



# Governance of Dams and Reservoirs



Spanish National Committee on Large Dams

## Index

INTRODUCTION .....	5
1. The role of reservoirs in Spain: current situation and future forecasts.....	7
2. Status of reservoirs in Spain: infrastructure safety and maintenance needs. ....	9
3. The pressures posed by dams and reservoirs .....	11
4. The ecological and chemical status of "reservoir" water bodies in Spain - Future forecasts. ....	14
5. Reducing pressures: environmental management of reservoirs .....	14
6. The role of dams and reservoirs in climate change adaptation.....	17
7. Application of information systems, IT services and BIM technology for dam maintenance and operation... ..	18
8. The cost of reservoirs and their recovery .....	19
9. Sustainable management of decommissioned dams.....	21
10. Active participation in the governance of dams and reservoirs (citizen involvement, responsible co-management).....	23
CLOSURE .....	25

This technical document has been prepared by the "Technical Committee of Activities of the Engineer in Water Resources Planning" of the Spanish National Committee on Large Dams (SPANCOLD). Together with the contributions of the members of the Technical Committee, the document draws on the main conclusions of two working sessions: an expert workshop, held in June 2019, in which a group of experts, belonging to both business and public administration, shared their different approaches to the governance of dams and reservoirs; and a dissemination conference entitled "Conference on the governance of dams and reservoirs", held in April 2021, which dealt with topics such as the current situation of reservoirs in Spain (the feasibility of building new reservoirs or the maintenance needs of existing infrastructures), the environmental governance of reservoirs (the ecological status of reservoirs and their environmental management), the social and economic governance of reservoirs (the cost of reservoirs or active participation in the governance of dams), and in which the work done so far by the CNEGP in this area was presented, presenting the document prepared by the "Technical Committee of Activities of the Engineer in Water Resources Planning".

This document is the result of the conclusions of both workshops and has a twofold **objective**. Firstly, to describe the state of governance of large dams and reservoirs in Spain. Secondly, to identify the measures to be adopted to improve the management of dams and reservoirs. We are at a decisive moment to achieve the Sustainable Development Goals set by the United Nations, which will require an effort on the part of governments, the private sector and civil society, so that, together, we are able to adapt infrastructures to the new challenges posed by sustainable development, including being able to meet the demands of water use that will arise as a result of climate change.

The experts participating in these workshops were:

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## INTRODUCTION

In previous documents prepared by the SPANCOLD "Technical Committee on Water Resources Planning Engineer Activities", it was analyzed how dams contribute to the fulfillment of the Sustainable Development Goals, specifically on the indicators of SDG 6:



In the current global context, in which the focus is aimed at achieving a better world through sustainable development, it is necessary to **improve the efficiency of key infrastructures** to ensure access to such a basic and necessary resource as water. This challenge, unquestionably, is associated with a process of analysis of the governance of dams, due to the climatic and geographical particularities of a Mediterranean country like Spain with a hydrological regime that **is irregularly distributed throughout the year and between regions**. The role of dams in these conditions is critical, to the extent that 80% of the water consumed in Spain is regulated with a total of 2,600 dams (according to the database of the Directorate General for Water).

Traditionally, reservoirs have been understood as hydraulic works for regulation, hydroelectric production and flood risk reduction. However, it is necessary to have a broader vision, since they are modified bodies of water, which must meet environmental objectives and **achieve good chemical status** and good ecological potential; in addition to not causing avoidable negative impacts on other bodies of water.

Another issue to consider in the governance of dams and reservoirs is that of **ecological flows**, which must be maintained to preserve biodiversity and the functionality of rivers. For this reason, the hydrological plans set discharge flows. In order to comply with these precepts, there is no doubt that reservoir management will have to be rethought, thinking not only of meeting the different demands, but also of meeting the needs of the river ecosystems.

Reservoirs can also play an important role in **adapting to climate change**, since systems with greater regulation capacity are less vulnerable and better able to adapt to climate change. Thus, the greater the climate variability, the greater the need for reservoirs for socioeconomic systems. It is undeniable that dams and reservoirs pose various pressures on water bodies, such as the alteration of the downstream hydrological regime, sediment retention, reduced water quality due to eutrophication, the possible

barrier effect against the migration of certain fish species or the effects that the presence of the dam and reservoir management can have on downstream bodies, at various levels (water quality, river morphology, modification of natural aquatic and riparian communities, etc.). These are therefore key issues to be analyzed and taken into account when planning, constructing and, above all, managing reservoirs.

On the social aspect, dam projects have a great impact, especially on the local communities that may be directly affected by their execution. Therefore, it is important to ensure that there is broad **public participation** in all stages of the life cycle of this infrastructure, seeking to minimize social conflicts and ensure that the project itself is accepted by society. For example, the public participation process could not only include a consultation on the execution of the dam itself, but also include the ecological restoration actions to be undertaken in the river as a result of the project. Along the same lines, the capacity of the reservoirs to accommodate leisure, recreational and sports activities could be explored, both in the dammed body of water itself and downstream; a type of activity that is clearly on the rise in Spain.

Dams must obviously be included in the Strategic Environmental Assessment, both in the River Basin Hydrological Plans and in the Flood Risk Management Plans, analyzing the different alternatives within the regulatory framework. Likewise, the corresponding Environmental Impact Assessment must be carried out for the specific project, which will make it possible to consider the economic, environmental and social aspects in an integrated manner.

European and Spanish<sup>1</sup> legislation regulates governance to ensure that Spain complies with international water and safety commitments. In the use of water there are many agents involved and very varied interests, such as the environment, users and consumers, irrigators, industry, etc. In this complex system of interrelationships, dam management must integrate all of them by establishing ecological flows, reducing interference with anthropic water uses and taking into account hydrological regimes, the migratory behavior of aquatic fauna and sediment management. To this end, it is essential to count on the participation of all, administrations, companies and society.

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<sup>1</sup> European Flood Directive of 2007, European Directive on Critical Infrastructure Protection of 2008, Spanish Dam Safety Legislation of 2008, etc.

