



Demonstration of Sustainable Hydropower Refurbishment

D5.2 Matrix of future water use



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Executive Summary

This deliverable is part of the ReHydro project, funded by the EU's Horizon Europe programme. It aims to:

- Develop a methodological framework to assess the satisfaction of future water use under different climate change scenarios.
- Apply this framework to Vouglans Saut Mortier (VSM) hydropower site in the Ain Valley, France.
- Create a matrix to assess the compatibility of various water use, based on physical parameters influenced by hydropower operations.

The water uses considered are grouped by ecosystem service categories (Supply, Regulation, Cultural, Support) and the retained physical criteria refer to quantity, quality and accessibility to water. Each criterion is based on a four-level scale (incompatible, limited, compatible, optimal).

Water use compatibility is assessed by season (winter, spring 1 & spring 2, summer, fall) with May-September being the most critical due to high water demand and low water availability.

The next steps will consist of developing the matrix as a spreadsheet tool for practical application, test the matrix on the Ain River (at the Vouglans Saut Mortier demonstrator) and other demonstrator sites (e.g. Rhône River), and link the matrix results to social benefits and stakeholders' perceptions.

List of acronyms

		Comment
BRA	Basse Rivière d'Ain	Low Ain River
DWS	Drinking Water Supply	
SAGE	Schema d'Aménagement et de Gestion de l'Eau	A set of planning documents established by the French Water Act of 1992, aimed at the balanced and sustainable management of water resources. It sets, coordinates and prioritises general objectives for the use, development and quantitative and qualitative protection of water resources and aquatic ecosystems. It identifies the conditions for implementation and the means to achieve these objectives, in accordance with the WFD
SBVA	Syndicat de la Basse Vallée d'Ain	Manager of the river Ain
SR3A	Syndicat de la Rivière Ain Aval et ses Affluents	Replaced the SBVA
VSM	Vouglans Saut Mortier	
WHO	World Health Organization	
WP	Work Package of ReHydro	

1. Background

The main objective of ReHydro is to demonstrate how European hydropower can be refurbished and modernized to fit for a leading role in the future power system, respecting sustainability requirements and societal needs in a climate change context.

In all countries, water is used for many purposes, covering aspects as diverse as hygiene and public health, socioeconomics (agriculture, industry, river transport, etc.) and leisure (fishing, swimming, etc.). In a context of increasing water scarcity and restrictions, particularly in southern Europe during the summer, conflicts arise mainly between different users of the same water body, requiring regulations to anticipate or prevent tensions (Balmot & Yandza, 2023). These tensions will increase in the future due to the reduction in low flows and/or the lengthening of their duration, in parallel with rising temperatures, raising more and more questions about the ability of biodiversity to adapt to these conditions. The intensification of extreme rainfall is also leading to increase flash flood events, causing damage to the land and disrupting aquatic ecosystems.

Tools need to be developed to anticipate how changes in water resources will affect different water use and to consider solutions to meet those uses in this new context, especially for reservoirs whose main use is hydropower production. The aim of the ReHydro Task 5.4 is to develop a methodological approach to assess how future water use will be met under different climate change scenarios and apply it to the Vouglans Saut Mortier (VSM) project. The purpose is to demonstrate the project's ability to meet these future needs while improving renewable energy production and services to the electricity system. To this end, the digital twin of the Ain Valley (ReHydro WP2) proposes scenarios for future hydro-thermal conditions under different climate change conditions and VSM management scenarios (Guenand, 2025 – ReHydro deliverable D2.1). These data will be compared with usage satisfaction criteria based on the matrix presented in this deliverable.

The conclusions drawn from applying the matrix to VSM and discussions with partners will further allow us to define the conditions of generalization to other countries where thresholds or prioritization criteria may be different.

2. Objectives

The main objective of Task 5.4 is to demonstrate that future VSM management methods will enable downstream water use to be maintained, including taking into account changes in the hydrology or thermodynamics of the Ain River linked to climate change.

This demonstration will be based on a usage satisfaction matrix built on physical parameters influenced by hydropower. The uses of the Ain River are known from previous studies (EDF 2014, Boyer et al 2018, SR3A 2024), and the physical parameters have been determined so that they can be easily entered using data from the digital twin of the Ain Valley developed in ReHydro WP2 (hydraulic parameters such as water temperature, water levels, water velocity, etc.) or from the characterization of the biodiversity carrying capacity estimated in ReHydro WP4 (biological habitat quality).

The purpose of this deliverable is therefore to a) identify and select the physical parameters; and b) document the threshold values that determine the feasibility of each use, based on data from the literature (mostly grey literature), feedback from the France Hydroelectric Park and/or local societal surveys.

3. Methodology

3.1. Selection of considered water use

3.1.1. Linked to or influenced by hydropower

The method is developed for a general case study, and it will be tested and validated on the Ain River and VSM. Therefore, it was decided to use the most comprehensive water use and physical criteria possible with a view to potential extension to other hydropower contexts. This means that the matrix can be used for watercourses or catchment areas whose general characteristics allow for the presence of hydropower. Thus, flat river sections that are strictly alluvial or cannot be developed are not included in this scope. This methodological choice aims to maintain the consistency of the grid, which is based on physical criteria and interactions specific to environments with existing hydropower.

3.1.2. Taking ecosystems into account

Water use reflects an ecosystem service consumed in a defined area over a given period. Different categories of ecosystem services can be distinguished:

- **Supply** services that provide extractable/obtainable goods from ecosystems (food, drinking water, production of materials and fibres, etc.).
- **Regulatory** services that are benefits derived from the regulation of ecosystem processes (carbon sequestration, erosion control, habitat and nursery, etc.).
- **Support** services are those necessary for producing other services; they are often considered with the Regulatory services (i.e. “Regulatory and Maintenance”, in the CICES classification¹)
- **Cultural** services are non-material benefits that ecosystems provide through spiritual enrichment, cognitive development, reflection, leisure and aesthetic experience (e.g. aesthetic, symbolic and recreational value, etc.).

