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National Council of Ethics for Life Sciences

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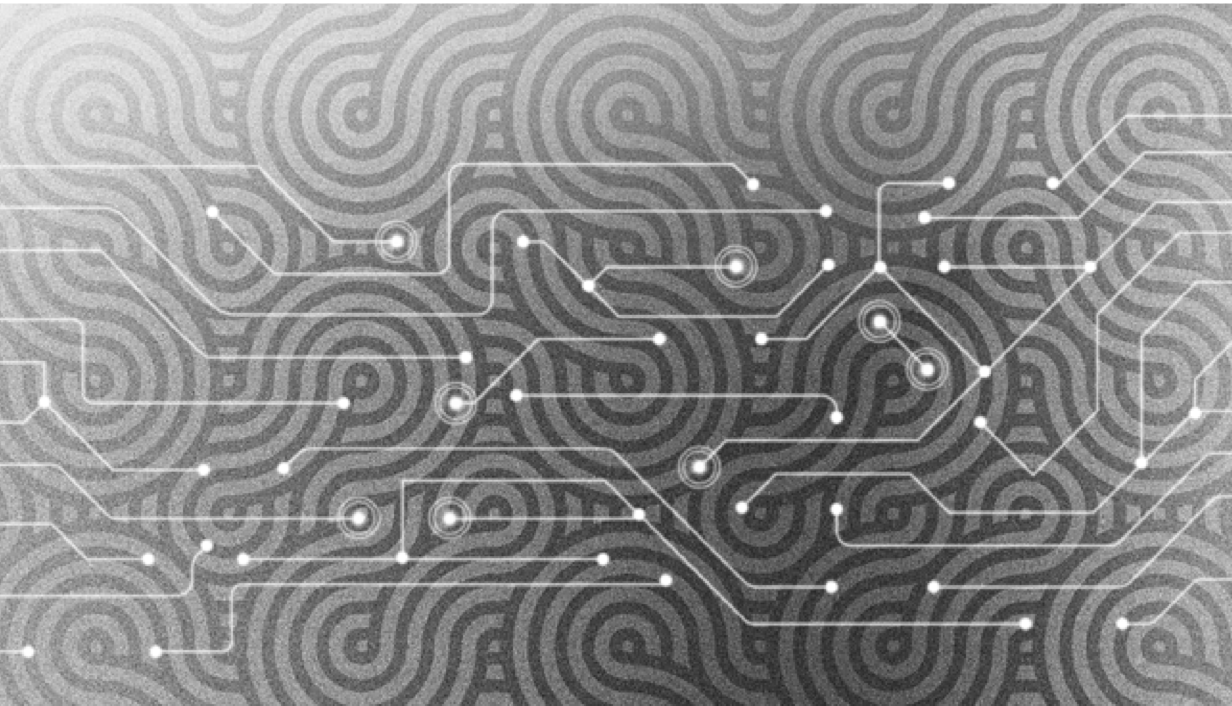

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TOWARDS AN ETHICS OF WATER GOVERNANCE AND WATER MANAGEMENT TECHNOLOGIES

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PREFACE

The mission of the National Council of Ethics for the Life Sciences (CNECV) is "to review the ethical issues raised by scientific progress in the fields of biology, medicine or health in general and the life sciences"[1], which gives the life sciences a broad remit that necessarily encompasses ethical issues relating to water. Ultimately, there is no life without water – the theme of this reflection the theme of our discussion "Towards an Ethics of Water Management and Use".

The council has addressed this topic on previous occasions. In June 2016, the CNECV published *Access to Water: Ethical Implications of a Fundamental Right*[2], as volume 1 of the collection Contemporary Issues in Bioethics. The importance of the just and equitable distribution of this limited resource was highlighted, emphasising the intrinsic moral dimension of the human relationship with the environment, a dimension that should extend beyond a restrictive and purely utilitarian perspective. This message remains as relevant today as ever.

In this broad field of human interaction with nature, the in-depth discussion undertaken by the council through its dedicated working group on 'One Health' merits particular mention. In November 2023 it organised its International Seminar on 'One Health, One Ethics'[3] and published the book *One Health: One Planet, One Health, One Ethics*[4]. In January 2024 it also published One Health, One Ethics[5], volume 2 of the collection *Contemporary Issues in Bioethics*. Very briefly, the common emphasis is on raising public awareness of the interdependence of all living beings and their habitats on a shared planet, advocating new forms of interaction between humans, non-humans and the environment so as to promote mutual benefit for global health. We also note the 2023 report *State of Application of New Technologies to Human Life* 2023 – *New Technologies Applied to Agriculture*, in which water is a cross-cutting theme across all the issues addressed.

In January of this year, 2026, the Council published *Towards an Ethics of Water Management and Use* (in Portuguese), as volume 3 of the collection Contemporary Issues in Bioethics, that operates as a broadly thematic reflection, providing a concise examination of the plurality of dimensions that must be considered when addressing water – a vital and scarce resource – and the duties incumbent upon us all in its management and use. The Council, in its 2025 Report on the State of the Application of New Technologies to Human Life, focused on the theme Technologies for Improved Access to, Recovery of, and Management of Water (in Portuguese)[6]. This report examines both existing and emerging water technologies that contribute to increasing the availability of water, expanding and facilitating access to it, and improving the efficiency of its management.

Towards an Ethics of Water Governance and Water Management Technologies, coherently brings together these two most recent works published in Portuguese. We would like to thank Anália Torres, Inês Godinho, and João Ramalho-Santos for their contributions to the portuguese version of *Towards an Ethics of Water Management and Use*.

1. Article 2, of Law No. 24/2009 of 29 May.

2. https://www.cnecv.pt/pt/publicacoes/monografias/acesso-a-agua, accessed: 26.09.2025.

3. https://www.cnecv.pt/pt/atividades/inscricoes-abertas-seminario-int, accessed: 26.09.2025.

4. https://www.cnecv.pt/pt/publicacoes/monografias/novo-lancamento-one-health-um-planeta-uma-saude-uma-etica, accessed: 26.09.2025.

5. https://www.cnecv.pt/pt/publicacoes/monografias/uma-so-saude-uma-etica, accessed: 26.09.2025.

6. https://www.cnecv.pt/en/deliberations/report-on-the-state-of-new-tech/report-to-the-portuguese-parliament-on-the-state-of-application

1. WATER AND LIFE

Water is an integral part of Earth: 70% of the Earth's surface is covered by water, while 97% of the planet's hydrosphere consists of salt water. Of the 3% of freshwater existing on the planet, 71% appears in solid form as ice in the polar ice caps; the remaining 29% of the world's potable water is distributed among groundwater aquifers (18%), rivers and lakes (7%), and atmospheric moisture (4%).

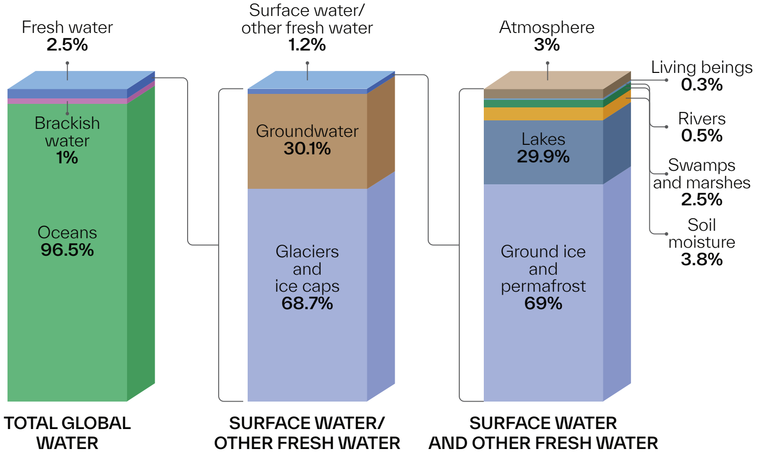

Figure 1 – Distribution of Earth's water[7]

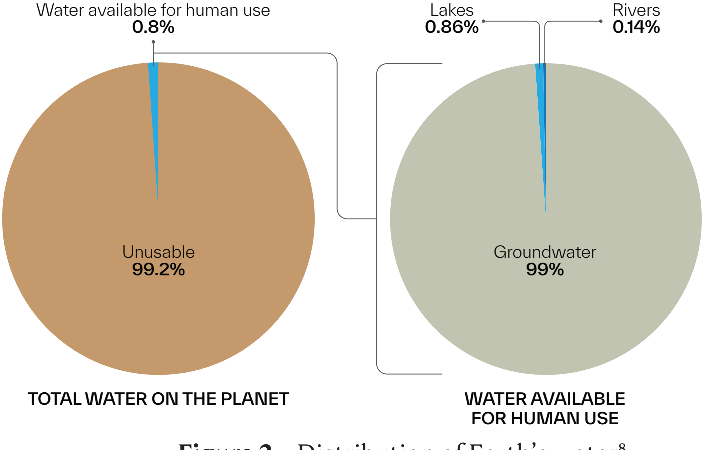

Figure 2 – Distribution of Earth's water[8]

7. Figure prepared using the template adopted in the chapter *World Fresh Water Resources* in Igor Shiklomanov's Water in Crisis: A Guide to the World's Fresh Water Resources, (1993) New York: Oxford University Press. Graphic design by Pedro Daniel.

8. Figure prepared using a template adopted in: https://www.pacificwater.org/pages.cfm/water-services/water-demand-management/what-water-demand-management/. Graphic design by Pedro Daniel.

Water is an integral component of all living beings: without water there is no life as we know it. It is estimated that living beings are composed on average of about 70% water, with this proportion ranging from approximately 95% in jellyfish, 60–70% in humans, and about 5% in the seeds of plants such as sunflowers. In humans, water accounts for roughly half to two-thirds of average body weight. Water is essential for most biochemical reactions, facilitates the transport of nutrients and waste, regulates body temperature and supports cellular functions. Its absence impairs the efficiency of solar energy capture by photosynthetic organisms, thereby reducing the production of chemical energy upon which virtually all biomass production on the planet depends. In fact, all living beings depend on the biomass generated by primary production, which itself consists largely of water.

In soils, water plays a predominant role in the decomposition and disintegration of rocks and in the mobilisation of nutrients, acting as an important medium for the transport of sediments, minerals and organic particles. It is therefore a decisive geomorphological agent. This function operates through erosion, transport and deposition of materials, continuously shaping landscapes and creating distinct landforms.

Water, however, is not only relevant in the tangible sense – in the biological domain, as in the origin of life, and in the geological domain as a geomorphological element – but has, throughout human civilisation and across all peoples, acquired profound spiritual significance in cultural and religious expressions[8]. In religious traditions of all kinds, water has long played a significant role, frequently symbolising the purification of the soul and the healing of the body, and marking transitions between different stages of life. This is evident, for example, in the Christian rite of baptism, where water is poured over the person as a sign of entry into a new stage of life as a child of God. Agricultural traditions also associate water with the fertility of the land and abundant harvests. In this way it transcends a purely natural and material function, acquiring a symbolic and spiritual dimension as a link between nature, the sacred and human existence in the world[9].

Water is also indispensable for a wide range of human productive activities. Most of the products we manufacture require water in their production process, sometimes in astonishing and, above all, disproportionate quantities, given the intrinsic value we attribute to water – that is, its intrinsic worth as something essential to all forms of life, irrespective of its uses, in contrast to the utilitarian value of production, whose worth derives

9. Oestigaard, T. (2021). Water and religion. Oxford Research *Encyclopedia of Anthropology*, 1-23. https://doi.org/10.1093/acrefore/9780190854584.013.477

from its purpose or application. For instance, a cotton T-shirt has a water footprint of around 2,500 litres, and the production of 1 kg of chocolate consumes approximately 17,000 litres of water[10], a resource that is becoming increasingly scarce.

Today, 663 million people worldwide lack access to safe drinking water, while 2.4 billion people do not have water for adequate sanitation[11]. With the global population projected to reach around 9.6 billion by 2050, it is estimated that approximately 40% of people will be affected by water scarcity[12].

In Europe, water scarcity – driven primarily by increasingly frequent and prolonged droughts – generates annual costs estimated at between €2 and €9 billion, excluding unquantified damage to ecosystems and their services[13]. Climate projections for the coming decades indicate an increase in both the frequency and severity of droughts, with their geographical extent potentially expanding, as suggested by the 2021/22 results, which recorded below-average precipitation in northern Portugal. Water scarcity already affects around 20% of European territory and 30% of Europe's population. Southern Europe is the region most affected, with around 30% of its population living in areas of permanent water stress and up to 70% experiencing seasonal water stress during the summer.

2. KEY AREAS OF WATER USE

We have highlighted the fundamental value of water – that is, its irreplaceable capacity to sustain life – from a range of perspectives, thereby reinforcing recognition of its importance, throughout human history and through all geographic regions, as a value that also extends across different contexts of life and fields of activity.