## 1. The role of reservoirs in Spain: current situation and future forecasts.

According to MITECO data, the water storage capacity in Spain is 56,000 hm<sup>3</sup>, with a total of 1,225 large dams (being the European Union country with the highest number of this type of structures, and the fifth in the world), which implies, according to the studies of the White Paper on Water, a maximum theoretical availability of 39,000 hm<sup>3</sup>, if all the reservoirs were put into operation. However, it is estimated that the maximum storage capacity is between 70,000 and 77,000 hm<sup>3</sup>, which leaves a margin for intervention of about 20,000 hm<sup>3</sup> and would mean a resource<sup>2</sup> availability of about 45,000 hm<sup>3</sup>.

Several factors influence reservoir capacity:

- ▶ The **relationship between the volume of demand and the volume of storage**. This ratio has been changing over time, due to siltation and the need to maintain increasingly larger reservoirs due to more frequent river floods. As a result of siltation, 9% of storage capacity has been lost and currently more than 1m<sup>3</sup> of storage capacity is needed to meet a demand of 1m<sup>3</sup>. This is in addition to the fact that, at a certain level, greater reservoir capacity is associated with an increase in demand, with no evidence of a relaxation of abstraction pressure. The regulatory role of reservoirs in the face of climate change is evident, so the reduction in reservoir storage capacity is a factor to be taken into account in this changing scenario for the design of new dams, planned modifications to existing dams and dam management in general. It is foreseeable that, due to the longer duration of periods of water scarcity and greater virulence of torrential phenomena and greater contribution of sediments, the volume of stored water will be reduced. If this is the case, efficient and sustainable solutions will have to be found to cushion the effects of climate change.
- ▶ The **forecasts of water contribution** to the reservoirs have been modeled with two different time series for the preparation of the Basin Plans: the long time series (which corresponds to the period 1940/41-2011/12) and the short time series (1980/81-2011/12). The long series establishes an average contribution of 109,233 hm<sup>3</sup> for the peninsular territory and the short series reduces it to 99,096 hm<sup>3</sup>. The main conclusion is that there is a

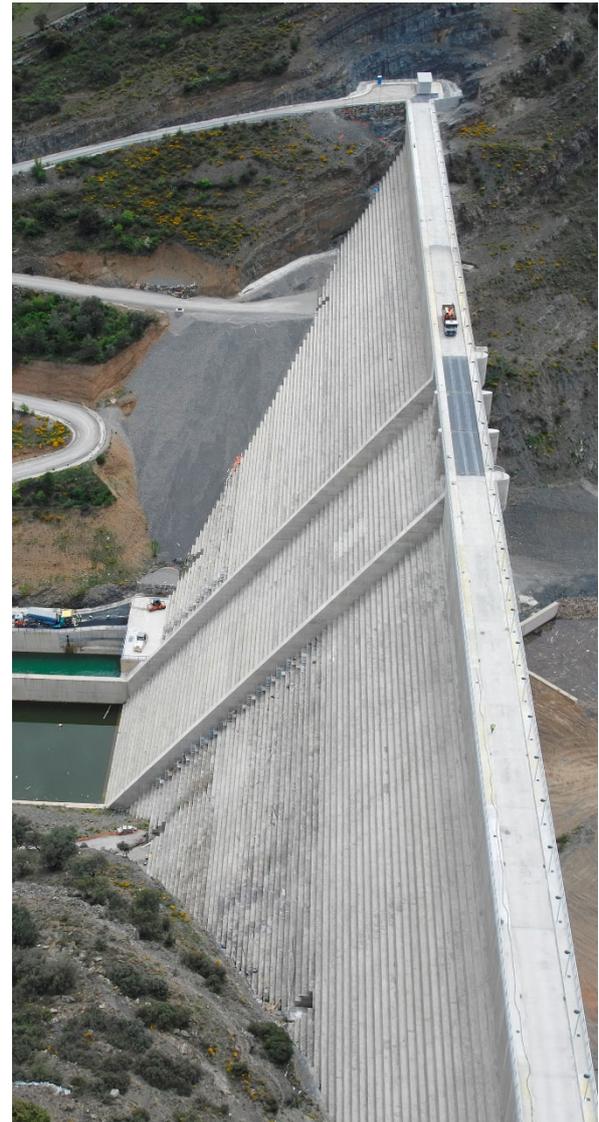
**Spain is the EU country with the largest number of large dams, specifically 1,225.**

<sup>2</sup> Possibilities of exploitation. Limits of regulation Vallarino, E. and Garrote, L., Revista OP nº 50. 2000. Págs. 54-63.

trend towards a reduction of the resource. The allocations of the Basin Plans were made on the basis of the short series; however, it could be reasonable to work in the future with long time series, in order to plan the availability of water resources.

- ▶ The **guarantee of the water resources exploitation system** is the capacity of these systems to satisfy certain demands during a time interval. Urban demand is different from agricultural or industrial demand. Consensus among the various stakeholders is complex because social, economic and environmental interests are involved. In the 1990s there was a change in the approach to guaranteeing supply, which, until then, was only associated with the contribution to the reservoir. In addition to the change in the guarantee criteria for the different uses, it is necessary to consider security against meteorological phenomena and ecological flows, which is associated with an inevitable reduction in available resources. To achieve this guarantee, hydrological planning also subjects the feasibility of building new reservoirs to debate because, although the easiest reservoirs have already been built and there are environmental conditions that have been reinforced over time, there is still a significant gap to achieve the environmental objectives set out in Article 4 of the Water Framework Directive for 2027. Following the guidelines of the European Green Pact, any project that does not fit into the strategic approach of achieving emission neutrality by 2050 will have problems to be implemented. Therefore, in order for reservoirs to be designed and built, they must comply with a series of environmental conditions reflected in Article 4.7 of the Framework Directive.

It is necessary to continue working on defining the point at which a balance is found between the demands of the actors involved, because any imbalance in this balance could have more adverse effects than climate change itself on the capacity of the reservoirs to meet the demands.



