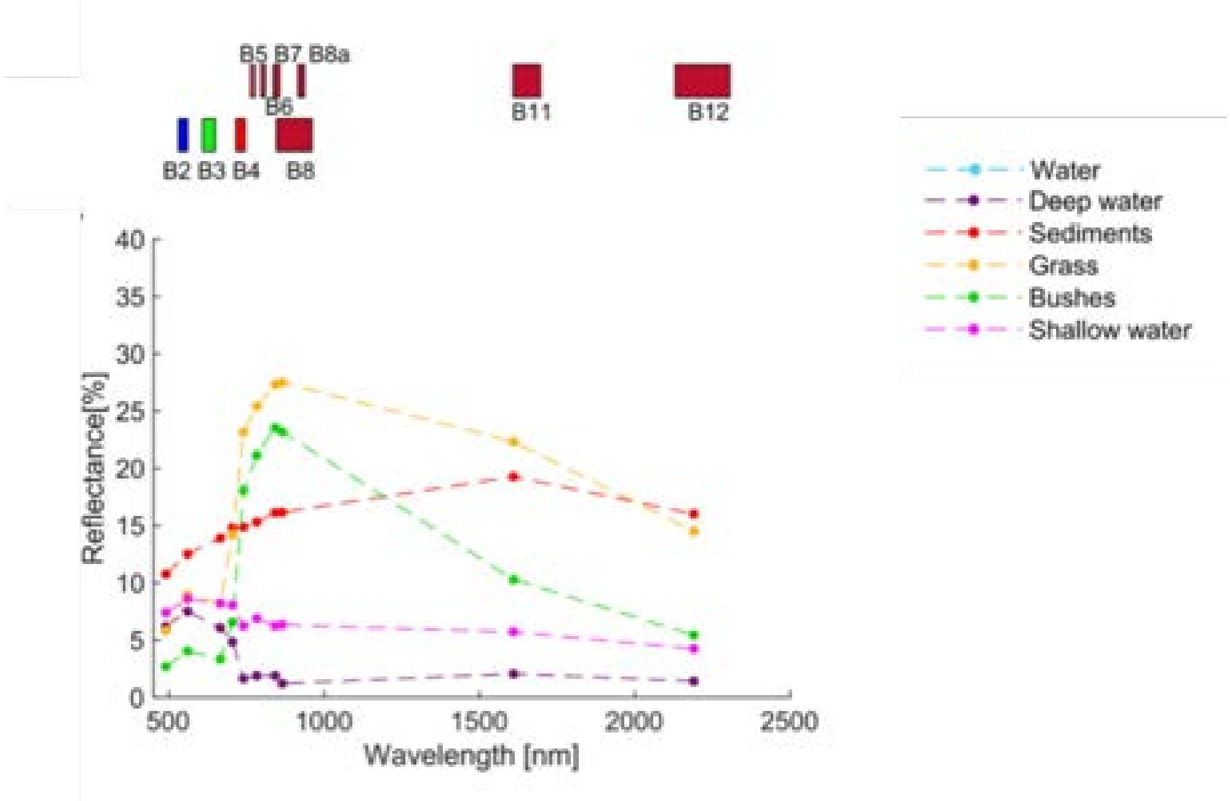
Draw polygons of different land cover classes over very high-resolution (VHR) images acquired by drone or available on Google Earth Pro.

CONTINUE

Spectral signatures of different land covers in temporary rivers extracted from Sentinel-2

Notice: this figure shows an example of a spectral signature extracted along a temporary river in Southern Italy.

Click on the image to enlarge it

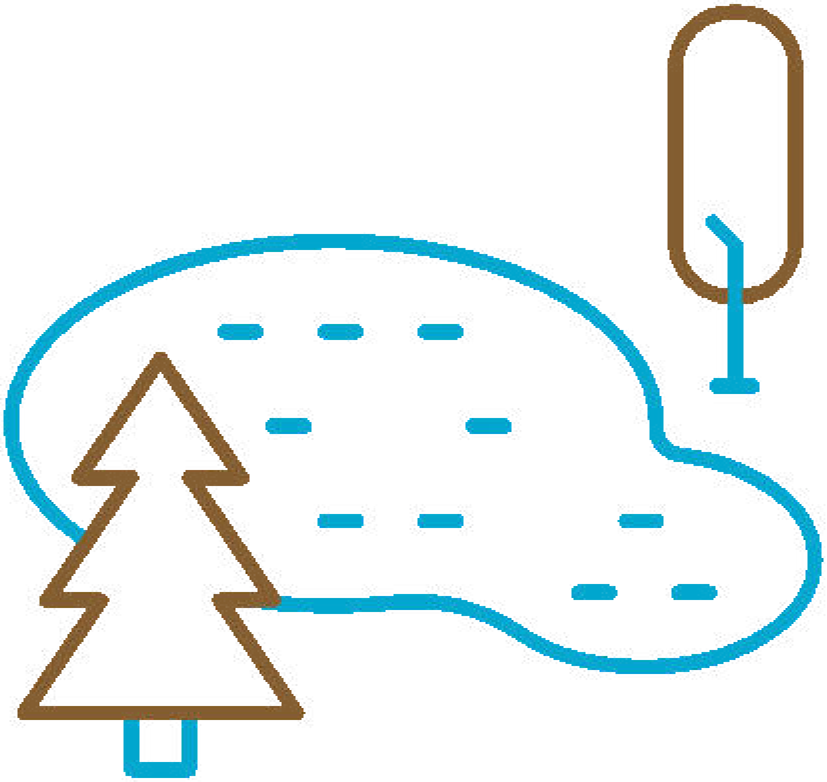


Spectral signatures of land covers within the fluvial corridor (Cavallo et al., 2022)

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

Second step:

For each band, compute the average value of reflectance over the polygons drawn at the first step in order to obtain the spectral signatures plot (reflectance over wavelength).



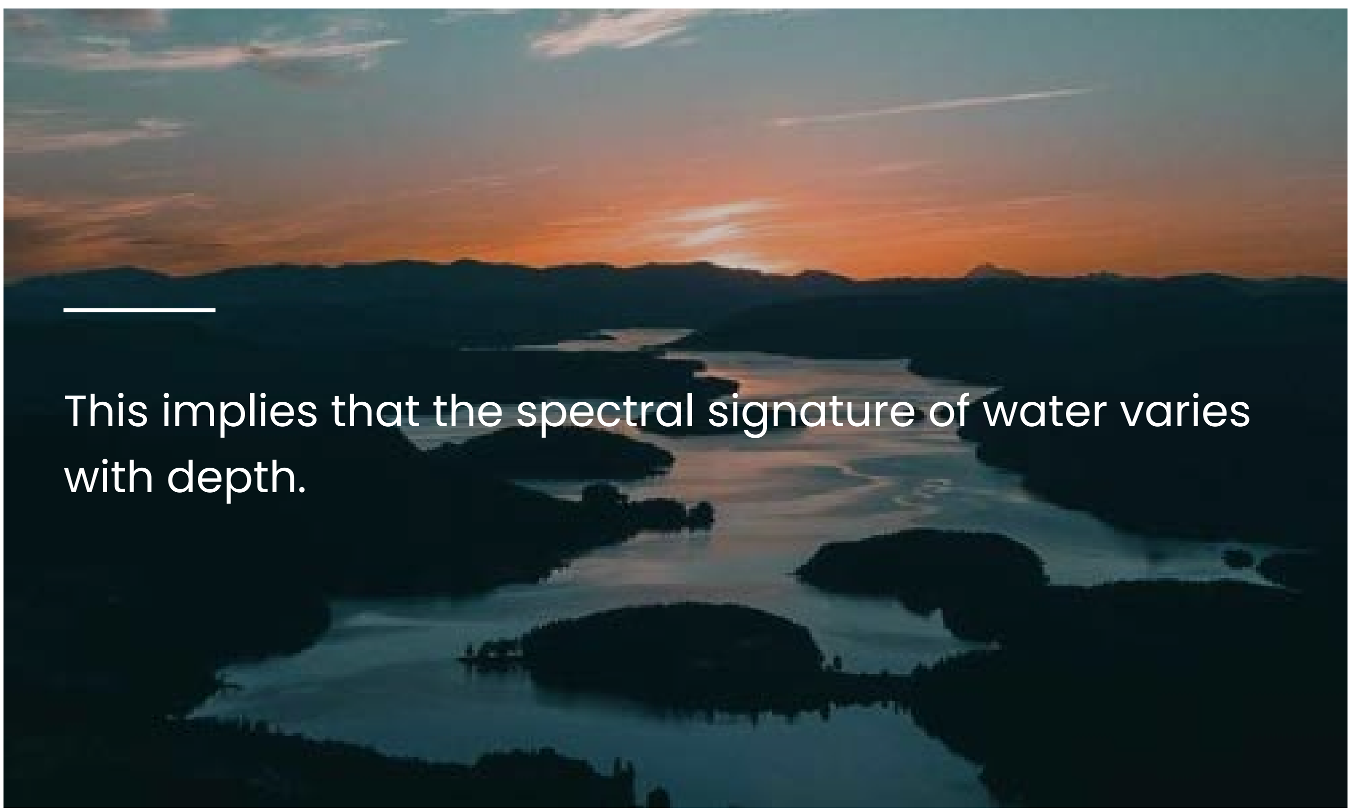
It is evident that the spectral signatures of both vegetation and sediment mirror the shape and the trend of spectral signatures documented in existing literature.

Deep waters

Similarly occurs for the spectral signature of 'deep waters'.

Shallow waters

The spectral signature of 'shallow waters', instead, exhibits notably high reflectance values in the infrared wavelengths (above 700 nm), showcasing a pattern entirely distinct from the literature.



This implies that the spectral signature of water varies with depth.

In particular, **as the depth diminishes, the reflectance values in the infrared wavelengths increase**, since the spectral signature is impacted by the underlying material.

Thus, **in the response of shallow water, both water and underlying sediments contribute**.

Generally, during the **summer season,** TRs are typified by **shallow waters,** thus the spectral signature of water aligns closely with that portrayed in the **'magenta color'.**

CONTINUE

What is the best combination of false-color bands?

What is the best combination of false-color bands to distinguish water in temporary rivers?

Taking into account the spectral signatures previously represented, try to identify the bands in which the land cover classes of the fluvial corridor are better distinguishable.

Copernicus Browser

Start exploring the Copernicus Browser (Copernicus Data Space Ecosystem Browser) and test various combinations until you identify the best band triplet that, in your opinion, allows to distinguish water from the other components of the fluvial corridor.

Copernicus Browser:

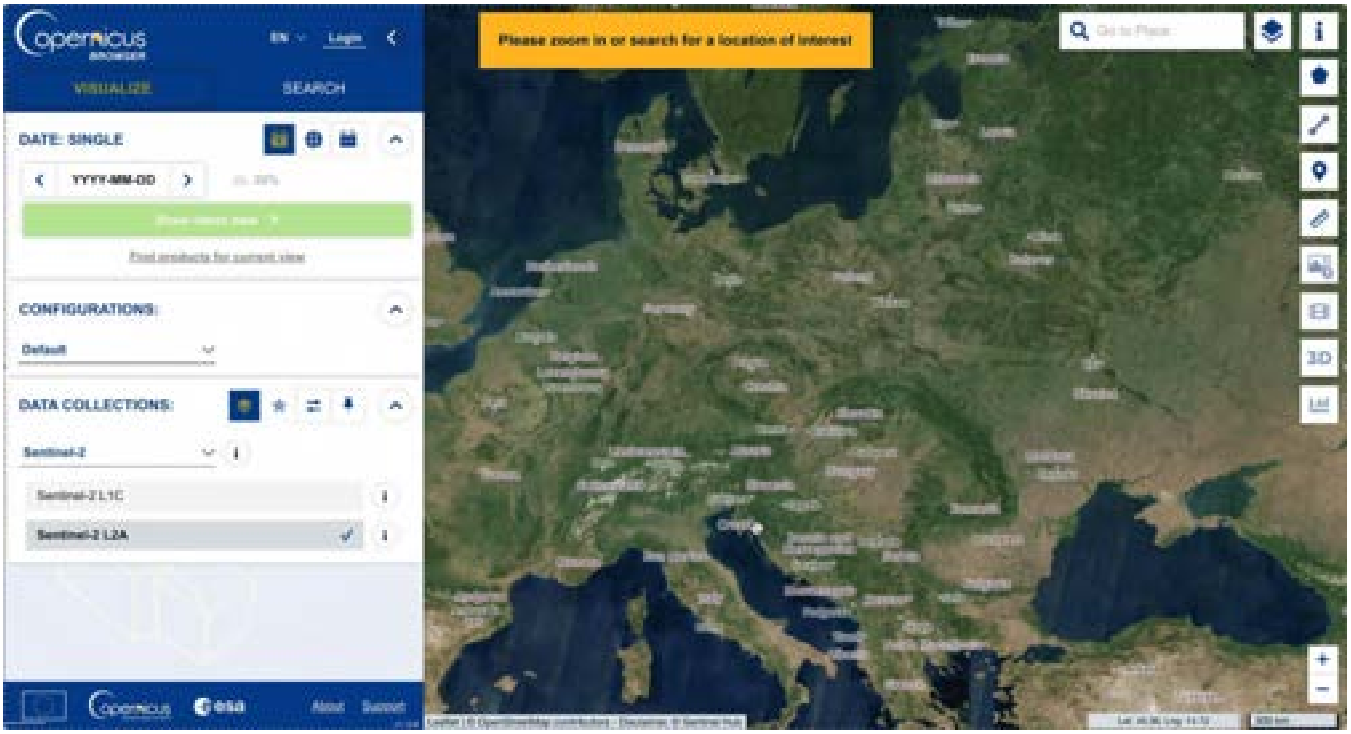
https://dataspace.copernicus.eu/browser/

The identification of water presence along temporary rivers

The task is to examine several proposals of false-color images, changing the band triplet and playing with Copernicus Browser platform, and to determine the combination that best allows the identification of water presence along temporary rivers.

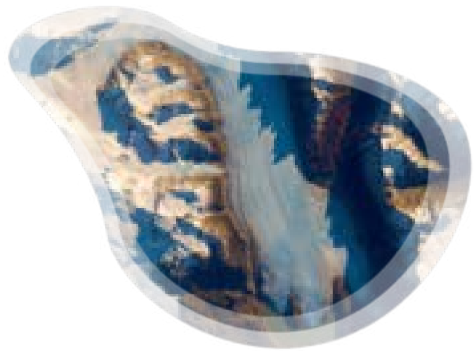
See the tutorial for learning how to use the Copernicus Browser platform

Click on play to view the video.



Click on the START button and discover each of the stepts

Instructions



2

Access Copernicus Browser

- Log in to Copernicus Browser via your favourite web browser.
- If you do not have an account, register for free to access additional features.

Uploading Sentinel-2 images

- Once logged in, select the Sentinel-2 platform on the discover tab.
- In the left window, select the desired date range of the image you want to access.
- Select the geographical area of interest via the navigation window.

4

Select the image you want to view

- Draw a polygon using the icon at the top-right of the visualized map to better identify a study area corresponding to a river reach
- Click on "Search"
- Select the satellite tile to visualize basing on the date under interest and on the preferred viewing condition

5

Create a false-color combination

- Under the tab visualize, select custom.
- Choose a different combination of bands by dragging and dropping the intended ones in the RGB channel.
- Evaluate the results.

In your opinion, **which is the best band combination to clearly distinguish the presence of water along rivers?**

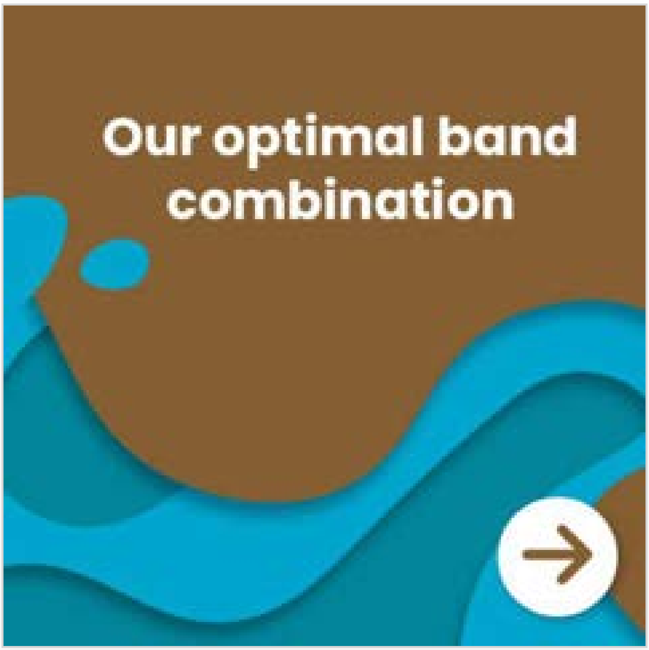
CONTINUE

What is the optimal band combination you have identified?

Do you want to know which is the optimal band combination we have

identified?

Click the card to flip



Our choice is:
B11-B8-B4

How did we do it ?

01

We observed that the classes of water, grass and bushes are little distinguishable in RGB images, because the red (B4), green (B3) and blue (B2) have very similar reflectance values. However, these bands allow us to easily differentiate the mentioned classes from the sediments.

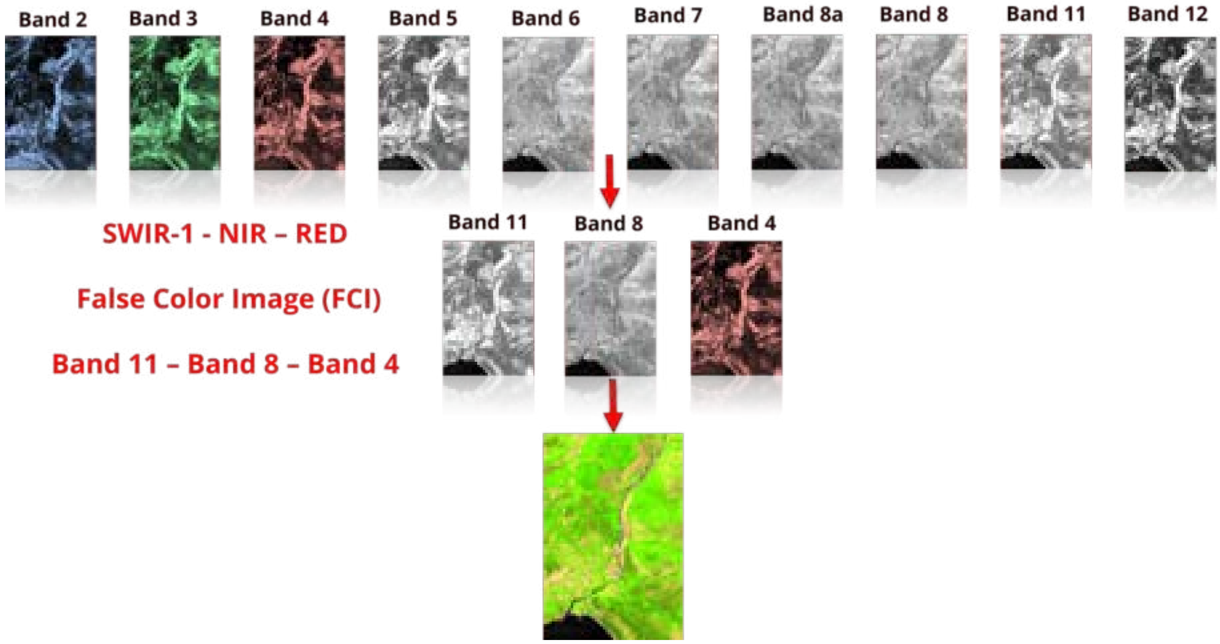
02

Instead, water and vegetation cover have different spectral behaviour in the NIR and SWIR regions and, thus, using bands in these regions, the two classes can be better differentiated.

03

Finally, the optimal composition was obtained by inserting in the RGB triplet respectively the bands B11 of the SWIR, the B8 of the NIR and the B4 of the visible. This selection was made by preferring the bands that have a spatial resolution of 10 m (B8, B4), then using the one with 20 m resolution of SWIR region (B11).

Click on the image to enlarge it

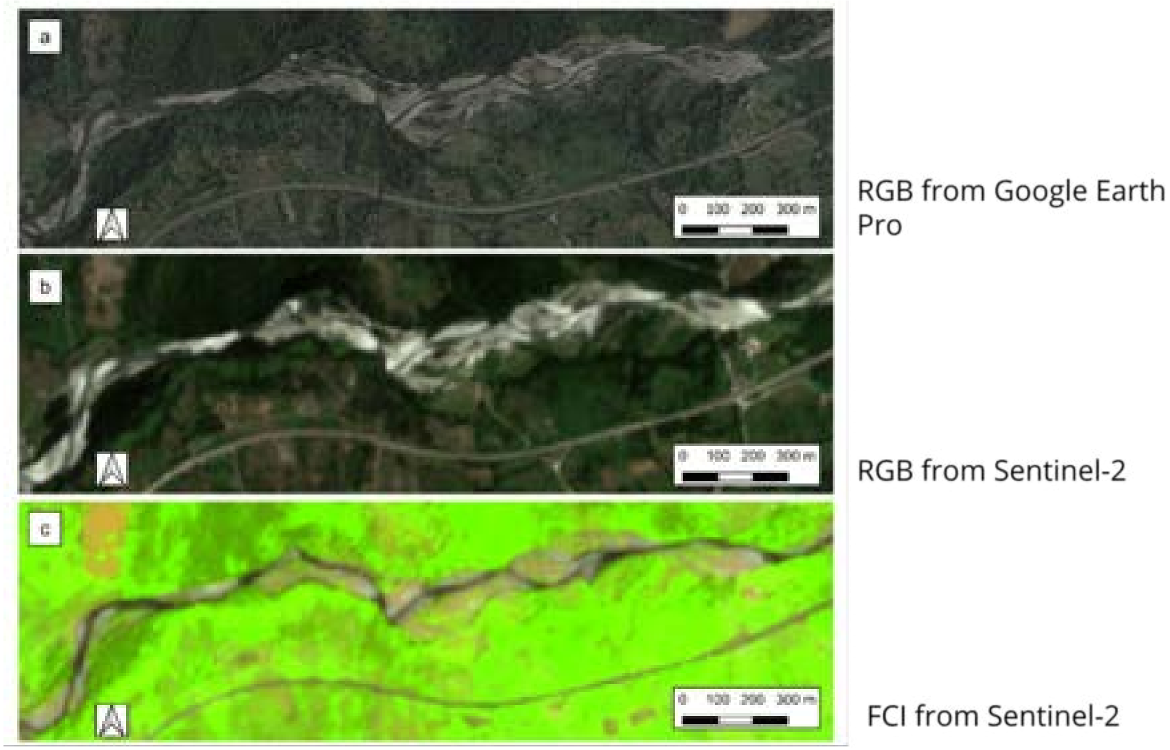


False-Color Images (FCI) composition. Image credits Carmela Cavallo

CONTINUE

Comparison among RGB images and FCI

Click on the image to enlarge it



Comparison among RGB provide by Google Earth Engine and RGB and FCI extracted by Sentinel-2 (Cavallo et al., 2022)

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

This figure illustrates the comparison between the RGB obtained from Google Earth Engine (Figure a) and the RGB (Figure b) and FCI (Figure c) extracted from Sentinel-2. From it, it is possible to observe that the FCI is very effective in highlighting the wet channel, which is put in evidence and appears in good detail.

CONTINUE

References

Bibliographic references

In the development of any academic course, bibliographic references play a crucial role by providing the necessary theoretical and practical support for the material taught.

References not only strengthen the credibility of the study materials but also allow students

This set of references has been carefully selected to provide a solid foundation of

to explore the topics covered more deeply, gaining a deeper understanding of key concepts and discovering new perspectives knowledge, encompassing a variety of sources, including books, academic articles, recent research, and digital resources.

We hope these references will be a valuable tool for learning, fostering a comprehensive and critical understanding of the topics addressed in this course.

Cavallo, C., Papa, M. N., Gargiulo, M., Palau-Salvador, G., Vezza, P., & Ruello, G. (2021a). Continuous monitoring of the flooding dynamics in the albufera wetland (Spain) by landsat-8 and sentinel-2 datasets. Remote Sensing, 13(17).

Cavallo, C., Nones, M., Papa, M. N., Gargiulo, M., & Ruello, G. (2021b). Monitoring the morphological evolution of a reach of the Italian Po River using multispectral satellite imagery and stage data. Geocarto International, 37(25), 8579-8601

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022a). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

Cavallo, C. (2022b). Monitoring freshwater environments by satellite data. PhD dissertation.

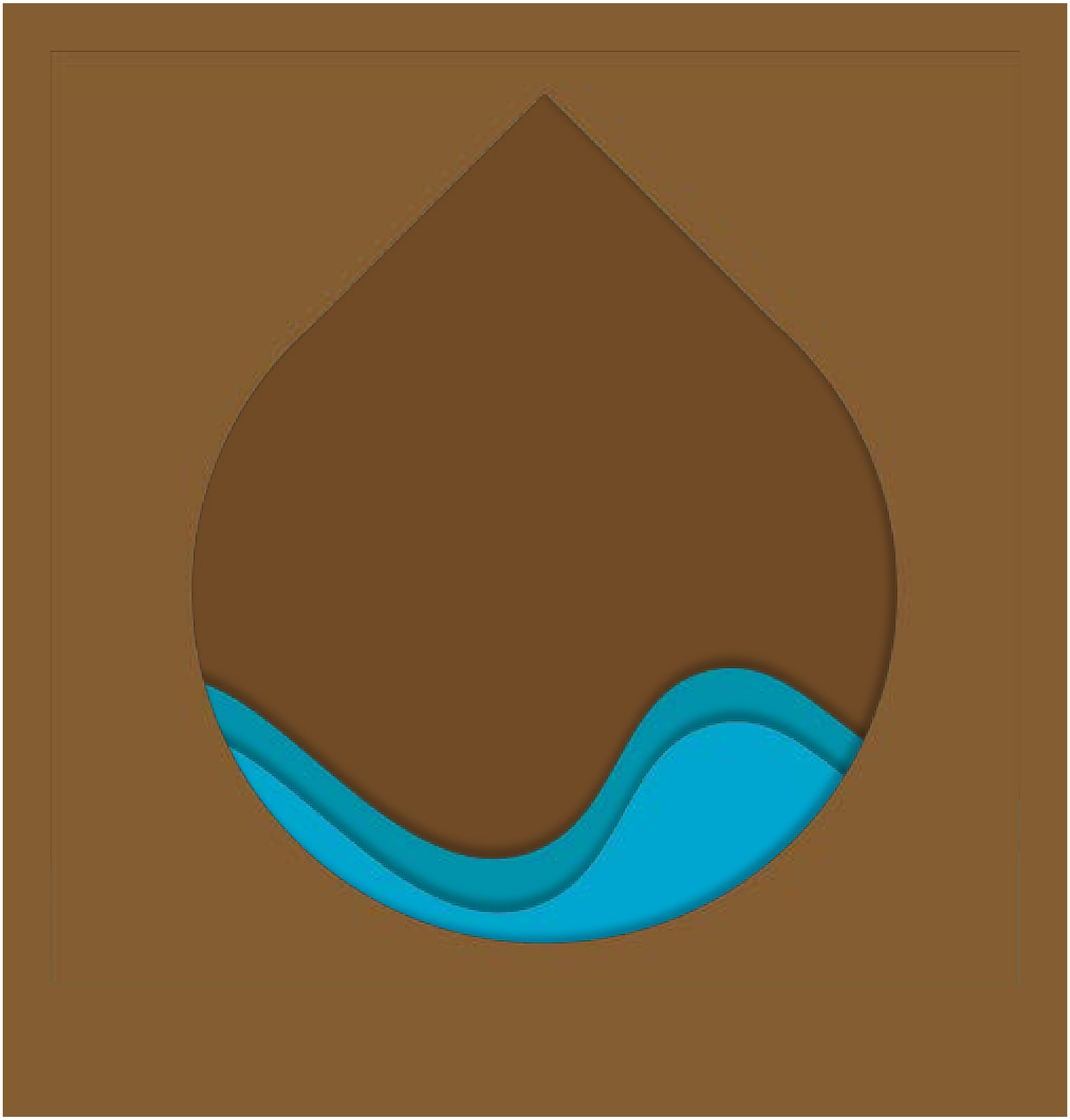
Pettorelli, N., Schulte to Bühne, H., Shapiro, A. C., & Glover-Kapfer, P. (2018). Satellite Remote Sensing for Conservation. WWF Conservation Technology Series 1(4). WWF.

Smith, R. B. (2012). Introduction to hyperspectral imaging. Microimages. Inc, 5-6. https://www.microimages.com/documentation/html/Tutorials/hyprspec.htm

Yeung, S. (n.d.). Tutorial 1: Introduction to computer vision. Stanford AI Lab. https://ai.stanford.edu/~syyeung/cvweb/tutorial1.html

CONTINUE

Closure



Congratulations!

You have **completed** this module.

Congratulations on your achievement! You have grasped how to use satellite images to identify the presence of water along temporary rivers. Keep progressing in your journey through the subsequent modules and try utilizing false-color images from the Sentinel-2 satellite mission to identify water presence along temporary rivers.

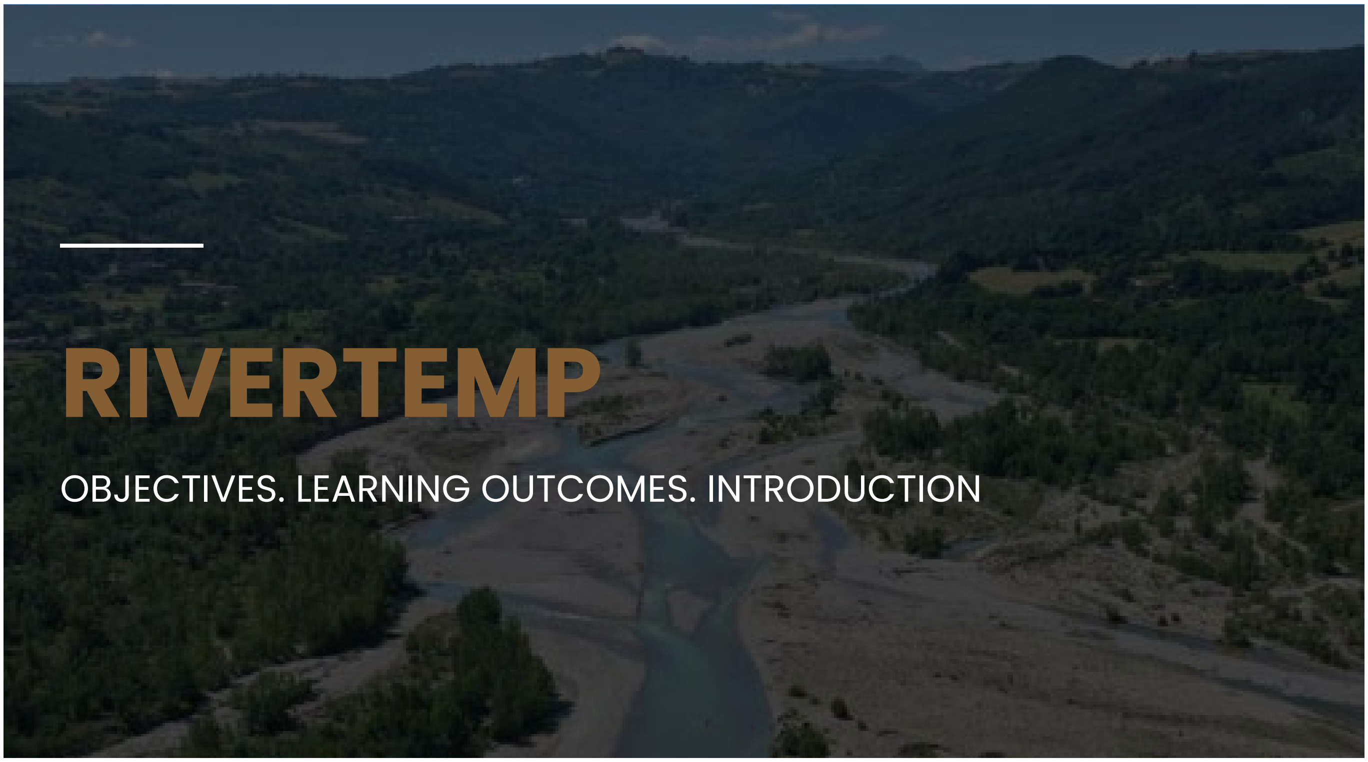
Let’s move to module 3!

MODULE 3: Classification of hydrological conditions: flowing, ponding, dry_v2_ES

In this module we will learn how to classify hydrological conditions in temporary rivers using satellite images.

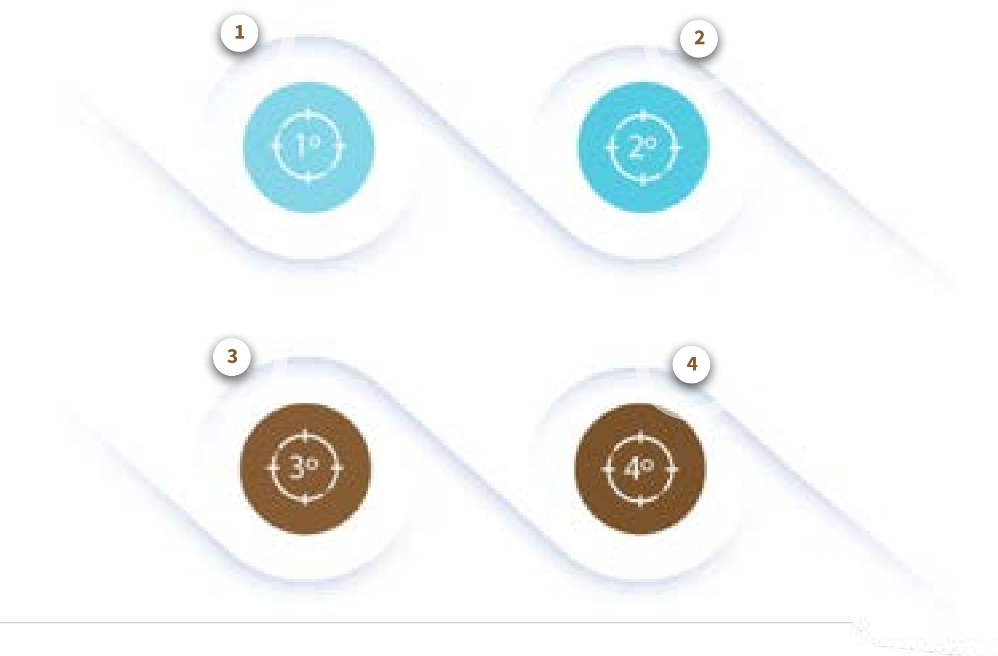
LET'S GET STARTED!

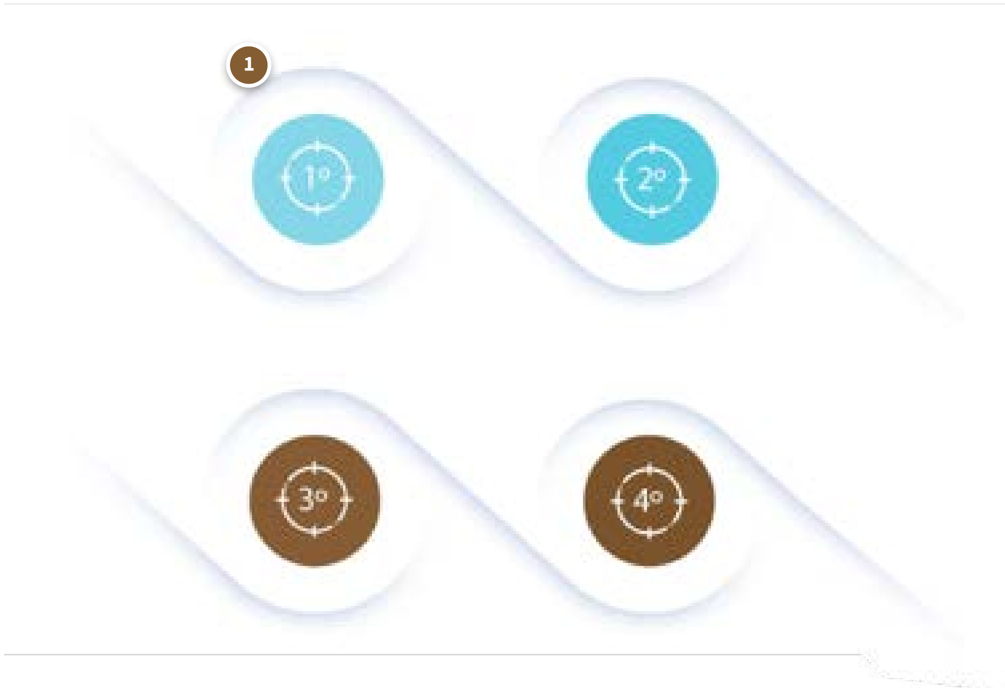
Objectives & Learning Outcomes



The **4 Objectives and Learning Outcomes** of this module are the following:

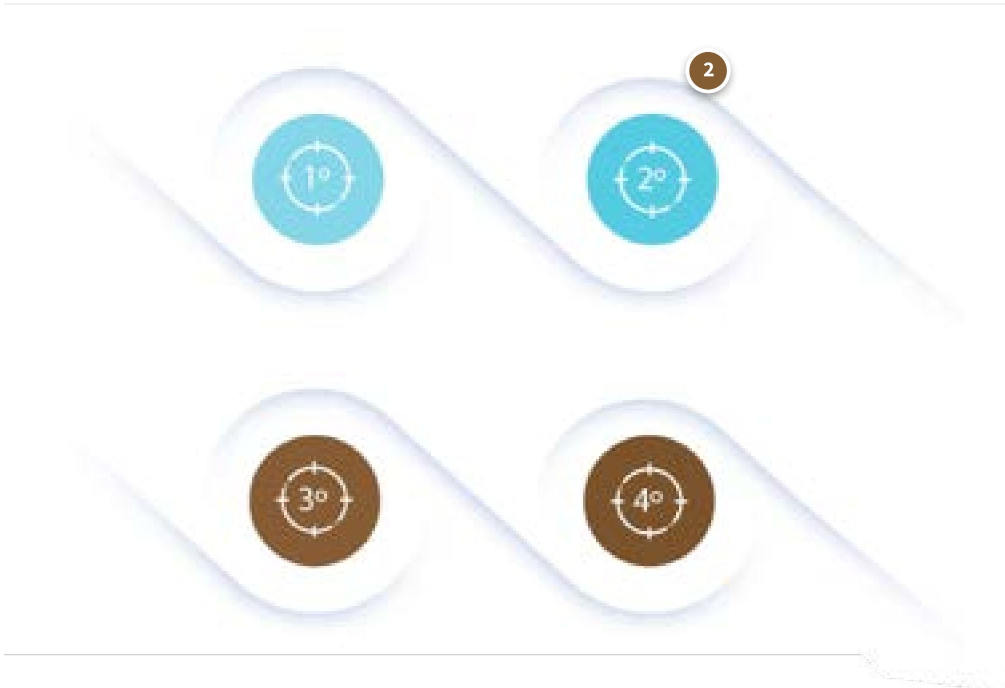
Click on the buttons to view the information.





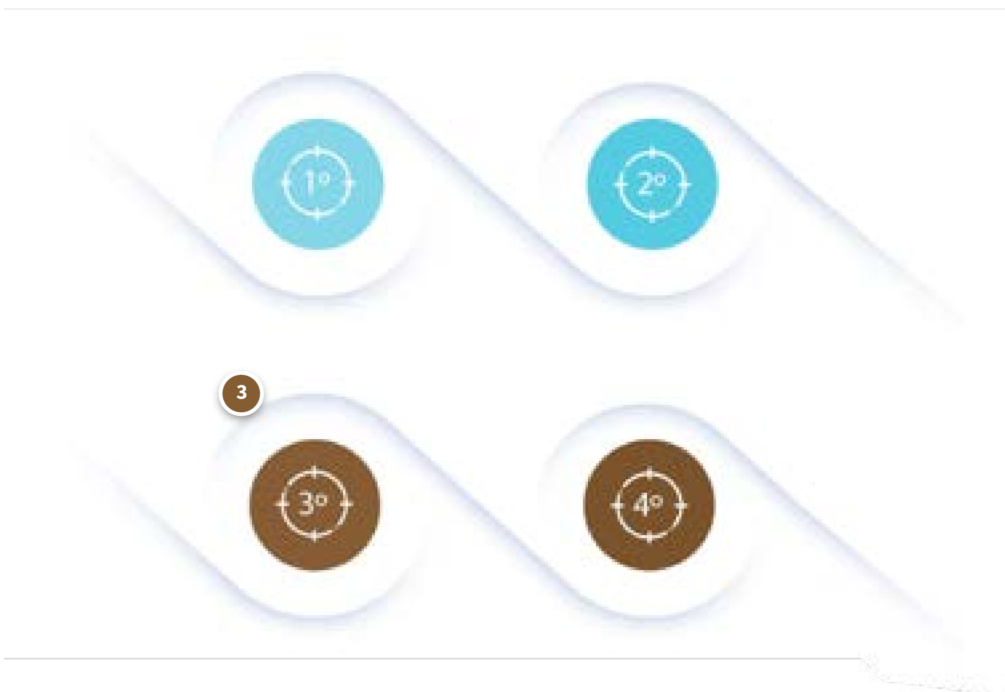
1

Understand the link between **presence of water** and **ecosystem functions**



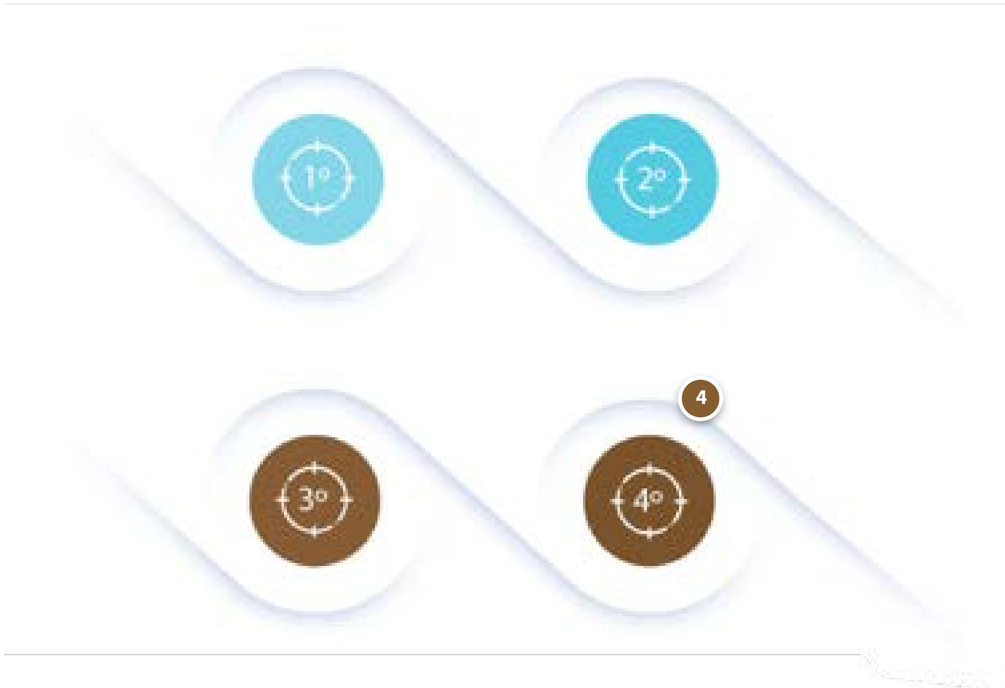
2

Learn how to distinguish **hydrological conditions** (flowing, ponding, dry) using **satellite images**



3

Recognise water presence in rivers and distinguish it from sediments and vegetation



4

Deal with cloud coverage and the presence of shadows in **Sentinel-2 images**

CONTINUE

Introduction

How to classify hydrological conditions?

In this module we will learn **how to classify hydrological conditions** in temporary rivers **using satellite images.**

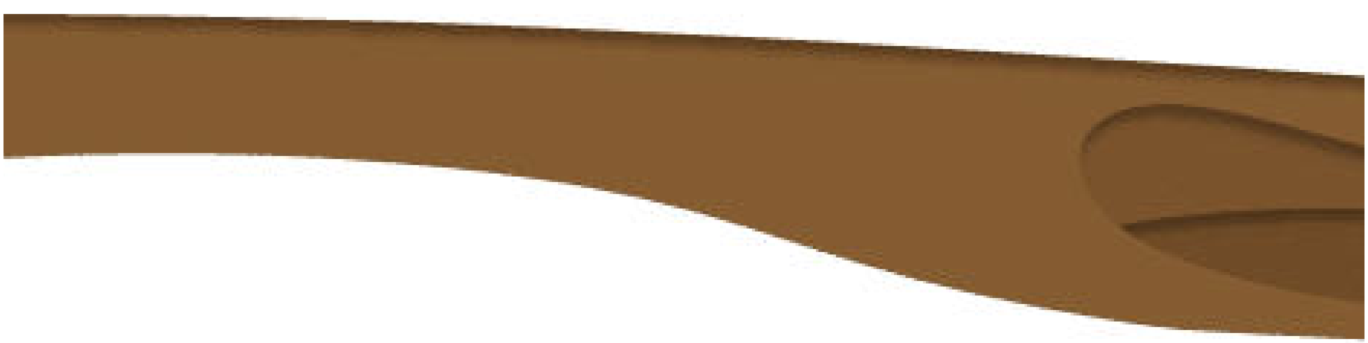
IMPORTANT

Remember that, in temporary rivers, three possible hydrological conditions can occur.

Flowing condition (F)
Visible continuous flow of water along the analysed river reach.

Ponding condition (P)
Discontinuous water presence; surface water is located in isolated ponds, pools or portions of the low-flow channel.

Dry condition (D)
Absence of surface water, with dry riverbed.



Click on the images to enlarge them

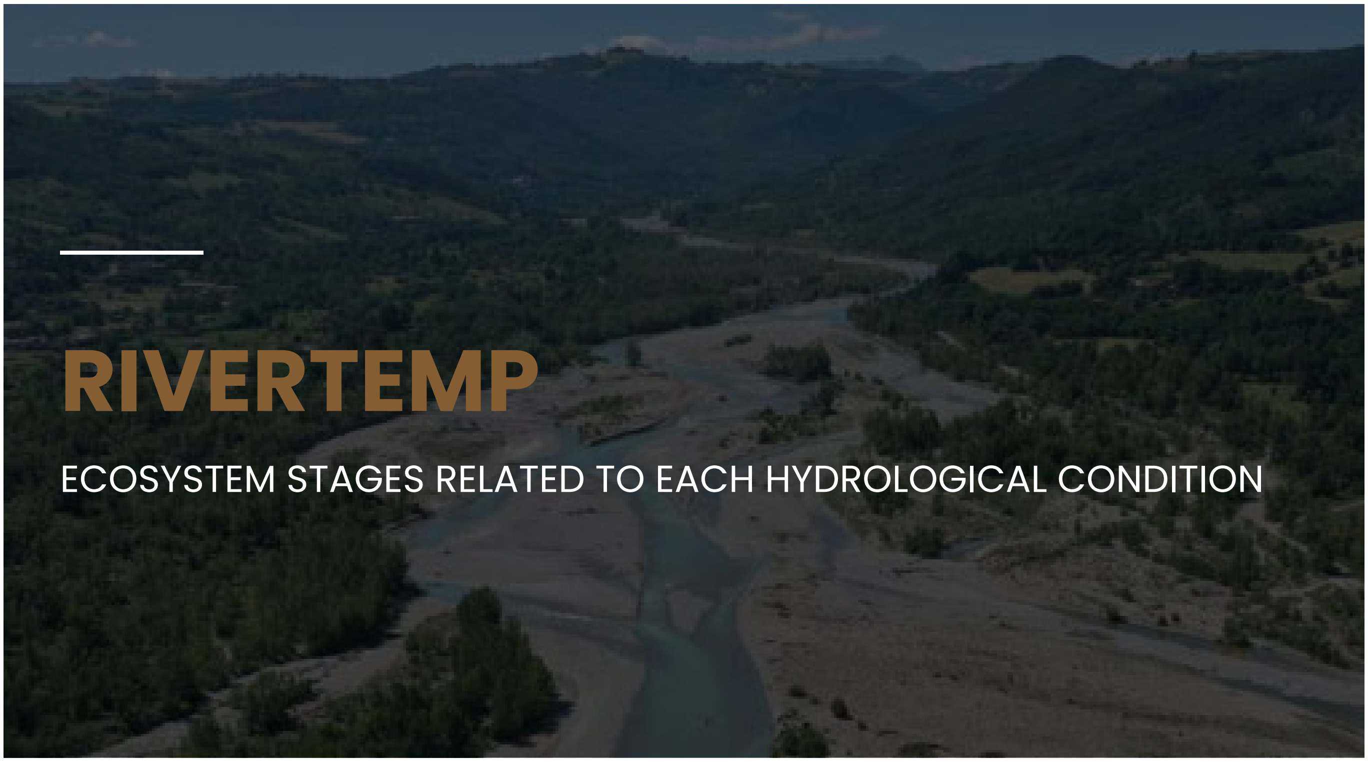
Sciarapotamo river, Salerno (IT) under the 3 hydrological conditions:
a) flowing, b) ponding, and c) dry.
Photo credits Carmela Cavallo (Cavallo et al., 2022)

i

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

CONTINUE

Fauna that inhabits during each hydrological condition



Temporary Rivers (TRs) can support both **Terrestrial and Semi-Aquatic Invertebrate** (named "**TSAI**") fauna, which inhabit different habitat types during each hydrological condition of the river ("flowing", "ponding" or "dry" conditions).

Click on the images to enlarge them

Gomphidae on Pellice river (Italy)

Heptageniidae on Pellice river (Italy)

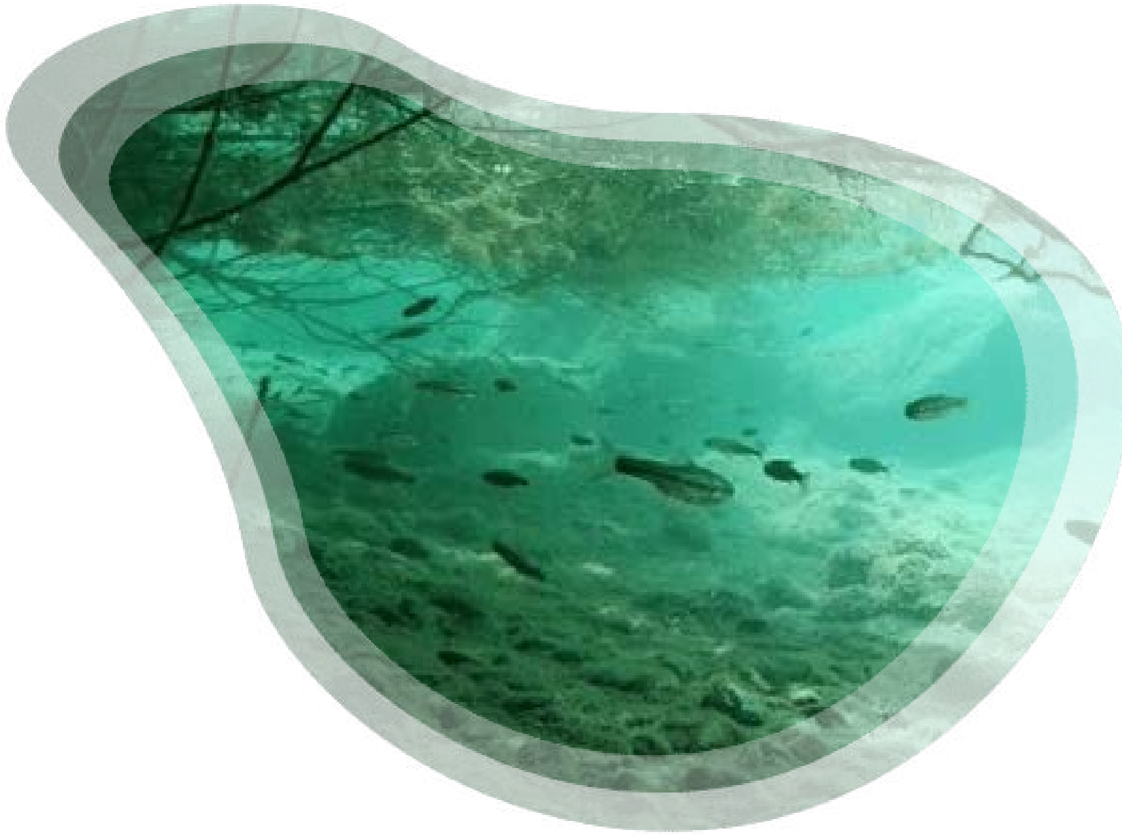
Trichoptera on Dece stream (Italy).

Photo credits Beatrice Pinna

These habitats can be:

1. Shorelines
2. River bars
3. Unsaturated sediment units

4. Dry riverbeds
5. Riparian zones
6. Floodplains



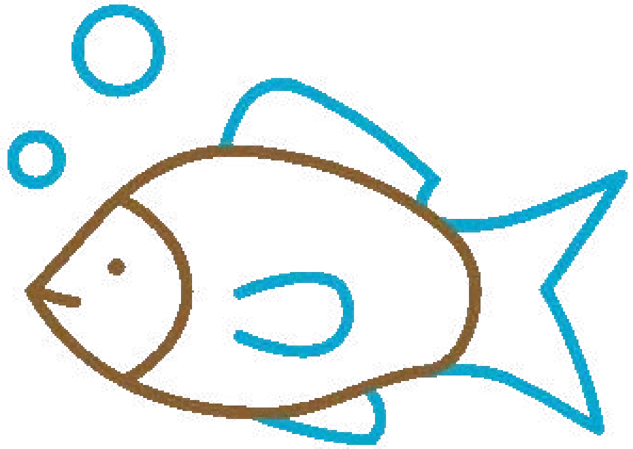
Fish recovering in a pond on the Trebbia River.

Photo credits Paolo Vezza

The **drying phenomenon of TRs** removes habitat for aquatic invertebrates and fishes but represents a potential habitat expansion for terrestrial fauna that can colonise the additional exposed area of the riverbed.

CONTINUE

Ecosystem stages related to each hydrological condition



Figures A to F provide six conceptual diagrams of ecosystem stages based on hydrological conditions for a generic TR.

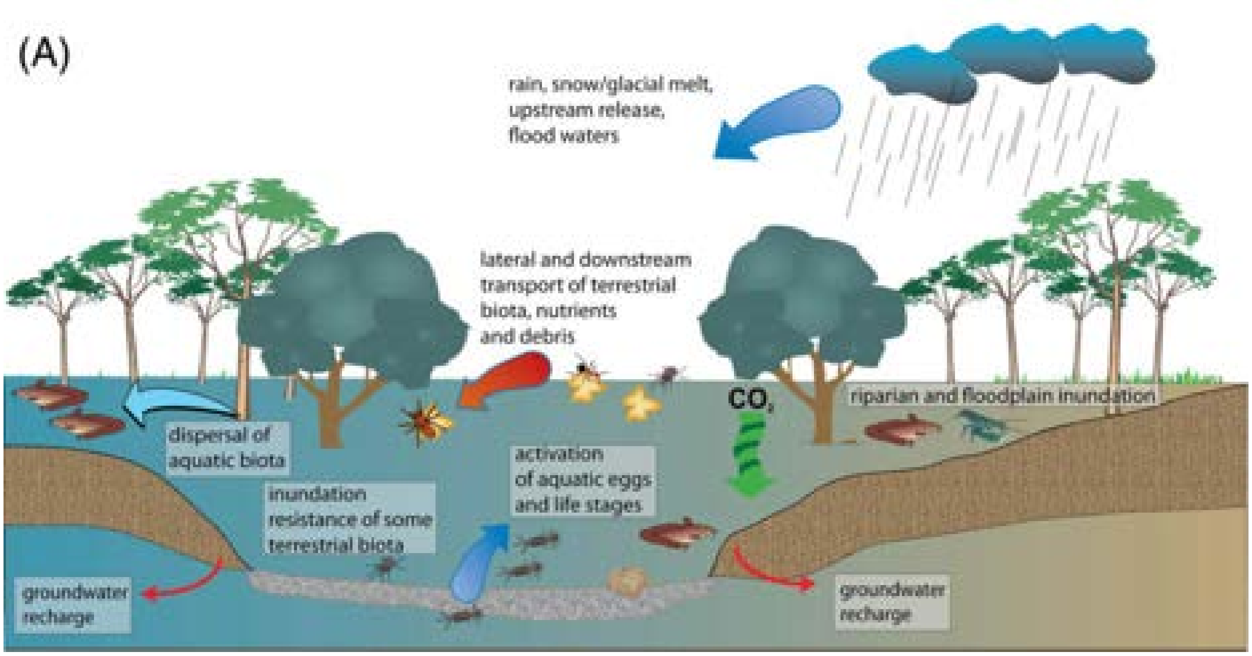
Note that the transition between stages can be gradual through time.

Click on the tabs to view the information.

A. FLOWING CONDITION DURING AN OVERBANK FLOOD | B. FLOWING CONDITION DURING A COMMON FLOW EVENT | C. PONDING CONDITION AFTER FLOW CESSATION

The dispersal of both aquatic and terrestrial fauna occur during these events. (Steward et al., 2022)

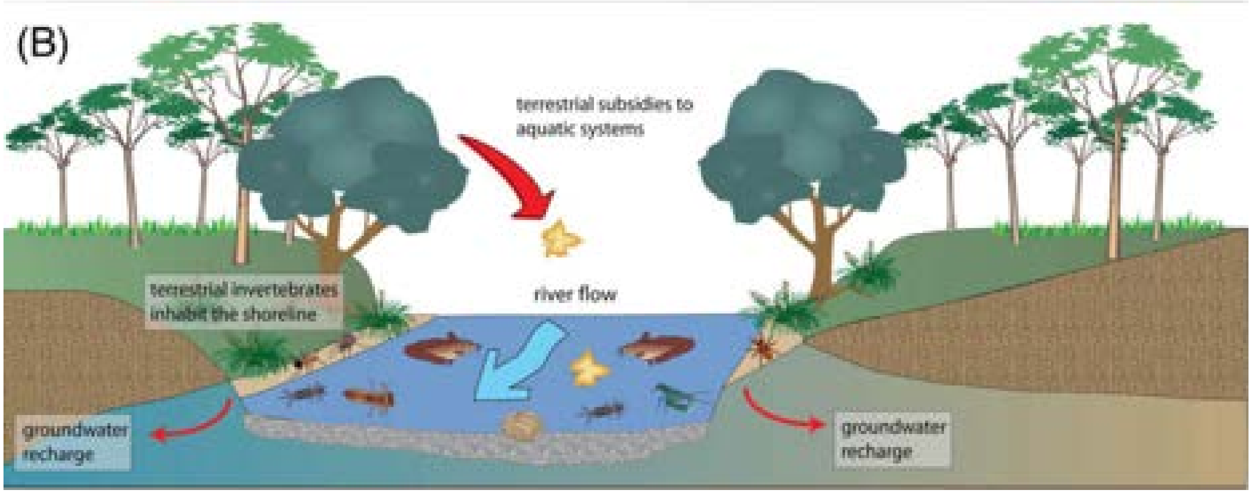
(Click on the image to enlarge it)



A. FLOWING CONDITION DURING AN OVERBANK FLOOD | B. FLOWING CONDITION DURING A COMMON FLOW EVENT | C. PONDING CONDITION AFTER FLOW CESSATION

Terrestrial invertebrates inhabit the shoreline, leaf litter and woody debris.

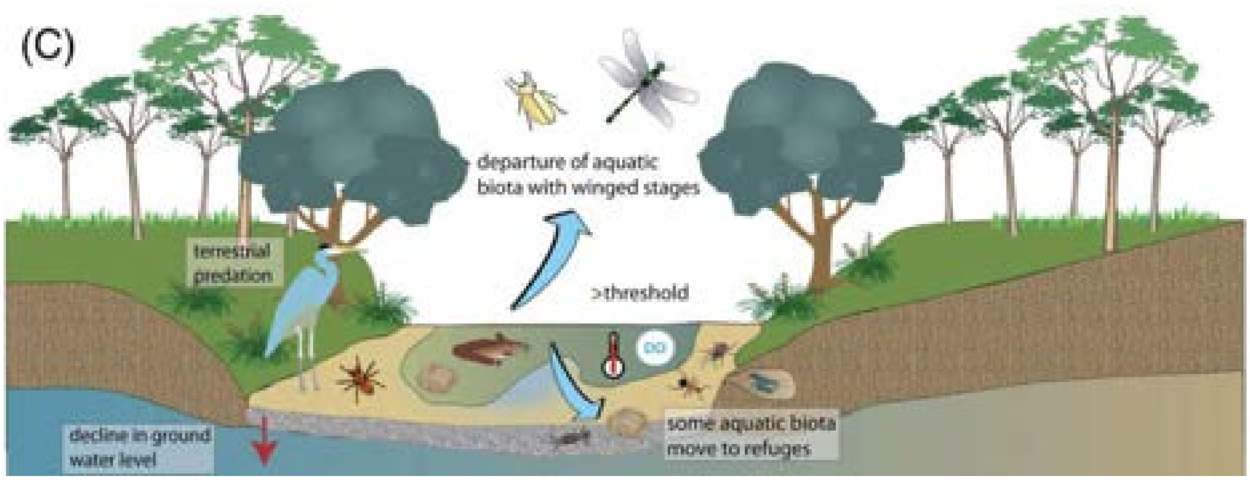
(Click on the image to enlarge it)



A. FLOWING CONDITION DURING AN OVERBANK FLOOD	B. FLOWING CONDITION DURING A COMMON FLOW EVENT	C. PONDING CONDITION AFTER FLOW CESSATION

- TSAIs colonise the riverbed in drying areas.
- Aquatic biota moves to refugees, the departure or winged stages are observed.
- Terrestrial predation of aquatic species begins.

(Click on the image to enlarge it)



Legend: Figures **A** to **C**

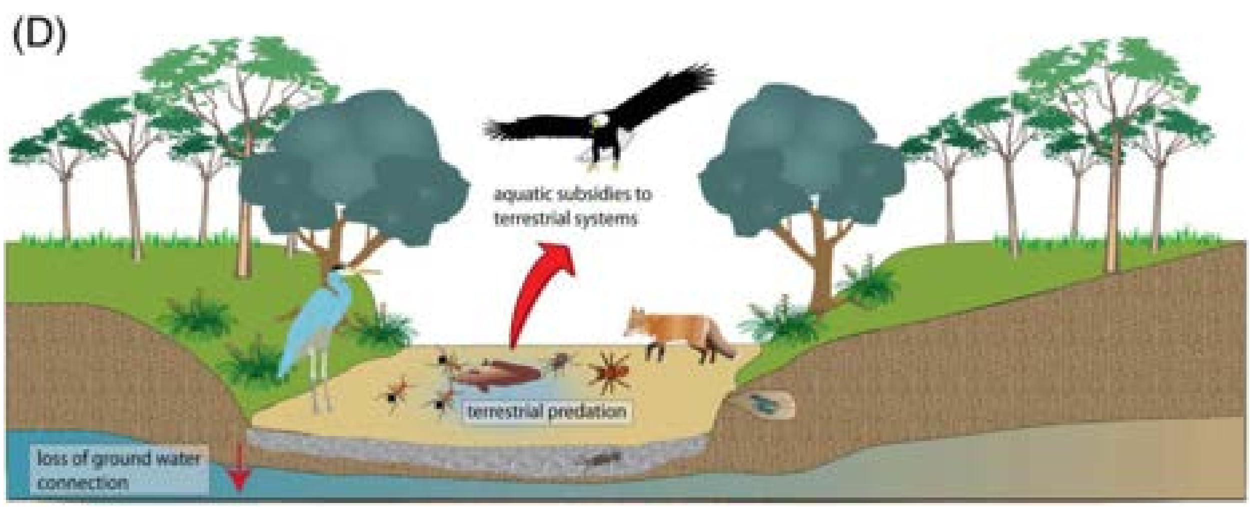
Reference:

Steward, A. L., Datry, T., & Langhans, S. D. (2022). The terrestrial and semi-aquatic invertebrates of intermittent rivers and ephemeral streams. Biological Reviews, 97(4), 1408-1425.

D. PONDING CONDITION WITH LOSS OF SURFACE WATER	E. DRY CONDITION IN THE SHORT-TERM	F. DRY CONDITION IN THE LONG-TERM

Terrestrial predation increases due to the reduction of surface water for evaporation and disconnection with the subsurface aquifers.