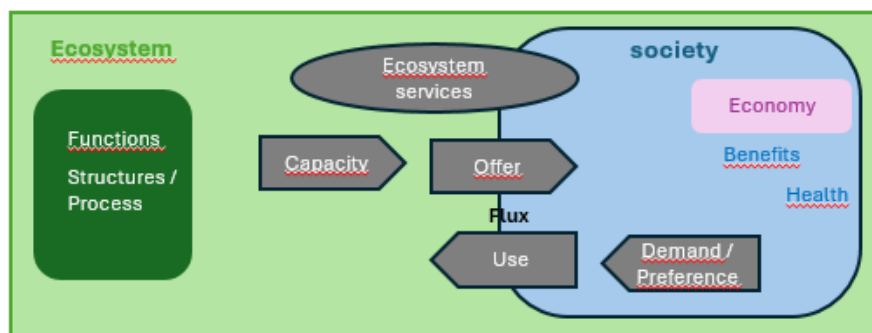


Figure 1 : Ecosystem services are « decomposable » (from Campagne & Roche, 2021)²

¹ <https://cices.eu/>

² In this diagram: Offer represents what Nature produces and provides as a service in a given period. Capacity is the hypothetical maximum yield of ecosystems. Flow corresponds to the share of supply in services produced and can be linked to supply or use, depending on the author. Demand encompasses what humans consume or use. Use is the ecosystem service consumed or used in a given period and a particular area. From Campagne & Roche, 2021.

Ecosystem services depend on ecological functions, i.e. the properties and/or processes specific to the ecosystem, carried out by living organisms (biocenosis) and the environment in which they live (biotope) (Gravel et al., 2010). Biodiversity (genetic, taxonomic or functional) is necessary for the efficiency and stability of ecosystem functioning and thus influences the level of provision of ecosystem services (Mouchet et al., 2023).

The water use considered (Table 1) are as representative as possible of the reality observed in the Ain Valley (see chapter 3.4) and in various other hydropower schemes in France. They correspond to supply services (sanitary, socio-economic or productive use) as well as regulation services (such as flood control, a consequence of hydropower operations, and water supply) and cultural services (e.g. recreational use). The support functions of ecosystems are also considered through biodiversity issues.

3.2. Selection and assessment of physical criteria

The physical criteria required to ensure that water uses are properly carried out were identified based on a review of scientific documents (e.g. Rietjens & Gailhard, 1998; Grizzetti et al, 2016) or regulatory documents, from best practices and observations and feedback, mainly in the French context. These physical criteria cover parameters that characterize ecosystems, including morphology (surface area, water level variation range, accessibility), hydrology and hydraulics (flow, velocity, water depth, stored volume), quality (oxygenation, temperature) and ecology (cyanobacteria abundance); the presence of infrastructure related to use is also considered.

It should be noted that not all criteria necessarily need to be systematically filled in. Depending on the type of reservoir, watercourse, development or project under study, only certain key criteria may be selected, particularly those affecting priority use or those that are easier to assess (in the case of redundant criteria).

Each physical criterion has been assessed according to a standardized scale with four levels of compatibility of use (from 0 = incompatible to 3 = optimal), based on thresholds identified in the literature, French standards and/or regulations, and feedback from existing reservoir operators in France.

The description and justification of the parameters and thresholds selected are given in chapter 5.2. They can be adapted to each specific context or added to for other water use not currently existing in the Ain Valley.

The modular design of the matrix allows it to be adapted to different operational contexts without losing the rigor of the analysis.

3.3. Generalisation

With a view to generalizing to other national contexts or in the absence of bibliographic data or standards, three approaches can be used to calibrate the matrix appropriately for the context:

- interviews with key stakeholders (regional authorities, operators, user representatives and stakeholders, NGOs, etc.),
- consulting local experts specializing in the ecosystems concerned,
- collecting direct information to refine quantified assumptions about the thresholds for carrying out activities (e.g. conditions leading to conflicts of use).

As the aim is to enable a simple and comparative assessment of the feasibility of uses based on the physical configuration of a site or watercourse, it is important to note that these adjustments must comply with the proposed four-level compatibility classification structure (incompatible/limited/compatible/optimal) and that it is necessary to determine the prioritisation of use (see chapter 4.3).

3.4. VSM and the Ain Valley

The VSM project is located in the middle valley of the Ain River, a tributary of the Rhône River, near the Vouglans and Coiselet hydropower plants (Figure 2).

