THE EUROPEAN GREEN DEAL AND DAMS

SPANCOLD
CNEGP

Spanish National Committee on Large Dams

Index

1) INTRODUCTION

The European Commission proposes to transform the EU economy and society in a drastic way to respond to climate ambitions. To this end, it has adopted proposals to adapt EU climate, energy, transport and taxation policies to reduce net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. Achieving these emission reductions over the next decade is crucial for Europe to become the world's first climate-neutral continent by 2050 and for the European Green Deal to materialize.

On 11 December 2019, the Commission presented its Communication on the European Green Deal. This is the new growth strategy for the European Union, which aims to put Europe on the path of transformation towards a climate-neutral, equitable and prosperous society with a modern, competitive and resource-efficient economy.

During the December 2019 European Council meeting, EU leaders reiterated the EU's determination to play a leading role in the global fight against climate change, endorsing in their Conclusions the EU's goal of achieving climate neutrality by 2050.

Subsequently, in December 2020, the European Council confirmed its determination to implement the EU's ecological transition. EU leaders endorsed a new binding target for the EU, namely to achieve a net internal reduction of greenhouse gas emissions of at least 55% below 1990 levels by 2030, thus surpassing the target agreed in 2014 to reduce emissions by at least 40% by 2030. EU leaders asked the Council and Parliament to reflect this new target in the "European Climate Law".

In July 2021, the Commission presented the "Target 55" package, a set of proposals and initiatives aimed at reviewing and updating EU legislation in order to adapt it to the EU's climate targets for 2030 and 2050. The package was presented to EU environment and climate ministers at an informal meeting during the Slovenian Presidency on 20-21 July.

According to the EU, the European Green Deal highlights the need for a comprehensive approach in which all EU actions and policies contribute to the objectives of the Green Deal. In its Communication, the Commission announced initiatives covering a range of policy areas, such as climate, environment, energy, transport, industry, agriculture and sustainable finance, all of which are closely interlinked. Again, as was the case in the UN Millennium Development Goals, water is not explicitly addressed, but it is clearly a cross-cutting resource that crucially affects many of these vectors and must contribute to climate change adaptation and mitigation.

In addition, in the framework of the Green Deal, all existing policies related to the goal of climate neutrality will be reviewed, with a view to amending them where necessary in line with more stringent climate targets. This concerns, for example, existing legislation on greenhouse gas emissions, renewable energy and energy efficiency.

To begin with, the EU is already actively working on drinking-water for domestic use1. The Commission has already sent to the European Parliament the final proposal for a new directive, the text of which updates drinking water quality standards set more than 20 years ago and sets new minimum hygiene requirements for all materials that come into contact with drinking water, such as pipes and taps, to avoid possible contamination.

[1] Roberto Di Giovan Paolo, The European Green Deal starts with water, p. 45. See: https://www.eni.com/static/en-IT/world-energy-magazine/water-stories/We_WorldEnergy_46_eng.pdf.

The new rules require the control of organic substances, pharmaceuticals and microplastics and set conditions for access to water for minorities who have limited or no access to it. They also provide financial support, including money from the European Social Fund for the installation of pipes and sources of supply. Special attention is given to water use in public places such as restaurants, bars and pubs, and the directive aims to act on costs to incentivize savings. There is also an emphasis on glass bottling at source and bottle recycling to ensure a reduction in the use of plastic.

It provides for the protection of water and its basins as a public good, ensuring clean and healthy water for all and universal access, establishing drinking water, the basins protection, lakes and rivers, reservoirs and maintenance and distribution structures as fundamental pillars of the European common good in the water sector.

Under the prism of the Green Deal, in the area of dams, there are a number of issues that, among others, need to be reviewed, which are addressed in this document:

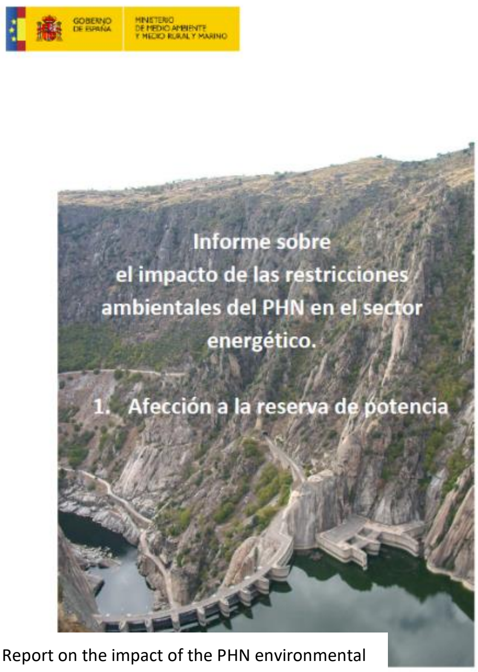
- ✓ The integration of energy systems and, within this, reversible reservoirs - as energy storage, the influence of the Integrated Energy and Climate National Plan (IECNP) or the water footprint of energy production.
- ✓ Adaptation to climate change, where the possible decrease in the quality of drinking water, the role that reservoirs can play in flood and drought management and the influence on the guarantee of water supply will be analyzed.
- ✓ The biodiversity strategy, which will address the restoration of obstacle-free rivers, ecological flows and sediment flow.

2) ENERGY SYSTEMS INTEGRATION

a) Reversible reservoirs - as energy storage

Ever since power transmission lines have been able to articulate networks on a national and even transnational scale, hydroelectric power plants, especially those associated with large dams, have played a strategic role, not only in terms of their contribution to the energy matrix by contributing a proportion of energy production, but also in guaranteeing the stability and security of the general electricity grid. Although not all hydroelectric power plants contribute equally to this second role, those that are assigned an autonomous start-up character constitute a security asset for the peninsular grids.

This role of rapid reaction to changes in demand, avoiding problems of frequency or reactive power, was also complemented by the stock of energy that could be mobilized quickly in reservoirs with dam footfalls. These reservoirs have always played and continue to play a storage function with power reserves.



Report on the impact of the PHN environmental restrictions on the energy sector.
1. Affection on the power reserve

This role at the state level was analyzed in earlier stages of national hydrological planning, concluding that the system can be stabilized by a series of large dams and/or the construction of pumping and counter-impoundment reservoirs.

Large plants discharging into a large reservoir offer flexibility to the system without compromising the ecological conditions derived from the high exchange rates required for this function. This is why the aforementioned study already proposed the promotion of reversible plants, either pure pumped storage or the provision of counter-reservoirs to some of the strategic plants where the rates of change could threaten the flexibility they provide to the network and to the Iberian system as a whole.

Since then, a greater, and growing, proportion of intermittent renewable energies, such as wind and solar, has become available. Both of these need - and this is not optional - to be complemented by a storage and reserve park not only for fast-reacting power, but also for energy. It is no longer simply a question of adapting supply and demand on a daily basis, or of avoiding one-off problems, but of storing variable renewable energy (VRE, wind or photovoltaic) over longer periods when there are production surpluses in order to return them when there are periods of production shortfalls. The latter service is provided by the hydroelectric component and to a lesser extent by combined cycle power plants.

Harnessing non-storable renewable potential, which is growing in magnitude and potential, requires the complement of functional security, but also, and above all, short-term storage. Again, it is the hydropower sector that offers the greatest response capacity, together with batteries, a sector that will also play a role in storage.

Thus, although the commitment to large-scale penetration of VRE will require the concurrence of different storage technologies, it is worth highlighting the strengths that work in favour of having hydro energy storage:

Unit capacity of the storage facility (power and energy):

- The power and energy capacity of Reversible Hydropower Plants (RHP) is typically one or two orders of magnitude above the values that characterise other currently available storage technologies.
- Technological maturity, reliability and availability of the necessary know-how and resources in Spain: This is by far the most mature and proven large-scale storage technology, for which Spain has extensive experience and technical knowledge.
- Duration of the charge-discharge cycle: It is flexible and adjustable to much longer times (mainly in discharge) than alternative systems.
- Ability to cope with different operating regimes (hourly, daily, weekly, seasonal): Large-scale hydro storage is the only technology that is currently and in the short-medium term capable of operating with such versatility.
- Cycle performance and energy efficiency: Although slightly lower than battery systems (75% vs. 85%) the performance of the RHP is reasonably high and far superior to future green hydrogen based systems.
- Installation lifetime: Much longer compared to other types of technology.
- Lifetime costs (investment, O&M, and, if needed, decommissioning and recycling): Considering its capacity (power and energy) it can be stated that the costs of hydro storage are competitive.
- Integration of storage in the country's energy planning: If the objectives of the PNIEC2021-2030 are to be met, it is important not to delay the processing of new RHP concessions, in coordination with the hydrological planning of the basins and that of the transmission network.
- Job creation, domestic added value and contribution to Just Transition principles: Undoubtedly far superior to what could be achieved with other energy storage technologies.
- Contribution to the stability, efficient operation and flexibility of the electricity system: Apart from storing and generating energy in the context of the ES, the RHPs contribute to its flexible and secure operation by providing, at the demand of the System Operator, adjustment and mechanical inertia services. The latter is necessary to maintain the synchronism of generation units and loads given the lack of contribution to inertia by wind and photovoltaic installations.
- Support for the massive penetration of variable renewable energies in the Electricity System (ES): Very notable, both in terms of scale (power and energy) and their participation in the technical adjustment services markets managed by REE.
- Contribution to the optimisation of transmission grid investments: The coordinated planning of new hydro storage facilities and the transmission grid will result in the optimisation of the transmission grid nodes and thus of infrastructure investment.
- Polyvalence and versatility of uses beyond the operation of the ES: The potential hydraulic use, in case of need, of the water dammed in the RHPs is an undeniable added advantage over other alternative technologies.

- Promotion of the creation of energy reserves in the public water domain and environmental value: The increase in the volume of hydraulic energy reserves will reduce dependence on other sources, in particular natural gas, and opens up possibilities of using these strategic reserves to guarantee the demands contemplated in the hydrological planning. This is another advantage of hydraulic storage, in this case related to the adaptation of the territory to the foreseeable effects of climate change in our country: extreme phenomena, drought, desertification, improving the resilience of our Spanish water management system.

In spite of the consensus in the sector on the need for these reversible headworks projects, whether they are pure pumping or not, the last decade has barely mobilized investment in more than a couple of cases, which are important but insufficient. The lack of attractiveness of investment has perhaps been a consequence of the uncertainty of revenues for the remuneration of investment and the legal and economic framework. This is a task to be developed at European level, where the regulatory framework must facilitate payment for a necessary service, storage, so that it is not the result of the future hourly price differential but of the planned demand for a specific and essential function for a zero-carbon matrix, the storage of temporary surpluses of intermittent renewable energy.

Good planning, both at basin and national level, needs to harmonize with energy planning and exploit their synergies as a necessity. An example is the urgency to find a meeting point between environmental requirements in terms of environmental flows and rates of change, such as the contribution to the development of renewables, with efficient grids to contribute to climate change mitigation.

In short, hydrological planning must foresee the role of strategic waterfalls, the need for counter-reservoirs that allow power plants to be coupled to environmental requirements and reversible pumping breaks, without waiting another decade for the essential energy storage infrastructure that the country needs to be created spontaneously.

b) PNIEC

The National Integrated Energy and Climate Plan 2021-2030 (PNIEC) was born out of the need to act in response to the risks detected in relation to climate issues, the vast majority derived from energy aspects, with the main objective of mitigating them as far as possible.

Three out of every four tonnes of Greenhouse Gases are generated in the energy sector, so energy transition and decarbonisation of the economy, both European and national, must be based on the decarbonisation of the energy sector, but without neglecting the reduction of emissions from other sectors.

From the national point of view, it defines the transition path towards climate neutrality and involves a profound transformation of the entire energy system, based on renewable energies. The figures planned by the PNIEC in 2030 for Spain are a 23% reduction in GHG emissions compared to 1990, a 42% share of renewables in energy consumption, 39.5% energy efficiency and an international electricity interconnection level of 15%.

However, the key to meeting the targets set will not only be based on the production of energy from renewable sources, but also on their storage capacity. This is why the PNIEC includes batteries and reservoirs as the main energy storage instruments and plans to incorporate an additional 6,837 MW of storage capacity by 2030, with a total of 3,500 MW in pumped storage from reversible power plants. The Energy Storage Strategy2 , published after the PNIEC, estimates a shift from the 8.3 GW of storage available today, mostly provided by pumped storage and thermal storage systems in solar thermal power plants, to a value of around 20 GW in 2030 and 30 GW in 2050 of total energy storage capacity available in those years, provided by a wide range of technologies.

The general positive features of pumped storage are the presence of a mature clean energy technology with high efficiency and a long service life for its installations, with consequently moderate operating and maintenance costs. All this would allow the energy transition without outages, frequency regulation and control of voltage and power factor, as well as the use of the market price spread.

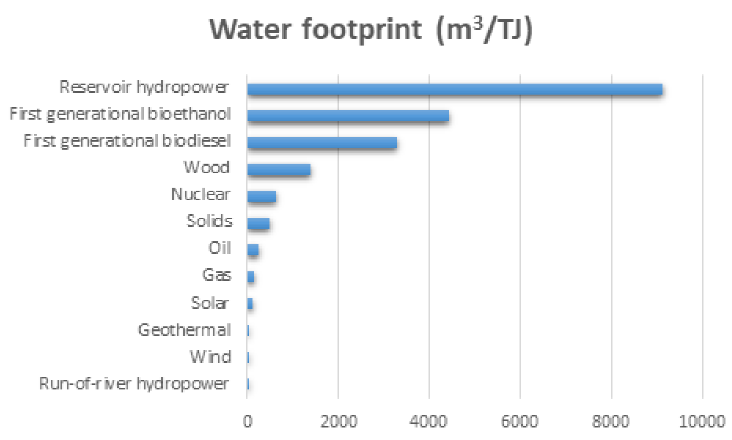
However, obstacles remain, such as technical complexity due to the diversity of typologies, dependence on the natural environment for efficient production (topography, geology and hydrology), and interference with other water uses.

c) Water footprint of energy production

Water is increasingly used in energy production, whether for electricity generation, or for the extraction, transport and processing of oil, gas and coal, as well as for irrigation of crops for biofuel production.