We should now specify a few areas that are of particular interest to us, in which the fundamental value of water is particularly evident.

10. www.waterfootprint.org, accessed: 05.01.2026.

11. Paquin, M., Cosgrove, C., & (WWAP), U. N. W. W. A. P. (2016). *The United Nations World Water Development Report 2016: Water and jobs*. UNESCO for UN-Water.

12. United Nations Department of Economic and Social Affairs, Population Division (2012), cited in Muller et al. 2015, p. 585.

13. Whytock, G. (2020). *Water resources across Europe: confronting water stress: an updated assessment* (No. 12). Copenhagen: European Environment Agency.

2.1. Health

Water, as an essential component of the human body[14], is crucial to life and a determining factor in the promotion and maintenance of health, both individual and collective. In all societies, access to water of adequate quality and in sufficient quantity to meet basic needs promotes the physical well-being of living beings and of people in particular. Conversely, scarcity or poor water quality creates conditions conducive to disease, infection and dehydration, seriously compromising quality of life.

With regard to human health, we may first highlight a number of essential functions of water: as a universal solvent, enabling chemical reactions in intracellular and extracellular environments; as a medium for the transport of nutrients and waste, delivering nutrients to cells and conveying waste to the excretory organs; and as a thermal regulator, maintaining thermal balance through perspiration and skin evaporation, while also playing a key role in the protection of sensitive organs such as the eyes, brain, spinal cord and joints[15]. These functions make water essential to the body's homoeostatic balance, and therefore a fundamental element of life. Without water, human life is not possible, and its absence can lead to death within a matter of days.

We highlight the role of water in various body systems, namely: in the circulatory system, water – as the main component of blood and the basis of plasma – is essential for maintaining blood volume and fluidity, for the transport of red blood cells, nutrients, oxygen and mineral salts, and for the removal of waste. Changes in hydration directly affect blood pressure and the efficiency of oxygen transport[16]. In the renal system, water plays a fundamental role in enabling the kidneys to filter blood, eliminate toxins and maintain fluid balance within the body. Adequate hydration helps to prevent kidney stone formation, reduces the risk of urinary tract infections and supports blood pressure stability. In the digestive system, water facilitates the breakdown and absorption of nutrients, supporting their transport to cells and the development of a balanced intestinal microbiome, which benefits digestion and immune function. It also softens stools and thereby helps to prevent constipation. In the lungs, water maintains hydration of the respiratory mucosa, ensuring that secretions such as mucus remain fluid and can be cleared efficiently and without obstruction. The skin, the human body's largest organ depends on hydration to preserve its elasticity and protective and healing functions, as well as immune defence;

14. https://www.sns24.gov.pt/pt/tema/prevencao-e-cuidados-de-saude/hidratacao, accessed: 03.04.2025.

15. Despa, F. (2006). Biological water: Its vital role in macromolecular structure and function. *Annals of the New York Academy of Sciences, 1066*(1), 1-11.

16. Molnar, C., & Gair, J. (2022). 21.2. Components of the Blood. *NSCC Academic Biology 1050*.

dehydration accelerates skin ageing, causing it to become dry and fragile. Muscle tissue also relies heavily on water to maintain cellular volume, which supports effective contraction, physical performance and the prevention of fatigue and injury. In the central nervous system, water provides structural and functional support for neurons, facilitating neurotransmitter transport and contributing to the regulation of brain temperature. We would also note that insufficient hydration impairs essential cognitive processes such as attention, memory, mental clarity and mood regulation, and may lead to increased headaches, cognitive fatigue and episodes of hallucination, particularly in very young and older age groups[17,18]. In view of the broad conception of "health" adopted by the World Health Organisation (WHO), understood as a state of complete physical, psychological and social well-being and not merely the absence of disease[19], water has an even more decisive impact on individual and collective well-being. Thus, in the field of public health, it is well established that water quality is directly linked to health outcomes across the world, and that poor water quality can turn water into a vehicle for disease transmission. For instance, it can be noted that globally more than 80% of wastewater generated by human activities is discharged into rivers or oceans without any treatment, resulting in numerous diseases affecting human beings (over fifty known), as well as indirect effects on other species and the consequent impact on human health[20].

It is therefore clear that the distribution of water for human consumption must be subject to robust monitoring and regulation. However, this concern should not be limited solely to human consumption because, as we have been emphasising, the profound interdependence between all forms of life, with water as the common denominator cannot be ignored.

It is precisely within this framework of interdependence between humans, animals and ecosystems that a contemporary and integrated understanding of the relationship between water and health arises. The fluidity and adaptability of water now underpin an innovative conceptual understanding of its relationship with health. In fact, the present prevailing view is that of

17. Rani, J., Sharma, U. K., & Sharma, D. N. (2018). Role of adequate water intake in purification of body. *Environment Conservation Journal, 19*(1&2), 183-186.

18. Robinson, J. R. (1957). Functions of water in the body. *Proceedings of the Nutrition Society, 16*(2), 108-112.

19. The Constitution of the World Health Organisation was adopted by the International Health Conference held in New York from 19 June to 22 July 1946 and signed on 22 July 1946 by representatives of 61 states. It entered into force on 7 April 1948. It was approved for ratification under Portuguese law by Decree-Law No. 36406 of 10 July 1947.

20. Lin, L., Yang, H., & Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: a review. *Frontiers in environmental science, 10*, 880246.

the 'One Health' approach. According to the World Health Organisation[21], 'One Health' is an integrated and unifying framework that aims to sustainably balance and optimise the health of people, animals and ecosystems. The 'One Health' approach recognises the interdependence of human, animal, plant and environmental health, encompassing ecosystems[22]. This relatively recent concept first emerged in the context of public health and the impact of epidemics at the beginning of this century and has evolved towards a modern understanding of global health. In this setting, it seeks to promote supranational efforts, coordinated by institutions under the auspices of the United Nations, with a view to achieving equitable access to healthcare for all people worldwide[23].

A compelling example of the importance of 'One Health' is the growing presence of contaminants and micropollutants in the aquatic environment. These arise from various factors, notably the increasing and indiscriminate use of medicines such as antibiotics for human or animal use, and the excessive production of microplastics, which also poses risks to human health and the sustainability of ecosystems[24]. Hence the need for a new approach to wastewater treatment in urban areas, which should be a core objective of modern, smart and sustainable cities.

Adopting the broadest possible perspective on health, as embodied in the 'One Health' approach, requires particular attention to water, its accessibility and quality. This requirement in turn entails planning, management and governance of water quality, which may be described as an ethics of water quality[25]. In fact, water provides the clearest conceptual expression of 'One Health', interconnecting different forms of life and, through its fluidity, integrating them in an indivisible and endurable relationship.

2.2. Environment and Biodiversity

Water plays a crucial role in maintaining ecosystems and in the survival of living beings. The water–environment relationship is highly complex, involving diverse interactions that affect both natural ecosystems and human societies.

21. https://www.who.int/health-topics/one-health#tab=tab_1, acedido a 12.12.2025.

22. "One Health": One planet, one health, one ethics. National Council of Ethics for the Life Sciences. Ramalho--Santos, João; Horta, Sandra (coordination) Lisbon, 2023.

23. Nunes, R. (2021). *Healthcare as a universal human right: sustainability in global health* (p. 224). Taylor & Francis.

24. Figueiredo, S (2024). Emerging contaminants: Challenges in monitoring and treatment. Water Academy: Building the future. Jorge Cardoso Gonçalves (coordination). Portuguese Association of Water Resources, Lisbon.

25. MacAfee, E. (2023). Critically assembling water quality ethics beyond thresholds, hierarchies and best practices. *Environment and Planning E: Nature and Space, 6*(4), 2595-2613. https://doi.org/10.1177/25148486221146686

Freshwater watercourses (rivers, lakes and wetlands) host numerous animal and plant species, each playing a specific role in their ecosystem. Aquatic plants, for example, produce oxygen and provide food for aquatic animals, while wetlands act as natural filters for pollutants and play a key role in essential processes such as flood regulation. Water use and the infrastructures for water abstraction also have multiple impacts on habitats and ecosystems, both surface and subterranean. Changes in water volumes and flow rates, as well as in water quality, contribute to a reduction or profound alteration of biological diversity and living biomass, both within the water body and its surroundings, including riparian woodlands, with effects on native species. River barriers break up the links between animal populations, obstruct fish migration and alter local climatic conditions, among other consequences. In Portugal, ecological flow regimes have been established ranging between 5% to 10% of the average annual flow, which makes it possible to mitigate the impacts of changes in the hydrological regime without eliminating them.

In the meantime, water quality is increasingly under threat due to a variety of factors. A first factor to highlight is pollution, which affects not only the environment but also poses significant risks to human health. Pollution originates from a variety of sources, including industrial waste, agricultural runoff and domestic wastewater. As an example, excess nutrients from agricultural fertilisers can promote the proliferation of certain algal species, leading to eutrophication and consequently to a reduction in oxygen levels in the water, thereby limiting its capacity to support life.

The most significant factor affecting water availability and quality today is undoubtedly climate change. Changes in precipitation patterns, increased evaporation rates and glacier melt may alter the supply of freshwater. Some regions may experience severe droughts, leading to water scarcity, while others may face floodings due to more intense rainfall, placing existing infrastructure under strain and causing erosion and habitat destruction[26]. Conversely, increased surface runoff during heavy rainfall can lead to higher pollutant levels, while rising temperatures may exacerbate the growth of harmful algae.

26. Kennedy, J., Trewin, B., Betts, R., Thorne, P., Foster, P., Siegmund, P., ... & Naran, B. (2024). State of the Climate 2024. World Meteorological organization. Update for COP29.

The effects of climate change are increasingly predictable at a global level, although complex variability means they cannot always be effectively parameterised locally. Besides the average increase in atmospheric temperature, related examples include increased polar ice melt, changes in sea level and coastal erosion in certain regions, and the rise in desertification and extreme events such as floods, storms and inundations. This kind of environmental change has led to the displacement of species, with animals and plants typically associated with tropical environments now appearing in more temperate climates. This widely publicised example concerns mosquitoes that can act as vectors for various diseases (malaria, dengue, yellow fever and Zika), or pests such as the citrus psyllid, which can carry a bacterium responsible for a serious disease affecting orange and tangerine orchards. These species are increasingly being detected in non-tropical areas, including Portugal.

Changes in ecosystems due to climate change may be clearly evident when assessed from a global perspective, although specific predictions for a particular location do not carry the same degree of certainty[27]. Although many of these changes alter hydrological cycles, the effects of climate change on water availability – whether for maintaining or increasing human use or for ensuring ecosystem stability – remain difficult to predict. In any case, an increase in atmospheric temperature in different locations may not directly result in proportional changes in water availability, partly due to the role of water itself in regulating and influencing climate - a topic that is attracting increasing research attention. Changes in water resources may also, as already mentioned, affect their quality[28].

Different disciplines can contribute to the study and monitoring of hydrological dynamics and water resource management in ecosystems, including information and communication technologies (ICT), Earth observation from space, remote sensing via sensors, and big data analysis. Additionally, from a more local perspective, particular emphasis is placed on the contribution of citizen science. Supported by low-cost technologies, it involves the regular observation and recording by members of the public of various changes related to the hydrological characteristics of a region. As in other

27. Douville, H., Allan, R. P., Arias, P. A., Betts, R. A., Caretta, M. A., Cherchi, A., ... & Renwick, J. (2022). Water remains a blind spot in climate change policies. PLoS Water, 1(12), e0000058. https://doi.org/10.1371/journal.pwat.0000058

28. Wutich, A., Thomson, P., Jepson, W., Stoler, J., Cooperman, A. D., Doss-Gollin, J., ... & Westerhoff, P. (2023). MAD water: Integrating modular, adaptive, and decentralized approaches for water security in the climate change era. *Wiley Interdisciplinary Reviews: Water, 10*(6), e1680. https://doi.org/10.1002/wat2.1680

areas, the use of artificial intelligence (AI) has been proposed to help address the challenges and enhance predictability in this context[29].

From a broader perspective, the extent of ecosystem degradation, its contribution to conflicts and the resulting decline in prosperity are attracting increasing academic attention. It has been suggested that ecosystem restoration contributes to improving water availability and quality, while also promoting adaptation to climate change and the mitigation of its impacts. Nature-based solutions[30] fall within this scope.

A recent topic of discussion has been whether excessive groundwater extraction, and the consequent redistribution that it entails, could even alter the Earth's axis of rotation, with the potential to further contribute to climate change. From another perspective, appropriate strategies can be developed for mobilising different water sources (retention, extraction, decontamination and selective use) with a focus on sustainability and renewability, considering the interdependence of local and global ecosystems. Although very difficult to guarantee, circularity in water use remains a relevant concept, aiming to balance consumption and recovery – for example through aquifer replenishment via rainwater. These issues depend strongly on local conditions.