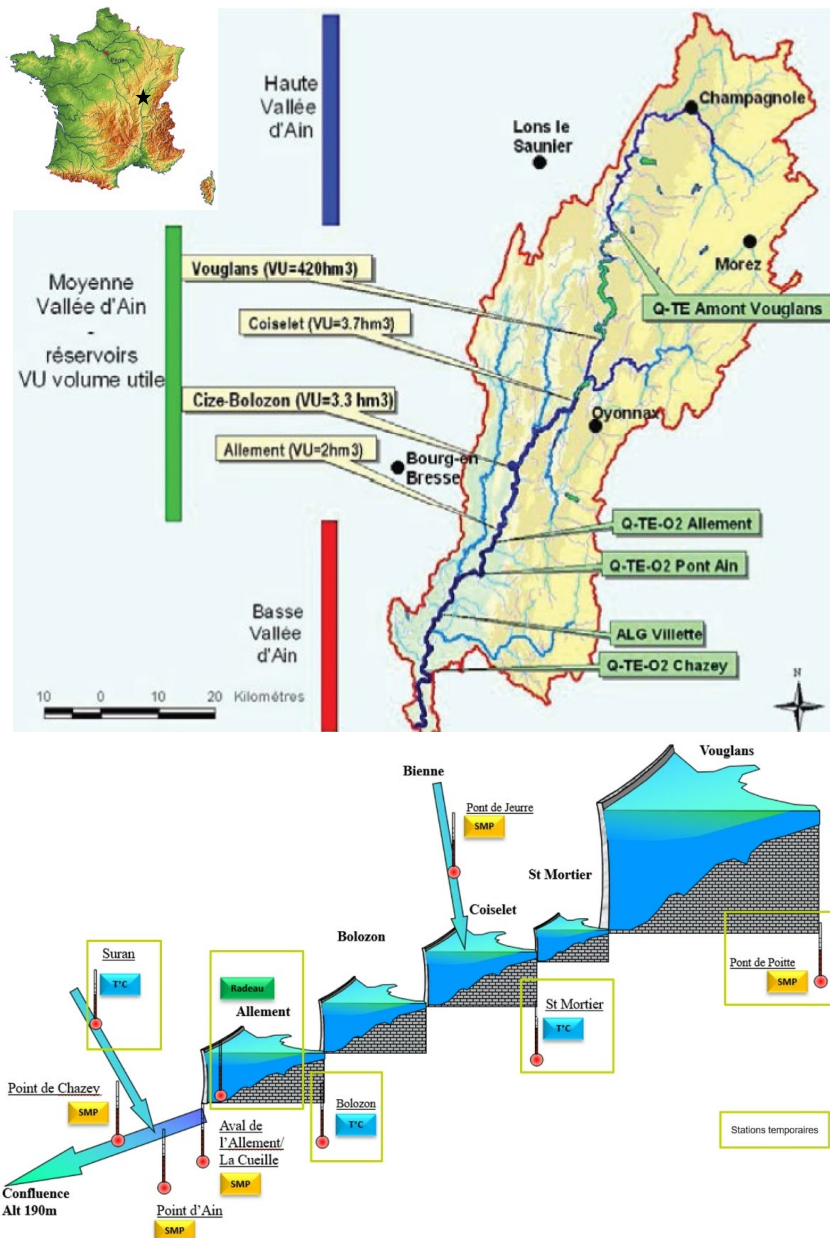


Figure 2 : (top) Location of the Ain Valley (from Poirel et al, 2016). The valley has a network of sensors for temperatures (TE), flows (Q) and dissolved oxygen (O2); (bottom) Hydropower scheme in the mean Valley of river Ain.

The project involves adding a pump-turbine to the Saut Mortier plant, enabling water to be pumped from the Coiselet reservoir to the Saut-Mortier reservoir, from where it can be pumped further upstream to the Vouglans head reservoir. The new installed capacity is 84 MW. Due to the possibility of pumping more water from the tributary Bienne River into the Coiselet downstream reservoir, the system will also increase overall production by approximately 140 GWh.

Thus, the valley is strongly structured by this central chain of hydropower schemes, creating a « hydro-social » discontinuity (Boyer et al, 2018), particularly in terms of the social perception of the catchment area and the river and the differentiation of water uses. The Ain valley can thus be divided into four socio-environmental sections: from the sources to the Vouglans reservoir, Vouglans reservoir, the chain of large dams, and the lower valley (between Allement dam et the Rhône confluence) (LeLay et al, 2015; Boyer et al, 2018).

4. Characterisation of water use

4.1. Categories

Table 1 lists the main use of water identified in France, linking them to the different categories of ecosystem services (according to MEA, 2005); the main use of surface water identified in the Ain Valley and the Vouglans reservoir are indicated in bold in the table (source: SBVA, 2013); uses not included in the matrix are non-existent in the Ain Valley or only marginally interfere with VSM management.

Table 1. Typology of water use – use in the Ain valley are in bold (from the Environmental impact study of VSM and from SR3A – see Appendix for details) – The main CICES V5.2 codes are indicated for main correspondence (<https://cices.eu/>)

	Supply	Regulation	Cultural	Support
CICES V5.2	4.1.1.1, 4.1.1.2, 4.1.1.3, 4.1.2.1, 4.1.2.2, 1.1.6.1	5.1.1.1, 5.2.1.2, 2.2.2.1, 2.2.2.2, 2.2.3.2	3.1.1.1	5.2.1.2, 2.2.2.1, 2.2.2.2, 2.2.3.2, 2.3.2.3, 2.3.2.4, 2.3.6.2, 2.4.x.x
Considered in the matrix	Water (drinking, watering) Food (irrigation) Fish (fishing) Hydropower	Drought mitigation Flood control Water purification	Aquatic recreation	Regulation of the hydrological and thermal regime, Habitat/Biodiversity
CICES V5.2	4.1.x.x, 4.2.1.2, 1.1.5.2	2.2.1.1	6.2.1.4, 6.4.2.1	2.3.6.1, 4.1.1.2
Not considered in the matrix	Construction materials (wood, gravels), Artificial snow production Industry Municipal landscaping	Run-off	Landscape aesthetics Cultural heritage and identity	Navigation (non-recreational) Carbon sequestration

These uses³ are representative of the use frequently associated with hydropower reservoirs in France and correspond well to the integrated assessment framework defined by Grizzetti et al (2016) (see Figure 3).

4.2. Seasonality

Water use varies according to the four seasons of Western Europe's temperate climate and their start/end dates may differ slightly both from the ephemeris and from country to country.

In France, and particularly in the southern half of the country (where almost all hydropower schemes are located), there are also two sub-periods for spring. Table 2 lists, for the main water uses, the preferred periods for practices identified on the Vouglans reservoir and the river Ain.

³ The different uses are the ecosystem service consumed or used in a given period and a particular area (here the Ain River and a period of the year)

Table 2. Preferred periods for water use on the Vouglans reservoir and the river Ain - Winter: 1/12 au 5/3 – Spr1: 15/3 au 30/4 and Spr 2: 1/5 au 15/6 – Summer: 15/6 au 1/9 – Fall: 1/9 au 30/11.

	Use in the Vouglans Reservoir					Use in the Ain River				
	Winter	Spr1	Spr2	Summer	Fall	Winter	Spr1	Spr2	Summer	Fall
Biodiversity	X	X	X	X	X	X	X	X	X	X
Drinking water						X	X	X	X	X
Irrigation								X	X	
Watering	X	X	X	X	X					
Recreational fishing		X	X	X	X		X	X	X	
Bathing			X	X				X	X	
Recreational boating	X	X	X	X	X	X	X	X	X	X
White water sports							X	X	X	
Hydropower	X	X	X	X	X	X	X	X	X	X
Low-water support			X	X						
Flood control	X	X			X					

The period from May to September includes the highest concentration of use, both in the reservoir and the river; this period corresponds to the low-water period in the catchment, as well as the highest demand for water due to the summer heat, which can potentially lead to water use conflicts. It is therefore necessary to consider prioritization (chapter 4.3) at the same time as the season.

Note:

Depending on the local context, use may require slightly different physical characteristics:

- **Recreational fishing:** fishing can be practised from the bank or in the watercourse (wading) or by boat. Physical constraints may therefore vary in terms of accessibility, water levels and current speeds. In the case of the Ain River, these differences do not significantly affect the physical compatibility thresholds used in the grids; all these practices have therefore been grouped under a single 'entry' to ensure the tool's readability and transferability. This approach reflects the general feasibility of the activity, while allowing for local adjustments if necessary.
- **Recreational boating:** The use can be subdivided into several technical sub-uses to better represent the diversity of practices encountered on lakes or rivers:
 - Lake navigation includes practices such as sailing, light motorised navigation, pedalos, paddleboats, etc. It requires large water bodies with small water level variations and low currents and specific infrastructure (launching facilities). This use (with all its sub-categories) is present on the Vouglans reservoir.
 - River navigation covers sub-categories requiring stability criteria (low water level variation range or current, canoeing or paddleboarding) as in reservoirs, or, on the contrary, fast currents (with sufficient water depth) for activities like white water sports. Both categories coexist on the Ain River (family canoeing or paddling, and kayaking).