The Water Footprint is nothing more or less than an environmental indicator of the volume of freshwater used in the production chain of a good or service, distinguishing between the green Water Footprint of precipitation stored in the ground, the blue Water Footprint of groundwater or surface water resources, and the grey Water Footprint of water used to dilute polluted water in production processes.

Within the EU Water Footprint, more than 20% comes from the electricity sector, with 1300 L/inhabitant out of 5000 L/inhabitant total, and within energy production biofuels have a huge water footprint, even without considering soil moisture (which would increase these values).



Graph of the average Water Footprint of different renewable and non-renewable energy sources, not including soil moisture.

[2] Ministry for Ecological Transition and the Demographic Challenge, 2021.
See: https://www.miteco.gob.es/es/prensa/estrategiaalmacenamiento_tcm30-522655.pdf

Source: EU, 2019 ( )

A study by TOTAL[3] shows that the production of electricity from fossil fuels and nuclear energy requires massive withdrawals: 342 billion m3 in 2014. But 325 billion m3 of this is returned to the natural environment, the difference being mainly due to evaporation.

Primary energy production (coal, oil, gas, biofuels) uses smaller quantities (47 billion m^3), but returns very little (16 billion). In total, therefore, it "consumes" more than hydropower electricity production: hydropower plants do not draw or consume water (apart from increased evaporation from reservoirs). They extract energy from the water flows they channel, without changing its quantity, and are therefore generally considered a non-consumptive use.

In geothermal energy, hot water from deep underground aquifers is used to generate steam. The cooled steam is re-injected, forming a closed loop with few losses.

In thermal power plants, all of them need water to cool the steam that drives the turbines that generate electricity. Nuclear power plants draw the most water (from rivers or the sea). The water circulates in a secondary circuit isolated from the reactor and is returned to nature at a temperature that does not affect the ecosystem.

Coal-fired power plants are by far the most numerous and mobilize the most water on the planet.

Thermodynamic solar power plants, i.e. those whose parabolic mirrors capture the sun's heat, also require large amounts of water, which is often a problem because they are often located in arid or semi-arid areas.

Wind and photovoltaic energies, on the other hand, consume very little water, apart from that needed to manufacture the solar cells (washing them requires very pure water, which generally circulates in a closed circuit).

Finally, biofuels, produced from plants, require large volumes of water for irrigation. According to the TOTAL study, in 2014, biofuels accounted for a quarter of the water consumption dedicated to energy, i.e. more than coal, more than oil and much more than gas.

The International Energy Agency (IEA) estimates that "the need for water for energy production is expected to grow twice as fast as energy demand".

The IEA indicates that approximately 9% of water abstracted for energy production is consumed, i.e. does not return to its source, and that the volume of water consumed is set to increase, so the water footprint of energy projects should be an increasingly important factor in their assessment.

As for hydropower generation, it has historically been considered as a non-consumptive water use; however, Hoekstra himself, creator of the water footprint concept, in published studies (Mekonnen and Hoekstra, 2012)[4] , through the estimation of the blue water footprint of hydropower in 35 different cases, concludes that hydropower is a large consumptive consumer of water. The amount of water lost annually through evaporation from the selected reservoirs is equivalent to 10% of the global blue water footprint related to crop production. In addition to depending on the influence of

[3] Source: https://www.planete-energies.com/fr/medias/decryptages/l-intime-relation-entre-l-energie-et-l-eau.
TOTAL Foundations. DOSSIER: Energy and natural resources

[4] https://www.linkedin.com/pulse/water-footprint-energy-summarising-10-years-research-arjen-hoekstra/
Mekonnen, M.M. and Hoekstra, A.Y.(2012) The blue water footprint of electricity from hydropower.
Hydrology and Earth System Sciences, 16, 179-187, 2012, www.hydrol-earth-syst-sci.net/16/179/2012/
doi:10.5194/hess-16-179-2012
The blue water footprint of electricity from hydropower
M. M. Mekonnen and A. Y. Hoekstra

the local climate, the water footprint increases linearly with the area flooded per unit of installed capacity.

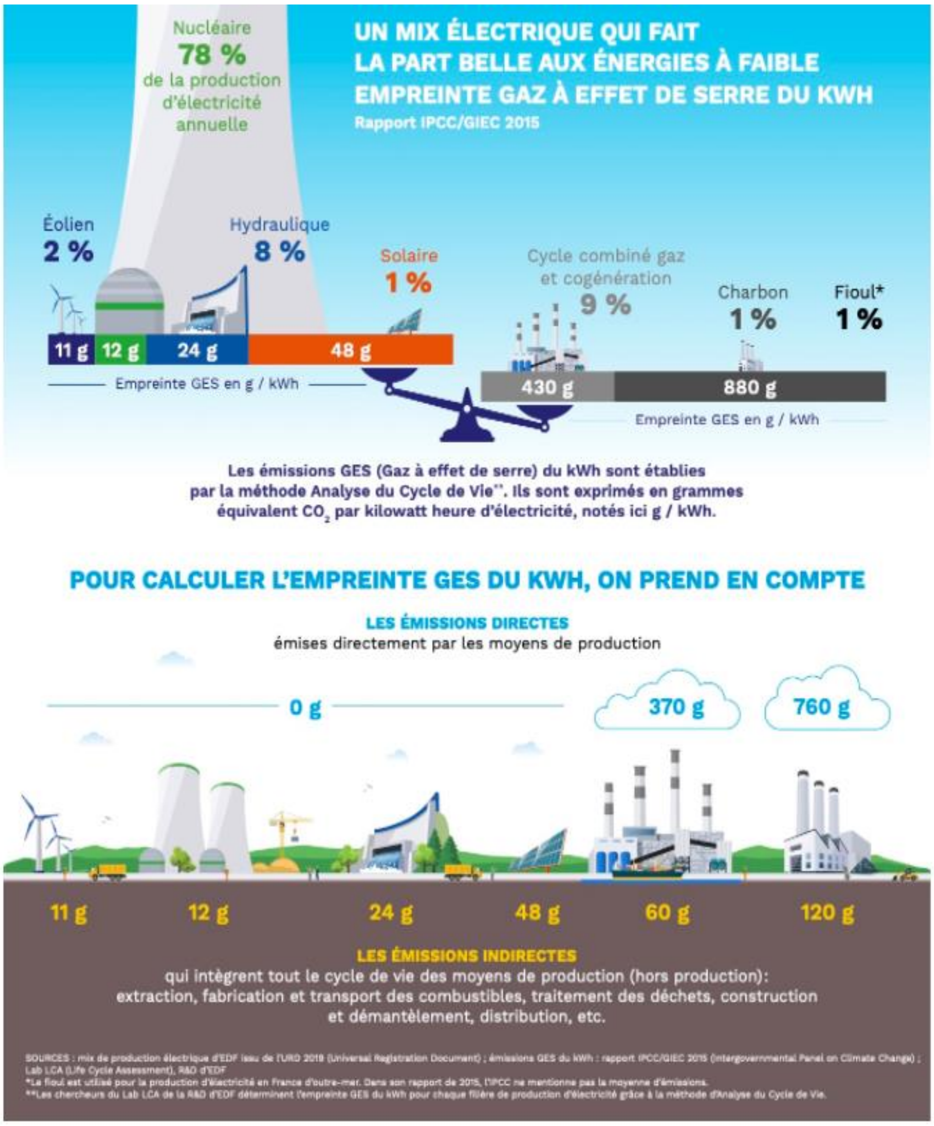
However, water evaporated from the reservoir is rarely taken into account when assessing the pros and cons of dam construction for hydropower generation. Mekonnen and Hoekstra's study argues that accounting for evaporative water loss is a consideration that should be taken into account when assessing the environmental, social and economic sustainability of a proposed dam or in the evaluation of hydropower as an energy source. The water footprint of hydropower dams must, of course, also be considered in the context of the river basin in which it occurs, as competition for water and possible alternative uses of water differ from basin to basin. In addition, sustainable hydropower development would also require accounting and internalisation of all external costs, including water consumption. Internalising means that the economic and environmental costs of the water consumed are charged to the operator of a hydropower plant and included in the hydropower price, which should vary according to the degree of water scarcity and competition for water use, depending on the period within the year and local circumstances.

If hydropower is to be further developed, all associated environmental and social costs must be taken into account. In this respect, the water footprint of hydropower, i.e. the consumptive use of water, should be considered as a further indicator in the environmental impact assessment. But it would also be necessary to contrast through rigorous research the real losses that are foreseeable in each area, validating the conclusions of the aforementioned authors and adapting them to specific cases.

In terms of **Greenhouse Gas Emissions** in energy production, EDF has studied the carbon footprint of the different modes of energy production. The Life Cycle Analysis (LCA) method was used to determine the GHG footprint of the different means of production that make up the electricity mix.

To calculate the balance of emissions, in addition to the production of electricity itself (direct emissions during plant operation), many other parameters are taken into account, such as extraction, manufacture and transport of fuels, waste treatment, construction and dismantling, distribution, etc., which produce indirect emissions.

Not all sectors have the same greenhouse gas footprint. Nuclear, hydro, wind and solar sources have zero direct CO2 emissions. While combined cycle, coal and fuel oil power plants are the biggest emitters.



The greenhouse gas footprint of electricity production.

Source: La Neutralité Carbone (https://www.edf.fr/groupe-edf/inventer-l-avenir-de-l-energie/r-d-un-savoir-faire-mondial/pepites-r-d/neutralite-carbone/mix-production-electricite-tres-bas-carbone)

The carbon footprint should also be taken into account in new hydropower developments.

3) ADAPTATION TO CLIMATE CHANGE

a) Decrease in drinking water quality

The decline in drinking water quality as a result of climate change is a reality that is already present in many places but threatens to spread to many others and amplify with the evolution of temperatures and the proliferation of extreme weather events.

The issue is addressed in the hydrological planning of the different basins, and is present in most of the Schemes of Important Issues, in one way or another. Although it is true that its presentation does not coincide exactly with the approach of loss of water quality as a consequence of climate change, but rather, most of the time it is necessary to compose the different factors in a single, more direct approach.

The main problem considered is the guarantee of supply and the decrease in general or specific availability in episodes of drought. For example, future climate scenarios and the mitigation needs that may arise in relation to meeting supply demands, or the repercussions of climate change on aquatic ecosystems, are discussed. General issues common to most of the Schemes are the effects of climate change on the availability of resources, the satisfaction of demands, environmental objectives or extreme hydrological phenomena (droughts and floods), and diffuse or point source pollution (although without analysing the negative synergies with climate change and its consequences). The problem, if it is to be found in the Schemes of Important Issues, must be composed from different sections, which, on the other hand, is not particularly complicated (in the Ebro, for example, improvements in purification are proposed as a measure for adaptation to climate change for the third planning cycle).

The origin - from a climate change point of view - of the loss of drinking water quality lies in multiple factors, but we could focus on three main triggers:

- On the one hand, the **increase in temperature** has an impact on the quality of the water in the reservoir, favouring certain stratification and eutrophication processes which may even make it unviable to use the water for water supply. The typical cycle in which, during the autumn, the mass of surface water sinks due to the drop in temperature, bringing dissolved oxygen to the bottom of the reservoir, is altered by the higher temperatures, which heat up the surface water to a greater extent and cause the cooler bottom water to be trapped under the thermocline and never rise, exhausting its oxygen and sometimes giving rise to anaerobic digestion processes which degrade the quality of the water. On the other hand, if the inputs of matter and nutrients to the reservoir are excessive, the reservoir tries to assimilate the inputs and incorporate them into its flows. This leads to a state of eutrophy, with greater stratification, an increase in suspended solids, a generalized decrease in dissolved oxygen (with fish mortality and organoleptic changes in the water, an increase in colour and taste, a sulphuric smell and an explosive increase in phyto and zooplankton populations), leading, as has happened on occasions, to a reduction and even interruption of supply, as well as the expenditure of large material and economic resources to try to satisfy the priority purposes foreseen.

- Secondly, the **increased loads** of sediment, nutrients and pollutants that runoff brings to water bodies due to heavy rainfall are also among the causes of such quality affectation. This is often accompanied by the interruption of the operation of treatment facilities during floods. Occasionally heavier rainfall can lead to sewer overflows, which can cause flooding and pollution of low-lying or densely populated areas and receiving water bodies. These increased inputs of nutrients and pollution favour the phenomenon of eutrophication mentioned above, and therefore, in addition to constituting, in themselves, a decrease in quality and an increase in pollution, they trigger a progressive degradation of the water.

- Thirdly, the higher **concentration of pollutants** during droughts, due to the lower dilution capacity of water bodies, is also a cause of water quality loss and reduced suitability for human consumption. This higher concentration of pollutants makes the operation of treatment plants more difficult, especially in economically disadvantaged areas with fewer resources, and droughts can intensify the use of inadequately treated wastewater. The scarcity and lack of dilution capacity also aggravates all the aforementioned problems of pollutant concentration in reservoirs, inability to self-purify and greater ease of occurrence of eutrophication phenomena and loss of biodiversity.