The Sustainable Development Goals (SDGs) of the United Nations have proven very useful, not only in identifying and defining the major societal problems affecting humanity, but also in establishing benchmarks and targets for each of them. This constitutes an important reference framework, although SDG targets remain far from being achieved globally and, in some cases, tangible progress appears to be inversely related to the level of media attention the SDGs have received.

29. Chaturvedi, A., Pandey, B., Yadav, A. K., & Saroj, S. (2021). An overview of the potential impacts of global climate change on water resources. *Water conservation in the era of global climate change*, 99-120. https://doi.org/10.1016/B978-0-12-820200-5.00012-9

30. UNESCO. (2020). UN-Water, 2020: *United Nations World Water Development Report*.

The SDG most directly linked to water is SDG 6 – clean water and sanitation – which specifically identifies water as an essential resource.

Access to water and its quality are relevant to a greater or lesser degree, directly or indirectly, to the achievement of other SDGs such as 2, 3, 7, 9, 10, 11, 12, 14 or 16. In other words, water is essential across multiple dimensions to the quality and sustainability of our survival as a species. Within this section, particular relevance is attached to SDG 13, which focuses on adopting urgent measures to combat climate change and its impacts. However, progress in this area, where it exists, is likely to be quite limited.

UNESCO (2024)
https://unesdoc.unesco.org/ark:/48223/pf0000388950_por

It is important to note that it is virtually impossible to conceive of ecosystems that have not been subject to some degree of human intervention. However, a given location may have different types of water sources suitable for distinct purposes. These potential water sources also include the desalination of seawater or brackish water, a strategy implemented or explored in areas where natural freshwater sources are limited. Such strategies invariable require treatment processes that may entail significant energy costs and generate waste. The subsequent use of this waste should be carefully assessed considering its potential applicability in different contexts.

The widespread implementation of these strategies will therefore depend on specific circumstances in which a favourable cost–benefit analysis can be demonstrated. Their use may also vary according to different applications, not limited to human consumption, particularly to reduce the use of potable water for tasks that do not actually require it. On the other hand, this type of use may be perceived differently across communities. It is therefore necessary to promote research, assess the potential relevance of fiscal incentives or legislative changes and, above all, invest in monitoring, education and 'water literacy'[31]. Raising public awareness of the importance of water conservation can lead to more responsible use and greater support for environmental policies. Addressing these issues in a collaborative and proactive way will lead to healthier ecosystems, improve public health, and enhance resilience when faced with environmental challenges.

31. Van Vliet, M. T., Jones, E. R., Flörke, M., Franssen, W. H., Hanasaki, N., Wada, Y., & Yearsley, J. R. (2021). Global water scarcity including surface water quality and expansions of clean water technologies. Environmental Research Letters, 16(2), 024020 https://iopscience.iop.org/article/10.1088/1748-9326/abbfc3

2.3. Agriculture, Industry and Energy

At present, the demand for water is also increasing across a range of human activities, particularly in agriculture, industry and energy production.

As far as agriculture is concerned, population growth and changing dietary habits – including increased protein consumption in many parts of the world – are driving up demand for food, the production of which, in turn, requires greater quantities of water. The world currently consumes approximately 28,887 km^3 of water per year for food production[32], representing around 70% of total freshwater use in human activities.

Different foods require varying amounts of water for their production, with their water content ranging from 95% to 5%. On average, 1 kg of beef requires 16,000 litres of water to be produced, while 1 kg of green coffee requires 17,400 litres, 1 kg of wheat and rice requires 1,334 litres and 2,291 litres respectively, and 1 kg of apples and grapes requires 697 litres and 655 litres respectively[33]. Moreover, the estimated global use of water for crop production is 5,400 km^3 per year, and this usage is increasing rapidly.

The water footprint per unit of production weight, or Crop Water Footprint (CWF), represents a useful indicator of water-use efficiency. Notwithstanding the volumes referred to above, at a global level water-use efficiency has been increasing, while the water footprint of crops has been decreasing. Between 1960 and 2005, the CWF for wheat decreased from around 6,000 m^3 per tonne to approximately 2,000 m^3 per tonne, while for maize the drop was from about 3,500 m^3 to 1,600 m^3 [34]. This reduction, which extends to all major crops, is associated with the adoption—often in combination—of various technologies, including agricultural practices such as maintaining soil cover, direct seeding and no-tillage methods, modern irrigation techniques, and the use of plant varieties requiring less water. For instance, water-use efficiency in irrigation varies according to the technology employed: less than 50% for gravity irrigation and around 90% for micro-sprinkler or drip irrigation.

In Portugal, 73% of abstracted water is used in agriculture (data from the DGAR, or Direção-Geral de Agricultura e Desenvolvimento Rural [Directorate-General for Agriculture and Rural Development]). In 2024, 4,324 hm^3 of

32. https://www.watertofood.org, accessed: 05.01.2026.

33. Hoekstra, A. Y., Chapagain, A., Martinez-Aldaya, M., & Mekonnen, M. (2009). Water footprint manual: State of the art 2009.

34. Tamea, S., Tuninetti, M., & Rolle, M. (2020). Green and blue water use for agricultural production: Volumes and efficiencies. In *Water Resources and Economic Processes* (pp. 78-97). Routledge.

water were abstracted (APA [Portuguese Environment Agency] and DGADR), with agricultural consumption amounting to 3,156 hm^3 in that same year[35].

Water also plays an essential role in industry, as a key resource for various production processes. The scope of its relevance reaches far beyond simple consumption, encompassing critical functions that directly impact efficiency, product quality, environmental sustainability and business competitiveness.

In industry, water is used mainly in various production processes, in machine cooling, in the cleaning of industrial facilities, and also in material transport and energy production. In many industries, water plays a direct role in chemical reactions or in the processes required to manufacture products.

Currently, industry in Portugal consumes around 47 hm^3 per year (equivalent to 47 million cubic metres of water per year), which accounts for around 20% of the country's total water consumption. approximately 20% of the country's total water consumption. The paper, food, metallurgical, chemical and textile sectors are the largest consumers[36]. Nonetheless, consumption may also vary in these sectors according to the technology and materials used: in the textile sector, consumption can range from 20 to 350 litres per kilogram of product while cotton production may require between 10,000 and 15,000 L/kg[37].

The intensive use of water in industry poses significant environmental challenges, particularly in relation to excessive abstraction and the discharge of effluents into the environment. Accordingly, industries have invested in water-efficiency technologies and in practices of water reuse and recycling, as well as in systems for monitoring consumption and water quality[38].

35. This also explains the concern regarding the need for efficient use of this resource in agricultural activity. The use of wastewater is very low in percentage terms, corresponding in 2023 to 1.2% (ERSAR [Portuguese Regulatory Authority for Water and Waste Services]). As an additional note, the annual volume of wastewater in the Lisbon Metropolitan Area, approximately 200 hm^3 per year, would be sufficient to irrigate around 50,000 hectares of crops.

The agricultural area in Portugal is about 3.7 million hectares (INE [Portuguese National Institute of Statistics] 2019). About 15% of this area is irrigated land, equating to 555,000 hectares, of which 357,000 hectares constitute public irrigation areas (2024 – DGADR). Half of these 357,000 hectares are used for irrigated temporary crops and the remainder for permanent crops (2024). The irrigated area has grown by around 98,000 hectares in the last decade, with a further increase of approximately 75,000 hectares predicted for the next decade (DGADR).

The expansion of irrigation is directly linked to irrigated crop productivity and the economic return on agricultural activity: the average standard production value of irrigated agriculture in mainland Portugal is 6.8 €/ha, whereas that of rain-fed agriculture is 0.8 €/ha. The area of irrigated permanent crops has increased by 4.6% (118,000 ha), while that of irrigated temporary crops has decreased by 7% (18,000 ha).

36. Water that Unites - National water management strategy. 2025. https://www.portugal.gov.pt/download-ficheiros/ficheiro.aspx?v=%3d%3dBQAAAB%2bLCAAAAAAABAAzNDExMwEAUSHgrgUAAAA%3d

37. Study of water use in the textile industry within the SUDOE area (covering Portugal, Spain, Andorra and south-western France). 2025. https://interreg-sudoe.eu/wp-content/uploads/2025/05/E.1.1.4_PT_Annex_v2.pdf

38. Water use in Portugal. Observing, understanding and engaging with key stakeholders. 2020. Calouste Gulbenkian Foundation. https://gulbenkian.pt/wp-content/uploads/2020/06/Uso-da-%C3%A1gua-em-Portugal_Estudo-Gulbenkian.pdf

The national strategy 'Água que Une' (Water that Unites) points to a paradigm shift in industrial water management, promoting three key pillars of action:

- **Water efficiency:** Modernisation of industrial processes to optimise water use, reduce losses both in supply networks and internal circuits, and rehabilitate infrastructure. Rational use implies making use of treated wastewater (TWW), a measure that is particularly relevant for industries in areas of water stress, aligning the sector with circular economy principles.
- **Resilience:** Industrial resilience depends on increasing water storage and diversifying water sources (fresh, saline and reused), enabling industry to respond more effectively to droughts, climate fluctuations and variations in production demand. Considerable investments are planned in dams, interconnections and reversible systems, as well as technological modernisation to ensure uninterrupted supply.
- **Smart systems and digitalisation:** The commitment to technological innovation (digitalisation, real-time monitoring and artificial intelligence) enables industry to measure and adjust consumption according to specific needs, promote good practices and anticipate risks related to the quality and availability of water.

Water that Unites - National water management strategy. 2025.
https://www.portugal.gov.pt/download-ficheiros/ficheiro.aspx?v=%3d%3dBQAAAB%2bLCAAAAAAABAAzNDExMwEAUSHgrgUAAAA%3d

The balance between efficient water use and water preservation calls for innovation, investment in technology and commitment to environmentally sustainable practices.

These uses of water in agriculture and industry are called consumptive uses[39]. Water is also used for non-consumptive purposes, such as energy production, as well as activities including navigation, fishing and recreation.

Water and energy are currently recognised interdependent resources (the 'water–energy nexus'), and efficient management of both is seen as crucial for the flexibility and security of each sector. This integrative model has gained prominence in recent years, and is reflected in national and international policies such as the United Nations Water Action Agenda, to which Portugal has adhered through the National Energy Agency (ADENE) and the European Energy Network (EnR)[40,41].

39. Consumptive – water that is abstracted from a water body, used and subsequently returned to the natural environment, often indirectly, with altered quality and sometimes in reduced quantity.

40. Briga-Sá, A. (2025). Water-energy nexus: challenges and solutions. https://www.revistasustentavel.pt/transicao-energetica/nexus-agua-energia/, accessed: 03.04.2025.

41. https://www.adene.pt/hidrica-2/, accessed: 03.04.2025.

In Portugal, a significant proportion of electricity originates from hydroelectric power stations, whose production depends on water availability and its management. Hydropower, besides being renewable, provides regulation of the energy system and helps reduce greenhouse gas emissions. However, climate change and prolonged droughts jeopardise the continuity and sustainability of this energy production model, reinforcing the need to develop strategies to diversify and improve water-use efficiency across the entire energy system[42].

Energy, in turn, is essential for the abstraction, treatment and distribution of potable water, as well as for wastewater treatment. In this context, a reduction of more than 30% in water consumption in residential buildings and even higher values in tourist operating (as demonstrated by the AQUA+ index, developed by the National Energy Agency – ADENE - in partnership with national and international entities) would directly translate into reduced energy requirements, including for water pumping, heating, treatment and distribution. This efficiency would translate not only into environmental benefits but also economic ones, by reducing energy bills and overall resource consumption.

Water, as a strategic resource in energy production, is not only a vector for renewable energy generation but also an opportunity for a sustainable future. It will only be possible to bring about a transition towards improved energy systems if environmental guidelines, technologies and behaviours promote efficiency and the integrated management of water and energy. In Portugal, it is imperative to align domestic policies with European targets and international commitments on climate and energy, clearly indicating the need for a direction which values innovation, technological development, and leadership in the water–energy nexus is necessary.

42. Helerea, E., Calin, M. D., & Musuroi, C. (2023). Water energy nexus and energy transition — A review. Energies, 16(4), 1879.

3. MANAGEMENT, GOVERNANCE AND SUSTAINABILITY

We are currently experiencing a global water crisis, characterised by its strong multidimensional nature, which makes it extraordinarily complex. This crisis involves a wide variety of serious problems, including the scarcity of potable water (since water cannot be destroyed, its manner of use may hinder or prevent its reuse), sanitation deficits, pollution and the depletion of water resources, all of which affect public health, food production and the economy. These problems have social, ecological, cultural and economic dimensions.

