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# CUMULATIVE IMPACT OF RESERVOIRS ON THE AQUATIC ENVIRONMENT

## Joint scientific appraisal



Water storage has increased considerably worldwide since the 1950s. Water is collected and stored in reservoirs to supply towns and cities with drinking water, and for agricultural and industrial purposes, fish farming, leisure activities and low-flow period support. In the late 20th Century, there was a considerable increase in small reservoirs in France, reaching a total of 125,000 by the early 2000s. The creation of new water storage structures continues in parallel with the exploration of water use reduction solutions. These developments raise a whole host of environmental issues, such as the impact of reservoirs on the aquatic environment, particularly in areas where there are already a number of reservoirs and water resources are in high demand.

By law, building a new reservoir requires a planning application or government authorization, which require an environmental impact study. Such studies must now assess the cumulative effects of the project together with other known similar projects. The “cumulative” aspect of the impact of water storage structures on a single catchment area is often poorly understood, probably due to a lack of relevant knowledge and methods.

Consultants and government services therefore face a lack of operational tools for processing new reservoir applications, which gives rise to other problems around water management planning and the supervision of the development of new reservoirs.

In this context, the French Ministry of the Environment, Energy and Marine Affairs (MEEM), supported by ONEMA, requested a joint scientific assessment (ESCo) from Irstea, in partnership with INRA, on the cumulative impact of reservoirs on the aquatic environment. It was produced by around fifteen experts from a range of disciplines and research organizations, and is based on analysis of a thousand or so international scientific articles and reports.

## BACKGROUND, ISSUES AND APPROACH OF THIS SCIENTIFIC ASSESSMENT

### A regulatory framework requiring knowledge and usable methods

Application of the water abstraction reform, based on the 2006 Water and Aquatic Environments Act, may lead to the creation of new water storage structures, or reservoirs, on certain catchment areas, in addition to reducing water use. The construction of such reservoirs is subject to a planning application or government authorization, depending primarily on the size of the structure, and the plan submitted must include an environmental impact study. The reform of these impact studies, implemented in application of the French National Environmental Commitment Act (known as the Grenelle-2 Act) dated 12 July 2010, requires all new reservoir construction applications to take into account the cumulative effects of planned structures. Furthermore, some strategic water management plans (SDAGE<sup>1</sup>) took measures in 2016 to request an assessment of the cumulative effects of all existing reservoirs in a catchment area.

Since a lack of knowledge, tools and methods hinders both

applicants and government departments in assessing the cumulative effects of reservoirs, the Ministry of the Environment requested a scientific assessment to provide methods with a view to improving the quality of project approval procedures and the associated impact studies.

The main questions explored were as follows: How can we characterize the short and long-term effects of a group of reservoirs on their aquatic environment? How can these effects be identified? What are the other environmental impacts? For equivalent volumes, how can the effects of numerous small reservoirs be compared against those of a few large reservoirs? How can we assess the impact of planned works in advance? Can threshold effects be identified in the hydro-ecological behaviour of the catchment area that will be modified by the planned structure?

<sup>1</sup>SDAGE = Schémas Directeurs d'Aménagement et de Gestion de l'Eau (French strategic water management plan).

## A multidisciplinary approach

By storing and diverting water, and flooding land and plants, reservoirs directly influence flow regimes and sediment, nutrient and contaminant transfer, and thereby modify the ecological behaviour of the aquatic environment, the continuity of rivers and the habitats of organisms living in them. The effects of reservoirs therefore need to be examined from the viewpoint of the various functional characteristics associated with rivers, which can be classified into four main categories : hydrology and hydrogeology; sediment transport and hydromorphology; physico-chemical quality of water ; biology and ecology. The term “functional characteristics” covers the dynamics of water flow, flows themselves and associated concentrations of matter (suspended solids, nutrients and contaminants). It also includes the characteristics of physical (river bed, banks, etc.) and biological compartments of the river, and the interactions between these various components. Since all these parameters interact, taking them all into account requires a multidisciplinary approach, with experts in hydrology, hydrogeology, agronomy, sediment transport, hydro-morphology, physico-chemistry, ecotoxicology and aquatic ecology (primarily fishes, amphibians, invertebrates and plants). Here, cumulative effects mean all the effects from a group of reservoirs, and therefore involve a large set of variables.