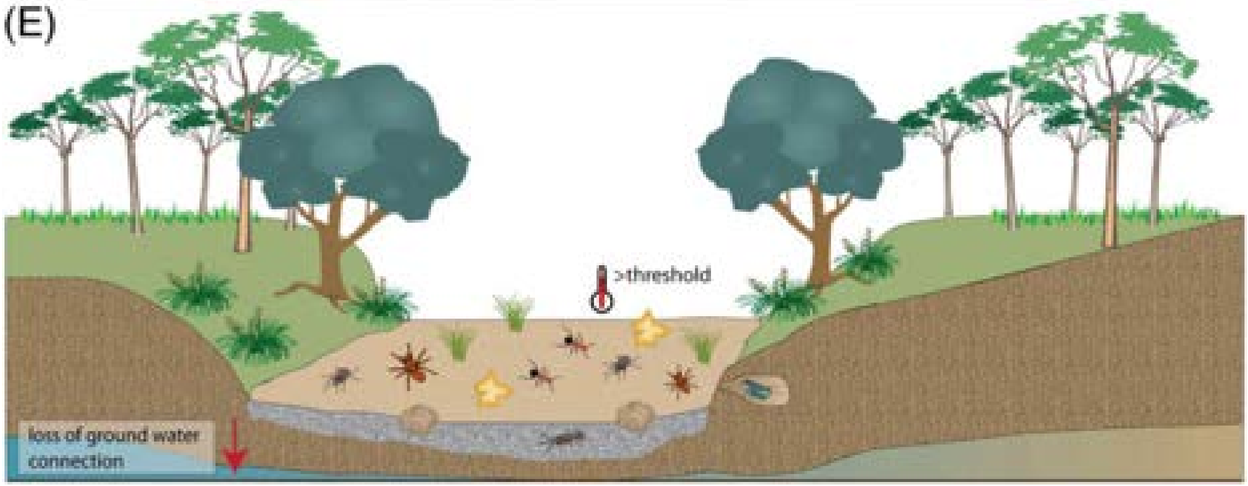
(Click on the image to enlarge it)



D. PONDING CONDITION WITH LOSS OF SURFACE WATER	E. DRY CONDITION IN THE SHORT-TERM	F. DRY CONDITION IN THE LONG-TERM

Taxa able to tolerate short-term drying may dig to avoid predators and remain in refugees characterised by high soil humidity.

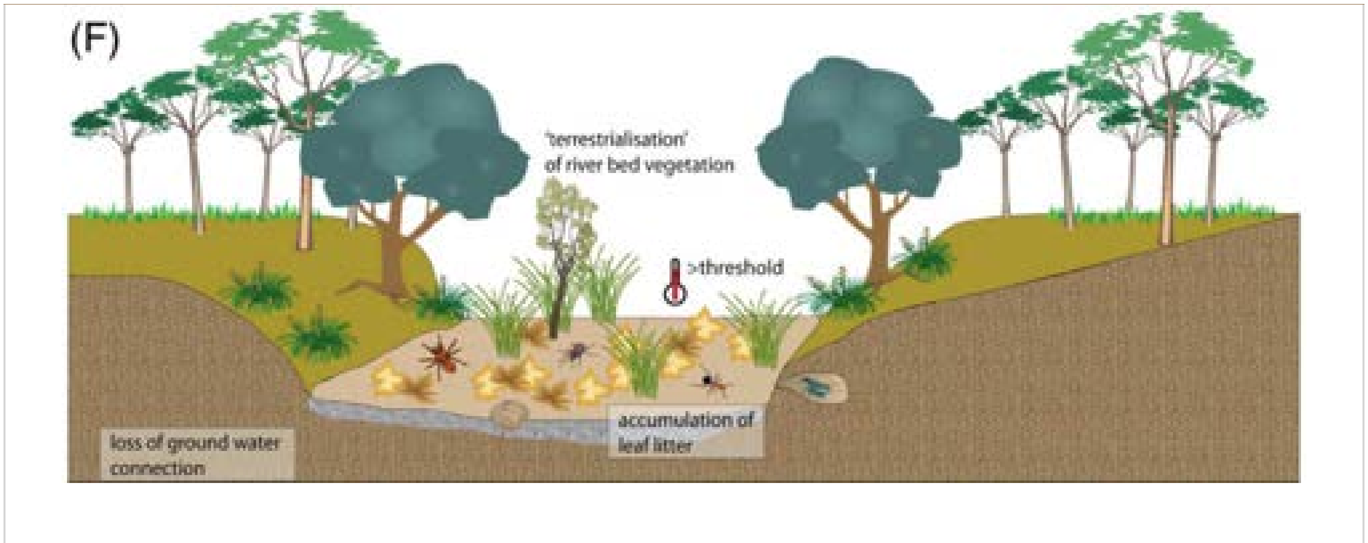
(Click on the image to enlarge it)



D. PONDING CONDITION WITH LOSS OF SURFACE WATER	E. DRY CONDITION IN THE SHORT-TERM	F. DRY CONDITION IN THE LONG-TERM

- Dry riverbeds become more and more terrestrial environments.
- Long-term drying can be harsh; exposed places devoid of vegetation experience lower humidity, higher fluctuations in air temperature and solar radiation between day and night.
- Vegetation presence in the main channel and shaded riparian zones slow down the drying process.
- Accumulation of leaf litter and loss of ground water connection also occur during this phase.

(Click on the image to enlarge it)



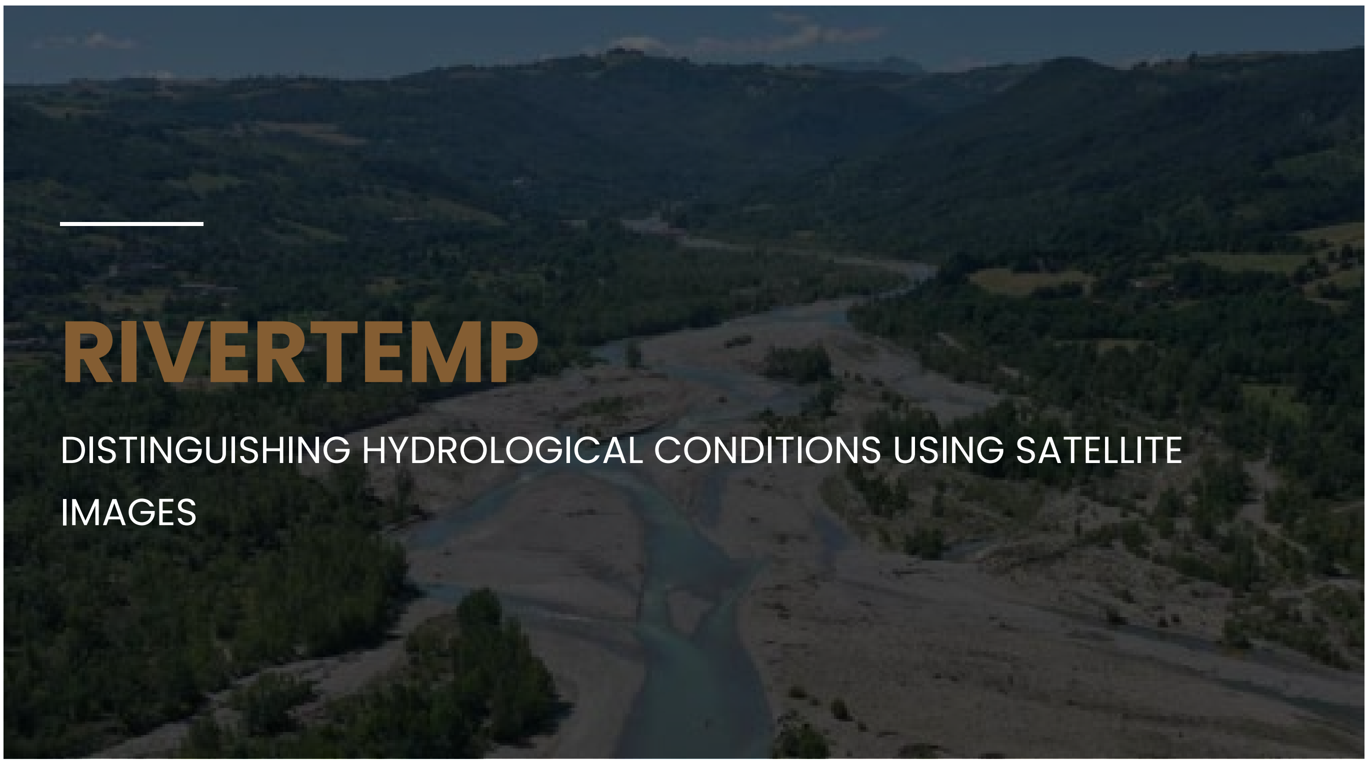
Legend: Figures **D** to **F**

Reference:

Steward, A. L., Datry, T., & Langhans, S. D. (2022). The terrestrial and semi-aquatic invertebrates of intermittent rivers and ephemeral streams. Biological Reviews, 97(4), 1408-1425.

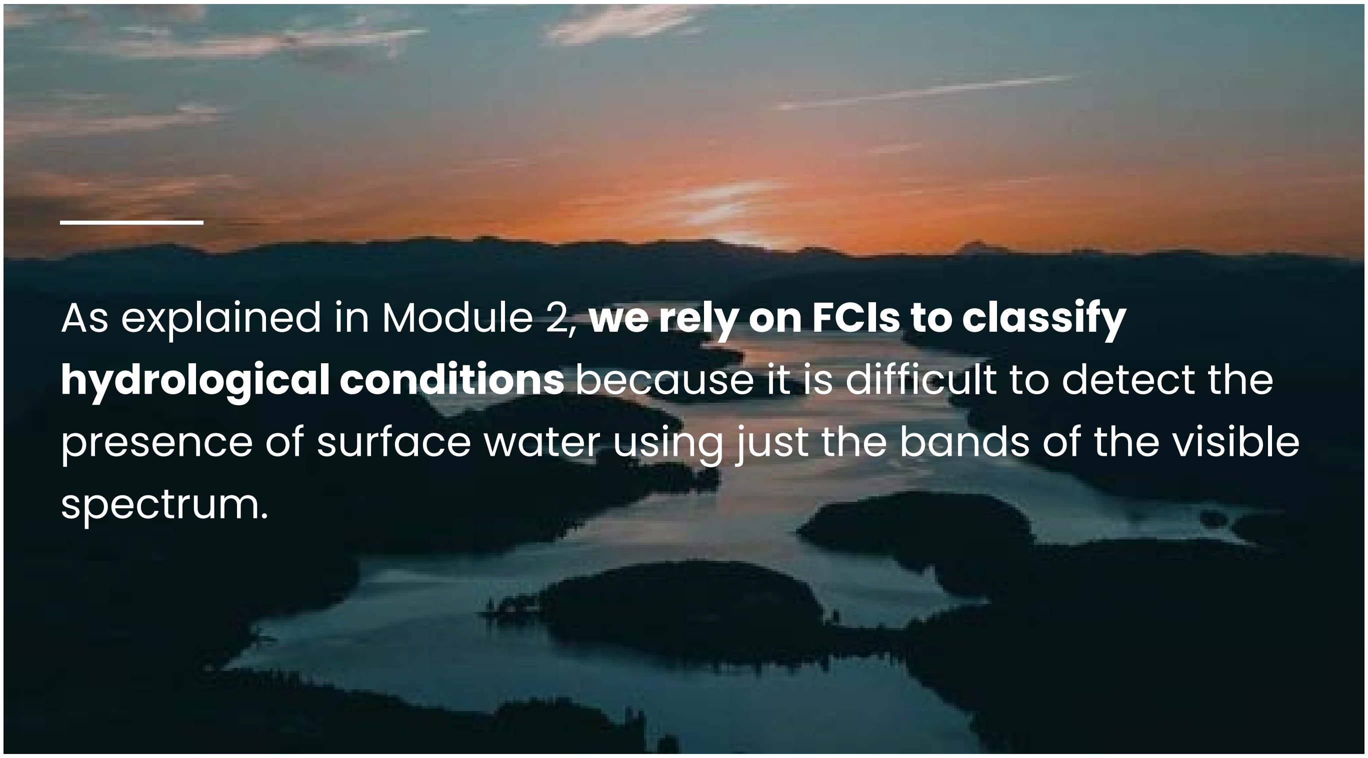
CONTINUE

Learn how to distinguish hydrological conditions using satellite images



IMPORTANT

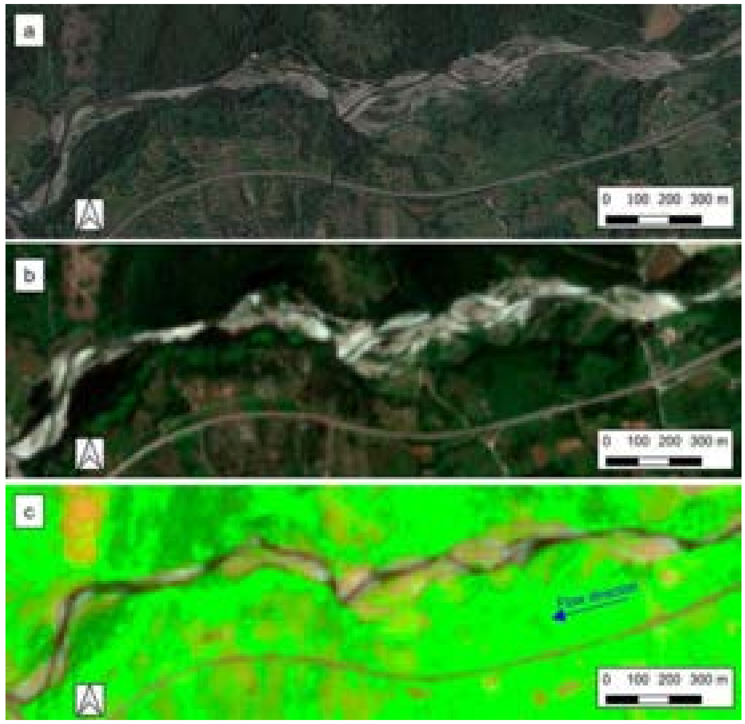
From the False-Color Images (**FCIs**) of **Sentinel-2**, it is possible to identify the presence of surface water for distinguishing the three distinct hydrological conditions of temporary rivers: “flowing” (F), “ponding” (P) and “dry” (D).

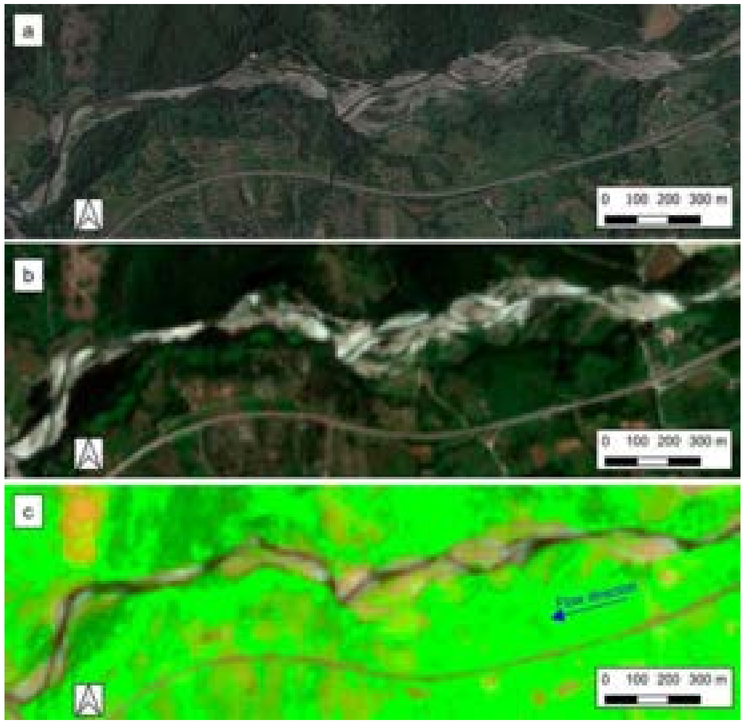


As explained in Module 2, **we rely on FCIs to classify hydrological conditions** because it is difficult to detect the presence of surface water using just the bands of the visible spectrum.

Now, pay attention to the following **3 images of the Mingardo river (Italy):**

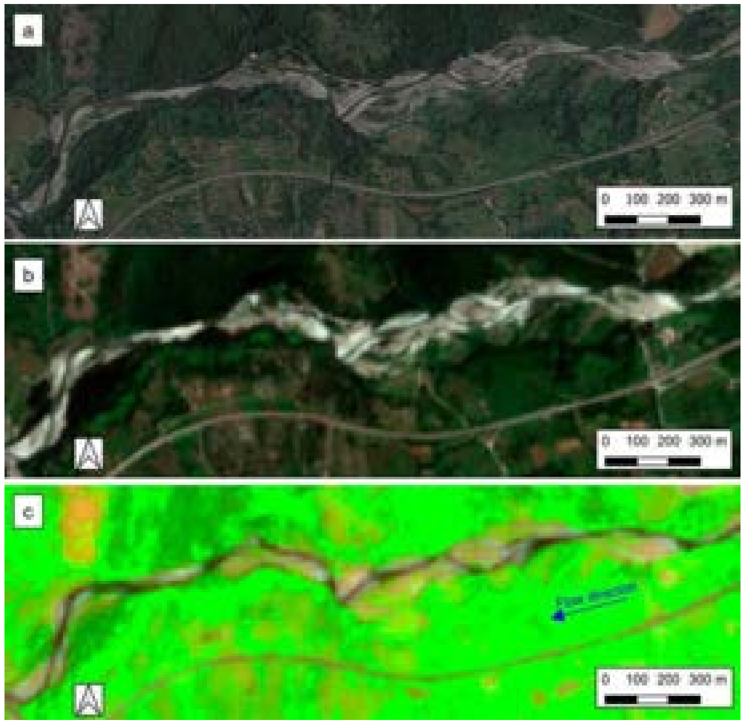
Click on the buttons to view the information.


a
0 100 200 300 m
b
0 100 200 300 m
c
0 100 200 300 m



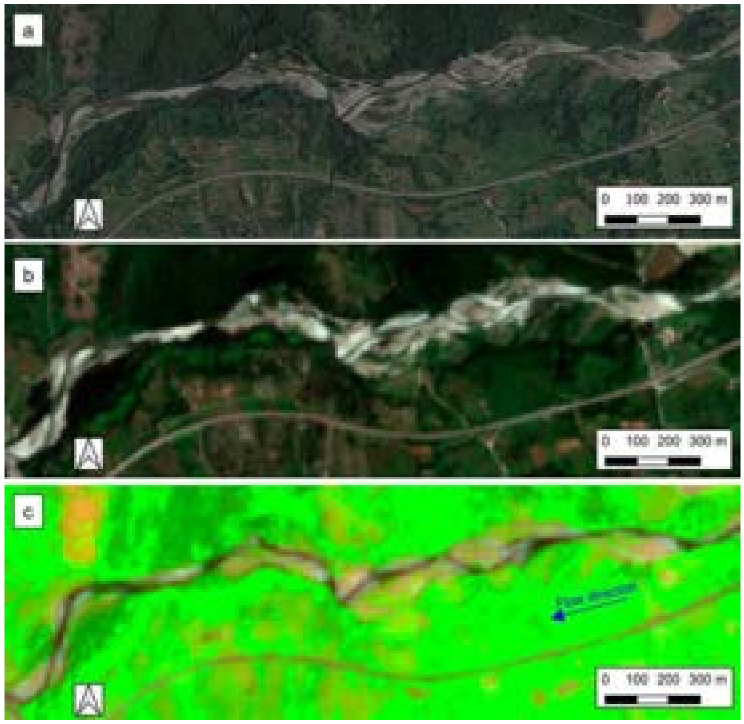
Very-High Resolution (VHR) Image

This Very-High Resolution (VHR) image shows the wet channel in the river corridor. Despite its great detail, these images have a revisit time that is too long (typically spanning months to years), making it unsuitable for monitoring temporary rivers.



True-Color Image (TCI)

The True-Color Image (TCI), obtained from the same Sentinel-2 acquisition, does not allow for easy distinction of the wet channel. The exclusive use of visible spectrum bands in this type of image can make identifying water bodies under certain conditions more difficult.



False Color Composite Image (FCI)

In the Sentinel-2 FCI, which uses the combination of bands B11-B8-B4, the wet channel stands out clearly. Despite its lower resolution compared to the VHR image, the wet channel is about equally visible and the flowing condition can be clearly identified.

The flowing condition in Mingardo river (Italy); a) Google Earth Pro data of June 14th 2019 and b) TCI and c) FCI in B11-B8-B4 extracted from Sentinel-2 acquisition of June 12th 2019 (Cavallo et al., 2022)

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

In summary you can observe that:

1. From the **False-Color Images** (c) of Sentinel-2 in bands B11-B8-B4, it is possible to identify the presence of surface water and to distinguish the three hydrological conditions of TRs.

2. While in the **True-Color image of Sentinel-2** (b) the land covers are confused, in the FCI (c) and **Very-High Resolution image** (a), the wet channel is about equally visible, despite the much coarser resolution of the FCI.

3. In fact, in FCI the **wet channel clearly stands out** from the other components of the river corridor, such as sediments and vegetation.

CONTINUE

Other examples

Sangone river (Italy)

Palancia River (Spain)

Sciarapotamo river (Italy)

1

Sangone river (Italy)

In this figure , which represents a FCI in the identified band triplet on the Sangone river, the presence of a continuous black line, which is representative of a flowing condition along the river, is clearly identifiable.

Click on the image to enlarge it

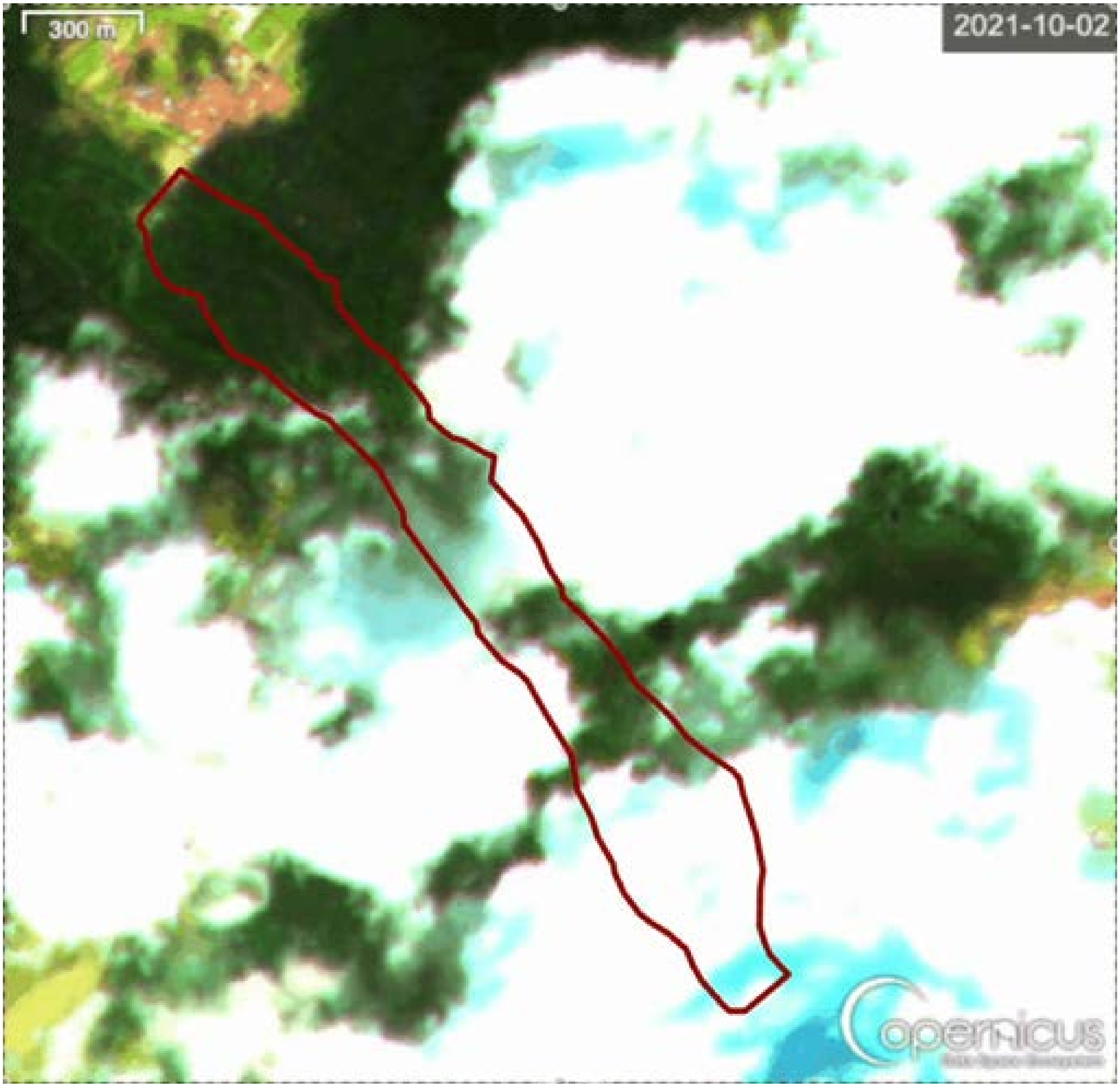
The flowing condition in the Sangone river (Italy), FCI extracted by Sentinel-2 acquisition of October 18th 2021 (Cavallo et al., 2022)

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

2

Palancia River (Spain)

A timelapse of FCIs from the Palancia river reach highlights how this band triplet clearly reveals the evolution of hydrological conditions.


300 m
2021-10-02
Copernicus

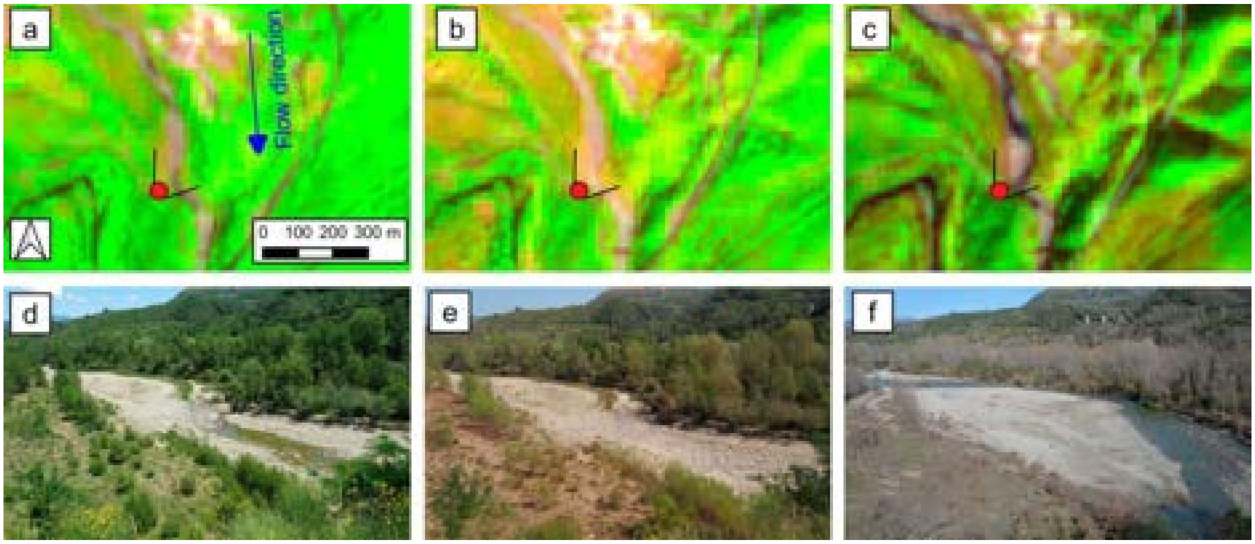
EO Browser, https://apps.sentinel-hub.com/eo-browser/(opens in a new tab), Sinergise Ltd.

3

Sciarapotamo river (Italy)

During the ponding condition, brownish and **dark-violet areas** can be seen in the riverbed (a). At the end of the summer that for Sciarapotamo river corresponds to the dry season, **the riverbed is completely dry** (b, e). In the FCI of the subsequent winter (c) the F condition is easily detectable (f).

Click on the image to enlarge it



Sciarapotamo river (Italy) under the 3 hydrological conditions; a) FCI of June 26th 2020, b) FCI of September 19th 2020, c) FCI of February 6th 2021 and related photos taken on d) June 26th 2020 “P”, e) September 19th 2020 “D”, and f) February 6th 2021 “F”. Red points show shooting location (Cavallo et al., 2022)

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

CONTINUE

Special conditions when using satellite images

In this section you will see **3 special conditions** to take into account when using satellite images:

Very small ponds or pools

Cloud coverage

Shadows and related issues

Pay attention that each one will be explained in more detail

below.

CONTINUE

1º. Very small ponds or pools

If the pond or the pool is very small (a few meters wide), it cannot be easily distinguishable from FCIs. Using Sentinel-2 images we generally have problems in identifying ponds or pools characterised by a width lower than 6 m.

What would be the minimum width identifiable by the FCI?

The analysis described in Cavallo et al. (2022), showed that the minimum width of ponds identifiable by FCIs **is highly variable.**

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

In some cases, **it is possible to identify ponds with widths between 6 and 10 m.** However, in other conditions, ponds or wet channels larger than 10 m and less than 15 m are not clearly identifiable.

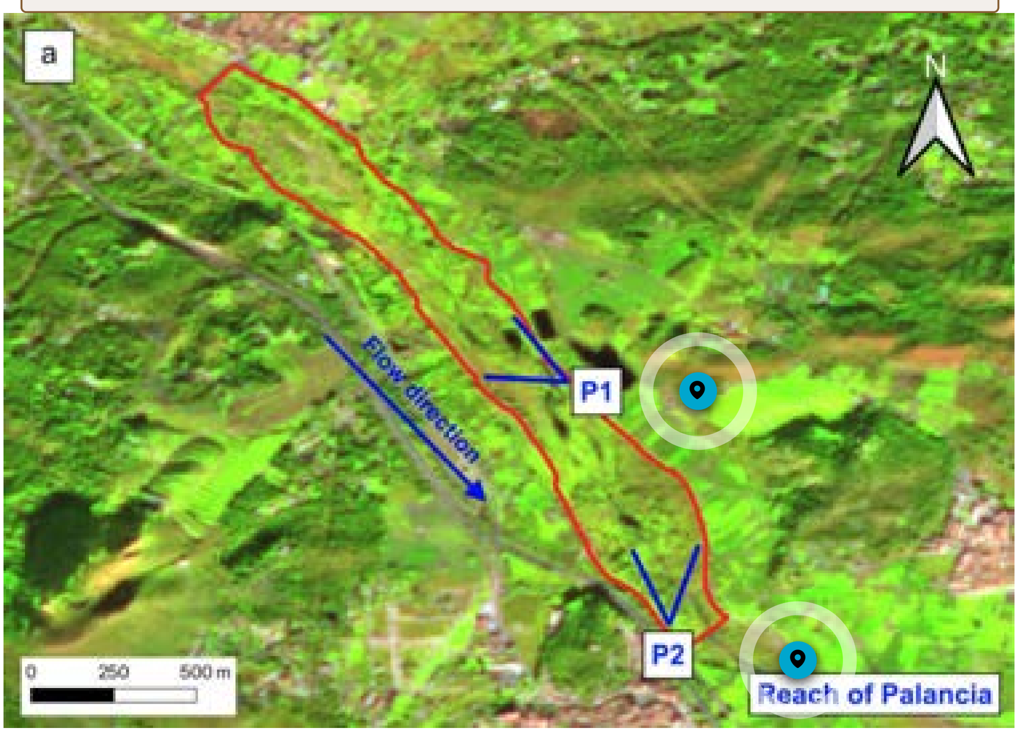
This **depends on the water depth and on the relative position of the surface object** with respect to the pixel grid of the satellite.

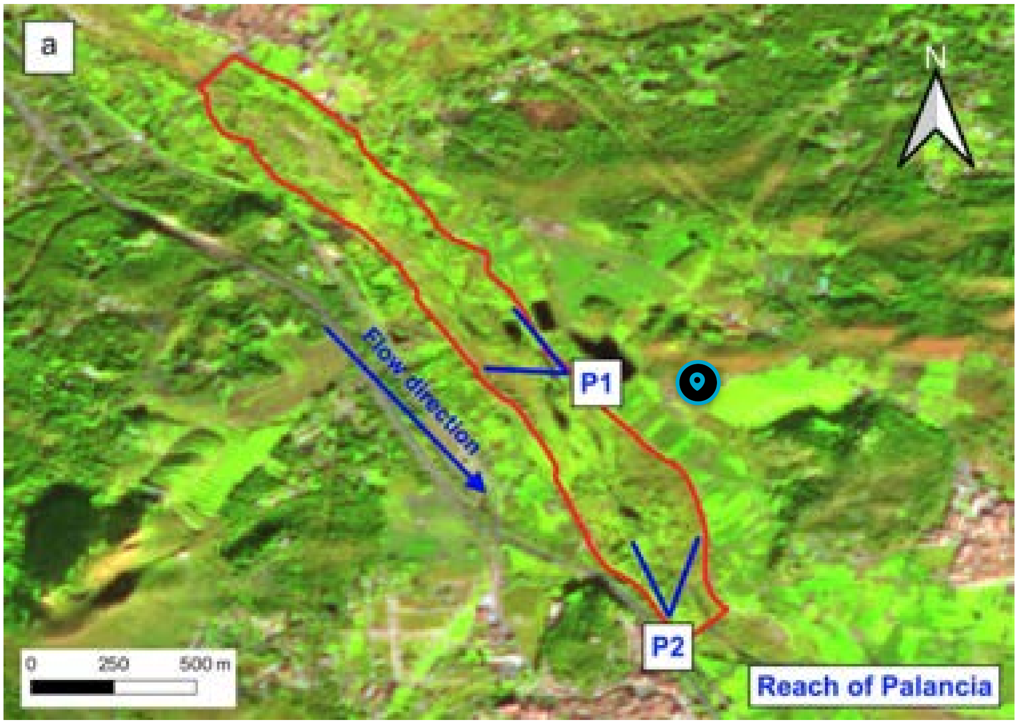
In fact, a pixel-size water surface contained in only one pixel can be reported, whereas if the water surface covers only partially two or more pixels, the identification is more complicated.

Comparison between a FCI from Sentinel-2 and the corresponding geolocated pictures

This figure provides a comparison between a FCI from Sentinel-2 taken on December 16th 2022 and the corresponding geotagged pictures taken the day after along the Palancia river (Spain).

Click on the buttons to view the information.

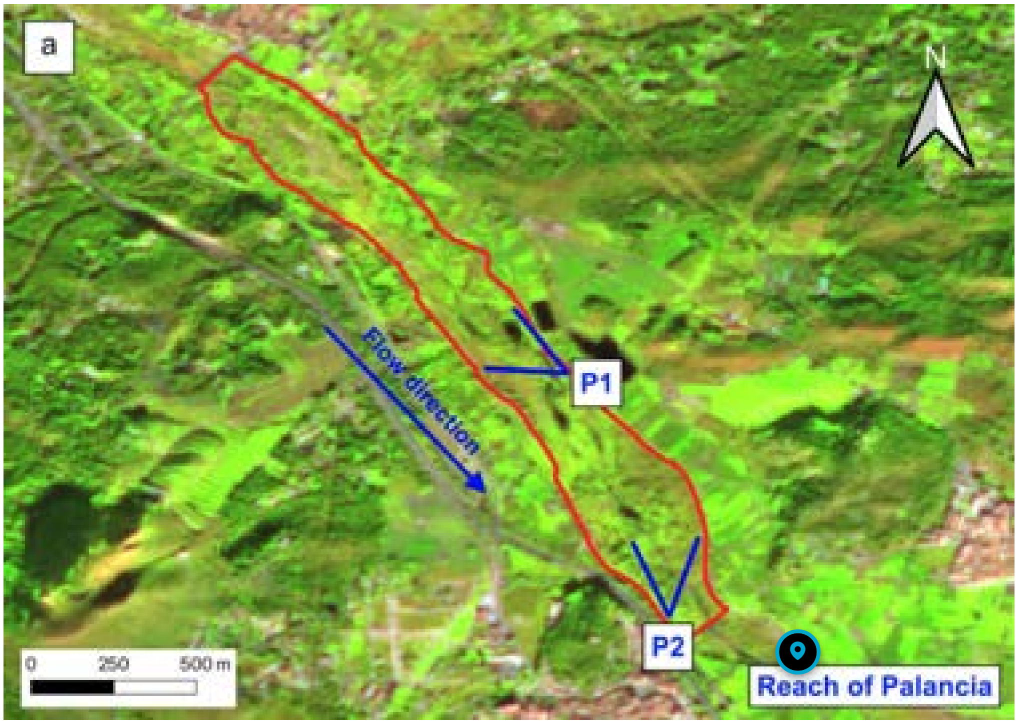




P1

(*Click on the image to enlarge it*)

In particular, in this figure are visible a low-flow channel of 15 m average width (in the center of the photo) and a pool of 40 m diameter (in the upper-right), water surfaces that are also clearly visible from the FCI.



P2

(*Click on the image to enlarge it*)

This figure, instead, reports a pond with an average width of 6 m.

a) Sentinel-2 FCI of Palancia river (Spain) in ponding condition on December 16th 2022 and related photos from shooting location b) P1 and c) P2 taken on December 17th 2022. Photo credits Isabelle Brichetto

IMPORTANT

The field survey confirmed the non-flowing condition with isolated water ponds, depicting the ponding status as observable from the FCI.

CONTINUE

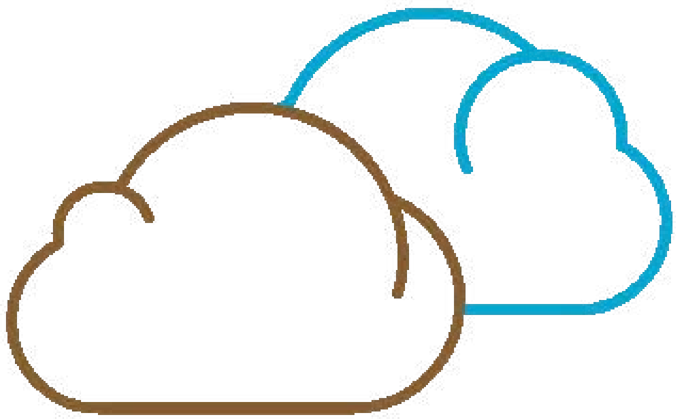
2º. Cloud coverage and the impossibility of seeing the river

What is the revisit time of Sentinel-2?

Sentinel-2 has a nominal revisit time of 5 days under the same viewing condition on the majority of

Due to the overlapping between tiles, **in some zones at mid-latitudes it is possible to have an acquisition every** global areas (excluding polar regions in which it is of 10 days).

2-3 days, relying on slightly different viewing conditions.



However,

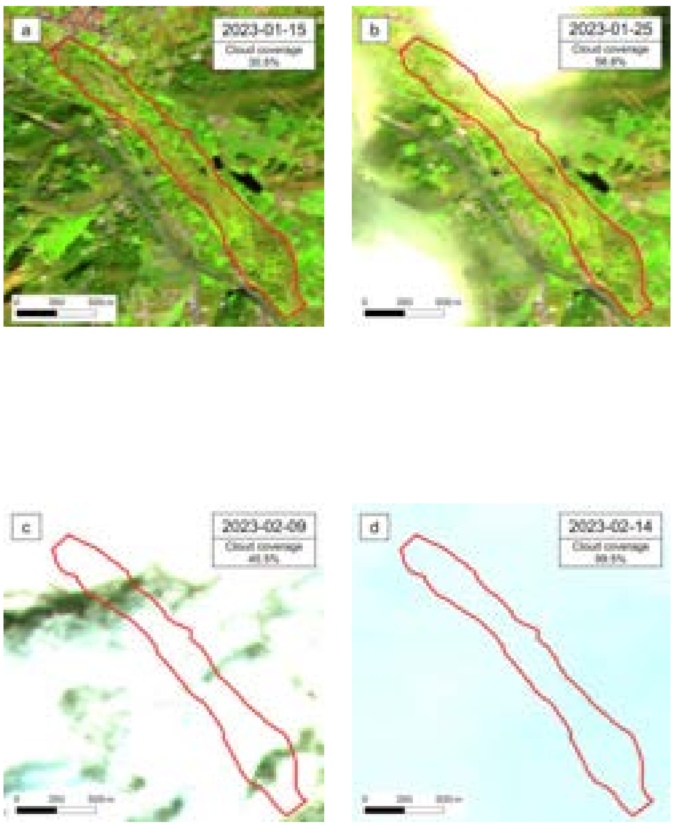
due to occasional cloud cover, which prevents the classification of hydrological conditions, **the effective revisit time can be longer**.

Examples of FCIs on different cloud cover conditions for a reach of the Palancia river (Spain).

In Figure below, we collect four example of FCIs on different cloud cover conditions for a reach of the Palancia river (Spain).

The percentage of cloud coverage that is reported for each image is relative to the whole tile detected by the satellite (i.e, the ortho-image of 110x110 km²).

Click on the images to enlarge them



Sentinel-2 on different cloudy conditions for a study reach of Palancia river (Spain), from tile 30SYJ

Despite the first figure represents the range in cloud-free conditions, the tile from which it was extracted (30SYJ) had 30.5% cloud coverage (acquisition date January 15, 2023). Therefore,

filtering Sentinel-2 images by cloud cover may be ambiguous if the interest is in a subportion of the mosaic.

IMPORTANT

Therefore, we suggest **disregarding cloudy images only when cloud cover affects the classification of hydrological conditions** for the selected river reach.

CONTINUE

3°. Shadows and related issues for water presence detection

The Presence of shadow is one the main obstacles when detecting surface water presence.

Is there a **method to automatically remove shadows** from FCI images?

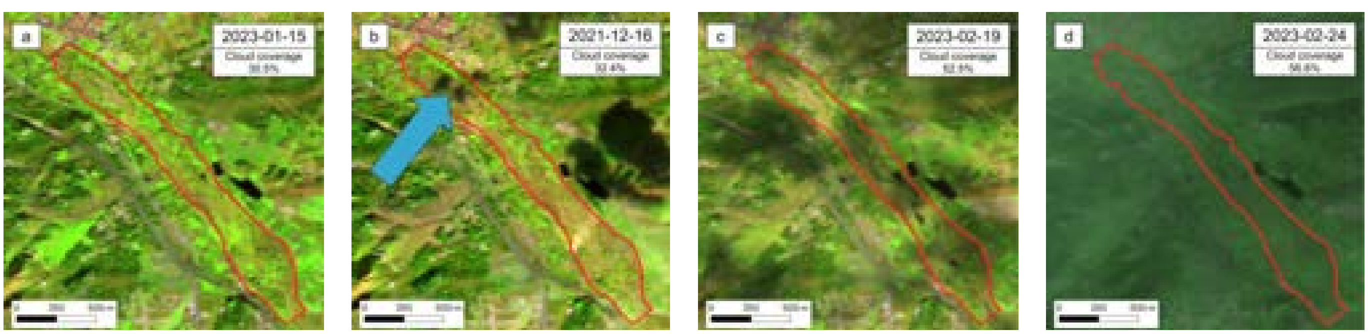
Several methods are reported in the literature to automatically eliminate shadows from multispectral satellite images.

However, **these methods can have problems when water is also present within the imagery** because water shares similar spectral characteristics with shadows.

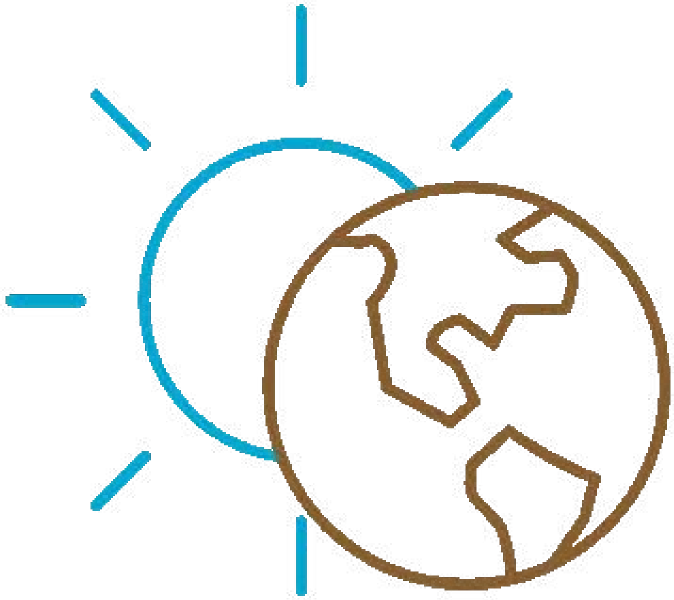
Indeed, **both water and shadow areas provide low reflectance,** making water and shadow pixels difficult to distinguish from each other.

Figure shows **how the cloud shadows falling into the river reach can be mistaken for water,** while the other images report the different extensions and influences of cloud shadows.

Click on the images to enlarge them



Sentinel-2 FCIs reporting the problem of cloud shadows for a study reach of Palancia river (Spain)



We suggest **carefully observing the presence of shadows in the selected Sentinel-2 images,** taking care of possible misclassification errors due to the presence of shaded areas.

The **characteristics of the river channel have also to be considered** for a correct interpretation of satellite FCIs.

The plants of vegetated river banks may cover a portion of the active channel with their canopy or generate shadows that are then observed inside the channel and that could be misinterpreted as water.

In incised river channels, inner shadows can be generated directly by the river banks, depending on the orientation of the solar radiation at the moment of the image acquisition.

Examples of shadows

In figure the Sentinel-2 FCI of October 11^{th} 2022 is associated with contemporary ground photos along the reach, giving examples of shadows.

Click on the buttons to view the information.

P1

(Click on the image to enlarge it)

Example of shadows generated by river banks.

P2

(Click on the image to enlarge it)

Example of shadows generated by plants

P3

(Click on the image to enlarge it)

Example of shadows that fall inside the riverbed and that can be misclassified as water in the FCI.

a) Sentinel-2 FCI of Sangone river (Italy) on September 11th 2022 and related photos from shooting location b) P1, c) P2, d) P3 taken on September 11th 2022 and showing bank and vegetation dome shadows. Photo credits Giammarco Manfreda

IMPORTANT

Field surveys may help in understanding where ponds and pools are normally located in the river reach and where the shadows generated by river banks or riparian vegetation are instead usually present.

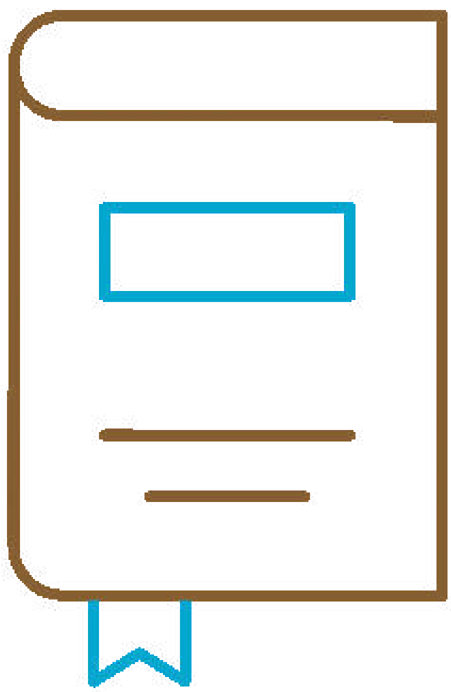
CONTINUE

A Mediterranean case study: Rio Palancia

Case study

A Mediterranean case study: Rio Palancia

It is time to see the given information as applied to a river reach!



Rio Palancia

The Palancia is a regulated river that flows in Eastern Spain in the area managed by the Confederación Hidrográfica del Júcar (CHJ). It has a basin of 976 km^2, for a river length of 90.7 km, flowing from low-mountains to the Mediterranean Sea.

According to the Spanish classification of rivers based on temporality (order “ARM/2656/2008”, IPH, 2008), it is defined as “perennial”, despite the numerous water abstractions for irrigation purposes make it “temporary” in its last 25 km.

We will engage you in **an interactive online simulation** that presents images of the same reach under different hydrological conditions.

By observing and analysing the river components, you will **gain a deeper understanding on the TRs functioning** and impact on ecosystems.

CONTINUE

Let´s start!

Look at the images and answer the following questions.

The photos represent a portion of river Palancia at Gilet municipality: the first one was taken in the winter of 2023, on the date January 20th 2023, while the second one in the spring season of 2023, on April 16th.

Click on the images to enlarge them

Palancia river at Gilet (Spain) shooted under different hydrological conditions.

Photo credits Isabelle Brichetto

Based on what is visible in the pictures:

1. **Which hydrological condition** will you attribute to the images? Why? Are you able to exactly determine it?

2. **Which ecosystem stage**, from the ones presented at the beginning of the module, will you attribute to the visible segment of the river for each date?

Check your answers

Solution

Check your answer and discover more about the reach by navigating on Earth Observation platforms

Copernicus Browser

- Check your answer on hydrological conditions by searching the Sentinel-2 acquisition closest to the shooting dates for the particular area of interest.
- Photos at single point are not sufficient for evaluating the hydrological condition among the hydro-morphologically homogeneous river reach, that is the scale among which the classification must be done.
- For the given photos, the portion of river to take into consideration while navigating on Copernicus Browser is the Palancia between Albalat dels Tarongers and Gilet municipalities (Spain).
- Once searched for the area and selected a date, you have to customize the visualization to see false-color images with the combination of bands B11-B8-B4.

Google Maps

You can also observe the river on Google Maps, setting the satellite basemap.

Google Earth Pro

Alternatively, you can explore the river reach from Google Earth Pro App.
Using this application, it is possible to visualize orthophotos taken on different dates, by navigating into the acquisition history.

Click on the links to open websites.

Copernicus Browser

GO TO WEBSITE

Google Maps

GO TO WEBSITE

Google Earth Pro

GO TO WEBSITE

CONTINUE

Quiz

It is time to test what you have learned!

Please select the best response for each question based on your understanding of phase recognition and on the scenarios presented in the simulation.

You must answer all the questions correctly to continue with the course.

Question

01/05

In the ponding phase...

- ◯ The groundwater is always connected to the river.
- ◯ A bunch of species can reproduce.
- ◯ All the species die.

Question

02/05

Drying of TRs renews habitat for TSAI fauna?

- ◯ True
- ◯ False

Question

03/05

What happens to the ecosystem in the passage from a flowing to a ponding hydrological condition?

- Aquatic biota dies and TSAI colonise the riverbed.
- Aquatic biota moves to refugees and terrestrial vegetation grows in drying areas of the riverbed.
- Aquatic biota moves to refugees and TSAI colonise the drying areas of riverbed.

Question

04/05

In the false-color image of Sentinel-2, surface water appears:

- ○ Difficult to distinguish from vegetation and sediments.
- ○ In dark tones color.
- ○ In a green-blue color

Question

05/05

Ponds with an average width between 6 to 10 m are...

- ◯ Detected only if they represent a portion of the low-flow channel.
- ◯ Not always detected, depending on the relative positioning with respect to the pixel grid.
- ◯ Always detected, due to their visibility in false color image.

References

Bibliographic references

In the development of any academic course, bibliographic references play a crucial role by providing the necessary theoretical and practical support for the material taught.

References not only strengthen the credibility of the study materials but also allow students to explore the topics covered more deeply, gaining a

This set of references has been carefully selected to provide a solid foundation of knowledge, encompassing a variety of sources, deeper understanding of key concepts and discovering new perspectives

including books, academic articles, recent research, and digital resources.

We hope these references will be a valuable tool for learning, fostering a comprehensive and critical understanding of the topics addressed in this course.

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

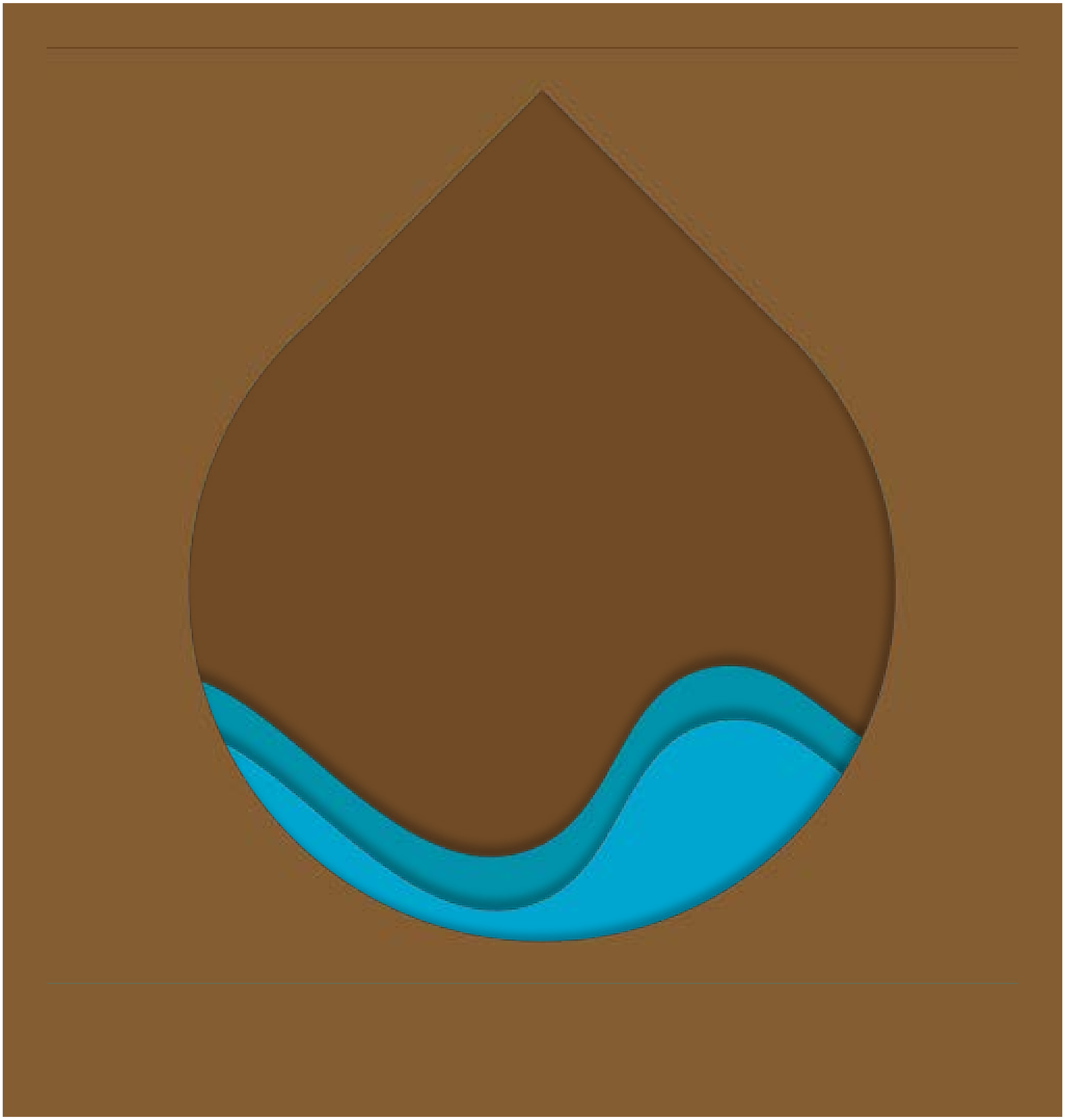
EO Browser, https://apps.sentinel-hub.com/eo-browser/, Sinergise Ltd.

IPH. (2008). Orden ARM/2656/2008, de 10 de septiembre, por la que se aprueba la instruccion de planificacion hidrologica. Ministerio de Medio Ambiente, Y Medio Rural Y Marino. BOE (Boletín Oficial Del Estado), 229, 38472–38582.

Steward, A. L., Datry, T., & Langhans, S. D. (2022). The terrestrial and semi-aquatic invertebrates of intermittent rivers and ephemeral streams. Biological Reviews, 97(4), 1408-1425.

CONTINUE

Closure



Congratulations!

You have **completed** this module.

We trust that this journey has increased your knowledge about ecological functioning of temporary rivers and the way to easily classify hydrological conditions (flowing, ponding and dry) using satellite images.

Your ability to classify Sentinel-2 images will be useful when using the Temporary River Classifier (TRC) in Module 4!

Let’s move to module 4!

MODULE 4: A web classifier for temporary rivers_v2_IT

This module will teach you how to use the RiverTemp classifier tool, which is available online on the web.

LET'S GET STARTED!

3. EXPLORE SENTINEL-2 IMAGES

Navigate the map

Satellite imagery classification

Resume or modify one of your classifications

See registered data

Regions of interest

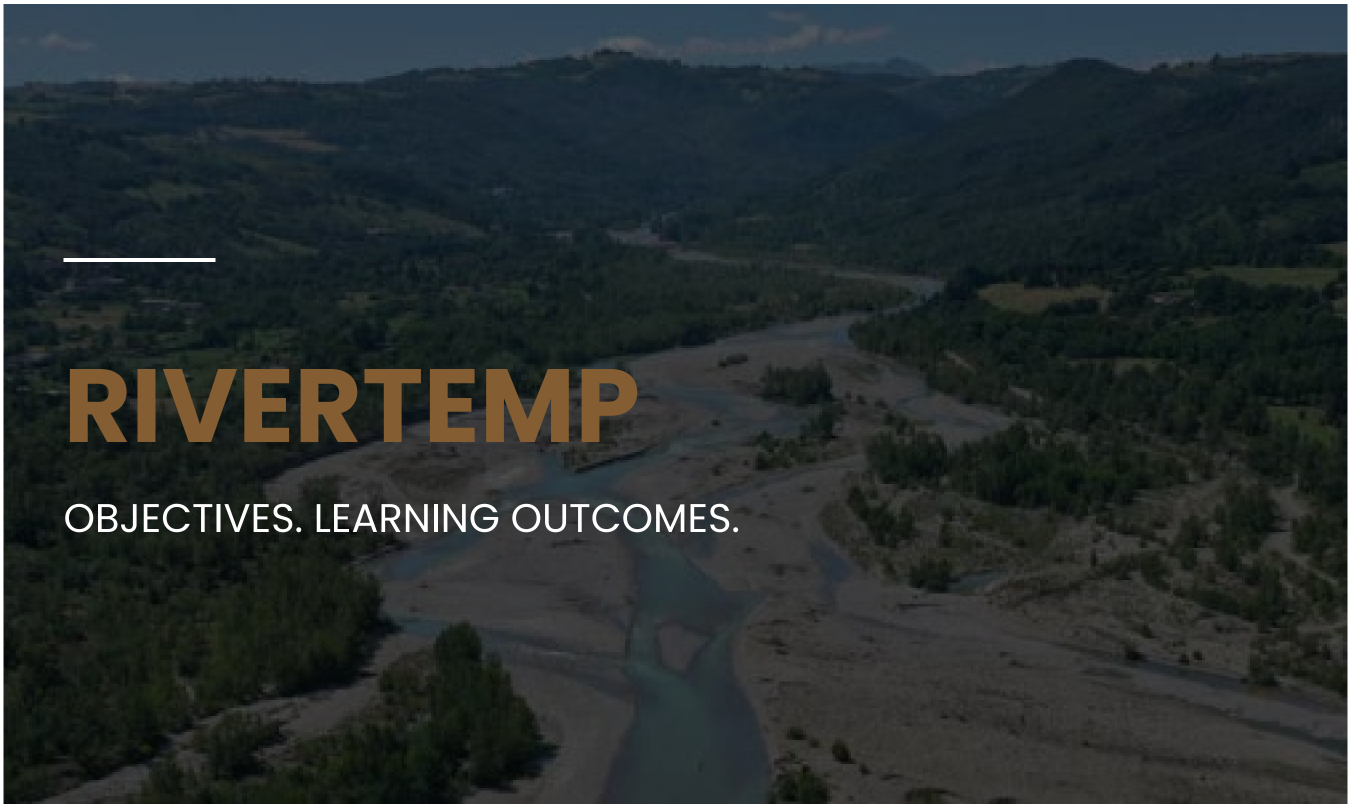
4. EXPORT CLASSIFICATIONS

Export classifications

5. CLOSURE

Closure

Objectives & Learning Outcomes



The **3 Objectives and Learning Outcomes** of this module are the following:

Click on the buttons to view the information.

1

Create an account for the IT tool, **Temporary River Classifier** (**TRC**).

2

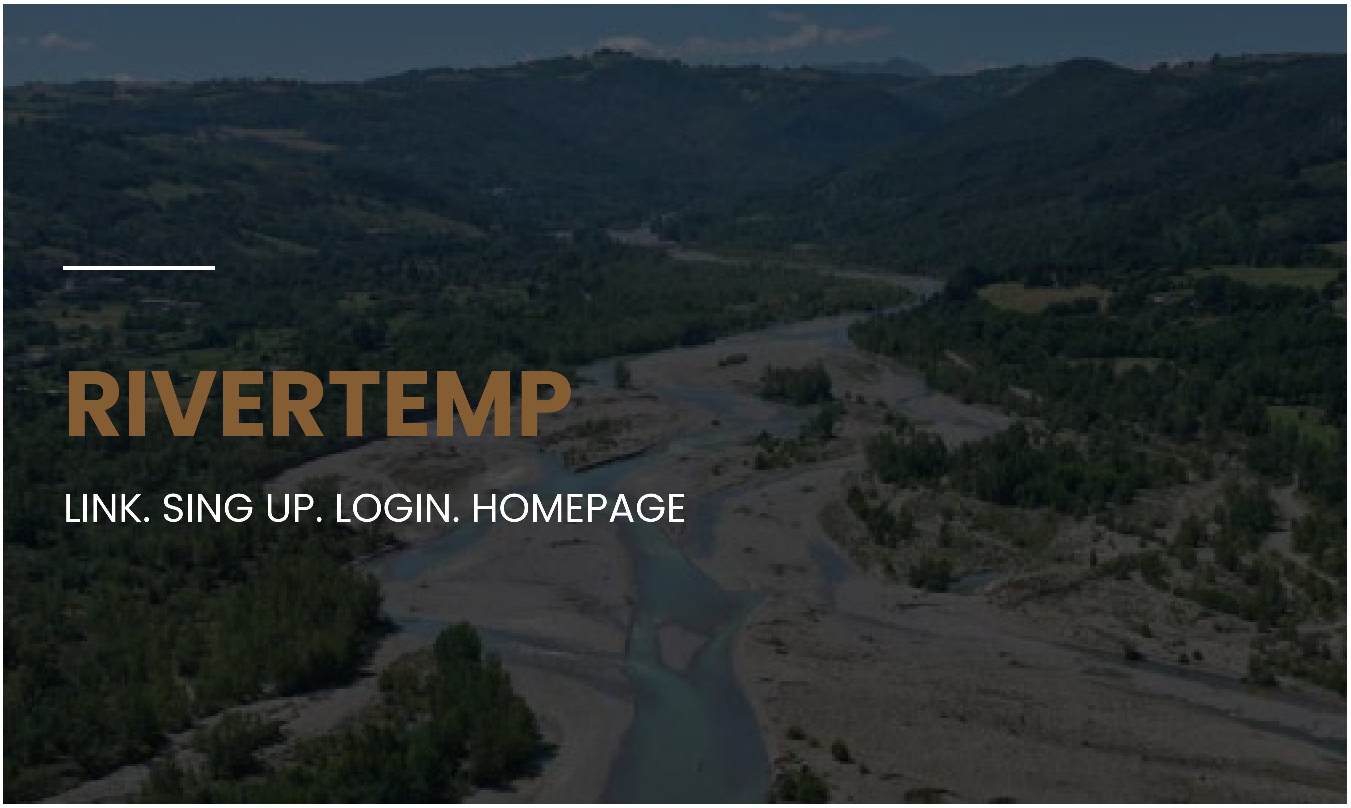
Explore the **capabilities** and **potential** of the **TRC.**

3

Familiarize yourself with the use of this **IT tool.**

CONTINUE

Link to the River Temp Classifier



The first thing you should do is enter the tool's website

Click on the button to begin the sign-up process for the tool.