4.3. Water use prioritization in France

In the context of gradually dwindling water resources, prioritizing water use is becoming a key governance issue, particularly in relation to multifunctional hydropower reservoirs and watercourses.

At the national level in France, the watershed coordinating department (préfecture) use drought framework decrees to set the priority use to be preserved during periods of water stress, in accordance with the recommendations of the Ministry for Ecological Transition and the Water Framework Directive (2000/60/EC). This prioritization follows the same pattern throughout France, with:

- four levels of authorized use: Vigilance, Alert, Enhanced Alert, Crisis (corresponding to specific hydrological, groundwater and meteorological conditions for each river watershed)
- four categories of users: Individuals, Businesses, Local authorities, Farmers, for whom restrictions are precisely defined and specific to each river watershed.

The main trends observed show that drinking water supply is a constant priority, followed by low water support for ecological purposes and, lastly, agriculture (irrigation), industry and leisure activities (swimming, fishing, boating), which may be restricted, if necessary, especially in watersheds subject to quantitative stress. In some cases, depending on national legislation, hydropower production is identified as a priority use (but less than drinking water supply or biodiversity). Table 3 illustrates the example of the Ain Valley.

Table 3. Grid for prioritizing water use in the Ain valley, based on SAGE guidelines, government directives and the principles of sustainable management of water resources (from SR3A).

Level of priority	Use	Justification
Priority 1: absolute use	Drinking water supply (DWS)	Ensuring the supply of current and future populations
	Biodiversity	Preserve ecosystem functioning
Priority 2: important use under normal conditions	Agriculture (irrigation)	Main use (around 65%) of groundwater abstraction. Supports the local economy but is subject to restrictions during drought periods
	Industry	Maintenance of economic activity with incentives to reuse water
Priority 3: secondary or recreational use	Leisure, fishing, tourism	Non vital use often restricted during periods of tension

The matrix takes this logic into account by integrating all uses into a single structure; the criteria and thresholds are defined for the period/season of use. It also allows for flexible interpretation depending on the local context, based on regulatory, concerted or regional guidelines. It will thus provide a flexible tool for prioritizing, negotiating or conducting technical analyses of projects involving reservoirs and watercourses. For example, users will be able to weigh certain use according to their local or regional regulatory status.

5. Assessment of physical criteria

5.1. Criteria selected for the matrix

The literature review⁴, regulations and factual observations concerning aquatic environment show that the satisfaction of use depends on certain physical criteria influenced by hydropower management.

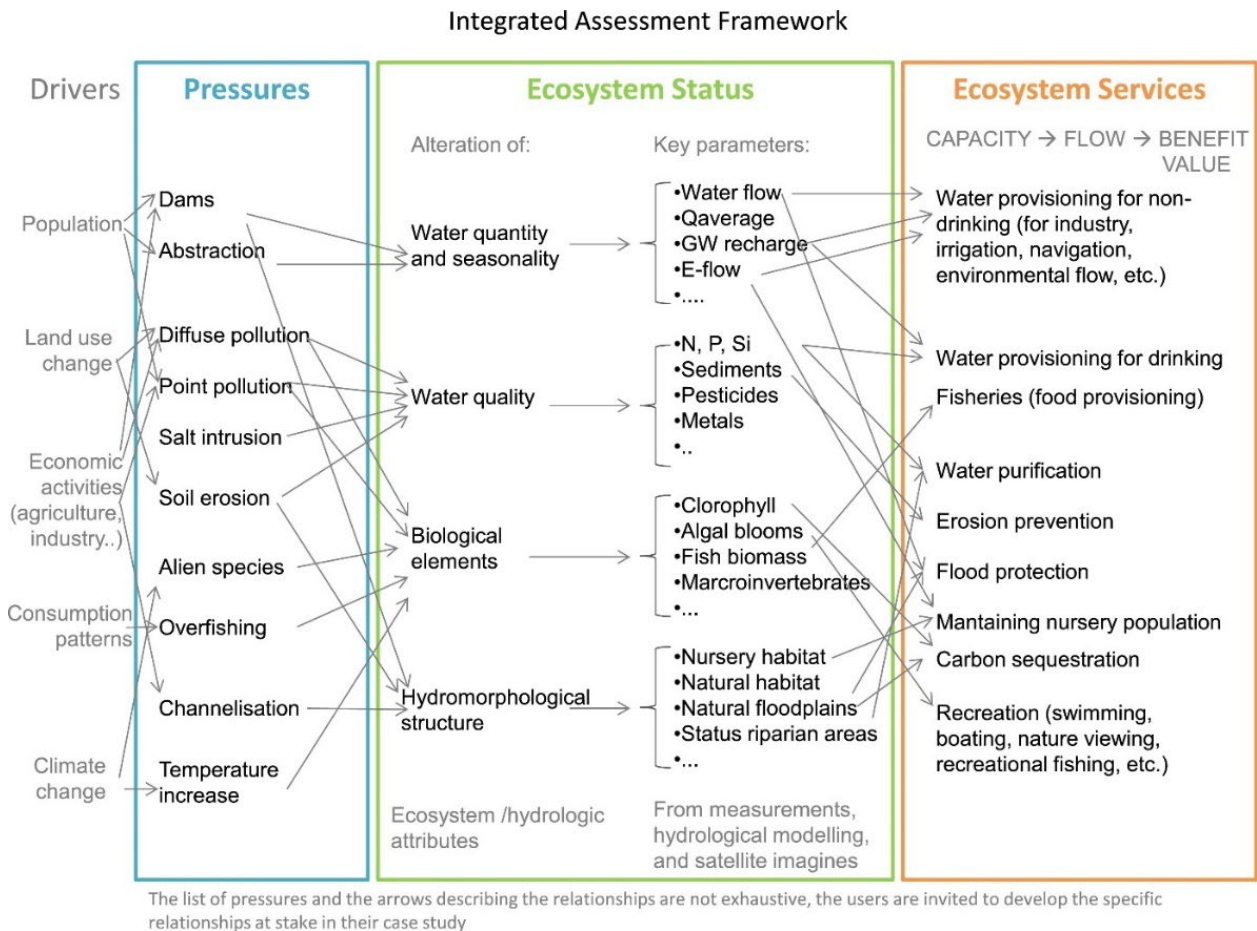


Figure 3 : Assessment framework showing the link between key ecosystem parameters and human pressures (including dams) or the services enjoyed by water users (Grizzetti et al, 2016).