The scientific assessment only considered small and medium-sized reservoirs, i.e. with a capacity of less than a few million m<sup>3</sup>.

## A multistage process

Given the complexity of the topic and the high expectations at the operational level, the review of the international literature undertaken for the joint scientific assessment (ESCo) was preceded by an exploratory phase. This involved investigation of the knowledge and methods used in France for operational management of the cumulative effects of reservoirs. This first stage was based on analysis of available documents and field visits to a variety of situations. The ESCo then focused on results from international scientific literature that might improve the existing knowledge of operators. Review of the scientific literature focused first on the effects of an individual reservoir on the functional characteristics of a river and reservoir. This stage proved essential for understanding the processes involved and their interactions, in order to identify influencing factors, before moving on to study several reservoirs at a time. It then focused on the cumulative effect of reservoirs by studying both the knowledge available, and the methods and tools that can be used. Focusing on the methodological aspects of cumulative impact assessment made it possible to situate reservoirs in the broader context of the various projects and planning processes liable to involve the assessment of cumulative effects.

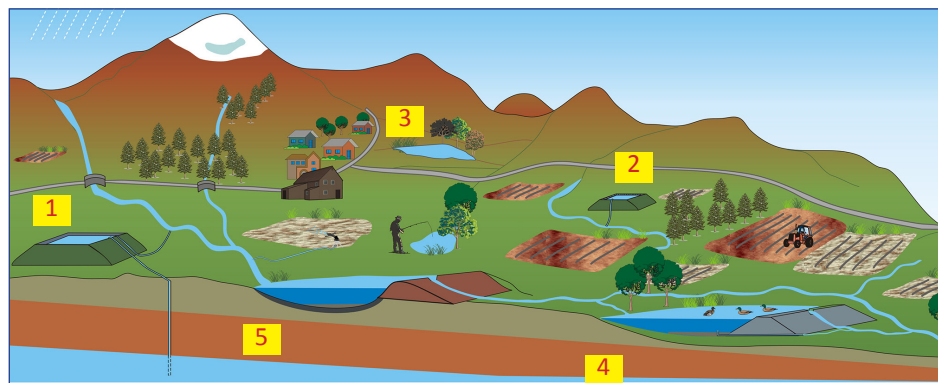
The ESCo will be followed by a final stage aimed at providing operators with more directly exploitable methodological approaches.

# RESULTS OF THE SCIENTIFIC ASSESSMENT

## A broad diversity of structures

**Studying the effects of reservoirs is complicated by the considerable diversity of water storage structures** in terms of their use, water supply and return methods, location in the catchment area, connection with the river, and their size and

shape. These factors all contribute to the influence a reservoir can have on its aquatic environment. This diversity led to the proposal of a classification of reservoir types (Figure 1), based on their supply method, which seems to be a key determining factor.



**Figure 1: Location of reservoirs depending on their supply method.**

1. Artificial pond supplied by pumping groundwater.
2. Artificial pond supplied by pumping in the river.
3. Hillslope reservoir supplied by runoff water. Disconnected from the hydrographic network.
4. Diversion reservoir.
5. Dam reservoir on river.

This diversity determines the scientific literature that can be used for an area of the scientific assessment. For instance, the literature on hydrology mainly deals with small fill-and-spill reservoirs, while hydromorphology and physico-chemistry studies mainly focus on large reservoirs. Biological and ecological studies seldom specify the type of water body studied, and works

on physico-chemistry are so scarce that the cited references had to be supplemented with studies on lakes, or even wetlands. So, in order to cover all the functional characteristics required for the assessment, we had to draw on knowledge from a range of very different situations.

Moreover, apart from for hydrology, the reservoirs studied in the literature analysed were primarily based on rivers, with no diversion : type 5 in Figure 1 is predominant. Finally, there is rarely mention of how reservoirs are managed or of compensation water (for a minimum flow rate to be maintained

## EFFECTS OF AN INDIVIDUAL RESERVOIR

### The multiple effects of a reservoir...

The state of a river is the result of the dynamic interactions between its functional characteristics. Altering any one of them can affect the entire system, which is why it is important to understand how a given reservoir modifies each functional characteristic. The effects of a reservoir depend on a range of factors, which are all interrelated. Before attempting to determine the effects of multiple reservoirs on a river, work had to be done to determine the order of magnitude of the processes involved and identify the main influencing factors.