River Temp Classifier

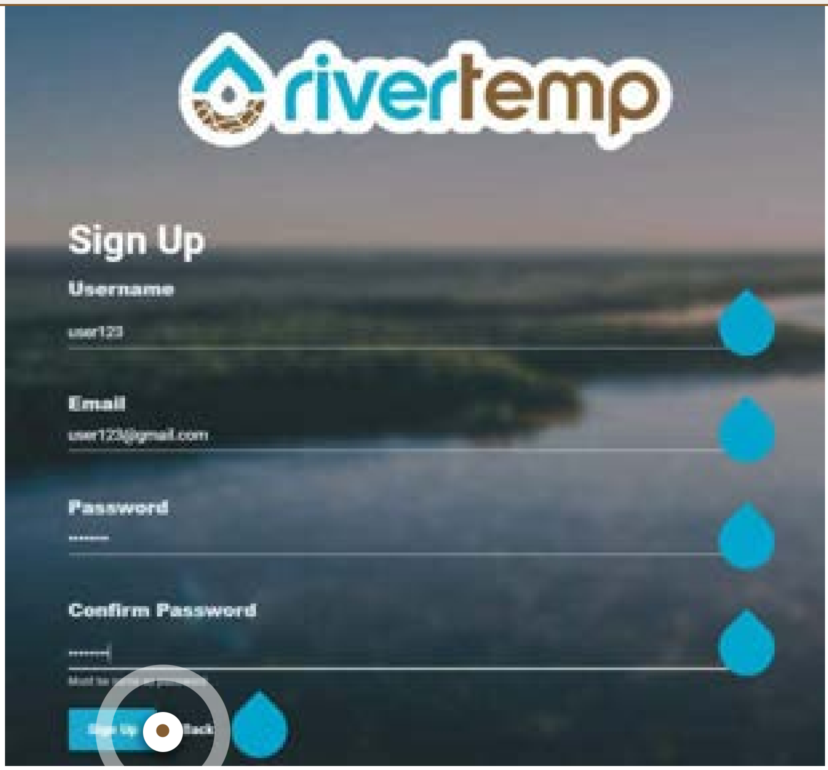
WEB

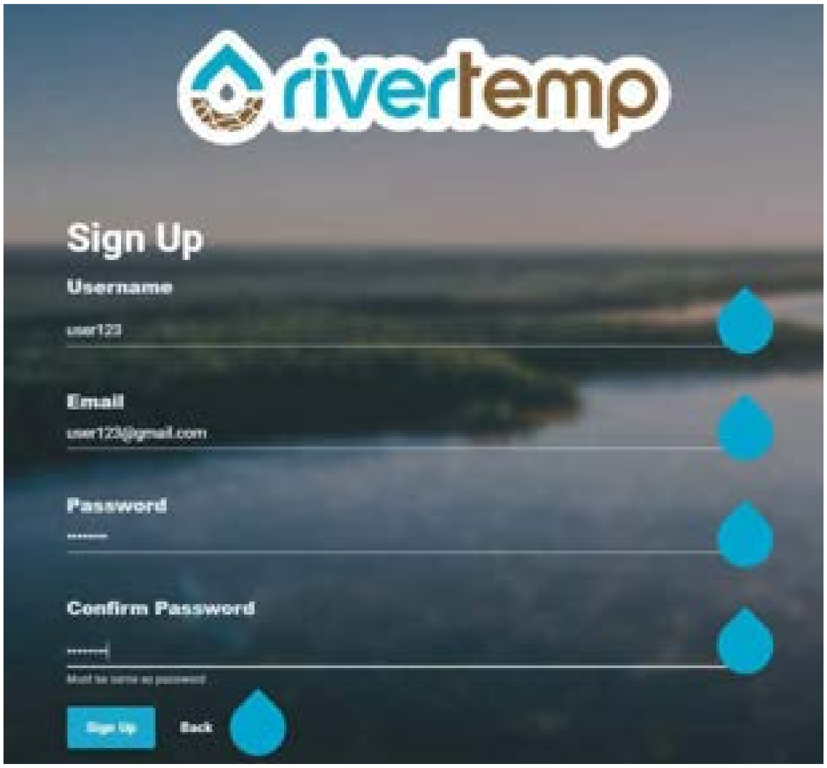
CONTINUE

Sign-up

To **sign up** you must fill out the following fields:

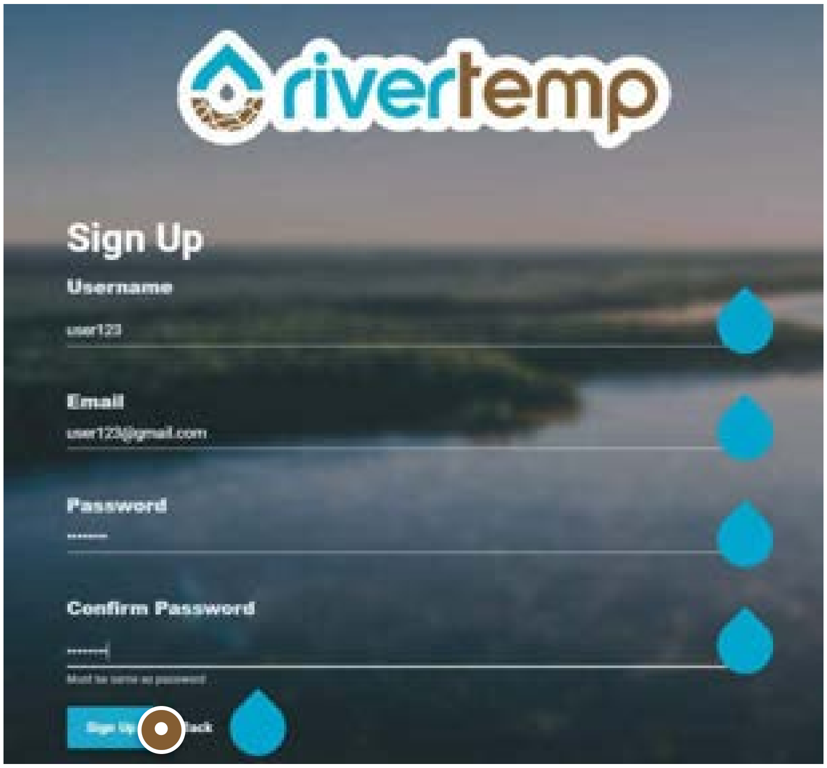
Click on the buttons to view the information.





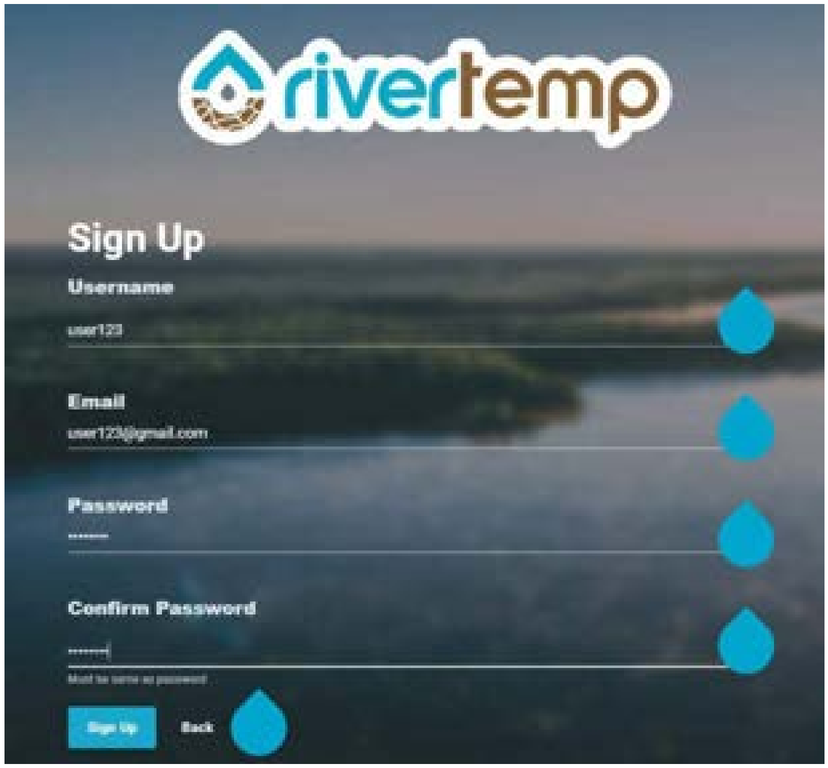
Username

Enter your username.
This is the public name that will appear in the polygons you create.



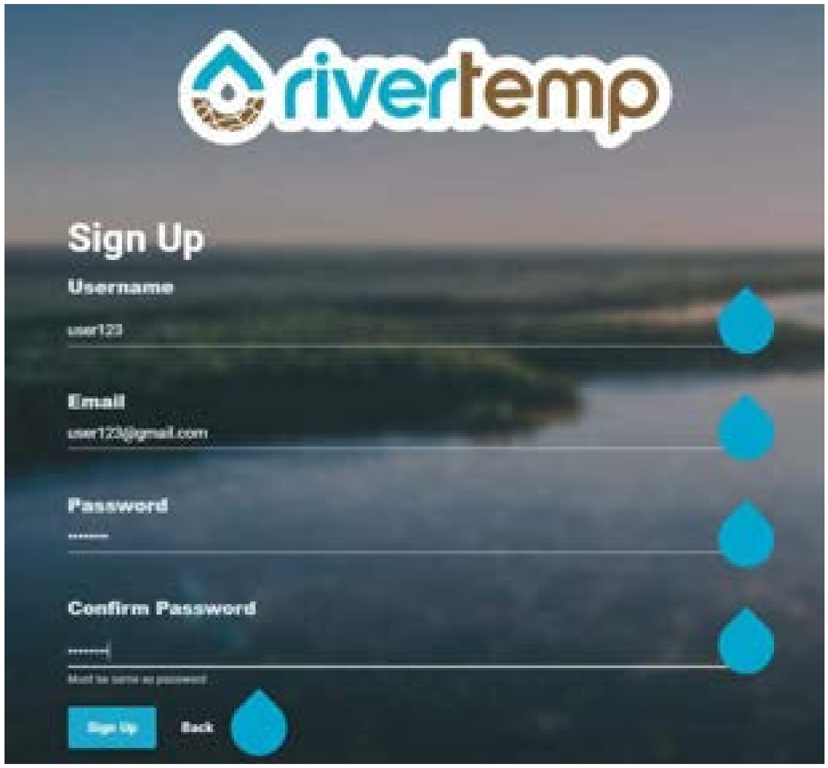
Sign Up

Click the **Sign up** button and check your email for the «Email Verification».



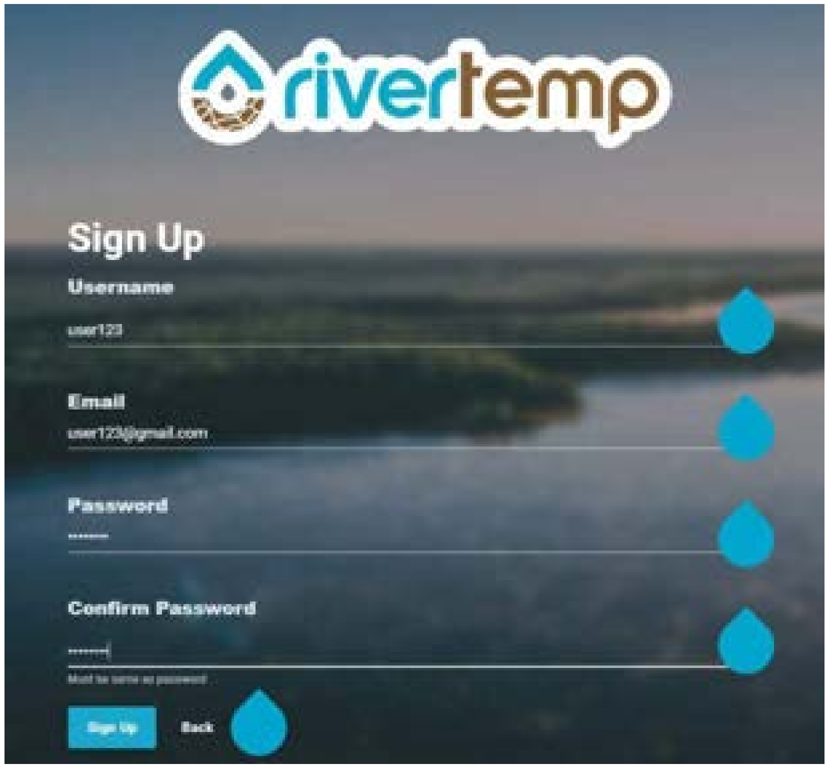
Email

At this email address you will receive a message to complete the registration process.



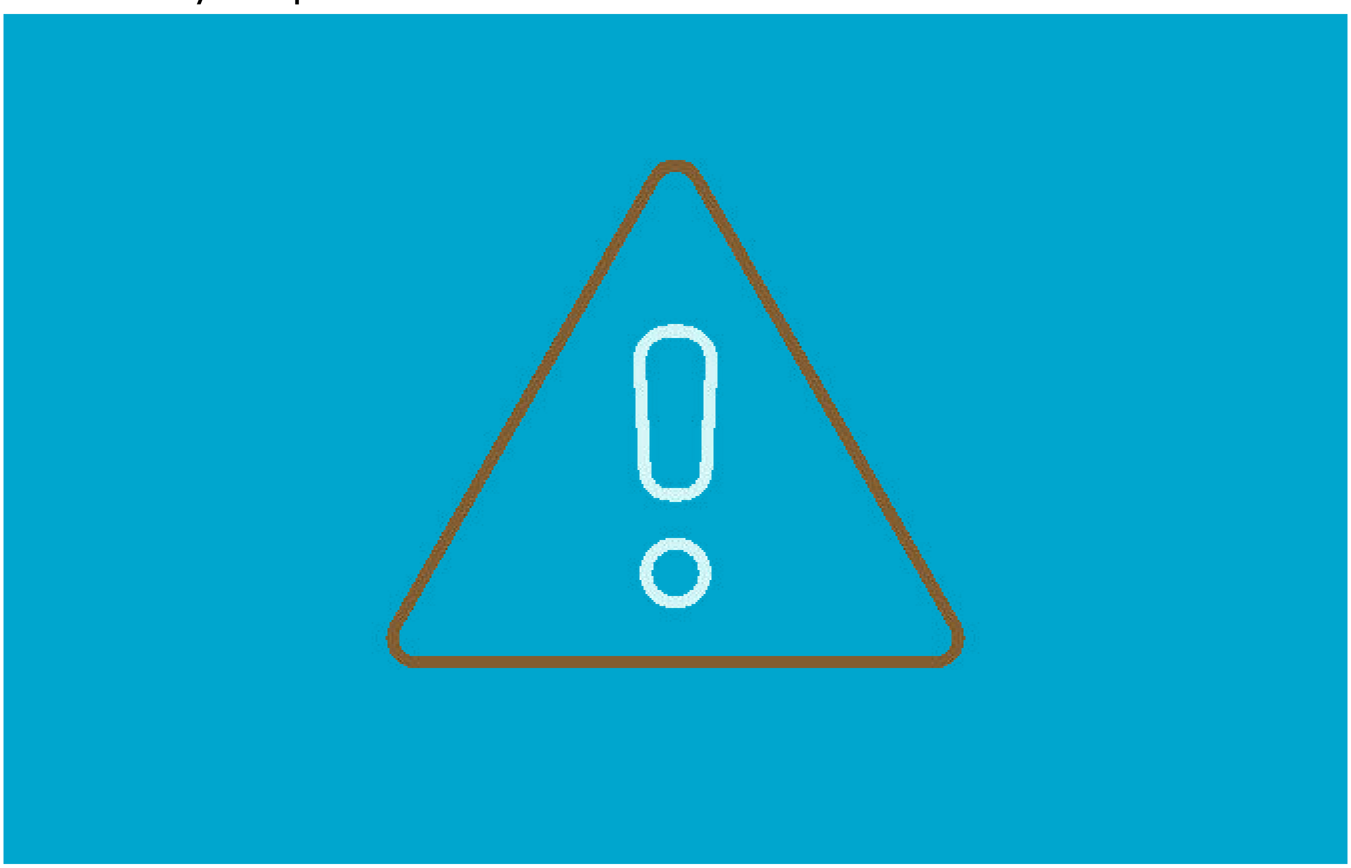
Password

The minimum length of the password is 8 characters.



Confirm Password

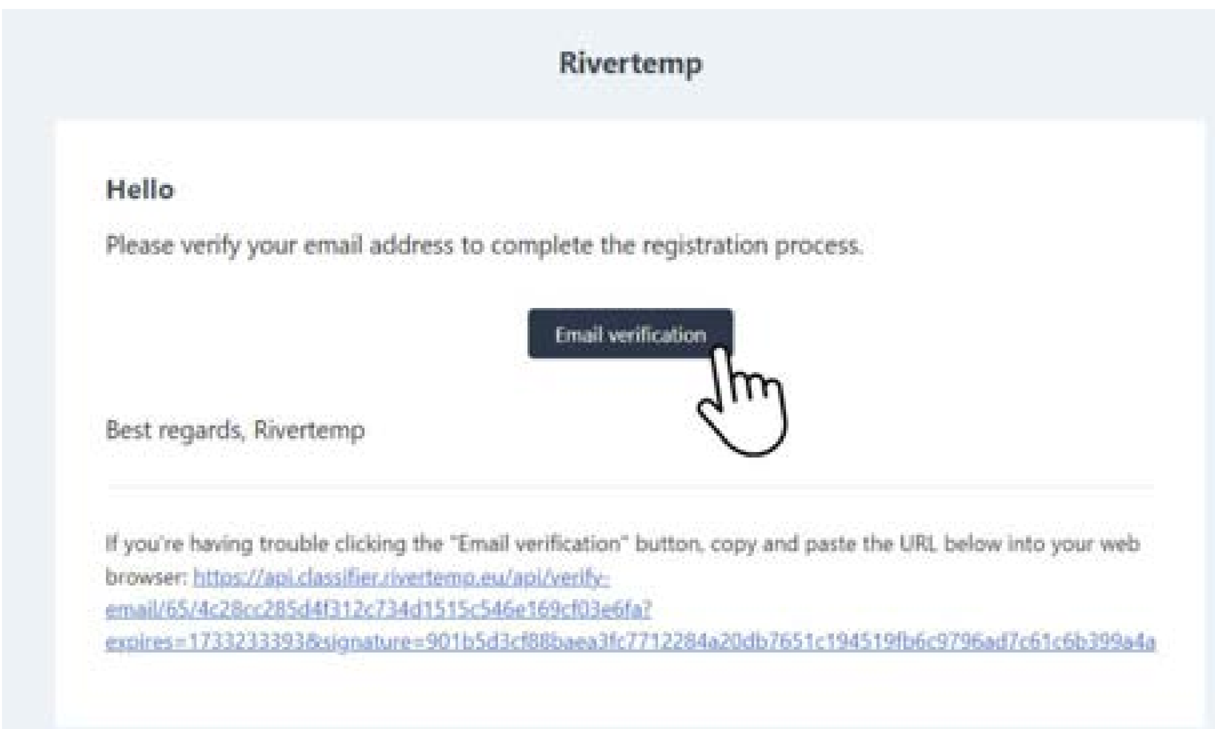
Re-enter your password to validate it.



IMPORTANT

Stay tuned because an email will appear in your inbox shortly. To complete the registration process, you have to click on the Email Verification button:

Click on the image to enlarge it


Rivertemp

Hello

Please verify your email address to complete the registration process.

Email verification

Best regards, Rivertemp

If you're having trouble clicking the "Email verification" button, copy and paste the URL below into your web browser: https://api.classifier.rivertemp.eu/api/verify-email/65/4c28cc285d4f312c734d1515c546e169cf03e6fa?expires=1733233393&signature=901b5d3cf88baea3fc7712284a20db7651c194519fb6c9796ad7c61c6b399a4a

The link in the «Email Verification» email will direct you to the login page.

CONTINUE TO THE LOGIN PAGE

Login

Click on the button to open the website.

The confirmation email redirects you directly to the website:

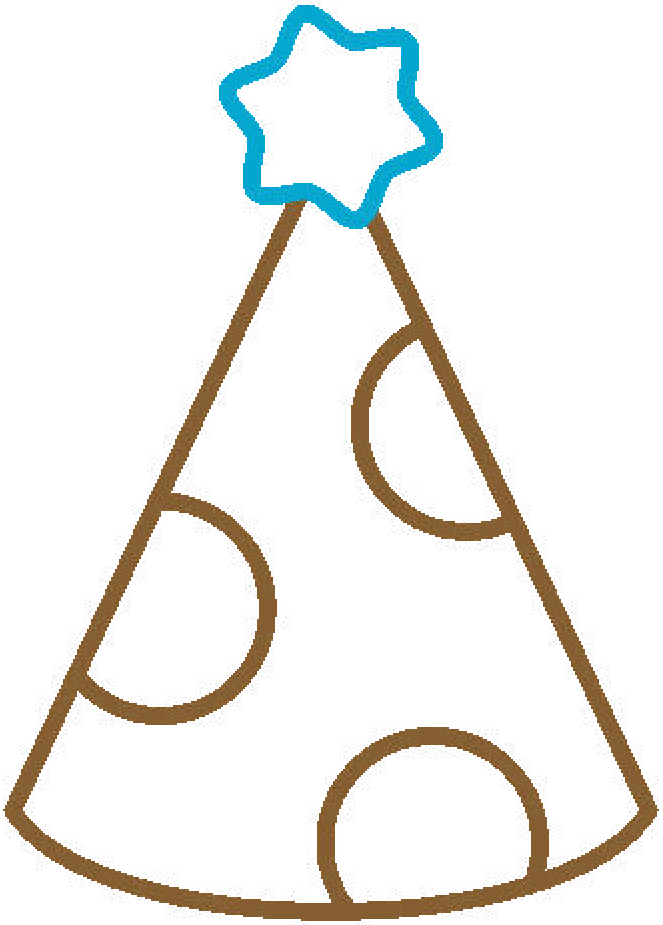
WEB

Click on the image to enlarge it

You just have to enter your credentials and press the **Log In** button to open the web tool.

CONTINUE

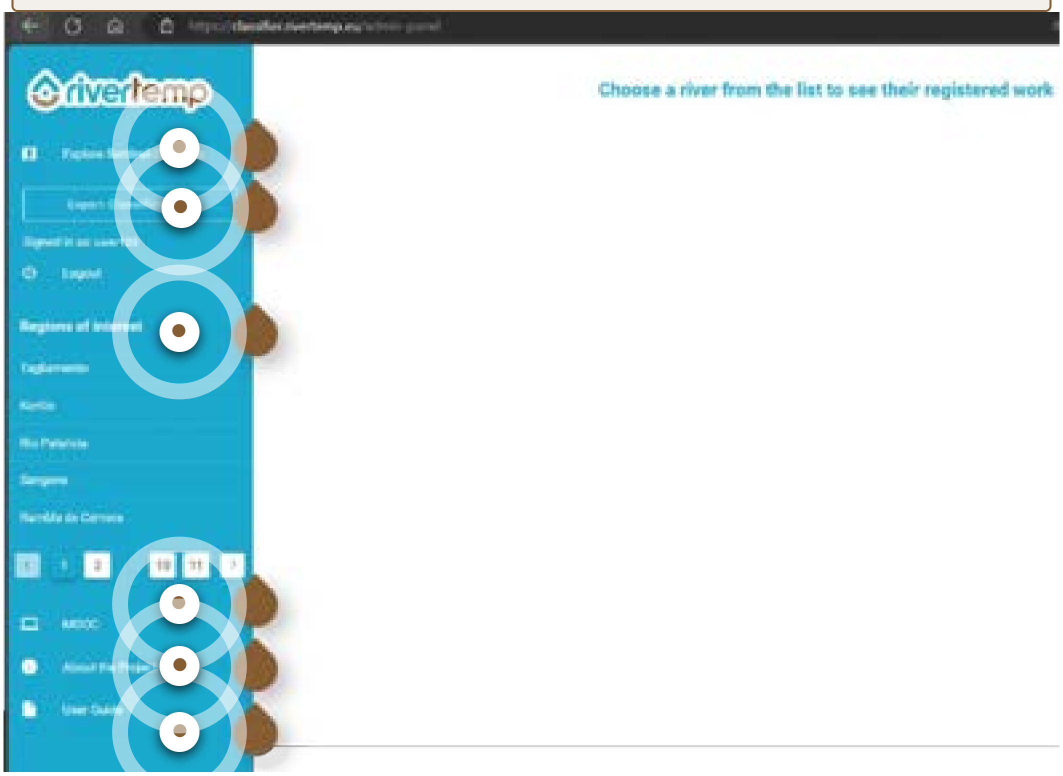
Homepage

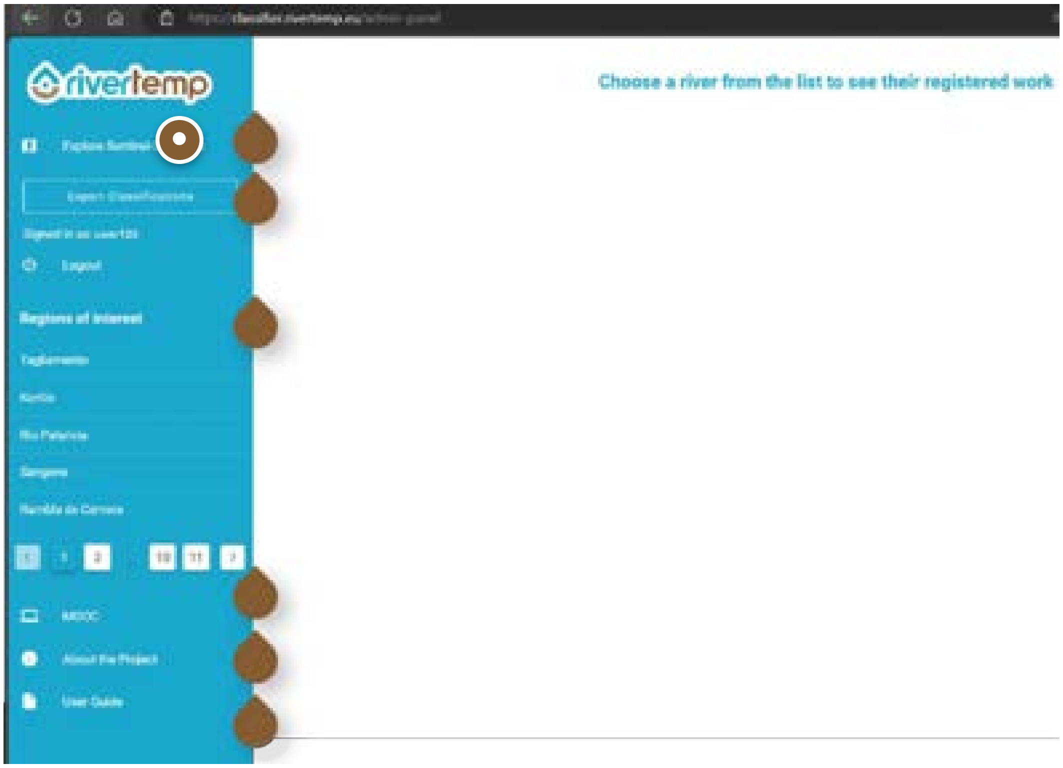


Congratulations!

You have accessed the homepage of the website.

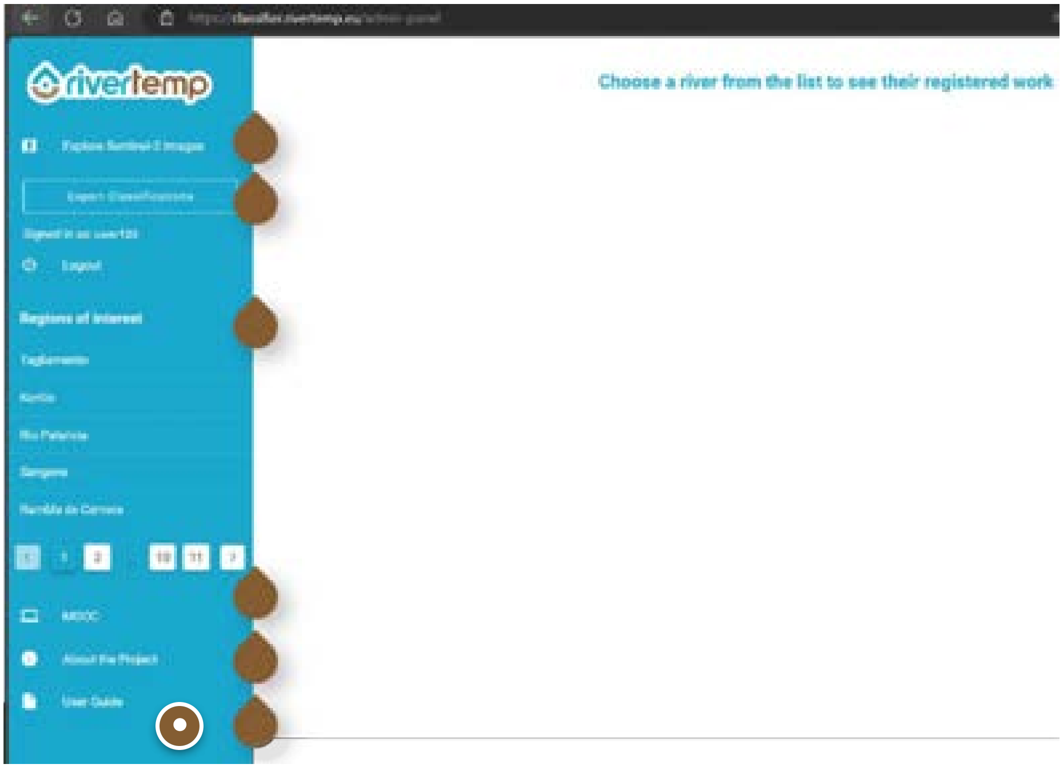
Click on the buttons to view the information.





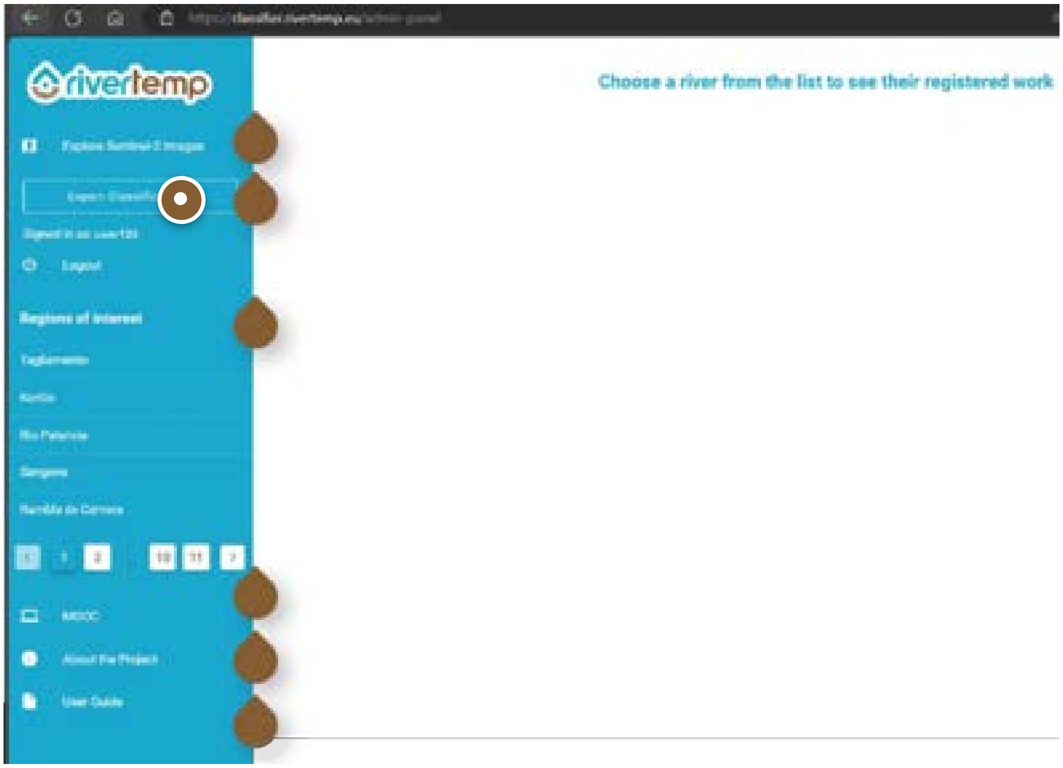
Explore Sentinel-2 Images

Click **Explore Sentinel-2 Images** button to go to the map.



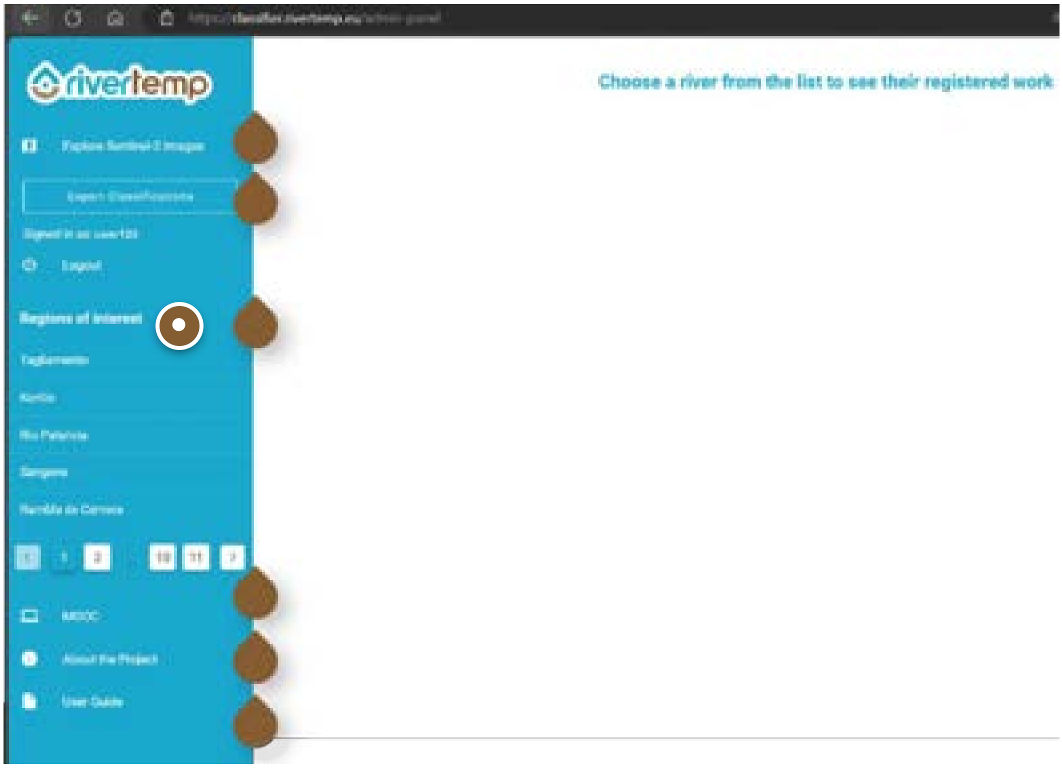
User Guide

Click **User Guide** button to download the User Guide pdf for this tool.



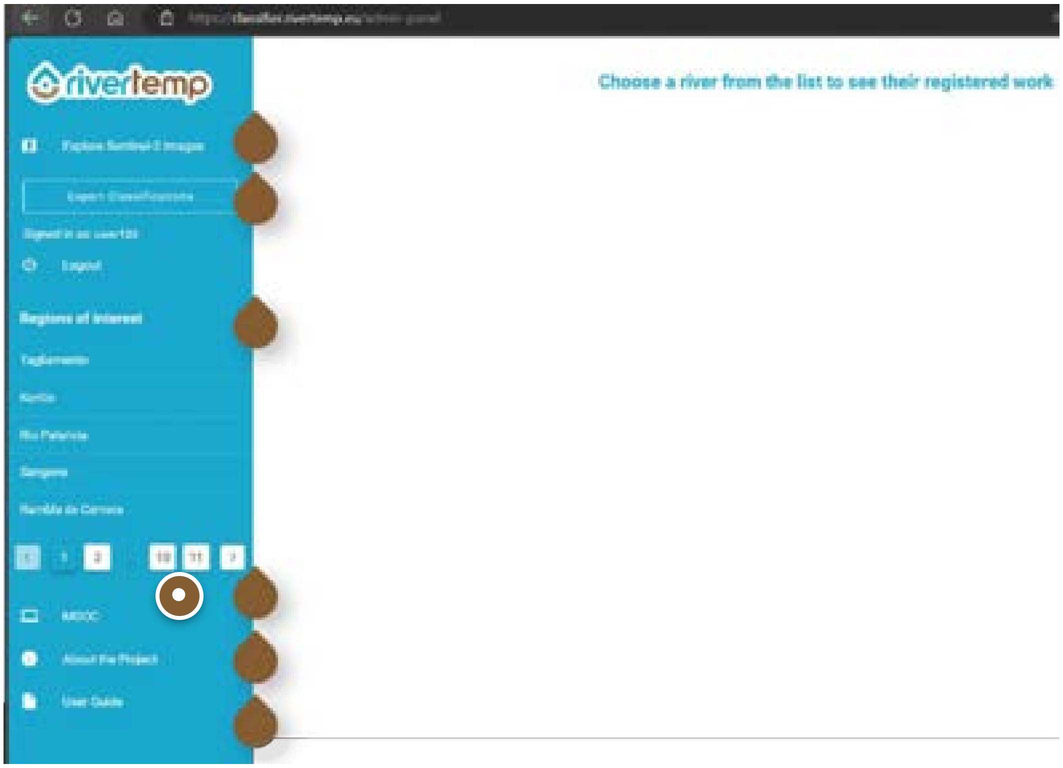
Export Classifications

Click **Export Classifications** button to download classifications that are saved in the tool.



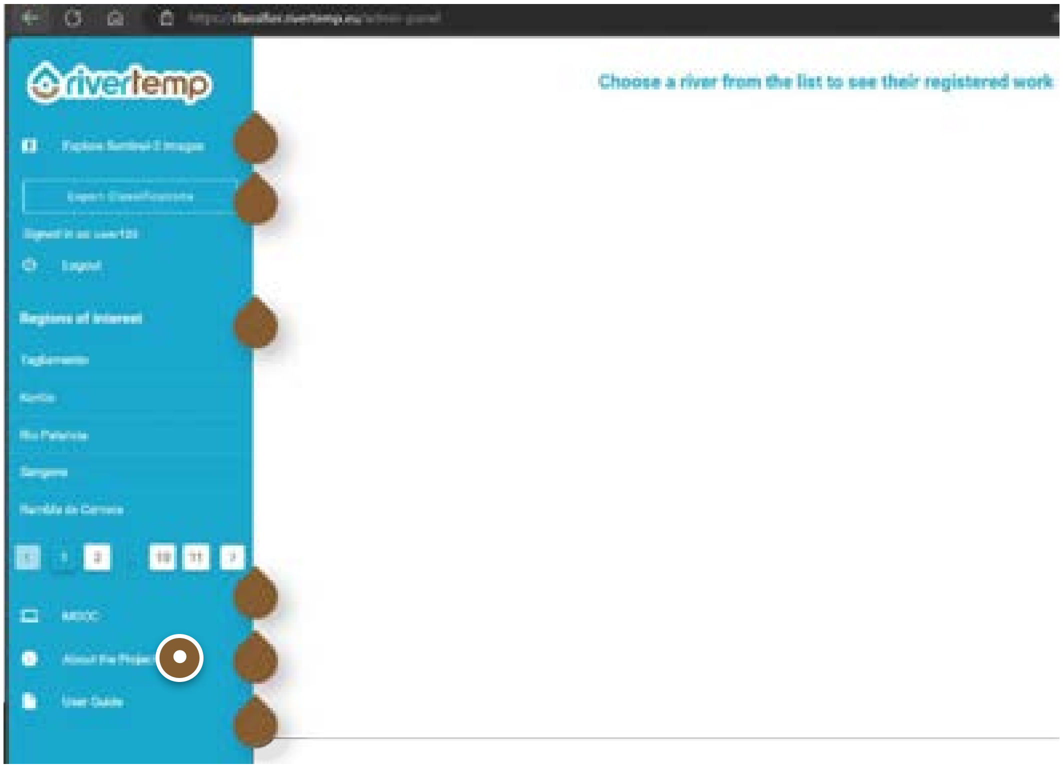
Regions of interest

Navigate through the Regions of Interest (**ROIs**) already classified.



MOOC

Click **MOOC** button to access the online lectures and explore the modules on the RiverTemp platform.

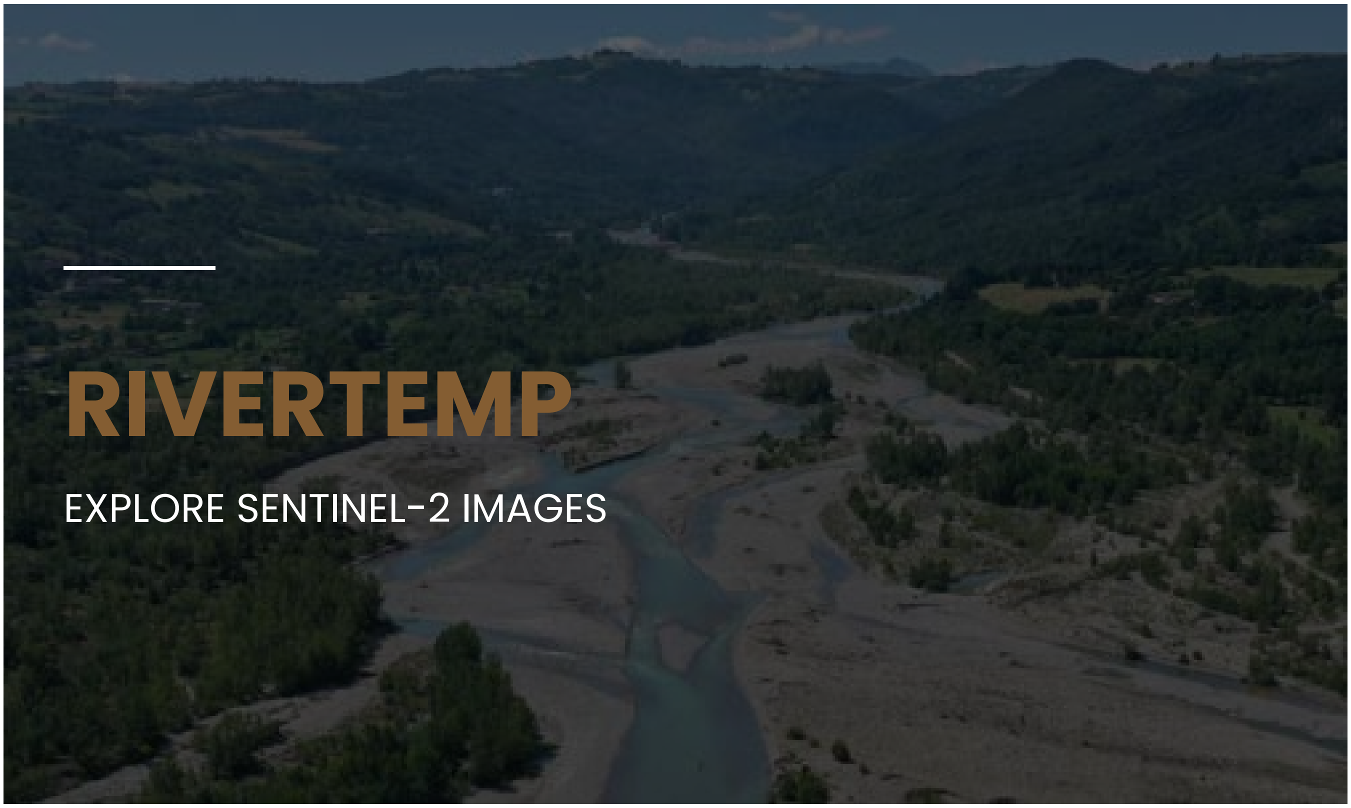


About the Project

Click **About the Project** button to explore the RiverTemp website.

CONTINUE TO THE MAP

Navigate the map

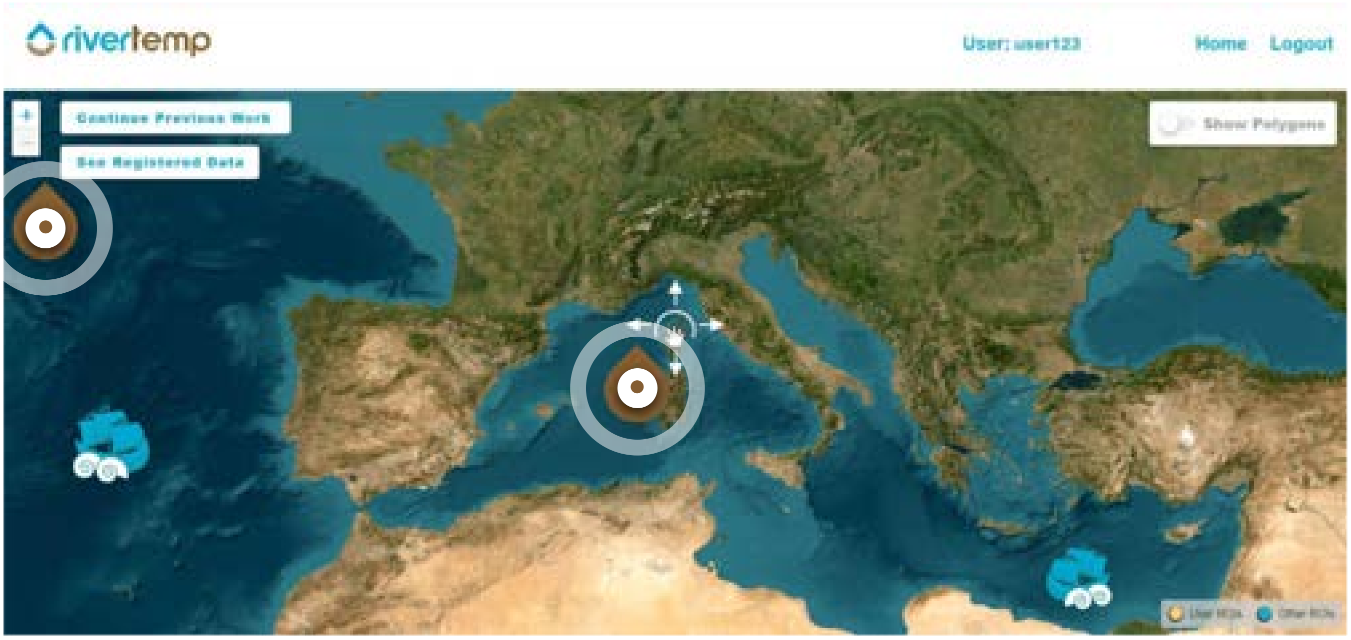


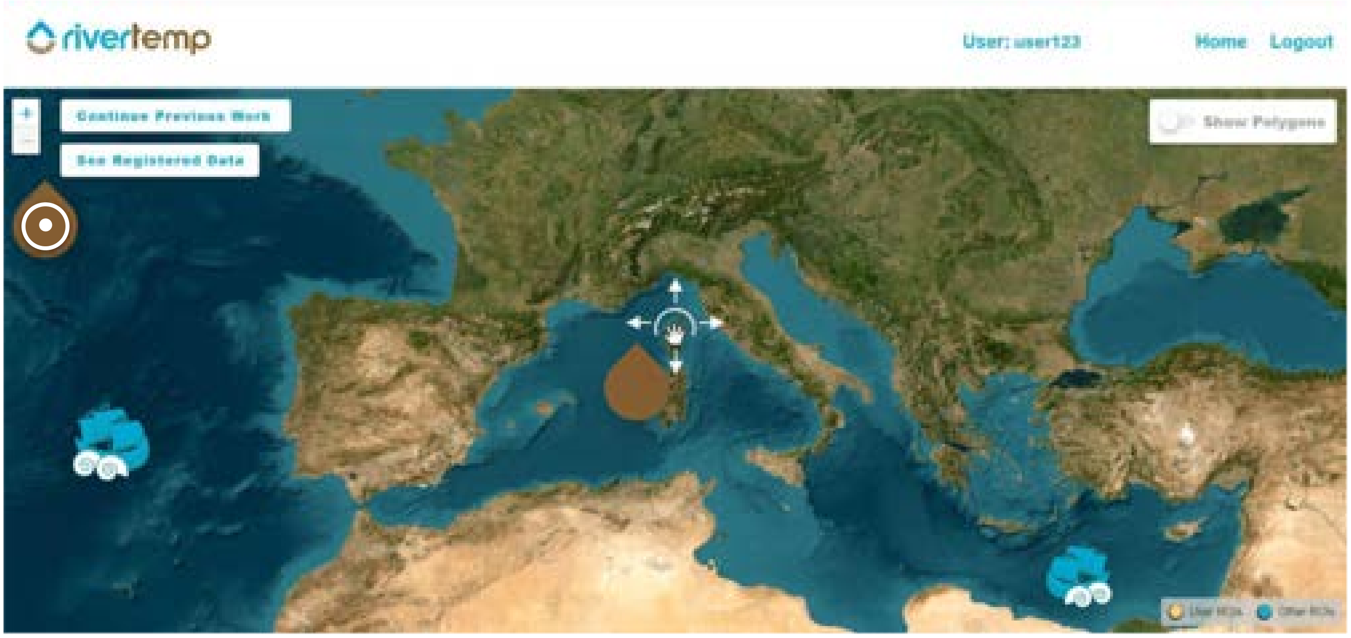
To access the map from the home page, click on the **Explore Sentinel-2 Images** button:

You can navigate the map to find and classify a temporary river reach:

CONTINUE

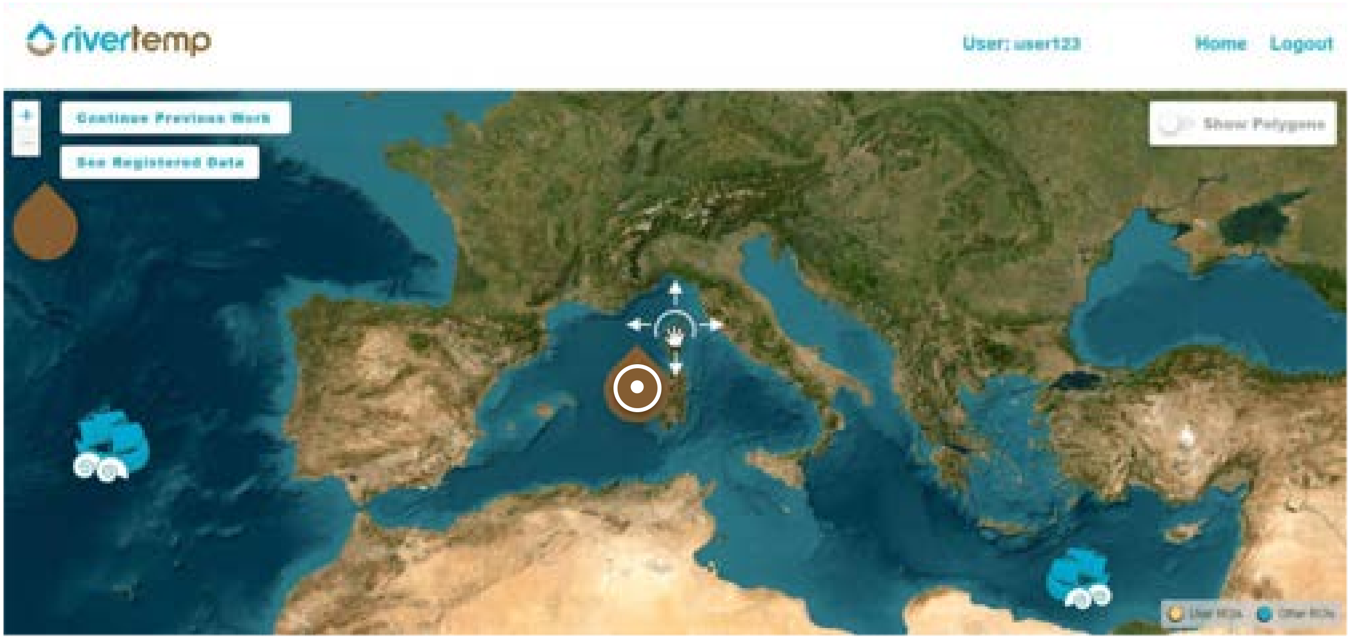
Click on the buttons to view the information.


rivertemp
User: user123
Home
Logout
Continue Previous Work
See Registered Data
Show Polygons



Zoom in and Zoom out

Zoom in to see the global river network.



If you hold down the left mouse button, you can move around the world map.

Now **zoom in on the area of the map** that interests you until the rivers appear:

Click on the buttons to view the information.

Continue Previous Work
See Registered Data
Show Polygons
User ROIs
Other ROIs

Drawn a polygon

This button enables the function of **drawning** the polygons (or **ROIs**).

Polygons

This **polygon** appears on the screen because you have the toggle button **Show Polygons** enable.

It is **blue** because it was created by another user. The ones you create will appear in **yellow** to distinguish them.

Legend

Legend for distinguishing your polygons (also called **ROIs**) from the other ones.

Show Polygons

With this toggle button you can **show or hide** the **polygons** on the screen.

This button **will be enabled only when you zoom**.

Delete polygons

This button enables the function of **deleting** the polygons (or **ROIs**).

After drawing a polygon (1), for European rivers, the river name is automatically recognized (2):

Click on the image to enlarge it

Continue Previous Work
See Registered Data
Classify River: Torrente Torre
2
1

CONTINUE

Satellite imagery classification

Starting

To start the satellite imagery classification **click on the polygon** or on the blue box saying **Classify River**.

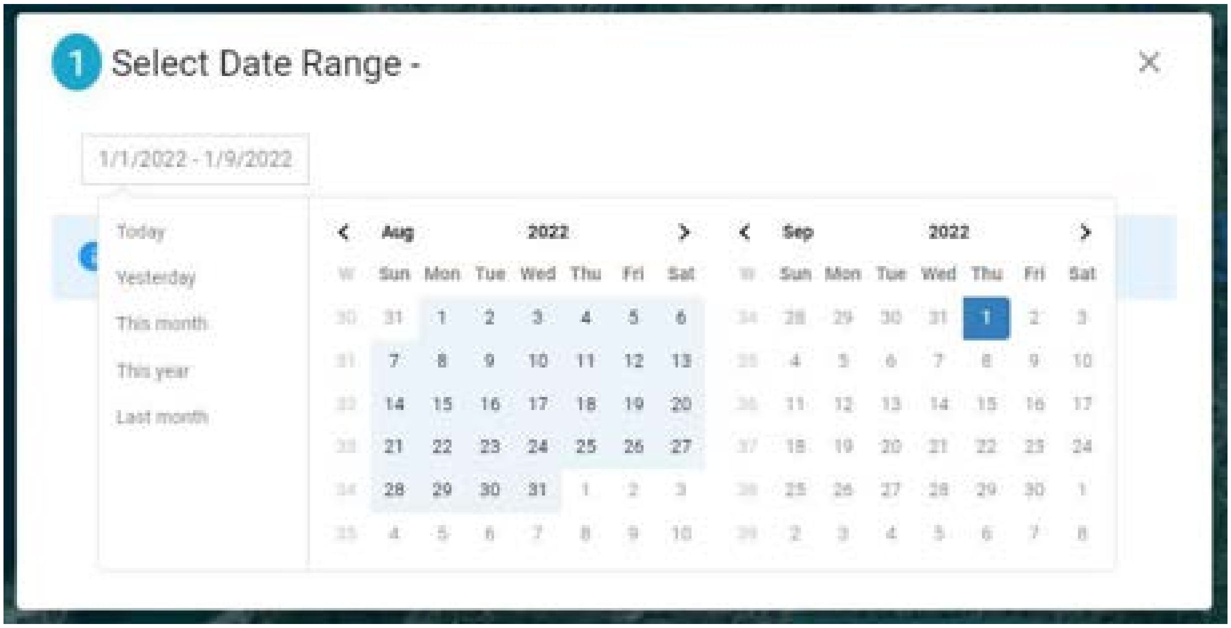
Click on the image to enlarge it

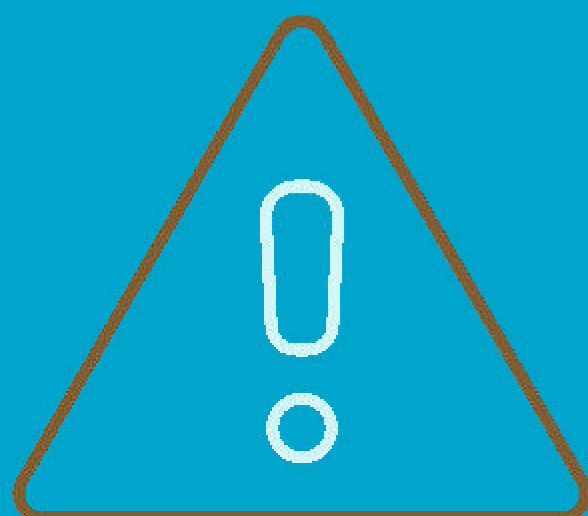
CONTINUE

1

Select the date range

A screen will automatically appear to select the **date range**:





IMPORTANT

Do not exceed the length of the data range.

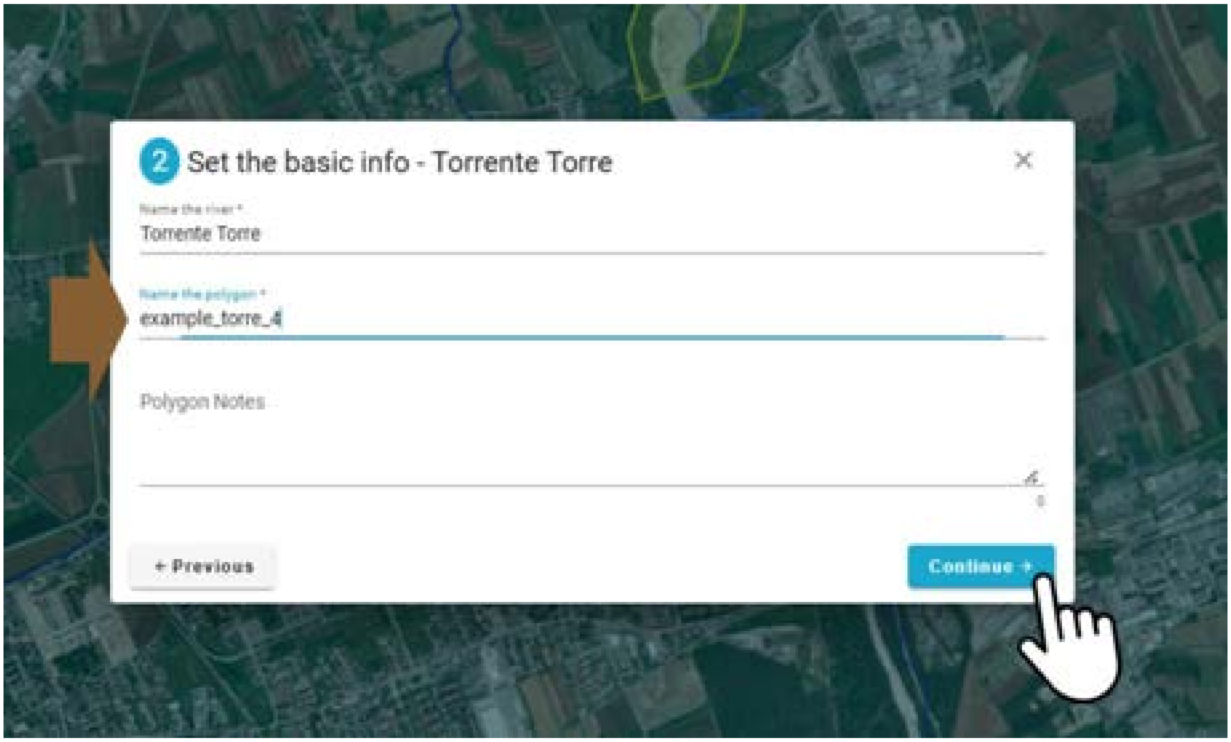
To avoid uploading too many images, **a maximum number of 250 days is set.**

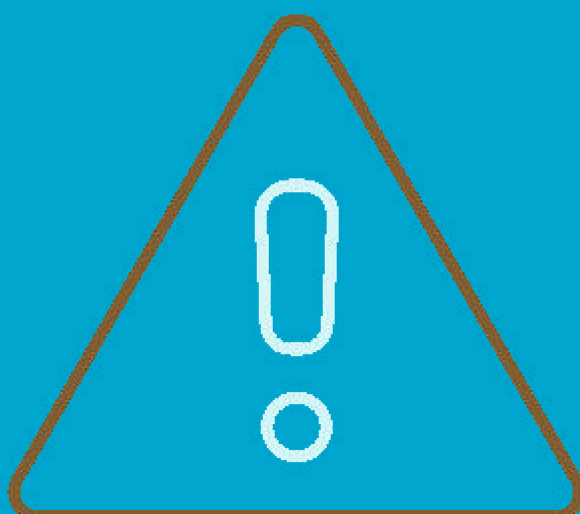
CONTINUE

2

Set the basic info

If available, the **river name is automatically filled**. **Name the polygon** and optionally **add notes**. Then click the **Continue** button:


2 Set the basic info - Torrente Torre
Torrente Torre
example_torre_4
Polygon Notes
← Previous
Continue →



IMPORTANT

An error pop-up will inform if no satellite image are available for that reach for the selected date range or if the polygon size is too large.