With regard to water scarcity, it is estimated that it will worsen considerably in some regions as competition for water increases between the main consuming sectors: agriculture, industry, energy, and urban use[43]. Conflicts may take various forms, including competition between geographical locations for water use or between current and future uses. Policymakers are responsible for promoting the efficient and sustainable use of water resources, as well as designing and implementing sustainable management plans and investing in new methods for obtaining potable water, specifically through technological innovation.

In this context, complex questions arise in quick succession. How can we ensure, in an equitable manner, that everyone has access to an adequate supply of drinking water? How should access to water be managed? For instance, might local populations contribute to water management? What role can scientific development and technological innovation play in achieving this goal? What is the scope and purpose of water management plans? In this domain we would also need to consider questions regarding the best methods of water abstraction, storage and distribution, and their respective costs.

The following figure is intended to illustrate, in a simple and clear schematic form, the complexity of the dynamic interrelationships involved in integrated water resources management.

43. https://www.researchgate.net/publication/23731520_Water_resource_as_a_factor_of_production_-_water_use_and_economic_growth.

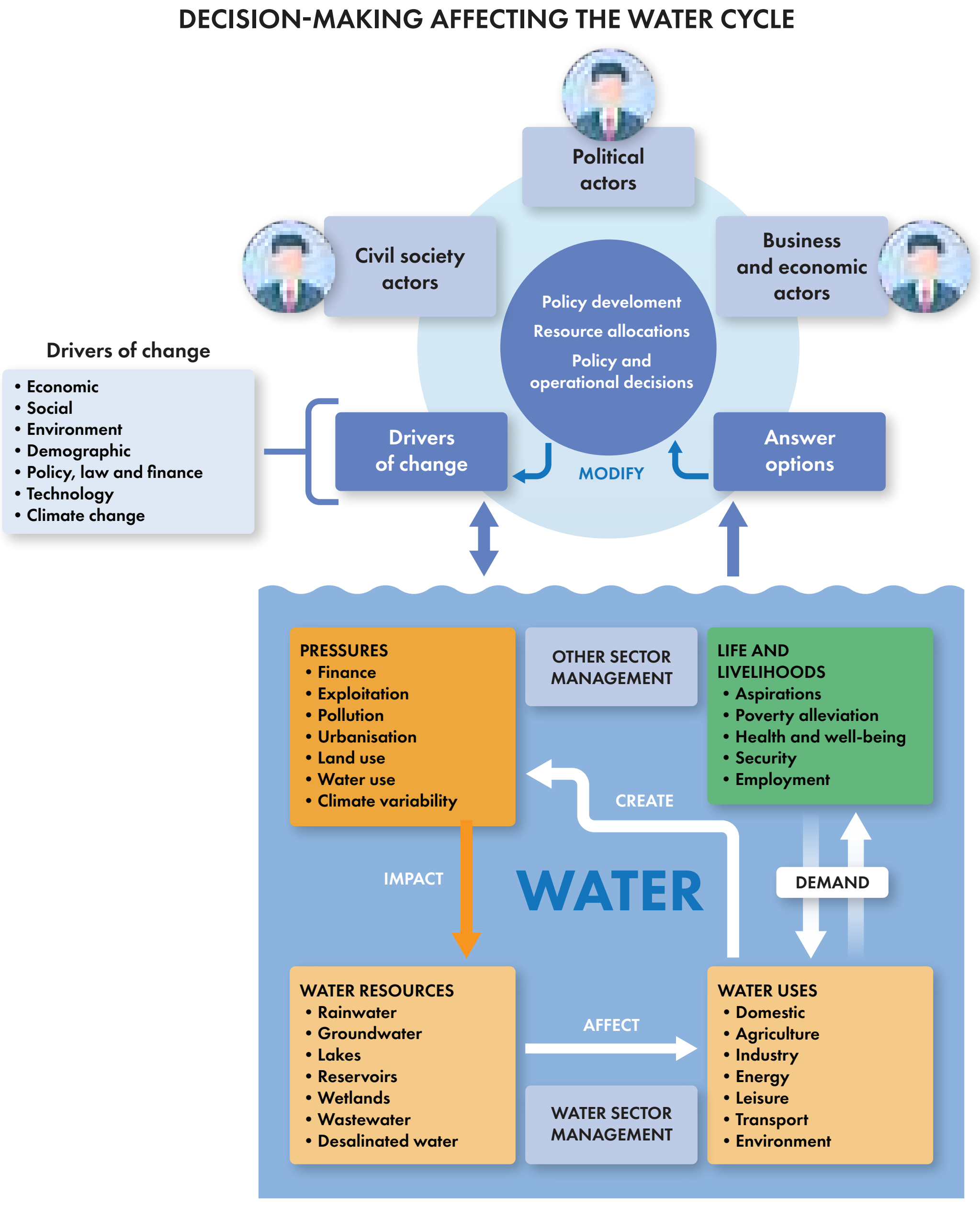

Figure 3 – Decision-making affecting the Water Cycle[44]

44. Figure prepared following a template adopted in international documents in this field, as exemplified by the report Water in a changing world, produced within the scope of the 2009 edition of The United Nations World Water Development Report 3. Graphic design by Pedro Daniel.

At the same time, we must also consider the implications of climate change for the quality and quantity of freshwater. Also, how can individuals and communities be compensated for damages and losses related to water supply and access without generating additional animosities? Another set of questions would relate to access to water for non-human living beings like animals and plants. How can humankind consider the water needs of other living beings? And those of future generations?

These questions are inherently ethical, as they concern a natural resource essential to the survival and well-being of living beings that is currently under threat. However, the ethical dimension of water-related issues has not been given the attention it deserves in decision-making on water policy and management[45]. It will be necessary to move beyond a strictly utilitarian and predominantly economic approach to water management in order to adopt "an integrated and holistic approach that views people and the environment as interconnected parts of a greater whole"[46].

In turn, water resource management – which encompasses all uses of water, both within and beyond its courses and basins, including ecosystem requirements – requires policies that improve its allocation to fulfil societal needs without compromising its availability for future generations or for the environment. This implies the implementation of sustainable practices, including the protection of natural watercourses, regulation to control pollution, the promotion of water conservation methods, constant monitoring of implemented measures and the assessment of the impact of measures in place[47,48].

Local populations should be involved in the design and implementation of water management, as many communities around the world have their own water management systems that are effective and environmentally friendly. Water resource management should encompass all uses of water, both within and beyond watercourses and basins, and consider ecosystem requirements, since changes in water volumes, flows and quality contribute to profound changes in biodiversity. Only ecologically informed and ethically responsible water management can preserve resources for future generations of all forms of life. To sum up, sustainable water management has become a global issue, requiring public policies, technological innovation and changes in consump-

45. Schmidt, Jeremy J. (2010). Water ethics and water management. In *Water ethics. Foundational readings for students and professionals*, edited Peter G. Brown and Jeremy J. Schmidt, 3–15. Washington: Island Press.

46. Al-Weshah, R. A., Saidan, M. N., & Al-Omari, A. S. (2016). Environmental ethics as a tool for sustainable water resource management. *Journal-American Water Works Association*, 108(3), E175-E181.

47. Nguyen, M. D., Thomas, M., Surapaneni, A., Moon, E. M., & Milne, N. A. (2022). Beneficial reuse of water treatment sludge in the context of circular economy. Environmental Technology & Innovation, 28, 102651. https://doi.org/10.1016/j.eti.2022.102651

48. Sauvé, S., Lamontagne, S., Dupras, J., & Stahel, W. (2021). Circular economy of water: Tackling quantity, quality and footprint of water. *Environmental development, 39*, 100651. https://doi.org/10.1016/j.envdev.2021.100651

tion habits. Hence the need for broad global consensus around the most important ethical principles that can contribute to sound water management[49].

National, international and global water governance thus represents a major challenge, while at the same time constituting a vital and ethical imperative that cannot be disregarded, under penalty of failing to meet responsibilities.

With a view to drawing up a plan for water management and its sustainable governance, we consider that certain aspects require particular attention and are set out below:

- Water is a vital asset, an essential resource for the generation and preservation of life and a social and economic resource indispensable to development.
- Access to water is unequal, which can contribute to exacerbating chronic inequities. In many nations, marginalised populations face difficulties in accessing potable water, affecting public health and underlining inequalities of class, gender and ethnicity. In urban contexts, there are significant differences in access to treated water between more affluent neighbourhoods and peripheral areas; in rural contexts, the lack of infrastructure often places a heavy burden on women and children, who are forced to travel long distances to fetch water.
- Different power relations influence the level of access to and the extent of water distribution. Governments and privately owned companies may monopolise water sources, limiting access for the most vulnerable populations, and conflicts may arise both internally (e.g. disputes between agricultural and urban sectors, or instances of neighbourhood violence over access to water) and externally (geopolitical disputes).
- Human culture shapes perceptions of the value of water. In some indigenous cultures, water is viewed as a living entity with its own rights, whereas within a capitalist logic it tends to be treated as an economic resource. Water consumption also reflects cultural patterns, with industrialised Western societies tending to consume more than traditional communities.
- In the current scenario, climate change is one of the most important factors to consider in water management, given its impact on availability and its role in amplifying droughts, floods and extreme events.

To further sustainable and equitable water governance we should emphasise the role that international organisations and social movements have played in defending “water justice”, promoting water as a human right. The growth

49. Kelbessa, W. (2022). Water ethics. In *African philosophy in an intercultural perspective* (pp. 161-180). Stuttgart: JB Metzler.

of environmental awareness has also led to changes in how water is used (bearing in mind the needs of future users of that water[50]) and managed, with incentives to reduce waste and promote sustainable use.

In this context, the contribution of international water law is also fundamental, as it develops principles and norms that pave the way for transboundary water cooperation and may further help resolve disputes and contribute to regional stability. Indeed, the geographical reality can be a significant geopolitical issue, since water management and governance concerns not only the existence of water resources but their relative distribution between different countries and within the same country. In this context, Brazil presents a paradigmatic case: it possesses the largest reserve of freshwater on the planet while at the same time having areas in many states experiencing severe drought. It is also known that water scarcity associated with global warming has an impact on migratory movements, as illustrated by the Sahel in North Africa.

In fact, many issues relating to water use have a regional dimension (between different regions of the same country) or a transboundary component (between countries). This may result, for instance, in differences in tariffs and policies within the same nation, as is the case in Portugal. Even more significant is the possibility that water retention or abstraction in one location may have effects in another, whether downstream or where aquifers are shared, as well as through inter-basin water transfers. It is therefore important to ensure that water retention upstream does not cause irreparable changes downstream, and that any such changes are socially accepted and properly framed by local communities. This is particularly relevant when different regions or countries are involved, and it is important to discuss what types of effects a society is willing to accept owing to changes in water resource policies, and how such effects might be distributed, and by whom[51,52].

recently been signed to mitigate disputes in this area. In the domestic sphere, it should be emphasised that there is considerable concern regarding water management, and the "National Strategy – Water that Unites" has recently been introduced, based on three major pillars: efficiency, resilience, and intelligence, with the aim of ensuring efficient water management throughout the national territory[53]. This national tradition of a bond with water, from the seas to river basins, can and should serve as an example for the world, with

50. Groenfeldt, D. (2019). *Water ethics: a values approach to solving the water crisis*. Routledge.

51. Akpan, V. E., Omole, D. O., & Bassey, D. E. (2020). Assessing the public perceptions of treated wastewater reuse: opportunities and implications for urban communities in developing countries. Heliyon, 6(10). https://doi.org/10.1016/j.heliyon.2020.e05246

52. Verhoest, P., Gaume, B., Bauwens, J., Te Braak, P., & Huysmans, M. (2022). Public acceptance of recycled water: A survey of social attitudes toward the consumption of crops grown with treated wastewater. *Sustainable Production and Consumption, 34*, 467-475.

53.https://www.portugal.gov.pt/download-ficheiros/ficheiro.aspx?v=%3d%3dBQAAB%2bLCAAAAAAABAAzNDExMwEAUSHgrgUAAAA%3d

Portugal presenting itself as a 'Hydro Nation'. The term 'Hydro Nation' means a country that manages its water resources in a sustainable manner and applies its knowledge to maximise social, economic and environmental benefits, making a decisive contribution to public health and to the 'One Health'[54] approach.

'Water diplomacy' focuses on preventing, mitigating and resolving disputes over transboundary water resources, while also developing joint water governance agreements, applying foreign policy instruments at different levels and through multiple channels. It may involve actors other than government entities, including academia, relevant authorities or civil society organisations, which encompass indigenous and traditional communities, often with ties that transcend political and geographic borders. It is of the utmost importance that the decision-making process be inclusive and participatory, with water management as far as possible co-created and involving ongoing communication between the various entities concerned to minimise (or resolve) potential disputes, and it should be underpinned by robust data to allow better governance.