A reservoir impacts a river both upstream and downstream, and it also affects the new aquatic environment it creates, sometimes involving flooding of areas of ecological or functional interest.

**The conditions within water bodies created by reservoirs promote certain physical, chemical and biological processes.** Reservoirs mean a loss of water for the downstream river due to an increased surface area for evaporation and sometimes significant infiltration. They always act as sediment traps with a trapping rate of nearly 100% for coarse sediment. Reservoirs favour the creation of reserves of phosphorus and/or trace metals or pesticides that can become resuspended and released at any time. Due to the accumulation of mineral and organic particles they cause, reservoirs can become sinks for carbon, nitrogen and phosphorus. Conversely, because of the biogeochemical transformations they make possible, reservoirs can also become sources of these same elements. Numerous determining factors affect the balance between “sink” and “source”, including the biogeochemical properties of the compounds or elements considered. This hydrochemical balance is highly sensitive to seasonal variations and hydrological dynamics. Denitrification (nitrate consumption) is yet another potential effect of reservoirs, which increases with the nitrogen inflow. On the other hand, the risk of eutrophication, usually associated with high levels of dissolved phosphorus in continental waters, is worthy of special attention, since it is a widespread phenomenon that can threaten certain uses of water bodies and propagate downstream. Reservoirs also provide new biotic environments likely to host a range of new species, and may promote the establishment of problem species, especially exotic invasive species.

**Downstream, a reservoir has an impact on all the functional characteristics of the river, by modifying the nature of flows as well as their spatial and temporal dynamics.** Fluctuations in the hydrological regime and sediment transport can lead to changes in river bed morphology and corresponding habitats. Changes

downstream of a dam). The effect of resupply reservoirs, which sustain river flow rates in low-water periods, is not covered. Given their potential significance, these two aspects should nevertheless be taken into account when applying the results of the ESCo to the situation in France.

in the physico-chemical characteristics of water (particularly temperature, dissolved oxygen concentration, suspended solids and nutrients) can lead to changes in communities that vary depending on the biological and ecological characteristics of species.

**The ecological impact of a reservoir on a river usually extends well upstream of the area it is located.** Reservoirs sometimes create an obstacle that is impassable for organisms that are strictly dependent on the river, such as certain fish or invertebrate species. This can disrupt their reproductive cycles and restrict the exchange of individuals between sub-populations.

### ...which depend on the siting of the reservoir, its characteristics and its water return method downstream

**The significance of the multiple effects of a reservoir depends on a number of factors which can be classified according to three components :**

- **Inflows into the reservoir**, which are determined by catchment area characteristics : geomorphology, soil, hydrological functioning, climate (rain, evapotranspiration), land use and agricultural practices, connection between the reservoir and the river ;
- **The specific characteristics of the reservoir itself** : size, morphology, volume and abstraction dynamics (depending on uses), water return method, which influence what happens to inflows and the material already present (internal loading). For the physico-chemical characteristics, the residence time for the water in the reservoir is a key factor ;
- **Downstream**, in cases where water is returned to the river, the impact of the reservoir will depend **on the magnitude of the flow returned by comparison with the downstream river flow rate**, i.e. , once again on the position of the reservoir in the catchment area (upstream or downstream) and in relation to the hydrographic network (depending on whether or not it is connected), on whether there is a diversion or not, on whether or not there are tributaries or major inflows further downstream, and on the fragility of the environment. The water return method (overflow, depth of water intake, whether or not compensation water is maintained) influences both the quantity and quality of the water returned.

The interactions between these various components are complex and highly season-dependent. We know which processes are involved and their order of magnitude, but accurate quantification in a given context still requires research. These interactions depend in particular on the relative size of inflows and outflows according to reservoir capacity and management.