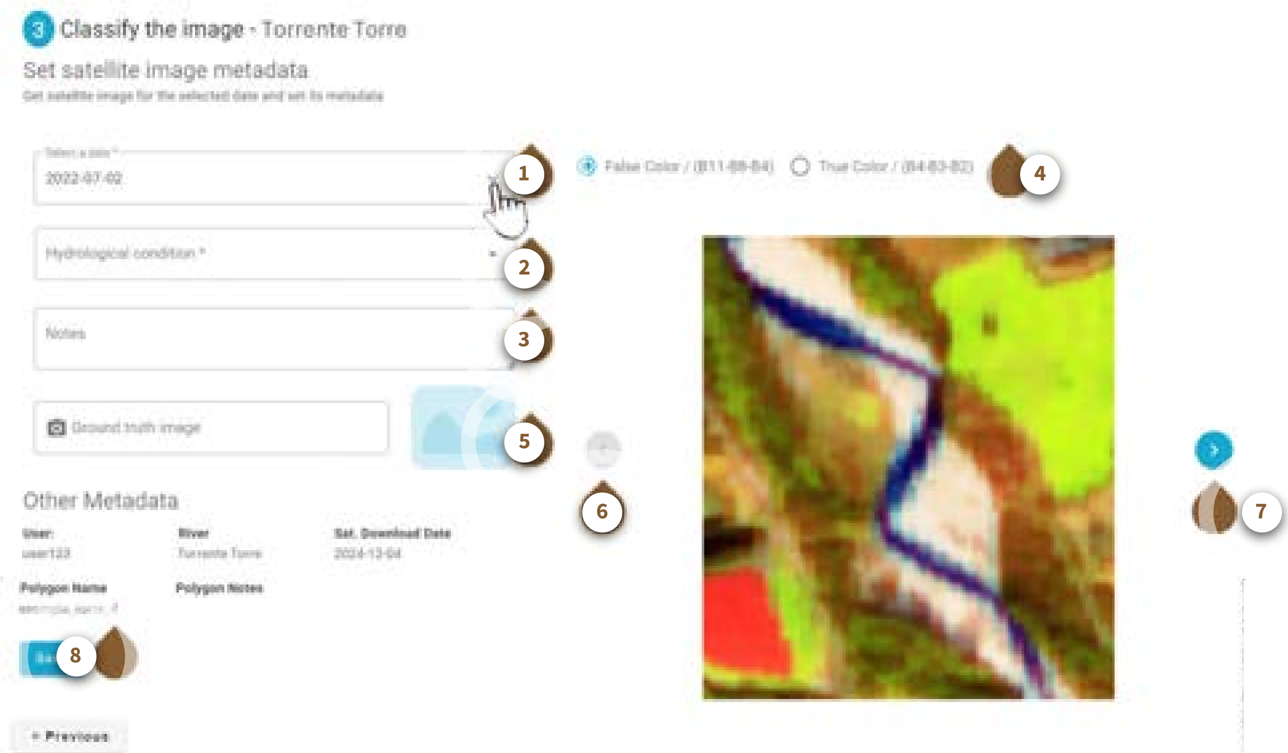
CONTINUE

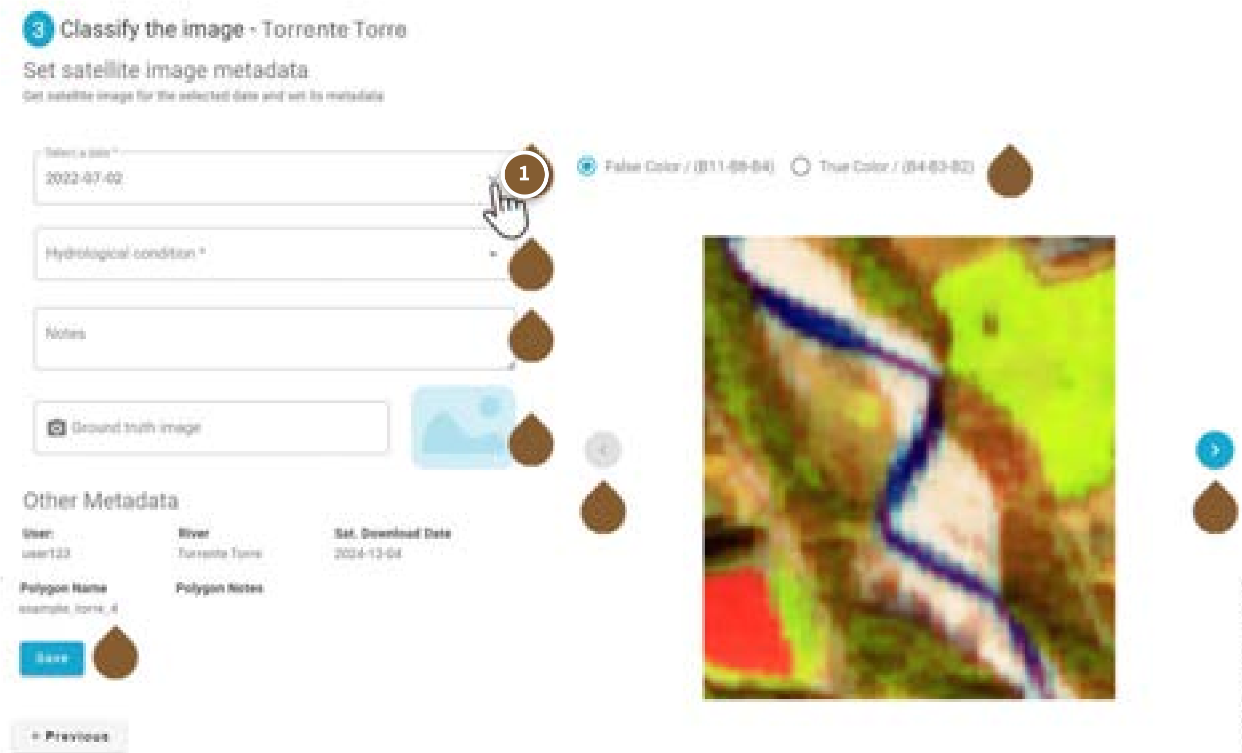
3

Classify the image

Be patient. It may take some time, but finally the following screen will appear:

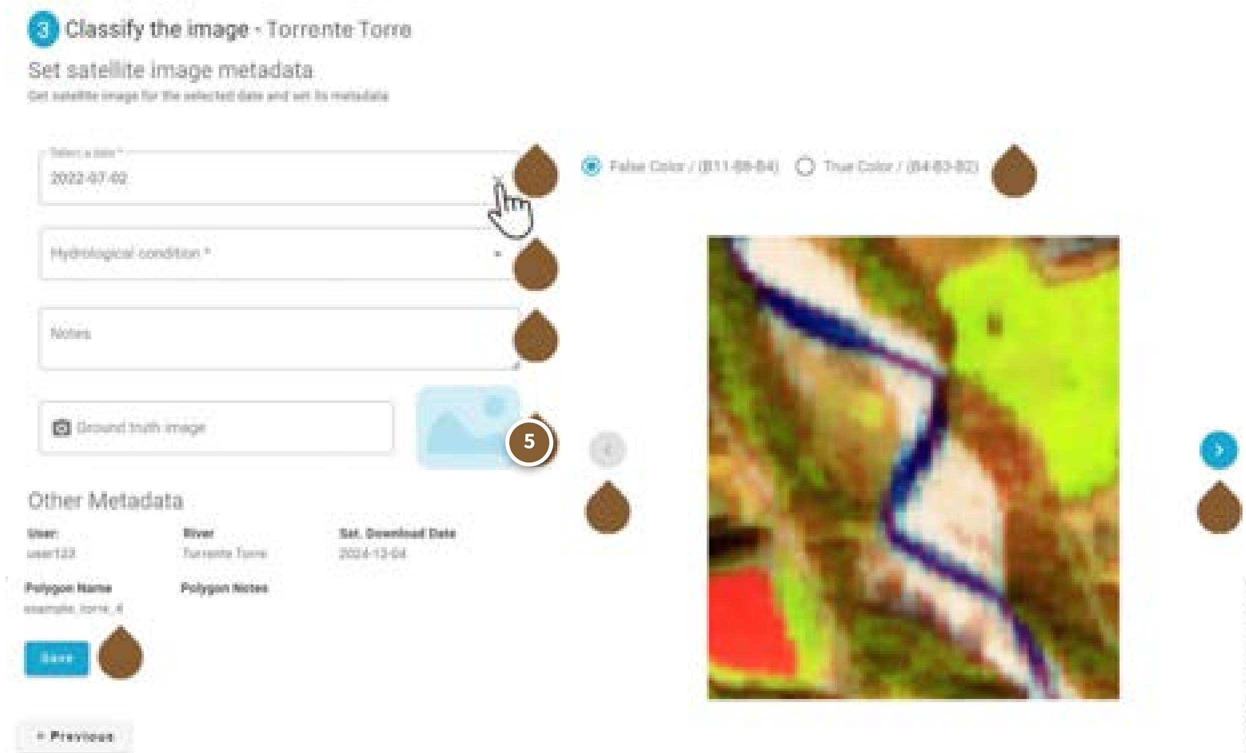
Click on the buttons to view the information.


3
Classify the image - Torrente Torre
Set satellite image metadata
2022-07-02
Hydrological condition *
Notes
Ground truth image
False Color / (B11-B8-B4)
True Color / (B4-B3-B2)
Other Metadata
User
user123
River
Torrente Torre
Sat. Download Date
2024-12-04
Polygon Name
Polygon Notes
Previous
1
2
3
4
5
6
7
8



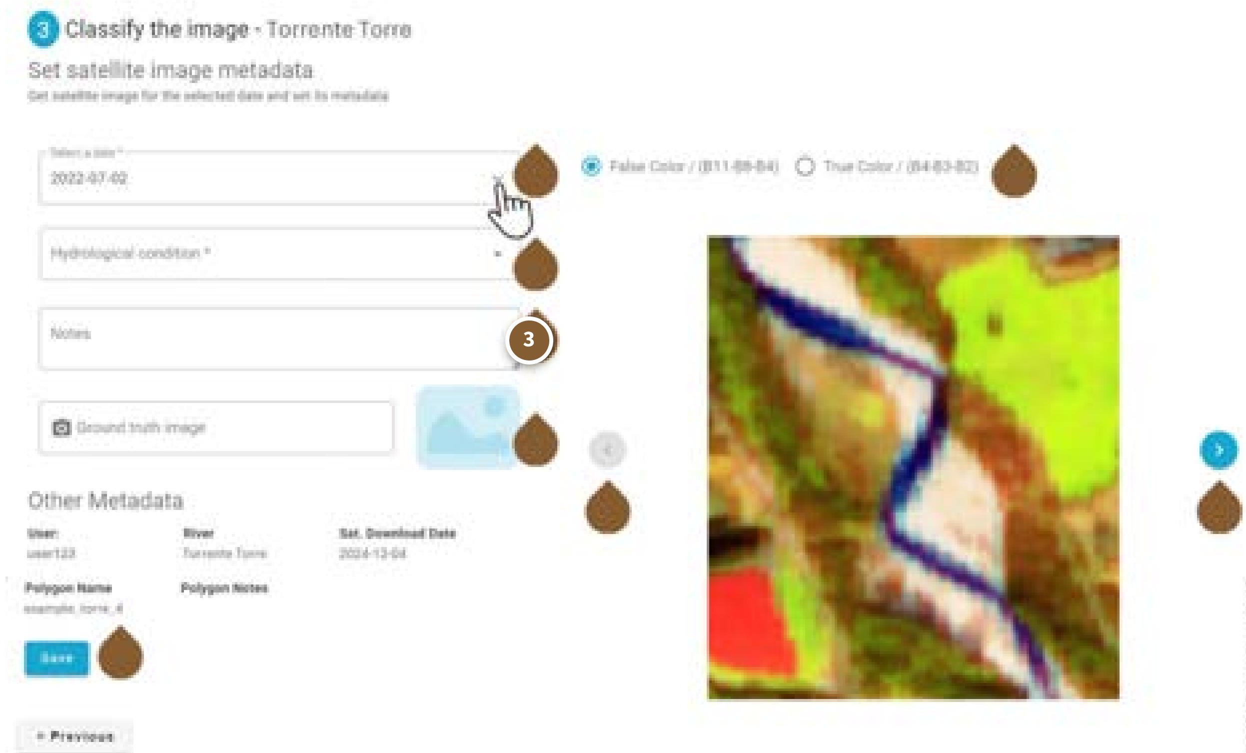
Select the date to classify

From the dropdown menu, search whatever image in the date range.



Ground truth image

Optionally, upload field survey photos to confirm the classification.



Notes

Optionally, leave notes.

(e.g. «Low confidence» if you have doubt about the classification).

Hydrological condition

You must classify the hydrological condition:

- **Flowing**: visible continuous flow of water along the reach.
- **Ponding**: discontinuous water presence, with isolated ponds along the reach.
- **Dry**: absence of surface water.
- **Cloudy**

You must select an hydrological condition to enable the **Save** button.

False / True Color

When **False Color** is enabled (default setting), the false colour image is generated using **B11** (as **Red**), **B8** (as **Green**) and **B4** (as **Blue**) bands.

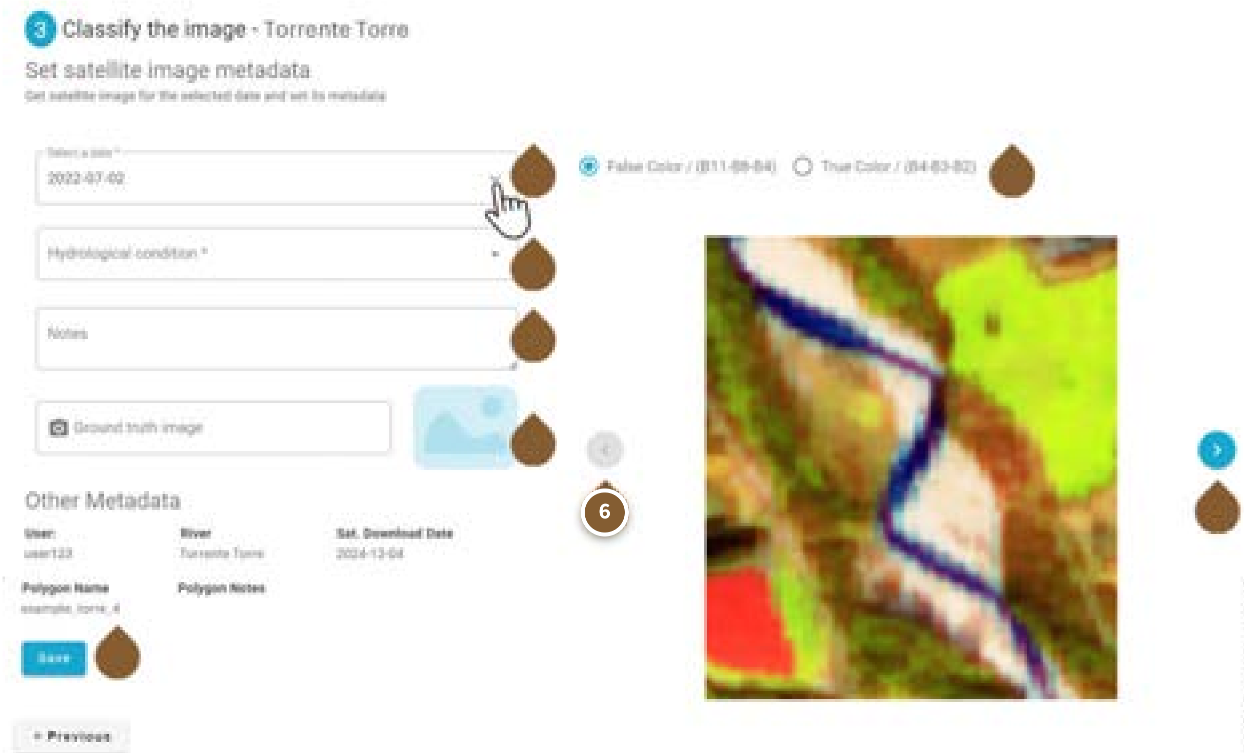
Clicking on **True Color** button, the image switched in **RGB** bands only.

Save

Selecting a hydrological condition enables the **Save** button, allowing you to save the image classification.

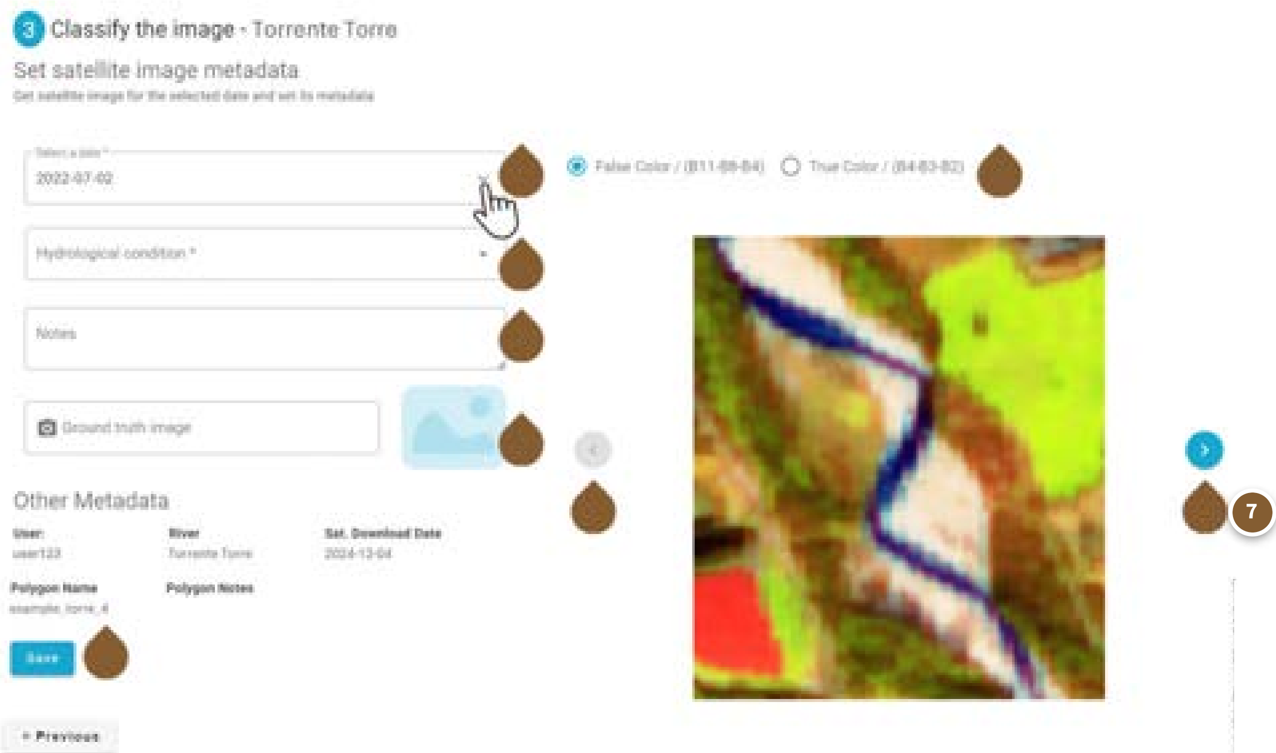
ATTENTION:

Save every classified image!



Previous image

Move to the previous image.
(Note that the button appears disabled because this is the first image of the range selected in previous steps of this example).

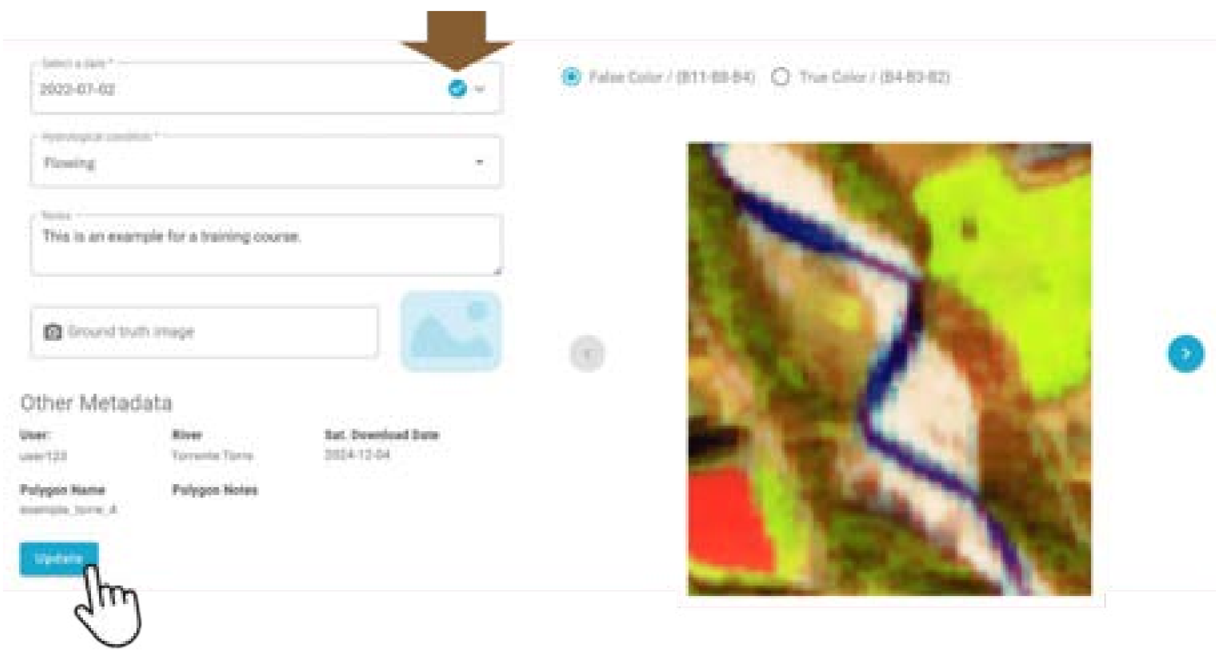


Next image

Move to the next image.

This **checkmark** indicates that the image classification has been **saved**.

Click on the image to enlarge it



After saving the image, you can make changes (such as hydrological condition, notes, color type). By clicking this button you will save the **updates**.

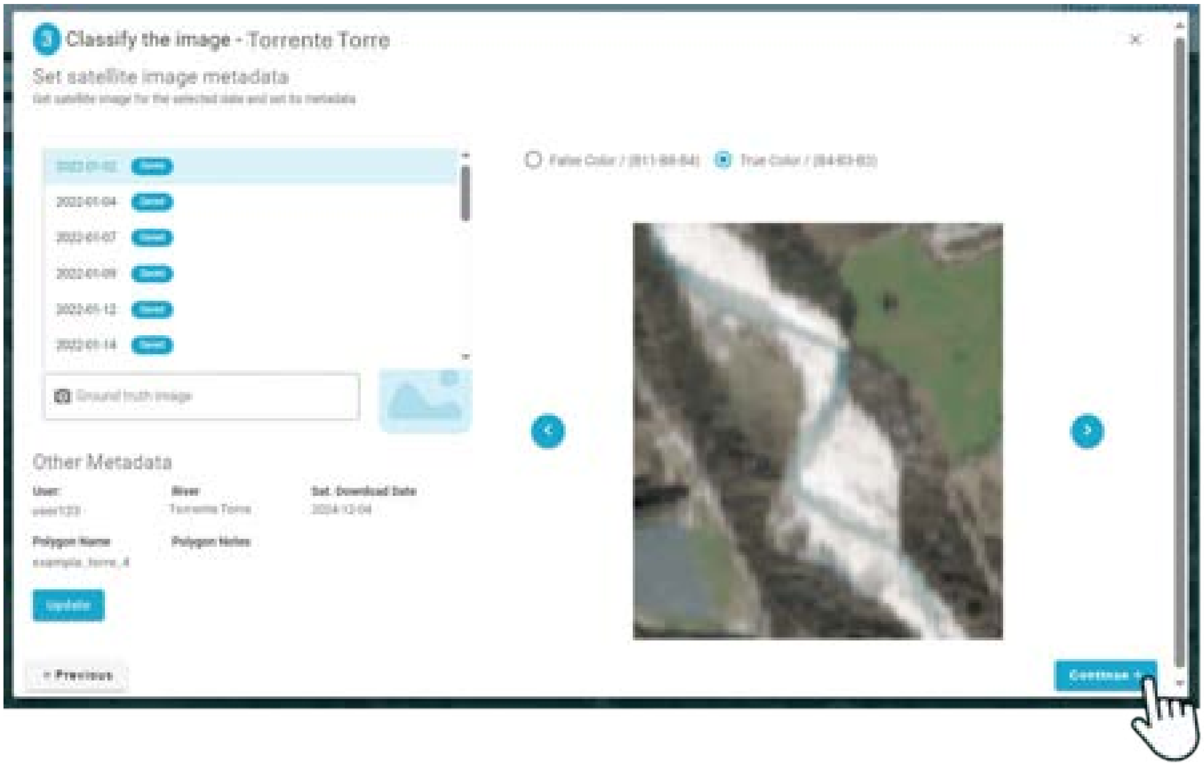
CONTINUE

4

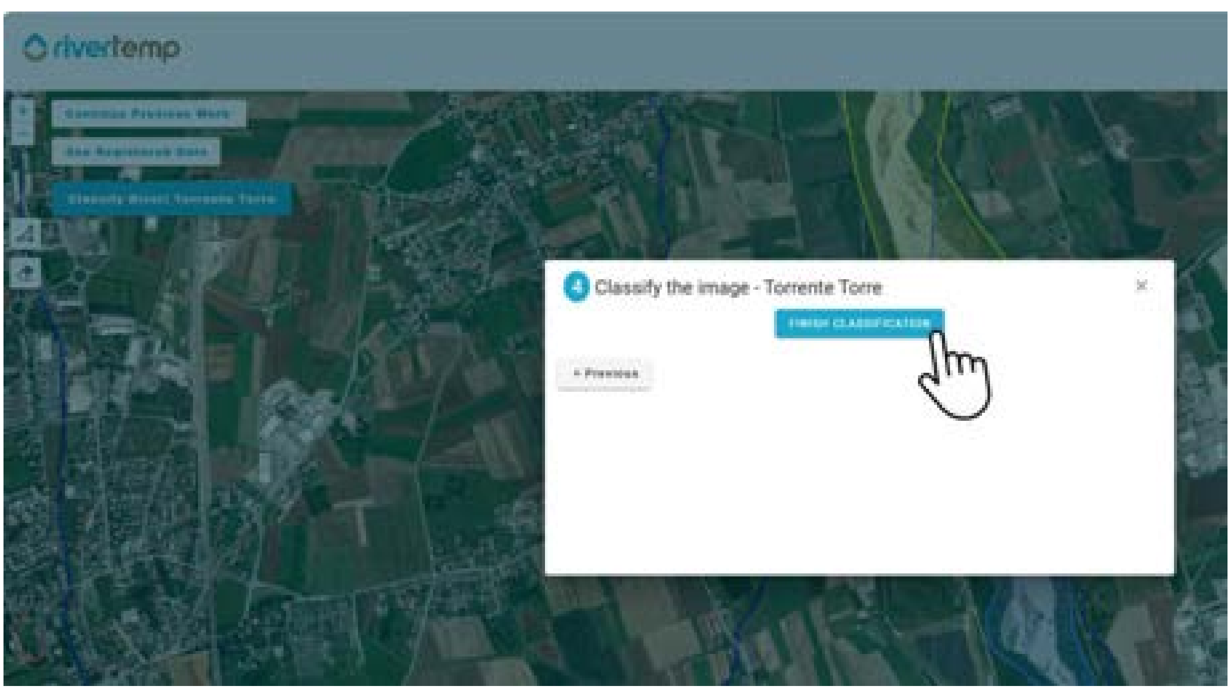
Finish classification

Once all the images have been reviewed, press the **Continue** button...

Click on the images to enlarge them

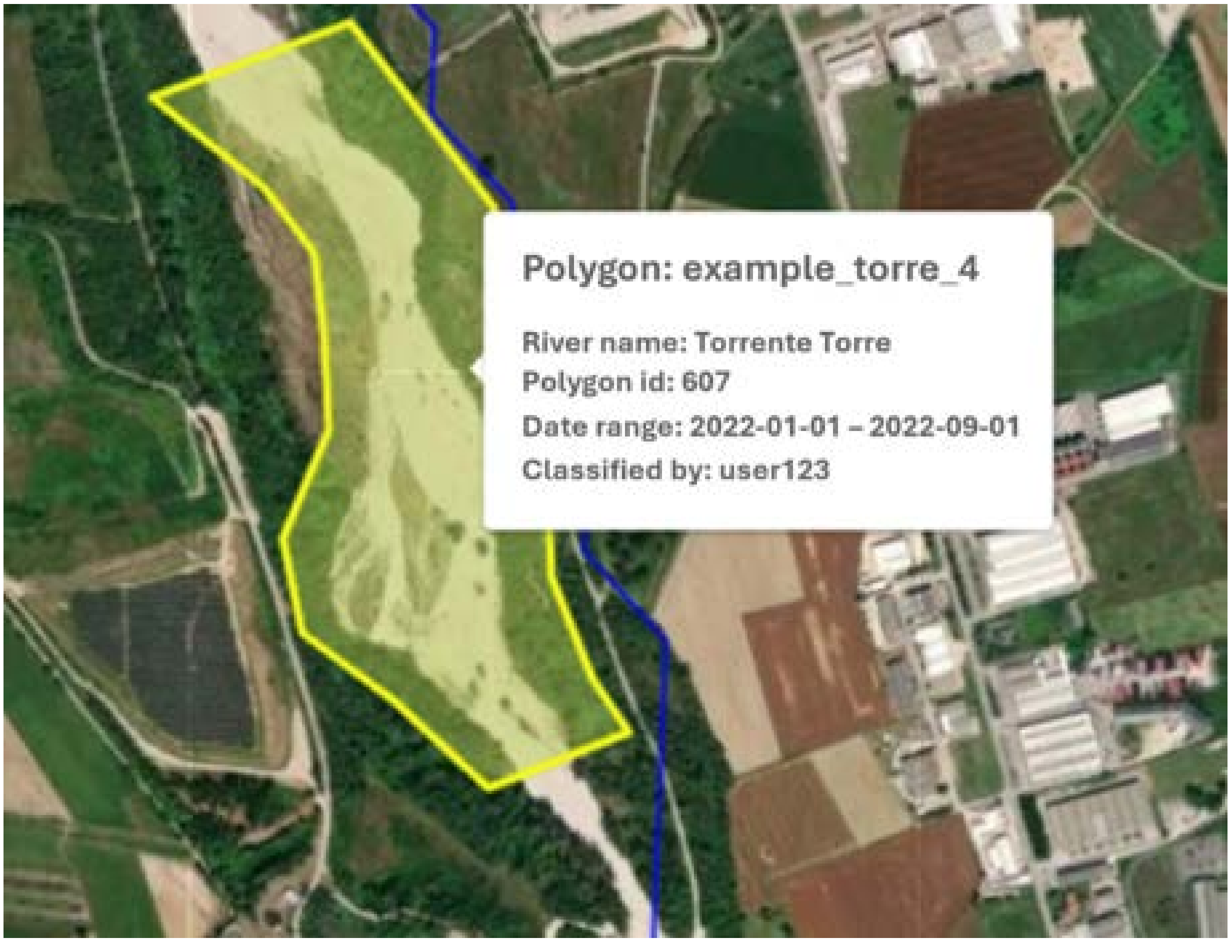


...and click on **Finish Classification** button to **confirm**:

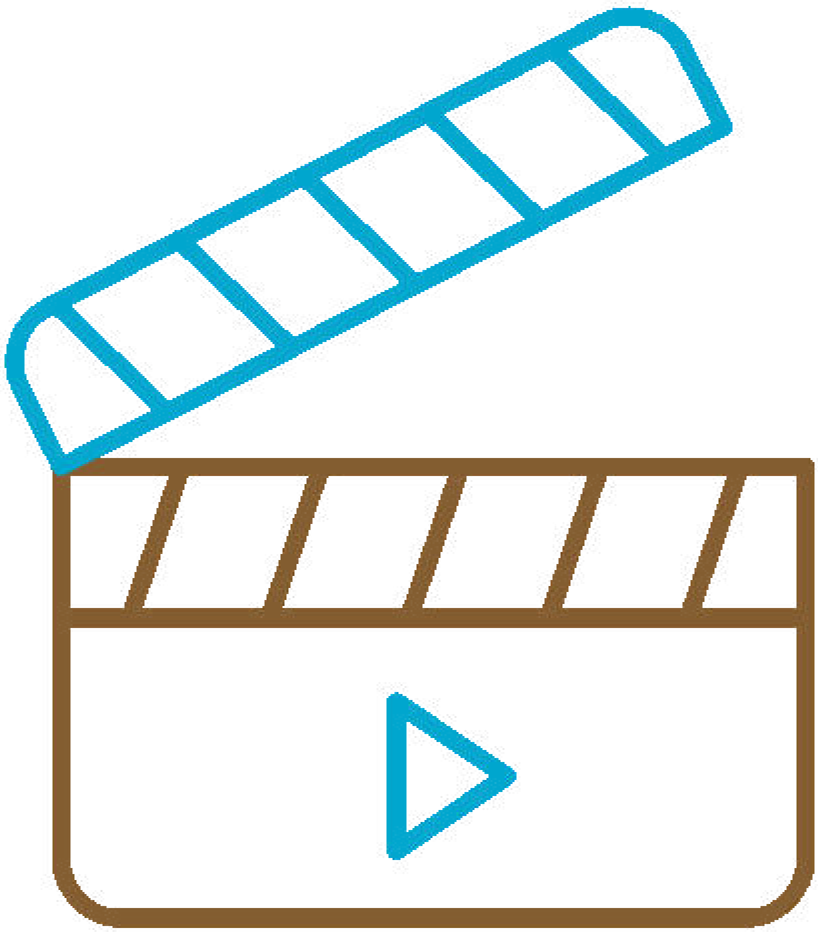


Now, the polygon is yellow:

If the mouse hovers over the polygon, the **metainformation** will appear.



Click on the image to enlarge it



1.

VIDEO

In the following videos you will see an example of all the steps that we have seen so far:

1. Navigate the map.

2. Create polygons.

3. Delete polygons.

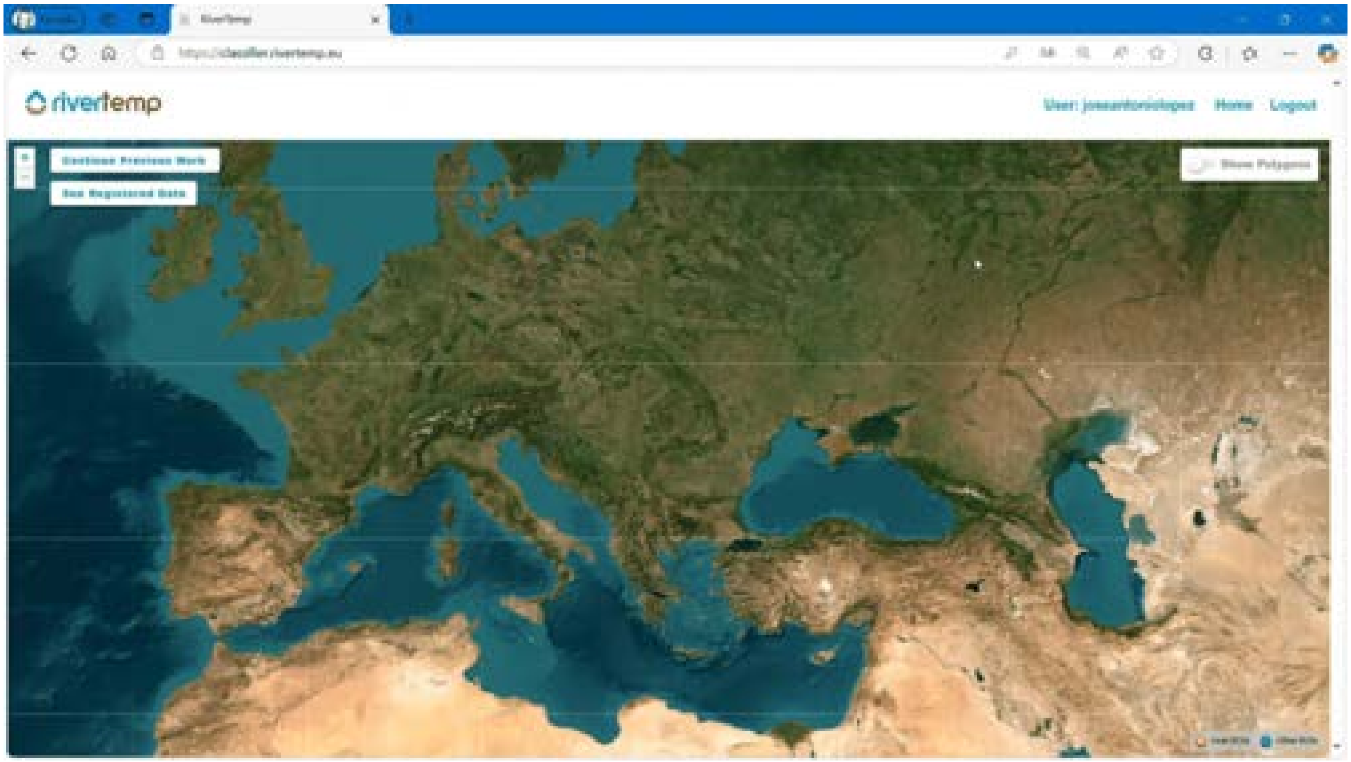
4. Select the date range.

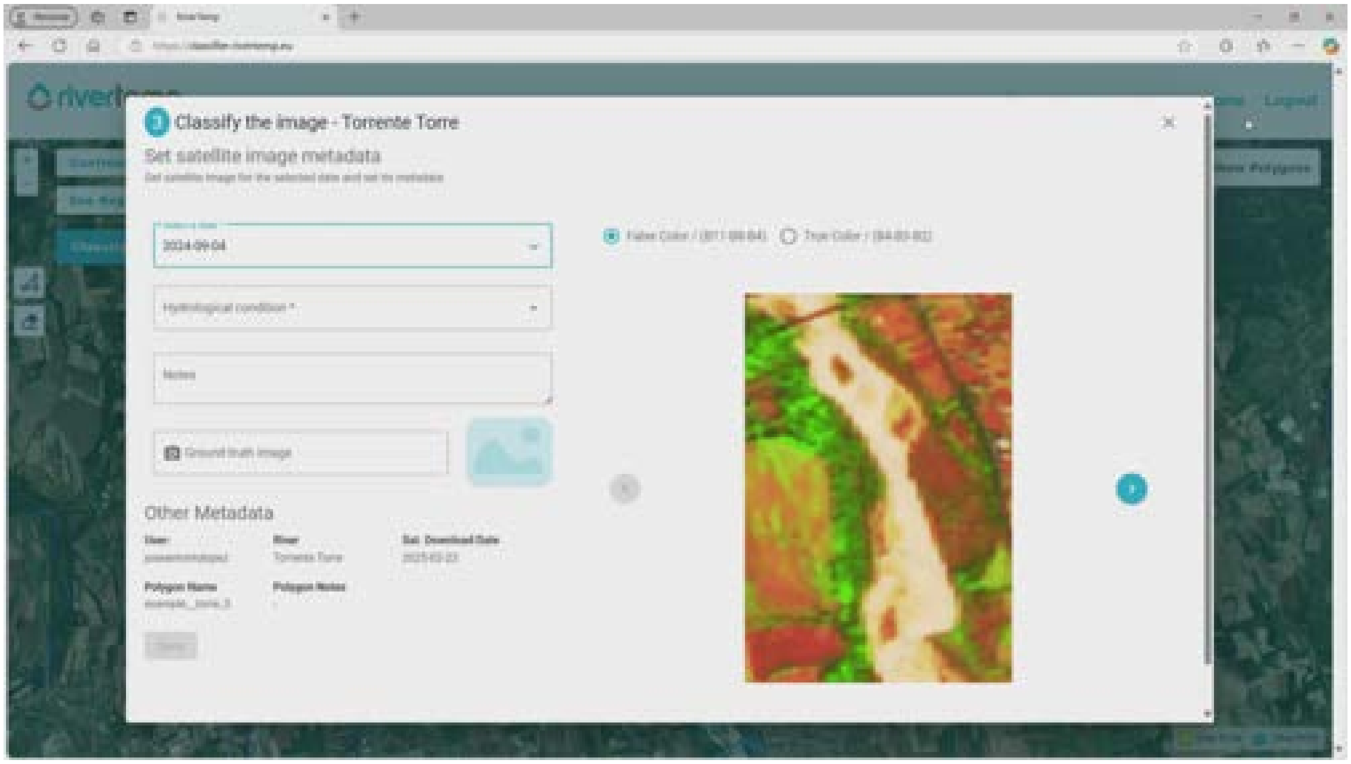
5. Set the basic info.

6. Classify satellite images.

7. Finish classification.

Click on the images to watch the videos.


RiverTemp
https://classifier.rivertemp.eu
rivertemp
Home
Logout
Continue Previous Work
See Registered Data
Show Polygons



CONTINUE

5

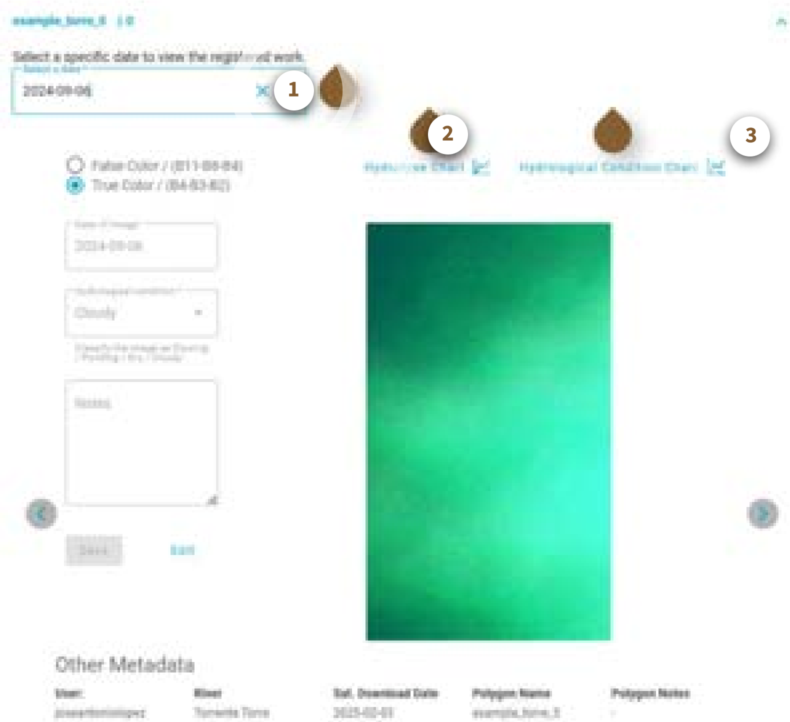
See the classification results

To see the classification results, click on the polygon:

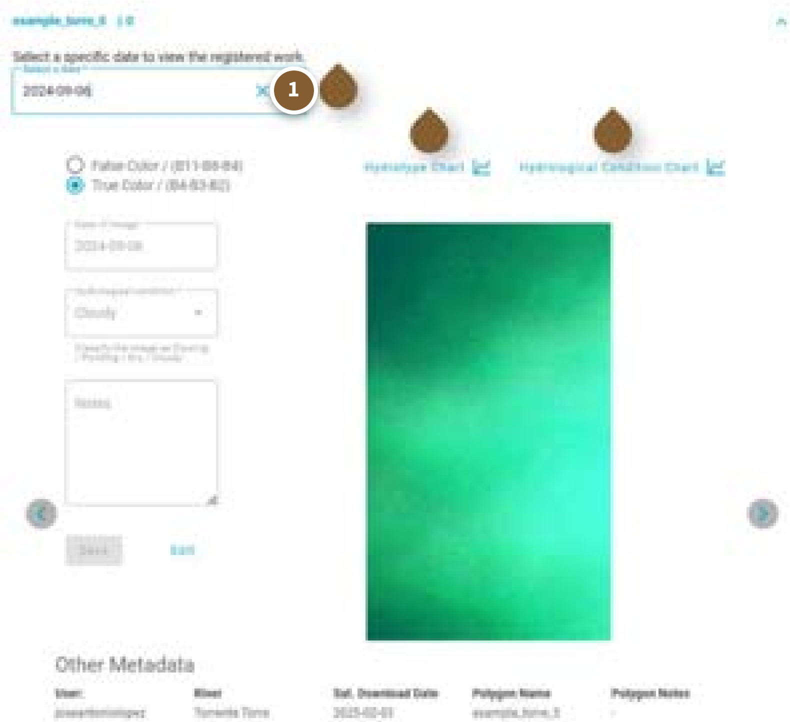
Click on the image to enlarge it

You will access a new screen that contains the following fields:

Click on the buttons to view the information.

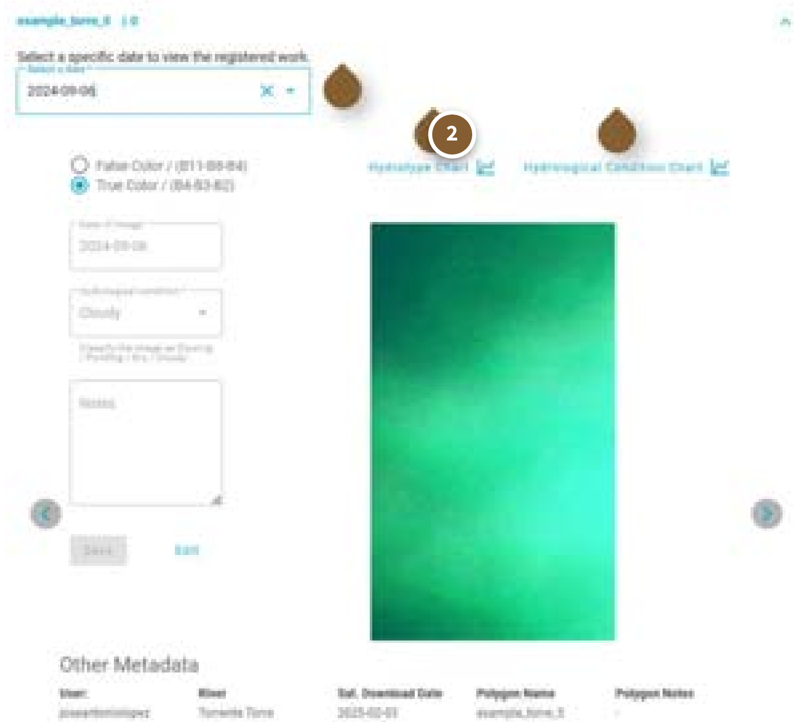


2024-09-06
1
2
3
False Color / (B11-B8-B4)
True Color / (B4-B3-B2)
Hydrological Condition Chart
2024-09-06
Cloudy
Notes
Other Metadata
User:
River
Sat. Download Date
Polygon Name
Polygon Notes
Torrente Torre
2025-02-03



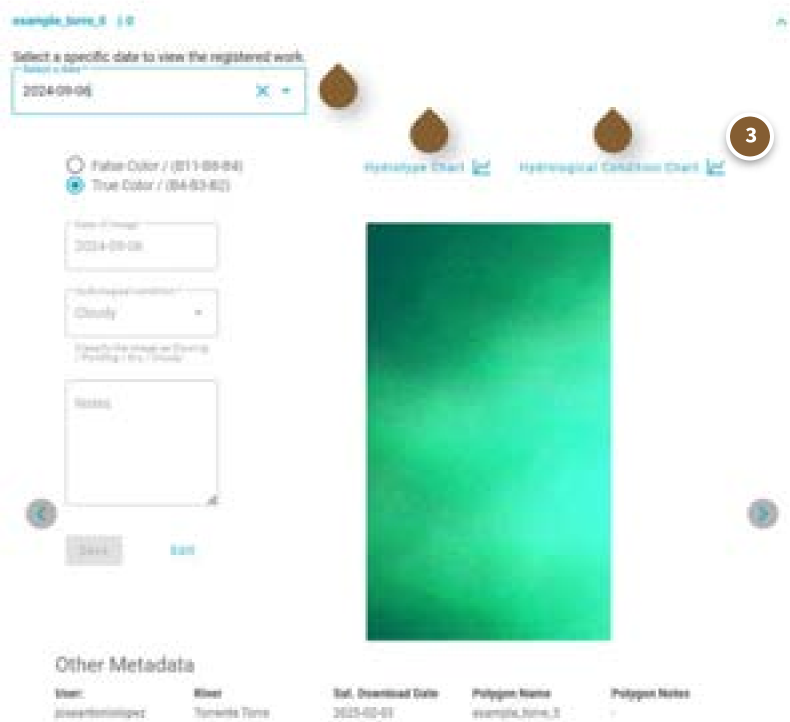
Classified data

Select the classified date you want to see.



Ternary plot

Click **Hydrotype Chart** button to see the ternary plot.



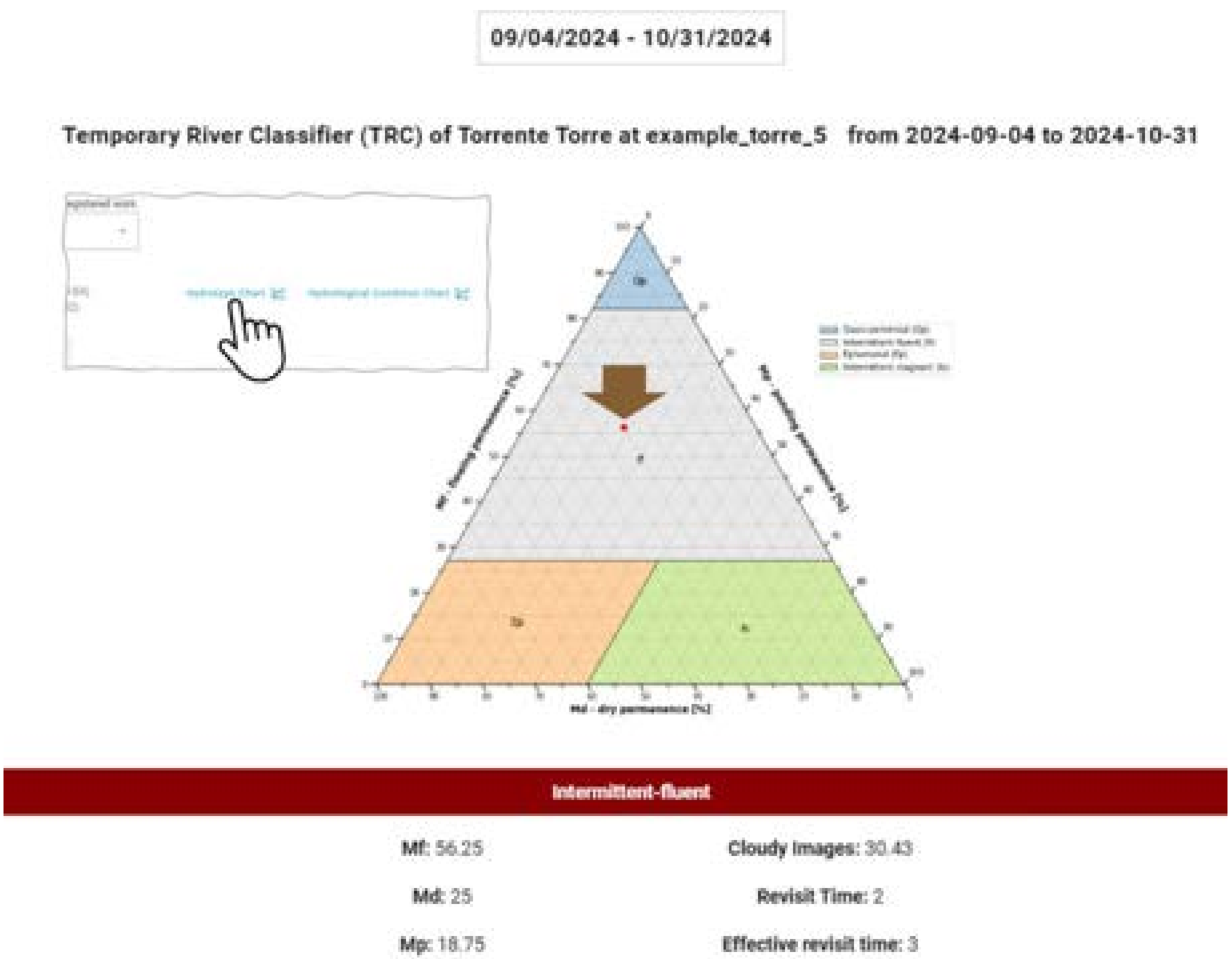
Time series

Click **Hydrological Condition Chart** button to see the time series.

Hydrotype Chart

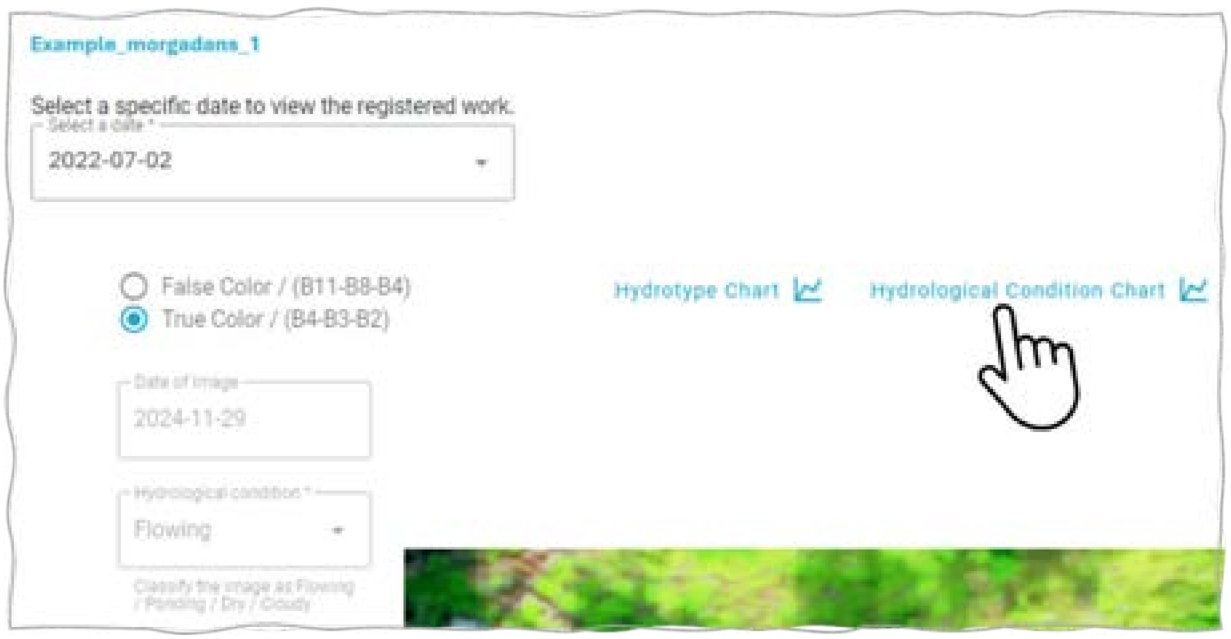
If you click on the **Hydrotype char** button, you will be able to see the ternary plot:

> **Click on the image to enlarge it**



The **red dot** is indicating the river hydrotype.
The 3 metrics (Mf - Md - Mp) are automatically

calculated.

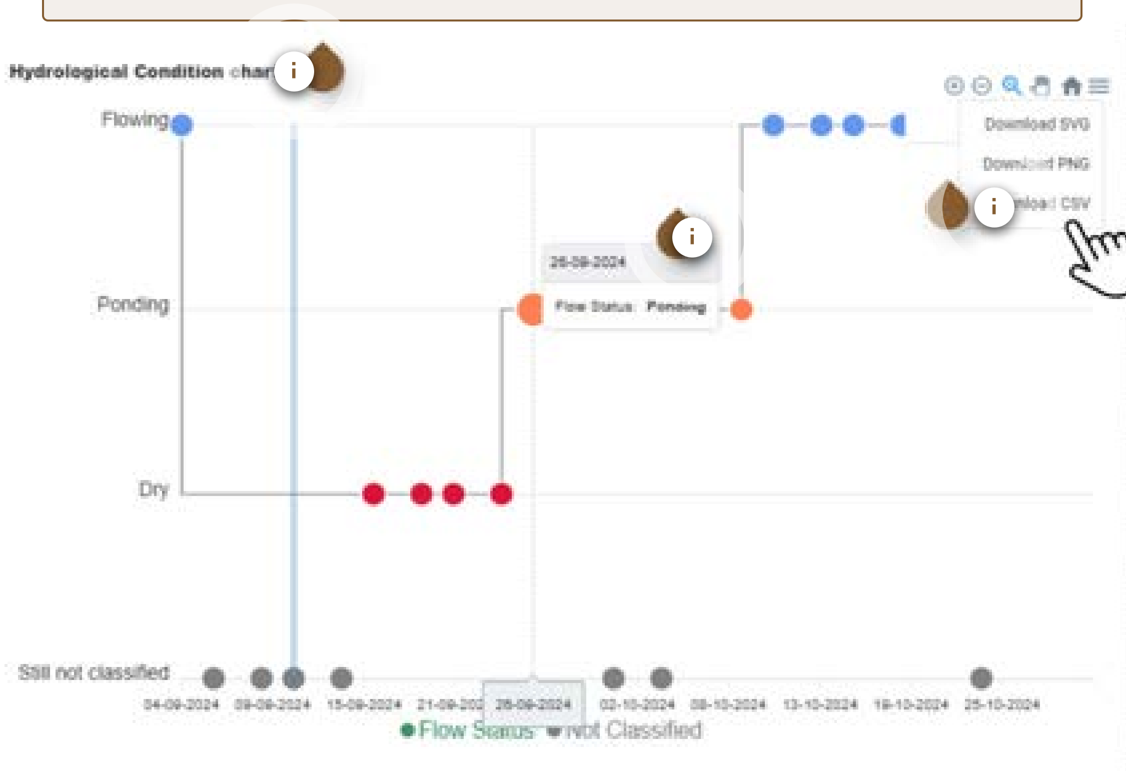


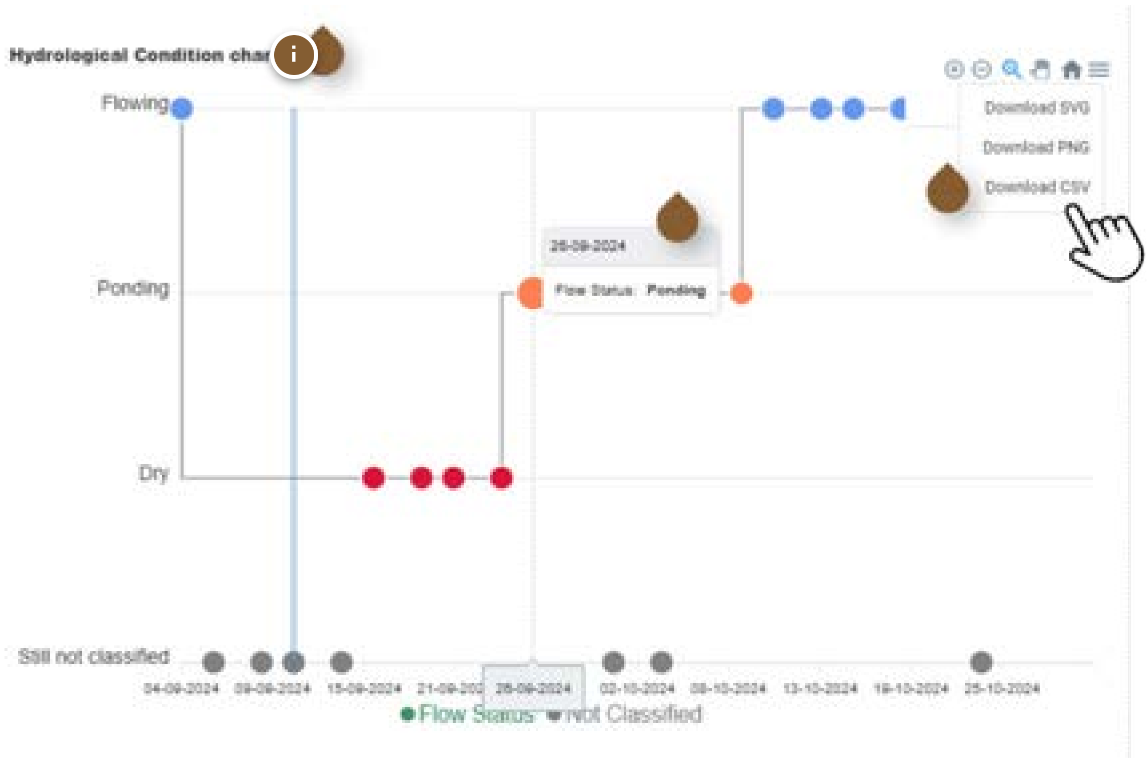
Click on the image to enlarge it

Hydrological Condition Chart

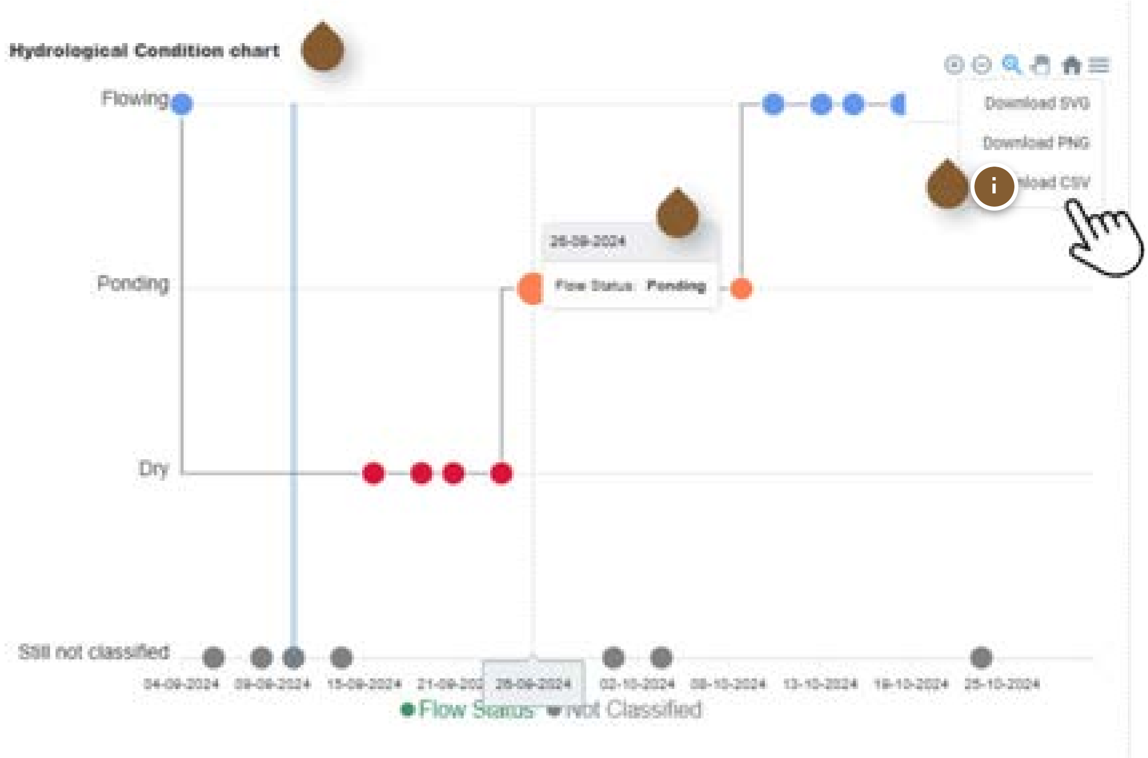
If you click on the **Hydrological Condition Chart** button you can see the **time series**:

Click on the buttons to view the information.

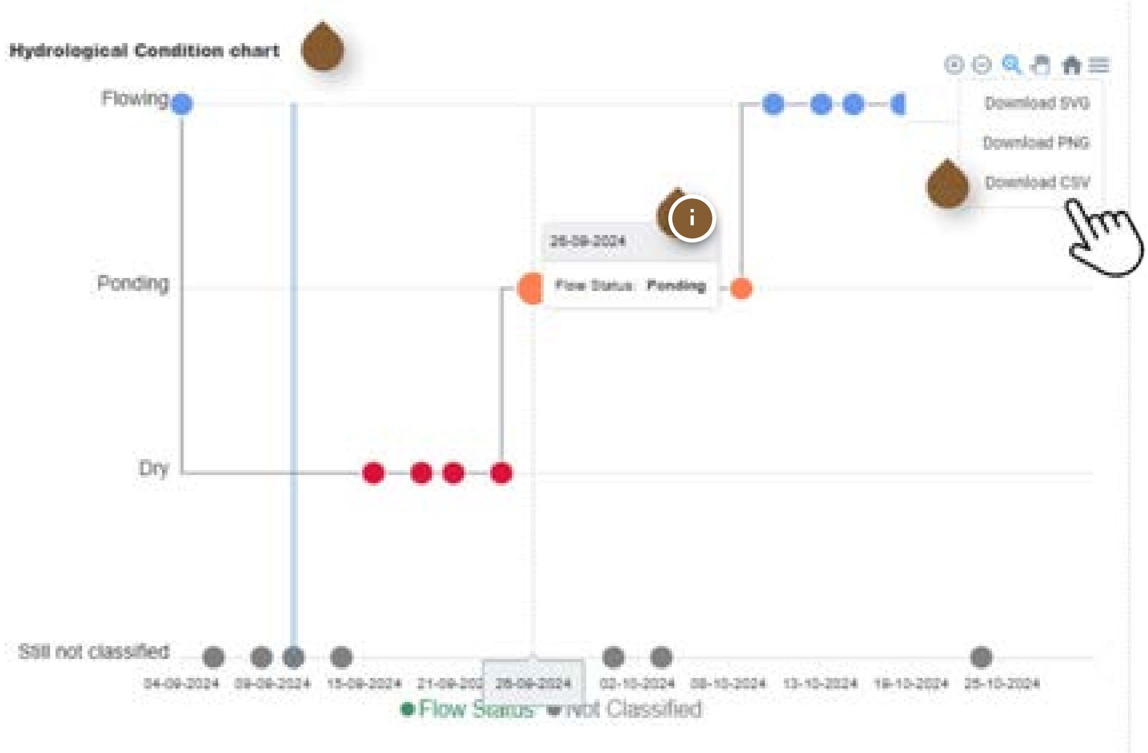




The graph is showing the time series of classified satellite images.

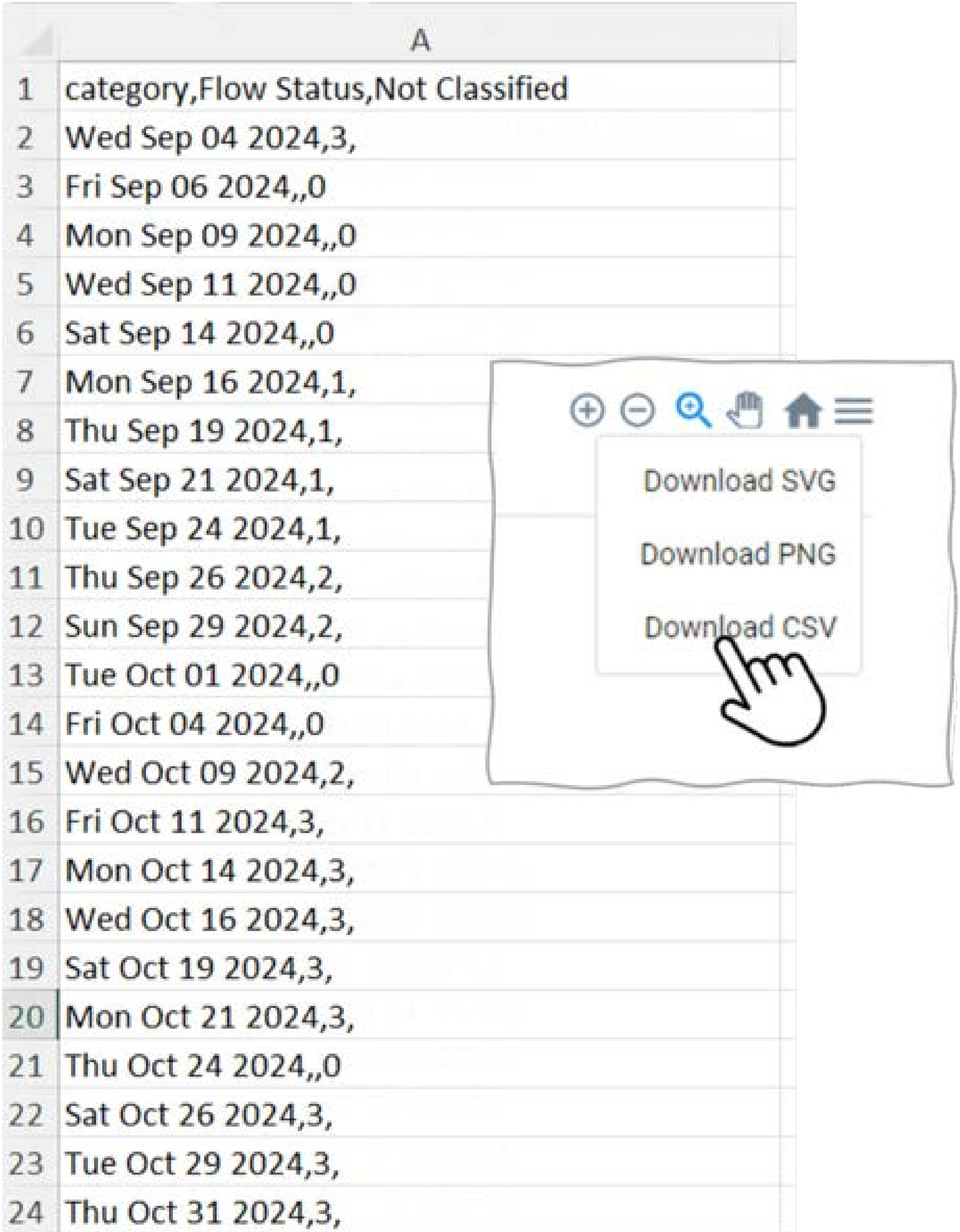


You can download the chart in different file formats.