54. https://ohbp.org/our-work/one-health-water/, accessed: 12.12.2025.

4. WATER TECHNOLOGIES: IMPACTS ON ACCESS TO, RECOVERY AND MANAGEMENT OF WATER

Water technologies merit special mention, as they can make a significant contribution to increasing water availability across all the sectors mentioned, including domestic consumption, and to promoting access to water as both a vital global resource and a human right. In fact, innovation in water resources is almost as old as the process that led to the settlement of the first human communities, and even then aimed at facilitating access to water and its management, given the importance of this vital resource.

Today, as we have pointed out, the critical situation regarding the availability and accessibility of freshwater is unprecedented. Meanwhile, the technological means available to change the current situation are also more advanced than ever. From here on, the challenges posed by the development and implementation of water technologies are also unique.

Currently, there are several technologies being implemented (in some cases at an early stage) which, given the current challenges, are also undergoing a process of development and improvement that requires multidisciplinary expertise to move from concept to practice. These solutions are relevant both in countries with cutting-edge technology and in those where a shortage of fresh and drinking water has a significant impact on people's health and economic activities.

The range of water technologies we are presenting is not comprehensive, but merely illustrative. It is intended to provide a broad and diverse overview of what is already possible – in terms of improving access to water, promoting its recovery and optimising its management – as well as to highlight the real, positive impacts of the expansion of these technologies.

We structured it around three key priorities – accessibility, recovery and management – and framed its potential impacts within the ethical obligations applicable to a global asset such as water, a human right that must be universally respected.

4.1. Technologies that promote water recovery

The first ethical requirement for freshwater protection and preservation is to avoid wasting it and invest in its recovery, both of which can be supported by technological solutions. Detection and smart monitoring of leaks are now a highly effective way of fighting water wastage. Simultaneously, the proper treatment of water, which has already been used for various purposes, enables it to be reused. Both procedures are the most feasible options due to their accessibility, whilst also offering the potential for a significant increase in the available volume of drinking water.

Detection and Smart Monitoring of leaks

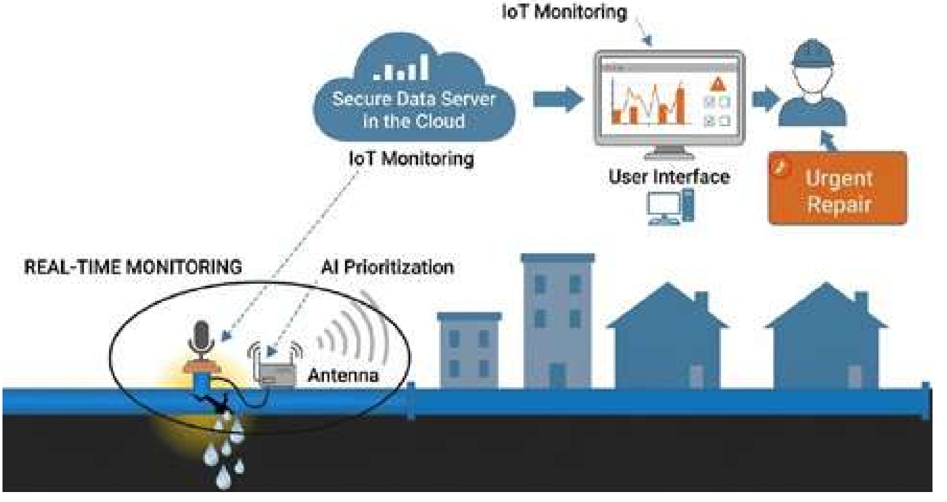

Figure 4 – Explanatory infographic on Smart Detection and Monitoring of leaks. Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

One of the most common yet overlooked causes of water waste is the breakage of infrastructure which, whilst may seem insignificant at first sight, is in fact responsible for the wastage of a huge volume of treated water[54], estimated by the US Environmental Protection Agency (EPA) to account for 30% of the water supply. EPA illustrates the impact of domestic water wastage by pointing out that a typical American household can lose around 680 litres of water every week due to leaks, which amounts to more than 34,000 litres a year – roughly the amount needed to wash 300 laundry loads. In Europe, the EU's Directorate-General for the Environment estimates that, on average, 23% of treated water is wasted during distribution[55].

Disruptions to infrastructure are, therefore, key factors in: massive water loss (the *Infrastructure Report Card* reports out that, in the US alone, water utilities lose around 7.6 trillion dollars' worth of treated water each year); growing pressure on the infrastructure due to the deterioration of the piping system and the prospect of increased future repairs; higher costs for users' water bills.

Against this backdrop, investing in smart leak detection systems is both envi-

54. Farah & Shahrour (2024) Water Leak Detection: A Comprehensive Review of Methods, Challenges, and Future Directions. Water 16(20), 2975; https://doi.org/10.3390/w16202975

55. https://environment.ec.europa.eu/topics/water/water-wise-eu/poorly-managed-water_en# accessed on 19 February 2026

ronmentally and economically advisable[56,57,58]. We are referring, for instance, to the use of sensors, acoustic monitoring and real-time data analysis, which can detect and locate small leaks even before they become noticeable. These solutions are in line with the efficiency pillar outlined in the "Água que nos Une" [Water that Unites Us] (2025) Portuguese strategy, which aims to reduce network losses (81 hm^3/year) and produce 116 hm^3 of reclaimed water by 2040 through wastewater treatment plants[59].

Among the most effective technologies, one that stands out is that of the smart sensors (e.g. acoustic sensors, satellite images), that is, devices incorporated into IoT (Internet of Things) systems that provide real-time data on water consumption, monitor water flow and pressure, and spot irregular consumption patterns, thereby enabling them to detect leaks - including in underground networks - and thus minimise both the loss of drinking water and repair/maintenance costs.

Another relevant technology in this area is that of AI-supervised systems. Machine learning analyses water consumption patterns to predict and identify leaks before they become critical. Predictive models can identify flawed components in the infrastructure before they break down, thus making routine maintenance more effective and reducing potential water losses. Also, wireless monitoring, that is, remote systems that transmit real-time alerts to property managers or owners, are useful in preventing water wastage, as they enable immediate action.

The benefits of these detection and monitoring systems for water distribution infrastructure leaks are obvious and highly significant from an environmental perspective, particularly in helping to maintain sustainable supply chains in both developed and developing regions. From an economic perspective, they prevent wastage and ensure the availability of greater volumes of water; they reduce operational costs for local authorities and improve the efficiency of water distribution; they also reduce water bills for businesses and households.

Nonetheless, it is important that their implementation does not overlook issues relating in particular to the privacy of consumers and their autonomy regarding the data collection entailed by these water-saving technologies. Actually, its use establishes a pattern of consumer habits and behaviour at both domestic and industrial levels, where this data may be used for

56. https://energy.sustainability-directory.com/term/water-reuse-ethics/ accessed on 3 February 2026.

57. https://prism.sustainability-directory.com/scenario/data-privacy-and-smart-water-infrastructure/ accessed on 3 February 2026.

58. Reynaert, E., Hess, A., & Morgenroth, E. (2021). Making Waves: Why water reuse frameworks need to co-evolve with emerging small-scale technologies. Water Research X, 11, 100094.

59. A Água que Une: Estratégia nacional para a gestão da água (2025). Ministry of the Environment and Energy / Ministry of Agriculture and Fisheries. Available at https://www.portugal.gov.pt/download-ficheiros/ficheiro.aspx?v=%3d%3dBQAAAB%2bLCAAAAAAABAAzNDExMwEAUSHgrgUAAAA%3d, accessed on 18 March 2026

a variety of purposes, including automated decision-making and must therefore be subject to informed consent. These issues can be safeguarded in the contract between the consumer and the service provider, which must also comply with robust data protection regimes to ensure client confidentiality. Whenever possible, anonymisation must be ensured, along with regular independent audits to enable supervisory oversight, thereby reducing the need for drastic decisions, safeguarding users' autonomy and integrity, and providing them with mechanisms for challenging and rectifying decisions.

Advanced Wastewater Treatment and Reuse

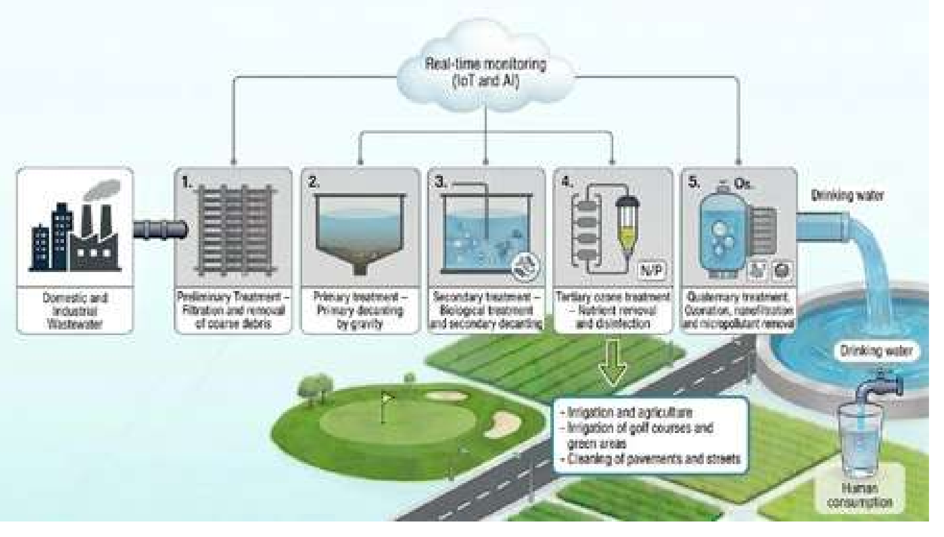

Figure 5 – Explanatory infographic on Advanced Wastewater Treatment and Reuse. Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

The proper treatment of water that has already been used for various purposes is one of the most promising water conservation methods, representing a potentially very important source for promoting water availability and reuse, particularly in regions where droughts and water shortages are common.

Around 80% of wastewater (greywater) is discharged worldwide without proper treatment, which has a first strong negative impact on the environment, polluting rivers, soil and coastal environments, and exposing the surrounding areas – including flora, fauna and ecosystems – to harmful substances.

Currently, wastewater treatment requires a four-stage process; a fifth stage (quaternary treatment) will be added in 2027 within the European Union, following the implementation of Directive (EU) 2024/3019:

Preliminary treatment – the wastewater generated by domestic use or industry is discharged into Wastewater Treatment Plants (WWTPs), where larger particles are filtered out and separated.

Primary treatment – the water undergoes a primary decanting, during which suspended solids are removed by gravity.

Secondary treatment – at this stage, a biological process takes place, whereby bacteria break down the organic matter present, followed by a secondary decanting phase, allowing the sludge produced by the bacteria to settle.

Tertiary treatment – removal of bacteria, suspended solids, excess nitrogen and/or phosphorus, and specific toxic compounds. Once this treatment stage is complete, the water can be used for agriculture, watering green areas, washing pavements and streets, among other possible applications.

Quaternary treatment – to produce drinking water, micropollutants such as microplastics and organic micropollutants, which account for a significant proportion of pollution, are removed.

Whilst wastewater treatment is by no means a new concept, recent technological advances have made it possible to treat wastewater with greater efficiency and, above all, to a level of purity unmatched by any other method, rendering it safe for human consumption. Among these technologies, there are some particularly promising ones, such as: advanced oxidation processes that use oxidising agents[60] – i.e. ozonation and hydrogen peroxide – to break down pollutants, including those resistant to conventional treatments; adsorption and biosorption, through which activated carbon and certain biological materials capture contaminants and improve water quality; biological[61] and anaerobic treatments (bioremediation) in which microorganisms break down organic waste and reduce sludge, producing water suitable for non-potable uses; electrocoagulation, which uses electric currents to destabilise and aggregate suspended particles and dissolved pollutants; phytoremediation, which makes use of plant beds whose roots are capable of absorbing and metabolising various organic pollutants, thereby removing them from effluents, particularly industrial effluents from the textile and paint industries.