## DATA IS CRUCIAL FOR CHARACTERIZING THE EFFECTS OF RESERVOIRS ON THEIR AQUATIC ENVIRONMENT

**Several types of data are required to determine the impact of a reservoir on a river, and this is even truer when several reservoirs are concerned** : their position in the catchment area, their supply method, their capacity (surface area, volume) and water return method, the water uses and resulting abstraction and return dynamics. Without this data, any attempt at assessing the impact of a reservoir leads to much uncertainty, whether in terms of hydrology, sediment transport or water quality. However, such data for a given catchment area is hardly ever comprehensively available, and the data that is varies considerably between different countries and catchment areas. In France, planning applications only include some of the information required, and many small reservoirs were built last century without the proper documentation. National databases do not include all the data required for assessing the environmental effects of reservoirs. Some departments have developed, or are developing, such databases using **field surveys** which require considerable human resources. **Remote sensing techniques** can be used to explore vast areas and give access to a broad range of data : in addition to geometric characteristics,

Numerical modelling can help quantify the impact of a reservoir on some river functional characteristics. However, a number of conceptual issues remain. Furthermore, modelling requires data to drive and validate the model, which brings us back to the crucial importance of data availability.

other attributes give access to proxies of nitrogen, phosphorus and suspended solid concentrations, as well as surface temperature and algal blooms. These methods are usually applied to large water bodies and smaller bodies would require higher resolution images. Moreover, the implementation of such approaches requires a high degree of skill, and they are therefore not yet used for small reservoirs. In addition, these methods do not yet give access to such essential information as **the way in which reservoirs are connected to rivers, or water abstraction dynamics**.

Reservoir abstraction dynamics are seldom documented, particularly for small individual reservoirs. They are usually, at best, estimated from the evaporative demand of irrigated crops. This lack of information leads to considerable uncertainty on the water balance of the reservoir, since abstraction dynamics affect reservoir filling dynamics and the volumes a reservoir is able to collect, which is particularly crucial when the reservoir cannot be disconnected from the river. It has been observed that a reservoir can collect up to 3 to 4 times its volume in one year.

## THE CUMULATIVE EFFECTS OF RESERVOIRS

### A seldom considered aspect

**The cumulative effects of reservoirs have seldom been investigated**, except in relation to hydrology and the quantitative aspects of water resources. For this reason, the analysis was extended to grey literature where relevant, and to exploring the knowledge and methods related to types of bodies of water (large reservoirs, lakes, ponds, wetlands) other than the reservoirs considered in this assessment, when it seemed that they would be able to feed discussion. The goal was not to transfer the results from these projects as is, but to draw on them as inspiration, at least from a methodological perspective. Moreover, the cumulative effects of reservoirs have generally only been studied for individual functional characteristic types - the interactions between characteristics have rarely been studied. Similarly, water bodies (lentic environments) and rivers (lotic environments) are most often studied by specialists in each of these environments who do not necessarily share the same approach. This does not make it easy to develop an overall

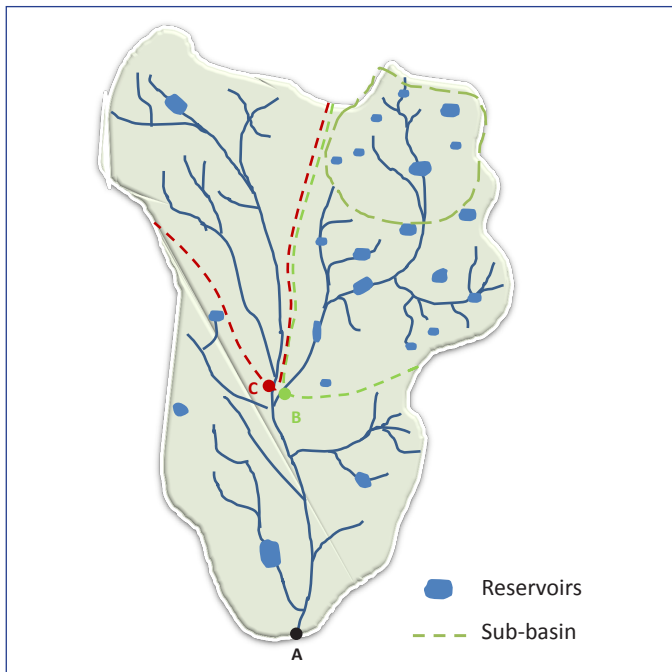
understanding of the cumulative effect of reservoirs on the behaviour of their catchment areas and associated rivers.