*Aerial view of the Enciso Dam.*

## 2. Status of reservoirs in Spain: infrastructure safety and maintenance needs.



The **maintenance** of dams has an uneven development in the Spanish territory. In the case of Castilla y León, in recent years there has been a great depopulation and agriculture is a very important driving force in the region's economy. Fresh rainfed crops are an increasingly widespread solution among farmers in Autonomous Communities such as Castilla y León, but, faced with an increase in maximum temperatures and lower rainfall, guaranteeing the water supply requires the modernization of irrigation systems and the proper maintenance of dams to ensure the water supply.

Investing in the safety of dams prevents possible problems that could cause environmental and/or social catastrophes and becomes a necessary action, since 75% of the dams in Spain currently require complementary studies (geological, hydrological, geotechnical, geotechnical, structural, etc.) to confirm and improve their safety. In addition, investment in the maintenance and safety of dams and reservoirs presents benefits in the future, since the fact that the infrastructures are in better condition allows for greater reservoir capacity and greater cost recovery. This seems a very obvious reasoning; however, it is not so obvious to determine how to approach these actions. The difficulty lies in the dispersed management of small dams because the responsibility for their maintenance and safety lies with the irrigators or owners of the dams. These often do not have sufficient resources to carry out the maintenance work, so the Administration subsidizes the irrigators so that they can undertake these actions. This financial aid is often insufficient.

As a result, the state of conservation of many small dams is well below the recommended levels and a greater effort is required on the part of individuals, users and administrations to reverse this situation, if we want to extend the life and take advantage of the regulatory role of dams.

In relation to dam **safety**, it is important to highlight the entry into force of the Technical Safety Standards for dams and reservoirs approved by Royal Decree in April 2021. These unify the regulatory framework for hydraulic infrastructures located on watercourses. Their application is mandatory for all large dams and small category A or B dams. The Regulations make the dam owner responsible for comprehensive safety management, based on an adequate organization of personnel and material resources in order to correctly carry out the tasks defined in the mandatory documents of the Operating Regulations, the surveillance program, the maintenance plan and to carry out periodic safety inspections. The licensee must implement the Emergency Plan in category A and B dams, as already established in the 1995 Basic Directive on Civil Protection Planning in the event of Flood Risk. The emergency plans are developed to determine the intervention strategies for the control of situations involving the risk of dam failure or serious damage to the dam and to establish the appropriate organization for their development. They also determine the flood zone in the event of a breach and have the appropriate organization and means for obtaining and communicating information on incidents, the communication of alerts and the implementation of alarm systems. In this way, and in conjunction with the results obtained in the periodic safety reviews, risks such as climate change, which leads to a reduction in rainfall throughout the year and the concentration of rainfall in torrential rain, can be foreseen and, therefore, appropriate measures can be taken to deal with them in advance, such as the extension of the drainage capacity or the increase in protection.

At present, the Spanish Hydrographic Confederations intend to implement at least one hundred emergency plans in the next 2 or 3 years, many of which are already approved, but have not yet been put into operation. In addition, the current emergency plan documents are being transformed into simpler and more operational ones, as well as the implementation of second safety reviews in some confederations.

It is important to point out that the age of the dams in Spain in the different hydrographic basins is quite high, being around 50 years old on average. This makes adequate maintenance necessary to guarantee their safety. The Ministry for Ecological Transition and the Demographic Challenge (MITERD) should dedicate 225 M€/year to this activity in order to achieve the recommended level of conservation, due to the age of the dams and the construction of new structures. This is an objective that has not yet been met, but which the Ministry is getting closer to, with the latest tender contracts for the maintenance of dams or with the implementation of emergency plans and investment in safety plans.

The Hydrographic Confederations, as autonomous bodies with full functional autonomy, are responsible in their basin for hydrological planning, management of resources and uses, design and execution of new hydraulic infrastructure and dam safety programs, among others.

In the Ebro Hydrographic Confederation, the estimated cost of maintenance is €100,000/company and year, which, on many occasions, has to be outsourced due to the lack of in-house personnel. On the other hand, more than 50% of the dams of this CH currently have an emergency plan. The lack of resources makes it difficult to complete this task for all the dams, despite its importance. The demand from the regional administrations is for better coordination between administrations and more resources (personal and economic) in order to develop the emergency plan for all the dams and, perhaps, to resize the number of teams in some of the dams where maintenance would be oversized, prioritizing actions according to the potential risk that each one is capable of avoiding, thus reducing the costs derived from inefficient management.

### 3. The pressures posed by dams and reservoirs

*Dams are structures that represent considerable environmental pressures on the bodies of water they regulate. In the case of Spain, the implementation of these infrastructures is even more relevant than in other countries, due to the need and background related to hydrological regulation and the country's status as a country with exceptional environmental diversity and values.*

Specifically, with the information of the hydrological plans in force, there are 4,390 bodies of water in the "river" category, of which 3,480 are considered natural. The remaining 910 are heavily modified water bodies (HMWB): 421 because they have been transformed into reservoirs, 478 because of their strong hydromorphological alteration, as they are generally located downstream of large reservoirs, and 11 artificial water bodies, which are canals rather than rivers. It should be noted that, although there are some 1,650 reservoirs (and more than 1,800 dams inventoried in the Inventory of Spanish Dams, which actually counts infrastructures, and in many cases there is more than one for each reservoir), only some 420 have sufficient surface area to be considered bodies of water (more than 1,200 reservoirs are less than 0.5 km<sup>2</sup>), a figure that coincides with the 421 bodies that were considered to be rivers heavily modified by reservoirs and which is equivalent to 9.5% of the bodies in the "river" category.

These environmental pressures imply a **rupture of the river's longitudinal continuity**, since they **interrupt the river's water flow**, reducing the water supply, among others, to the sections downstream of the dam. Ecological flows are the measure that allows maintaining the flow of water for the preservation of ecosystems.

The hydrological regime of ecological flows determines the biological processes in the fluvial ecosystem and associated terrestrial systems. Its management is not capricious, but is regulated<sup>3</sup>, and responds to the need to take environmental criteria into account in the management of exploitation systems.