These physical criteria are shown in Table 4 (and the parameters are developed and justified in chapter 5.2). They concern:

- **Water quantity** (all uses): this can be assessed in terms of storage volumes (in relation to water level variation range and/or depth) or river flows (water levels and current speeds).
- **Water quality** (certain uses, such as drinking water, bathing, etc.): the quality parameters most influenced by the management method are temperature, oxygenation and turbidity, and more indirectly eutrophication (mainly reflected here by the development of cyanobacteria blooms).

⁴ See for example Rietjens et al, 1994; Rietjens & Gailhard, 1998; Bohn et al, 2008; Pritchett et al, 2009; Girardi et al, 2011; Garcia et al, 2019; De Castro-Pardo et al, 2021; Carolli et al, 2017, 2025).

- **Accessibility** to the aquatic environment: the main criteria are the slope of the banks, as well as the substrates and the exposed surface area in the case of water level variation ranges, and more broadly the hydro-morphological characteristics (see Thorp et al, 2010). Certain uses (agriculture, navigation, etc.) sometimes require specific access conditions or even special infrastructure (more or less light), the proper functioning of which may depend on water level variation range.

Table 4. Main physical criteria influenced by hydropower management that interfere with the ability to maintain water use.

	Water quantity	Water quality	Access (banks)
Reservoir	Volume Water level Depth / Surface	Temperature Oxygen Eutrophication (cyanobacteria abundance)	Slope Water level
River	(Flow) Water level Current speed Width of wetted bed	Temperature Oxygen Turbidity Eutrophication (cyanobacteria)	Slope

Biodiversity is considered to be a supporting function for other use (Diaz et al, 2015). It requires that the characteristics of the environment to be maintained within a range of all these criteria (water quantity and quality) which, together with morphological characteristics (particularly those of the banks), determine the carrying capacity (or habitat quality) for aquatic biocenoses.

The Table 5 summarizes the criteria selected for each use in the matrix. It is proposed to retain the most significant and inclusive measurable parameters, with a view to applying the matrix as widely as possible (turbidity is mentioned for information purposes only – see chapter 5.2.2.4). Some parameters may be redundant for a given use, allowing either one to be used depending on the local context

Table 5. Physical parameters influenced by hydropower management and conditioning the use of the Vouglans reservoir (top) and the river Ain (bottom) – Turbidity is indicated as a reminder – NC = not concerned.

Vouglans reservoir							
	Water level	Access	Surface	Volume	T°	Cyano.	O ₂
Biodiversity	x	x	NC	NC	x	x	x
Drinking water	x	x	x	x	x	x	x
Irrigation	x	x	x	x	x	x	NC
Watering	x	x	x	x	x	x	x
Recreational fishing	x	x	x	x	x	x	x
Bathing	x	x	x	NC	x	x	x
Recreational boating	x	x	x	x	x	x	x
White water sports	NC	NC	NC	NC	NC	NC	NC
Hydropower	x	NC	x	x	x	NC	NC
Low-water support	x	NC	x	x	x	x	NC
Flood control	x	NC	x	x	NC	NC	NC
River Ain							
	HxV or H	Access	Width	(Turbidity)	T°	Cyano.	O ₂
Biodiversity	x	x	x	x	x	x	x
Drinking water	x	x	NC	x	x	x	x
Irrigation	x	x	x	x	x	x	NC
Watering	x	x	x	x	x	x	x
Recreational fishing	x	x	x	x	x	x	x
Bathing	x	x	x	x	x	x	x
Recreational boating	x	x	x	NC	x	x	x
White water sports	x	x	x	NC	NC	NC	NC
Hydropower	NC	NC	x	NC	x	NC	NC
Low-water support	x	NC	x	NC	x	x	NC
Flood control	x	NC	x	NC	NC	NC	NC

5.2. Justification of parameters and thresholds

It was decided to assess each physical criterion according to a **standardized scale with four levels of compatibility** (0 = incompatible; 1 = limited; 2 = compatible; 3 = optimal), for the measurable parameters selected. This classification is based as far as possible on thresholds identified in the scientific literature, but above all on French standards, regulations or practices.

The thresholds are as generic as possible so they can be used beyond the case of the Ain valley and the VSM project. However, they may be adapted according to local practices or national rules in other European countries.

5.2.1. Quantity parameters

Below are proposed threshold values for the physical parameters selected to qualify the level of user satisfaction. The justifications are summarised before each summary table.

5.2.1.1. Water level

The water level is a direct result of hydropower production (a succession of start/stop cycles). It influences the volume of water available for other use.

- In reservoirs**, the water level can cause significant variations in wet areas, reducing access to water or the quality of riparian habitats. For example, Reverdy et al (2025) indicate that seasonal water level variations greater than 3 m led to a decline or even disappearance of helophytic vegetation and that those of 1 to 3 m are ecologically tolerable. In Vouglans, the societal survey showed good acceptability of water level variations up to 3-4 m; beyond that, acceptability was conditional on the implementation of specific infrastructure to allow access.

Water level – m	<1m; 1-3m; 3-7m; >7m	A low water level variations is ideal for biodiversity, stable (static) use and public access; variations >3m become incompatible with surface use (access, substrate quality, etc.) and coastal biodiversity, but are favourable for specific use (such as low water support or flood control)
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- In rivers**, the flow rates generated by the hydropower plant result in variations in water levels and current speeds (hydropeaking) that affect biodiversity and use: the impact can be negative for use requiring a certain degree of hydraulic stability (fishing, bathing, etc.) or, conversely, positive for use that depend on water releases (white water sports, low water support, etc.). Various compatibility grids for recreational use are available in the literature (Figure 4), based on the combination of water level and current speed rather than water level variation range alone.