Lack of access to water in times of scarcity or the risk of disease from faecal contamination of water during floods are possibilities that need to be considered in water resources planning. Waterborne diseases such as cholera are very sensitive to changes in temperature, precipitation and humidity5. The increased frequency of extreme weather events can exacerbate people's exposure to polluted water from agricultural runoff and wash-off, floods and poorly functioning wastewater treatment systems. The scarcity of stored water in adequate sanitary conditions, the lack of water resources in times of increased scarcity often leads to the need to consume, when available, stagnant water (habitat for toxic algal blooms and breeding grounds for disease vectors that increase the risk of malaria). These impacts manifest themselves in different ways in the short and long term, and the necessary planning and adaptation measures to respond to emergencies also involve both short and long term actions. Climate-resilient water safety - and sanitation - planning is a risk-based approach to managing health risks associated with water quality and climate change. It is not only the expansion of reservoir capacity that is necessary to ensure quality. The management of these reservoirs, the correct handling of sediment flows, the use of bottom drains, the specific protection of these resources, mechanisms for controlling and monitoring the quality of water bodies, the removal of pollutants or specific actions such as the removal of algae or the oxygenation of the upper strata of the reservoir with the highest level of eutrophication, must also be considered in water resource governance strategies.

Europe has addressed this issue through different instruments. The European Green Deal, which concerns us, addresses the issue of the loss of water quality for water supply due to climate change also indirectly, and within other more general approaches, without a frontal development, but with actions that tend towards a solution, with proposals, among its seven keys, such as protecting and restoring ecosystems and improving their resilience to climate change or the action plan to combat pollution in order to prevent water pollution. In particular, in the block on adaptation to climate change, it is divided into three sections, the first of which refers to the decrease in the quality of water for human consumption, as well as the problem of guaranteeing supply. In addition, the document insists on a decrease in availability, and mentions adverse scenarios such as waterborne diseases, shortages of water stored in unsanitary conditions, etc. Further on, it speaks of the need to expand reservoir capacity to guarantee this quality. In any case, it complies with the provisions of

[5] World Health Organization and World Meteorological Organization, *Atlas of Health and Climate* (Geneva, Switzerland, 2013).

articles 6 and 7 of the Water Framework Directive, which explicitly makes special mention of this protection of drinking water, and speaks of actively delimiting and protecting these bodies of water intended for consumption.

A more specific legislative development came later with Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption, focused on greater risk prevention and management, establishing the need for universal access to water. This approach requires a more comprehensive vision, ensuring that the objectives set out both in the directive, which are more specific with regard to quality, and those set out in the European Green Deal, which are more generic but have the same impact on drinking water, are met. In the European Green Deal, addressing the protection of biodiversity, measures are promoted to protect biodiversity and ecosystems, as well as to improve the quality of oceans and forests, and, when talking about sustainable food, the aim is specifically to reduce the use of pesticides and, more generally, to reduce all types of pollution, both in terms of emissions into the atmosphere and into the soil and bodies of water.

When addressing these aspects, the substantial difference in the origin of water in Spain compared to Europe is significant. In Spain, 74% of drinking water comes from surface water and only 17% from groundwater (the remaining 9%, essentially from desalination), while in Europe, surface water makes up only 36%, while more than 50% is groundwater. This fact, together with the previous ones, tells us about the importance of dams in terms of water management in Spain and how the transposition of the Directive into Spanish legislation should be approached.

The Directive takes up the guidelines of the European Green Deal and implements them along these lines. It establishes the need to monitor organic substances, pharmaceuticals and microplastics in water intended for human consumption and encourages the improvement and extension of distribution networks. In Europe, according to the European Environment Agency, more than 98.5 per cent of the analyses carried out on drinking water samples comply with the standards currently in force in the EU.

There is no express mention of dams. Also in the European Green Deal, there is practically no mention whatsoever of the role that dams play in all these dynamics, although it is clear that the reservoir ensures a certain continuity of "pre-potable" water quality, due to the possibility of acting and predicting the evolution in terms of quality. The Directive focuses on the protection of water and its basins as a public good, guaranteeing sanitary and healthy water for all and universal access, and establishing drinking water, the protection of basins, lakes and rivers, reservoirs and maintenance and distribution structures, as pillars of a common European asset in the water sector, in continuity with what was already proposed in the Water Framework Directive, which included the need for coordinated management of river basins.

However, given the proven fact that, on the one hand, regulations are increasingly demanding in terms of the quality of supply water and, on the other, the quality of natural waters is decreasing, both mitigation and adaptation measures are necessary. In the case of reservoirs, adaptation measures include the provision of mechanisms that allow the intake level to be selected according to water quality, usually intake towers, which optimise quality at source at all times and reduce the cost of the necessary treatment. Bearing in mind that, as mentioned, in Spain most of the supply comes from reservoir water, the need to undertake these actions in reservoirs that do not have the possibility of selecting the abstraction level may be particularly relevant.

b) The role that reservoirs can play in flood and drought management

The European Green Deal (Green Deal, 2019) has as its main objective to become the path to a climate-neutral Europe. This plan includes fifty concrete actions to combat climate change and aims to make Europe the first climate-neutral continent by 2050.

The aim of this European Green Deal is for Europe to have a clean, zero-emission economy and to protect our natural habitat to improve the well-being of people and businesses, thereby providing leadership on climate action across the globe.

This Green Deal is organized along the following main lines:

- Clean energy
- Sustainable industry
- Renovation and efficient construction
- Sustainable mobility
- Biodiversity
- From farm to table
- End of pollution

Reviewing the detailed contents of these axes, it is difficult to find an obvious direct link between this deal and the dams; there is no direct or indirect reference to them.

This is also the case in the document "*Water elements in the European Green Deal*" by the European Commission's Directorate-General for Environment, discussed at the informal meeting of the EU General Directors for Water in December 2020.

To find any connection, one must look at the detail of the strategies that seek to address climate change, both in terms of combating and adapting to it.

This is the case, for example, with the second National Climate Change Adaptation Plan (NCCAP) 2021-2030, approved by the Council of Ministers of the Spanish government on September 22nd, 2020, as a tool whose main objective is to build a country that is less vulnerable, safer and more resilient to the impacts and risks of climate change, capable of anticipating, responding and adapting to a changing climate context.

This NCCAP gathers data from the State Meteorological Agency, which shows the most relevant evidence of the impacts of climate change in Spain over the last 40 years and highlights the fact that there are already more than 32 million people who are directly suffering its consequences.

A scenario of climate change is confirmed with such visible effects as the expansion of semi-arid climates, the lengthening of summers (almost 5 weeks longer than in the early 1980s), more days of heat waves and tropical nights, and an increase in the surface temperature of the Mediterranean of 0.34 °C per decade. The data show that large cities and the Mediterranean coast - key pillars of our country's wealth - are particularly hard hit, making them especially vulnerable to climate change.

In this context, adaptation to climate change comprises a broad set of strategies aimed at avoiding or reducing the potential impacts of climate change, as well as enabling better preparedness for recovery from damage.

The NCCAP defines 18 areas of work, specifying objectives for each of them. Among these areas of work, water and water resources are singled out as one of the areas of special attention.

Among the changes projected as a consequence of the impact of climate change, the NCCAP identifies the following for the purposes we are now concerned with:

- Moderate decrease in rainfall
- Increased evapotranspiration
- Decrease in average river flows
- Decrease in aquifer recharge
- Increased droughts
- Increased heavy rainfall and flooding events in some areas

We now try to analyse the role that reservoirs can play in relation to the last two points: droughts and floods.

Apart from the well-known and ample experience in Spain regarding the role played by reservoirs in terms of spatial and temporal regulation, there is a very relevant fact about the role assigned to reservoirs in Spain today in relation to droughts; scenarios that are much better known today, and which, as is well known, are managed with the help of the Special Drought Management Plans (PES).

When establishing scarcity scenarios, these plans work with weighted status indicators based on a series of variables such as reservoir reserves, piezometric levels, rainfall, foronomy and even snow reserves.

In all the Spanish river basin districts, these indicators are evaluated by system of exploitation, so that in each system a prior study is carried out to establish the level of weighting between the various indicators related to the different variables, so that the best possible reflection is achieved of the known historical situations of drought due to scarcity.

Well, after consulting these plans, the conclusion is that, however many euphemisms are used ("storage"), dams and reservoirs are the best water insurance in Spain, given the spatial and temporal irregularity of rainfall and runoff.

In fact, in the ESPs we work with weighted status indicators based on a series of variables such as reservoir reserves, piezometric levels, pluviometry, foronomy and even snow reserves. The weight of the reservoir volume indicator - in systems with this type of infrastructure - is overwhelmingly higher than that related to the rest of the variables.

85% of the UTEs (and all the important ones, including water supply, irrigation and industry) have this indicator of the volume of water stored in the reservoir.

The values of these weights are generally very close to unity (100 % of the weight in the weighted indicator), with average values for the demarcations between 0.95 and 1. Only in some (Júcar), it can go down to 0.41 (compared to 0.21 for piezometry, 0.28 for foronomy, and 0.10 for pluviometry).

Table. Basins, ETUs, reservoir volumes as indicators of drought and main uses

BASIN	NO. JVss	JVs with reservoir volume indicator	Weight of indicator (%)	Main uses dependent on reservoirs
CANTABRICO ORIENTAL	4	4	62,33%	Supplies to Bilbao, Getxo, Barakaldo, Irún, Donostia, Hernani, etc. (in total, 1.8 million inhabitants); hydroelectric production of 69.8 MW; production in thermal power stations of 1,952 MW.
CANTABRICO WESTERN	4	3	14,64%	Supply of Avilés, Gijón, Oviedo, Santander, Torrelavega, etc. (in total, 1.06 million inhabitants); hydroelectric production of 1,216.7 MW, production in thermal power stations of 21,240 GWh/year.
MIÑO-SIL	6	3	57,09%	Supply in Lugo, Ourense, Ponteareas, Ponferrada, O Porriño, Tui, Mos and Salceda de Caselas (in total, 347,285 inhabitants); hydroelectric production of 3,130.39 MW; production in thermal power stations of 1,632.8 MW.
DUERO	13	11	80,32%	Ávila, Salamanca, Segovia, León, Burgos, Soria, Zamora, etc. (in total, 1.3 million inhabitants); irrigation 420,000 ha; hydroelectric production of 3,865.55 MW; production in thermal power stations of 1,171 MW.
TAJO	17	17	100,00%	Supply of Madrid, Aranjuez, Trujillo, Alcalá de Henares, Guadalajara, Talavera de la Reina, Toledo, Cáceres, Plasencia, etc. (in total, 7.6 million inhabitants); Irrigation of 237,000 ha; hydroelectric production of 3,060.64 MW;
GUADIANA	21	16	82,04%	Supply of Badajoz, Don Benito, Villanueva de la Serena, Tomelloso, Valdepeñas, Villarobledo, Isla Cristina, etc. (1,630,000 inhabitants): Irrigation of 480,000 ha (250,000 ha with surface water).
GUADALQUIVIR	23	22	96,21%	Supply of Seville, Cordoba, Granada, Jaen, etc.; Irrigation of 880,000 ha (433,000 ha dependent on reservoirs).
SEGURA	4	2	72,72%	Supply of Murcia, Alcantarilla, Cartagena, Torrevieja, Totana, Alicante, Elche, etc.; Irrigation of 490.000 ha.
JUCAR	9	7	40,56%	Water supply to Valencia, Sagunto, Castellón de la Plana, Gandía, Denia, Benidorm, Cuenca, Albacete, etc. Irrigation of 390,000 ha
EBRO	18	17	91,44%	Water supplies to Zaragoza, Pamplona, Logroño, Lleida, Huesca, Tarragona, Vitoria, Bilbao and Santander (in total, 5.2 million inhabitants); Riegos del Alto Aragón, Canal de Argón y Cataluña, Canales de Urgel, Canal de Bardenas, Canal de Navarra, Canal Segarra Garrigues, Canal Imperial de Aragón, Canal de Lodosa, Canales del Delta, private irrigated land (in total, 925,000 ha); Hydroelectric production of 8,000 GWh/year; 6 thermal power plants (4,000 Mw installed); Ascó NPP (2,000 Mw installed); Ascó NPP (2,000 Mw installed).000 ha); Hydroelectric production of 8,000 Gwh/year; 6 thermal power stations (4,000 Mw installed); Ascó NPP (2,000 Mw).
TOTAL	**119**	**102**	**80,27%**	

On the other hand, and again understanding the connection of this report with the European Green Deal in the framework of strategies to mitigate the effects of climate change, there is an open debate on the role that dams can continue to play in mitigating flood risk and, specifically, how that role may be modified due to climate change.