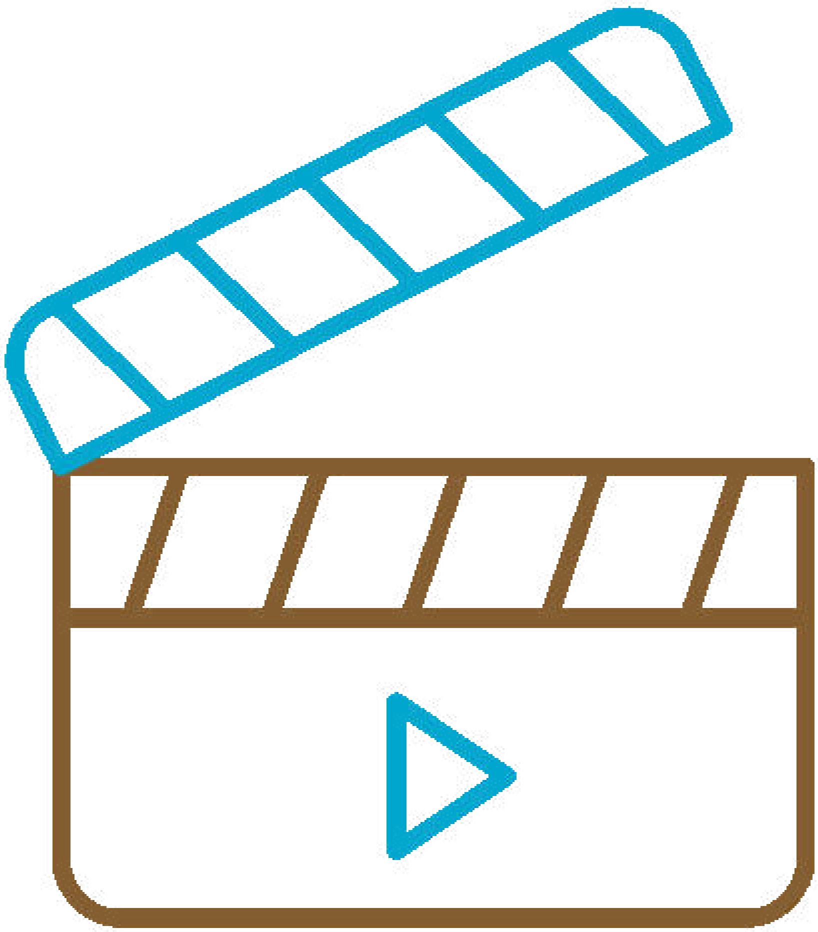


If the mouse hovers over a point, the data values are popping up.

In the following image you can see an example of a downloaded **.csv file:**



	A
1	category,Flow Status,Not Classified
2	Wed Sep 04 2024,3,
3	Fri Sep 06 2024,,0
4	Mon Sep 09 2024,,0
5	Wed Sep 11 2024,,0
6	Sat Sep 14 2024,,0
7	Mon Sep 16 2024,1,
8	Thu Sep 19 2024,1,
9	Sat Sep 21 2024,1,
10	Tue Sep 24 2024,1,
11	Thu Sep 26 2024,2,
12	Sun Sep 29 2024,2,
13	Tue Oct 01 2024,,0
14	Fri Oct 04 2024,,0
15	Wed Oct 09 2024,2,
16	Fri Oct 11 2024,3,
17	Mon Oct 14 2024,3,
18	Wed Oct 16 2024,3,
19	Sat Oct 19 2024,3,
20	Mon Oct 21 2024,3,
21	Thu Oct 24 2024,,0
22	Sat Oct 26 2024,3,
23	Tue Oct 29 2024,3,
24	Thu Oct 31 2024,3,

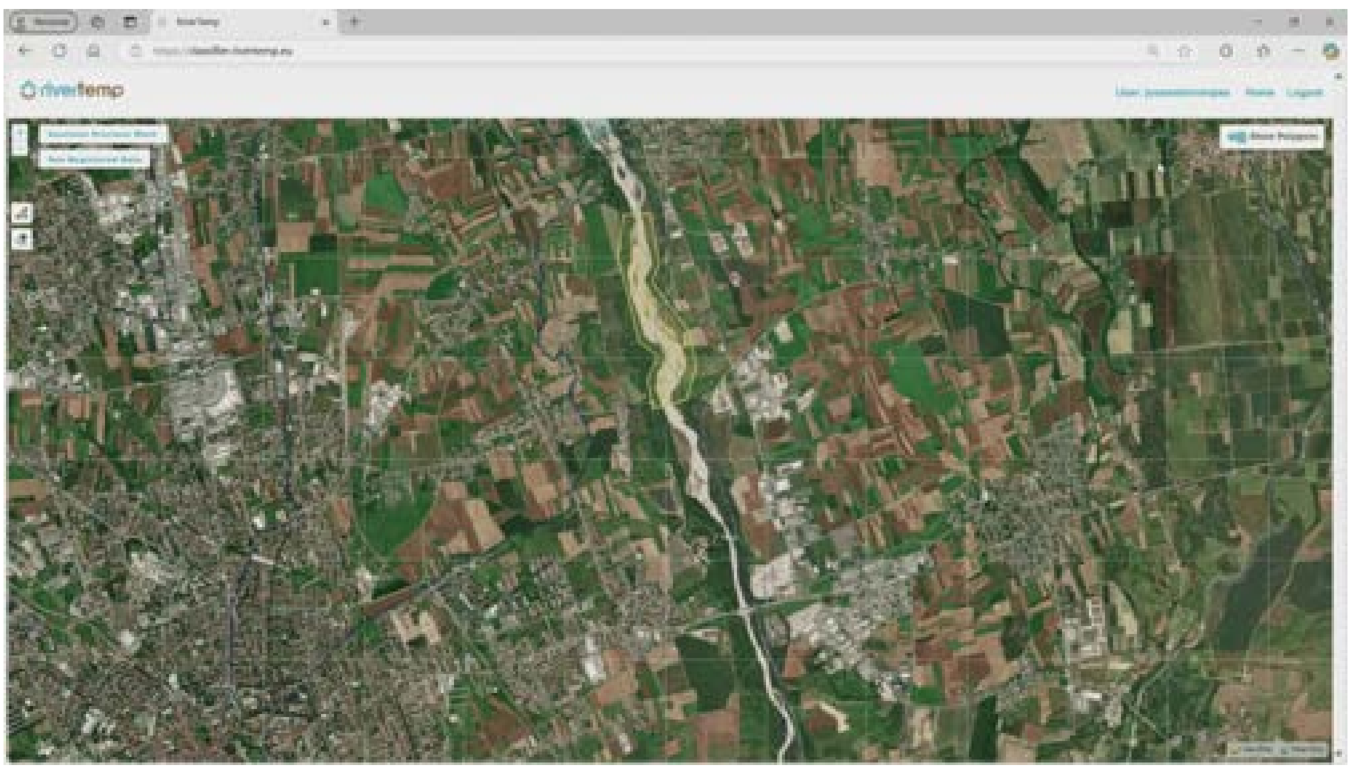


1.

VIDEO

In the following video we see the classification results of the ROI that we have created.

Click on the button to watch the video.



CONTINUE

Resume or modify one of your classifications

Recapitulation

Before continuing, let's stop and look back.

What have we done so far?

1. We have **signed up** for the IT Tool, namely **Temporary River Classifier** (**TRC**).
2. We **log in** and access the home page of the IT tool.
3. We **navigate the world map** and locate the temporary river reach that we want to classify:
   Torrente Torre
4. We select the **date range** that we want to classify:
   01/09/2024 - 31/10/2024.
   (Remember: a maximum number of **250 days is allowed**).
5. We **create** a **polygon** and name it:
   example_torre_5

6 Then, we **classify** most of the images and save them.

7 Finally, we **finish the classification** and save the work.

At this point you may have the following **questions:**

Click cards to flip

Can I **modify** data in the polygon I just saved?

Can I **expand** the classification of an existing polygon?

Obviously, the answer is yes. Continue with the course and discover how it is done.

CONTINUE

1

Click on the buttons to view the information.

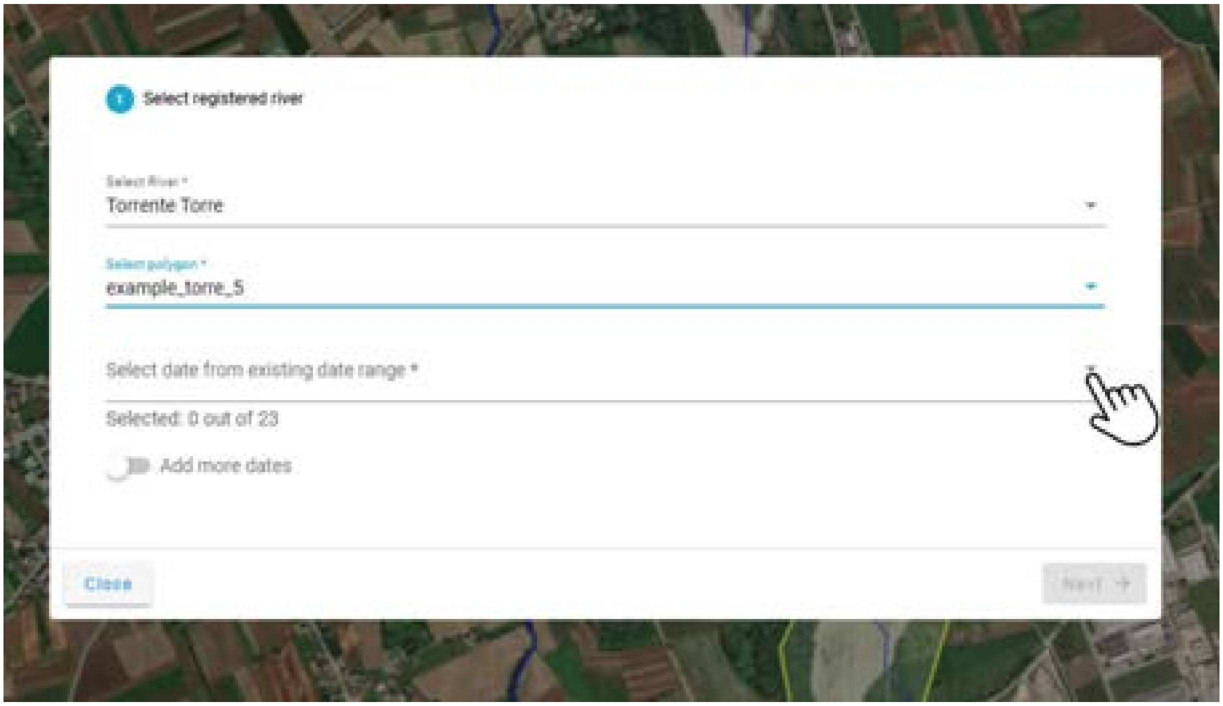
Modify a classification

Press the **START** button and discover how to **modify** data in an already created polygon:

2

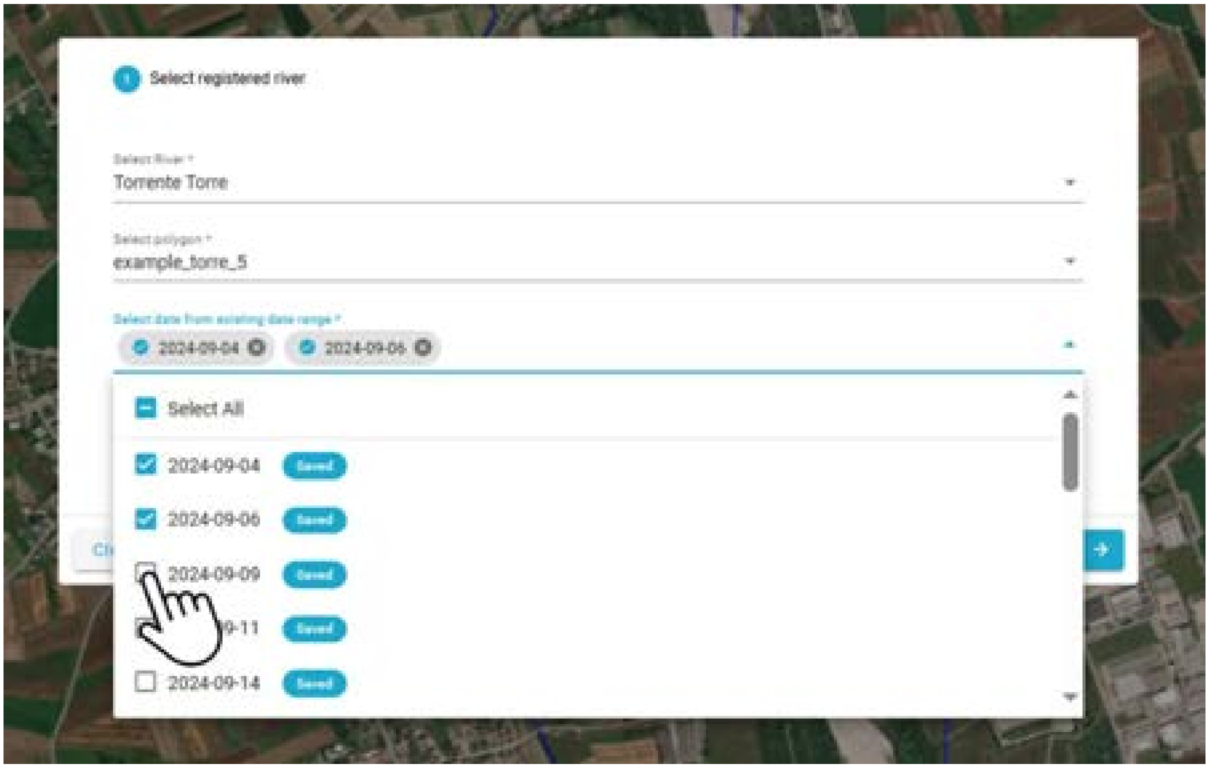
In the world map, click the **Continue Previous Work** button.

3



Select the river and the polygon.
Then select the dates from the existing date range
(in this example: 01/09/2024 - 31/10/2024)

4

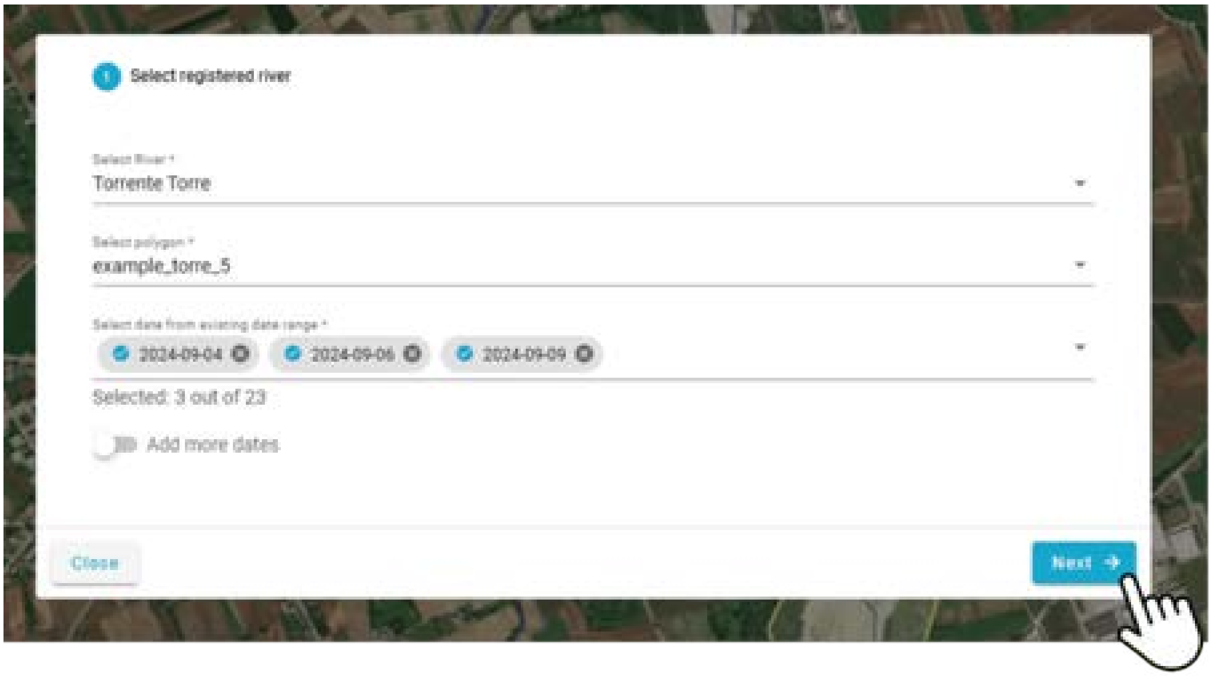


In the pop-up window, you can select all the dates you want.

You have the option to select all of them by clicking on **Select All**.

In this example we will select the first 3 dates.

5



Once we have selected the dates we want to investigate, click on the **Next** button.

6

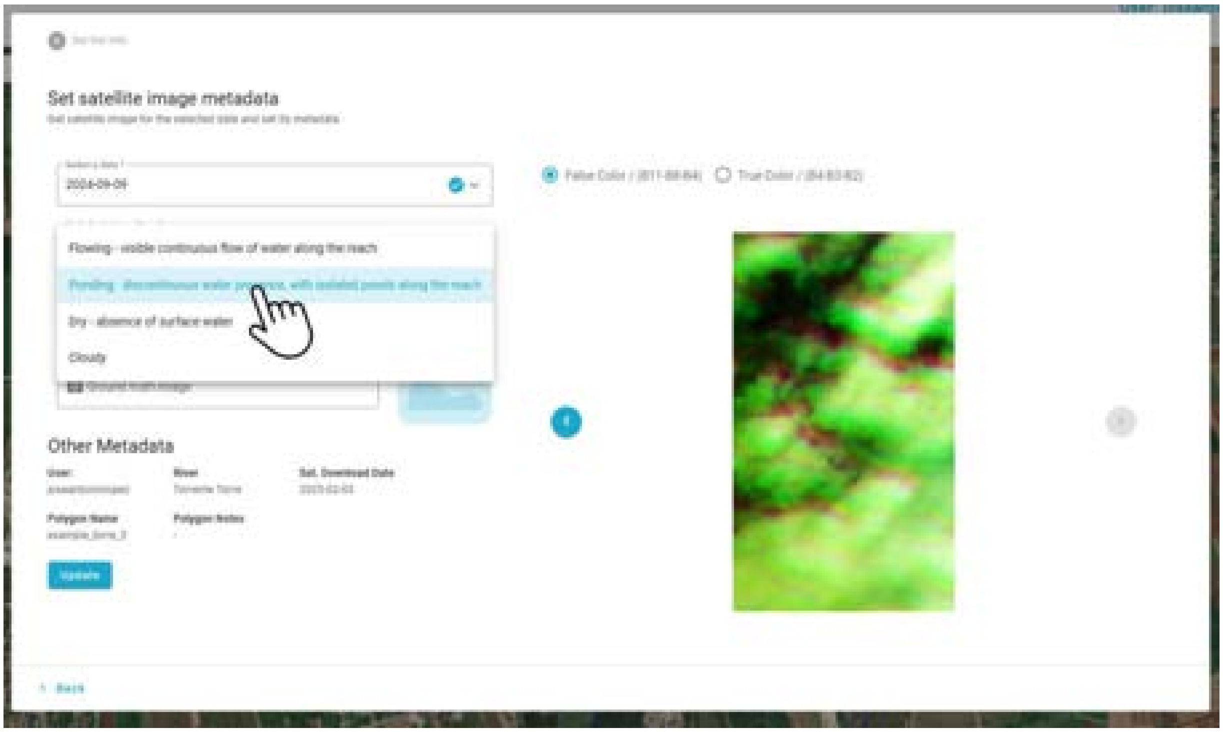
On this screen we can modify all the data we want.
First we select the date.

7

If you notice, only the 3 dates that we selected in the previous step appear.

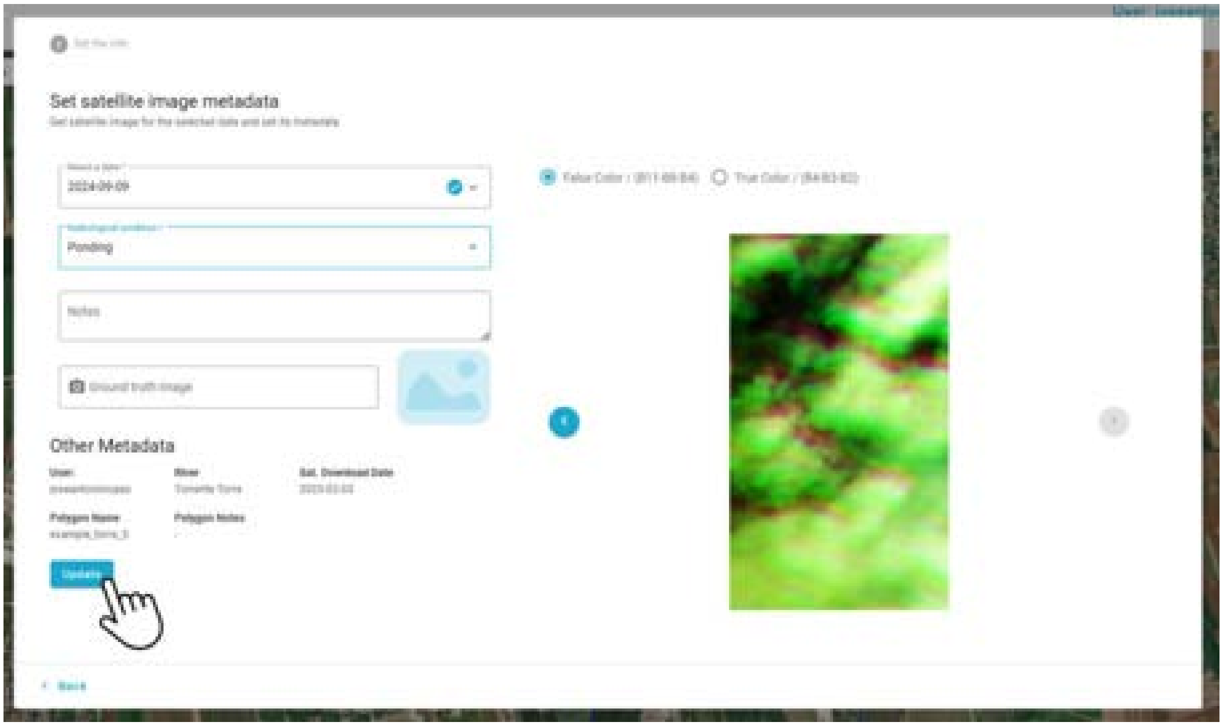
In this example, we select the third.

8



Now we make a modification: we change the hydrological condition from cloudy to ponding.

9



Remember to click the **Update** button to save the changes.

But we can go further. We can add new dates to an already created polygon.

CONTINUE

2

Click on the buttons to view the information.

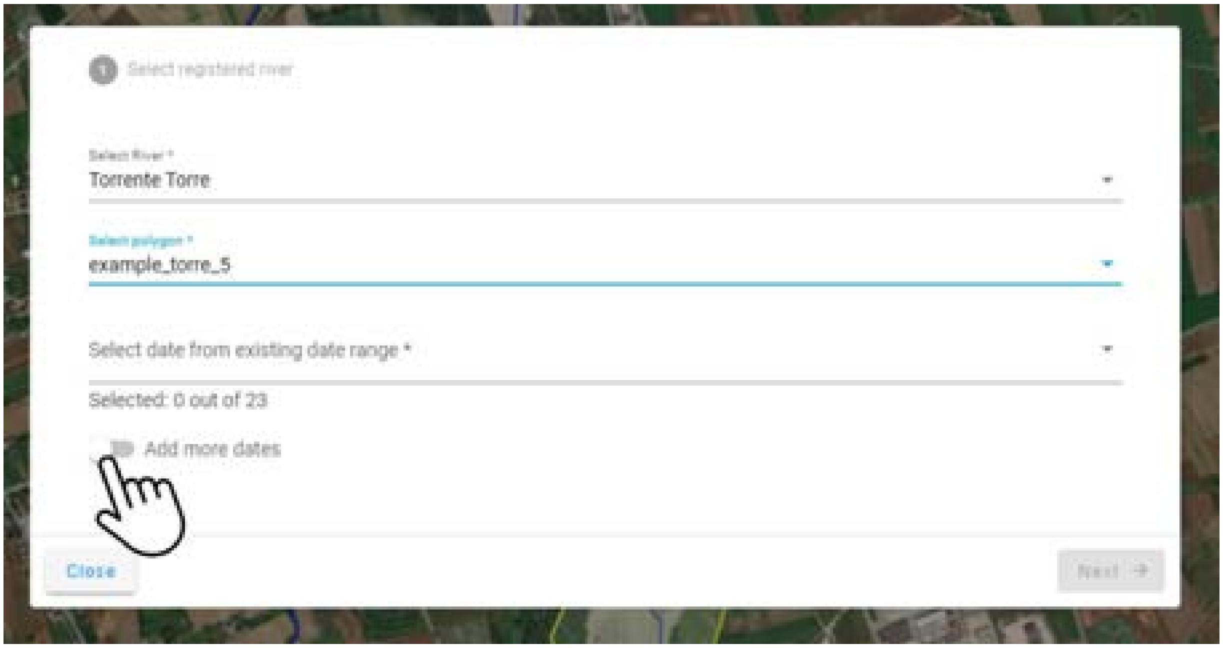
Resume a classification

Press the **START** button and discover how to **add dates** in an already created polygon:

2

As we saw in the previous example, we click again on the **Continue Previous Work** button.

3



Pay attention:

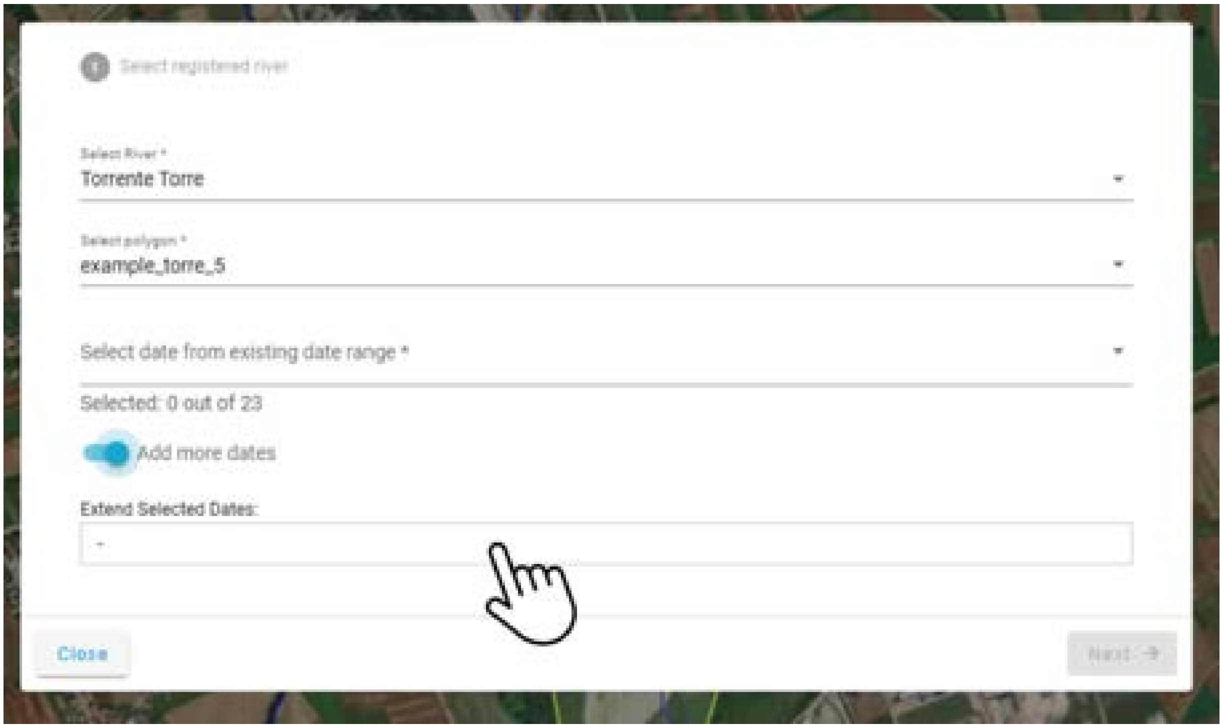
We currently have 23 images corresponding to the selected interval when the polygon was defined: September 1, 2024 to October 31, 2024.

Now, we want to include images from November and December 2024.

How can we do this?

Switching on the toggle button to extend the date range.

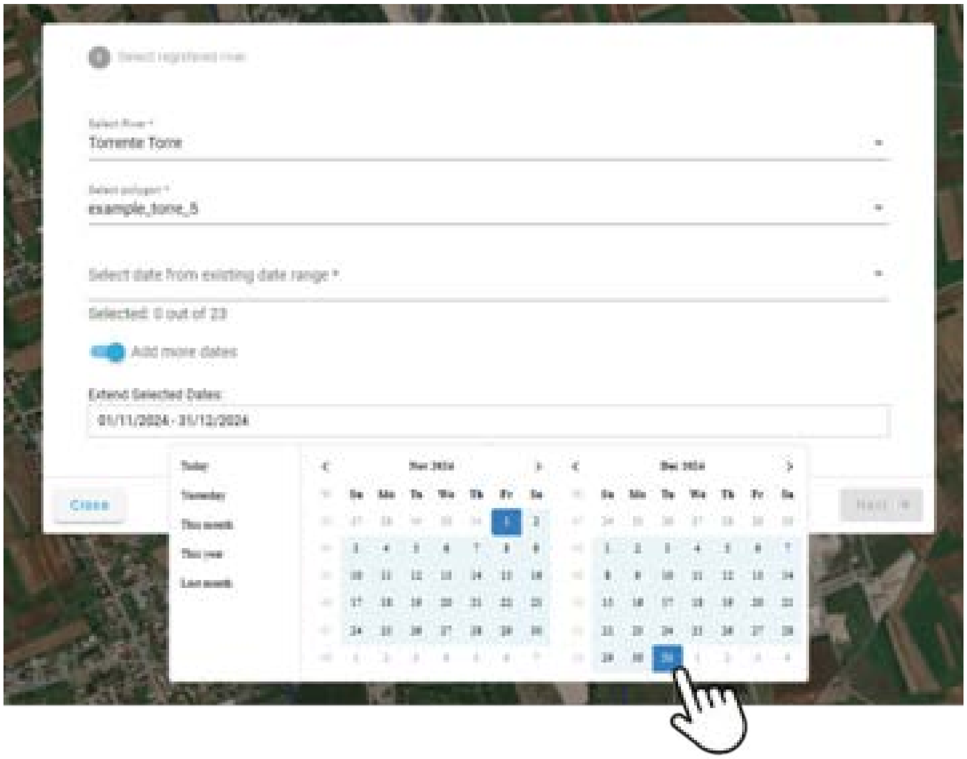
4



A new selection bar appears: **Extend Selected dates**.

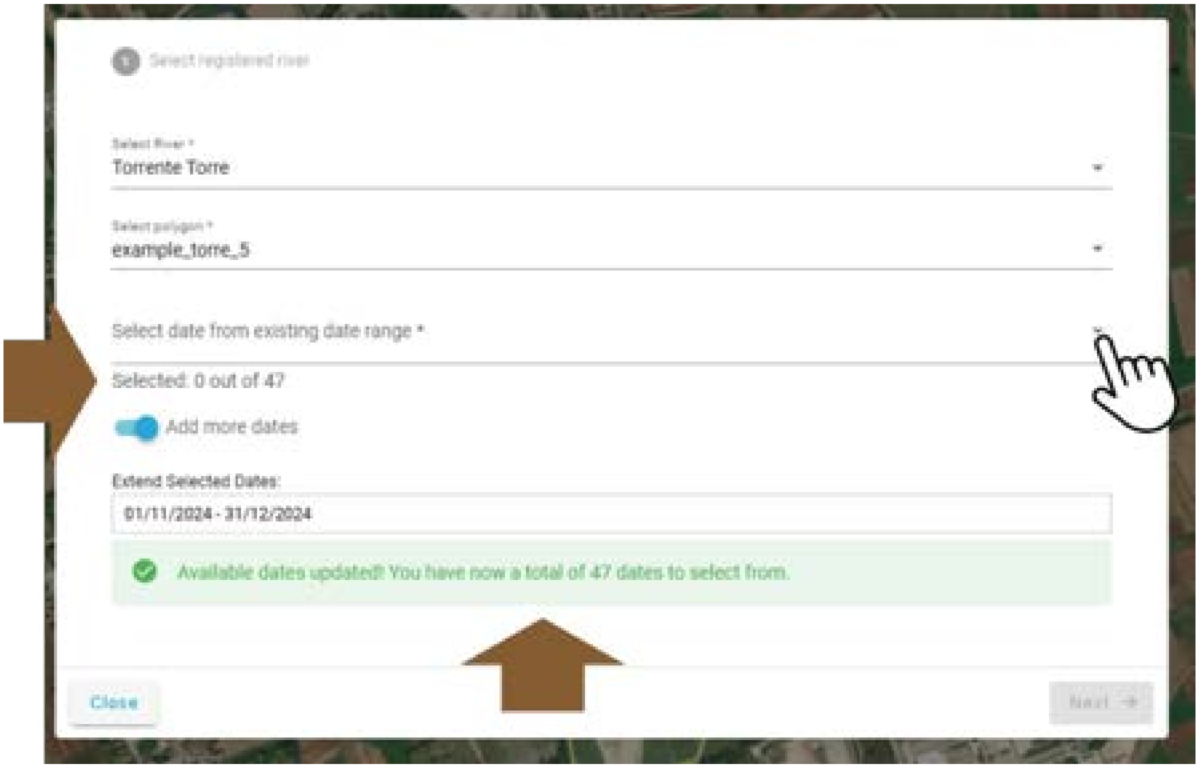
We click on it.

5



Now we select the date range that we want to add:

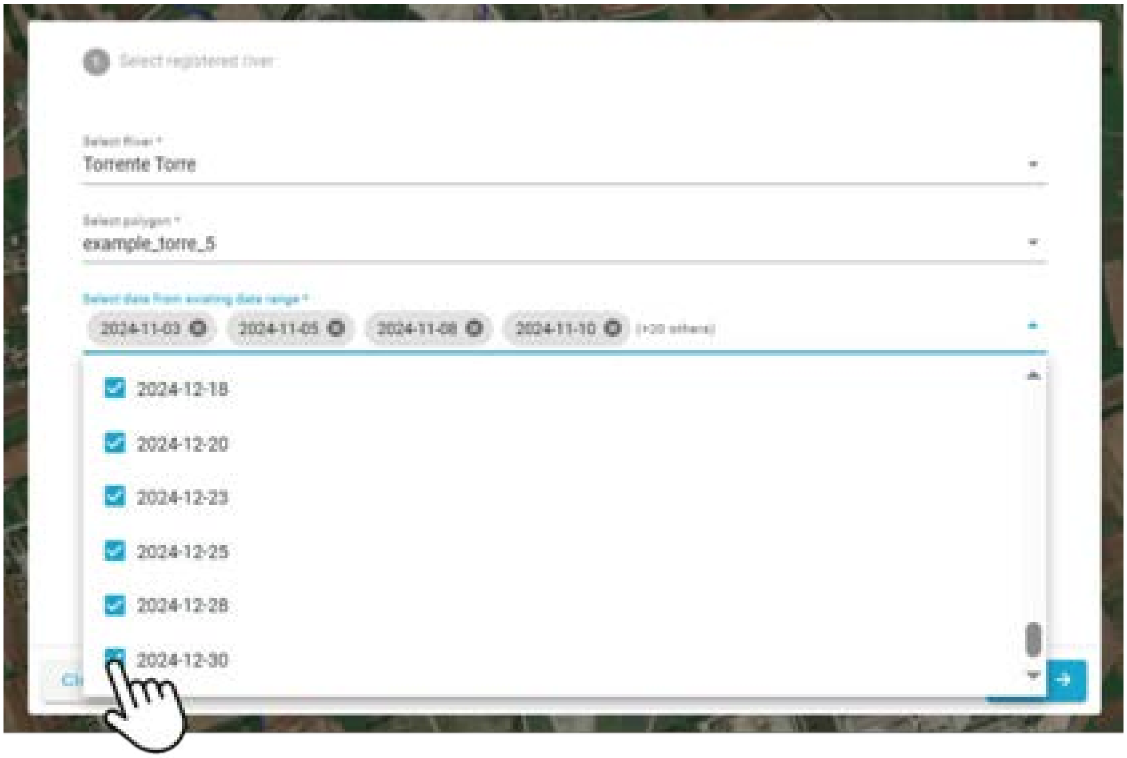
01/11/2024 - 31/12/2024



Take a look!

The system informs us that we have added new dates. If you recall, we had 23 dates. Now, we have a total of 47. Therefore, we have just added 24 new dates.

7



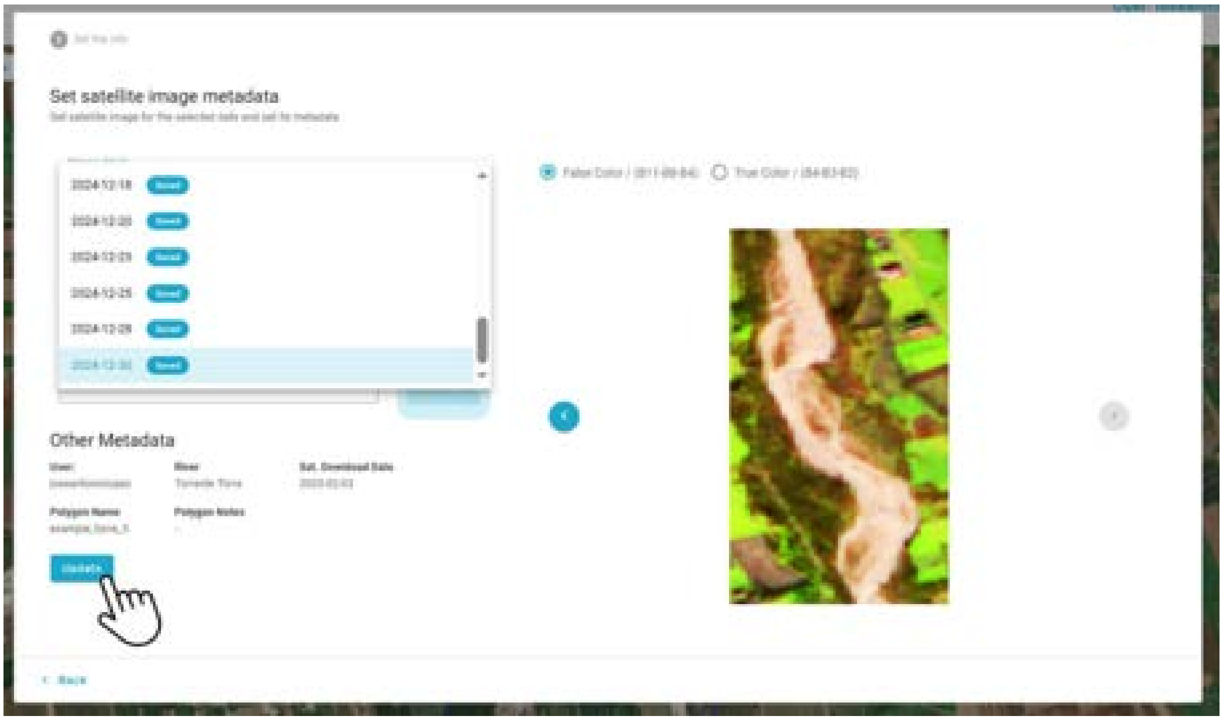
Just as we did in the previous example, we expand the Selected date from existing date range dropdown menu.

Now we can see the new 24 dates that we just added. We select them.

8

And now we can classify the new images, just as we did in previous examples.

9



Remember to click the **Update** button to save the changes.

CONTINUE

See registered data

At any time we can consult the data stored in our polygons

How do we do it?

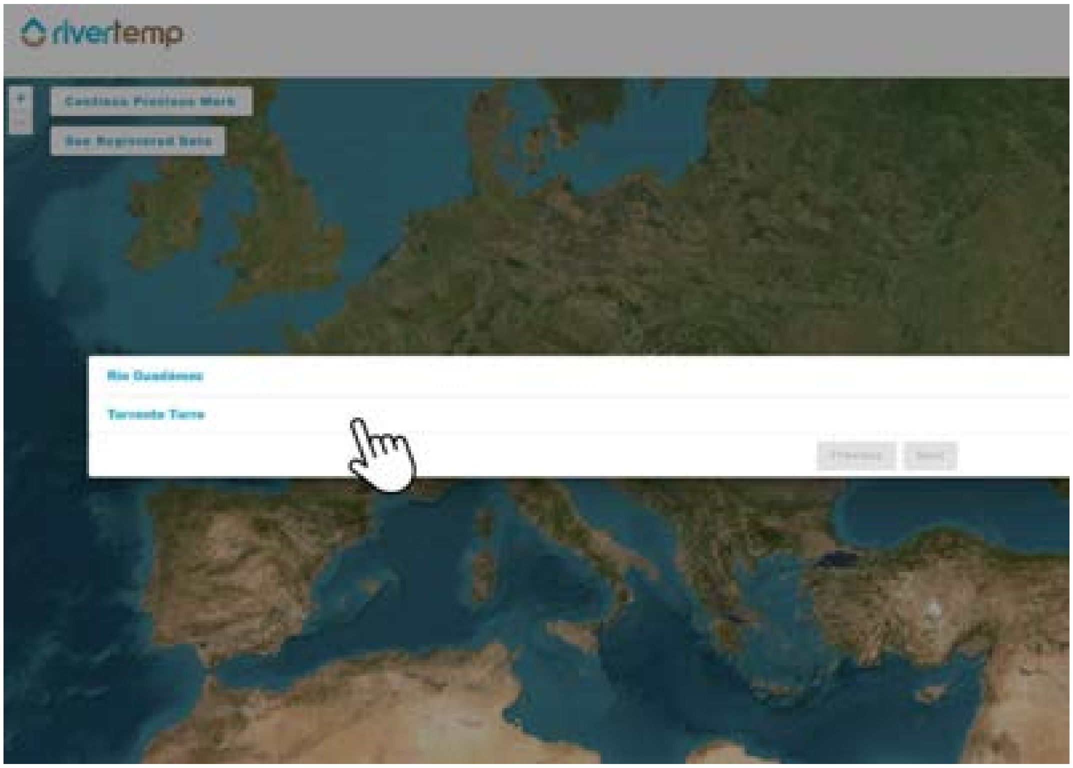
1

Click **See Registered Data** button to check the classifications and the charts.

2

Select the **river** from these dropdown menu.

In this example: ***Torrente Torre***



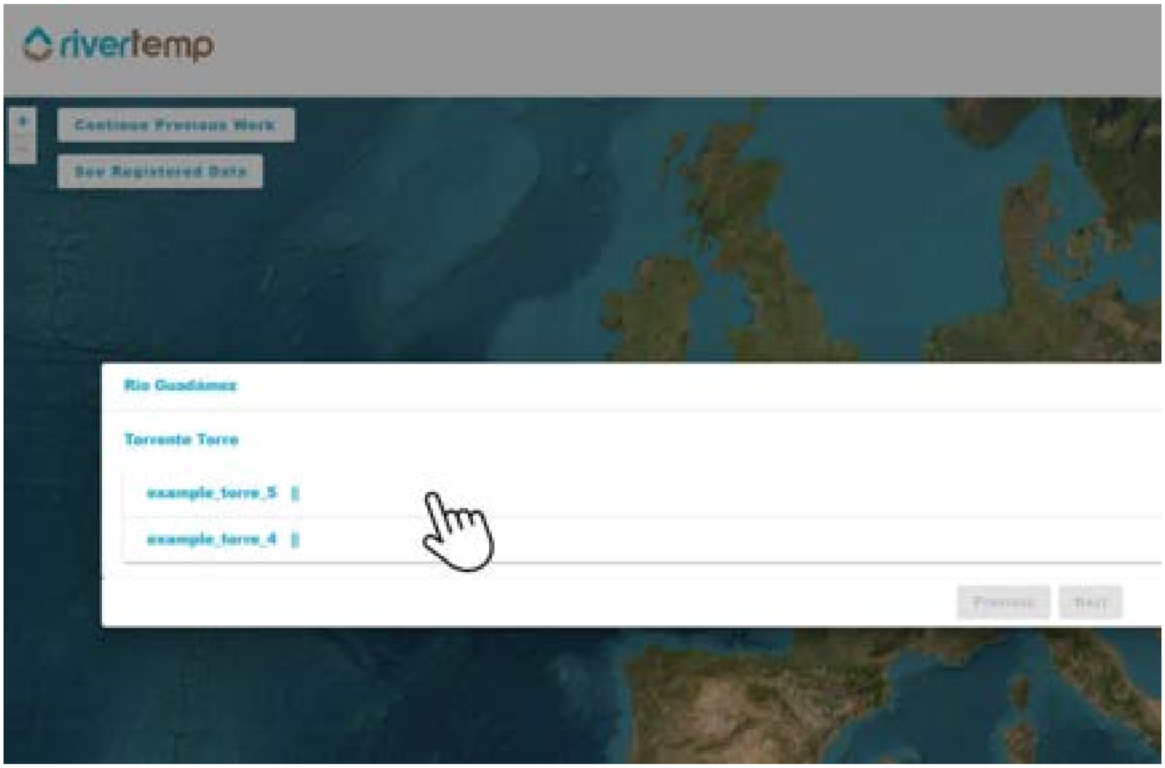
3

Now select the **polygon**.

In this example: ***example_torrente_5***

Note:

In this river, we have created 2 different polygons.

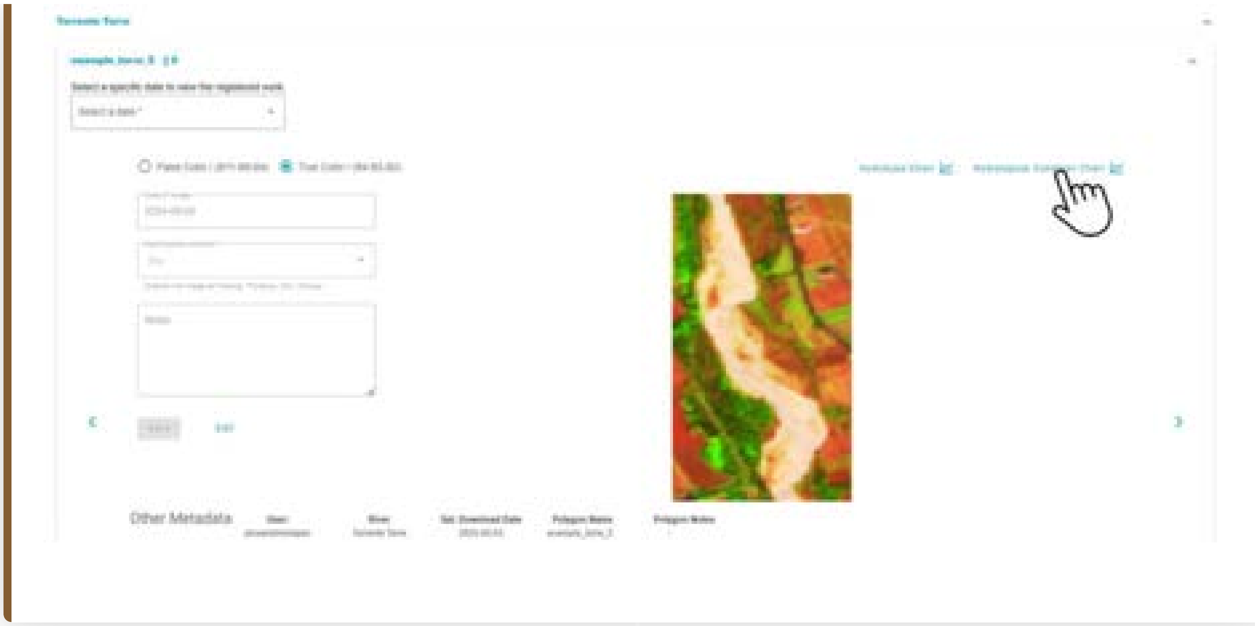


4

Now you can consult all the data you want.

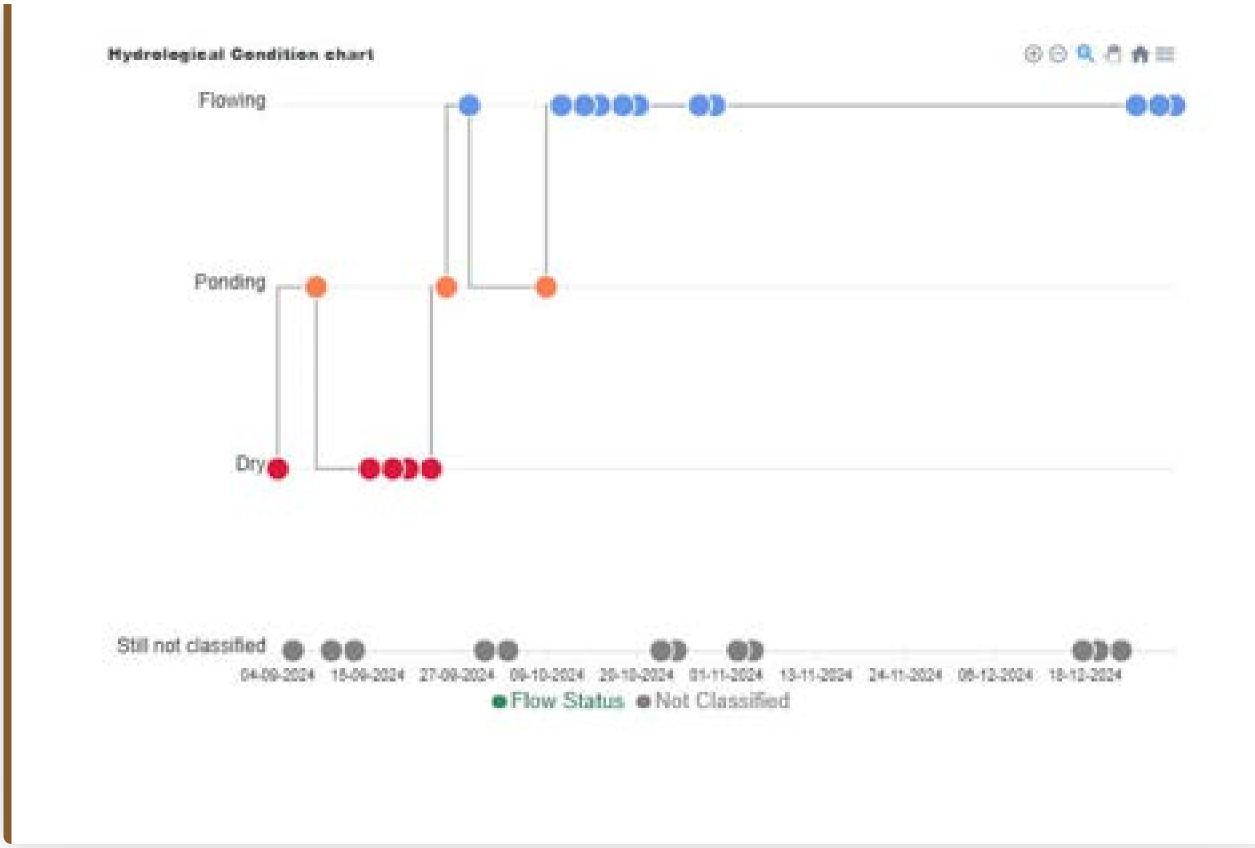
For example, the **hydrological condition chart**.

Click on the button.



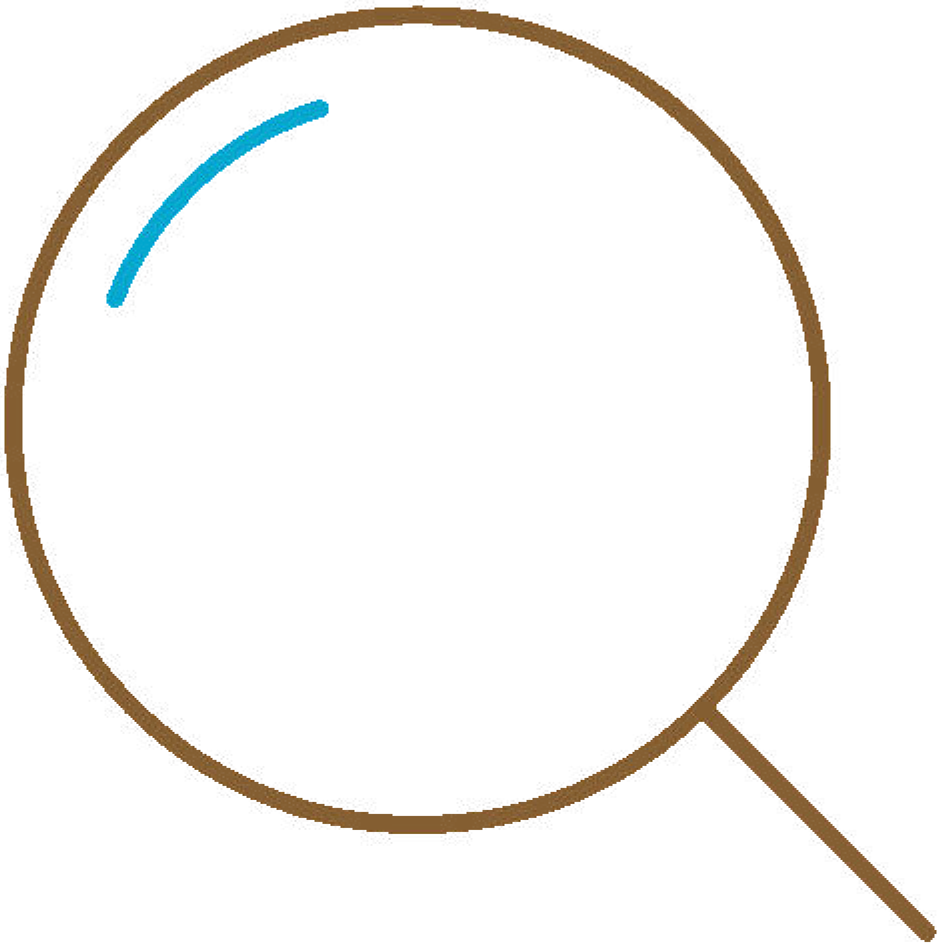
5

Notice that now appear the points corresponding to the last classifications we made (those for the months of November and December 2024).


Hydrological Condition chart
Flowing
Ponding
Dry
Still not classified
04-09-2024
15-09-2024
27-09-2024
09-10-2024
20-10-2024
01-11-2024
13-11-2024
24-11-2024
06-12-2024
18-12-2024
Flow Status
Not Classified

CONTINUE

Regions of interest

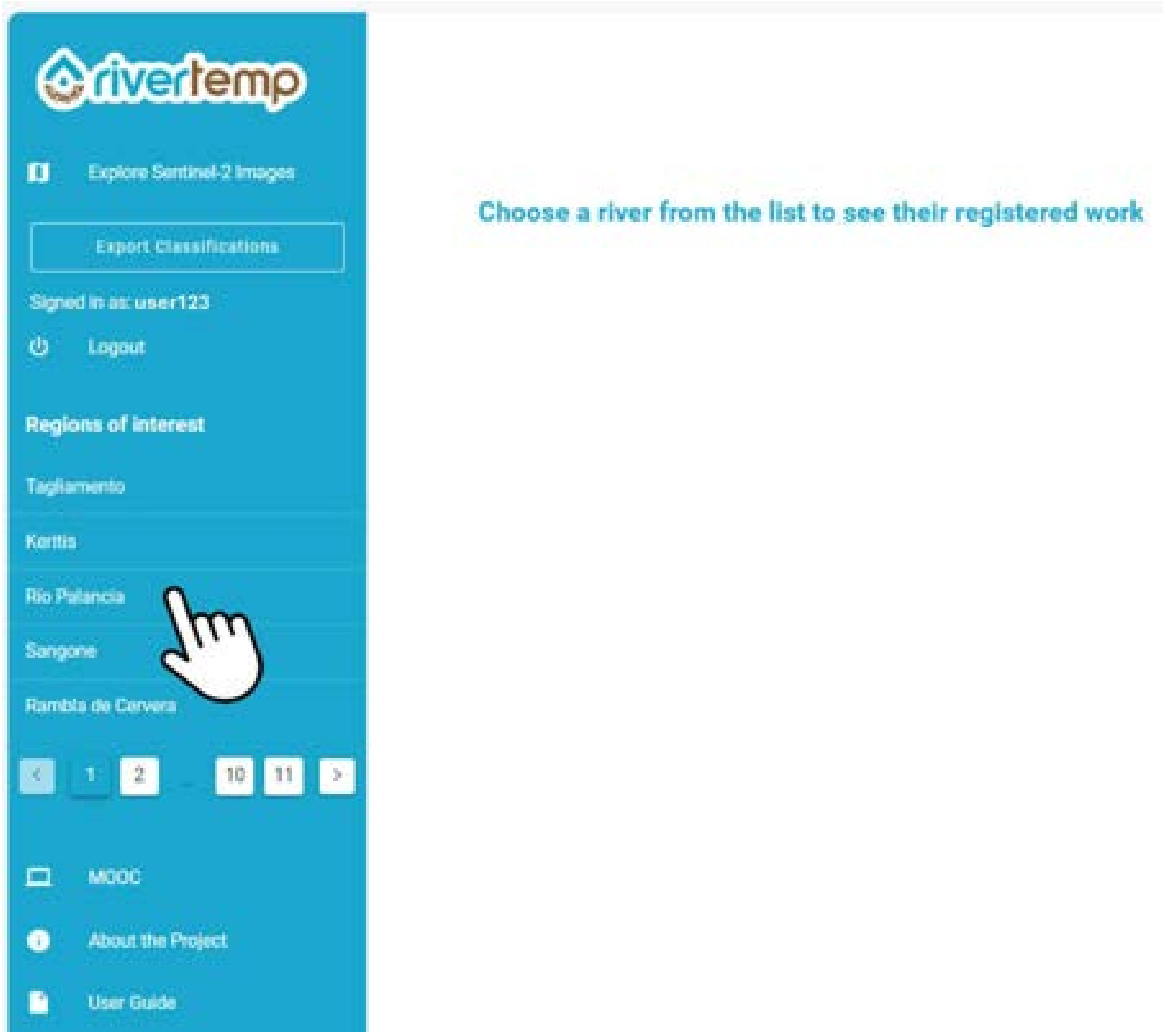


From the home page we can also consult the data of other users' ROIs.

Click on the tabs to view the information.

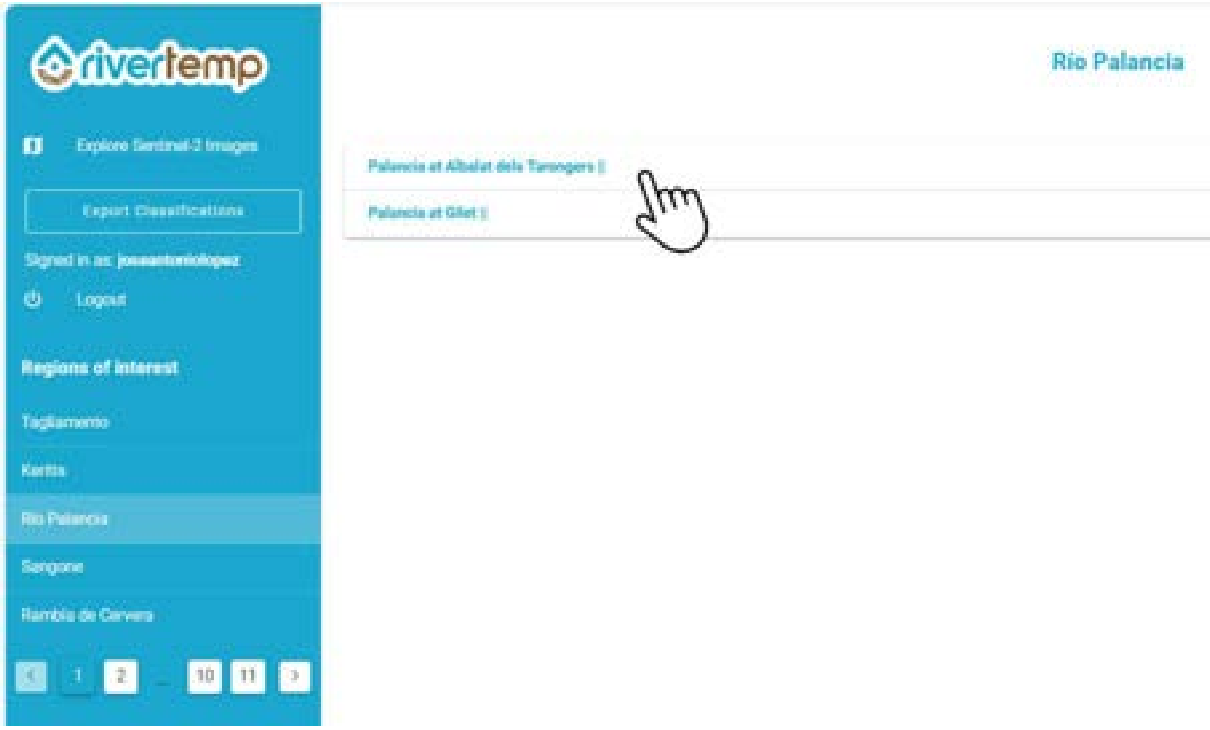
SELECT THE RIVER	SELECT THE POLYGON	VIEW THE REGISTERED WORK	EXAMPLE: THE TERNARY PLOT

On the **Home page**, in the **Regions of interest** section, select the **river**.