The water regulatory framework seeks to protect the damaged Spanish river network. The management of water resources is difficult due to the diversity of actors involved, as well as the permanent changes that occur in the territory, resulting in different types of impacts. We can differentiate between impacts of a more direct and primary order, mainly affecting water quality, hydrology and solid load; second order impacts, which affect the primary production of algae, plankton and the morphology and morphodynamics of rivers (conditioning their condition and the services they provide); and third order impacts,

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<sup>3</sup> Order ARM/2656/2008 of Hydrological Planning Instruction, Law 29/1985 on water, Law 10/2001 of the National Hydrological Plan, Royal Legislative Decree 1/2001 approving the rewritten text of the Water Law, Law 11/2005 amending the National Hydrological Plan, Royal Decree 907/2007 of Hydrological Planning Regulations, Decree 638/2016 amending the Regulations of the Public Hydraulic Domain.

in which invertebrates and fish suffer from the transformation of hydro-sedimentary conditions. An example of changes in the environment is the impermeabilization of soils due to urbanization and construction. The lack of infiltration in the soil and the encasing of water cause changes in runoff; this is known as urbanized runoff, which produces increasing erosion in the watercourses into which they discharge their waters, causing an increase in sediments downstream.

The evolution of regulated rivers in Spain has followed a clear pattern of simplification and homogenization, and those with the necessary regulations have simplified banks. We currently find narrower and more homogeneous rivers in terms of morphometric and hydromorphological diversity, with narrow and dense vegetation on the banks, which causes an additional environmental problem, as it is protected vegetation in many cases.



*Castrovido Dam  
(Spain)*

**Disruption of sediment flow** is another environmental problem associated with dams. Sediment accumulates upstream of the dam and reduces the volume of water stored. In times of abundant water, rivers carry more sediment and it is retained in the reservoir. When this occurs, the dam reduces its storage capacity. In addition, sediment retention can have unfavorable effects downstream, due to the greater erosive capacity of water that does not carry suspended solids. For proper active sediment management, it is necessary that bottom outfalls are fully operational and that adequate guidelines are provided for their management.

Obviously, a dam has negative effects, just as it has many positive ones.

**River fragmentation** must also be taken into account in dam management. Dams constitute physical barriers to the movement of organisms, both fish and seeds and propagules of aquatic and riparian plants. This can lead to fragmentation of populations, loss of diversity and even local extinction of species. Specifically, 2,861 surface water bodies significantly affected by hydromorphological pressures are documented in PH-Web. Although there is no exhaustive study with which to document the total number of dams and weirs that constitute a transverse barrier in the rivers of Spain, we can say that they may be of the order of 20,000 or more; by way of example, in the Duero basin there are 5,229 documented (Mírame data) and in the Júcar basin there are 1,220 documented (SIA-Júcar).



One of the solutions to minimize this impact is the demolition of weirs currently in disuse. This is a practice that is already being carried out in some Spanish rivers. Specifically, within the framework of the National River Restoration Strategy, more than 150 obsolete dams have been demolished in recent years.

To mitigate the pressures generated, the European Commission obliges to carry out a series of procedures for modified and artificial water bodies, which have been collected and developed in the guides called "*WFD CIS Guidance document No. 4. Identification and Designation of Heavily Modified and Artificial Water Bodies*" and the "*Guidance Document No. 37. Steps for defining and assessing ecological potential for improving comparability of Heavily Modified Water Bodies*". Based on both documents, on Spanish<sup>4</sup> legislation and on studies of Spanish hydromorphology, MITERD has published in April 2021, the "*Guide to the process of identification and designation of Heavily Modified and Artificial Water Bodies Category River*", which includes the procedure to carry out the designation of water bodies as heavily modified or artificial, as well as mitigation measures to be adopted to ensure that the environmental objectives established (good ecological potential and good chemical status) of these bodies of water due to regulation or other pressures are maintained under standards considered appropriate for each hydrological plan and each moment. The measures established for their achievement will be included in the Program of Measures of the hydrological plans.

All these factors are key to dam management. There are numerous studies related to the impacts and the solutions developed to minimize them, but the information is very scattered, which is a problem for the management of these infrastructures. Therefore, it is necessary to continue working on the integration of the vast existing knowledge in order to develop effective dam management measures. Among other measures, it is necessary to incorporate the information from studies on eutrophication, impacts, water quality, etc., into the reservoir operating rules.

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<sup>4</sup> The Hydrological Planning Instruction, the Hydrological Planning Regulation and Royal Decree 817/2015, which establishes the criteria for monitoring and evaluation of surface water status and environmental quality standards, have been considered.

## 4. The ecological and chemical status of "reservoir" water bodies in Spain - Future forecasts.

Reservoirs are bodies of water with a high risk of eutrophication. To mitigate this risk, it is necessary to take measures at the basin and reservoir management levels, designing appropriate exploitation curves, including the management of intakes and bottom outflows.

Everything seems to indicate that global change will determine changes in:

- ▶ The thermal organization of reservoirs in relation to mixing and stratification periods.
- ▶ The water renewal rate, which will tend to decrease.
- ▶ Nutrient and sediment inputs, which are likely to increase.

There is currently a large percentage of natural and modified reservoir-type bodies in which the environmental objectives established in the current plan are not being met, and if these changes are confirmed, they will lead to an increase in eutrophication and silting up of the reservoirs, which will worsen the current situation of the bodies of water. For possible new reservoirs, it will be necessary to take into account and include in the corresponding projects the water uses and the basin conservation status, as well as the morphology of the reservoir basin, its size and volume, the suitability of tailing dams and the design and location of both the reservoir drainage bodies and the possible intakes for irrigation, supply or other uses. The implementation of limnological management protocols for the first filling of a reservoir can contribute substantially to maintaining the quality of the water in the reservoir, especially in the first years of operation. For existing reservoirs, the introduction of environmental criteria in the management of reservoir levels, periodic emptying (partial or total) and the conditioning of the riverbed downstream of the dam are relevant aspects in controlling the manifestation of eutrophication and other environmental effects derived from the presence of dams and reservoirs.