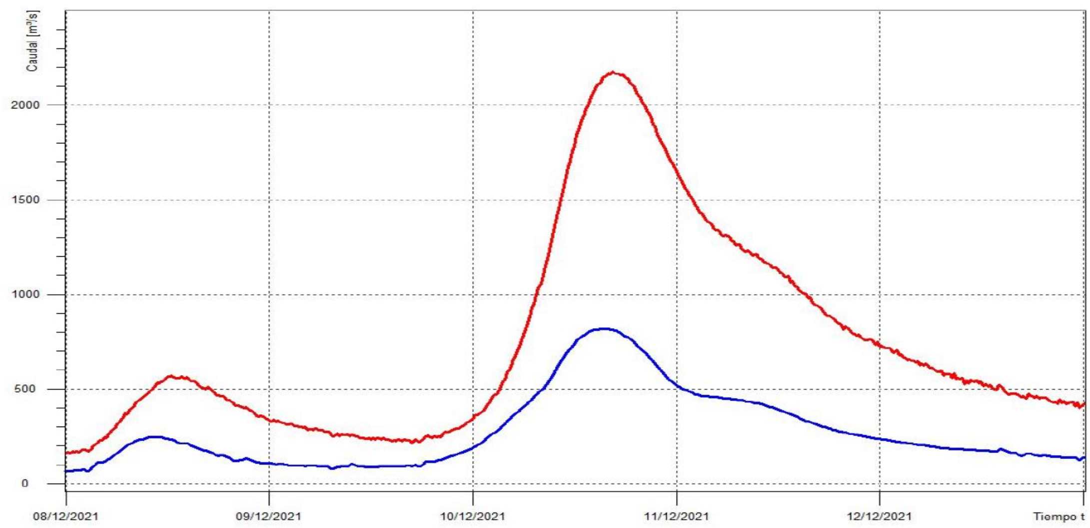
Flood risk assessment and management in the European Union has a regulatory framework derived from the European Directive 2007/60. In Spain (Berga, 2006)[6] cases have been accurately described in which dams, when properly designed and operated, have provided great benefits in reducing the frequency and severity of recurrent floods. The development of the aforementioned European directive in Spain has involved the drawing up of Flood Risk Management Plans which, although they have focused on the use of non-structural measures, have continued to propose certain structural measures, including some new dams, as a further component of the actions for the mitigation of the hazard and its effects.

Furthermore, there is no doubt about the very significant positive effect that existing dams and reservoirs are currently having in terms of flood risk protection.

For example, in the Avenida del Ebro, the volume of contributions in December 2021 reached the figure of 1,350 Hm3, of which 730 Hm3 were stored in reservoirs, of which 256 Hm3 in the Yesa reservoir and Iotiz, and 254 Hm3 in Mequinenza-Ribarroja.

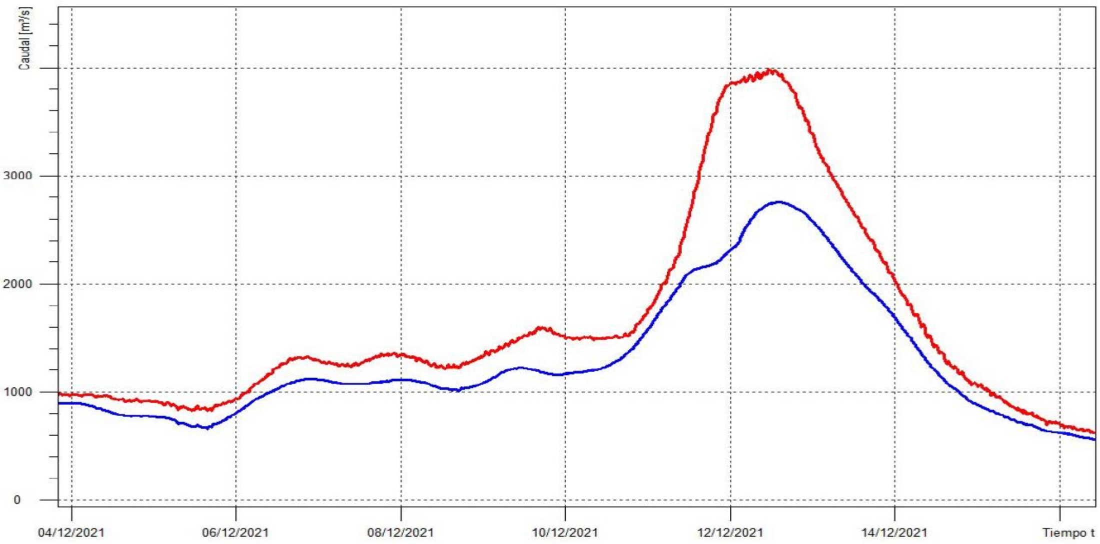
Table. Laminating effect of reservoirs on river flows

	No laminating effect	With laminating effect
River Ebro in Tudela	4,000 m /s^3	2.759 m /s^3
River Zadorra in Vitoria	500 m /s^3	126 m /s^3
River Aragón in Sangüesa	2,200 m /s^3	800 m /s^3
River Ebro in Flix	2.245 m /s^3	1,500 m /s^3



Comparison of the flow observed in the river Aragón at Sangüesa (blue) versus the estimated flow that would have passed through Sangüesa in a natural regime (without taking into account the lamination by the transmission from Itoiz to Sangüesa) (red).

[6] Berga, L. The role of dams in flood mitigation. *Civil Engineering* **144** (2006).



Comparison of the flow observed in gauging 9284 Ebro in Tudela (blue) versus the estimated flow that would have passed through Tudela in a natural regime (without taking into account the lamination due to the transmission of the flood through the Aragón and at its confluence with the Ebro) (red).

But should we define a new role for dams in river flood abatement as a consequence of climate change and work to adapt existing dams, as well as those that are planned or under construction, to this new role?

Today, about half of the world's major river systems are regulated by dams and there are more than 3,700 major dams in the pipeline or under construction, so the above question is of great economic, social and environmental significance.

Predicting changes in flood risk due to global warming requires simulations using complex hydrological and hydraulic models taking into account the exposure of the population, and comparing the results in the current situation and in different climate change scenarios. Doing this on a global scale requires a major effort and scientific references are not abundant. Uncertainties are large, but they are beginning to be reduced as to the direction of change. A warmer climate would increase the risk of floods in many regions of the world, although the frequency of floods could also be reduced in some areas (Hirabayashi et al., 2013)[7] .

On the other hand, the general population growth itself, without considering substantial changes in the spatial planning of demographic expansion, will naturally lead to an increase in flood risk.

A recent study led by researchers from the National Institute for Environmental Studies in Japan, the University of Tokyo and Michigan State University has analyzed, on a global scale, the role of dams in mitigating flood risk due to climate change (Boulange et al, 2021)[8] . Although the study itself points out methodological limitations, the results are of interest due to their global nature, especially in terms of the direction of expected changes in flood risks. Thus, in a climate scenario of low greenhouse gas emissions (RCP2.6), the flows associated with a return period of 100 years in the current situation (according to statistical estimates based on data from the period 1975-2004), would occur on average once every 107 years in the future (period 2070-2099), thus showing no significant

[7] Hirabayashi, Y., Mahendran, R., Koirala, S. *et al.* Global flood risk under climate change. *Nature Clim Change* **3,** 816-821 (2013). https://doi.org/10.1038/nclimate1911

[88] Boulange, J., Hanasaki, N., Yamazaki, D. *et al.* Role of dams in reducing global flood exposure under climate change. *Nature Communications* **12,** 417 (2021).
https://doi.org/10.1038/s41467-020-20704-0

change in direction. However, in a medium-high emissions scenario (RCP6.0), these flows would occur on average once every 59 years, which points to a significant increase in risks. The study also analyses future scenarios in which there are no dams and concludes that the risks to the population would increase much more significantly in both climate scenarios.

Thus, new measures may be necessary to maintain current levels of flood protection, or at least to ensure that these levels do not decrease severely as a result of climate change. Among these, it is perceived that new operating rules for dams may be needed. These new rules may negatively affect energy production and water supply guarantees.

Moreover, technological developments aimed at providing more accurate and reliable hydrometeorological forecasts will be of great value in improving flood protection and avoiding excessive flooding. And it should be considered that improved forecasts may also allow for more precise adjustments in operating rules that reduce negative impacts.

There remains a need, given the uncertainties associated with climate change, and the many negative environmental and social impacts of dams, for sustainable water resources development to require comprehensive assessments that take into account both potential benefits and adverse effects under various climate change scenarios. Methodologies such as the World Bank's Decision Tree Framework (DTF) (Ray and Brown, 2015)[9] that advance the comparative understanding of these effects are of great value and should be widely used in investment programmes.

c) Dam safety and the impact of climate change

Traditionally, dam safety management has been carried out assuming stationary conditions in all climatic parameters - such as the frequency and magnitude of extreme precipitation events - as well as in the non-climatic parameters that govern safety risks. However, changes in climate can affect the different factors that govern risks at dams10 . A stationary approach is no longer perceived as appropriate for assessing dam safety risks in the medium and long term.

A number of agencies are developing guidance and tools to include climate change analysis in their decision-making. In particular, efforts have been made to analyse the specific impact on dam safety monitoring, but more needs to be done.

Climate change may affect factors related to the loads on the dam system, but also the response of the system itself or the consequences that a failure may generate. In other words, the same failure may have different consequences for different climate change scenarios.

Table. Summary of the impacts of climate change on the different components of dam safety (Source: adapted from Fluixá-Sanmartín et al., 2018).

Risk component	*Effect of climate change*
Loads on the dam system	
Floods	Variations in local flooding are to be expected as a consequence of changes in extreme rainfall patterns, snow melt and snow melt processes and changes in soil moisture.
Water levels in reservoirs	Variations in the level of stored water are due to variation in precipitation patterns, in potential evapotranspiration in the basin or a decrease in water retained in the basin in

[9] Ray, P. A. and Brown, C. M., 2015. Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework. Washington, DC: World Bank. World Bank. https://openknowledge.worldbank.org/handle/10986/22544

[10] Fluixá-Sanmartín, J.; Altarejos-García, L.; Morales-Torres, A. and Escuder-Bueno, I. Review article: Climate change impacts on dam safety. *Nat. Hazards Earth Syst. Sci.* 18**,** 2471-2488, https://doi.org/10.5194/nhess-18-2471-2018, 2018.

	the form of ice or snow. It is also due to changes in land use and water demands as a result of adaptation to climate change.
Operation of gates	An increase in the solid content can lead to increased abrasion and blocking of the doors due to the effect of suspended solids. Changes in temperature can result in increased structural stresses and deformations.
Strategies for flood alleviation operation	Operating rules may need to be modified to adapt to new climatic conditions (changes in extreme rainfall patterns leading to changes in hydrograph concentration times).
System response	
Failure models	New failure modes may emerge, in particular related to snowmelt and slope stability. Glacial lake outburst floods (GLOFs) can even have a direct impact on the dam structure.
Probability of failure	Fluctuations in temperature can induce additional stresses in concrete dams. Drier soils and fluctuations in water levels can increase processes such as internal erosion in loose material dams.
Output hydrographs	The outflow hydrograph resulting from the lamination produced by the dam can be affected by surface roughness and by changes in water viscosity due to solids concentration.
Socio-economic consequences	
Direct damage	The direct consequences may be changed by the changes themselves due to population growth, or by an update of the economic value of the assets at risk.
Indirect damage	There are indirect consequences such as changes in the value of water resources for irrigation or hydropower production which in turn lead to changes in the cost of interruption of services or activities.

There is a clear role for dam practitioners, in collaboration with climate modellers, in the analysis of these changes. There will be a need to update the quantification of the various risk components taking into account different climate change scenarios. The methodologies to be used can be very diverse and include:

- Combination of global climate projection analysis, downscaling techniques taking into account local variables (downscaling) and classical hydrometeorological or hydraulic modelling (flood models) of various scenarios.
- Sensitivity analysis
- Fault tree analysis
- Demographic and socio-economic patterns of the territory downstream of the dam
- Expert judgement

The correct application of these methodologies by teams of qualified professionals can provide dam owners with useful information for their decision-making processes. The objective is to quantify the additional risks imposed by climate change in order to facilitate the definition of adaptation strategies for existing dams.

These methodologies will also allow new long-term investments to be planned more accurately.

It should be considered that methodologies are subject to multiple uncertainties, and appropriate allowances and limitations should be made in each case.

d) Guarantee of water supply

In this section, considerations are made in the context of adaptation to climate change and the framework defined by the European Green Deal with regard to the role of reservoirs in guaranteeing the demands associated with irrigation and supply.

The following table summarizes the information contained in the PHCs in force, 2015-202111 , on the demands associated with the main uses of water in Spain12 . Only the consumptive demands associated with the most relevant uses from a quantitative point of view are considered.

Table. Water demand (hm^3 /year) according to use.

HORIZONT	Urban use	Agricultural use	Industrial use	Total
Year of elaboration PH13	4.919	24.939	935	30.793
2021	4.987	25.750	1.097	31.834
Change (%)	+1,4	+3,3	+17,4	+3,4

It can be seen that agricultural demand accounts for 81% of the total estimated demand in the two horizons. However, it should bearin mind that, if actual supply is considered instead of estimated demand, which is what the hydrological plans reflect, this percentage can be significantly reduced, due to the existence of under-irrigated irrigation, irrigable surface area that is not irrigated in all seasons, etc. In other words, the estimated demand is different, and usually higher, than the actual supply in a season.

It should also be noted that, despite the global calculation, in 13 of the 1914 demarcations, no increases in agricultural demand are forecast for 2021, ranging from a reduction of 7.6% in the Júcar district to 0% in the Segura district. In the remaining six (Duero, Tajo, Guadiana, Tinto Odiel y Piedras, Ebro and Balearic Islands) the forecast increase ranged from 110% for the Tinto, Odiel y Piedras to 1.7% for the Duero. The most significant increase in volume corresponds to the Ebro D.H., with 699 hm3/year.

In contrast to agricultural demand, which represents the largest volume of demand in Spain (over 80% in the overall calculation for Spain in both horizons), urban supply demand accounts for around 15-16% of the total estimated demand in the two horizons considered.