### The determining influence of reservoir location in the catchment area

The position of a reservoir in a catchment area determines its inflows and outflows (size, timing, and speciation of chemical elements), the latter of which may be collected by reservoirs further downstream. Depending on the distribution of reservoirs in the catchment and in relation to the river, and on the functional characteristics considered, the cumulated effects can diverge significantly from a simple addition of individual effects. **The concept of hydrological and ecological connectivity<sup>2</sup> between reservoirs is essential** (Figure 2).

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<sup>2</sup>Connectivity is defined here as the degree of connection between the entities considered. It encompasses the degree of branching of the hydrographic network, the distance between reservoirs and whether they are located on the watercourse, and the degree of fragmentation of the hydrographic network created by the reservoirs.



**Figure 2 : Example of reservoirs interconnected via the hydrographic network, and other reservoirs in the catchment that are not connected.**

Hydrological connectivity mainly occurs via surface waters. Underground connections via groundwater are relatively insignificant for small reservoirs.

**The scale used for the assessment of cumulative effects is key.** In Figure 2, we can see that an assessment carried out at point B would conclude that there is a significant cumulative effect due to the reservoirs, a moderate effect when measured at point C and an intermediate effect at point A. The scientific assessment considered all the river reaches in the catchment area containing the reservoirs whose cumulative effects are being studied, and did not focus on the catchment area outlet. The downstream limit of the catchment to be considered should be set according to the issues identified.

### An overall reduction of flow volumes

From a hydrological point of view, **the main effect identified is a reduction in mean annual flow rates**, with a decrease ranging from 0 to 30 %, but always more pronounced for dry years (up to 50%) than for average or wet years. Characteristic flows are less often studied, such as high-water flow rates, low-water flow rates and durations, or the distribution of flow rate values along the hydrographical network. Where these parameters are taken into account, the way they are described varies from one study to another, which makes it impossible to compare situations. **The literature review did not identify any indicators that would allow an *a priori* assessment of the cumulative effects of reservoirs on hydrology.** The concepts of reservoir density or storage volume cumulated over a single catchment are only meaningful in relatively homogeneous areas (in terms of soil, vegetation, climate and presence of reservoirs).

Numerical modelling seems to be the best method for assessing

the cumulative effects of reservoirs on hydrology. Using flow rates alone (e.g. before and after reservoir construction) is complicated by changes occurring in other components of the system (climate, land use, agricultural practices, etc.), which makes them difficult to interpret. Also, measurement campaigns involving the monitoring of several reservoirs are lengthy and costly in human resources. However, modelling faces a number of problems, which arise mostly from inadequate characterization of the reservoirs themselves, assumptions about how their behaviour within the catchment is represented and the uses of reservoir water is accounted for, and the assessment of modelling-related uncertainties.

### Reservoirs act as sediment traps influencing the morphology of the downstream river

Whether studied individually or from the perspective of their cumulative effects, **reservoirs always function as sediment traps, especially for coarse sediment.** On a catchment area level, they may balance out, at least in part, the sediment created by increased erosion due to changes in the landscape and some agricultural practices. This effect can be evaluated using models that combine the assessment of hillside erosion, sediment transport capacity and routing along the river. However, trapping rates for small reservoirs still need to be studied in more detail. It is much more difficult to predict **the morphological adjustment of the downstream river**, caused by the trapping of coarse sediment and a reduction in flow rates. While conceptual models can explain the processes and influencing factors in operation, the development of a predictive model is still problematic, given the numerous factors involved and the long periods of time required for morphological adjustment of a river. The general trend observed is a reduction in the width of the active channel, i.e. the part of the bed subject to streamflow, and the lateral dynamics of its channels.