## 5. Reducing pressures: environmental management of reservoirs

### Ecological flows

Ecological flows downstream of dams are defined as the circulating flow between the ordinary minimum and the average annual flow, which allows maintaining the river section in good ecological status, and constitute a management measure for regulated rivers and reservoirs focused on the concepts of maintenance and contribution to the ecological status which, as such, requires monitoring and verification of its effects. Good ecological status is an established concept of maintaining the spatial diversity of the habitat, connectivity and functionality, among others, which is consistent with the objective of ecological flows, but which is in many cases a little lax. Therefore, there is room for improvement in the criteria that the Hydrological Planning Instruction establishes for the calculation of the ecological flow regime, and also in the implementation of the results, as it is a pioneer in the conceptual aspect, but presents excessive improvisations and a lack of a protocol for validation

of the results in ecological terms. Such an important management criterion for a river as the "ecological" flow, which should support the conservation of the entire river ecosystem, probably requires more solid hydrological, geomorphological and limnological bases than those currently proposed by the regulations in use, putting an end to the arbitrariness of the results, the notable hydrological inconsistencies, the confusion among the concessionaires of water uses, etc.

As for the implementation of environmental flows, it seems that an adaptive management strategy developed within a reasonable time frame, based on the principle of "*learning by doing*", could give better results than a taxation strategy, for all parties involved in water use and management, including the river itself, and would make it possible to really check the ecological effects produced by these flows.

### Minimum environmental volumes

The minimum impounded volume is a measure designed to provide adequate habitat conditions to meet the needs of the different biological communities, and to avoid deterioration of water quality and the risk of anoxia. It is usually established mainly for reservoirs and, unlike ecological flows, it is an enduring and manageable management measure.

The minimum environmental volumes are subject to very complex water balances, as they are carried out from artificial infrastructures, presenting a complicated management. For this reason, environmental minimum volumes should not be understood as a permanent management, but as a transitory management that gives way to a critical moment for some determined reason. A reservoir or a wetland cannot be subject to a permanent minimum environmental volume, in addition to requiring a specific determination for each specific case, so this management approach is considered essential.

Therefore, a rough definition of the minimum environmental volume would be the lowest volume that can be transitorily implanted in a water body without causing a persistent regression in its ordinary ecological status.

### Sediment management with the disruption of fluvial continuity

Currently there are technical resources to reverse the situations caused by the interruption of the longitudinal flow of sediments, such as tailing dams or the management of bottom drains, which help to reduce deposits. In Spain there are controlled experiences of water release with sediments and the results are satisfactory. An example of this is the controlled release of water from the La Baells reservoir (Llobregat), which increased its outflow to  $40 \text{ m}^3/\text{s}$ , taking into account that the flow usually released is  $1 \text{ m}^3/\text{s}$ . Along with the controlled increase in the flow of the Llobregat river, which brought environmental benefits to the river and its surroundings, sediments were injected to study their mobilization from the reservoir downstream, and their benefits on the river habitats.

Efforts are also being made to recover the sediment by-pass of the Cubillas dam, in the Guadalquivir River Basin District, which will provide valuable experience in sediment management in times of flooding.

However, sediment retention in Spanish dams is highly variable, and it is not possible to adopt general "recipes", as specific studies are required for each case.



### *Franqueability with the rupture of fluvial continuity*

The barrier effect of dams and reservoirs on the different fish species prevents the free movement of these species. The consequences of this effect can be summarized in the following four main points:

- ▶ Impossibility of the development of species cycles, thus preventing their survival. Examples include the specific cases of salmon and eels, migratory species whose behavior is totally affected by the barrier effect. The implementation of fish passage devices is a possible measure to reduce this impact.
- ▶ Isolation of non-migratory fish populations between upstream and downstream reaches, generating an interruption in gene flow and high inbreeding levels in the future between these impacts.
- ▶ The previous point can also be considered as positive, as it detects the protection of the gene pool of non-migratory fish populations upstream of the dams, avoiding their hybridization with specimens from excessive and not necessarily controlled restocking.
- ▶ Another positive application of the effects of dams would be to limit the dispersion of invasive exotic species to stretches of rivers where these species are not present.

There is an extensive and detailed specialized bibliography on the calculation and design of fish<sup>5</sup> scales. The criteria to be taken into account for the construction of scales are:

1. Consideration of the species for which it is designed, their swimming capacity, the speeds they can reach and their ability to maintain those speeds, are the essential criteria in the design of the scale.
2. The hydraulic characteristics of the design should favor that the velocity of the current is potentially surmountable by the species in question, that the distance to be traveled is such that its resistance is not exceeded, as well as the reduction or elimination of turbulence in the water regime.

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<sup>5</sup> The text is extracted from CICCIP & SPANCOLD (2016): DAM SAFETY TECHNICAL GUIDELINES: DAM AND DAM ENVIRONMENT, which includes more detailed information.

## 6. The role of dams and reservoirs in climate change adaptation.

Climate change is associated with great uncertainty with an enormous impact on water resources. In the case of hydrological planning, the uncertainty is mainly linked to the changes that may occur in the use of water for consumption or for agriculture and livestock, or for energy production. In contrast, future policies must be based on objective considerations, which makes it difficult to develop short- and medium-term management measures.

In a constant demand scenario, with a more or less constant operating rule, the availability of water resources is more or less guaranteed.

It seems obvious that the greater the reservoir capacity, the greater the regulation capacity. But determining how resources, demands, the cost of water or energy production will behave is a challenge subject to much uncertainty, which lies more in the prediction of water demand than in the calculation of allocations:

- ▶ The inventory of resources and demands must be adjusted to the variations produced by climate change. There are simulations of precipitation and temperature (maximum and minimum) resulting from six regional climate models (RCMs) developed by various research centers collaborating in the European PRUDENCE project. These simulations show the changes in the climate balance (precipitation-potential evapotranspiration) that can be expected in the future. The combination of higher temperatures and a decrease in precipitation points to a loss of regulation due to the loss of resources, but it is not possible to specify its extent at this time. The results of the simulations carried out were highly variable: although, in general, an average reduction in available water resources of 10% was estimated, at the river basin level the average reduction ranged from 6% to 17%.
- ▶ Regarding the evolution of water demand, the increase in temperatures is expected to result in an increase in crop water requirements, according to some studies; although there are others that indicate that a higher temperature will imply a greater release of CO<sub>2</sub> into the atmosphere.