On the other hand, despite the fact that in the overall calculation the average represents an increase of only 1.4% in urban demand from one horizon to another, for urban supply we find very disparate forecasts in each of the demarcations, ranging from maximum forecast increases for the Tajo and Tinto, Odiel and Piedras (of up to 16.6% and 13.3%) to reductions of 15.5% in the demarcation of the Balearic Islands and over 8% in basins such as the Duero and Júcar.

It should be borne in mind that the 2021 horizon constitutes a forecast, exclusively, with forecasts and projections that were based on the characterization of scenarios at that time, and that substantial increases in demand associated with the development of new irrigation areas are not easy to materialize in practice, although their possibility of supply is contemplated in the hydrological planning. The evolution actually produced can be verified in the Hydrological Plans of the third cycle (2022-2027), which are currently being drawn up.

Furthermore, in principle, these plans will be aligned with the approach to water management established in the European Green Deal and with the objectives of adaptation to climate change; as well as orienting the measures for adaptation to climate change for each demarcation, in coherence

[11] At the time of writing, the draft PHC 2022-2027 is still at the approval stage.
[12] Source: MITECO, Síntesis de los planes hidrológicos españoles. Second cycle of the WFD (2015-2021), 2018.
[13] This date may vary slightly from one district to another, but is expected to be around 2012.
[14] Grouping the 7 demarcations of the Canary Islands into one.

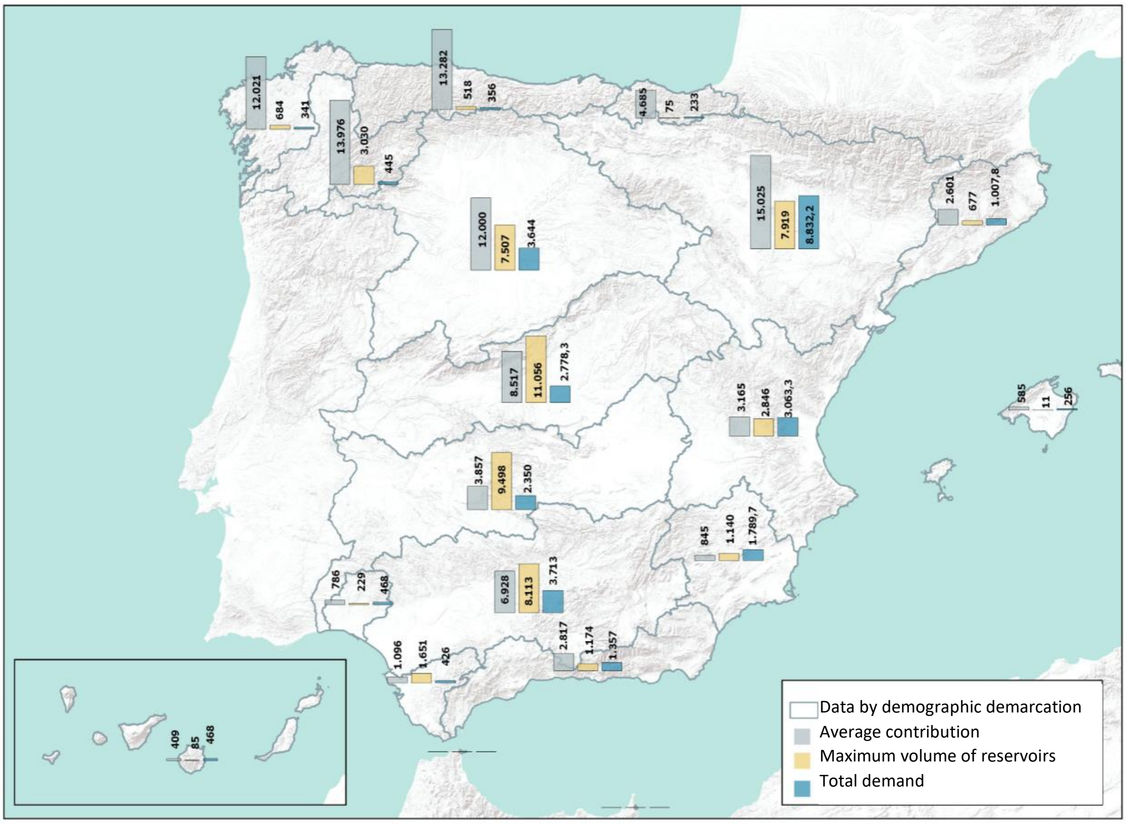
with the guidelines established by the new Law on Climate Change and Energy Transition and the National Climate Change Adaptation Plan (NCCAP 2021-2030).

On the other hand, the irrigated area at national level increased from 3,636,519 ha in 2015 to 3,831,181 ha in 2020, which represents an increase of 5.3% in six years[15] . Reaching a figure close to 4,000,000 ha irrigated has been possible thanks mainly to regulation in reservoirs.

Therefore, the study of the content of third cycle plans will complete the trend analysis and the analysis of the evolution of demand that is begun here.

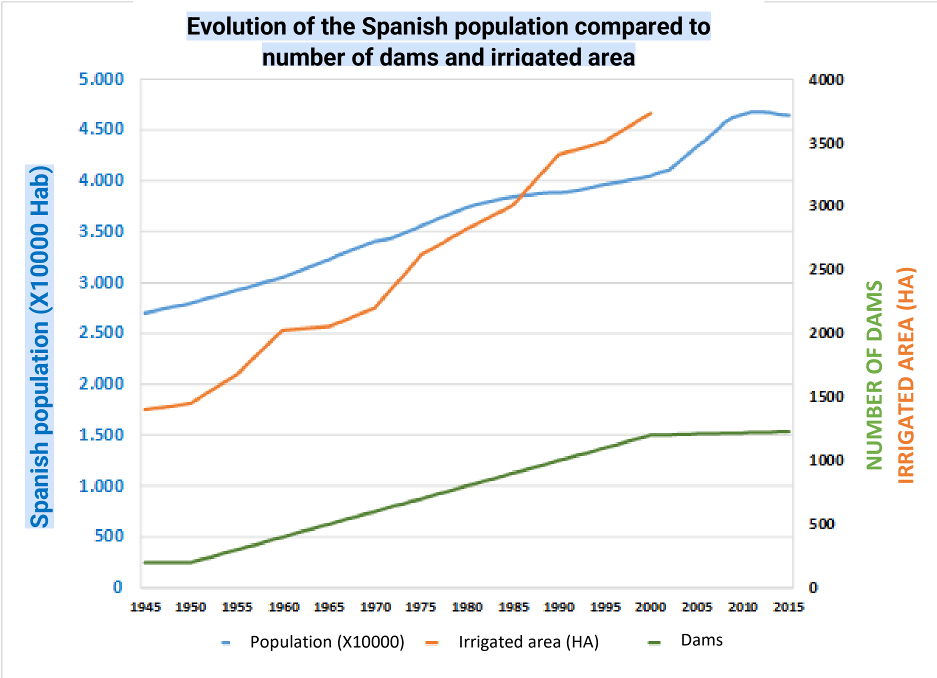
The spatial and temporal irregularity of water availability defines our country and has forced man to make a great effort to conquer the territory. Thus, in order to use water for the socio-economic development of our country, it has been essential to carry out large hydraulic works and develop a powerful system of governance.

Without these works, as demonstrated by the studies carried out for the White Paper on Water, only 7-8% of the natural resource could be used. Thanks to all this action, developed mainly in the 20th century, the water available for the various uses exceeds 30%, estimating that the maximum (joint average) sustainable rate of use should not exceed 40%. Undoubtedly, the hydraulic works that contribute most to this success are dams and reservoirs. Spain has 1,200 large dams and a reservoir capacity of 56,00 0 Hm3 and their evolution has accompanied the population and socio-economic growth of Spain, providing the necessary water for growing needs.



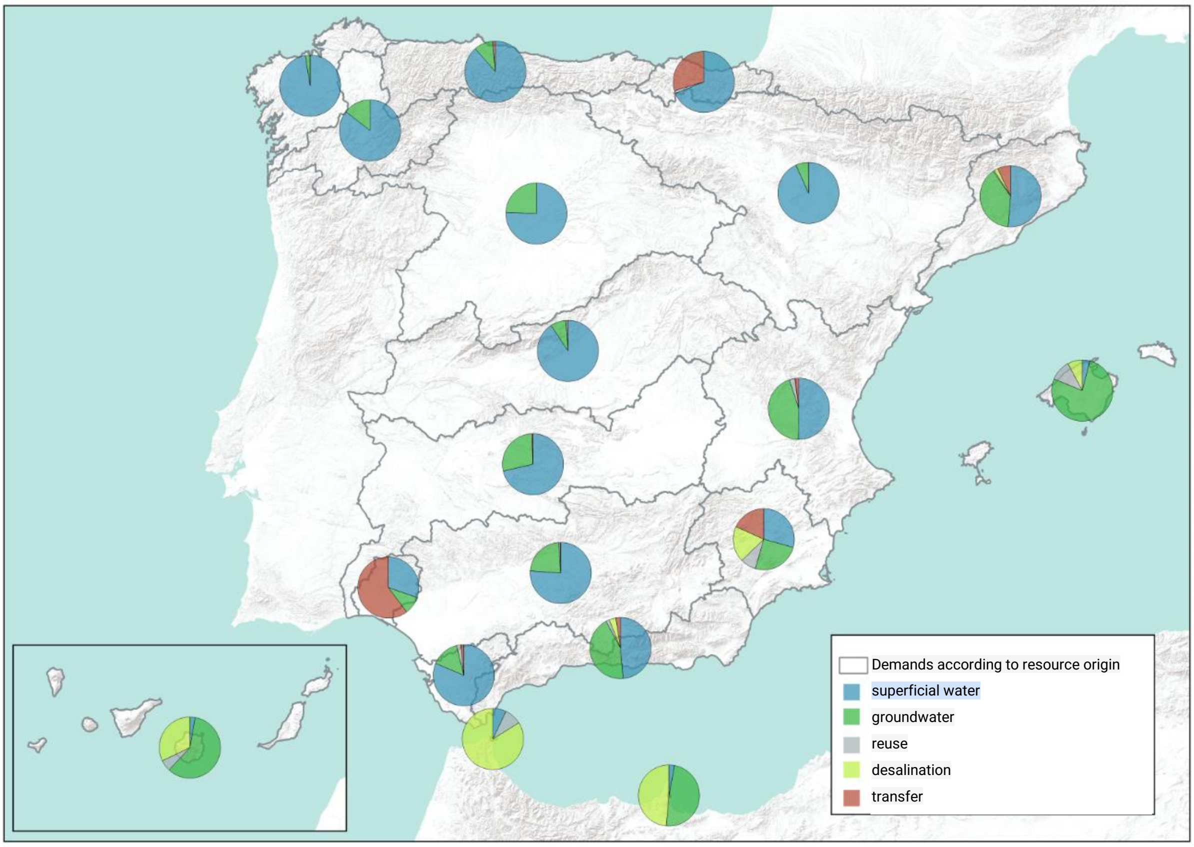
Average inflow, reservoir capacity and demand of River Basin Districts

[15] Source: MAPA, Survey on crop areas and yields (ESYRCE). Report on irrigation in Spain, 2020.



Evolution of the Spanish population versus number of dams and irrigated surface area

It is worth noting in this average scenario that the resource most used is surface water, which can be exploited thanks to the regulation provided by reservoirs, and also to the existing piping works, which connect the resources with the sources of demand. These hydraulic works constitute integrated water systems. Logically, these systems also make use of groundwater resources (especially in La Mancha and the Mediterranean basins). And systems to which new resources have been incorporated, water transfers from other basins and non-conventional resources (desalinated water and water reuse), which, although quantitatively not very relevant, are essential for water security, as they provide the necessary water, especially in areas with few resources. Without them, these areas are not very resilient to scarcity. It is very relevant that in supply, 8.9% of the resource already comes from desalinated water, a resource that is the protagonist in the Canary Islands, Ceuta and Melilla.

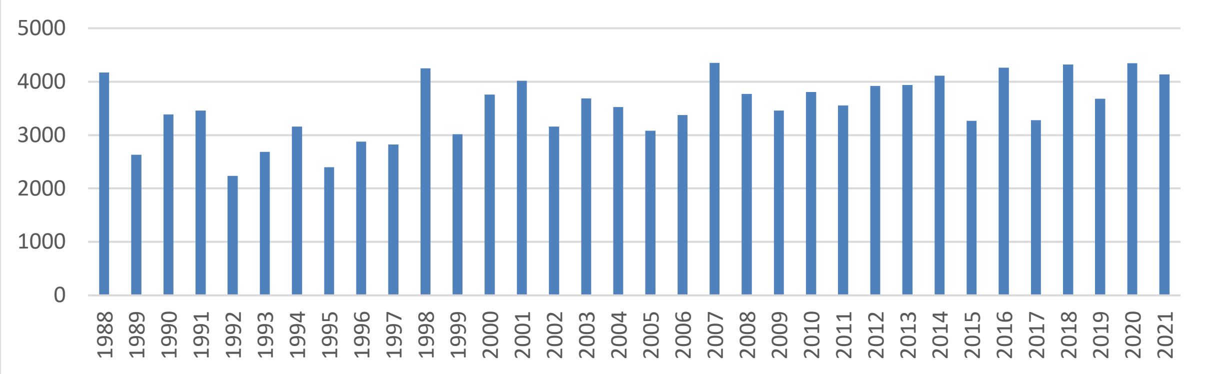


Demands according to the origin of the resource all Hydrographic Districts

It can also be observed that in the Mediterranean basins of eastern and southern Spain the use of groundwater is more intense. Also in the headwater areas of the Guadiana, Júcar and Segura there is an intense use of groundwater, which causes sustainability problems. In the rest, and given that the hydrological cycle is unique, water is used when the aquifers have already discharged into the springs and watercourses, avoiding the use of energy to pump water for its upwelling to the surface.