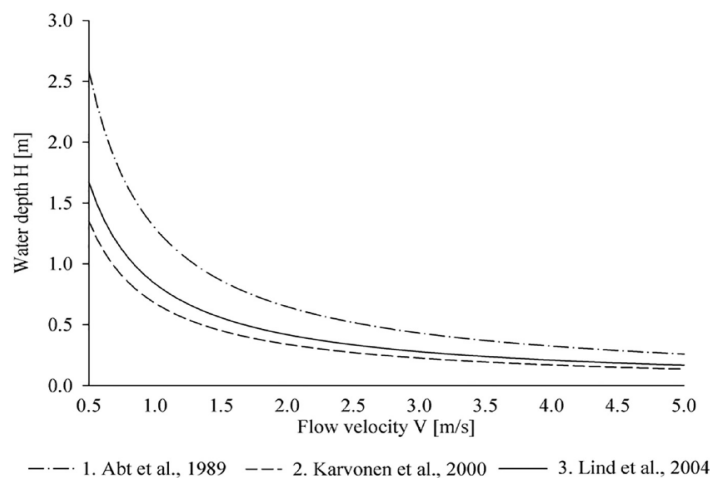
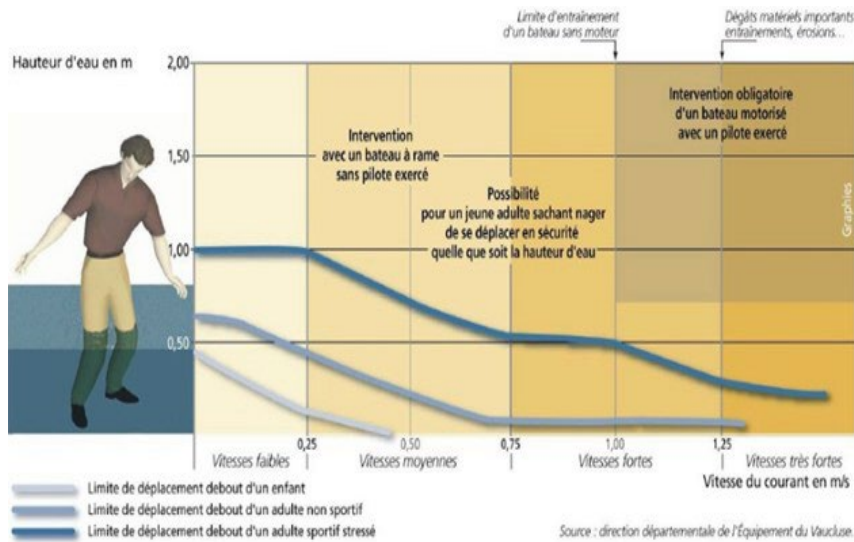
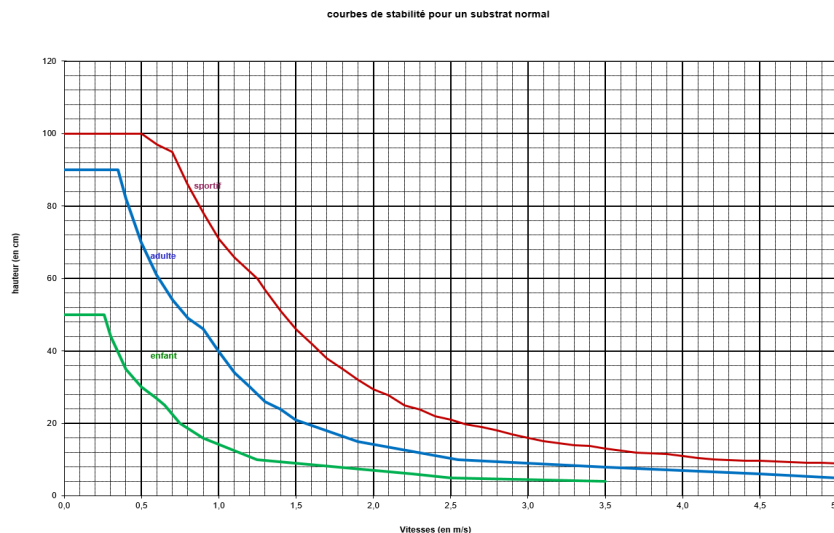


Fig. 3. Comparison between the human stability formulations (Eqs. (1)–(3)). Considered an adult with $m_p = 70$ kg and $h_p = 1.7$ m.

Comparison between human stability formulation, In Pisaturo et al, 2019



Source : MEDD, Note complémentaire PPR inondation – Ruissellement urbain.
 Displacement limit for individuals as a function of their size, and for boats (from MEDD)



Stability curves with normal substrate, used by EDF

Figure 4: Examples of stability or displacement grids for people (or boats) in the water as a function of water depth and current speed.

We propose to retain values inspired by these thresholds in a first stage (table below) and to test the different values on the Ain River for ‘bathing and ‘fishing’ use; the compatibility of the proposed thresholds with biodiversity can be verified through biological habitat modelling from ReHydro WP4; the grid may subsequently include thresholds in terms of gradients (inspired by scientific literature on hydropeaking) if necessary.

Water level variation range –m	<0,5m (A); 0,5-1m (B); 1-1,5m (C); >1,5m (D)	This criterion can be used for activities that do not require entering the water or for navigation or white-water sports (assuming that high tides are correlated with fast currents).
Water depth (m) x [Speed] (m/s)	<0,7 * [0,25] (A) <0,7 * [0,25-0,5] (B) <0,5 * [0,5-1] (C) >1 * [0,2] (D)	This criterion is preferably used for use requiring entry into the river (bathing, fishing in waders); the values can be adapted according to the use. The threshold values proposed here are adapted from the MEDD reference in Figure 4.

5.2.1.2. Surface

In reservoirs, the surface area can indirectly represent the volume of water available; we propose using it here as a representative criterion of a reservoir's capacity for multiple use, based on observations made on French hydroelectric reservoirs (Poutès, 35 ha, Saint-Guérin, 45 ha; Bort-les-Orgues 1070 ha; Serre-Ponçon, 2800 ha). It is also based on the INRAE collective expert report (Dufour & Burger-Leenhardt, 2023), which highlights the importance of characterizing reservoirs according to their size in relation to their impacts and governance issues.

Surface– ha	<50; 50-200; 200-1000; >1000	The larger the surface area, the more multi-use is possible in a context of strong territorial cohabitation within a shared governance framework. Smaller reservoirs generally have no other use than that for which they were created.
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5.2.1.3. Volume

The storage volume is another indicator of the reservoir size; it directly determines use such as low water support, water withdrawals (irrigation, etc.), hydropower generation, etc. In general, these two criteria (surface area and volume) are unlikely to change significantly for a given reservoir, except in the event of a significant change in operating methods to better consider the needs of other uses or climate change. The thresholds proposed below are based on examples of French reservoirs. (Montézic, 32 hm³; Pareloup, 169 hm³; Vouglans, 420 hm³; Serre-Ponçon, 1272 hm³).

Volume– hm ³	<1; 1-10. 10-100; >100	The higher the available volumes, the more reservoirs can provide multi-purpose structuring within a shared governance framework.
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5.2.1.4. Wetted width

In rivers, we propose using the width of the wetted low flow area, which will determine the satisfaction of certain use, the accessibility of the banks, and the resilience of the aquatic biocenoses. The proposed thresholds are based on local observations and can be adapted to suit the river type or context.