**Climate change has a huge impact on water resources**

The water demand for agriculture, however, is more influenced by other factors, such as agricultural policies and water management itself, which have a greater influence on the evolution of water demand than climate change itself. However, water demands for agriculture are more influenced by other factors, such as agricultural policies and water management itself, with greater weight even in the evolution of demand than climate change itself. Once again, there is great uncertainty in this parameter.

- ▶ The cost of water depends to a large extent on government subsidies. However, subsidy policies are constantly changing and are hardly predictable in the long term.
- ▶ The current Strategic Framework for Energy and Climate of the Spanish Ministry for Ecological Transition, defined in response to the 2015 Paris Agreement has the challenge of increasing renewable energy production, at the rate of 3,000 MW/year. The National Integrated Energy and Climate Plan foresees adding another 57 GW of renewable power and 6 GW of storage (3.5 GW of pumped storage and 2.5 GW of batteries), with a balanced presence of the different renewable technologies. Thus, the penetration level of renewables in the electricity generation sector will reach 74% in 2030, up from approximately 38-40% in 2018. Hydropower generated in dams is going to play a relevant role in this change of energy model. However, the concrete policies to advance in this direction are subject to successive modifications. A reduction in the demand for water needed for cooling thermal power plants is also to be expected.

Future forecasts for dams and reservoirs are based on the maintenance and conservation of existing infrastructures, studying the feasibility of building new works at the same time as the completion and expansion of those already started. In order to plan for the effects of climate change, the Hydrological Plans of the river basin districts will include, as measures, climate change adaptation studies, which will be developed with the support of the Spanish Climate Change Office and the National Climate Change Plan.

## 7. Application of information systems, IT services and BIM technology for dam maintenance and operation.

*Improving dam management necessarily involves incorporating lessons learned elsewhere.*

This is a pending task in Spain, where there is still no openly available information on the relationship between investment in dam maintenance and the reduction of the associated risk.

Risk analysis and management help to reduce uncertainty and to advance in the knowledge of dams. They are tools to support decision making and to prioritize some maintenance or safety actions over others, which helps in the governance process. The information required for the risk management approach must consider the three dimensions of sustainability: economic, social and environmental, so that information is available on the consequences of the dam's operation on the environment.

three areas, both in the case of potential failure scenarios and in normal dam operation scenarios. So far, the models have mainly considered the social component (ensuring the safety of the dam, to avoid a breach affecting

the downstream population) and the economic component (through cost-benefit analysis); environmental risks have yet to be incorporated into the models.

The information generated by the analysis of dams is not currently centralized. Existing technology could contribute to improve information management, but this line is hardly being developed. Specifically, BIM technology is a tool that improves information management capacity compared to more conventional tools, although it requires very specific technical knowledge. In addition, by working directly on a digital twin of the dam, it allows the definition of a strategy, if it is provided with information on the processes (how to optimize the processes and define what information to include in the models). In any case, and regardless of the technology used, it is advisable that all personnel involved in dam management be involved, from the very beginning, in the process of its application, because if the users do not know the technology and are not motivated, they will not see its benefits and will not use it in their daily management.

Some examples of existing technologies in the planning of hydraulic resources can be found in the GEISER computer portal of the Ebro Hydrographic Confederation, which integrates various web applications, such as SIGAP, PMP, LEVELS MANAGEMENT, EMERGENCY PLAN or TECHNICAL ARCHIVES. Among them, the SIGAP application, in particular, manages the auscultation data obtained through the instrumentation installed in the dams.

In short, new technologies offer many possibilities in the governance of dams and reservoirs, but they need to be well thought out from the outset, with the collaboration of reservoir managers and future users of the applications.

## 8. The cost of reservoirs and their recovery

Some relevant figures to see the investment made in water in Spain are as follows:

INDICATOR	Quantity
Spending on environmental protection	0.86% GDP
Spending on social protection	16.55% GDP
Water investment in Spain	0.22% GDP
Budget of the Hydrological Plans in force (2016-2033).	45.190 M€
Annual water investment	2,510 M€/year
Public Private Investments in Spain (2007-2016)	330 M€
PPP water investments	0.93% in total
Regulatory fee income	137 M€/year

These data demonstrate the current underinvestment in water in Spain, since the minimum necessary to have good management and defend the hydraulic heritage is close to 4,000 million euros per year, which is almost 50% more than the current annual investment.

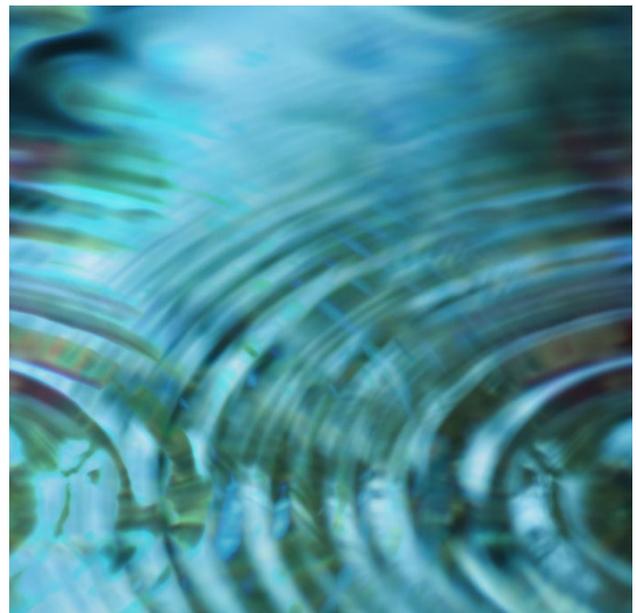
High water (untreated) has a lot of value, it is cheap but less and less resources are allocated to its management, despite the fact that it is strategic for the Spanish economy. **Eighty percent of the water used in Spain has been dammed.** The availability of water is 40<sup>3</sup> useful km, while if there were no reservoirs we would be talking about only 8 km<sup>3</sup> of available water, which would complicate the development of life in the months of July and August, and would mean the disappearance of tourism and that only 8 to 10 million people could live in the country. This is why Spain is considered a water-dependent country.