In general, groundwater has greater inertia and is a resource that is used counter-cyclically, intensifying its use in periods of drought and scarcity when surface water is scarcer. This is all part of integrated water resources management, which is complemented by water transfers and non-renewable resources (desalination and reuse). The artificial recharge of aquifers also contributes to improving the integrated management of surface and groundwater resources, as it allows for the supply and reserve of additional resources in groundwater bodies during years with water surpluses, improving the quantitative and, where appropriate, qualitative status of these aquifers, and favouring adaptation to climate change.

But the greatest weight falls on regulated surface water. The effect on low water levels is very illustrative: demand in August can be estimated at approximately 4,530 hm3/year. Well, analysing the historical series of the evolution of Spanish reservoirs, we find that between the 30th and 35th week of each hydrological year (practically equivalent to the month of August), the reservoirs have released an average of 3,633 hm3 , i.e., in average numbers they have supplied 80% of the consumptive demand:



Volume contributed weeks 30 to 35. Recorded historical series of evolution of volumes released (hm3) in Spanish reservoirs

In the last year, 2021, net releases amounted to 4,135 hm3, which is essential to supply all consumptive use and to maintain ecological flows during low water levels in the rivers.

By way of example, the global characterisation of total consumptive demands in the Tagus Demarcation for the 2022 and 2027 horizons is included in the future Hydrological Plan of the Tagus Demarcation for the third cycle (2022-2027).

Table. Consumptive demands of the Demarcation of the Tagus (horizon 2022 - 2027)

HORIZONT	DEMAND (hm3/year)					
	urban use	irrigation use	industry not connected to the network	power generation	other uses	**total**
actual horizont 2022 (with 2019 data)	686,32	2002,3	51,95	743,96	26,76	**3511,29**
2027 horizont	702,78	1919,12	55,47	743,96	27,44	**3448,77**

Thus, for example, for the 2022 horizon presented in the recent draft of the 2022-2027 TagusHP, urban demand in the Tagus basin, which has the largest population and is part of the Madrid supply system, would have been reduced by around 7% compared to the value contemplated for the year of preparation of the second cycle of the Plan and by up to 20% compared to the forecast for the 2021 horizon made in the second cycle (2015-2021).

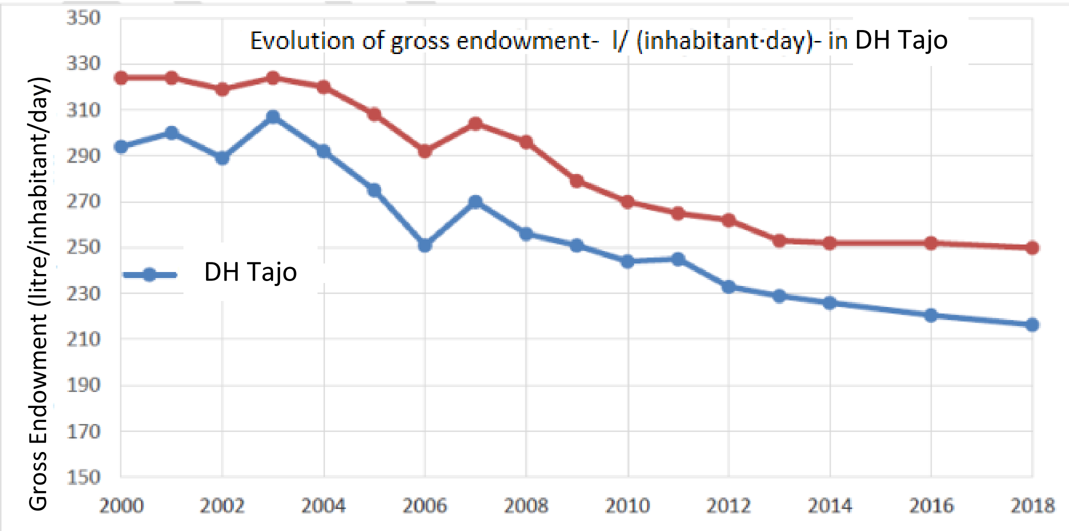
In this sense, taking data from the draft of the Tagus Hydrological Plan (2022-2027), and if we analyze the evolution of the volume of water supplied to urban supply networks and the resident population, we can obtain the evolution of the gross supply in liters per inhabitant per day in recent years.

Thus, it can be observed, and it should be highlighted, that during the first and second planning cycle, the average gross endowments for urban use have been following a marked downward trend in the country as a whole.

Specifically, in the last 15 years (from 2003 to 2018 shown in the graph, according to data from the Tagus Hydrological Plan (2022-2027)), gross endowments have been reduced by nearly 22% in the country as a whole (more than 26% in the Tagus Demarcation).

Year	Supply (hm³/ year)		Population (inhabitants)		Gross endowment (l/inh/day)	
	Spain	Demarcation	Spain	Demarcation	Spain	Demarcation
2000	4782	694	40 470 187	6 465 884	324	294
2001	4803	715	40 665 545	6 521 514	324	300
2002	4783	699	41 035 271	6 627 597	319	289
2003	4947	762	41 827 835	6 810 853	324	307
2004	4973	743	42 547 456	6 963 191	320	292
2005	4873	713	43 296 334	7 089 709	308	275
2006	4698	661	44 009 969	7 206 375	292	251
2007	4969	726	44 784 657	7 363 996	304	270
2008	4941	707	45 668 936	7 555 541	296	256
2009	4709	704	46 239 276	7 681 973	279	251
2010	4581	691	46 486 625	7 742 805	270	244
2011	4514	695	46 667 174	7 775 374	265	245
2012	4485	665	46 818 217	7 813 017	262	233
2013	4323	650	46 727 893	7 795 872	253	229
2014	4272	638	46 512 200	7 748 131	252	226
2016	4291	626	46 658 447	7 779 170	252	221
2018	4236	623	46 440 099	7 895 543	250	216

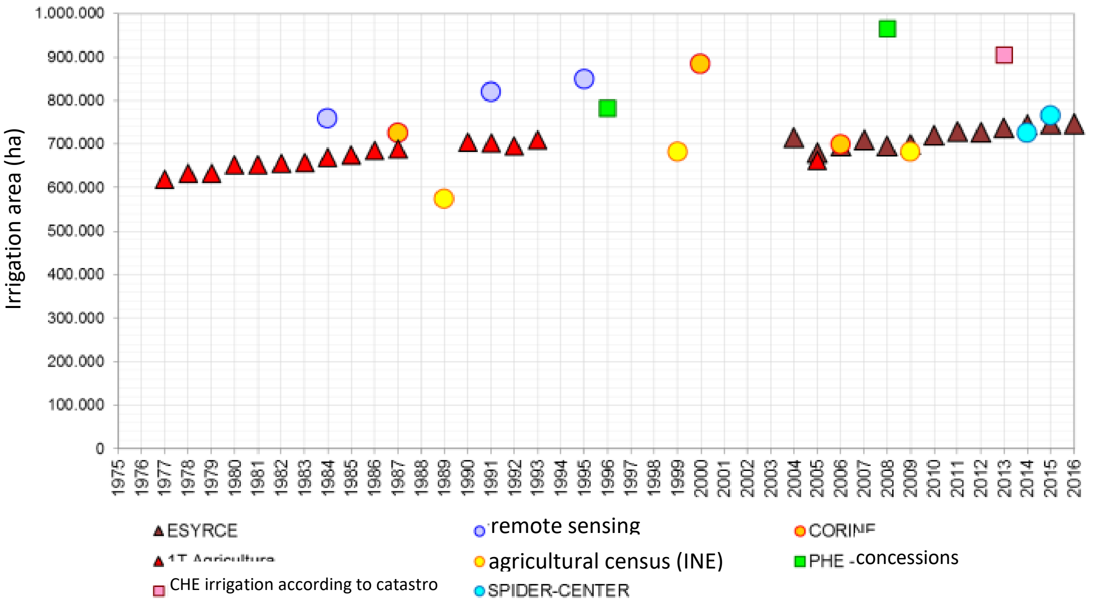
Evolution of supply, population and gross endowment to meet urban uses in the national set and DHTajo (draft of the PHTajo third cycle 2022-2027).



Graph of the evolution of the gross endowment to meet urban uses in the national set and DHTajo (draft of the third cycle of the PHTajo 2022-2027).

In other words, the gross supplies of urban supply systems (in short, their demand) in Spain as a whole have been following a notable downward trend in recent years, due to increased efficiency in management (reduction of losses in networks, promotion of leak and fraud detection, application of Drought and Emergency Plans, improvement and renewal of networks and infrastructures, pressure management, public awareness, improvement of the tariff system, etc.).

Also illustrative, in the field of irrigation, is the evolution of the irrigated surface area reflected in the initial documents of the process of revising the PH of the Ebro District (2021-2027), given that this is the district with the largest irrigated surface area in Spain and in which the current plan (2015-2021) considers the greatest increase in demand.



Evolution of irrigated areas in the DHE

In short, the above figures indicate, from the point of view of both water demand and irrigated area, that in recent years there seems to have been a sustained but very small increase at national level, although the behaviour is not homogeneous and there are specific deviations with respect to this trend in some demarcations.

This demand-side behaviour takes place in a context characterized by the following circumstances:

- Contrasted reduction of inflows in natural regime since 1980 and forecast of increasing reductions according to climate change model projections (average annual percentage reduction considering different global circulation models of between 3% and 7% at national level for the period 2010-2040 depending on the R.C.P.-scenario considered)[16] .
- Preparation and implementation of Special Drought Plans at national level, and Emergency Plans for drought situations in urban supplies.
- Implementation of more demanding guarantee criteria for urban supply as set out in the Hydrological Planning Instruction approved in 2008, which, as it is a priority use, may imply less availability for other uses, including irrigation. Consideration of environmental needs as a prior restriction, so that the volume to be distributed among the different uses is reduced by the volume estimated for these needs and generalized implementation of the ecological flow regime in river category bodies of water.
- The demand for irrigation and supply is mainly met by regulated water in reservoirs, followed by groundwater. Non-conventional resources, understood as the reuse of wastewater, desalination or desalination, are currently marginal from a quantitative point of view and at a notably higher cost due, among other factors, to the high energy consumption required to obtain them. The reuse of wastewater is not currently contemplated in the regulations for its use in urban supply.

[16] Source: CEDEX, Assessment of the impact of climate change on water resources and droughts in Spain, 2017.

There has been a marked increase in the marginal cost of building dams to generate new reservoirs, yet it remains the cheapest source of increased resource availability.

- Increasing difficulty for the construction of dams to generate new reservoirs, mainly due to environmental constraints.

  In particular, in relation to the European Green Deal, there are no explicit references to dams and reservoirs, focusing the increase in resources on increasing efficiency in the management and reuse of wastewater, which could well be promoted for the irrigation of parks and gardens, industry connected to the network, etc. In relation to water, it is logical to consider the achievement of the environmental objectives established in the WFD.

  Thus, the European Green Deal states that the recovery, transformation and resilience plans coincide in time with the hydrological plans and flood risk management plans for the period 2021.2027 and the associated funds are an opportunity to help member states to finance measures to achieve the objectives foreseen in European water legislation, which are the environmental objectives.

- Considerable investment effort in irrigation modernization and infrastructure renewal, together with other actions aimed at increasing efficiency in the use of water for urban supply, all of which will reduce consumption and water losses in adduction and distribution. It should be noted that the modernized surface area is around 80% of the total. The reduction in the consumption of urban supply systems has already been seen to be around 22% in the country as a whole (gross supplies).

The management of scarcity has been a reality for many years now, and the forecast is that this trend will not only continue, but will become more pronounced; therefore, the objective to be achieved is twofold. On the one hand, to ensure adequate attention to a demand for irrigation, stabilised or slightly increasing with increasingly scarce resources due to the effects of climate change. On the other hand, to ensure and improve the guarantee of urban supply, optimizing the management of reservoirs and the use of groundwater, increasing the efficiency of the adduction and distribution networks, promoting the detection of leaks and fraud, promoting the use of reclaimed water for irrigation of parks and gardens, industrial uses, etc., and raising public awareness of the rational use of water.

As adaptation measures related to dams and reservoirs to ensure that irrigation and supply demands are met in the above context, different lines of action can be suggested that fit within the framework defined by the European Green Deal:

- Monitoring of the effects of irrigation modernization already carried out and continuation of the modernization process.
- Detailed and rigorous justification, in accordance with the requirements of Article 4.7 of the WFD, of the need for new reservoirs and their reflection in the hydrological plans. As established in the IPH (Hydrological Planning Instruction), consistency with climate change forecasts must be considered.
- Analysis of the possibilities of generating integrated systems for resource management considering all existing sources, reservoirs, underground resources and non-conventional resources, including, for example, the analysis of the regulation of non-conventional resources in existing reservoirs for their subsequent treatment with adequate quality.