Width of low- waterbed –m	<3; 3-6. 6-15; >15	Narrow rivers limit use; the greater the width, the more uses can theoretically be developed (in the absence of other constraints). Increasing the width also increases the morphological diversity of the watercourse and its capacity to support a diverse range of biodiversity
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5.2.1.5. Access

The morphological characteristics of the river or body of water and the conditions of hydropower exploitation (water level range) influence access to water. The slope of the banks in particular is a very important criterion for recreational, agricultural and fishing use, as well as for biodiversity: gentle slopes (<15°) favour this different use, while slopes >25° are considered to be riskier (Lachat, 1994). This slope criterion can possibly be refined with a morphological criterion (type of substrate), but in this case, we propose to base our analysis solely on slope for the sake of transposability.

Bank slope – °	<15; 15-25. 25-35; >35	Steep or unstable banks limit access to water without equipment. Intermediate slopes may also restrict access depending on the nature of the substrate or the presence of dense riparian vegetation. Gently sloping beaches do not generally restrict access, regardless of the type of substrate or vegetation density.
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5.2.2. Quality parameters

5.2.2.1. Water temperature

This is an essential parameter that determines ecological quality and biodiversity, safety of use (risk of faintness following sudden immersion in cold water, health quality if temperatures are too high, etc.) and the technical performance of some of them (treatment for drinking water, for example). It depends on the size of the aquatic environment, its exposure to sunlight (or shade), flow conditions (current speeds, depths), exchanges with the water table, etc. (Beaufort & Moatar, 2015).

Temperature -m	<10; 10-18. 18-24; >24	Cold waters (<10°C) restrict recreational use or correspond to very specific ecosystems in terms of biodiversity. Waters that are too warm (>24 °C) become detrimental to all use due to the risk of quality degradation (eutrophication, pathogens, etc.) or may create operational constraints for hydroelectricity. For rivers, intermediate thresholds depend on the typological context, particularly in terms of biodiversity.
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5.2.2.2. Dissolved oxygen

This parameter is essential for the proper functioning of aquatic environments, biodiversity and for ‘supply’ use; it is also monitored for certain recreational use, as its degradation will indicate eutrophication phenomena that be a health risk to people (swimming) or animals (watering), or that reduce attractiveness or comfort (navigation). This parameter is influenced by hydropower via the characteristics of the reservoir and the operation of the power plant.

Oxygen -mg/l	<4; 4-6; 6-8; >8	Low oxygen levels (<4 mg/l) pose an immediate risk to wildlife and reflect broader problems of eutrophication and health risks. Above 8 mg/l, all use, and biodiversity are in ideal condition. Intermediate thresholds can be adapted to the local context.
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5.2.2.3. Cyanobacteria

These planktonic or benthic microorganisms are likely to form blooms and produce toxins in the water (neurotoxins, hepatotoxins) in close connection with water temperature (when >24 °C), the stability of water bodies or river current conditions (favourable between 0.6 and 1.1 m/s – ANSES, 2020). Their detection leads to bans on certain use (swimming, leisure activities) or additional constraints on water treatment processes. In France, usage limits are based on expert reports (ANSES, 2020) and advice from national authorities (MSS, 2021) based on WHO guidelines. The parameter considered for initial monitoring may be the biovolume of cyanobacteria or the concentration of chlorophyll a (see appendix), which are translated into alert levels by the organizations responsible for monitoring.

Cyanobacteria – risk level	None - Low (monitoring)– Medium (alert 1) – High (alert 2)	These risk levels correspond to alert levels that lead to the gradual strengthening of surveillance by managers, which may result in the restriction (Alert 1) or prohibition (Alert 2) of use. In the case of the use satisfaction matrix, it is proposed to consider the risk levels defined by the governing bodies.
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5.2.2.4. Turbidity

Turbidity is another quality parameter that can be affected by hydropower generation and may restrict certain use. Turbidity reflects the concentration of suspended solids in water, or even the colloid load (brown water). Turbid water can lead to a loss of attractiveness or reduced safety (swimming, fishing), increased treatment costs (drinking water production), and even influence biodiversity (reduction in photosynthesis, clogging of habitats, etc.). This is a dynamic parameter

that is highly context-dependent, as it is linked to both the natural characteristics of the catchment area (geology, land use, precipitation, biological production) and anthropogenic activities (wastewater discharges, construction work, etc.). However, there are no clear and consistent regulatory thresholds applicable to different use (except for swimming in reservoirs) and it is difficult to envisage general values that would allow for inter-site comparisons. As this parameter is not greatly influenced by VSM, especially during periods of sensitivity for use (May to September), it has not been included in the matrix and is mentioned here as a reminder.

6. Water use satisfaction matrix

The matrix summarizing the threshold parameters for each use is presented in Table 6. It will be used as a spreadsheet to calculate the level of compatibility of a given according to the physical characteristics observed.

Reminder of the classification code and reading:

Code 0 = « **Incompatible** »: use not recommended or dangerous

Code 1 = « **Limited** »: use feasible but with constraints

Code 2 = « **Compatible** » use possible with good yields/quality.

Code 3 = « **Optimal** »: favoured use, ideal conditions.

The rating corresponds to the satisfaction of the use at the season when it is practiced (see Table 2).

6.1. Further work

The next steps will consist of:

- Developing a spreadsheet tool
- Challenging the matrix coefficients using broader scientific review or partners practices
- Applying the final matrix to the Ain River and VSM to illustrate its interest and capacity to discriminate the water use satisfaction depending on limited criteria influenced by hydropower.
- Drawing up the link with social benefits perceived by local stakeholders and partners (task 5.2)

Then the tool will be available to be tested on CNR demonstrator sites in the lower Rhône River in France, and other demonstration sites in ReHydro.