60. Gavrilaș, Gerőcs, Chereji & Munteanu (2026) Trends in Advanced Wastewater Treatment Technologies: From Membrane Bioreactors to Advanced Oxidation Processes, Water 18(3), 350; https://doi.org/10.3390/w18030350

61. Mishra, Tiwari, Kanchan & Kesheri (2025) Advances in Microbial Bioremediation for Effective Wastewater Treatment, Water 17(22), 3196; https://doi.org/10.3390/w17223196

Nanotechnology also offers new solutions for water purification and filtration[62]. This is based on the manipulation of materials at the molecular or atomic level. One of the available resources is nanofiltration membranes, which are more selective than standard filters and more resistant to clogging, capable of removing a wider range of contaminants. Simultaneously, these allow a greater volume of water to pass through them, thereby increasing the water recovery rate and reducing the build-up of deposits. Nanofiltration membranes effectively remove pathogenic agents, heavy metals, microplastics and even per- and polyfluoroalkyl substances (PFAS), using less energy than the traditional filtration. For example, graphene oxide, which is a type of carbon-based nanomaterial, proved to be effective at removing heavy metals and other pollutants from water sources. A biomimetic membrane uses aquaporins (proteins that act as water channels in the membranes of living cells) to purify water, whilst blocking impurities. From the treatment of industrial wastewater to the purification of drinking water at home, and even on missions to space, this technology helps to save energy and reduce water wastage, providing safe, high-quality drinking water.

Industries that adopt these wastewater treatment technologies benefit from reliable alternatives for using non-potable water in operations such as cooling, cleaning or irrigation, and cities that use recycled water reduce the pressure on conventional water sources and freshwater ecosystems, ensuring the availability of greater volumes of water for consumption and strengthening resilience in contexts of scarcity.

Essentially, the reuse of wastewater allows for the creation of a closed-loop system[63] in which water is not regarded as a disposable commodity, but as a renewable resource, in line with the recognition of water as a global common good. From a strictly ethical perspective, it is important to address the scientific and social challenges associated with the use of wastewater. From a scientific and technical standpoint, it is important to guarantee accuracy and objectivity in the assessment of the safety of differentiated wastewater consumption, always ensuring high quality standards and continuous monitoring in the management of chemical and microbiological risks. Simultaneously and inseparably, at a social level, it is essential to maintain clear, unambiguous and transparent communication with the public to earn the trust of consumers on a sound basis, without whom the positive impacts of these technologies will fail (due to the rejection of recycled water). This public awareness campaign is particularly demanding for communities living near treatment

62. Tripathy, Mishra, Pandey, Thakur, Rout & Shahid (2024) Advances in Nanoparticles and Nanocomposites for Water and Wastewater Treatment: A Review, Water 16(11), 1481;

63. Sharma, Nagabhooshanam, Dasi, Guntaj, Srinivas, Kaur & Rajaram (2024) Design and implementation of closed-loop water reuse systems in urban and industrial settings for maximizing resource recovery and minimizing waste, Desalination and Water Treatment, V. 320, 100850, ISSN 1944-3986, https://doi.org/10.1016/j.dwt.2024.100850.

plants, as the fair distribution of benefits must take them into account, alongside large-scale industry and agriculture, as is sometimes the case. Considering this, it would be advisable to have a clearly defined regulatory framework in place to ensure legal certainty for the parties involved, a multidisciplinary ethical assessment, periodic review in case of new findings, and mechanisms for swift rectification in the event of failures.

4.2. Technologies that improve the accessibility to water

Regarding technologies that facilitate universal access to water, we highlight the improvement of Rainwater and Airwater Harvesting Systems and Seawater Desalination, which, taken together, have the potential to significantly increase the volume of drinking water available.

Rainwater and Airwater Harvesting Systems

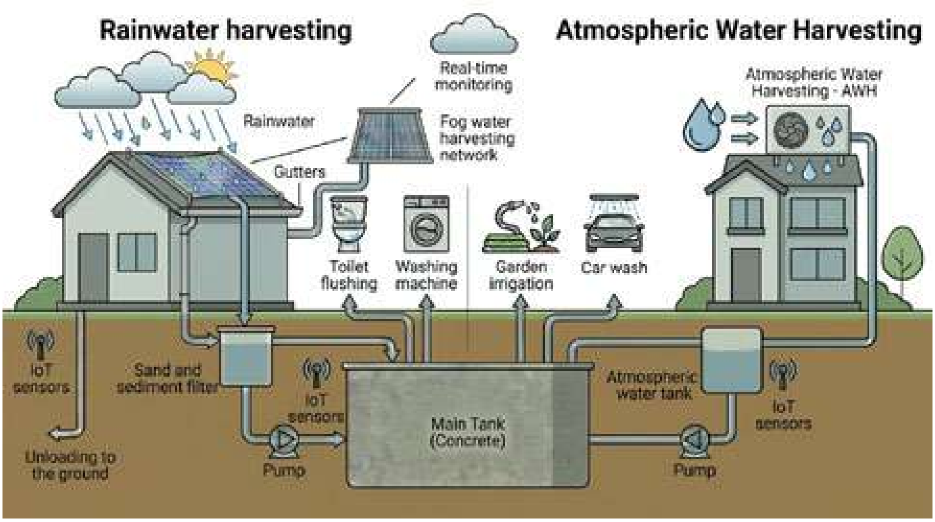

Figure 6 – Explanatory infographic on rainwater and airwater harvesting systems. Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

The direct collection and storage of rainwater is an ancestral method of improving water availability and access, which is environmentally sustainable (through water conservation and energy savings) and can also help reduce the cost of this vital asset.

Traditionally, rainwater harvesting systems may involve the construction of tanks of variable sizes, depending on their intended use – domestic or commercial – particularly in rural areas; and may also be installed on rooftops in urban areas. Meanwhile, the use of innovations such as filtration and purification technologies enables stored water to be treated to meet drinking water standards, allowing for more diverse uses and more efficient collection. The integration of smart pumps and monitoring tools also enhances the efficiency of these systems, giving users greater control over storage levels and usage. Simultaneously, it may reduce the impact of rainwater runoff[64].

It is also possible to collect water directly from the atmosphere[65]. Atmospheric Water Harvesting (AWH), using capillary condensation through cooling or adsorption with desiccants, is a technology that captures and condenses water vapour directly from the air, even in arid regions, and can produce between 25 and over 5,000 litres of water per day. Advances in nature-inspired materials, such as amphiphilic nanopores, and solar-powered capacitors are rendering the technology more efficient and accessible. This technology provides a decentralised way of ensuring a safe supply of drinking water in drought-prone areas without placing an excessive strain on existing water supplies.

Both water harvesting systems – whether designed to capture rainwater or atmospheric water – reduce the pressure of demand on river basins and municipal infrastructure, providing a sustainable supplement to conventional water supplies, and can serve as affordable and practical solutions that can be adapted to various regions around the world.

Notwithstanding these clearly positive aspects associated with water harvesting systems, it is worth noting the potentially high initial investment costs, particularly when technological innovations are involved. These will be unaffordable for some families and small or medium-sized businesses, which could exclude them from accessing a greater volume of water that, in the medium to long term, is expected to be available at a lower price. From an ethical standpoint, preventive and/or mitigating measures should be taken to address potentially discriminatory solutions.

64. Wartalska, Grzegorzek, Bełcik, Wdowikowski, Kolanek, Niemierka, Jadwiszczak & Kaźmierczak (2024) The Potential of RainWater Harvesting Systems in Europe – Current State of Art and Future Perspectives. Water Resour Manage 38, 4657–4683. https://doi.org/10.1007/s11269-024-03882-0

65. Kandeal, Joseph, Elsharkawy, Elkadeem, Hamada, Khalil, Moustapha & Sharshir (2022) Research progress on recent technologies of water harvesting from atmospheric air: A detailed review, Sustainable Energy Technologies and Assessments, V. 52, Part A, 2022,102000, https://doi.org/10.1016/j.seta.2022.102000

Seawater Desalination

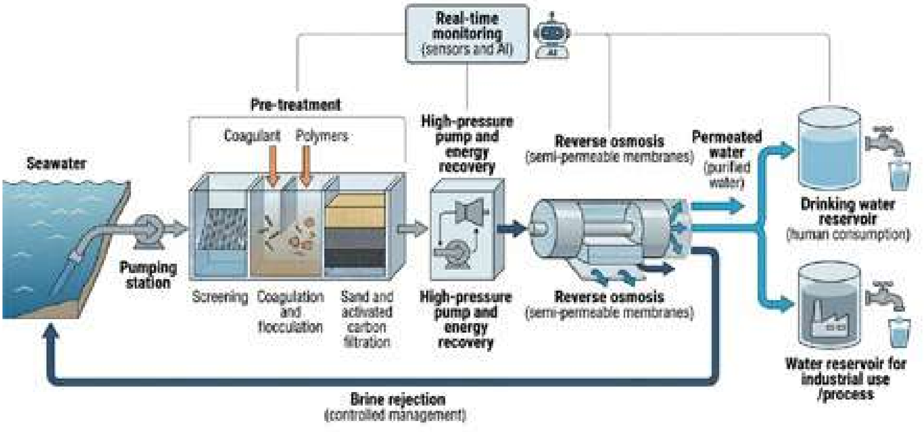

Figure 7 – Explanatory infographic on Seawater Desalination.
Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

Seawater desalination is a technological process for removing salt and other impurities to produce drinking water for human consumption or for other purposes.

The most common desalination techniques are reverse osmosis and distillation. Reverse osmosis involves applying pressure to reverse the natural process of osmosis[66]. By doing so, water is forced through a semi-permeable membrane that retains salt and other contaminants. Distillation is the process of evaporating water, followed by the collection of the resulting vapour, which condenses back into a liquid state, free of salt and impurities. This second method is more expensive than the first, due to the energy required.

Furthermore, and in general terms, the desalination process is energy-intensive[67], and may also pose a risk to marine life if the brine discharged back into the sea is not sufficiently dispersed. Its implementation, which in fact benefits from constantly evolving technology, must therefore first and foremost address negative environmental and energy impacts. For instance, energy consumption could be offset by using renewable energy sources.

Seawater desalination provides a reliable source of high-quality drinking water that would also relieve pressure on inland or groundwater supplies and is a

66. Osmosis is a physical-chemical process of passive transport in which water (the solvent) passes through a semi-permeable membrane, moving from a hypotonic (less concentrated) solution to a hypertonic (more concentrated) solution. In reverse osmosis, the process is the opposite: the water passes through the membrane in the opposite direction, that is, from a solution with a higher salt concentration to one with a lower concentration.

67. Almasoudi & Jamoussi (2024) Desalination technologies and their environmental impacts: A review - Sustainable Chemistry One World, V. 1, 100002, doi.org/10.1016/j.scowo.2024.100002

technique of critical importance in regions where fresh water is scarce, such as in many arid countries with access to the sea, or in island nations.

As described above, these technologies reinforce the resilience pillar of the Portuguese strategy "Água que Une" [Water that Unites] (2025), focusing on new water sources (desalination, interconnections) to mitigate shortages in vulnerable regions such as the Alentejo and the Algarve[68].

4.3. Technologies that optimise water management

The shortage of drinking water, which is now becoming increasingly severe across a growing number of regions, is also largely due to the poor management of this precious natural resource. This is why better water management is key to ensuring its availability and accessibility, and why, at present, an increasing number of technological solutions are being developed to help achieve this objective.

We mention a few that stand out for targeting human activities that consume large amounts of water – agricultural production and the use of household appliances – or as they represent more advanced and promising technologies in terms of optimising water management.

68. A Água que Une: Estratégia nacional para a gestão da água (2025). Ministry of the Environment and Energy / Ministry of Agriculture and Fisheries. Available at https://www.portugal.gov.pt/download-ficheiros/ficheiro.aspx?v=%3d%3dBQAAAB%2bLCAAAAAAABAAzNDExMwEAUSHgrgUAAAA%3d, accessed on 18 March 2026

Some methods and technologies that promote water efficiency in agriculture

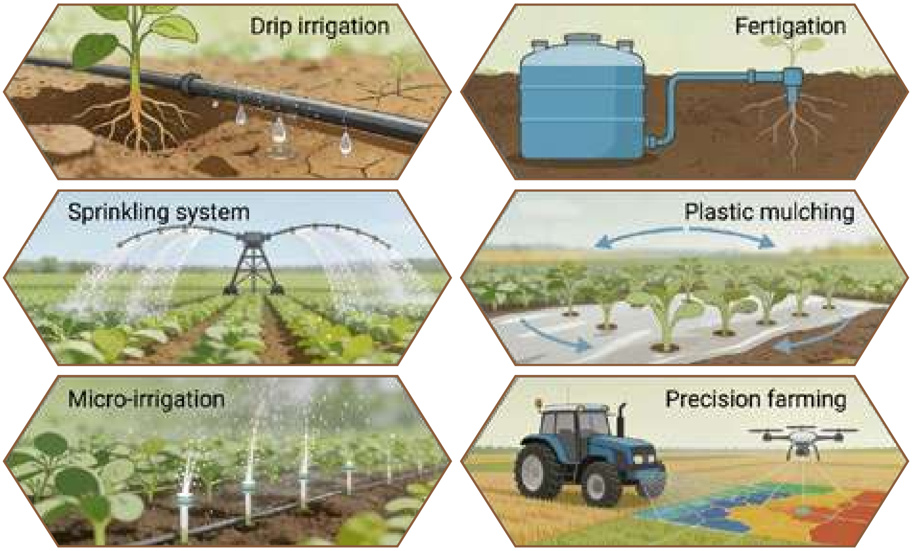

Figure 8 – Explanatory infographic on some of the methods and technologies that promote water efficiency in agriculture.
Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

It is common knowledge that farming is responsible for high water consumption. For instance, irrigation accounts for around 80% of available fresh water, producing 40% of the world's food and fibre on only 17% of agricultural land. And yet, production will have to continue to rise to feed a growing global population, concentrated in expanding urban areas and with increasingly demanding dietary habits. New management approaches are therefore needed, backed by innovative technologies, to help improve water use efficiency in agriculture.