From an operational point of view, **ascertaining the sedimentary context of the catchment area concerned, i.e. whether it is in deficit or excess**, is a first key step in assessing predictable impacts (bed incision or aggradation) and choosing the most suitable method for assessing the cumulative effects of reservoirs on sediment transport and river morphology. The connectivity of reservoirs with one another and with the river also plays a role since it controls the influx of sediment from tributaries that are not influenced by reservoirs, thus possibly almost “obliterating” the effect of reservoirs the further one goes downstream.

### Connectivity and distance of influence: two key concepts for characterizing the physico-chemical quality of water

For a given variable characterizing the physico-chemical quality of water, the distance of influence is the distance downstream of a reservoir that is required for the variable to recover the value it would have had without the reservoir.

Typically, this distance ranges from a few dozen metres for dissolved oxygen concentration to several hundred metres for temperature. If the distance between two reservoirs is greater than the distance of influence, there is no interaction between the effects generated by each reservoir. Otherwise, these interactions need to be taken into account and the effects can spread from upstream to downstream. Hydrological connectivity between reservoirs is key once again. The distance of influence varies with the variable considered, the degree to which it is modified in the reservoir, the water return method and the changes in the variable downstream linked to either physical and chemical processes, or hydrological conditions : diffusive supply of the river or presence of tributaries, for instance. This concept is relevant for temperature, dissolved oxygen content and concentrations of nutrients and contaminants. It does not apply when flows are considered.

The cumulative effect of reservoirs often involves a **decrease in nitrate flows downstream**. When the reservoirs are interconnected, the decrease is less than the sum of the depletions that each reservoir would trigger individually, and the cumulative reduction only increases marginally if there are a large number of reservoirs (infra-additive cumulative effect). The effectiveness of particle storage in reservoirs leads to the **build-up of an internal phosphorus load**, which can represent several decades of inflows and lead to the resuspension of dissolved phosphorus under certain conditions.

Two types of complementary approaches can be adopted to grasp the cumulative effects of reservoirs on the physico-chemical quality of water : (i) spatial modelling, which incorporates all the reservoirs in the catchment area and can forecast the potential effects of new reservoirs ; (ii) the statistical study of relationships between water quality at the catchment area outlet and landscape metrics used to account for the factors that determine the behaviour of catchments with reservoirs. For instance, indicators currently used to characterise the degree of connectivity between lakes in the same catchment area could be adapted to reservoirs. **The implementation of these two types of approach requires a considerable amount of data, as well as improved concepts and knowledge. The level of complexity of models to be implemented in a given context in order to pinpoint the emerging processes related to the cumulative impact of reservoirs still needs research.**

### An overall influence on biological communities

The presence of reservoirs can have an impact on the entire trophic network and habitats, as a result of changes in environmental conditions, connectivity and organisms' dispersal processes. The magnitude and nature of these impacts depend very much on their context. However, there are some common responses in terms of community characteristics to the presence and number of reservoirs : lower abundance of rheophilic fish

species<sup>3</sup>, changes in the structure of ephemeroptera, plecoptera and trichoptera communities in the case of macro-invertebrates, and the establishment of invasive species. Biological impacts can also be seen upstream or across the region, associated with the specific dispersal processes of organisms. There is no approach that can be used to forecast overall cumulative effects on the biological compartment.

However, potentially useful tools are available. Some **bioindicators, such as the structure of benthic invertebrate communities, are sensitive to the presence and number of reservoirs in the catchment area, so analysis of how they change along the river can be used**. Equally of interest are **the consequences of hydrological changes on biological communities**, particularly for fish and under low-flow conditions. Such indicators could be directly applicable to reservoirs, as could several other approaches dealing with the consequences of fragmentation on the viability of populations, or the risks of invasive species.

### Taking account of large time and space scales

The space scale considered in studies is most often the catchment area where the reservoirs are sited. However, the scientific assessment revealed the need to consider **larger areas**. For instance, a high number of reservoirs leads to a **reduction in water and sediment flows to the sea**, which impacts the functioning of estuaries and coastal areas. Overall changes in nutrient flows should also be considered, and particularly a highly likely increase in the flow of bioavailable phosphorus. Similarly, given the surface area covered by reservoirs, they must have a significant influence on the **production of greenhouse gases** (methane, carbon dioxide, nitrous oxide) on a global scale. However, the analysis did not show whether they serve as a carbon sink or source overall.