Our geographical reality as a Mediterranean country makes reservoirs very important for adaptation to climate change and energy transition. Accounting is more accurate in terms of financial costs, but progress still needs to be made in improving the internalization of environmental costs. At the same time, the positive socioeconomic externalities that water has and that all this complex system of current regulation entails are not being internalized in the value of water.

It is necessary to guarantee the availability of water and its sustainable management, an objective included in the Sustainable Development Goals approved by the UN. Progress must be made towards an integrated water system where resources (reservoirs, desalination plants, etc.) and demands are interconnected, a correct apportionment of water costs is possible, and the ecological flows necessary for ecosystems are maintained.

To this end, investor financing mechanisms and public-private partnerships should be promoted. Under public control and a reliable regulatory framework, these forms of investment would contribute to improve water management, i.e., to undertake in less time the necessary maintenance actions that improve the safety of dams and guarantee water quality and quantity. This requires cost recovery. Spain has a cost recovery procedure that determines that at least 50% of the investment cost and 100% of the maintenance and operating costs must be recovered.

According to Article 301 of the Public Hydraulic Domain Regulations, the amounts resulting from paragraphs a) and b) will be distributed among all the current users or beneficiaries obliged to pay the Canon, although a transitional regime may be established when the commissioning is carried out gradually. In practice, the State is also considered to be a beneficiary of the regulation works, given the flood defense functions they perform and the other general benefits they bring, and therefore bears a percentage of the total amount of the costs chargeable through the Regulation Charge. The Canon is approved by the Ministry, at the proposal of the River Basin Organization, and each regulation work is subject to a different decision.



The amount resulting from paragraph c) shall be distributed among the current and foreseeable users or beneficiaries of the existing regulation works. The distribution of costs must be made among the "users equitably in proportion to the participation in the benefits or improvements produced by the works". In the absence of further details, the TRLA imposes that the distribution of the overall amount will be made in accordance with criteria of rationalization of water use, equity in the distribution of obligations and self-financing of the service, in the manner to be determined by regulation (article 114.4 TRLA). Given that there are different groups of users: irrigation, population supply, industrial, hydroelectric, non-consumptive, etc., the Board of Exploitation agrees on tables of equivalences between uses, taking into account the estimated average total benefit of the works, known as the theoretical benefit.

In accordance with Article 61 of the TRLA, the water granted is assigned to the uses indicated in the title of use, and may not be applied to other uses, nor to different lands in the case of irrigation.

The rate of the Regulation Fee can be determined by two different procedures, as far as irrigation is concerned:

1. Per hectare: obtained by dividing the total budgeted expenses by the total irrigated hectares.
2. Per cubic meter used by each user: this involves establishing a price per cubic meter used.

The regulation fee payable for water for supply, industrial and "other uses" is determined per cubic meter used by each user, and the fee payable for water for hydroelectric uses is determined per kilowatt hour theoretically produced by each user.

Revenue from the regulation canon is around €137 million per year (General State Budget for 2016), with a relatively low range in the level of cost recovery, depending on the demarcation, between 12% and 52%. This figure applies to agricultural, industrial and urban uses. The costs of services are calculated on the basis of 3 components: infrastructure operating and maintenance costs, general chargeable costs and investment costs (amortizable over 50 years). This figure therefore takes into account the cost of services and future planning by reserving part of the catchment capacity for future uses. The application of the calculation formula currently in force in the case of the Regulation Charge results in an amount passed on to the different users of 102% if the costs are considered at current prices -costs at the time the investment was made without updating- over 50 years.

## 9. Sustainable management of decommissioned dams

The end of life of a dam can be postponed. Many reservoirs were projected to have a 50-year useful life (surely for financial amortization) but, as can be seen, they can last many more years (we have dams from Roman times). It does not make sense that because they have reached 50 years they should be demolished.

In any case, if, by virtue of different criteria (structural or other problems, safety, non-profitability, environmental problems, etc.) it becomes necessary to take a dam out of service, certain guidelines and criteria must be followed to guarantee both safety and avoid harmful disturbances to water circulation and environmental quality.

The decommissioning of a dam requires the development of a major project, as was once the case for its construction. It is necessary to contemplate different aspects and, in addition to the construction or deconstruction processes, to consider some key factors regarding safety and the environment

Perhaps the most obvious is the reestablishment of the river's natural regime, with all that this entails. Consideration should be given to the foreseeable change in biological diversity, with a possible increase in the mobility of allochthonous or invasive species, as well as all the effects derived from the disappearance of the barrier, such as the modification of sediment transport dynamics, the reestablishment of longitudinal corridors for aquatic fauna and reduction of the transverse barrier effect for terrestrial fauna, the homogenization of the temperature regime and other physical-chemical quality parameters, such as the amount of dissolved oxygen, pH and others, etc.

It is necessary to carry out a hydrological study to evaluate aspects such as the recharge of associated aquifers and changes in the hydraulic regime, with the consequent changes in resources, floods and environmental flows. The change in the functioning of the riverbed makes a floodability study necessary, with the new flood flows and sediment load and transport.

The risks are also modified and some new ones appear, such as the risk of breakage of the part of the structure that may eventually be left as residual, or those derived from possible modifications to the flood risk management plans.

It is also necessary to consider the stability of both the residual structure and that of the basin, after the modification of the water table, and the erosion it may suffer.



*Enciso Dam  
(Spain)*

The wetland area is altered and this entails changes in its effect on the fauna, flora and ecosystem associated with both the reservoir and the downstream channel. It will also be necessary to carry out a revegetation study of the reservoir.

The impact on the social environment is also marked. On the one hand, the uses, uses, facilities and other associated infrastructure are modified. There are also significant changes in the landscape, the disappearance of the sheet of water (and its effect on the microclimate) and the appearance of new recreational activities in the new space and the disappearance of previous cultural, sporting and other activities. On the other hand, the urban development that has taken place downstream is an absolutely essential conditioning factor.