SELECT THE RIVER	SELECT THE POLYGON	VIEW THE REGISTERED WORK	EXAMPLE: THE TERNARY PLOT

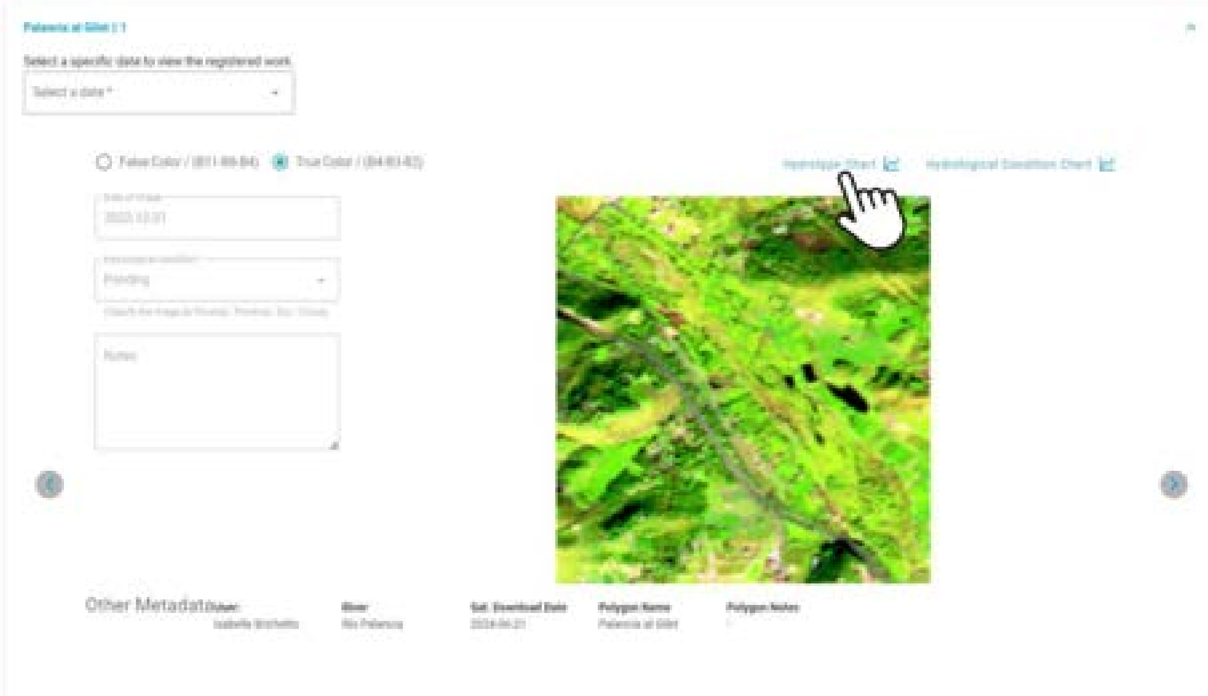
Once the river is selected, select the **ROI**.
Remember: the same river can have multiple **ROIs**.



SELECT THE RIVER	SELECT THE POLYGON	VIEW THE REGISTERED WORK	EXAMPLE: THE TERNARY PLOT

On this screen we can view all the data of this ROI:

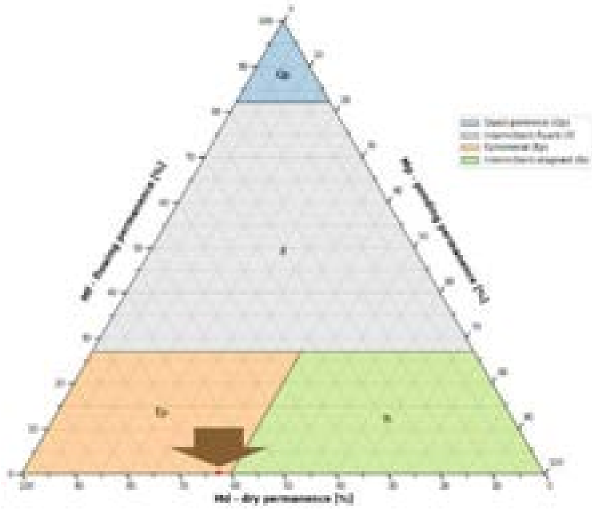
- Satellite images
- Hydrological conditions
- Hydrotype Chart
- Hydrological Condition Chart



SELECT THE RIVER	SELECT THE POLYGON	VIEW THE REGISTERED WORK	EXAMPLE: THE TERNARY PLOT

12/31/2022 - 06/19/2023

Temporary River Classifier (TRC) of Río Palancia at Palancia at Gilet from 2022-12-31 to 2023-06-19



Ephemeral

Mf: 0

Md: 62.5

Mp: 37.5

Cloudy Images: 31.43

Revisit Time: 4

Effective revisit time: 7

CONTINUE

Export classifications

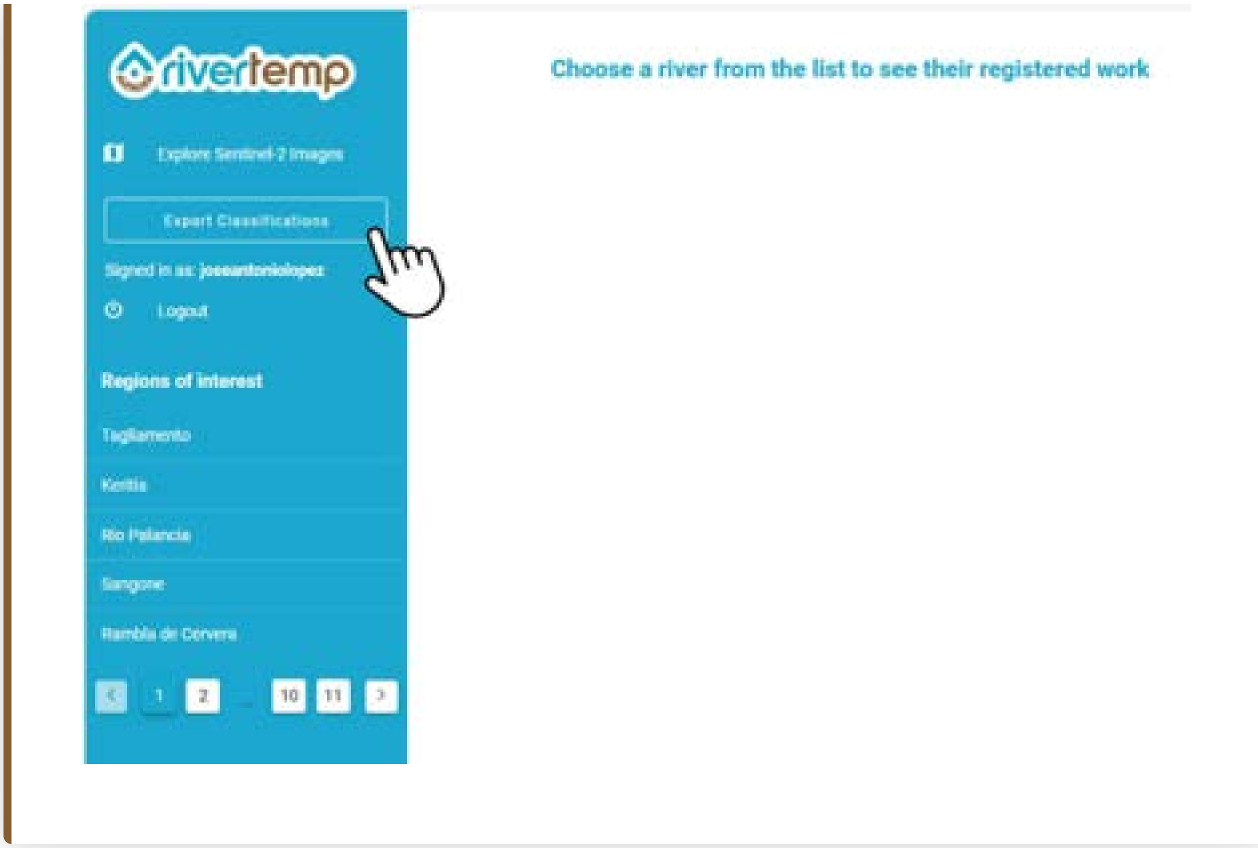
To **export** polygon data, you must follow the following steps:

STEP 1

Go back to **home page**.

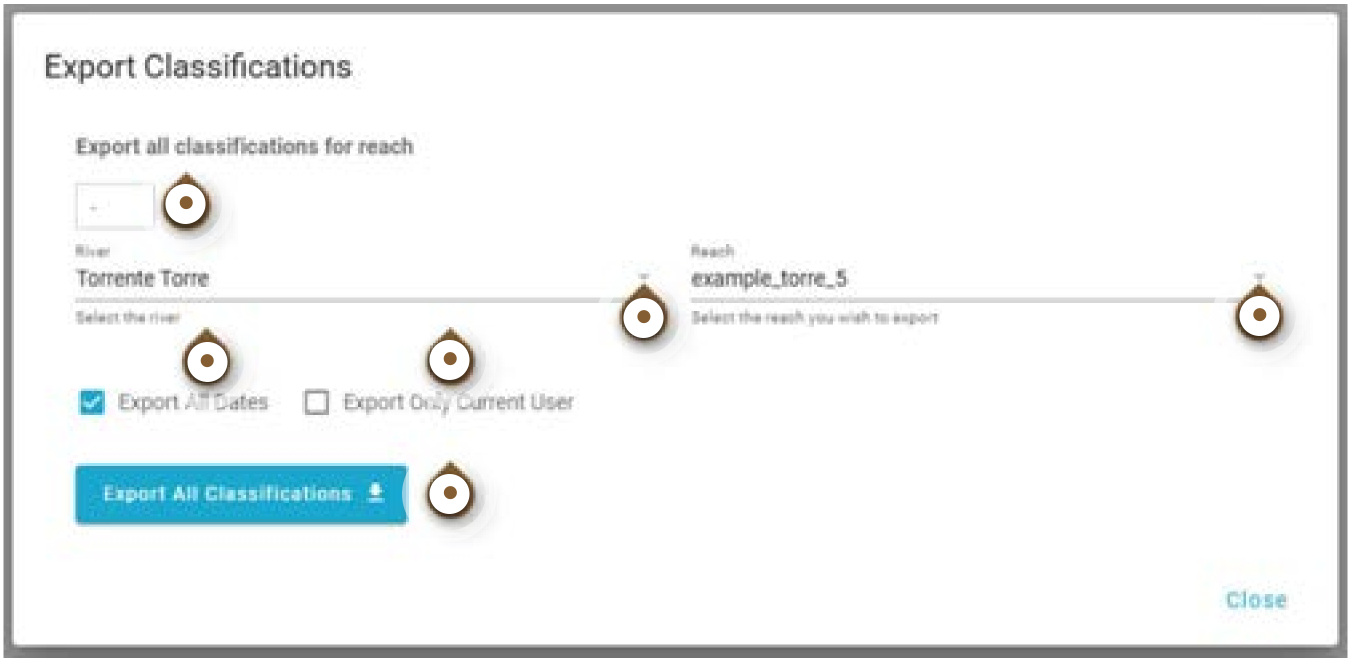
STEP 2

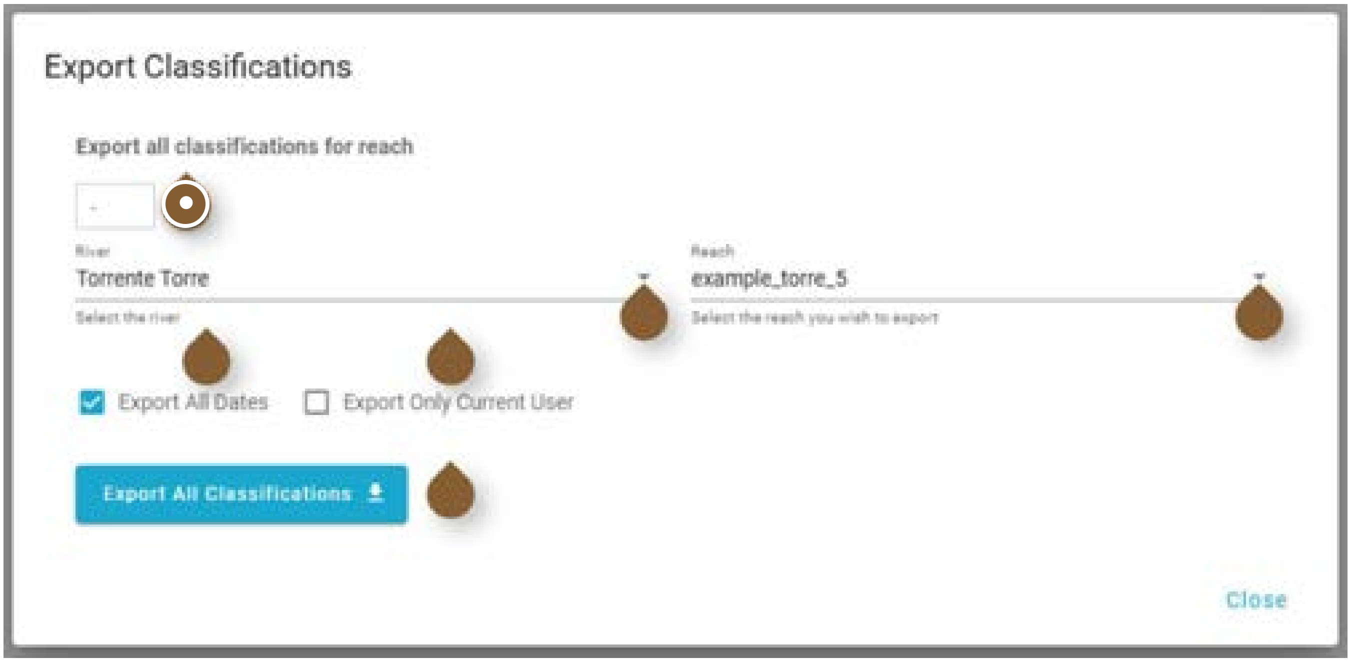
Click **Export Classification** to download classifications that are saved in the tool.



STEP 3

Click on the buttons to view the information.


Export Classifications
Export all classifications for reach
River
Torrente Torre
Select the river
Reach
example_torre_5
Select the reach you wish to export
Export All Dates
Export Only Current User
Export All Classifications
Close

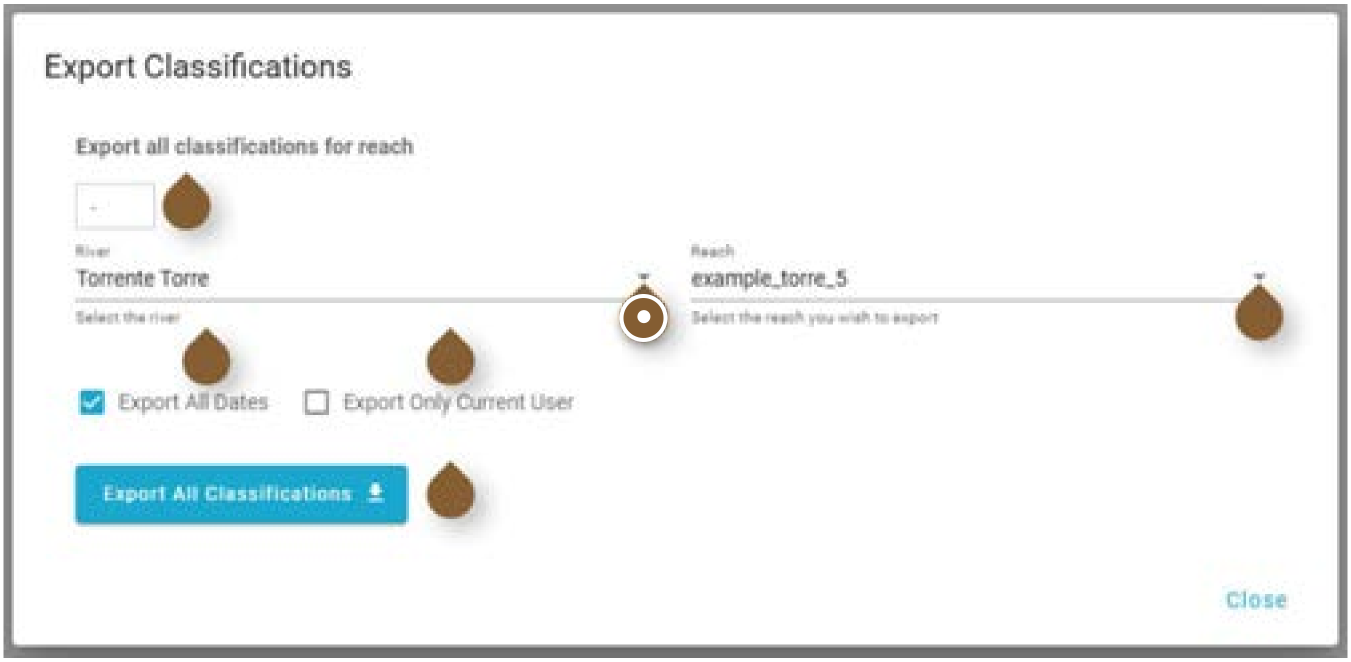


Date range

Select the starting and ending date.

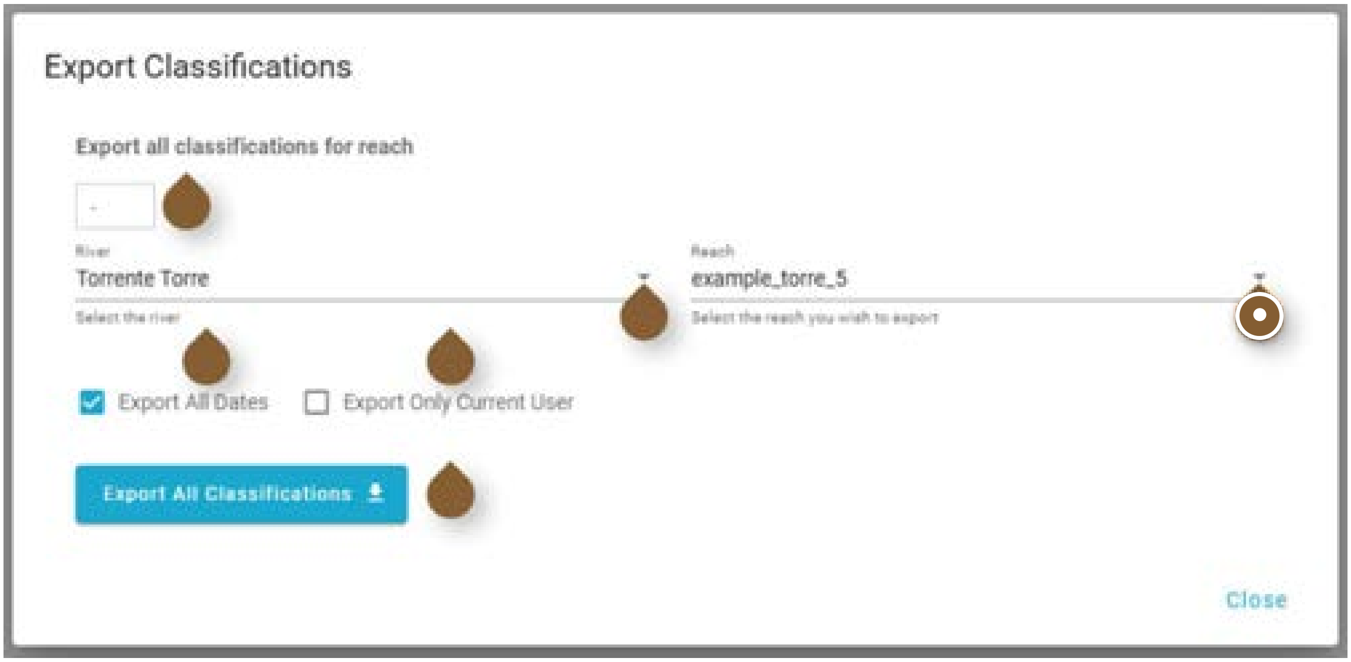
Note:

If you are exporting all available data, you do not need to select this field.



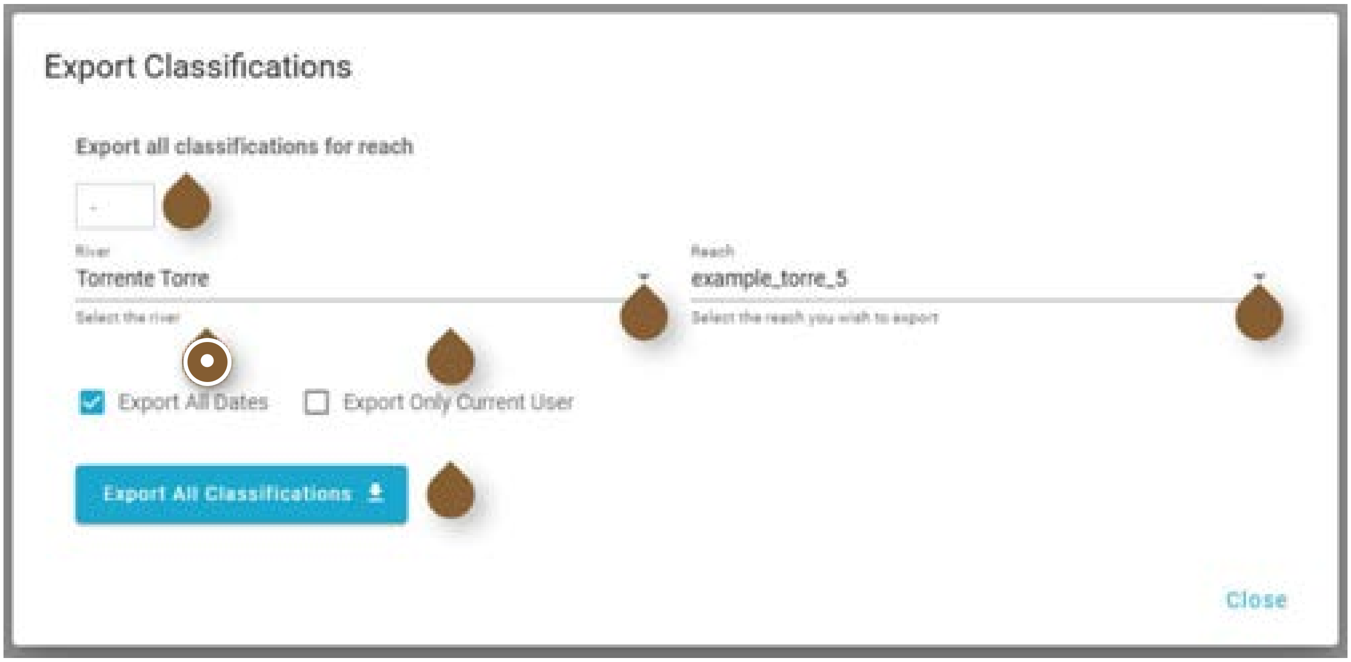
River

Select the river.



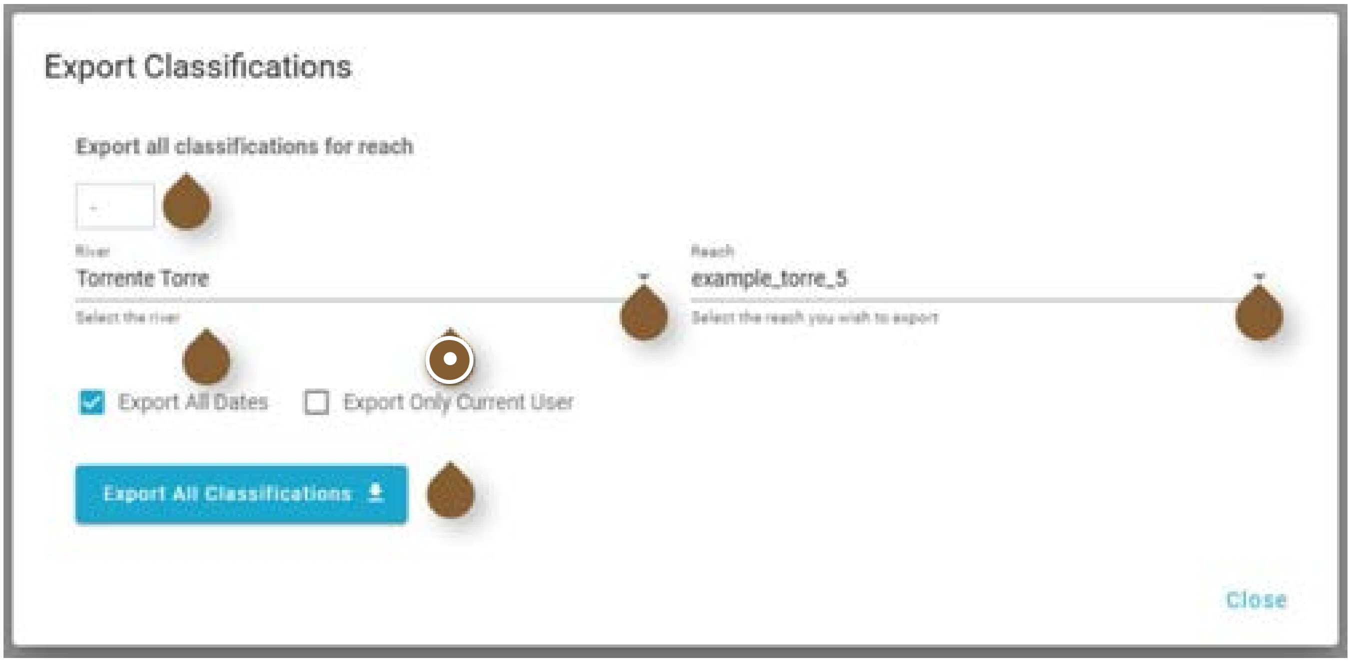
Reach

Select the polygon.



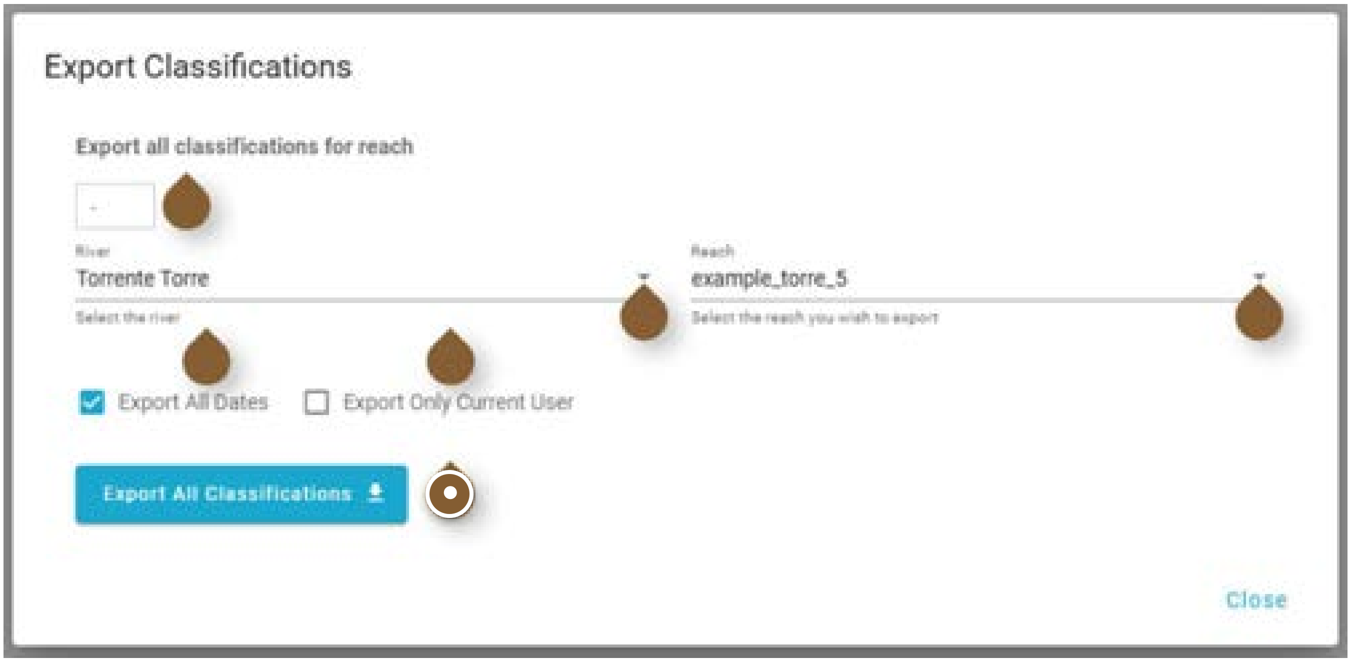
All Users

Select this box if you want to show all the rivers and polygons available in the tool, both yours and those of other users.



Current User

If you select this box, you will filter only your rivers and polygons.



Export All Classifications

By clicking this button you will export a **.xlsx** file.

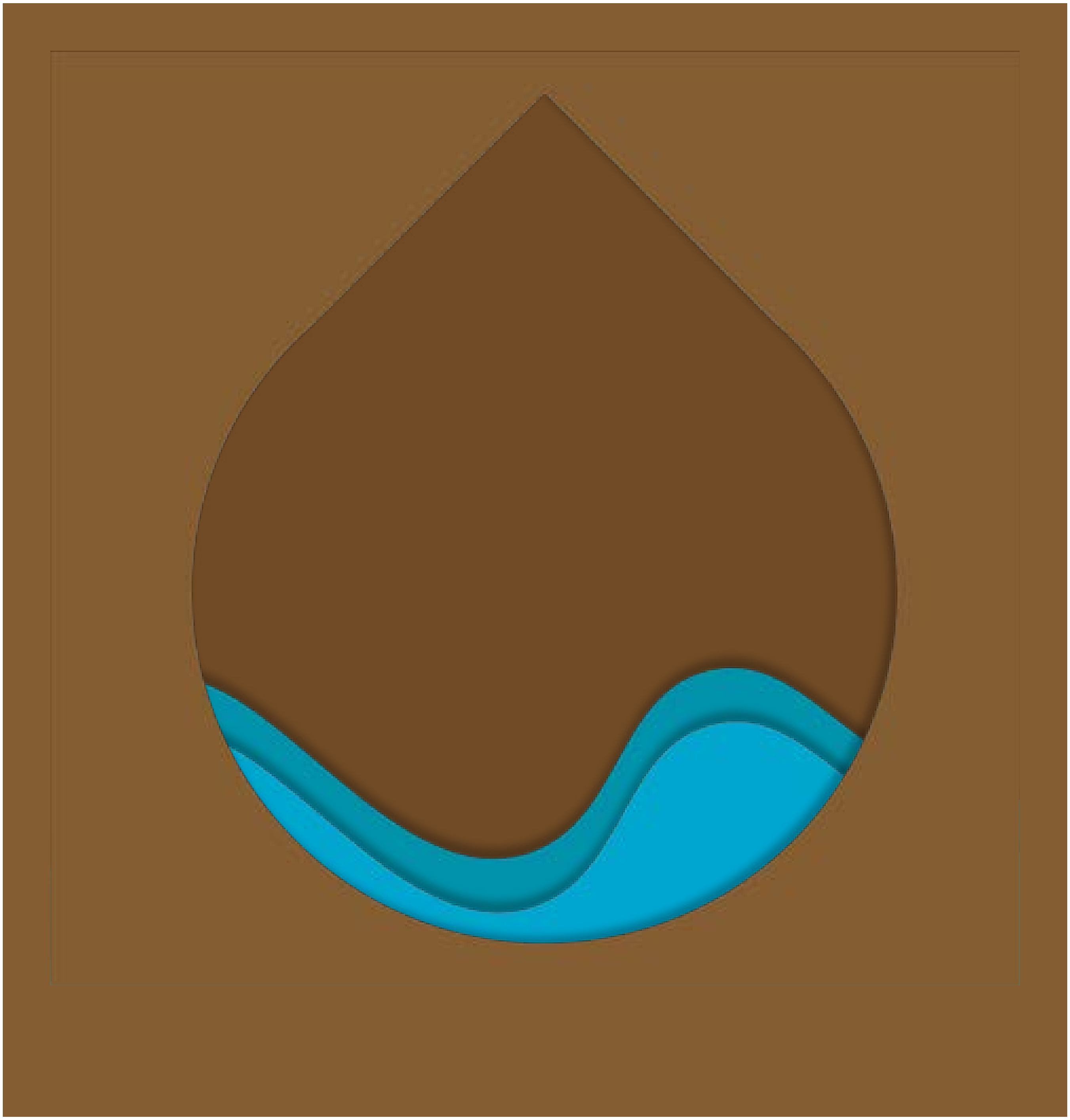
Click on the image to enlarge it

	A	B	C	D	E
1	Date	River	Polygon	Classification	User
2	2024-09-04	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
3	2024-09-06	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
4	2024-09-09	Torrente Torre	example_torre_5	Ponding	joseantoniolopez
5	2024-09-11	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
6	2024-09-14	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
7	2024-09-16	Torrente Torre	example_torre_5	Dry	joseantoniolopez
8	2024-09-19	Torrente Torre	example_torre_5	Dry	joseantoniolopez
9	2024-09-21	Torrente Torre	example_torre_5	Dry	joseantoniolopez
10	2024-09-24	Torrente Torre	example_torre_5	Dry	joseantoniolopez
11	2024-09-26	Torrente Torre	example_torre_5	Ponding	joseantoniolopez
12	2024-09-29	Torrente Torre	example_torre_5	Ponding	joseantoniolopez
13	2024-10-01	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
14	2024-10-04	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
15	2024-10-09	Torrente Torre	example_torre_5	Ponding	joseantoniolopez
16	2024-10-11	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
17	2024-10-14	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
18	2024-10-16	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
19	2024-10-19	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
20	2024-10-21	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
21	2024-10-24	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
22	2024-10-26	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
23	2024-10-29	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
24	2024-10-31	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
25	2024-11-03	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
26	2024-11-05	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
27	2024-11-08	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
28	2024-11-10	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
29	2024-11-13	Torrente Torre	example_torre_5	Cloudy	joseantoniolopez
30	2024-11-15	Torrente Torre	example_torre_5	Flowing	joseantoniolopez
31	2024-11-18	Torrente Torre	example_torre_5	[illegible]lowing	joseantoniolopez

*Exported **.xlsx file** with all the polygon data of the example*

CONTINUE

Closure



Congratulations!

You have **completed** this module.

We trust that this journey has increased your knowledge about the use of the RiverTemp classifier tool.

Let's move to module 5!

MODULE 5: Time series analysis and hydrological modeling_v2_IT

rivertemp

Co-funded by the European Union

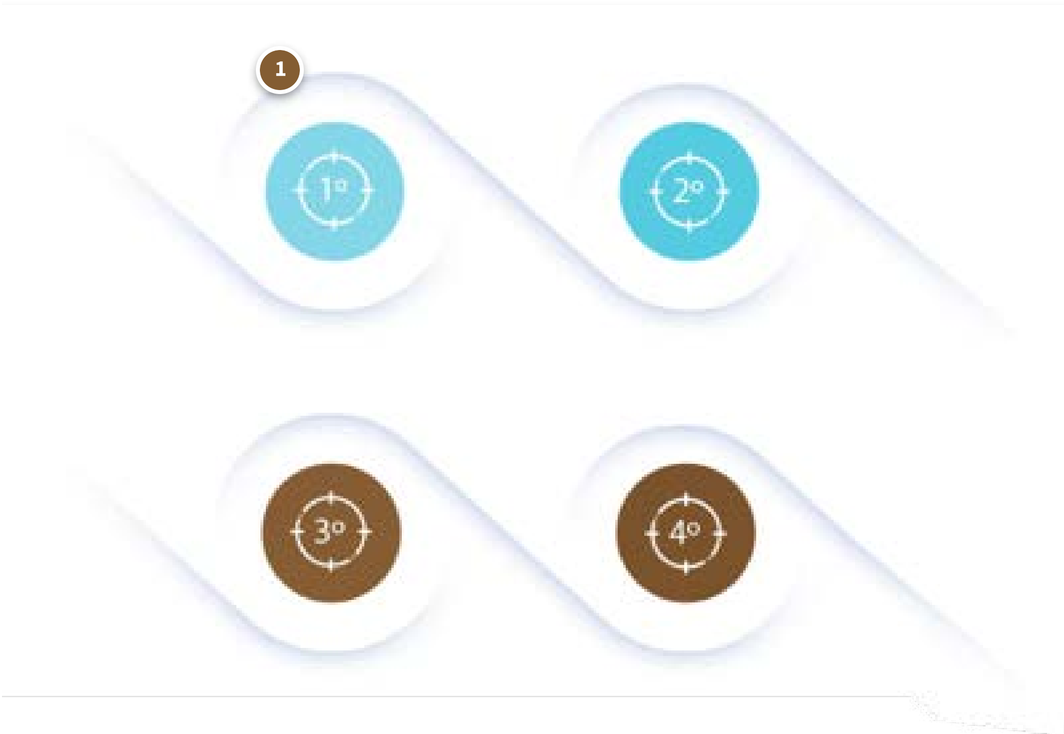
This module will teach you how to integrate hydrological modeling with classified satellite images. This integration will help to better determine the intensity of flow intermittency and understand the actual behavior of temporary rivers.

LET'S GET STARTED!

Objectives & Learning Outcomes

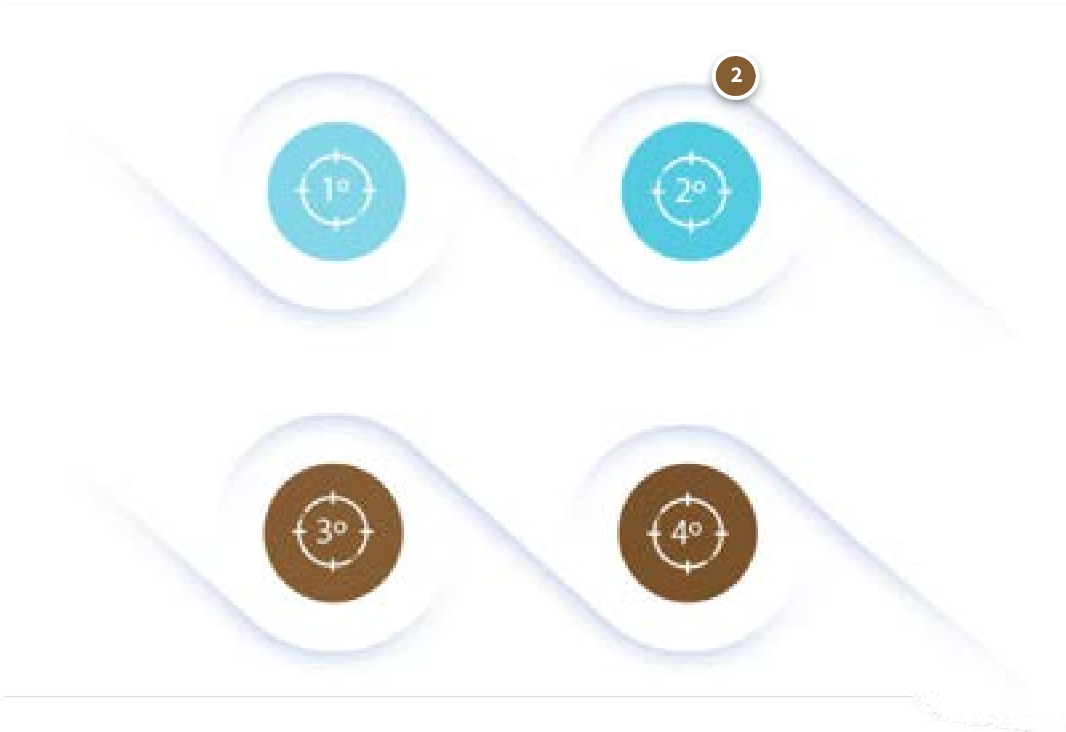
The **4 Objectives and Learning Outcomes** of this module are the following:

Click on the buttons to view the information.



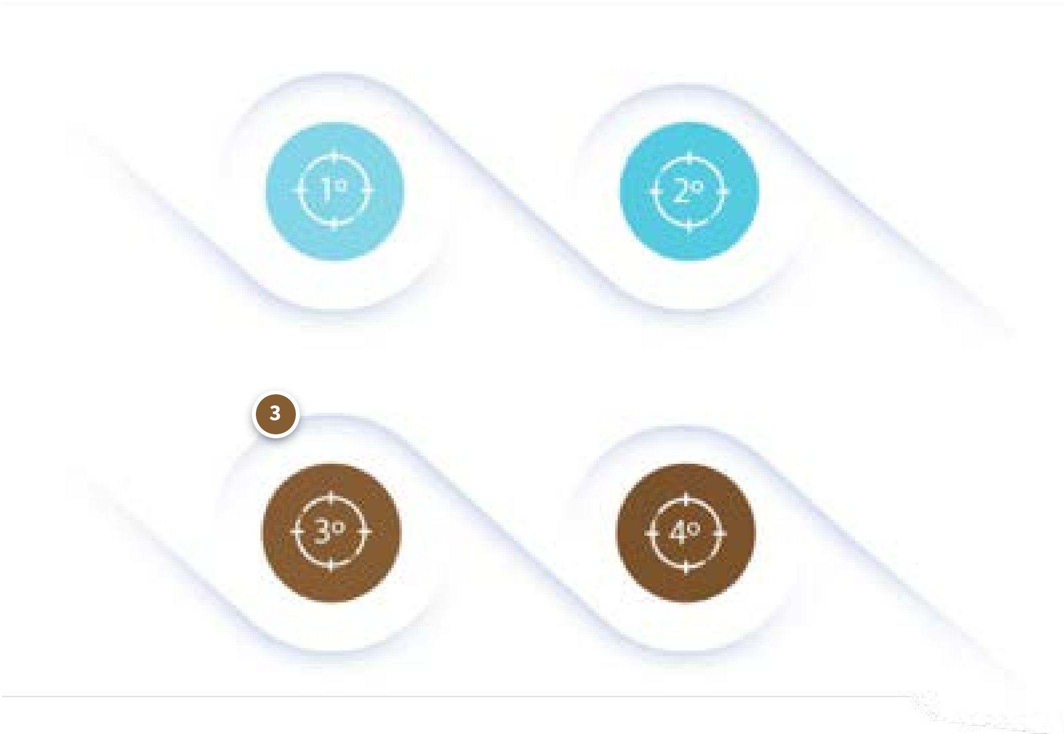
1

Learn how to **analyze time series** of satellite images.



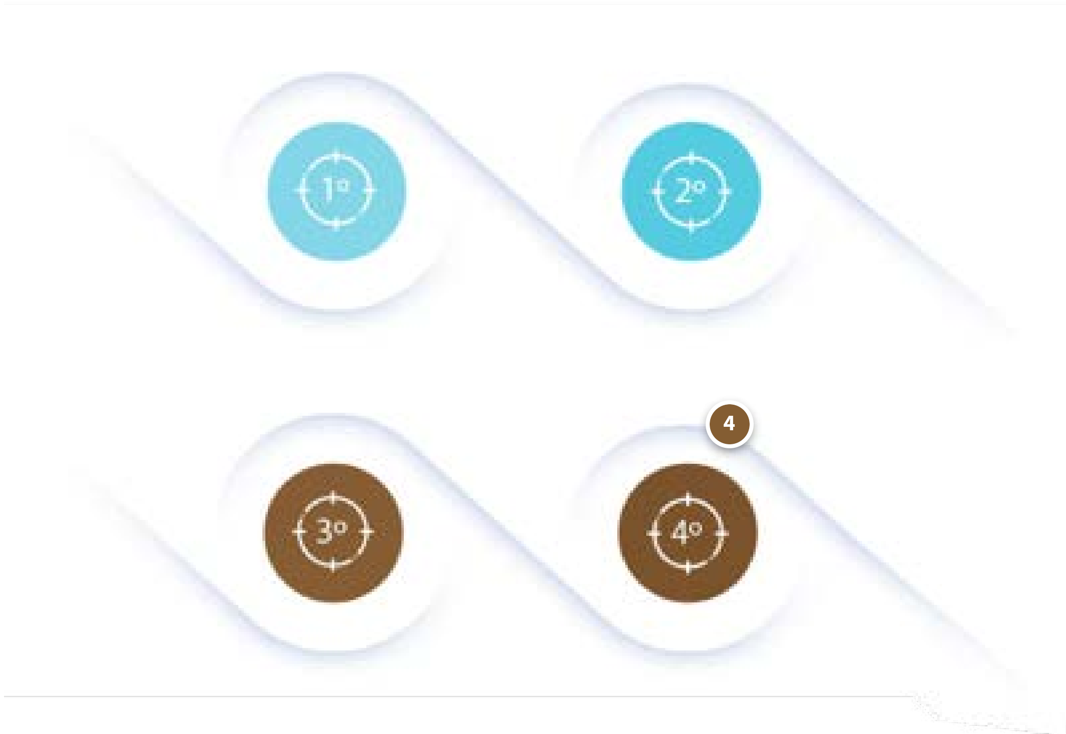
2

Understand the **satellite data and hydrological modeling limitations.**



3

Learn how to **integrate the results of hydrological models with satellite imagery.**

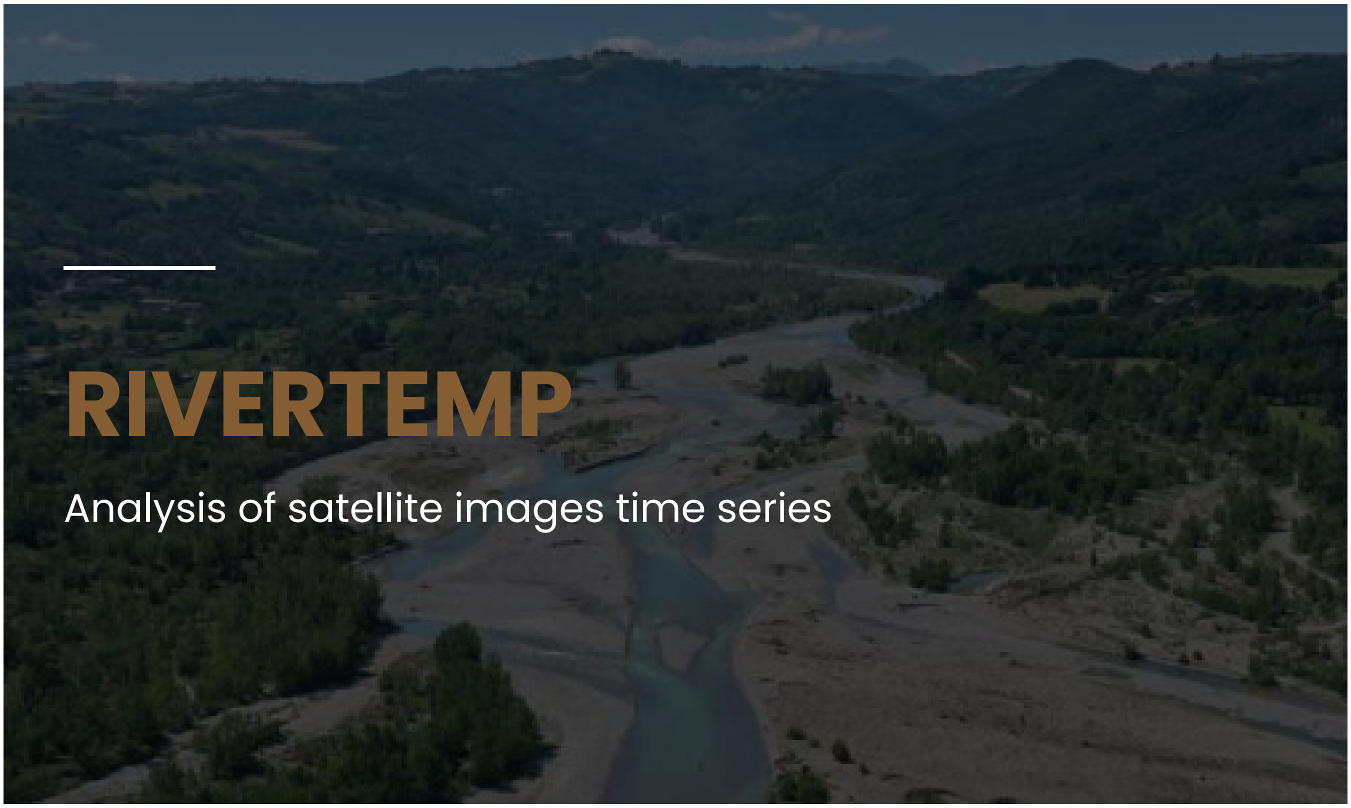


4

Use a **hands-on example** on the **Keritis river, Chania** (Greece).

CONTINUE

Analysis of satellite images time series



In previous modules, it was shown that satellite images could be used to assess the hydrological conditions of a temporary river and determine if the river is in:

F

Flowing condition

P

Ponding condition

D

Dry condition

CONTINUE

IMPORTANT

From an hydrological and ecological perspective, one of the most diffused approaches to estimate the frequency and duration of dry periods is based on the distinction of three different hydrological conditions.

Click on the START > button to view the information and click on the images to enlarge them.

Sciarapotamo river, Salerno (IT) under the 3 hydrological conditions F) flowing, P) ponding, and D) dry.

Flowing condition (F)

Visible continuous flow of water along the analysed river reach.

The flowing condition is easily detectable since there is a continuous surface flow in the river channel.

Ponding condition (P)

Discontinuous water presence; surface water is located in isolated ponds, pools or portions of the low-flow channel.

The ponding condition is more ambiguous, because it regroups intermediate states in which surface water is present along the river channel, forming isolated ponds, pools or submerged portions of the low-flow channel. This condition is typically stable when there is a significant connection with the groundwater or when having hyporheic fluxes connecting the riverbed and the water table.

Dry condition (D)

Absence of surface water, with dry riverbed.

The dry condition implies the absence of surface water inducing dry riverbed, and it is generally due to the complete disconnection of the river with the groundwater.

References:

(Cavallo et al., 2022)

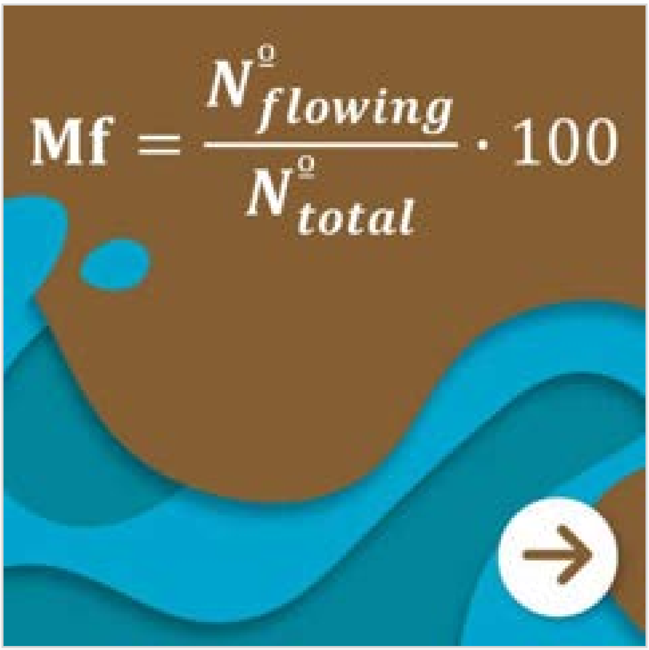
Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

As an output of the classification for a defined time period, the metrics we use are **Mf, Mp and Md,** representing respectively the temporal permanence of the **flowing, ponding and dry** hydrological conditions, expressed as a **percentage of the satellite cloud-free images**.

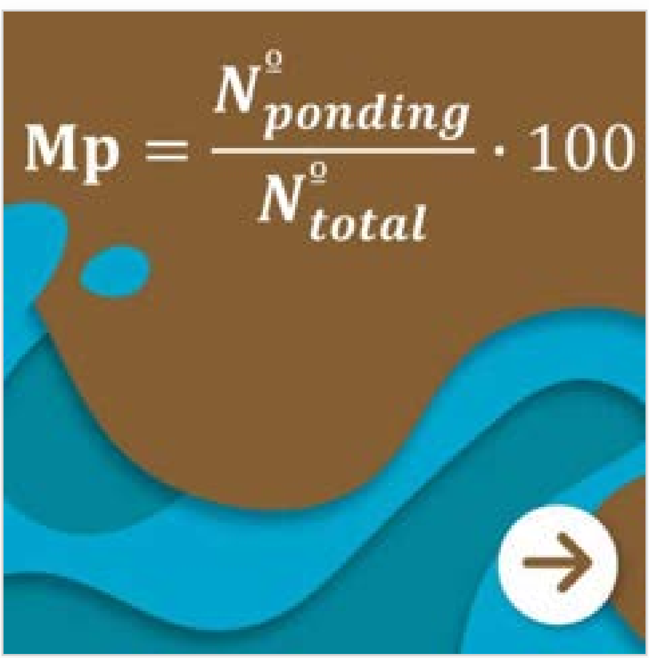
Specifically, these percentages are calculated based on the total classified images **(N_{tot}).**

Please, note that the total number of classified images does not include cloudy imagery.

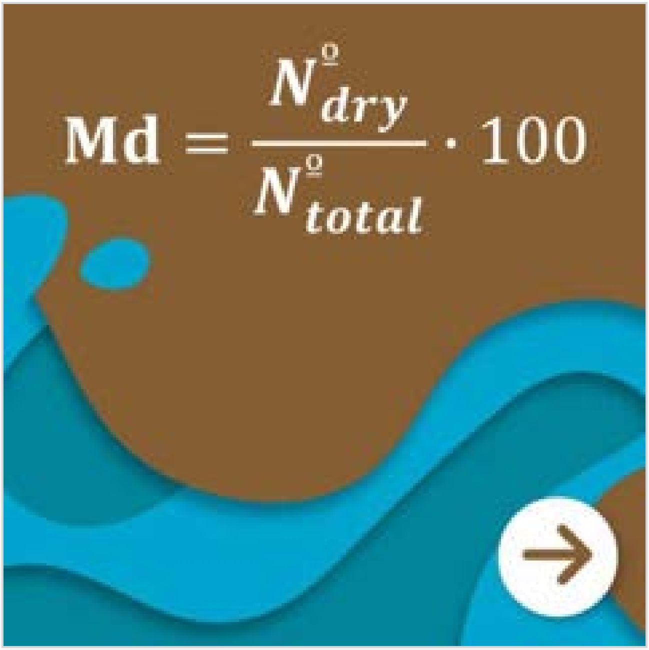
Click cards to flip



$N_{flowing}$ is the number of images classified as **flowing**.



$N_{ponding}$ is the number of images classified as **ponding**.



N$_{\mathbf{dry}}$ is the number of images classified as **dry**.

By definition, the sum of these three parameters is equal to 100%.

CONTINUE

Effective Revisit time

The **Effective Revisit time (ERt)** represents the average effective time elapsed between two classified images, excluding the cloudy ones. This parameter can be calculated as follows:

Click cards to flip

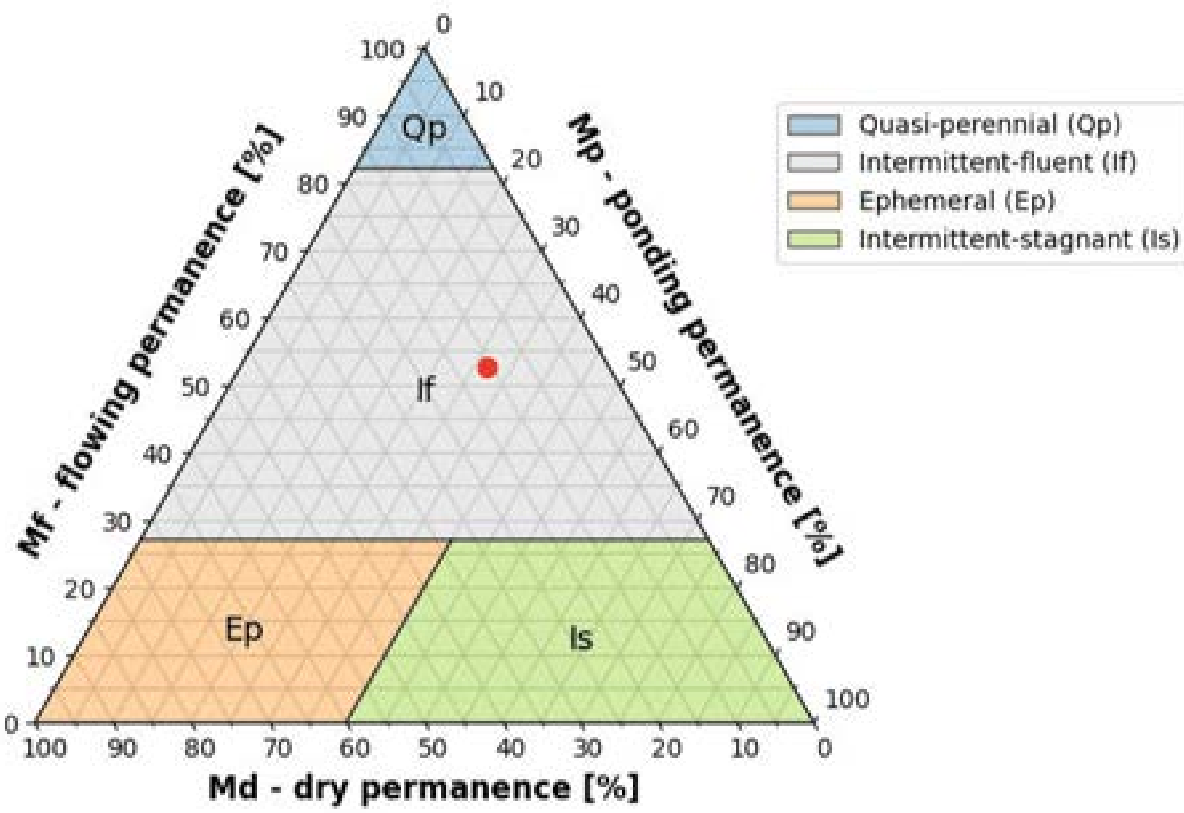
$$\mathrm{ERt} = \frac{N^{\underline{o}}_{days}}{N^{\underline{o}}_{total}}\ (\text{days})$$

Where $\mathbf{N_{days}}$ is the number of days in the analyzed period.

For example:

365 days for a selected period of 1 year.

Once the permanence of each hydrological condition **(Mf, Mp and Md)** has been calculated, it is possible to plot a point in the **ternary plot** and determine the **relative hydrotype**.



Hydrotype definition using the ternary plot for temporary rivers. The red dot can fall into one of the four following classes: “Quasi-perennial”, “Intermittent-fluent”, “Intermittent-stagnant”, and “Ephemeral” (**Munné et al., 2021**).

i

Munné, A., Bonada, N., Cid, N., Gallart, F., Solà, C., Bardina, M., ... & Prat, N. (2021). A proposal to classify and assess ecological status in Mediterranean temporary rivers: Research insights to solve management needs. Water, 13(6), 767.

Example

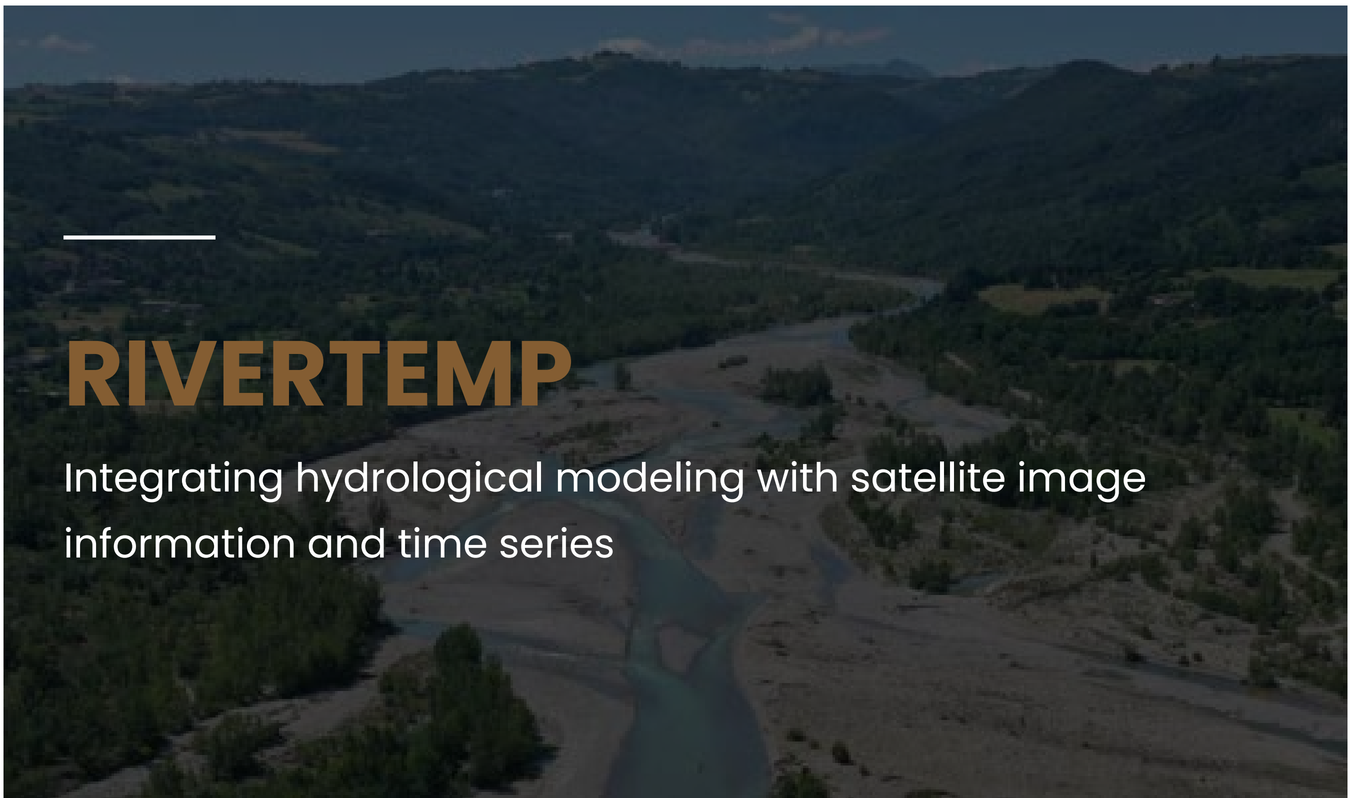
In the example, the values are:

- **Mf**=52.6%
- **Mp**= 31.6%
- **Md**=15.8%.

These values indicate that **the river reach is Intermittent-fluent** (named **If**, the area in gray color).

CONTINUE

Integrating hydrological modeling with satellite image information and time series



IMPORTANT

The **integration of hydrological model and satellite images** allows to determine hydrological conditions daily, filling the gaps in between satellite images.

Temporary river network suffers a lack of representation in the available digital hydrological datasets since **traditional streamflow gauging systems are generally installed in perennial rivers.**

In addition, **streamflow gauges only measure surface flow at one point or cross-section**. In temporary rivers, this type of measurement demonstrated limitations in representing the actual extension and spatial variability of submerged areas along the riverbed (e.g., during the ponding condition).

Therefore, linking the recorded discharges directly to the actual surface water presence in temporary river reaches is extremely difficult. **Hydrological modeling can be exploited to simulate the flow rate in a river when stream gauges are not present**.

However, both measured and predicted streamflow time series can be verified **using the available satellite imagery**.

Click cards to flip

What does this **mean**?

This means that a predicted flow rate can be related to a specific hydrological condition (flowing, ponding or dry condition).

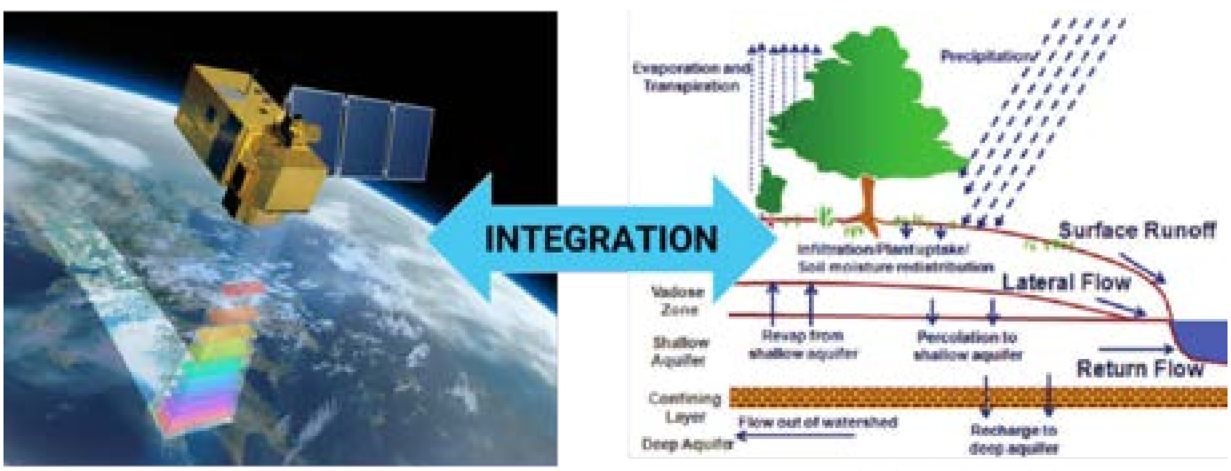
In addition:

If a hydrological model is successfully integrated with satellite images, its prediction performance may increase and can even be used to fill the gaps between satellite images.

In other words...

Classified satellite data can be used to validate the prediction of hydrological models and in turn, the results of hydrological model simulations can be used for the estimation of the hydrological conditions when satellite images are not available.

Click on the image to enlarge it



Sentinel-2 imagery *Hydrological model*

Integration of satellite images and hydrological modeling (left image source European Space Agency (**ESA**), right image source **Neitsch et al., 2011**. Adapted).

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute.

ESA, https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/revisit-coverage

IMPORTANT

It is important to note that this approach accomplishes the **Water Framework Directive** (**WFD, European Commission, 2000**) which requires continuous measurements or modeling of the natural flow rate in all water bodies belonging to the EU Member States.