In this context, there are three areas of intervention that require specification and implementation. The first is to increase agricultural productivity per unit of water used, which can be achieved by improving the management of available water. An example would be the implementation of controlled deficit irrigation through precise control of the timing and quantity of water applied, using real-time monitoring, and relying on climate, soil and/or plant data to predict and plan irrigation requirements. The deficit scenarios comprise managing drought throughout the growing season (e.g. regulated deficit irrigation, common in perennial crops), managing drought during part of the growing season (e.g. supplementary irrigation in arid areas) and temporarily leaving land fallow. A more efficient use of water can also be achieved by using crop varieties that have been selected or bred for drought tolerance, whose growing cycles are adapted to the local climate, and which have a lower rate of evapotranspiration, thereby reducing the crop's water consumption without compromising its productivity.

A second approach is to optimise the spatial distribution of production, particularly in geographical terms, by relocating crops to regions where the climate and soil are best suited to maximising their yield, thereby enabling a more efficient use of irrigation water. Another form of optimisation consists of land reallocation, whereby marginal land (low-yield or saline) is wholly or partially removed from irrigation perimeters, and the available water is used to irrigate the most productive areas, thereby contributing to higher productivity per unit of water consumed.

A third driver is the use of advanced irrigation technologies, such as micro-irrigation (e.g. drip irrigation), which applies water slowly and locally, achieving application efficiencies of over 95%; the self-propelled systems (central pivot, linear), which allow for uniform application over large areas, or variations on the above methods, such as low-energy, precision irrigation, which applies water directly to the soil, thereby reducing losses; precision irrigation, which adjusts water usage within a single field, using control technologies and sensors to respond to soil variability, topography and plant requirements, thereby generating significant savings. In such circumstances, support technologies – such as remote sensing, weather station networks, crop models and decision-support tools – are essential for real-time, data-driven irrigation management.

To be truly effective, the optimisation of water use for irrigation must take place at the level of the entire agricultural system (farm, district, river basin), in other words, it requires a systemic approach that integrates cultural, management, engineering and institutional dimensions. A synergistic integration of irrigation, fertilisation and pest control strategies is required, taking spatial and temporal variability into consideration. Any changes to a component of the water system must consider the overall impact, as losses upstream can represent resources downstream.

The application of such technologies, which serve social purposes – by increasing agricultural productivity and food security – and environmental objectives – by using less water, reducing non-point source pollution and protecting ecosystems – is not, however, free from ethical concerns. These implications fall mainly into two categories. The first relates to fairness among farmers. The access to Agriculture 4.0[69] is uneven and may exacer-

69. Agriculture 4.0 is a model of farm production that systematically integrates advanced digital technologies — such as sensors, the Internet of Things, geographic information systems, artificial intelligence and big data analytics — to optimise the control, monitoring and management of agricultural systems at every stage. Its main feature is the ongoing collection and integration of data on soil, crops and climate, enabling more precise and automated technical decisions, aimed at increasing productivity, improving resource efficiency (including water use) and enhancing the environmental and economic sustainability of farms.

bate the vulnerability of small-scale farmers, family farms, regions with complex soil and climate conditions, and those with limited financial capacity to invest in technology, raising issues of equity and solidarity. It is essential to be aware of this reality to establish mitigating measures that prevent the disappearance of these agricultural production models, which contribute to the common good and account for around one-third of global food production[70], through a range of externalities. Another cause for concern is technological dependence and, above all, the concentration of data. It requires transparency, accountability and democratic governance of digital systems used for irrigation, with water being recognised as a common asset and not just as a factor of production[71,72,73].

70. FAO - https://www.fao.org/newsroom/detail/Small-family-farmers-produce-a-third-of-the-world-s-food/en

71. Savari, M., Damaneh, H. E., & Damaneh, H. E. (2025). Ethical evolution in the management of water resources: The role of developed norms on decreasing groundwater usage in Iranian agricultural practices. Agricultural Water Management, 318, 109714.

72. Challenges and solutions for irrigation and water resource management in Portugal. https://ajap.pt/desafios-e-solucoes-para-a-irrigacao-e-gestao-de-recursos-hidricos-em-portugal/, accessed on 23 February 2026.

73. How Does Agriculture Impact Water Ethics? https://climate.sustainability-directory.com/question/how-does-agriculture-impact-water-ethics/, accessed on 23 February 2026.

Some artificial intelligence methods and technologies to promote water efficiency

– Household appliances and devices for efficient water use

Figure 9 – Explanatory infographic on household appliances and devices for efficient water use.
Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

A significant proportion of household water consumption stems from the use of various appliances and fittings, which are now designed to promote high standards of efficiency; in other words, to deliver the same performance but using only a fraction of the water previously used: efficient washing machines and dishwashers (using approximately 45L and 9L per cycle respectively), low-flow showers (5–7L/min), taps with aerators (flow rate of 2–4L/min) and dual-flush toilets (3L/6L), reduce domestic consumption by up to 50% and help to reduce waste in daily activities without compromising convenience[74].

In Europe, the European Association of the Tap and Valve Industry has established the Unified Water Label[75], a voluntary labelling scheme designed to improve the water consumption and performance of taps, valves, shower heads and other fittings, indicating the water flow rate in litres per minute and the energy consumption of the product when installed correctly.

This procedure has a direct impact on water conservation, as it not only reduces consumption at the point of use but also lowers the water and energy footprints.

74. https://energysavingtrust.org.uk/top-seven-water-saving-products-to-help-you-cut-water-use/

75. https://uwla.eu/

Hence, the adoption of water-efficient equipment, both by domestic consumers and, above all, by industrial companies, has become a key aspect of sustainability strategies.

Meanwhile, the regulation of this equipment and its potential adoption requires that users have access to clear, transparent and scientifically sound information regarding its water and energy performance and environmental impact, to prevent misleading commercial practices[76] and allow informed and responsible choices, thereby making every citizen an active participant in water management.

- *Artificial Intelligence and Predictive Analysis*

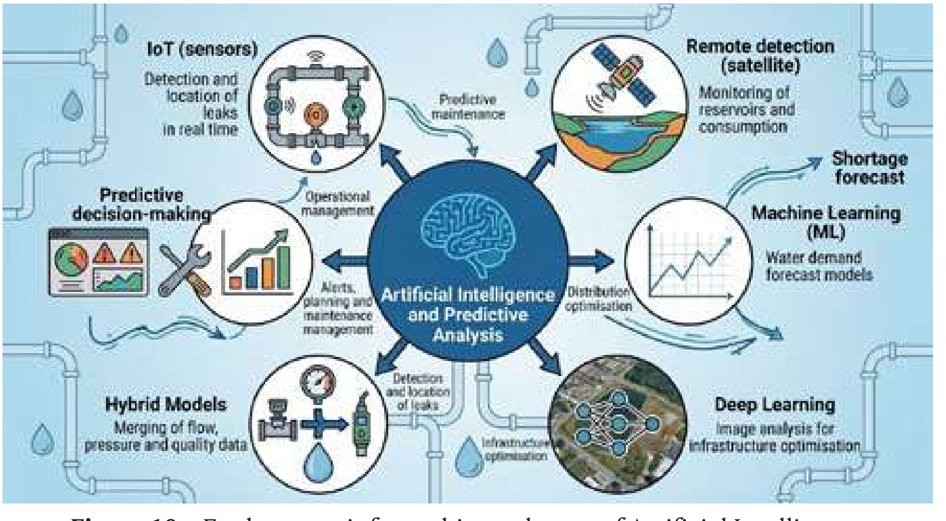

Figure 10 – Explanatory infographic on the use of Artificial Intelligence and Predictive Analysis in water management.
Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

The development of artificial intelligence is having an impact on every aspect of human activity, including water management[77]. In this application, machine learning models and the high capacity for predictive analysis provide good opportunities for improving the supply and treatment of water for human consumption, allowing the forecast of water demand and consumption levels, the

76. Girardin, B., & Fiechter-Widemann, E. (2019). Blue Ethics. Ethical Perspectives on Sustainable, Fair Water Resources Use and Management, Annex: water ethics principles and guidelines, https://doi.org/10.58863/20.500.12424/667727

77. Kamyab, Khademi, Chelliapan, SaberiKamarposhti, Rezania, Yusuf, Farajnezhad, Abbas, Hun Jeon, & Ahn (2023) The latest innovative avenues for the utilization of artificial Intelligence and big data analytics in water resource management, Results in Engineering, V. 20, 101566, https://doi.org/10.1016/j.rineng.2023.101566

detection of anomalies in water usage, and even the anticipation of equipment failures before they occur, thus reducing water losses. For instance, AI-powered systems can analyse historical water usage patterns in a city to predict periods of peak demand, enabling water companies to plan accordingly. They can also identify abnormal usage patterns, which may indicate leaks or unauthorised consumption.

The integration of artificial intelligence into existing infrastructure — which will need to incorporate and integrate flow meters at different usage levels — creates a powerful layer of insight that not only maximises the effectiveness of water conservation technology but also enables decision-makers to optimise operations, reduce inefficiencies and extend the infrastructure's lifespan.

Notwithstanding the aforementioned benefits, it is important to bear in mind that the use of complex algorithms in decisions that have a direct impact on access to drinking water raises issues of transparency, accountability and distributive justice, particularly when it affects vulnerable communities or fragile ecosystems.

In this context, it is crucial to make sure that the adoption of AI not only complies with the general principles of explainability and transparency and ensures human oversight of algorithmic decisions, but also safeguards personal data, promotes cybersecurity and prevents biases that exacerbate inequalities in access to water[78,79]. Therefore, it becomes necessary to embed technological innovation within governance frameworks that incorporate robust protection of personal data, transparency regarding purposes and the sharing of information, appropriate mechanisms for informed consent, and the effective participation of the communities concerned[80,81,82,83].

78. Ye, L., Dong, Q., McCright, A., & Gasteyer, S. (2026). An Innovative Approach to Predict Drinking Water Risks Using System, Community, and Regulatory Characteristics. *INQUIRY: The Journal of Health Care Organization, Provision, and Financing*, 63, 00469580251411440.

79. Moreno-Rodenas, A., Verbist, K., Mertens, A., Gerritsma, I., Deng, J., Haag, A., ... & Amarnath, G. (2025). Applications of AI for water management. UNESCO. https://doi.org/10.54677/VGVL7976

80. Dada, M. A., Majemite, M. T., Obaigbena, A., Daraojimba, O. H., Oliha, J. S., & Nwokediegwu, Z. Q. S. (2024). Review of smart water management: IoT and AI in water and wastewater treatment. World Journal of Advanced Research and Reviews, 21(1), 1373-1382.

81. Silva, J. B., De Oliveira, L. D., Duarte, R. M., de Rocha Souto, C., & Villanueva, J. M. (2025). Smart Water Management: An Energetically Autonomous IoT-Based Application for Pressure and Flow Monitoring in Water Distribution Systems. *Sensors*, 25(23), 7227.

82. Karale, A. (2021). The challenges of IoT addressing security, ethics, privacy, and laws. *Internet of Things*, 15, 100420.

83. https://prism.sustainability-directory.com/scenario/data-privacy-and-ethics-in-smart-water-metering-for-behavioral-interventions/, accessed on 23 February 2026.