- Studies on the appropriateness of promoting supra-territorial management models for the urban water cycle and the complete management of the cycle, as they provide economies of scale and synergies that improve the guarantee of supply.
- Promoting governance as a measure to reach agreements to facilitate the management of present and future scarcity.
- Analysis of possible modifications to the guarantee criteria for irrigation, making them more flexible depending on the type of crop for which they are intended, so that a greater demand can be met with the same volume. For example, an analysis could be made of the repercussions in terms of the resources needed to consider the demand met, which would entail maintaining stricter criteria for crops that require a greater investment and are more likely to be grown permanently and defining other less demanding criteria for seasonal crops. Logically, if it is of interest from a hydrological point of view, its viability should also be analysed from other points of view.
- Drought episodes are a major concern for urban water supplies. These episodes will undoubtedly be aggravated, both in frequency and intensity, by the effects of climate change.

  It is therefore essential to make progress in achieving greater protection of the guarantee of urban supplies through the corresponding regulatory modifications.
  From the point of view of water planning and management, for the purposes of adapting to climate change, and with the objective of achieving water security for people (according to Law 7/2021 on Climate Change), the criteria established in the current regulations for determining the guarantee of an urban supply can be improved.
  In this sense, for a large regulated supply, a situation of depletion of the reservoirs would be catastrophic. Natural inflows during a drought episode are usually much lower than consumption, so that there is a risk of a generalized shortage, which could last for months.
  A revision of the guarantee criterion is needed, which should focus on limiting the probability of reaching a situation of stock depletion (minimum storage curve in reservoirs of regulated supply systems, etc.).

- On the other hand, and also related to drought episodes, water legislation should also provide urban supply systems with clear technical criteria regarding the minimum level of protection that ensures the applicability of the principle of supremacy of supply use in regulated systems in situations of scarcity (taking into account the competition in water releases for the different uses that arises in such drought episodes), and also in relation to ecological flows.
- Technical improvements in the definition of the ecological flow regime in water bodies, in terms of the methodologies for its determination, so that the range of results obtained through the different procedures is limited within reasonable margins.
- Carrying out the studies that analyze the repercussions of the implementation of ecological flows on existing water uses in the terms established in section 3.4.5 of the Hydrological Planning Instruction in force and their inclusion in the consultation process that determines the regime to be finally implemented in the terms established in section 4.4.6 of the aforementioned regulation.

  The studies include a legal analysis of the effects of the implementation of the eco-flow regime on existing concessions, the impact on the guaranteed levels of the demand units concerned, and the economic and social impact of the implementation of eco-flows. In turn, one of the results of the concertation process must be the definition of an implementation plan and adaptive management based on the results obtained in the process of implementing the concerted regime.

- Study of the impact of the possible effects of climate change on the guarantee of reservoir-regulated systems:
    - Foreseeable increase in the risk of droughts with a reduction in inflows and an increase in losses due to evaporation of the reservoir sheet; lower availability of water in the reservoir, affecting the guarantee of the demands met by the system.
    - Foreseeable increase in frequency and intensity of extreme rainfall; increase in sediment accumulation in the bottoms of reservoirs with loss of reservoir capacity. Need to promote knowledge of the real capacity of reservoirs.
    - Foreseeable increase in the risk of floods and rise in maximum flows, with the foreseeable increase in the volume of protection in reservoirs necessary for flood abatement and maintaining the same level of safety.

4) BIODIVERSITY STRATEGY

a) Restoration of obstacle-free rivers

Within the European Green Deal, the preservation of river ecosystems plays an important role, with clear references to the impact of hydraulic works on them. The main lines of action in relation to the presence of dams and weirs are aimed at the removal of obsolete works and/or the conditioning to allow the passage of migratory fish, improving the hydro-sedimentary dynamics of rivers and recovering alluvial plains and wetlands.

Derived from the Green Deal, and as an extension and development of it, is the "EU Biodiversity Strategy 2030. Re-integrating nature into our lives"[17] , adopted in 2020, which states that more efforts are needed to restore freshwater ecosystems and the natural functions of rivers in order to achieve the objectives of the Water Framework Directive. "*This can be achieved by removing or adapting barriers to migratory fish passage and improving water and sediment flow. To this end, by* ***2030 at least 25,000 km of rivers will be returned to free flow, by removing essentially obsolete barriers and restoring floodplains and wetlands.***"

It requires Member State authorities to review water abstraction and impoundment permits to restore ecological flows so that, *"by 2027 at the latest, all surface waters will have good ecological status or good ecological potential, and all groundwater will have good status, as required by the Water Framework Directive".*

It also notes that "*large-scale investments in river and floodplain restoration can provide a strong economic boost to the restoration sector and local socio-economic activities such as tourism and recreation, while improving water regulation, flood protection, fish nursery habitats and nutrient pollution removal".*

The biodiversity strategy specifically refers to the minimum lengths of unobstructed rivers, which could be defined as those where biological communities could be stably maintained. River fragmentation poses problems in terms of population isolation and reduced gene flow (with the risks of inbreeding and extinction), a decrease in population resilience, with a higher probability of exceeding the demographic viability threshold and a lower probability of recovering from disturbances, and a decrease in geomorphological resilience mechanisms, the balance of sediment balance, supply of organic matter and detritus, habitat regeneration, regeneration of riparian pioneer species, etc.

It is proposed to apply the following criteria for the definition of priority actions in their transfer to the hydrological plans of the third cycle of the Water Framework Directive:

Obsolete dams and weirs will be demolished.

- Demolition or longitudinal permeabilization of barriers with major impacts, especially on migratory fish species (eel, saboga and others) will be carried out, taking into account the length of the liberalized river and the possible breeding sites or habitat for other parts of the life cycle concerned, as well as other specially protected species.
- Sediment transfer is improved through management measures in reservoirs, especially upstream of high value socio-ecosystems such as deltas.

[17] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions EU Biodiversity Strategy for 2030 Bringing nature back into our lives COM/2020/380 final

- The demolition or longitudinal permeabilisation of barriers in protected areas, e.g. Natura 2000 sites, will be promoted.
- An analysis will be carried out of the concessions for dams and reservoirs, which are due to expire between 2021 and 2027, and a prioritised catalogue of actions will be prepared, including a review of possible extensions of concessions, if appropriate.
- Cost/benefit studies will be carried out to prioritise measures.

The treatment of this issue in a sample of the draft water plans 2022-2027 is scarce:

- The Ebro Programme of Measures refers generally to the use of nature-based solutions to remove barriers, but includes only a €300,000 measure for the dismantling or adaptation of dams or weirs in La Rioja, and does not include a list of such barriers.
- The Douro Hydrological Plan refers to the fact that 41% of surface water bodies suffer from hydromorphological alterations and includes a set of 767 measures (with a budget of 194 million €) to these measures, but does not specify investments in the removal or adaptation of obstacles.
- In the Guadiana, 31% of surface water bodies are affected by hydromorphological pressures, and its Programme of Measures foresees an investment of 128 million €, without detailing the obstacles to be removed or adapted.
- In the Guadalquivir, it refers to the obstacles in the section on the analysis of uses and pressures, and the Programme of Measures includes measures such as river restoration.

In addition to what is included in the hydrological plans, the transfer of the Biodiversity Strategy to the national level has been established through various instruments, including the 'National Strategy for Green Infrastructure and Ecological Connectivity and Restoration' (in force since 14 July 2021, Order PCM/735/2021, of 9 July) and the continuity of the National Strategy for River Restoration (since 2005, in line with the Water Framework Directive).

Furthermore, it should be noted that within the framework of the National River Restoration Strategy, 559 dams or weirs have been removed or taken out of service; 529 fish ladders and fish passes have been built; lateral obstructions have been removed and set back (dykes and breakwaters), secondary and floodplain branches have been recovered, meanders have been connected and river spaces have been reclaimed.
The restoration of rivers involves giving them their fluvial space and recomposing their connections: vertical, horizontal and longitudinal. However, it is clear that there is a lack of scientific knowledge, research and monitoring of fish communities in Spanish rivers. It is necessary to provide urban planning with a fluvial scientific basis (delimitation and continuity of the fluvial territory, changes of use in fluvial territory, etc.), as well as to revise the catalogues of Protected Assets.

It is necessary to identify obstacles and carry out a cost/efficiency analysis of their removal, prioritising work in stretches where greater lengths of obstacle-free rivers can be achieved.

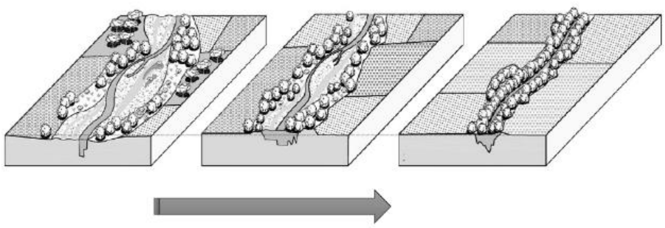
Finally, these actions need to be incorporated into the programmes of measures of the Hydrological Plans.

This removal of obstacles cannot be aimed at returning Spain's rivers to their natural state, which is socio-economically unfeasible. As has been shown, water, food and energy security depend on reservoirs. However, it is perfectly possible to remove obstacles in cases where they have lost their functionality, in a way that is compatible with the necessary regulation of our rivers by means of dams and reservoirs.

The biased debate based on ideological apriorisms in which either the removal of any dam is a serious problem, even if it does not have a regulating effect, or it is considered that the necessary environmental objectives will only be achieved if most dams are removed, without taking into account the functionality of the reservoirs created by them, must be overcome.
The elaboration of a technical guide seems a very opportune way forward.

b) Ecological flows

In Spain, it is quite possible that the objectives of the European Green Deal for river ecosystems will be achieved or not depending on the level of pragmatism adopted. The experience acquired in the transposition of the Water Framework Directive and compliance with the derived regulations, especially those referring to Hydrological Planning, should serve to establish simple, clear, objective and feasible guidelines that will allow, at the same time, progress to be made in the direction set by the European Green Deal and the results to be verified.
The recovery of floodplains in a country of highly regulated rivers and with a very high dependence on water availability (and not only for agricultural purposes) seems complicated. Progress can undoubtedly be made, but perhaps it should be done calmly, seeking ad hoc scenarios, where we can learn from the response of river ecosystems that have been constrained by human activity for years and that only manage to claim their own space through floods that are quickly interpreted as catastrophic situations, especially the longer the period of recurrence.
Regarding environmental flows, it should be borne in mind that the Water Framework Directive has never imposed the need for "environmental flows", but it does impose the obligation for all water bodies to reach Good Ecological Status or Good Potential (BEE-BPE) imperatively before 31 December 2027. There is a real possibility of making progress in the preservation of river ecosystems if it is understood that the sole aim is to achieve BEE-BPE in all bodies of water and not for all of them to have a regime of ecological flows. The logical thing is that in order to achieve the BEE-BPE, a certain regulated flow is required to support and maintain it, but once this good ecological status or potential has been achieved and consolidated, it makes no sense to invest effort in calculating ecological flows for these same bodies of water, while others are still unable to reach the required environmental status.



Ecological flows[18] are not a finalist element, but a tool designed to pursue objectives that are defined at each socio-political or environmental moment. These face the trajectory of rivers as a result of the pressures and impacts of human activities, tending towards narrower and much more embedded rivers where riverbank vegetation is linear and does not meet the habitat needs of species.
It is therefore necessary to improve the water bodies in biomorphological terms before determining the ecological flow of these bodies. In addition, monitoring should be carried out to check whether the objectives set for each water body are achieved, how they respond to the flow from the dams and whether readaptation is necessary to achieve them.

[18] The concept of ecological flow is covered by different sources: *TRLA (RDL 1/2001):* Ecological flows, understood as those that maintain as a minimum the fish life that would or could naturally inhabit the river, as well as its riverside vegetation. *RPH (RD 907/2007):* This regime of ecological flows will be established in such a way as to maintain in a sustainable manner the functionality and structure of aquatic ecosystems and associated terrestrial ecosystems, contributing to achieving good ecological status or potential in rivers or transitional waters. *RDPH (RD 849/1986):* The purpose of establishing the ecological flow regime is to contribute to the conservation or recovery of the natural environment and to maintain at least the fish life that would or could naturally inhabit the river, as well as its riverside vegetation and to achieve good ecological status or potential in bodies of water, as well as to prevent their deterioration. Likewise, the ecological flow shall be sufficient to prevent the survival of fish fauna and riparian vegetation from being put at risk for quantitative reasons.

In the section of the IPH, 3.4 Environmental flows, aspects and methodologies for determining the environmental flow regime are specified. "The regime of environmental flows shall be established in such a way as to maintain in a sustainable manner the functionality and structure of aquatic ecosystems and associated terrestrial ecosystems, contributing to the achievement of good ecological status or potential in rivers or transitional waters.

A temporal distribution of flows must be sought that is compatible with the requirements of the different vital stages of the main species of native fauna and flora. The components of the ecological flow regime to be considered are the minimum flows that must be exceeded to maintain spatial diversity of habitat and its connectivity; the maximum flows that must not be exceeded to avoid high flow velocities and thus protect the most vulnerable native species (both maximum and minimum flows include temporal distribution of flows); generating flow, which occupies the riverbed to regenerate the riverbed and banks (which also controls the presence and abundance of different species and maintains the physico-chemical conditions of the water and sediment); and the rate of change, which limits the variation of flow per unit of time, avoiding large fluctuations in a short time and consequences such as the entrainment of aquatic organisms.

According to art. 3.4 of the IPH, the establishment of the ecological flow regime shall be carried out through a three-stage process:

- Development of technical studies to determine the elements of the ecological flow regime in all water bodies.
- Concertation process, defined by several levels of action (information, public consultation and active participation).
- Process of concerted implementation of all components of the environmental flow regime and their adaptive monitoring.