European Commission. (2000). Directive 2000/60/EC of the European Parliament and of the Council of October 23, 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities, 22(12), 2000.https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/revisit-coverage

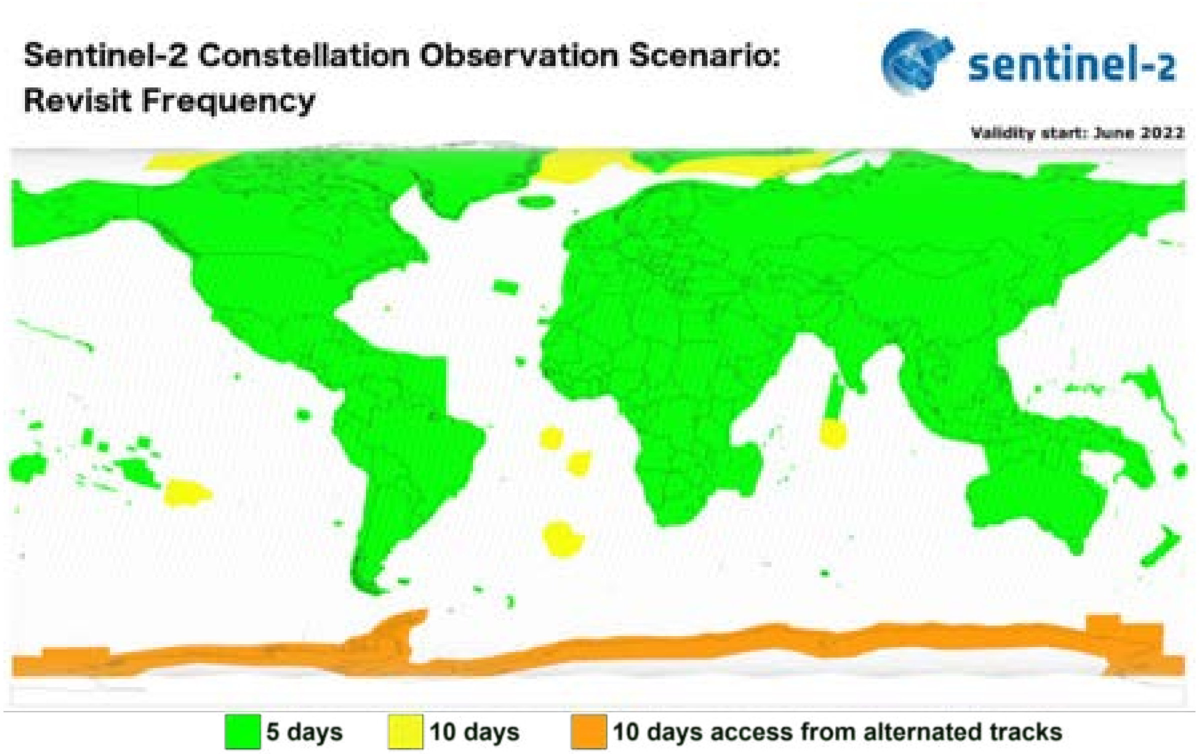
CONTINUE

Satellite limitations

The integration of hydrological modeling with classified satellite images can be used to overcome the following **limitations**:

Click on the buttons to view the information.

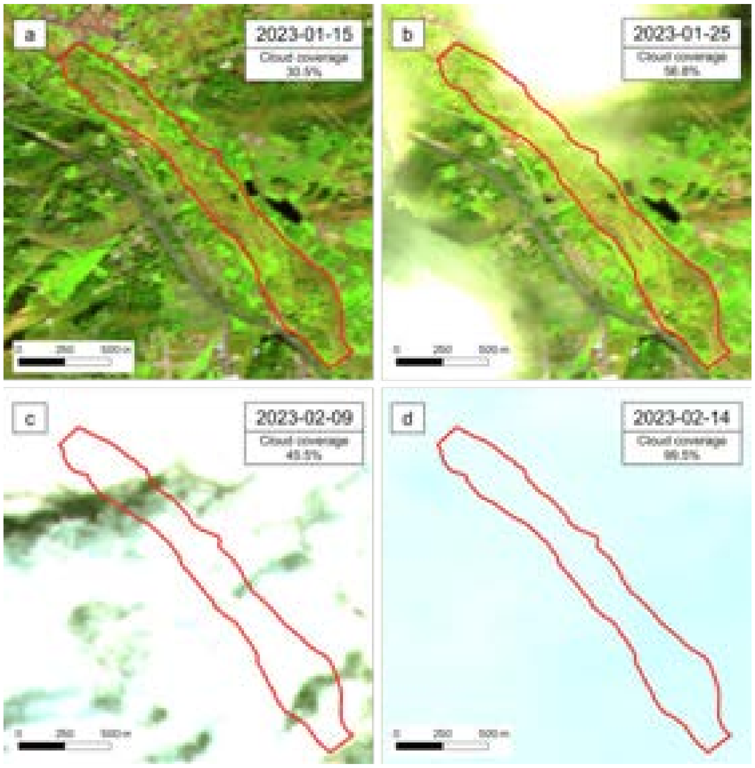
Large satellite revisites time



Map of revisit time frequency for Sentinel-2 Satellites (source ESA).
***Reference**: ESA, https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/revisit-coverage*

Sentinel-2 satellites do not pass over a certain location daily but on a nominal revisit time of **usually 5 days** (for non-polar areas).

Cloud cover



Different examples of Sentinel-2 satellite images in which cloud coverage is present. a-d) Examples of the Palancia river at Gilet (Spain).

The presence of clouds reduces the number of suitable satellite images.

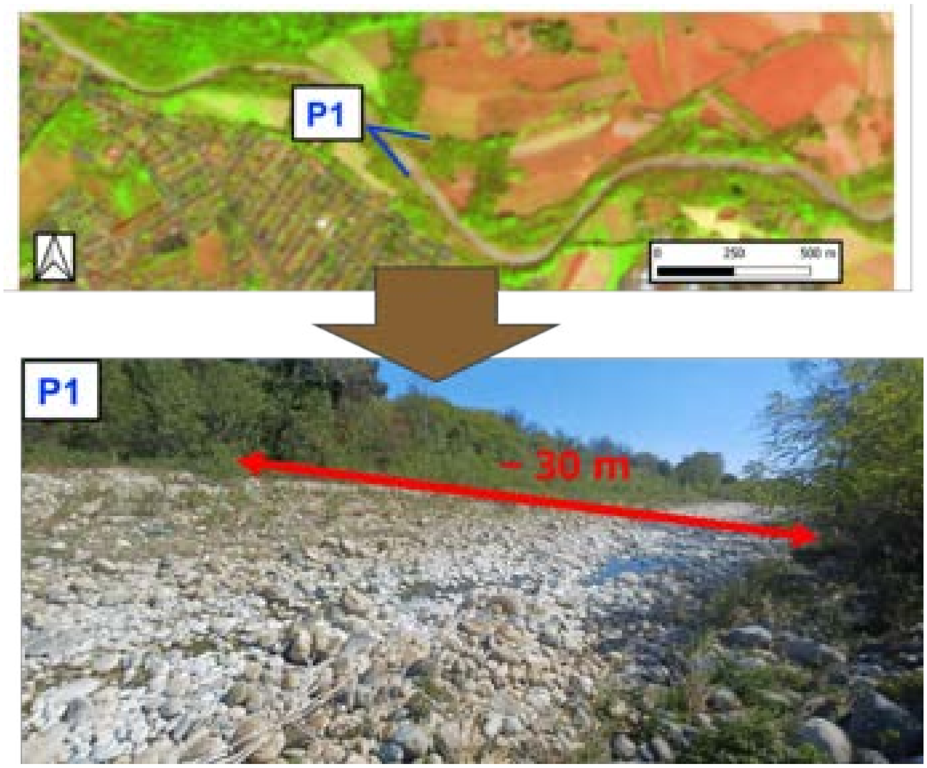
Presence of shadows

Example of Sentinel-2 satellite image in which cloud's shadows are projected in the Palancia riverbed at Gilet (Spain).

Shadows may be misclassified by water since the two have similar spectral behavior. Satellite images can be disregarded due to the presence of shadow produced by clouds, tall riparian vegetation, and high river banks.

4

Narrow river channel



Visualization from a satellite image and georeferenced pictures of Sangone river reach at Rivalta di Torino (Italy), 2022. Photo credits Giammarco Manfreda.

Considering the spatial resolution of Sentinel-2 satellites, which goes from 10 to 20 m for the bands under interest, thin river channels, with an average width lower than 30m, cannot be correctly interpreted.

5

Presence of vegetation dome

Vegetation dome on the Lurisia stream (Italy). Photo credits Paolo Vezza

If the active channel is partially or completely covered by vegetation domes or canopies, it is not possible to retrieve the ongoing hydrological condition from satellite observations.

CONTINUE

Example: Case study of Keritis basin, Chania, Crete (Greece) using the karst-SWAT model

Study area

Image credits Adrian Campfield

The study area used for the hydrological modeling example is the **Keritis river basin**, located in the **Northwestern** part of **Chania** Prefecture in **Crete Island, Greece.**

The **Keritis river** is one of the two principal river basins of the municipality of Chania (Greece). It flows for **11**

km, draining an area of about 136 km^2 (**Kanta et al., 2013**).

Kanta, A., Soupios, P., Barsukov, P., Kouli, M., & Vallianatos, F. (2013). Aquifer characterization using shallow geophysics in the Keritis Basin of Western Crete, Greece. Environmental Earth Sciences, 70, 2153-2165.

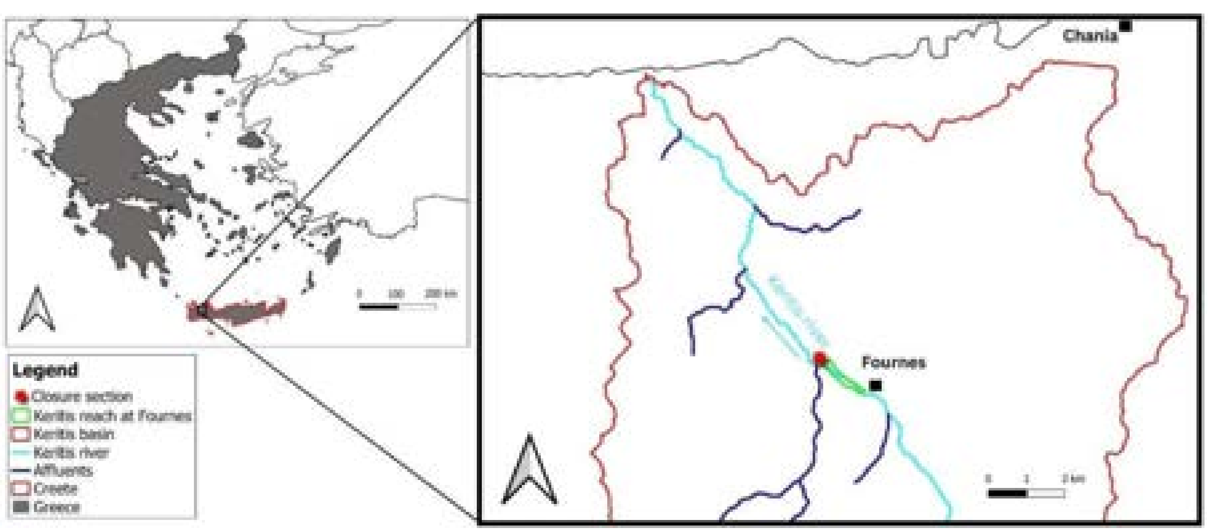
The specific geomorphology of this watershed can be simplified defining three principal zones (**Dimitriou et al., 2016**):

1. The **karst**.
2. A **transition zone**.
3. The **lowlands**.

Dimitriou, A., Giannakis, G., Nerantzaki, S., & Nikolaidis, N. P. (2016). Hydrologic and geochemical modeling of Keritis River Basin. Proceedings of the 2nd EWaS International Conference. 1–4 June, 2016, Chania, Crete, Greece. ResearchGate.

Within the hydrological network of the **Keritis basin**, a hydro-morphologically homogenous reach at **Fournes** was defined as a study area for implementing the integrated approach utilizing supervised satellite classification and hydrological modeling.

Clik on the image to enlarge it



Location of the analyzed Keritis river reach in the Chania

Prefecture, close to the Fournes village.

CONTINUE

Watershed modeling with SWAT model

In this module, we used the **Soil and Water Assessment Tool** (**SWAT**) to model the daily flow rates of the Keritis river at Fournes. **SWAT** is a hydrological model that assesses the impact of land management techniques on water resources (**Neitsch et al., 2011**).

SWAT is a process-oriented, spatially distributed model capable of simulating various facets of the hydrological cycle such as **precipitation**, **runoff**, **evapotranspiration**, **soil moisture**, and **nutrient transport**.

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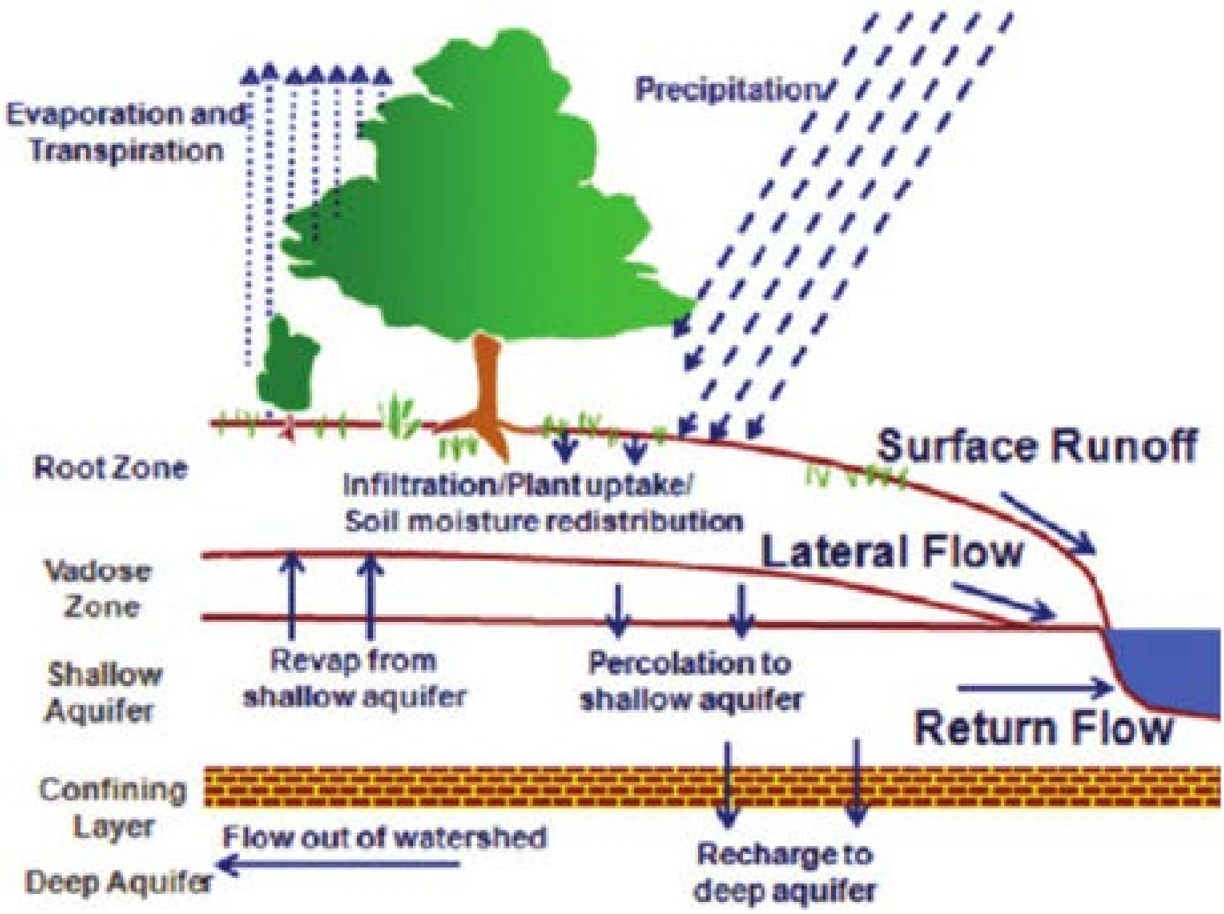
Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute.



SWAT model schematic representation (**Dimitriou et al., 2016**).

Dimitriou, A., Giannakis, G., Nerantzaki, S., & Nikolaidis, N. P. (2016). Hydrologic and geochemical modeling of Keritis River Basin. Proceedings of the 2nd EWaS International Conference. 1–4 June, 2016, Chania, Crete, Greece. ResearchGate.

Therefore...

The **SWAT model** is able to simulate **surface runoff** on the land surface when precipitation exceeds:

- The soil's absorption capacity.
- The lateral flow in the vadose zone (or unsaturated zone) above the water table level.
- The return flow from the shallow aquifer.

CONTINUE

Karst formations

Nevertheless, the **complexity of this watershed** is due to the extensive presence of **karst formations** in the upper part of the basin. The **hydrology** of karst formation is governed by the **epikarst zone**, the unsaturated zone characterized by **high hydraulic conductivity** due to large fractures.

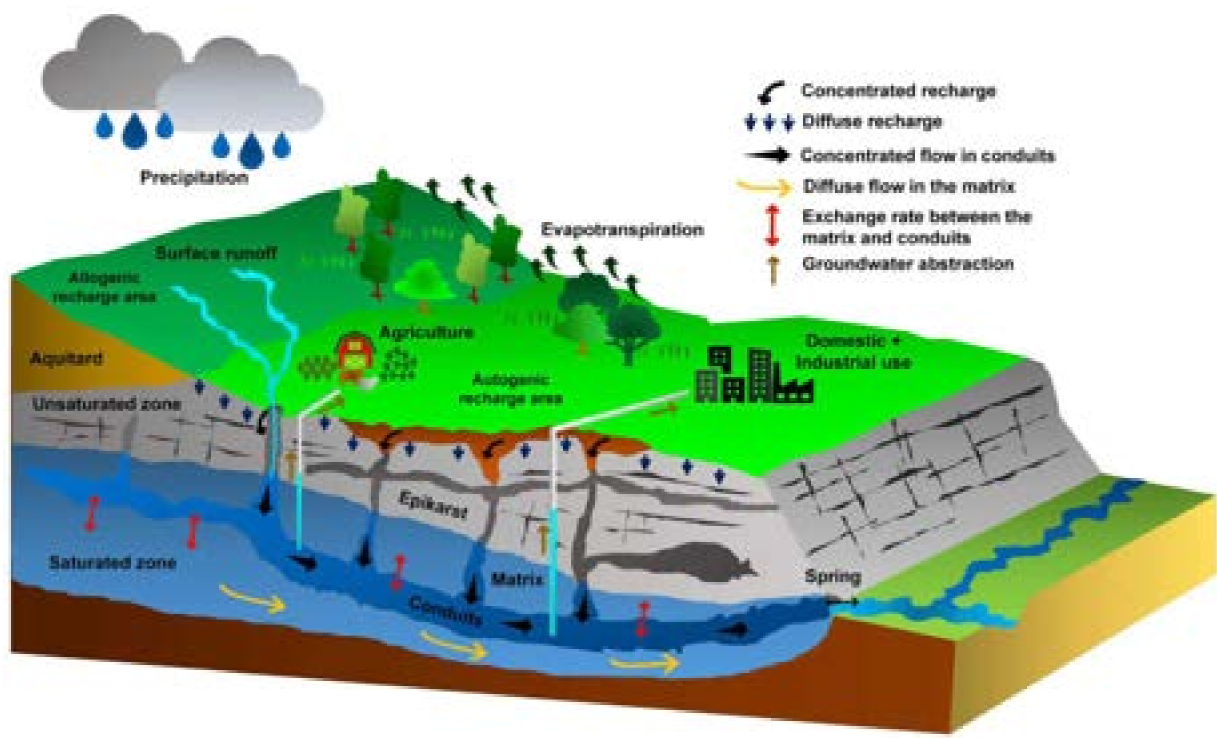
The **epikarst** is the **primary drainage** to the saturated zone composed of the **matrix**, **low permeability**, and **karst conduits**, channels or tunnels formed by erosion of rock over time, responsible for high flow rates in the deep aquifer.

When the **conduits of the deep aquifer** reach the surface, they form the **karst springs**, usually where karst formation interfaces the transition zone. It is important to note that, for the **Keritis river**, **the contribution of this system** is not negligible, estimated to be **around 60% of the total discharge** (**Nikolaidis et al., 2013**)

i

Nikolaidis, N. P., Bouraoui, F., & Bidoglio, G. (2013). Hydrologic and geochemical modeling of a karstic Mediterranean watershed. Journal of Hydrology, 477, 129-138.

Click on the image to enlarge it



Conceptual schematic of hydrological processes in a kars system (**Al Khoury I et al., 2023**).

Al Khoury I, Boithias L, Labat D. A Review of the Application of the Soil and Water Assessment Tool (SWAT) in Karst Watersheds. Water. 2023; 15(5):954.

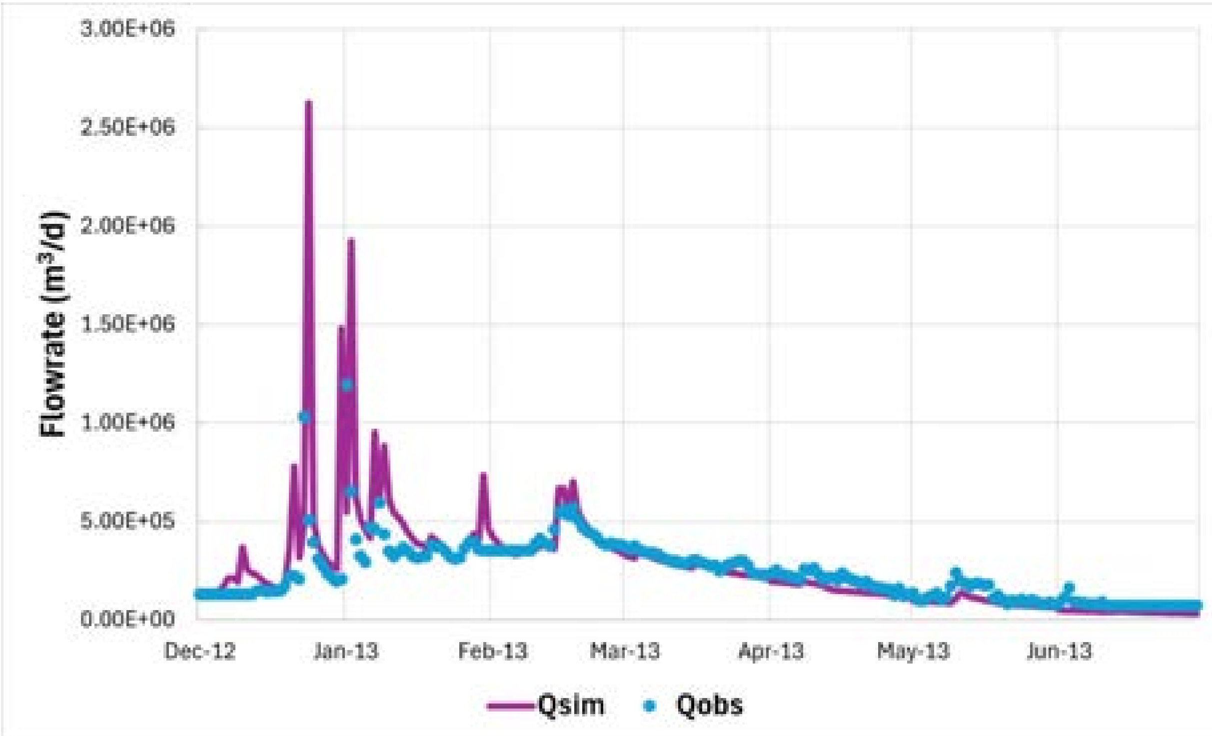
CONTINUE

Karst-SWAT model results

In the **SWAT model**, the water recharging the deep aquifer is considered lost from the system. Due to the significant presence of **karst formation**, this limitation has to be overcome. For this purpose, **a karstic model has been integrated into the SWAT model to quantify the contribution of the springs to the Keritis river flow rate**.

The Figure below exhibits the **comparison between observed flow rates in the Keritis river and the simulated flow rates** with the integrated karst-SWAT model. Although the available field data are limited, **the hydrological model demonstrates the capability to predict the trend of the total discharge of the river**.

Click on the image to enlarge it



Comparison between **simulated** (**Qsim**) and **observed** (**Qobs**) flow rates.
Example of Karst-SWAT performance for the total daily flow of the Keritis river between December 2012 - June 2013.

CONTINUE

Integration of satellite imagery and hydrological

models

The integration of hydrological modeling and satellite images is explained in the following **three steps**:

Click on the tabs to view the information.

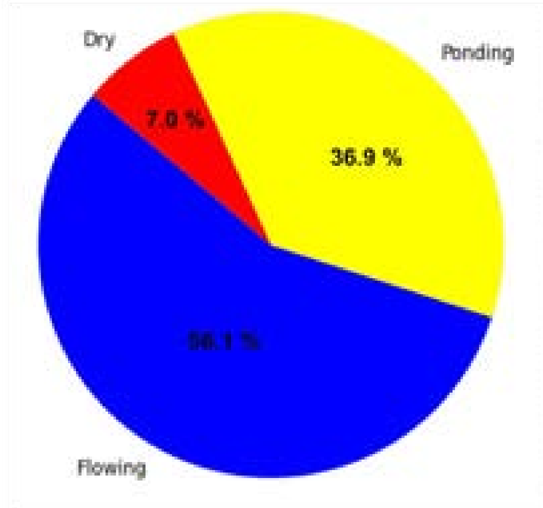
STEP 1 - SATELLITE CLASSIFICATION	STEP 2 - DEFINITION OF THRESHOLDS	STEP 3 - HYDROTYPE IDENTIFICATION

First of all, we can associate the modeled daily flow rate with the satellite image classification (figure on the left).

The satellite classification of the imagery has been performed during the period 2019-2023 on Keritis river reach. This analysis revealed a permanence of the three different hydrological conditions equal to Mf=56.1%, Mp= 36.9% and Md=7.0% (figure on the right).

Date (dd/mm/aaaa)	Qtot (m³/s)	Satellite classification
05-01-2020	38.41	
06-01-2020	5.85	Cloudy
07-01-2020	5.05	
08-01-2020	4.40	
09-01-2020	4.10	
10-01-2020	3.85	
11-01-2020	5.02	Flowing
12-01-2020	5.86	
⋮	⋮	⋮
30-12-2020	2.75	
31-12-2020	2.68	Flowing
01-01-2021	2.60	

Modeled daily flow rates associated with the hydrological conditions derived by satellite image classification



Pie chart showing the permanence of each hydrological condition in the Kentis river in the period 2019-2023

STEP 1 - SATELLITE CLASSIFICATION	STEP 2 - DEFINITION OF THRESHOLDS	STEP 3 - HYDROTYPE IDENTIFICATION

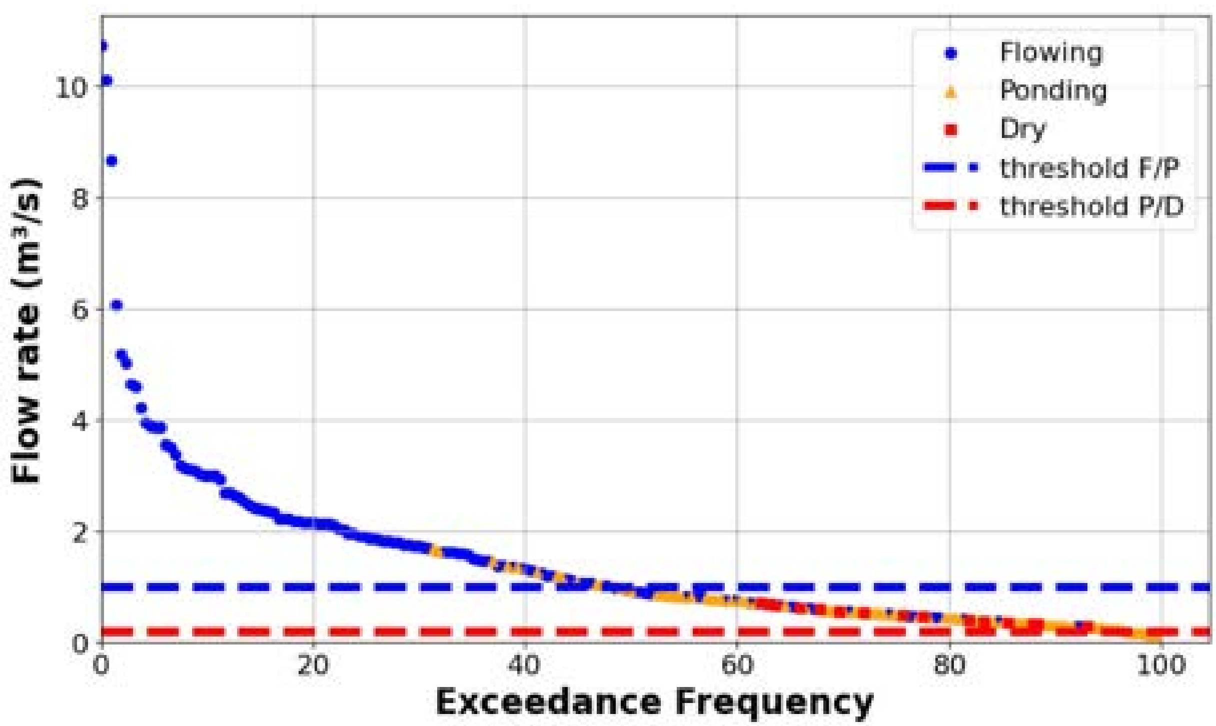
As a second step, we created a **flow duration curve** (**FDC**) for the entire analyzed period (2019-2023). FDCs represent the relationship between the magnitude and the frequency of the flow rate (figure below).

Looking at the results, the **FCD** does not report zero flow events (figure below). However, several ponding and dry conditions have been observed from satellite images.

Using the combined information from both satellite images and hydrological modeling, it is possible to set thresholds to distinguish between **flowing-ponding** (**F/P**) and **ponding-dry** (**P/D**) conditions in the **FDC**. These thresholds can be then employed to correct the hydrological modeling results.

However, one can argue that the threshold selection can be quite subjective. As a possible example, in this module, we used a threshold of 1 m^3/s to distinguish between **flowing** and **ponding** conditions (F/P), and 0.2 m^3/s to distinguish between **ponding** and **dry** conditions (P/D, figure below).

Flow duration curve (FDC) for the Keritis river reach with the dashed lines indicating the flowing/ponding (F/P) and ponding/dry (P/D) thresholds. Blue circles represent the flowing conditions (F), yellow triangles represent the ponding conditions (P) and red squares the dry conditions (D) estimated using the classified satellite images.



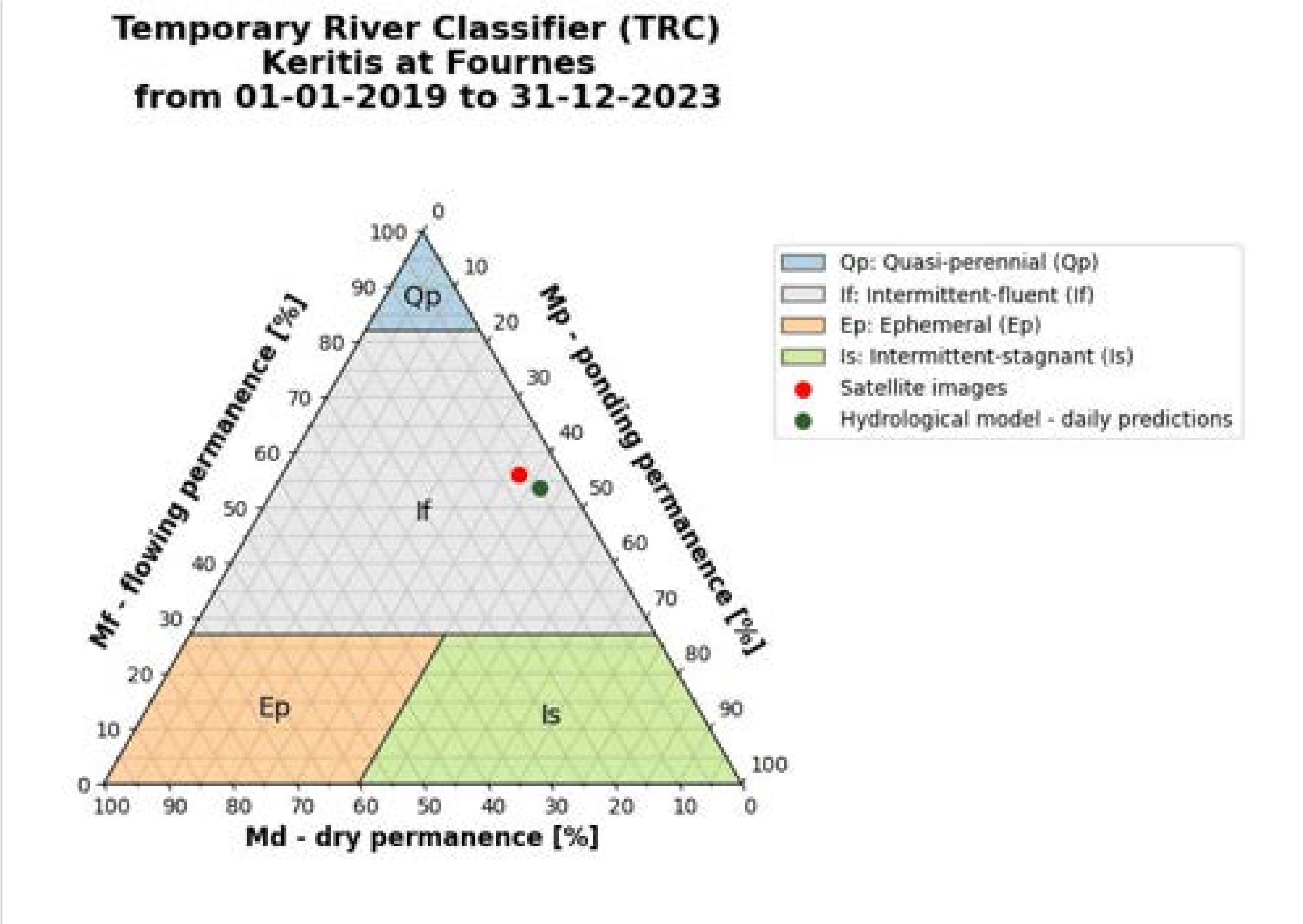
When **thresholds** are defined, it is possible to compare the hydrotype classification carried out through satellite images only and through the integration of hydrological modeling and satellite images.

The hydrological model, corrected using the defined thresholds, permits to fill the gaps between the images and, thus, to foresee the hydrological condition for each day in the entire period 2019-2023.

As reported in the figure below, **the two results are quite similar**. The supervised classification of satellite images yields values of **Mf**, **Mp** and **Md** equal to 56.1%, 36.9% and 7.0%, respectively. Conversely, the integrated approach produces the permanence percentages of **Mf**= 53.7%, **Mp**=41.5% and **Md**=4.8%.

The graph in the figure below also demonstrates how both classifications fall in the same hydrotype: Intermittent-fluent.

*Ternary plot showing the satellite classification (**red**) and the resulting daily predictions of hydrological condition (**green**).*



To improve the performance of the hydrological model, thresholds can be estimated on an annual basis.

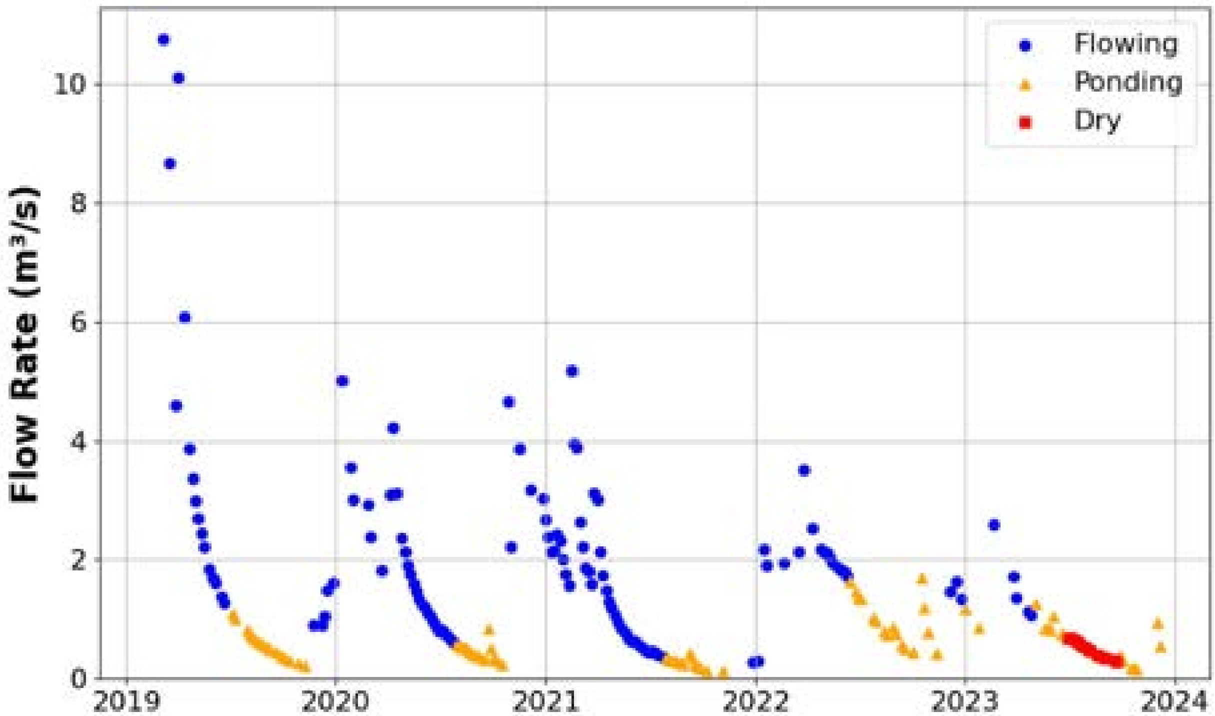
This temporal variation can be caused by **different**

Indeed, the interannual variability shows important differences in terms of flow rate to distinguish between flowing and ponding and ponding and dry conditions (**figure below**).

water table elevation or water use during the analyzed period.

Considering the use of annual thresholds for calibrating the hydrological model appears to be a more suitable approach in the context of our case study.

Click on the image to enlarge it



Time series of flow rate values modeled between 2019-2023. Blue circles represent the flowing conditions (**F**), yellow triangles represent the ponding conditions (**P**) and red squares the dry conditions (**D**).

CONTINUE

Final question

If we generate a ternary plot for every year (from 2019 to 2023), do you think we will find significant movement of the point from one year to another?

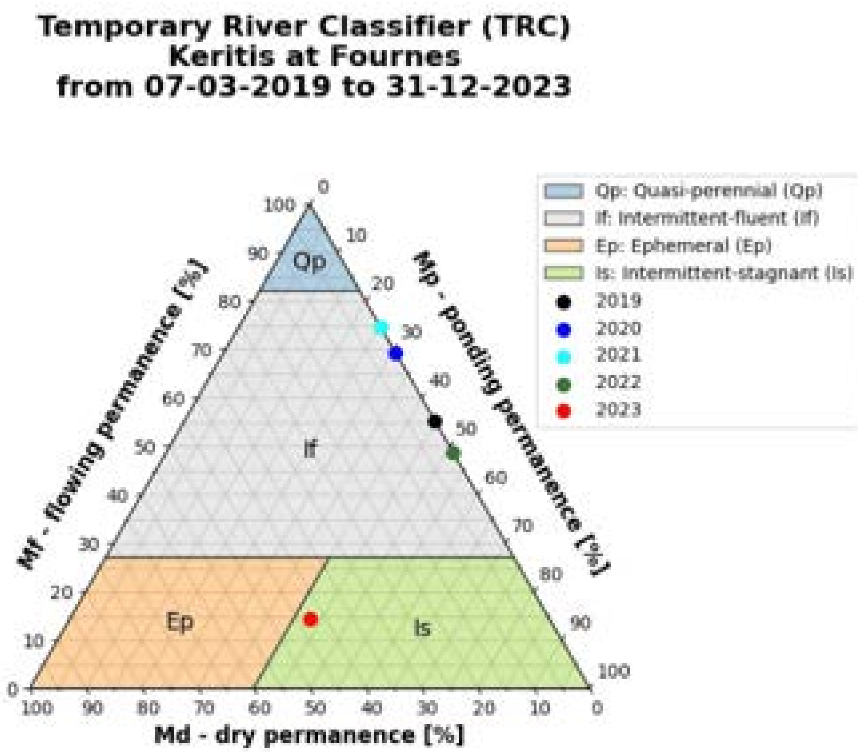
Does the hydrotype remain the same for each year?

CLICK TO VIEW THE ANSWER

ANSWER

The hydrotype may vary from one year to another.

In the figure below you can see the **Hydrotype classification** for each year between 2019 to 2023 using the Keritis river as a case study.



CONTINUE

References

Bibliographic references

In the development of any academic course, bibliographic references play a crucial role by providing the necessary theoretical and practical support for the material taught.

References not only strengthen the credibility of the study materials but also allow students

This set of references has been carefully selected to provide a solid foundation of

to explore the topics covered more deeply, gaining a deeper understanding of key concepts and discovering new perspectives knowledge, encompassing a variety of sources, including books, academic articles, recent research, and digital resources.

We hope these references will be a valuable tool for learning, fostering a comprehensive and critical understanding of the topics addressed in this course.

Al Khoury I, Boithias L, Labat D. A Review of the Application of the Soil and Water Assessment Tool (SWAT) in Karst Watersheds. *Water*. 2023; 15(5):954

Dimitriou, A., Giannakis, G., Nerantzaki, S., & Nikolaidis, N. P. (2016). Hydrologic and geochemical modeling of Keritis River Basin. Proceedings of the 2nd EWaS International Conference. 1–4 June, 2016, Chania, Crete, Greece. ResearchGate.

ESA, https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/revisit-coverage

European Commission. (2000). Directive 2000/60/EC of the European Parliament and of the Council of October 23, 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities, 22(12), 2000.

Kanta, A., Soupios, P., Barsukov, P., Kouli, M., & Vallianatos, F. (2013). Aquifer characterization using shallow geophysics in the Keritis Basin of Western Crete, Greece. *Environmental Earth Sciences*, *70*, 2153-2165.

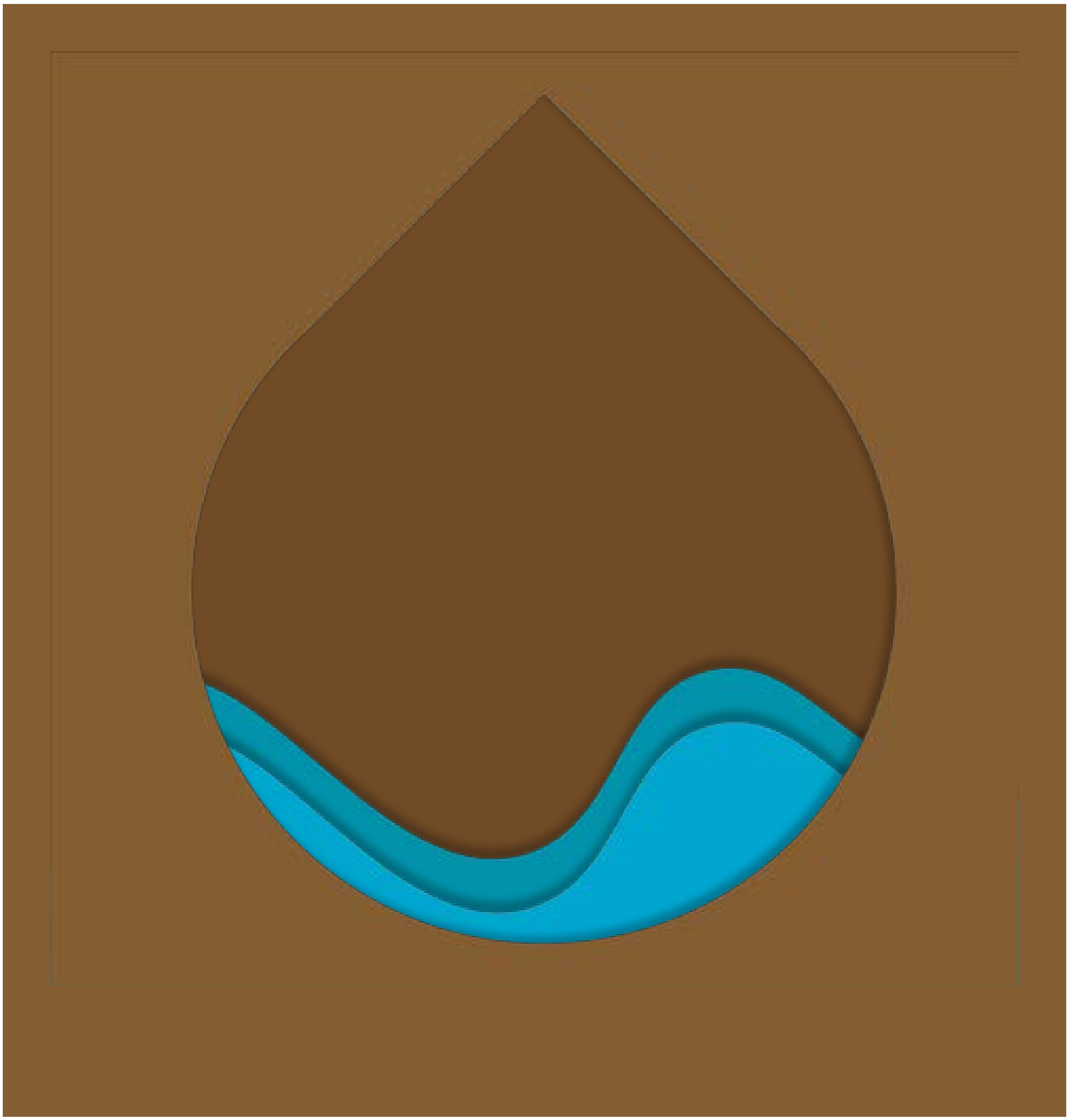
Munné, A., Bonada, N., Cid, N., Gallart, F., Solà, C., Bardina, M., ... & Prat, N. (2021). A proposal to classify and assess ecological status in Mediterranean temporary rivers: Research insights to solve management needs. *Water*, *13*(6), 767.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute.

Nikolaidis, N. P., Bouraoui, F., & Bidoglio, G. (2013). Hydrologic and geochemical modeling of a karstic Mediterranean watershed. *Journal of Hydrology*, *477*, 129–138.

CONTINUE

Closure



Congratulations!

You have **completed** this module.

By successfully completing the fifth module, you have learned how to determine the hydrological status of a river using a combination of hydrological modeling and satellite images results and compare the statistics of flow frequencies between satellite images alone and in combination with hydrological modeling.

Well done!

Let’s move to module 6.

MODULE 6: Field activity_v2_IT

This module provides the opportunity to directly survey a temporary river during a field data collection campaign. The field survey offers students a fantastic chance to put into practice the knowledge gained from the preceding modules.
Make sure to wear comfortable and adaptable shoes or waders, and get ready for an exciting field survey!

LET'S GET STARTED!

3.1. THE LENGTH AND LOCATION OF THE RIVER REACH

Defining the length of the river reach

3.2. ACTIVITIES IN THE FIELD

Activities in the field

Recognition of the hydrological condition in the field

Compare the hydrological condition with satellite images

Geotagged photos acquisition

Validation of hydrological conditions

3.3. ADDITIONAL ACTIVITIES (SUBJECT TO FEASIBILITY)

Observation of terrestrial and aquatic biota

Topographic data acquisition

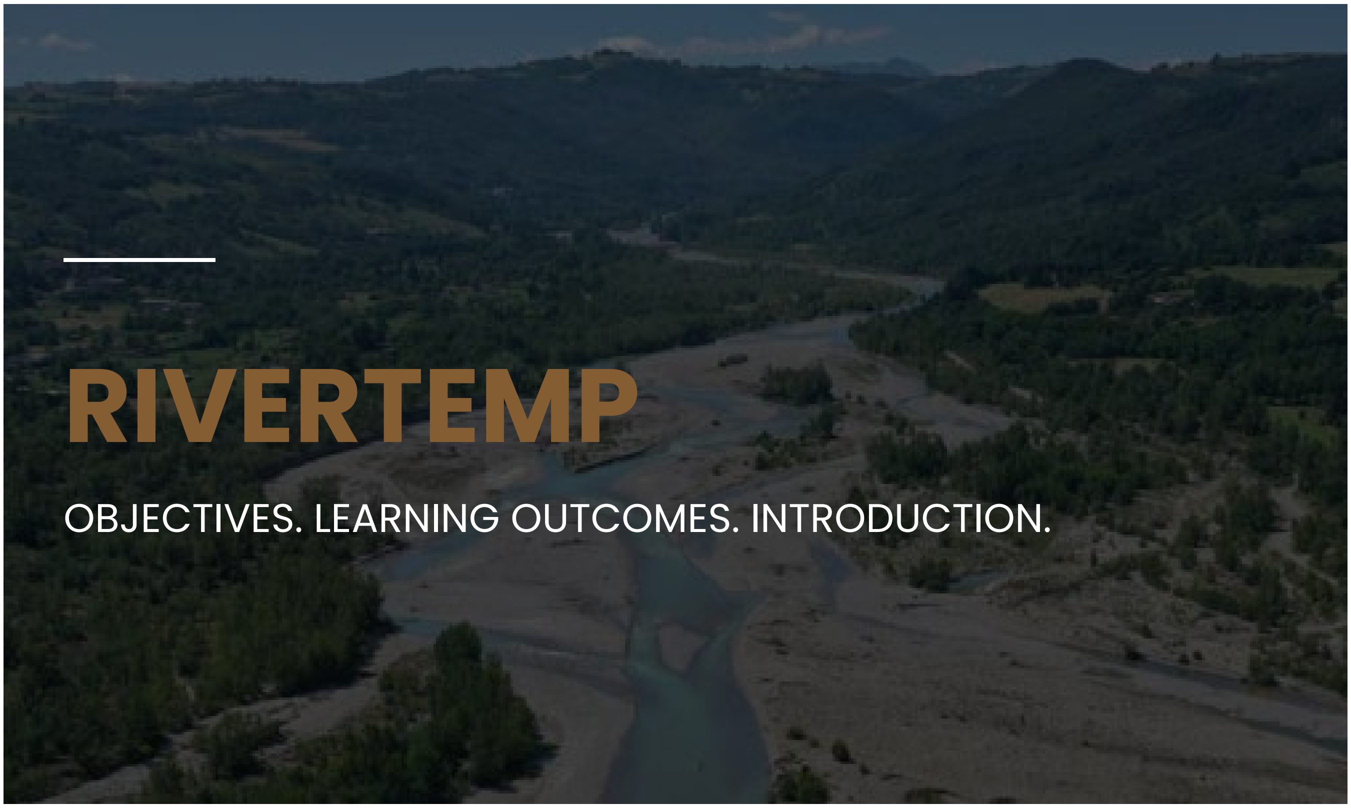
4. REFERENCES

References

5. CLOSURE

Closure

Objectives & Learning Outcomes



The **5 Objectives and Learning Outcomes** of this module 6 are the following:

Click on the buttons to view the information.

1

Observe directly and describe a temporary river.

2

Acquire skills and knowledge about morphological river features.

3

Recognize the hydrological condition of a temporary river.

4

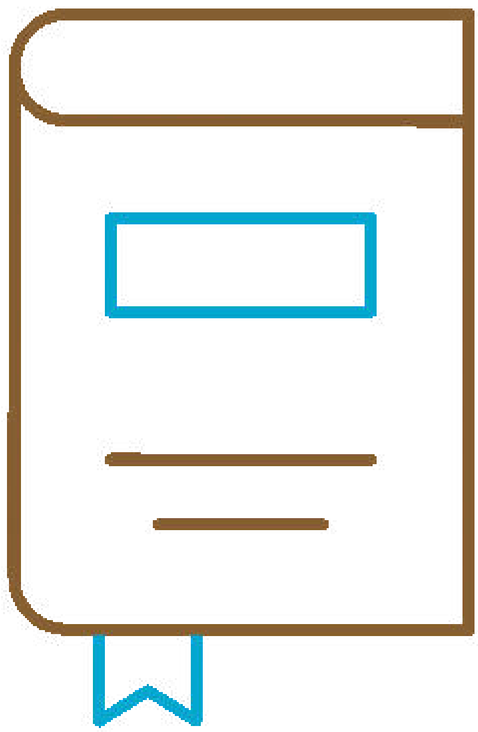
Collect geotagged pictures for the validation and comparison with contemporary Sentinel-2 satellite image.

5

Observe terrestrial and aquatic biota in their habitat.

CONTINUE

Introduction



Test yourself

If there is a temporary river reach around you, take your smartphone, follow the steps outlined in this module and conduct **your first field survey in a temporary reach**!

Why are field surveys important?

The field surveys are essential for **improving the knowledge of the river reach** you want to investigate.

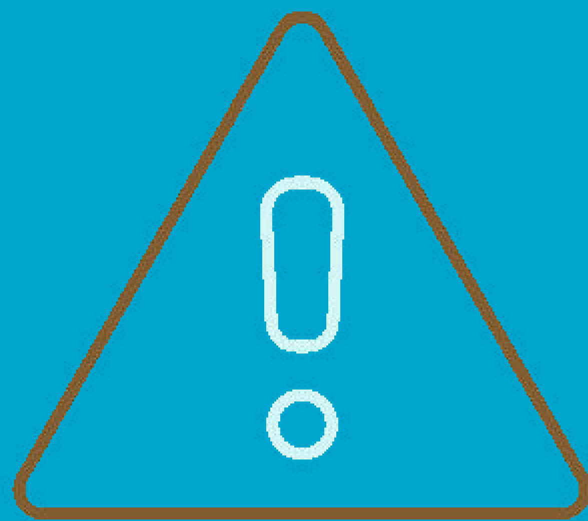
An operator acquiring a geotagged photo during a field survey in the Keritis river (Greece), on the 11th of

September 2024.
Photo credits Isabelle Brichetto

Field surveys can help you to understand the river's morphological processes and the presence of different species of flora and fauna.

Two operators **searching for macroinvertebrates** during a field survey in the Keritis river (Greece), on the 11th of September 2024.

Photo credits Isabelle Brichetto

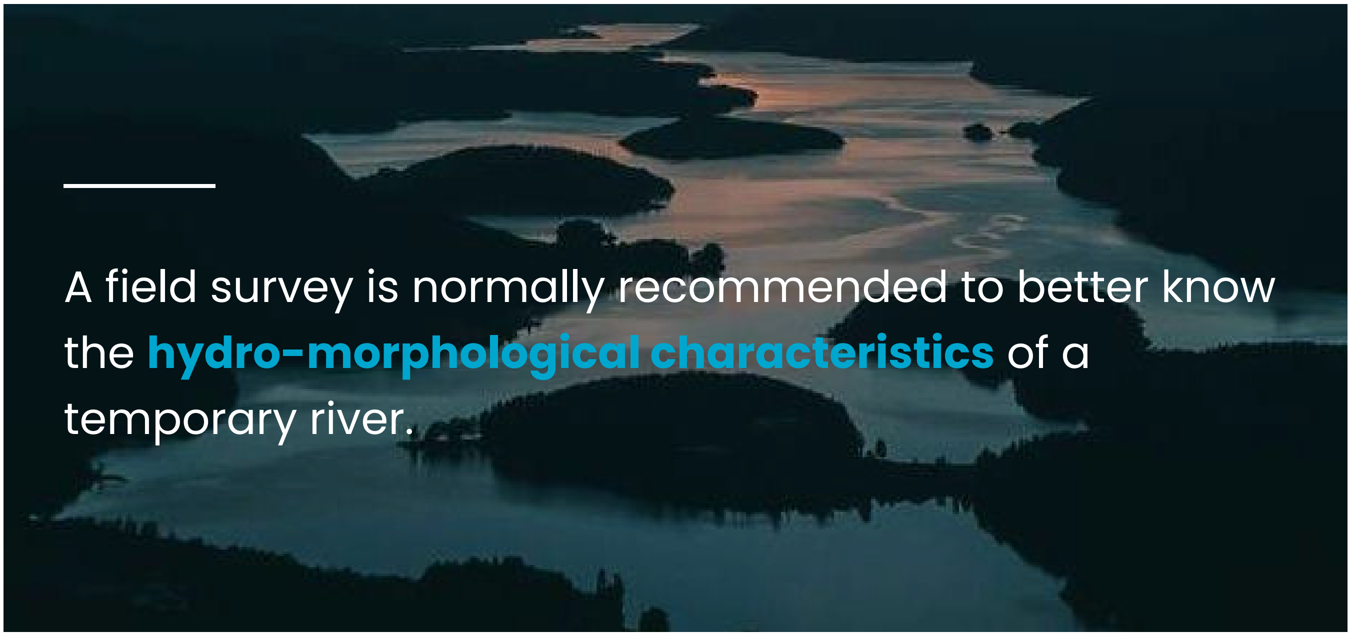


IMPORTANT

The field surveys are fundamental to better identifying surface water presence using satellite images, improving the supervised classification of hydrological conditions and avoiding potential misclassifications.

CONTINUE

When?



A field survey is normally recommended to better know the **hydro-morphological characteristics** of a temporary river.

To verify and improve your supervised classification of hydrological conditions, please select a day on which the analysed river reach is expected to experience a **non-flowing condition** (this means **ponding** "**P**" or **dry** "**D**" conditions).

This is because the two non-flowing conditions that characterise temporary rivers are the most difficult to identify from **satellite images**.

The field survey should be scheduled on a sunny day and when a satellite of the Sentinel-2 mission passes over the considered location. This will ensure the possibility of collecting field data that can be compared with a contemporary cloud-free Sentinel-2 image.

By using **Copernicus Browser** (introduced in Module 2) it is possible to assess the revisit time and predict future acquisition dates for a specific study area.

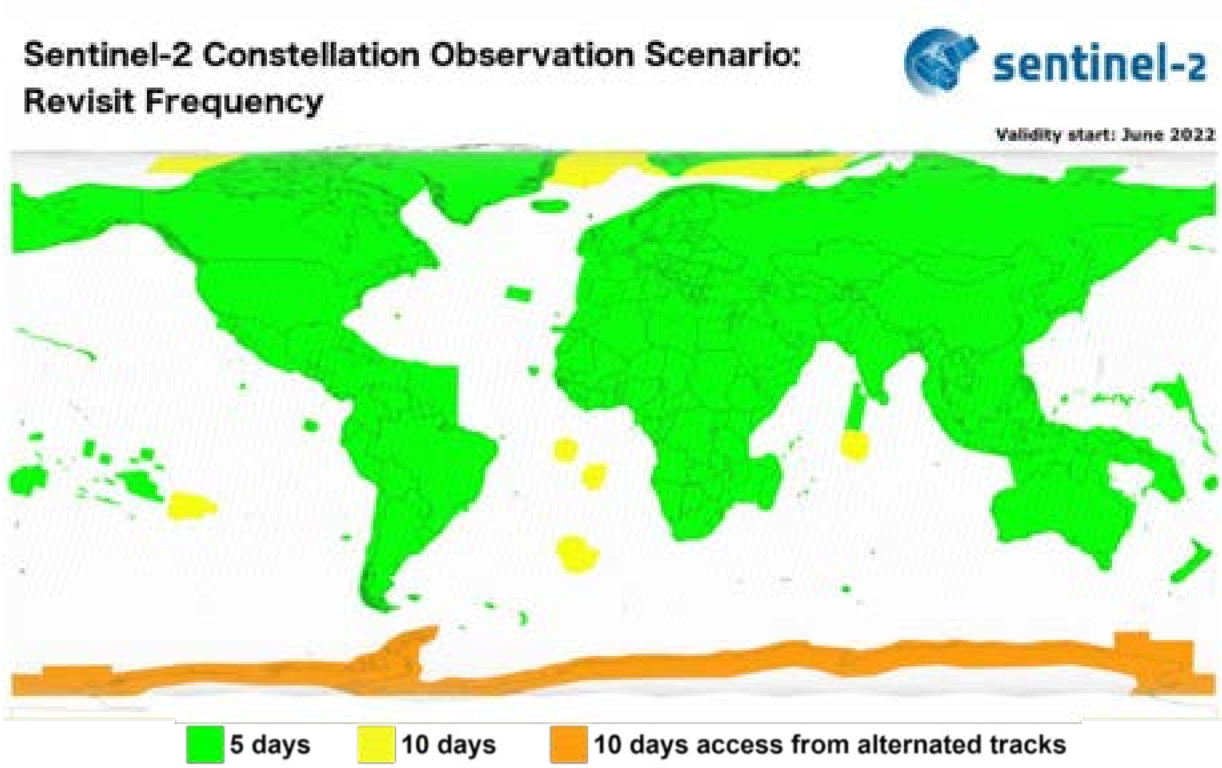


Illustration of the coverage and revisit time foreseen for SENTINEL-2 MSI acquisitions (source European Space Agency)

Reference:

ESA, https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/revisit-coverage

Click on the button to open the website.

Copernicus Browser

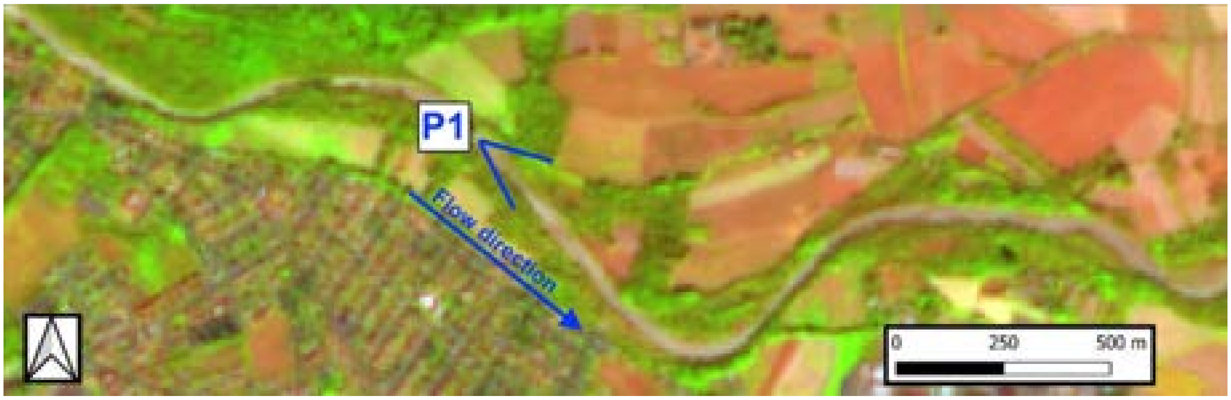
GO TO WEBSITE

CONTINUE

Where?

For the field survey, we suggest selecting a river within a **minimum width of 30 m**. This will help identify **river morphological features** and verify the presence of **surface water in the riverbed** from satellite images.

Click on the images to enlarge them



Visualization from a satellite image (above) and a geotagged picture (below) of the Sangone river at Rivalta di Torino with a width of approximately 30m, September 2022.
Photo credits Giammarco Manfreda

IMPORTANT:

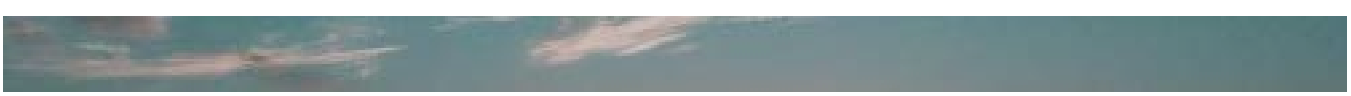
It is important to note that, if a **vegetation dome** is present, it will not be possible to see water presence in the riverbed from satellites and, therefore, classify the hydrological conditions.

Vegetation dome on Lurisia stream (Italy), 2009.

Photo credits Paolo Vezza

Finally, selecting a river reach where **shadows are absent** or extremely limited is important, as **shadows can exhibit similar reflectance to water**.

If it is not possible to entirely avoid their presence, **take care in identifying areas with potential shadows in satellite images**.



These shadows can result from various factors, such as:

1. Clouds.
2. Riparian vegetation.
3. Steep banks.
4. Vertical walls.
5. Bridges.

Example:

Sentinel-2 satellite images in which shadows are present in the riverbed of Palancia river at Gilet (Spain), 2021. FCI (above) and High resolution image from Google Earth (below).

Click on the images to enlarge them

FCI

High resolution image from Google Earth

CONTINUE

Defining the length of the river reach

What should we do to start?

As a preliminary step, it is important to **define the location and the length of the river** reach that will be surveyed during the field activity.