Table 6. Proposed water use compatibility matrix based on physical parameters potentially influenced by hydropower.

aquatic ecosystem	Parameters	Threshold	Biodiversity	Drinking water	Irrigation	livestock	Recreational fishing	Bathing	recreational navigation	White water sports	Hydropower	Low-water support	Flood control	
Reservoir	Tidal range (m)	<1	3	3	3	3	3	3	3		1	1	0	
		1-3	2	3	3	2	2	2	2		2	2	2	
		3-7	1	2	2	1	1	1	1		3	3	3	
		>7	0	1	1	0	0	0	0		3	3	3	
	Surface (ha)	<50			1	1	2	1	1	0		2	0	0
		50-200			2	2	3	2	2	1		2	0	0
		200-1000			3	3	3	3	3	2		3	2	2
		>1000			3	3	3	3	3	3		3	3	3
	Volume (hm ³)	<1			1	1	2	1		0		1	0	0
		1-10			2	2	3	2		1		2	1	0
		10-100			3	3	3	3		2		3	2	2
		>100			3	3	3	3		3		3	3	3
Reservoir or River	Access (bank slope, °)	15	3	3	3	3	3	3	3	3				
		15-25	3	3	3	2	2	2	1	2				
		25-35	2	3	2	0	1	1	1	0				
		>35	1	1	1	0	0	0	0	0				
	Temperature, °C	<10	2	3	3	3	3	1	0	0		2	2	
		10-18	3	3	3	3	3	3	1	2		3	3	
		18-24	2	2	3	3	3	2	3	3		3	3	
		>24	1	1	2	2	2	1	1	2		2	1	
	Oxygen, mg/l	<4	0	1		1	0	0	1	1				
		4-6	1	2		2	1	1	2	2				
		6-8	2	3		3	2	2	3	3				
		>8	3	3		3	3	3	3	3				
	Cyanobacteria (risk)	none	3	3	3	3	3	3	3	3			3	
		Low	2	2	2	2	2	2	2	2			3	
		Medium	1	1	1	1	1	1	0	1			2	
		High	0	0	0	0	0	0	0	0			1	
River	Height or HeightxSpeed (see text)	A	3	3	3	3	3	3	3	0		3	0	
		B	2	2	2	2	2	2	2	3		2	0	
		C	1	1	1	1	1	1	0	0	1		0	1
		D	0	0	0	0	0	0	0	0	0		0	3
	Width (wetted low-water, m)	<3	1			2	1	1	0	0	0	2	0	0
		3-6	2			2	2	2	1	0	1	2	0	0
		6-15	3			3	3	3	2	1	2	2	2	1
		>15	3			3	3	3	3	2	3	2	3	2

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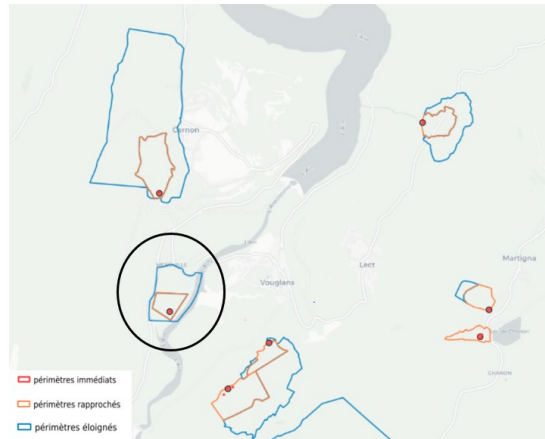
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A1. Appendix

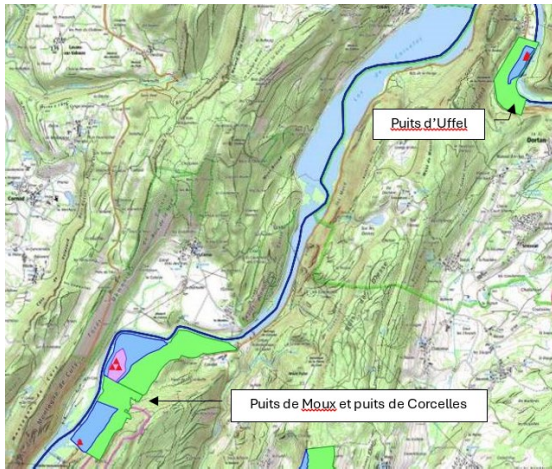
A1.1. Water use of the Ain River

From: SAGE, for the lower Ain River and Environmental impact assessment for the upstream section

Water use	Location	Uptaken volume
Drinking water (see charts below)	Sources uptake, outside the Vouglans perimeter	-
	Larnay's borehole – underground uptake linked to Coiselet reservoir	-
	Menouille's borehole – underground uptake linked to Saut-Mortier	-
	Uffel's borehole – underground uptake linked to the Bienne's floodplain	-
	50 water uptakes (alluvial plain) 11 strategic areas for future drinking water	2,5 million m ³
Irrigation	1 river uptake (St Jean de Niost) 250 underground uptakes in the Ain floodplain	about 20 to 25 million m ³ /y
Livestock	51 500 Cattle Units– quite marginal in the Ain Valley (max 10 000 CU)	1,3 million m ³
Industry	21 uptake points – mainly underground	3,5 million m ³
Hydropower	Ain Valley (Vouglans, Saut Mortier, Coiselet, Cize Bolozon, Allement) 4 micro hydropower plants (Neuville, Oussiat, Pont d'Ain – 2 powerplants on the same barrier)	-
Water quality	Domestic waste from 4030 population equivalents No direct rejects: infiltration in soil or reject in the Bienne River (Dortan)	-
Recreational	Vouglans: 3 supervised swimming areas + nautical sports (sailing, water skiing, rowing, kayaking, diving, motor boating) + fishing + cruising BRA: 5 supervised swimming areas + 1 on Allement reservoir; Kayaking; fishing	-
Recreational fishing	4 fishing societies (BRA) 2 000-2 500 fishermen in the Ain River Unknown number of users on the reservoirs	-



Protection area of Ménouille 's borehole (in black)



Protection area of Uffel 's borehole



Protection area of Larnay's borehole

Protection areas of underground water uptakes linked to Vouglans and Saut-Mortier reservoirs

A1.2. WHO guidelines for bathing waters

Source: World Health Organization, 2021. *Toxic cyanobacteria in waters: A Guide to their public health consequences, monitoring and management, 2nd ed.*. *Report*.

According to the World Health Organisation (WHO) guidelines for bathing water (updated in 2021), the thresholds for cyanobacteria in freshwater (reservoirs, rivers, lakes) are defined as follows:

Level	Biovolume (mm ³ /L)	Chlorophyll a (µg/L)	Indication
Vigilance	1 – 4	1 – 12	Moderate presence, monitoring recommended
Alerte 1	4 – 8	12 – 24	Increased risk, management actions to be considered
Alerte 2	Visible foam or transparency < 0,5–1 m	> 24	High risk, possible ban of use

These thresholds are used to assess the health risks associated with recreational use (bathing, water sports) and can also be used as a reference for other sensitive use such as drinking water or irrigation.