With regard to compliance with the ecological flow in reservoirs, article 49c of the RDPH states that "the ecological flow regime will not be enforceable if the reservoir does not receive natural inflows equal to or greater than the ecological flow established in the corresponding hydrological plan, being limited in these cases to the regime of natural inflows to the reservoir". And further on "In any case, the enforceability of compliance with the flows shall be maintained taking into account the state of the rivers downstream due to previous situations of water stress when, despite the cessation of natural inflows upstream, additional inflows from dammed water can be made that could contribute to mitigate such stress."

With regard to this compliance with ecological flows, it should be noted that the 2018 Judgment[19] eliminates the consideration of possible margins of tolerance of the instantaneous values of minimum and maximum flows or rates of change. The Confederación Hidrográfica del Júcar, for example, has differentiated the concept of "failure" from the term "non-compliance". And it analyses the cause of failure when the ecological flow regime is not reached in any of these situations:

a) In a percentage of time equal to or greater than 2% (maximum equivalent to 7 days/year or 175 hours/year), irrespective of the deviation from the established flow rate.

b) In a percentage of time equal to or greater than 4% (maximum equivalent to 15 days/year or 350 hours/year) and the deviation from the mean daily flow component is less than 20%.

In the event that the above cases occur, it is up to the CHJ to diagnose their causes, which may be due to natural causes or measurement errors of the measuring device, in which case it is not considered non-compliance, or conduct by the operators (concessionaires or operating services) that may have led to this situation, in which case it is considered non-compliance.

[19] Ruling no. 1460/2018 of the Fifth Section of the Contentious-Administrative Chamber of the Supreme Court.

A proven feasible measure to regenerate impoverished systems is controlled floods, ending the minimum flow patterns that hindered adequate regeneration of habitats. These floods have the capacity for robust transport of nutrients and biota, and allow passage for many populations. They have even been combined with sediment injections to enhance environmental improvement for habitats and species downstream of dams.

In this sense, the release of adequate generating flows from reservoirs must be studied in accordance with the capacity of the dam's spillways and the capacity of downstream watercourses, and on occasions it may be necessary to adapt these spillways or even to build new ones.

In order to prepare the land in such a way that the environmental flow is of optimum benefit, the recovery of the transversal lateral connectivity of the bodies of water where there is still a possibility of recovery of the alluvial plains is also proposed, with cases of success in the Ebro and Duero basins. In this way, the energy and speed with which floods reach areas where this impact is greater would be avoided.

It is also relevant to understand the environmental flow and its implementation in temporary rivers, with highly differentiated hydromorphological behaviour and very vulnerable biological communities in terms of conservation, so that the environmental flow regime must understand the existence of this type of water bodies with cessation of flow.

A final underlying idea is that perhaps the European Green Deal should not be interpreted as an action plan to restore a "wild" or "pristine" nature, not least because this is impossible in the European context and, moreover, would be unsustainable20 ; It would be a matter of improving the interaction of hydraulic works with current river ecosystems by adopting the aphorism attributed to Voltaire that "the best is the enemy of the good", opting without too many exceptions for real objectives as opposed to possible ones (even if they are perceived to be better), approaching actions to preserve Spanish river ecosystems on the basis of thoughtful, clear, simple and pragmatic criteria that allow, in any case, for the objectification of the results.

c) Sediment flow

The management of sediment transport and storage in reservoirs has been a major challenge for many years and is becoming increasingly important. Nowadays, the increasing erosion in many of our catchments, together with the accumulation of sediment in reservoirs over the years and the existing imbalances downstream of the reservoirs, including the need to use these sediments in stabilising the waterfront and combating marine erosion and sea level associated with climate change, makes it increasingly relevant to work on the management of the associated sediments.

The Environmental Profile of Spain 2020 published by the Ministry for Ecological Transition and the Demographic Challenge states that the area of soil affected by "Moderate" erosion processes is above 60%. According to data from the INES-National Soil Erosion Inventory, in 2020, almost 29% of the erodible soil surface in Spain suffers from medium and high erosion processes (soil losses of more than 10 t/ha per year). This represents a national average loss of about 13.6 t/ha/year, which in terms of volume is about 7 m3/ha/year.

The erosive process of soil erosion in rainy episodes ends up reaching the reservoirs, so that the retention of solids carried by the water in this process is currently one of the most serious problems in their management, both in terms of the loss of their useful capacity and the negative effects

[20] In recent years, the term "sustainable" has often been associated with exclusively environmental connotations. Sustainable" action is often interpreted as simply being environmentally sound. However, the original meaning of "sustainability" in the 1987 Brundtland Report, where the term was coined, included not only the environmental component, but also the economic and social components.

caused on the rivers downstream of them. This translates into a reduction in the guarantee of being able to meet water demands, but also into a serious hydromorphological alteration of the riverbeds located downstream of the reservoirs, putting the state of the surface water bodies at risk of deterioration.

The drafters of the Law for the Drafting of Reservoir Projects of 1905 were already aware at that time of the negative effects that the loss of reservoir capacity entailed, and especially, what it meant for the management of the operation of the reservoir when the drainage elements that were covered by them were put out of service; for this reason, the Law recommended that to reduce this influence, the so-called Spanish cleaning system, which had been used with good results up to that time in some dams on the Mediterranean slope, should be used.

The SPANCOLD Technical Committee on Reservoir Sedimentation, on the basis of studies carried out by CEDEX (Centro de Estudios Hidrográficos) on a hundred Spanish reservoirs, estimated a few years ago that the global "average" annual loss of reservoir capacity due to sedimentation was around 0.5%, i.e. around 300 hm3/year, estimated a few years ago that the "average" annual loss of reservoir capacity at global level for this reason in the 1300 reservoirs should be around 0.5%, i.e. around 300 hm3/year, so that in the year 2025 this total loss would reach 12.5% of the maximum theoretical total volume stored by them and 17.5% in the year 2050. And this is without taking into account the negative effects of climate change, which will probably contribute to aggravating the problem, as although average annual rainfall will decrease, it will be more torrential, leading to erosion and increasing the volume of sediments trapped in the reservoirs.

Despite the clear importance of the subject, however, it has not been of priority interest to the pressurisation community, as evidenced by the fact that it has only been discussed on three occasions at the International Congresses on Large Dams organized by the International Commission on Large Dams (ICOLD):

- In 1951, Question 14: Sedimentation in reservoirs and related problems.
- In 1982, Question 54: Reservoir sedimentation and slope stability. Technical and environmental effects.
- And in 2009, Q89: Management of siltation in existing and new reservoirs (2009).
- And two at the Jornadas Españolas de Presas: in 1996, Corrección hidrológica de cuencas y aterramiento de embalses (Hydrological correction of basins and silting of reservoirs), and in 2010, Las presas y el terreno (Dams and the terrain).

Good management for a good sediment balance begins with appropriate land use planning (good agricultural practices) and hydrological-forestry restoration actions to reduce erosion in the contributing basins.

The management of the sedimentation produced in reservoirs has been analyzed until very recently by carrying out periodic bathymetric surveys of the contour of the reservoir basins to compare them with the original ones, with those existing at the end of the construction of the dams, thus analysing the historical trend of this clogging process. This practice, however, has been gradually reduced in recent years until it has almost disappeared, being limited to isolated interventions in a few reservoirs, those whose negative evolution has given rise in practice to an almost total silting up of their storage volume.

These results now lack the necessary spatial and temporal representativeness to make an adequate interpretation of the complex processes of river transport and sedimentation in each of the river physiographic units and to propose an adequate management of the exploitation of the reservoirs through which to permeate them in terms of the circulation of solid elements in suspension in the water. It is necessary to resume sediment monitoring activities in reservoirs, in line with the Guide drawn up by the US Bureau of Reclamation for the United States in 2021.

The dam safety regulations in force require that all dams have Operating Rules that include all the necessary provisions in relation to the safety and correct operation of the dam and the installations and reservoir they contain, under any circumstances in which they are found, including in documentary form, the tasks to be carried out by the team in charge of their operation to ensure compliance with these safety requirements over time.

Nothing is included in them, however, in relation to what operations would have to be done to discharge and discharge downstream the accumulated sediments in the reservoir, in order to avoid, or at least to try to reduce, physical environmental changes in the river channel downstream, as well as their negative effects on fish and other species.

And just as a periodic water balance of the reservoirs is usually included in the Operating Regulations to determine the volume of water stored inside them, it seems logical and necessary to carry out a balance of the content of solids entering and leaving the reservoir, which should begin to be included in these Standards, in order to determine the flows or volumes of water to be discharged, the time or times at which these actions should be carried out, as well as their duration, operating the most appropriate drainage elements in each case, in order to return to the river what is its own: the sediments that may have temporarily accumulated in the reservoir during periods of flooding.

In addition, the well-known concept of these processes called "turbidity flow" should be examined in much more detail in reservoirs, which is the flow of water with high concentrations of very small sediment transported as a result of erosion of the substratum in the catchment area and which, by placing one or more obstacles as retaining walls along its course, it is possible to block the flow of the turbidity current and retain much of the sediment it transports, which in some cases could extend the life of the dam by 20 to 50 years compared to the situation without these obstacles.

Recent studies show that sediment flow through reservoirs can be improved in certain cases. There are proven techniques for passing sediment through or around reservoirs to preserve reservoir capacity and reduce downstream impacts. A distinction is made between methods for routing sediment through or around the impoundment, and methods for removing accumulated sediment from the impoundment to restore capacity.

A fundamental issue is the proper management of the bottom spillways to allow sediment to pass through in flood situations or when releasing the generating flows, but it cannot be ignored that, especially in cases where the length of the reservoirs is very considerable and the slope of the bed is small, the settling effect of the solid matter exceeds the sediment flow through the old riverbed, the settling effect of the solid matter exceeds the sediment flow through the old river bed, and the dam is not always able to permeabilize itself even with proper management of its bottom outlets, especially for the larger solids. However, the presence of intermediate tributaries in the reservoir basin, closer to the dam, can facilitate this permeabilisation.

It is therefore necessary (as well as for safety reasons) to maintain the bottom outlets of the dams, to operate them periodically and to open them during flood episodes. And, on certain occasions, their adaptation, especially by providing sluice gates that do not pose any obstacle to the flow of water and sediments.

Aggregate supply methods are also being tested downstream of reservoirs so that the passage of floods or generating flows can feed sediment to the lower part of the basins and the coastline associated with the corresponding river basin district.

Downstream of dams, reduced coarse sediment supply results in channel incision and spalling of bridges and other infrastructure, and degradation of aquatic habitat quality, including loss of gravels needed for spawning by certain fish species such as salmon. Fine-grained sediment (silt and clay) is important for the structure of some river forms, such as vertically accreted floodplains and estuarine mudflats, but also has important functions distinct from coarse sediments, such as a source of turbidity, and its role in the transport of nutrients and pollutants adsorbed on clay particles.

River sediment inputs are anthropically conditioned not only by dams: changes in land use, occupation of flood zones, extraction of aggregates, bank protection...

Already in the lower part of the river basins and on the coast, unique and highly interesting areas (estuaries, deltas, marshes, marshlands and wetlands) are influenced by the transport of fluvial sediments.

Progress in adequate sediment management in river basin districts and their reservoirs is a necessity in order to move forward on the path of sustainable development and adaptation to climate change.

CREDITS

This technical document has been prepared by the **"Technical Committee on Water Planning and Management"** 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 related to the EU strategy to achieve its climate neutrality objective by 2050, which has materialized through the European Green Deal, presented by the European Commission in December 2019. The two sessions were: a workshop, held in November 2021, in which a group of experts from both business and public administration shared their different approaches to the relationship between dams and reservoirs and the European Green Deal; and a dissemination day entitled "Dams and Green Deal", held in April 2022, which covered topics such as the integration of energy systems (hydraulic energy storage, the new National Integrated Energy and Climate Plan 2021-2030 and the water footprint of energy production from different sources), adaptation to climate change (the decrease in water quality as a result of climate change, the role of reservoirs in flood and drought management, and guaranteeing the supply of water resources) and the biodiversity strategy for dams (the restoration of free-flowing rivers, ecological flows and sediment flow) and in which the work carried out by the Committee in this area at that time was presented, presenting the draft document produced up to that time.

The panel of experts at the conference was as follows.

Worshop November 2021:

Belén Benito Martínez	Director of Operations, Supply and Drainage of Canal de Isabel II
Antonio Burgueño Muñoz	Chairman of the SPANCOLD Technical Committee on Water Planning and Management. Quality, CSR and R&D Director at FCC Construcción
Enrique Cifres	Vice President ICOLD. PhD in Engineering from the Polytechnic University of Valencia.
Ignacio Escuder Bueno	PhD in Civil Engineering from the Polytechnic University of Valencia. Past-President of SPANCOLD
Ángel García Cantón	Associate Professor at the Polytechnic University of Madrid. Member of the SPANCOLD Technical Committee on Water Planning and Management.
Luis Garrote de Marcos	Professor at the Polytechnic University of Madrid. Department of Civil Engineering: Hydraulics, Energy and Environment.
Marta González del Tánago	Lecturer at the Polytechnic University of Madrid. Department of Systems and Natural Resources.
Francisco José Hijós Bitrián	Technical Director. Ebro Hydrographic Confederation.
César Lanza Suárez	TECNOVA
Fernando Magdaleno More	Area Coordinator. Directorate General for Water. Ministry for Ecological Transition.
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Conference "The European Green Deal and Dams" April 2022:

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This document is the result of the combined conclusions of both workshops and **aims** to address current water management challenges and to highlight the close relationship between dams and reservoirs and the European Green Deal and the achievement of climate neutrality in Europe by 2050.