The scientific assessment also identified the **need to take long periods of time into account**, whether for the morphological adjustment of rivers, the build-up of phosphorus or pollutant reserves, or species extinction processes associated with landscape fragmentation by reservoirs, since all these processes extend over several decades. The establishment of reservoirs contributes to changes in land use and associated cultivation methods; in return, these influence catchment area behaviour, an indirect effect that should be considered over the long term. Given the long service life of reservoirs (several decades), the influence of climate change on catchment area behaviour and the filling capacity of reservoirs must be considered whenever the cumulative effects of reservoirs are studied, particularly since these effects are all the more significant during dry years.

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<sup>3</sup>Organisms that prefer to live in flowing water.

## Lessons learnt from cumulative effect assessment methods

Theoretical considerations on **methods for assessing cumulative effects** beyond reservoirs alone highlight the need to adopt a two-pronged approach. This makes it possible to focus on certain parts of the catchment area while maintaining an overview of its behaviour, and that of the sub-basins. These considerations

also underline the importance of **assessment governance going beyond the scale of the projects being considered**. This ensures a transparent and homogeneous process over a vast area in selecting the environmental components to be preserved, and the use of common metrics and thresholds to determine whether certain effects are significant.

## CONCLUSIONS – WAYS FORWARD

The scientific assessment has revealed a lack of knowledge about the cumulative environmental effect of reservoirs. Very few studies address the cumulative effect of reservoirs on all the different functional characteristics investigated in the assessment, even though there are strong interactions between them. **The presence of reservoirs in a catchment area modifies all the functional characteristics**. This modification can become problematic when it affects an **already vulnerable river**. Assessing the significance of effects on a given catchment therefore requires **identification of the issues for a catchment, and characterization of its condition with respect to these issues**. A **two-pronged approach** can be used to characterize the entirety of a catchment area by identifying the most vulnerable sub-basins and associated issues before starting to assess the cumulative effects of new projects on these sub-basins.

By analysing the cumulative effects of reservoirs, the processes involved and the influencing factors, the assessment identified the main interactions between the functional characteristics and the need to take them into account when assessing cumulative effects. For instance, changes in low-water flow rates and flow rates during the reproduction period will influence the living conditions of fish ; variations in the frequency and magnitude of bankfull discharges will influence the morphological adjustment of the river and, consequently, habitat conditions ; changes in nutrient inflows and residence time in reservoirs is linked to flow dynamics and will have an effect on abiotic conditions in the river, which affect aquatic organisms.

**The lack of data and knowledge noted here restricts the number of relevant indicators and validated methods for immediate characterization of the influence of a set of reservoirs on a catchment area, or indeed forecasting the effect of building one or more new reservoirs.**

The analysis performed can be used to develop a **methodological framework** to address the issue of cumulative effects of reservoirs on a given catchment area. This will form the focus of the operational phase due to follow this ESCo.

Improving the assessment of the cumulative effects of reservoirs on the aquatic environment requires the following inputs :

- Survey and characterization data for reservoirs located in catchment areas affected by cumulative effects: position in the catchment area, supply and return method, capacity (surface area and volume) uses and, ideally, water abstraction dynamics where appropriate.
- Knowledge of causal relationships between the presence of several reservoirs in a catchment area and the general condition of the river there, in order to deal with all the functional characteristics covered by the assessment. A data acquisition process conducted on a few pilot catchment areas with contrasting characteristics should lead to the development of an organized and quantified body of knowledge on the cumulative effects of reservoirs, thus contributing to the development of integrated models and validated indicators required, in order to facilitate informed decision making.

The ESCo focused on the cumulative effects of reservoirs on the environment, but did not take into consideration the economic and social aspects related to their use. Nevertheless, these findings contribute to the study of uses, ecosystem services and disservices associated with hydrosystems modified by reservoirs, thus objectifying the assessment of their overall value in a catchment area, including economic and social dimensions.



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For further information:

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**A full report of this scientific assessment and its summary are also available online:  
<http://expertise-impact-cumule-retenues.irstea.fr/>**

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