Defining the length of the river reach can influence the **hydrological condition** and **hydrotype classification**.

A segmentation of the river morphology into hydro-morphologically homogeneous river reaches would be useful to select a portion of the river that has homogeneous geological characteristics and homogeneous response to flow cessation.

(As described in Rinaldi et al., 2013)

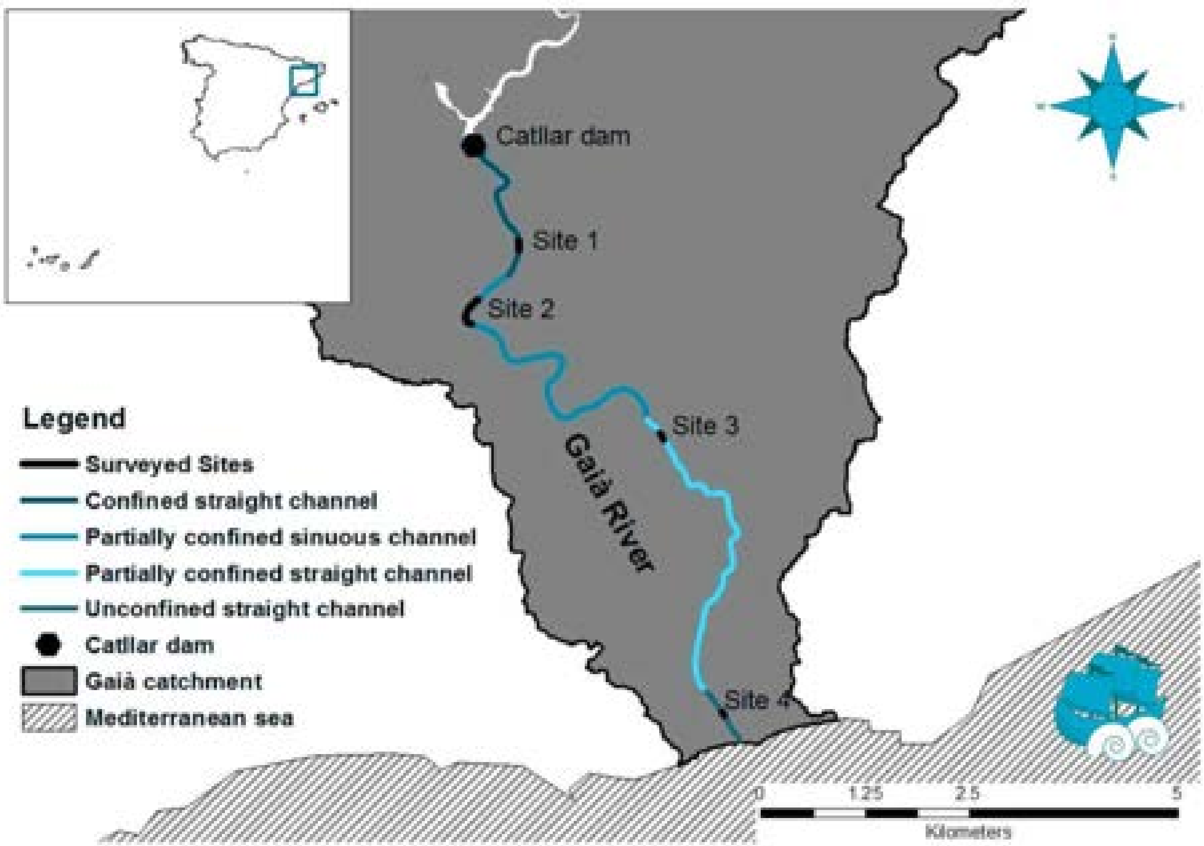
i

Rinaldi, M., Surian, N., Comiti, F., & Bussettini, M. (2013). A method for the assessment and analysis of the hydromorphological condition of Italian streams: The Morphological Quality Index (MQI). Geomorphology, 180, 96-108.

IMPORTANT

Where available, it is preferable to utilise **existing morphological segmentation.** In cases where such segmentation is unavailable, **high-resolution satellite imagery** should be employed to identify and delineate areas that can be interpreted as **homogeneous hydromorphological reaches.**

Click on the image to enlarge it



Segmentation of Gaia river (Spain), downstream the Cattlar Dam, into 4 hydro-morphologically homogeneous river reaches. In each homogeneous reach, a portion (called sub-reach) was analysed during field surveys (Vezza et al., 2020)

i

Vezza, P., Negro, G., Jorda-Capdevila, D., Munné, A., Bardina, M. (2020). Application of meso-scale habitat models in temporary rivers. SMIRES Project Final Conference. Tirana - Albania 4-5 of February 2020.

CONTINUE

Activities in the field

During the **field survey**, it is crucial to:

Recognize the hydrological condition of the river. Is the river in flowing, ponding or dry condition?

Compare the observed hydrological condition with the most recent satellite images available.

Acquire geotagged photos using smartphones.

Validate the observed hydrological condition, when a new satellite image becomes available for the date of interest.

Additional Activities (Subject to Feasibility):

Click on the labels to view the information.

Observe terrestrial and aquatic biota —

Including flora and fauna in both emerged and submerged areas of the river. These observations are particularly valuable if a biologist can participate in the field survey.

Acquire topographic data —

If needed, acquire topographic data utilising specific instruments for detailed mapping of the study area.

CONTINUE

Recognition of the hydrological condition in the field

First, the **hydrological condition** of the homogeneous river reach should be recognized.

Do you remember that there are three possible hydrological conditions?

Sciarapotamo river, Salerno (IT) under the 3 hydrological conditions F) flowing, P) ponding, and D) dry. Photo credits Carmela Cavallo (Cavallo et al., 2022)

Click on the **START > button** to view the information and click on the images to enlarge them.

2

Flowing condition (F)

Visible continuous flow of water along the analysed river reach.

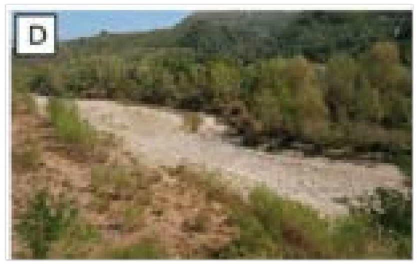
The flowing condition is easily detectable since there is a continuous surface flow in the river channel.

Ponding condition (P)

Discontinuous water presence; surface water is located in isolated ponds, pools or portions of the low-flow channel

The ponding condition is more ambiguous, because it regroups intermediate states in which surface water is present along the river channel, forming isolated ponds, pools or submerged portions of the low-flow channel. This condition is typically stable when there is a significant connection with the groundwater or when having hyporheic fluxes connecting the riverbed and the water table.

Dry condition (D)



Absence of surface water, with dry riverbed.

The dry condition implies the absence of surface water inducing dry riverbed, and it is generally due to the complete disconnection of the river with the groundwater.

References:

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

CONTINUE

Compare the hydrological condition with satellite images

Using the **latest available satellite image**, you can compare what you observe in the field with what is visible in satellite images. You can do it using the **Copernicus Browser** from your **smartphone**.

Operator studies latest satellite image from the Copernicus Browser in a field survey on Keritis river (Greece), 2024.

Photo credits Isabelle Brichetto

Click on the button to open the website.

The Copernicus Browser

GO TO WEBSITE

Example

Click on the images to enlarge them

Comparison of a pond visualization in satellite imagery (above) and a georeferenced picture of the Sangone river, Italy (below), taken on the same date in September 2022.
Photo credits Giammarco Manfreda

CONTINUE

Geotagged photos acquisition

Using **active mobile positioning**, you can collect pictures of **areas submerged by water** with your mobile phones like the operator.

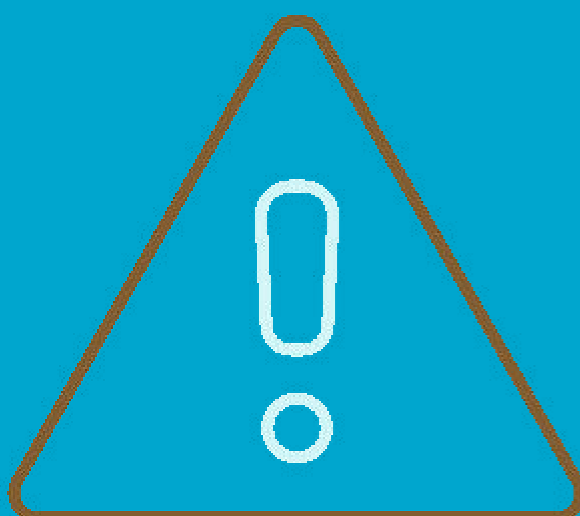
These areas should be located within the **active channel of the river**.

GPS receivers in cell phones and tablets can determine their position on Earth by utilising two processes called **triangulation** and **trilateration.**

Click cards to flip

Triangulation involves measuring the distance from the receiver to each satellite in view above the horizon.

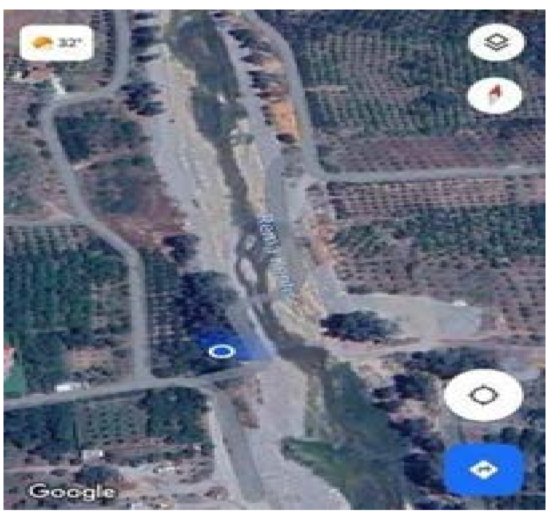
Since the location of each satellite is accurately known, trilateration involves intersecting spheres with the receiver at the center and the distances to the satellites as the radii. The intersection point of these



IMPORTANT

Remember to **enable your phone's GPS** before taking the photos.

Press the button to see the operator's smartphone screen.



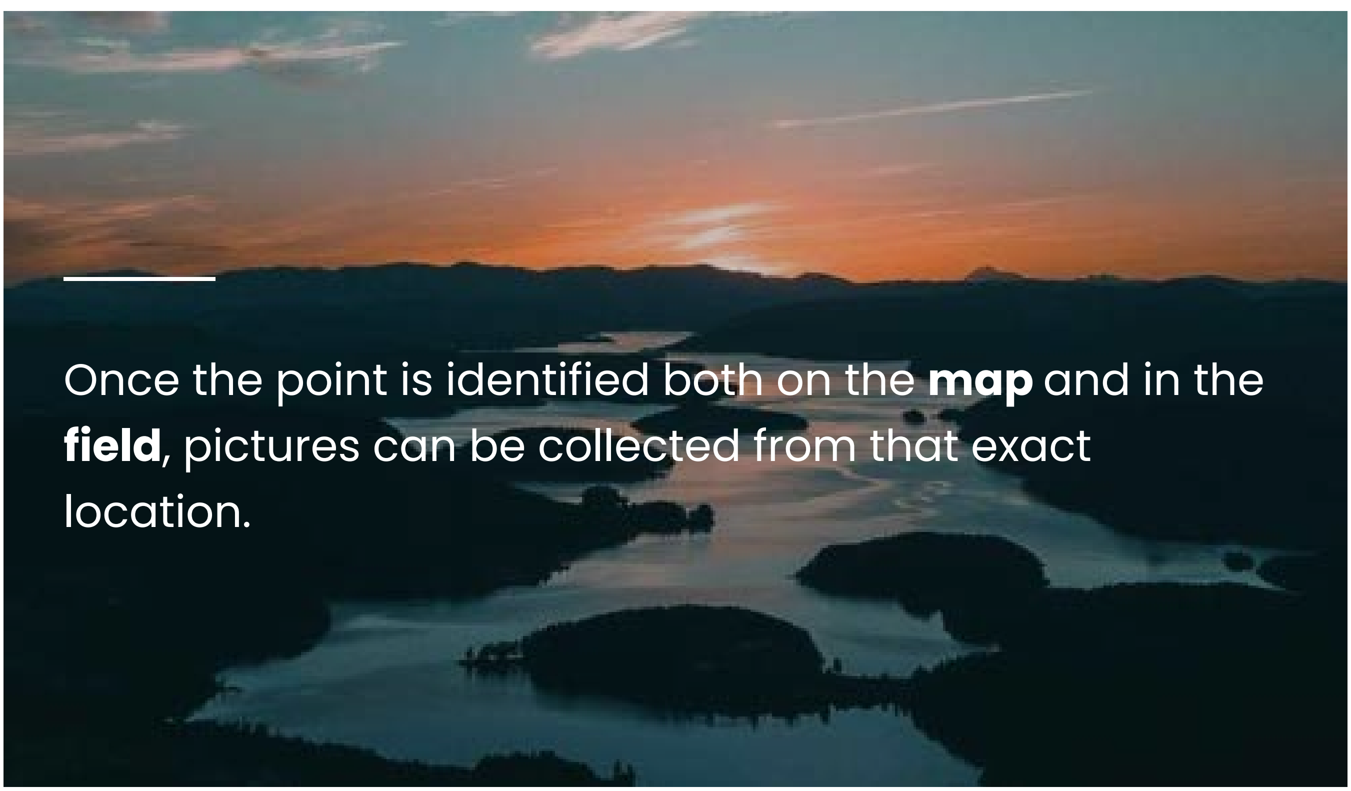
Using GoogleMaps, the operator acquires a geotagged picture during a field survey on Keritis river (Greece), 2024.

Photo credits Isabelle Brichetto

CONTINUE

It is fundamental to **identify your location on the map** and to **record the orientation of the photo**.

The location in which the picture is collected should be selected to be easily accessible during all possible **hydrological conditions** (**flowing**, **ponding**, **dry**), providing a clear and comprehensive view of the targeted river portion.



Once the point is identified both on the **map** and in the **field**, pictures can be collected from that exact location.

Locus Map is an app for outdoor activities like geocaching or hiking.

To manage the acquisition of **geotagged photos**, it is also possible to use dedicated apps such as **Locus Map**.

This app, for example, allows users to capture photos with **embedded location data**, which can later be imported into **GIS** for further analysis.

Click on the button to open the website.

Locus Map

GO TO WEBSITE

Even in the absence of water **(dry riverbed**), capturing geotagged images remains important for improving the correlation between satellite imagery and ground truth data, helping to **minimize potential misclassification errors**.

Focus should be placed on photographing **key locations where water tends to remain during ponding conditions** (e.g., topographic depressions in the channel bed).

Additionally, **areas with shadows should also be documented**, as they may introduce errors in the classification of remote sense data, particularly between **ponding** (**P**) and **dry** (**D**) conditions.

These images serve as essential references for **validating** and **comparing ground truth data** with **satellite observations**.

Example

Click on the buttons to view the information.


a
P1
Reach of Sangone
Flow direction
P2
P3
0
250
500 m
b
P1


a
P1
Reach of Sangone
Flow direction
P2
P3
0
250
500 m
c
P2

Examples of shaded areas during dry conditions in the Sangone river with corresponding geotagged photos acquired on the field (IT), 2022.

Photo credits Giammarco Manfreda

Did you know?

QGIS offers various plugins, such as **Import Photos**, that enable users to overlay geotagged photos onto satellite imagery.

These tools facilitate the **comparison between satellite images and photos** by creating a dedicated layer for the photos, enhancing spatial analysis and visualization.

Import Photos is a **QGIS plugin** to import **geotagged photos** on a map

---

Click on the button to open the website.

Import Photos

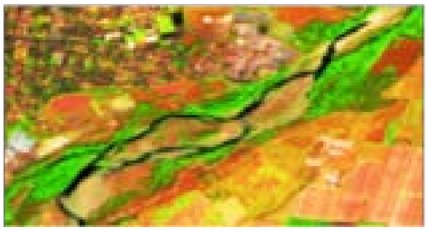
GO TO WEBSITE

CONTINUE

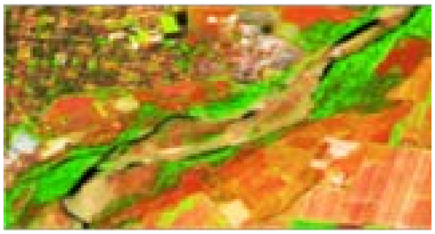
Validation of hydrological conditions

When the new satellite image for the target date becomes available, the hydrological condition can be **classified** and **validated** using the **data collected** during the field trip.

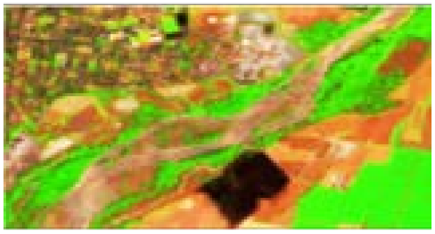
This allows for an accurate comparison between **remote sensing observations** and **on-the-ground measurements**.



Flowing condition
29/02/2022



Ponding condition
24/08/2022



Dry condition
15/07/2022

Examples of three different satellite images of the same Trebbia river reach in three different hydrological conditions

CONTINUE

Observation of terrestrial and aquatic biota

An additional challenge could involve investigating the presence or absence of **riparian vegetation species** and **aquatic fauna**, such as **macroinvertebrates**, **fish**, and **macrophytes**.

Click on the images to enlarge them

Ephemeroptera (Oligoneuriella rhenana) collected in the Trebbia river

Fish sampling using electrofishing in an isolated pond in the Trebbia river

(Italy). *Photo credits Gemma Burgazzi*

(Italy). *Photo credits Paolo Vezza*

CONTINUE

Topographic data acquisition

Topographic data acquisition

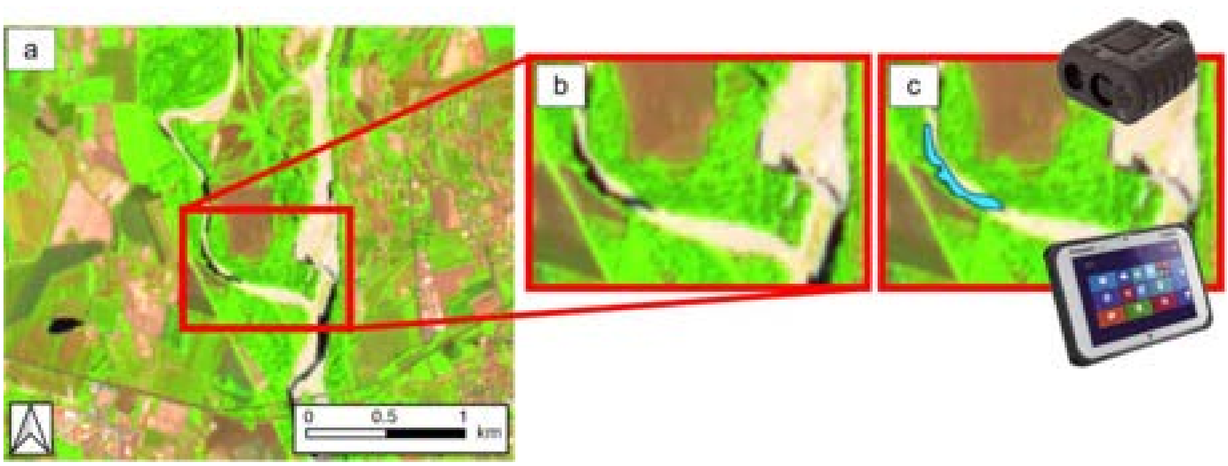
Did you know?

If available, laser rangefinders and other topographic instruments (e.g. **theodolites**, **total stations**, **Global Navigation Satellite System - GNSS - antennas**) can be used to map water presence in the river channel or to collect the precise position and spatial extension of river geomorphological features.

Example:

The figure compares a **satellite image in the background** and the **georeferenced polygon** representing a pond in the riverbed.

Clik on the image to enlarge it



Examples of a georeferenced water polygon acquired with topographic instruments in the Torre river (IT), 2022:

a) Visualization of the river reach.
b) Detail of the investigated pond.
c) Detail of the georeferenced polygon acquired with laser rangefinder and handheld computer.

CONTINUE

References

Bibliographic references

In the development of any academic course, bibliographic references play a crucial role by providing the necessary theoretical and practical support for the material taught.

References not only strengthen the credibility of the study materials but also allow students

This set of references has been carefully selected to provide a solid foundation of

to explore the topics covered more deeply, gaining a deeper understanding of key concepts and discovering new perspectives knowledge, encompassing a variety of sources, including books, academic articles, recent research, and digital resources.

We hope these references will be a valuable tool for learning, fostering a comprehensive and critical understanding of the topics addressed in this course.

Cavallo, C., Papa, M. N., Negro, G., Gargiulo, M., Ruello, G., & Vezza, P. (2022). Exploiting Sentinel-2 dataset to assess flow intermittency in non-perennial rivers. Scientific Reports, 12(1), 21756.

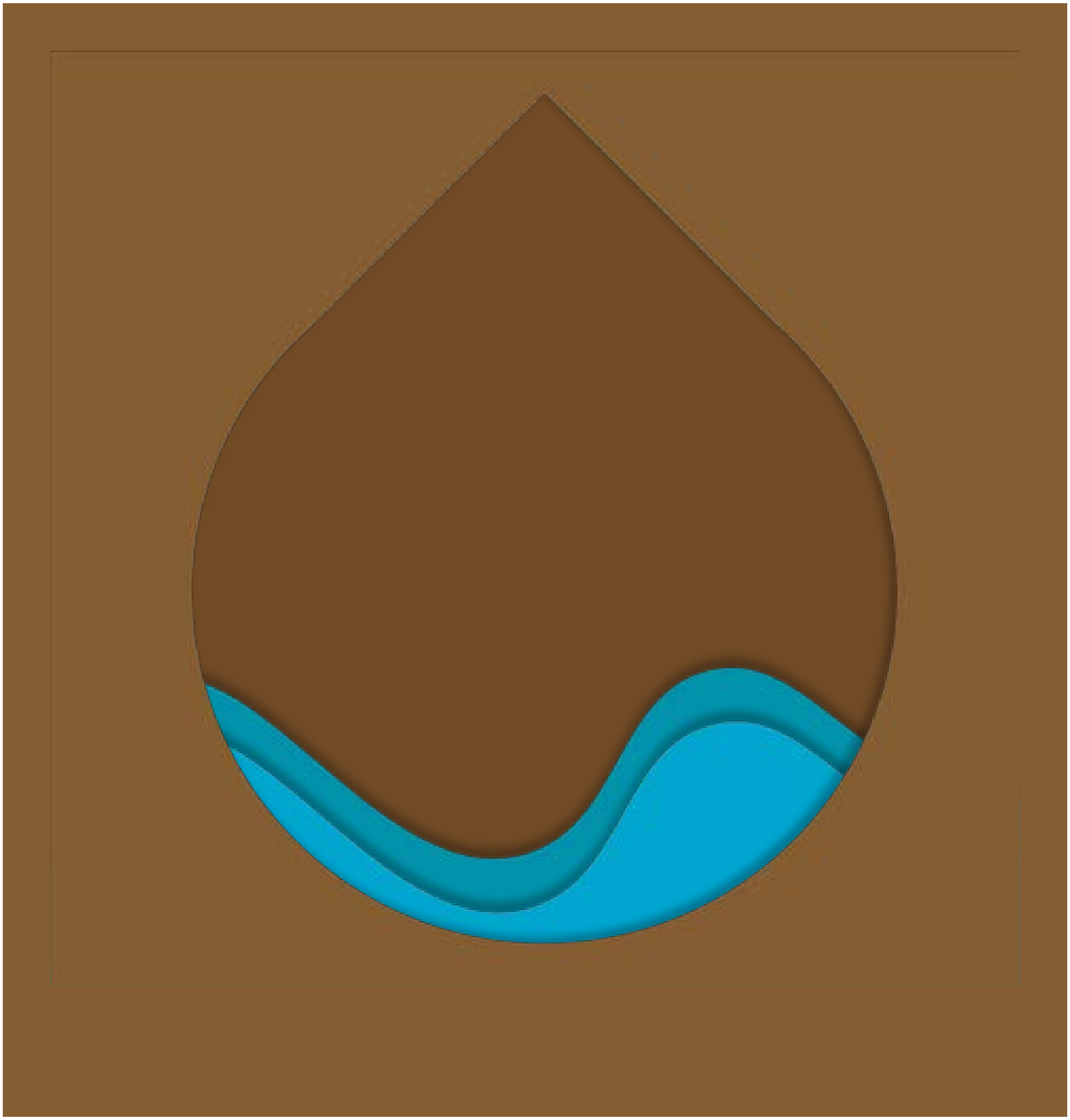
ESA, https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/revisit-coverage

Rinaldi, M., Surian, N., Comiti, F., & Bussettini, M. (2013). A method for the assessment and analysis of the hydromorphological condition of Italian streams: The Morphological Quality Index (MQI). Geomorphology, 180, 96-108.

Vezza, P., Negro, G., Jorda-Capdevila, D., Munné, A., Bardina, M. (2020). Application of meso-scale habitat models in temporary rivers. SMIRES Project Final Conference. Tirana - Albania 4-5 of February 2020.

CONTINUE

Closure



Congratulations!

You have **completed** this module.

Fantastic accomplishment! Through this module, you've gained a significant wealth of knowledge about field data collection in temporary rivers, spanning both theoretical insights and practical on-field experiences.

Now, you're well-prepared to tackle the final module of the course.

Well done!

MODULE 7: Workshop on satellite imagery analysis_v2_IT

All the information and knowledge gained in the **previous modules** and during the **field trip** will now be put into **practice** with an **exercise**. The ultimate purpose of this exercise will be to learn **how to use and manage satellite images** of the Sentinel-2 with the Temporary River Classifier (**TRC**), a web tool for observing and classifying temporary rivers.

With this activity, you will be able to **classify the hydrotype of a river reach for a selected time period** (see e.g., Munné et al., 2021). You will also be able to **manage the satellite image time series** and **interpret the results** obtained.

LET'S GET STARTED!

3. MATERIALS TO DOWNLOAD

Materials to download

4. EXERCISE

Exercise

3. DISCUSSION

Discussion

4. REFERENCES

References

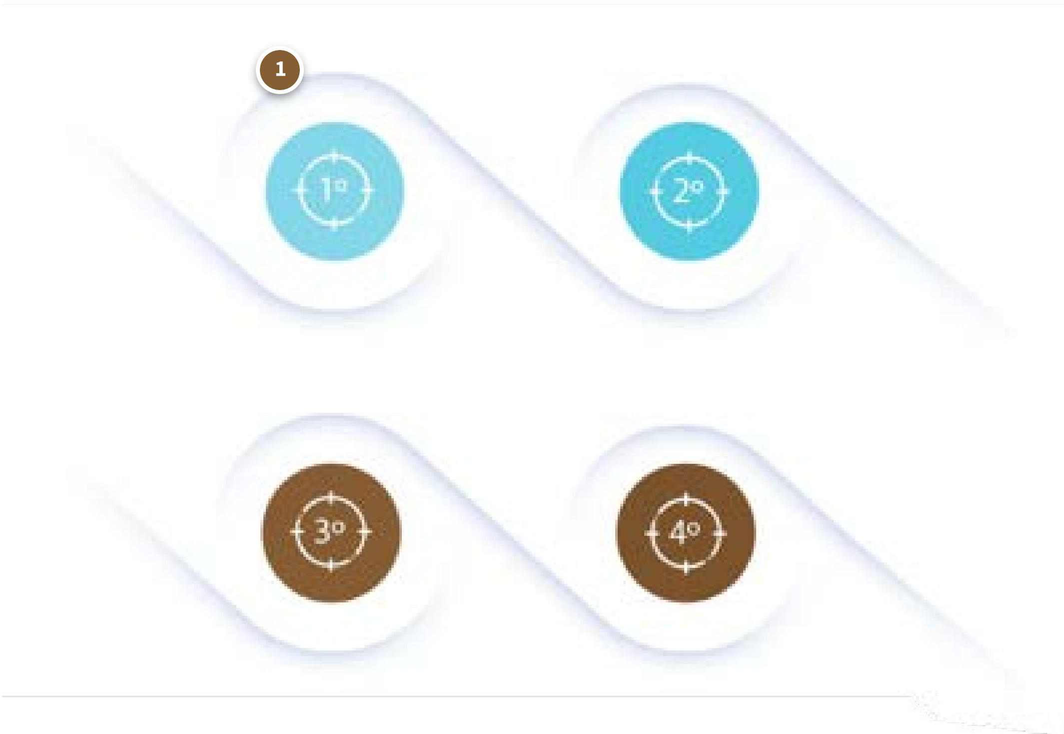
8. CLOSURE

Closure

Objectives & Learning Outcomes

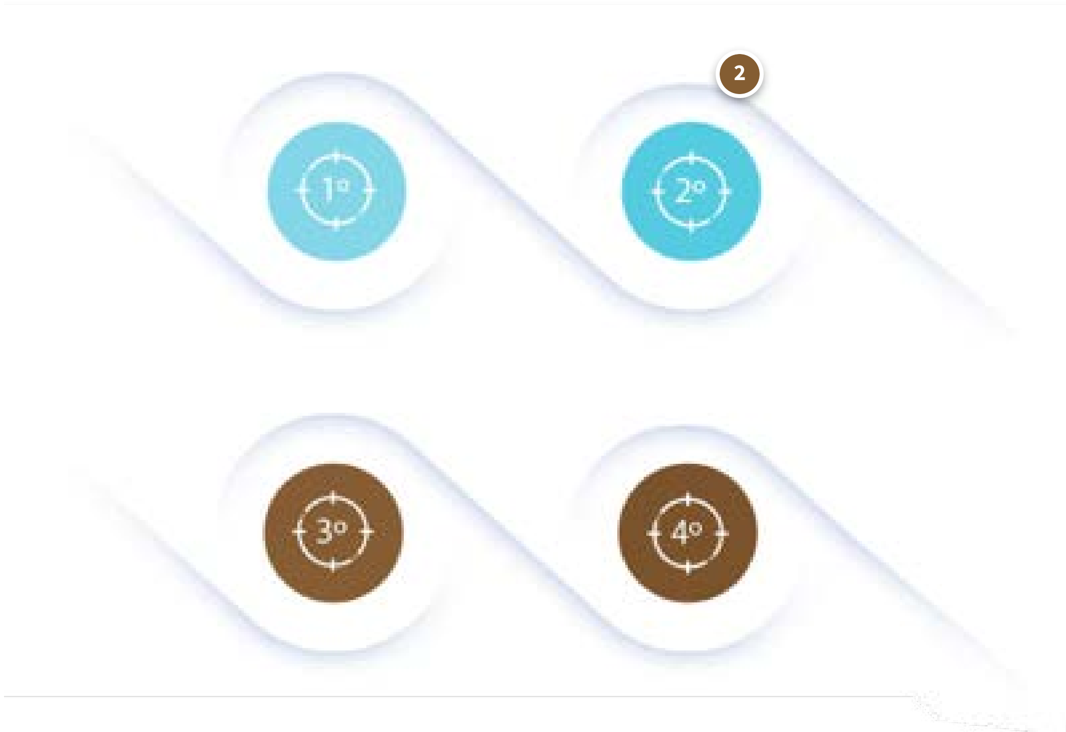
The **4 Objectives and Learning Outcomes** of this module are the following:

Click on the buttons to view the information.



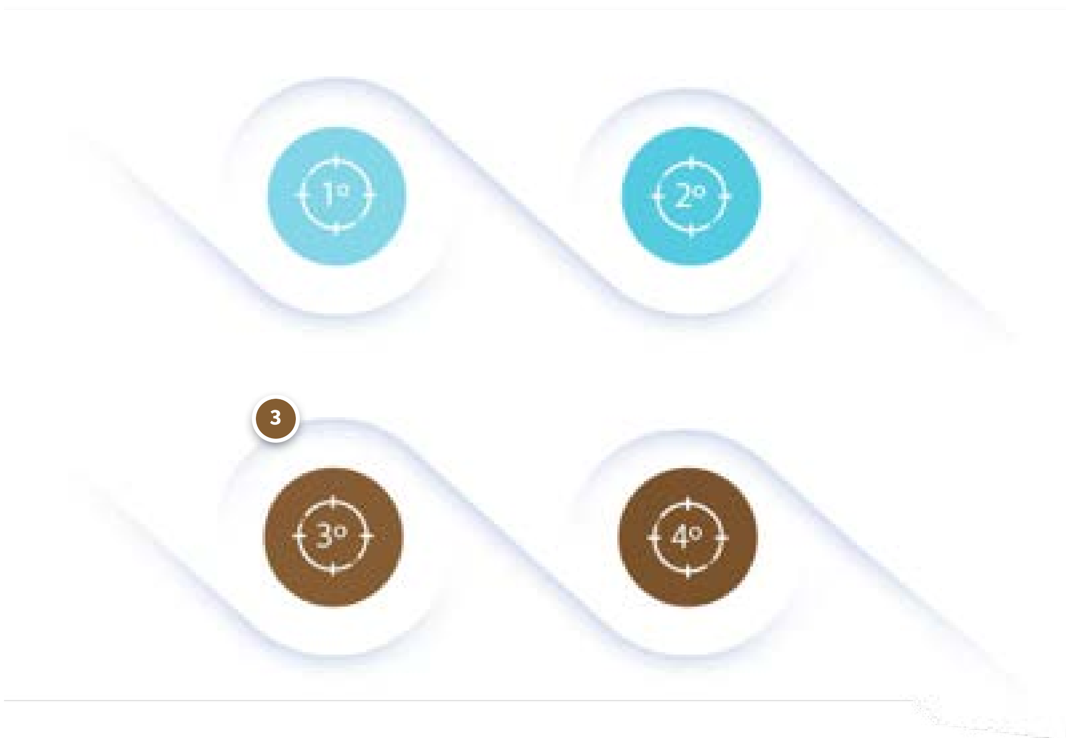
1

Familiarise with the use of the IT Tool, namely **Temporary River Classifier** (**TRC**)



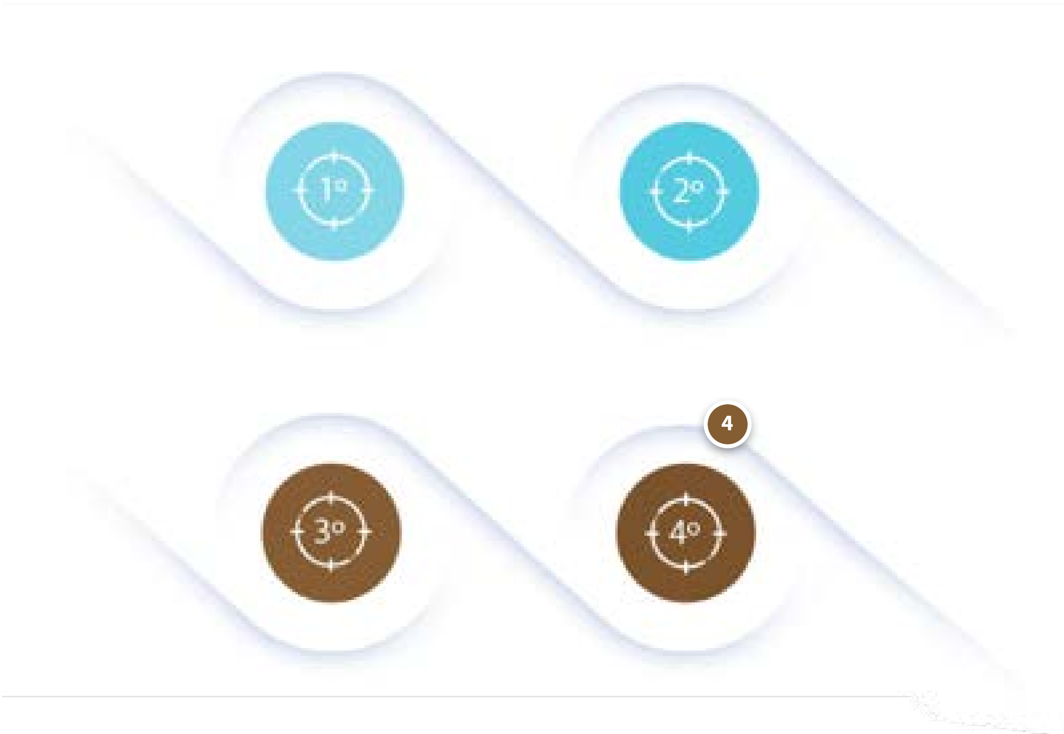
2

Manage the **comparison** between **field** and **satellite data**



3

Carry out **satellite imagery classification** for a temporary river reach



4

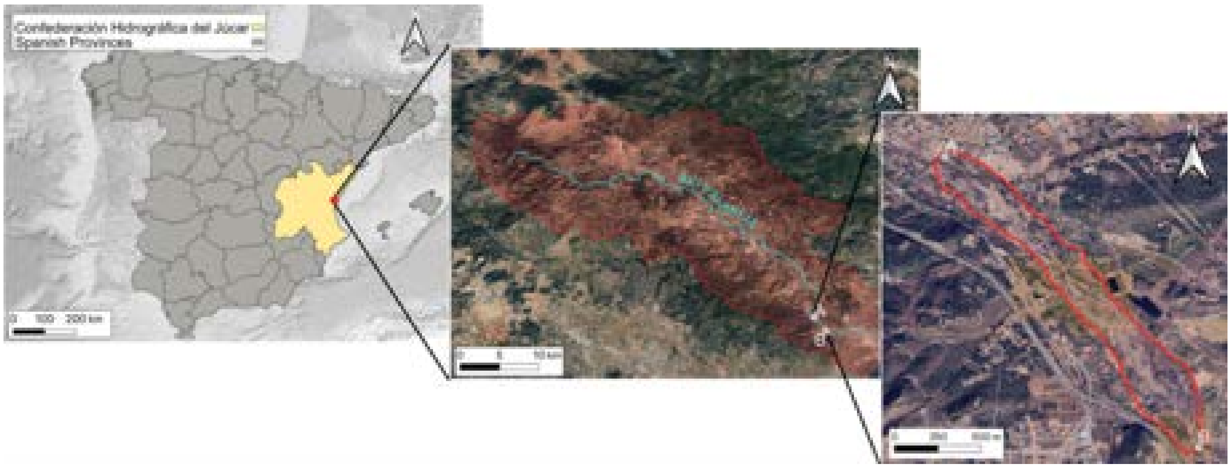
Analyse and quantify the **frequency** and **duration of non-flowing periods** in temporary rivers

CONTINUE

Study area

The case study for the workshop is the reach of the **Palancia river** close to the Gilet village (Valencia, Spain):

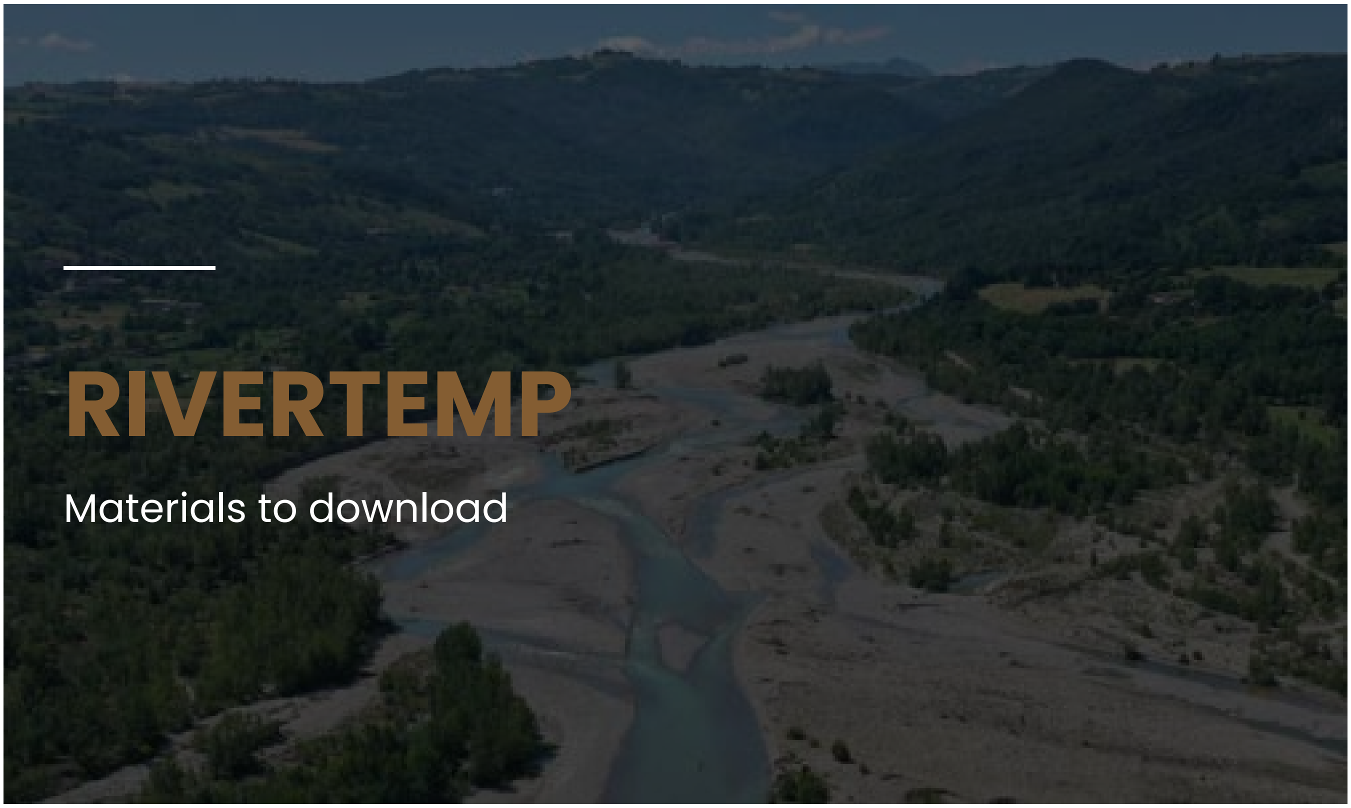
Click on the image to enlarge it

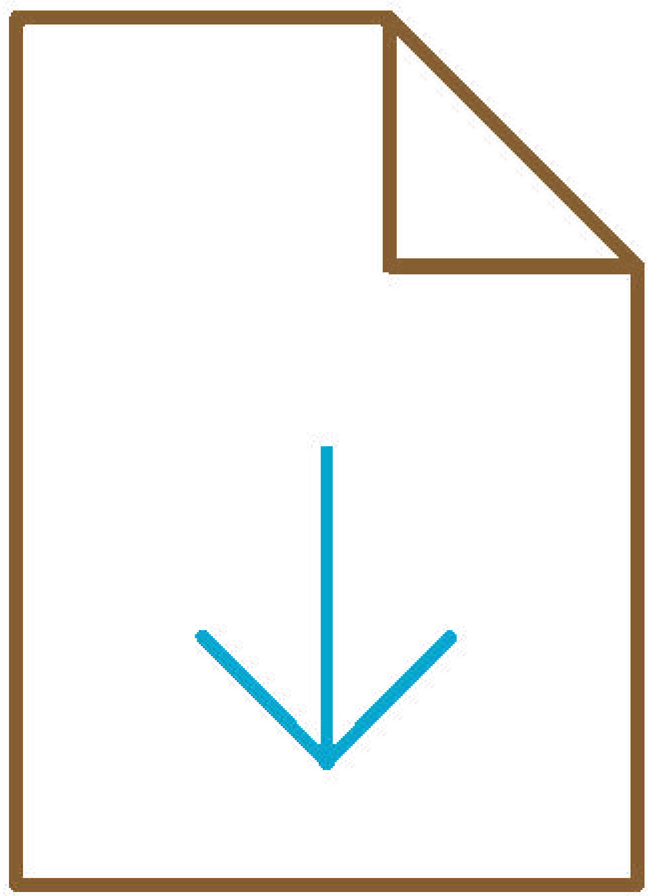


Overview of Palancia river at Gilet reach (Spain)

CONTINUE

Materials to download





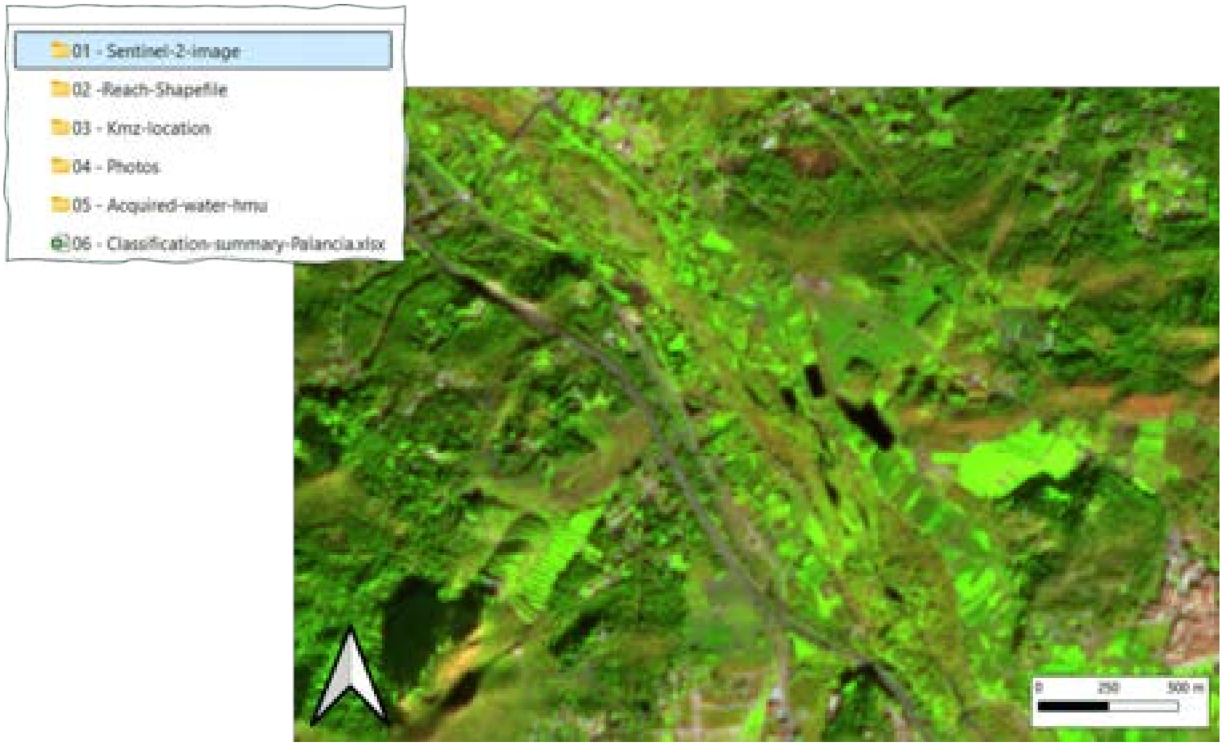
A **Zip folder will be provided** containing the files required for the workshop.

Click on the buttons to view the information.

In the **zip folder** you will find the following **files**:

2

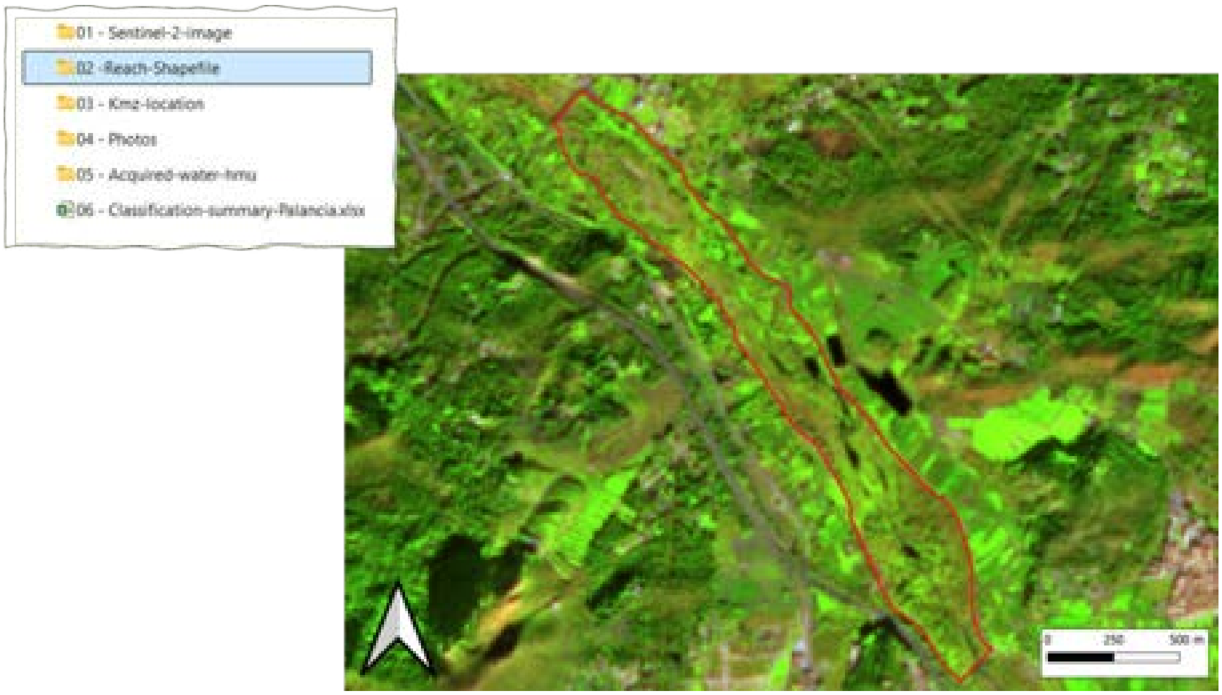
Satellite image



Satellite image of 16/12/2022 which has to be compared with georeferenced polygons and photos acquired during the 17/12/2022 field survey.

3

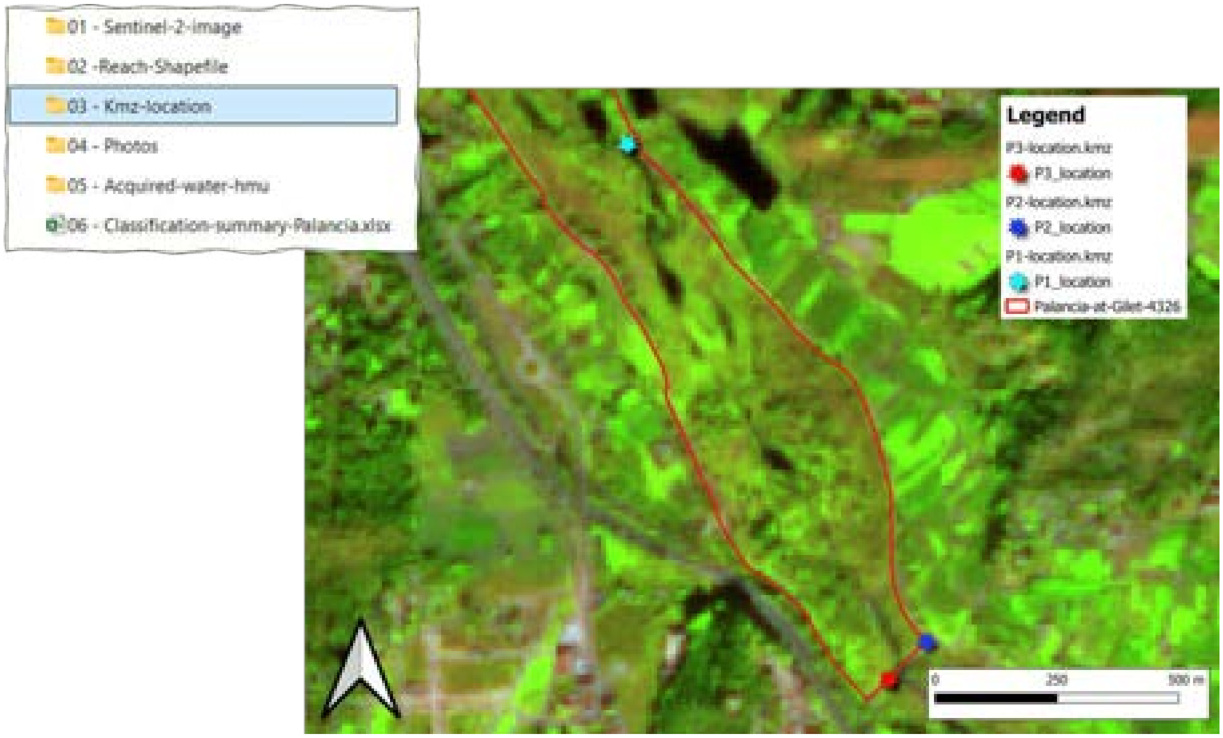
Shapefile



Shapefile for Palancia river reach at Gilet, defining the investigated river reach.

4

Kmz-location



The .kmz points **P1** (in **cyan**), **P2** (in **blue**) and **P3** (in **red**) from which the operator acquired geotagged photos.

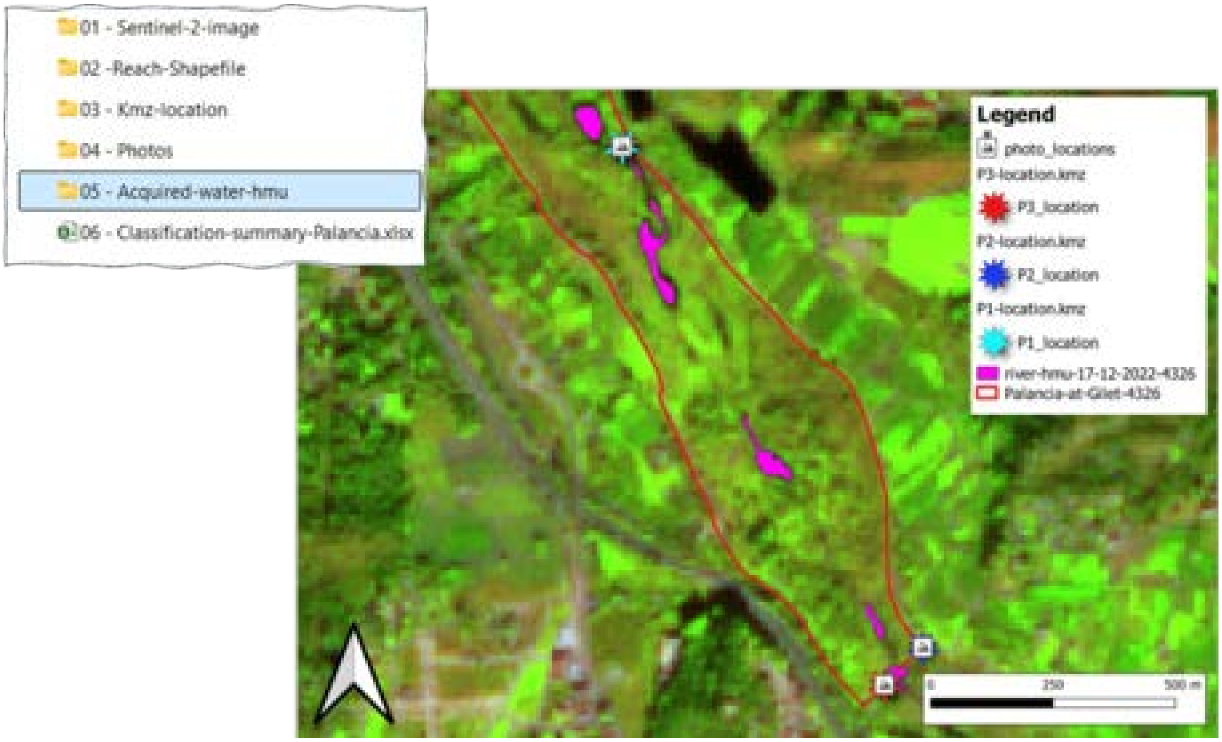
5

Geotagged photos

Geotagged photos acquired for different dates.

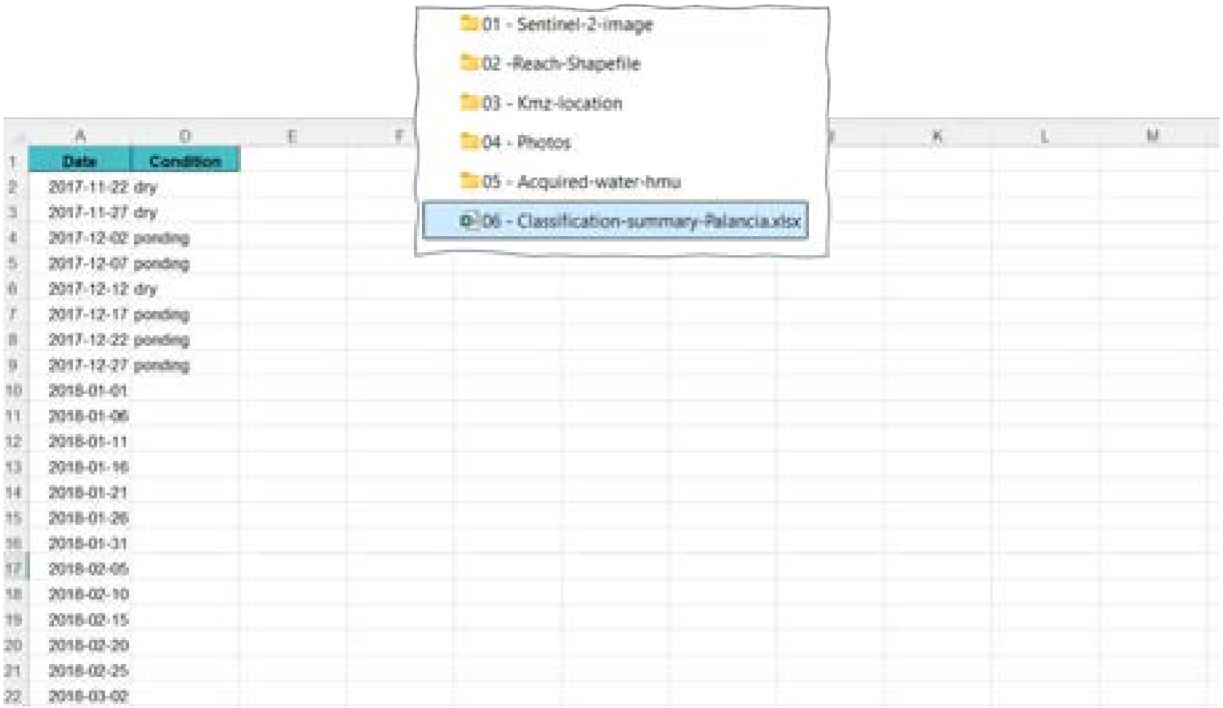
6

Georeferenced water polygons



Georeferenced water polygons acquired during the field survey with topographic instruments.

Excel file



An Excel file containing the classification of satellite images from 2017 to 2024. As you can see, the year 2018 is missing. Please, select this year to carry out your own satellite imagery classification.

Click on the button to download the zip folder.

Workshop_Palancia_at_Gilet_MOOC-Module7.zip
23.3 MB

CONTINUE

Exercise

Now it is your turn to challenge yourself!

Using the **Temporary River Classifier** (**TRC**), you will perform a satellite classification for the **year 2018**. The expected results of the workshop are:

1. The **time series** of classified satellite images for **2018**.
2. The number of **cloudy images**.
3. The **Effective Revisit time** (**ERt**).
4. The **permanence** of each hydrological condition (**Mf**, **Mp**, **Md**, expressed as %).
5. The **definition** of the hydrotype of the analysed reach for **2018**, provided by the

hydrotype ternary plot.

Using the classifications reported for the other years in the Excel file, you are encouraged to conduct comparative analyses to assess whether and how the temporariness of the Palancia river reach varies between in the period 2017-2024.

CONTINUE

Discussion

We will ask you to

ponder these

questions:

1

Based on your classified satellite images, which **hydrological condition dominated** the year you analysed? What **environmental or climatic factors** could explain this pattern?

2 How do the **permanence values (Mf, Mp, Md) align with the expected seasonal changes**? Can you identify any **anomalies**, and how might you explain them?

3 When comparing the classification results of different years, what **significant differences** do you observe? Could these differences indicate **a clear hydrotype classification or a trend** for the river hydrological conditions?

4 **Would you suggest** a **year-based management plan** for temporary rivers or a **general management plan** that can be valid in the long term? Please motivate your choice.

CONTINUE

References

Bibliographic references

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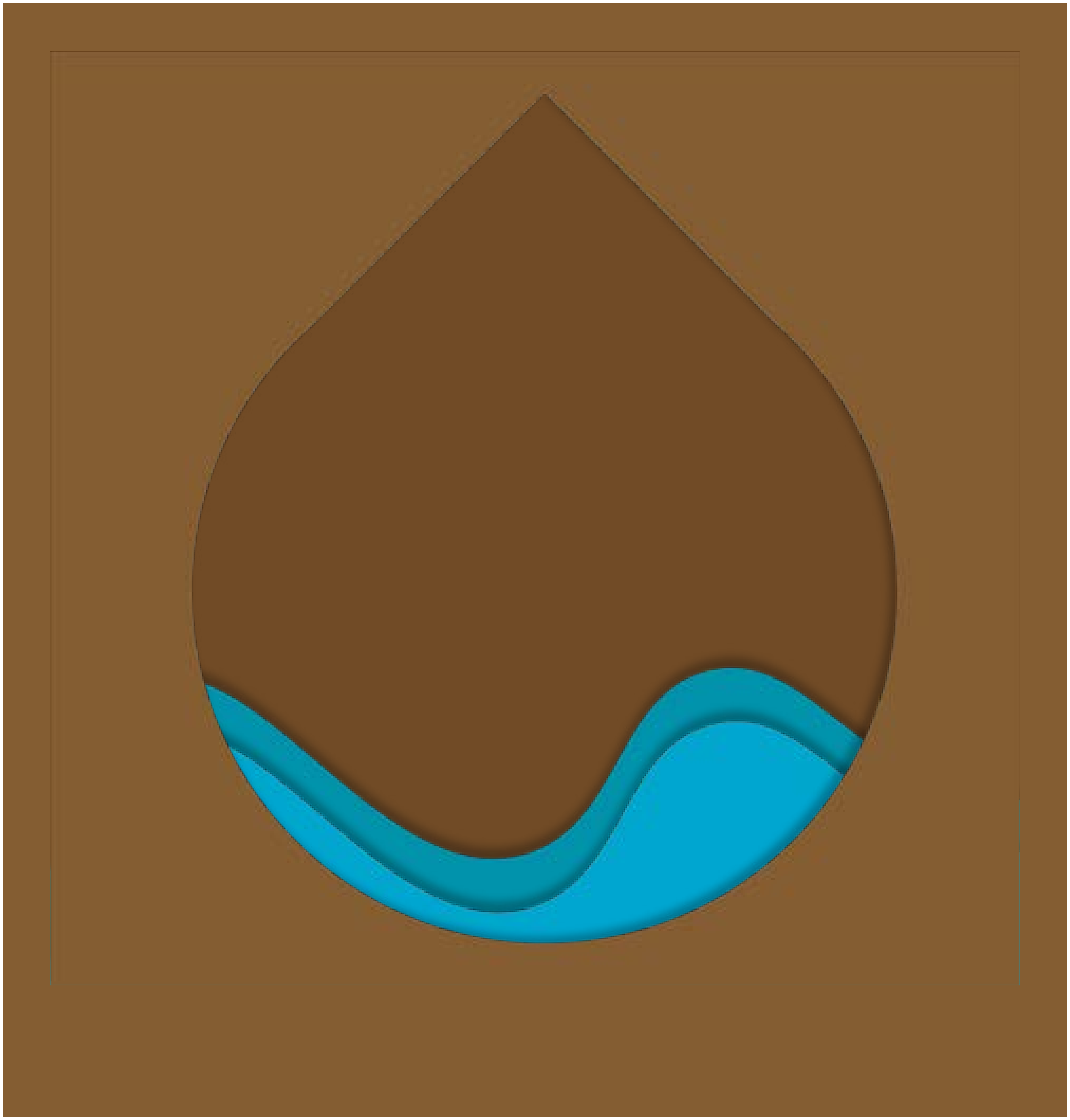
Munné, A., Bonada, N., Cid, N., Gallart, F., Solà, C., Bardina, M., ... & Prat, N. (2021). A proposal to classify and assess ecological status in Mediterranean temporary rivers: Research insights to solve management needs. Water, 13(6), 767.

We hope these references will be a valuable tool for learning, fostering a comprehensive and critical understanding of the

topics addressed in this course.

CONTINUE

Closure



Congratulations!

You have **completed** this module.

Here we are at the end of this training course. You acquired knowledge and skills to identify and classify TRs, so congratulations on your outstanding achievement!

You can continue to use the Temporary River Classifier (TRC) on your own to describe river reaches all over the world!

You can also help scientists and researchers by taking photos of rivers specifying the date and the location using the **DRyVER APP**

Temporary rivers need more attention, and you are now within the ones that give them the correct importance.

Well done!