Sediment management deserves a separate chapter, both because of the new dynamics of drags that appear and because of the state of the sludge and the possible persistent contamination linked to the quality of the sludge, which will have to be treated before releasing the water into the channel. The impact of the lower quality of the deeper water strata, with lower oxygen content and a different temperature, around 4°C, must also be considered.

Problems such as the recharge of aquifers and the possible increase in their salinization, the disappearance of ecosystems associated with the reservoir itself, or the destruction or impact on others downstream must be taken into account in the management and decision making related to the decommissioning of reservoirs.

It is necessary to study and decide what to do with the different elements or installations of the dam, such as the structure of the dam itself, its intakes, conduits, pipes or channels, stilling basin, col dams, lateral spillways, etc. Likewise, it is also necessary to consider the rest of the complementary works and facilities such as power lines, access roads and communications network of the area, possible perimeter roads to the reservoir, wharf, offices, warehouses, workshops, etc.

It is also necessary to consider up to what level the dam should be dismantled. If it is enough to remove gates or other elements, or the definitive closure of the spillway, or the total or partial demolition of the body of the dam, it is even necessary to consider whether the foundations of the dam should also be removed, or even to remove the waterproofing screen, the permanence of which would lead to the existence of a subway reservoir that could hinder the total regeneration of the river section.

Morphologically, the silting up of the reservoir will have led to the disappearance of the original riverbed, which will have to be reconstructed, the regeneration of part of the reservoir basin, which in its upper parts will have lost its soil layer, and the location of the accumulated sludge, which, if it is necessary to remove it, will occupy an important part of the surrounding landscape.

## 10. Active participation in the governance of dams and reservoirs (citizen involvement, responsible co-management).

The governance of dams and reservoirs involves numerous stakeholders and, therefore, diverse interests. This makes their management very complex.

With the most technical vision, we find the personnel who work in the dams. This figure, in the process of disappearing, is key in the management of the dams because they know in detail the operation of the dams. The operating plans must have the opinion of these technicians, because their knowledge allows decisions to be adapted to the specific circumstances of each dam. This is a figure that should be valued.

Users and consumers are other stakeholders in dam management. Their participation in dam governance is diffuse because, not being familiar with the regulations, they have a partial view of the problems of dam management and express uncertainty about the measures adopted. Likewise, these stakeholders are the main participants in the Reservoir Release Commission, a management body whose mission is to release and make proposals on the proper filling and emptying of reservoirs, taking into account the users' concessionary rights.

Irrigators are a sector whose economy depends directly on the availability of water. Aware of the growing water scarcity associated with climate change, a strong investment has been made in recent years for the modernization of Spanish irrigation, with the participation of both irrigation communities and Public Administrations, achieving greater water profitability.



In many cases, irrigators are the first to be affected by water supply restrictions during periods of scarcity, which leads them to demand that the age of the farm be respected when allocating resources and to agree with the public administrations on ecological flows so as not to see their guarantees reduced. Cases in which it has been possible to reconcile environmental needs with those of irrigators should be taken as a reference for the solution of future conflicts.

The users, through the Exploitation Boards and Reservoir Commissions, have made a great effort to make the different demands compatible and to introduce, by means of agreements, the ecological flows.

In the implementation of emergency plans for dams, the main objective is to know and evaluate the possible risks, with the aim of avoiding or minimizing them as far as possible with a series of actions organized in an orderly manner, ensuring the protection of the population. For their implementation, they have to be directed by the

Implementation Committee, defined by the regulations. The implementation of emergency plans consists of two main parts. The first is the provision of infrastructures, establishing emergency rooms, internal communications systems that allow to know the state of the dam, and what will be the warning system to the affected population. This is followed by the dissemination phase, which is more sensitive, as all the agents involved and the population must be made aware of what the emergency plans consist of. It is here where it is particularly important to promote public participation in the governance of dams, since the emergency plans are aimed at the public. Active citizen participation in the governance of dams should be sought, involving them as if they were another responsible agent. An example could be the voluntary collaboration of town councils and citizens of towns near dams in emergency drills.

Uncertainty generates conflicts. In the management of water, a resource of vital importance for the health and development of the population, conflicts require a rapid response from the competent administrations and, to this end, the strategy to be followed must be clear. First of all, a mapping of the conflicts must be made to determine the causes, dimension and possible solutions. Next, it is necessary to generate conflict prevention dynamics and establish permanent structures for participation. In this way, conflicts will be reduced through rapid and efficient measures, while at the same time improving the information that reaches consumers and users.

***Communication must always be the answer to improve dam management and avoid conflicts between the different stakeholders involved.***

## CLOSURE

The "Green Paper on Water Governance in Spain", still under preparation, identifies the objectives and priorities of water policy; the generation and updating of the knowledge necessary for its development and implementation; the mobilization of the resources (human, financial and institutional) needed to achieve the objectives set; the development of the regulatory and normative framework that determines the way in which policies are developed; the establishment of mechanisms for the implementation, follow-up and continuous evaluation of policies; and the development of instruments for resolving conflicts that inevitably arise between actors with different interests and understandings of reality.

The current water governance model needs to be modified in several dimensions:

- ▶ strengthen public administration and improve coordination of sectoral policies and coherence between the different administrative levels.
- ▶ improve information and knowledge generation and transparency.
- ▶ to promote cooperation and co-responsibility of citizens and social agents, including users.
- ▶ enhance the flexibility and adaptability of the management model.



Casasola Dam  
(Spain)

Reservoirs are key instruments in water management, whose advantages compared to other solutions must be highlighted. It is important to continue analyzing the advantages and disadvantages of these solutions compared to other possible solutions, without forgetting that dams and reservoirs are part of the cultural heritage.

It is necessary to move towards integrated management in which exploitation rules and hydrological planning instructions are integrated and updated, and all stakeholders are taken into account.

*Reservoirs are key instruments in water management, whose advantages over other solutions must be highlighted.*