- IoT-enabled smart water networks

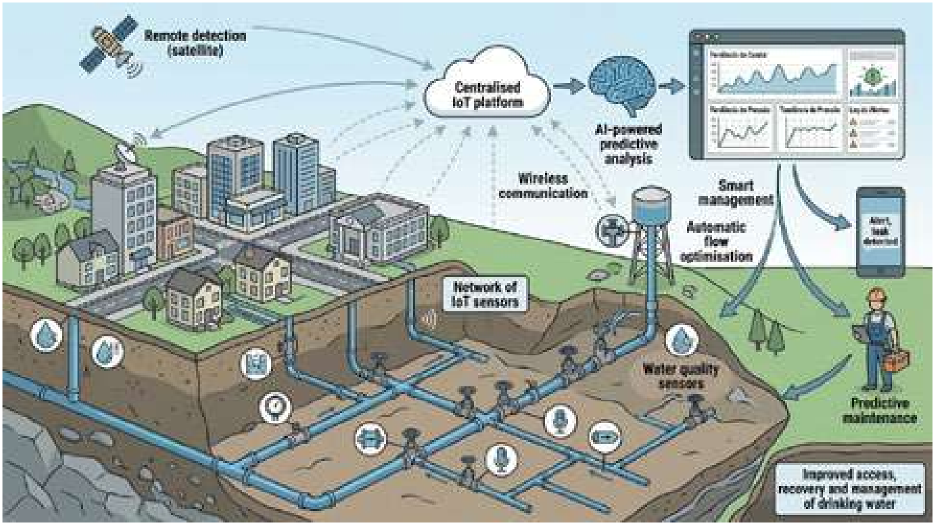

Figure 11 – Explanatory infographic on IoT-enabled smart water networks. Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

The Internet of Things builds networks connecting sensors and devices. In water management, the IoT can monitor almost all processes, from reservoir levels to distribution flows and individual consumption, or water quality indicators in real time[84]. As a matter of fact, it can drive a range of technological innovations that are bringing about significant changes in water conservation. We are referring, for instance, to smart water meters, which incorporate IoT sensors and provide real-time data on water consumption. These devices detect leaks, measure consumption patterns and alert users to any irregularities, helping to reduce wastage and promoting responsible water use, both for local authorities and households.

On the other hand, smart water management systems, through the integration of AI, can model water consumption forecasts by analysing historical data, weather patterns and soil moisture levels. For instance, AI-based irrigation systems make sure that water is supplied to crops only when necessary, preventing over-irrigation and conserving precious groundwater. Traditional rainwater harvesting has also been upgraded with the integration of sensors and cloud-based data tracking. These smart rainwater harvesting systems can automatically control water inflow and outflow, monitor storage levels and provide data to aid better planning of water use.

84. Smart Water-IoT: Harnessing IoT and AI for Efficient Water Management, ACM Computing Surveys, V. 57, Issue 12, Art.nº 304, Pages 1 – 36, https://doi.org/10.1145/3744338

We also refer the monitoring of water quality using smart analysis, which, through smart sensors, monitors in real time water quality parameters — such as pH, turbidity, conductivity, and the presence of contaminants — enabling rapid intervention and preventing waterborne diseases. Thus, local authorities can address problems in real time, rather than waiting for physical inspections. Also, farmers can irrigate their crops only when and where they need it most.

The new paradigm in the monitoring, management and distribution of water resources introduced by IoT-enabled smart water networks can provide crucial support for sustainability policies. The fact that smart systems may exacerbate inequalities should not be overlooked, particularly during the initial phase of implementation, especially if this phase prioritises economically more attractive areas or if dynamic pricing models penalise vulnerable users, thereby contravening the principles of distributive justice and equitable access to water.

- Virtual submeters and Data Transparency

Figure 12 – Explanatory infographic on virtual submeters and transparency in water management.
Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

Virtual submeters (such as portable ultrasonic flow meters) have emerged as an innovative solution for the accurate measurement of water usage. Indeed, traditional meters track water usage at the building or facility level, but virtual submeters break down consumption between individual units or fixtures and provide detailed cloud-based tracking without the need for extensive hardware installation.

This technology also strengthens transparency regarding differentiated consumption, helping property managers, businesses and even individual households to acquire a clear understanding of their usage patterns. By highlighting areas of waste, the virtual submeter empowers people to take informed and responsible steps that lead to substantial reductions in consumption and costs.

By doing so, it fosters a culture of responsibility and care, strengthening water conservation efforts at community level. It is, however, equally important to look beyond recognised technical and economic efficiency-and always consider potential negative social impacts, with a view to mitigating them.

– Blockchain for water resource management

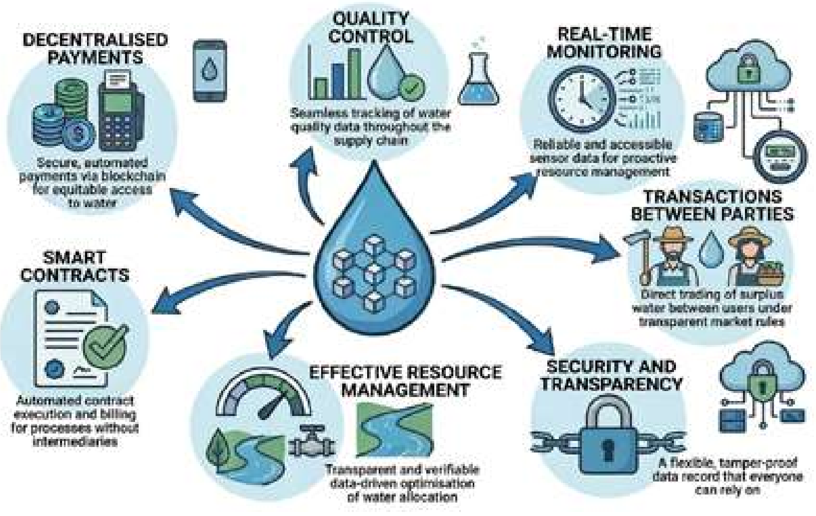

Figure 13 – Explanatory infographic on Blockchain for water resource management.
Designed by Joana Araújo, using *Perplexity AI PRO* (2026).

Blockchain technology enables the use, distribution and quality of water to be permanently safeguarded, even in the event of changes to distribution systems, thereby significantly reducing the risk of contamination and facilitating the tracking and regulation of water resources in a highly efficient manner for governments and various sectors of the economy[85].

These platforms, which guarantee that water resources are distributed efficiently, particularly in areas where water is scarce, also allow clients to nego-

85. Satilmisoglu, Sermet, Kurt & Demir (2024) Blockchain Opportunities for Water Resources Management: A Comprehensive Review Sustainability 2024, 16, 2403. https://doi.org/10.3390/su16062403.

tiate water volumes and prices. Autonomous smart contracts can carry out transactions, supplying water to clients in real time, depending on current demand and availability.

Consequently, this technology is being viewed as a means of enhancing transparency, accountability and efficiency in water resource management, although its application to the commercialisation of water may pose challenges to the universal access to water that is sought.

The ethical concerns raised by these and other innovative water-related methods and technologies, powered by artificial intelligence, are largely the same. Above all, these concerns relate to the high temporal and spatial resolution of the data, the extreme level of detail in the consumption data they capture, which provides insight into citizens' lifestyles regarding the use of water for human consumption, giving rise to significant threats to privacy, information security and digital surveillance, as well as potential discrimination, with an impact on the autonomy and dignity of individuals and their families.

In this context, it is crucial to make sure that the adoption of AI not only complies, in its application, with the general principles of explainability and transparency, and that there is human oversight of algorithmic decisions, but also safeguards the protection of personal data, cybersecurity and the prevention of biases that exacerbate inequalities in access to water, constituting ethical requirements to be met when using artificial intelligence in water management[86,87,88]. Therefore, it becomes necessary to embed technological innovation within governance frameworks that incorporate robust protection of personal data, transparency regarding purposes and the sharing of information, appropriate mechanisms for informed consent, and the effective participation of the communities concerned[89,90,91,92].

86. Ye, L., Dong, Q., McCright, A., & Gasteyer, S. (2026). An Innovative Approach to Predict Drinking Water Risks Using System, Community, and Regulatory Characteristics. INQUIRY: The Journal of Health Care Organization, Provision, and Financing, 63, 00469580251411440.

87. Moreno-Rodenas, A., Verbist, K., Mertens, A., Gerritsma, I., Deng, J., Haag, A., ... & Amarnath, G. (2025). Applications of AI for water management. UNESCO. https://doi.org/10.54677/VGVL7976

88. Kamyab, H., Khademi, T., Chelliapan, S., SaberiKamarposhti, M., Rezania, S., Yusuf, M., ... & Ahn, Y. (2023). The latest innovative avenues for the utilization of artificial Intelligence and big data analytics in water resource management. Results in Engineering, 20, 101566.

89. Dada, M. A., Majemite, M. T., Obaigbena, A., Daraojimba, O. H., Oliha, J. S., & Nwokediegwu, Z. Q. S. (2024). Review of smart water management: IoT and AI in water and wastewater treatment. *World Journal of Advanced Research and Reviews*, 21(1), 1373-1382.

90. Silva, J. B., De Oliveira, L. D., Duarte, R. M., de Rocha Souto, C., & Villanueva, J. M. (2025). Smart Water Management: An Energetically Autonomous IoT-Based Application for Pressure and Flow Monitoring in Water Distribution Systems. *Sensors*, 25(23), 7227.

91. Karale, A. (2021). The challenges of IoT addressing security, ethics, privacy, and laws. *Internet of Things*, 15, 100420.

92. https://prism.sustainability-directory.com/scenario/data-privacy-and-ethics-in-smart-water-metering-for-behavioral-interventions/, accessed on 23 February 2026.

Several studies demonstrate that AI-based systems, when not subject to robust regulation, can be exploited by public or private entities to attempt to exert social control or impose unfair behavioural or pricing profiles, thereby exacerbating socio-economic inequalities and environmental injustices. By contrast, the adoption of distributed ledger technologies (DLT, blockchain) can enhance transparency, traceability and accountability in water resource management, particularly in preventing corruption, in controlling the illicit use of water and in promoting a fairer distribution of water, which requires a robust data protection system and participatory governance mechanisms, so as to ensure that the 'digitalisation of the water sector' contributes to sustainability and not to new forms of vulnerability and exclusion[93,94,95,96].

93. Velayudhan, N. K., Zaman, D., Devidas, A. R., Tiwari, M. K., von Lieres, J. S., & Ramesh, M. V. (2025). Blockchain-IoT and optioneering driven framework for smart water management in emerging urban areas. *iScience*, 28(12).

94. Zhang, X. Y., Guo, P., Kuenzel, S., & Yin, C. (2024). Ethical considerations in advanced metering infrastructure integration: A systematic review. *Energy Strategy Reviews*, 56, 101571.

95. Camões, D. (2023). The impact of smart meters on data protection law. Revista Electrónica de Direito – June 2023 – No. 2 (VOL. 31). DOI: 10.24840/2182-9845_2023-0002_0004

96. Mahmood, M., Chowdhury, P., Yeassin, R., Hasan, M., Ahmad, T., & Chowdhury, N. U. R. (2024). Impacts of digitalization on smart grids, renewable energy, and demand response: An updated review of current applications. *Energy Conversion and Management: X*, 24, 100790.

5. ETHICAL REQUIREMENTS FOR WATER MANAGEMENT AND USE

Water, as a vital resource that is essential to all forms of life and indispensable to the survival and health of living beings, as well as to the sustainability of ecosystems, must be recognised as a common good. In this context, water management and use — in particular the way in which water is made available and accessed, and how it is used outside the aquatic environment, whether or not it is returned to nature — are of fundamental importance. Indeed, different uses have different return rates, with domestic uses returning approximately 80% of water, whereas agricultural uses retain or consume about 80%, with average return rates below 20%.

Water abstraction, conveyance and distribution systems always experience losses, resulting in a difference between the volume abstracted and the volume actually used[97]. It is difficult to accurately determine the volume of losses in Portugal, but it is estimated that in 2022 these ranged between 10% and 40% in major hydro-agricultural projects (DGADR).

Prospective scenarios in the River Basin Management Plans forecast an increase in water use of 3-5% by 2027 and 5-14% by 2033[98]. Climate change, along with declining water reserves and lack of access to potable water and sanitation, could cause high-income countries to lose, on average, 8% of their GDP by 2050. In lower-income countries, losses could reach between 10% and 15%. Water scarcity may have a detrimental impact on agricultural growth prospects and some regions of the world could see their agricultural growth rates decline by up to 6% of GDP by 2050, because of water-related losses in agriculture, income and property[99].

Despite recognised advances in strategic water management planning, most recently through the 'National Strategy – Water that Unites', significant weaknesses remain in meeting current and future water needs, particularly regarding the uneven temporal and regional availability of water, as well as high loss rates and low levels of reuse. These weaknesses are expected to worsen with ongoing climate change.

In this context, it is important to stress that freshwater is a finite, though renewable, global resource, determined by the hydrological cycle of evaporation, condensation and precipitation – as illustrated below.

97. Oliveira, R. P. (2024). Água em Portugal (Water in Portugal). Francisco Manuel dos Santos Foundation.

98. Global Commission on the Economics of Water - https://watercommission.org, accessed: 12.12.2025.

99. Metulini, R., Riccaboni, M., & Serti, F. (2020). Water-in-food, conflicts, and refugee movements: A comprehensive analysis. In Water Resources and Economic Processes (pp. 224-261). Routledge.

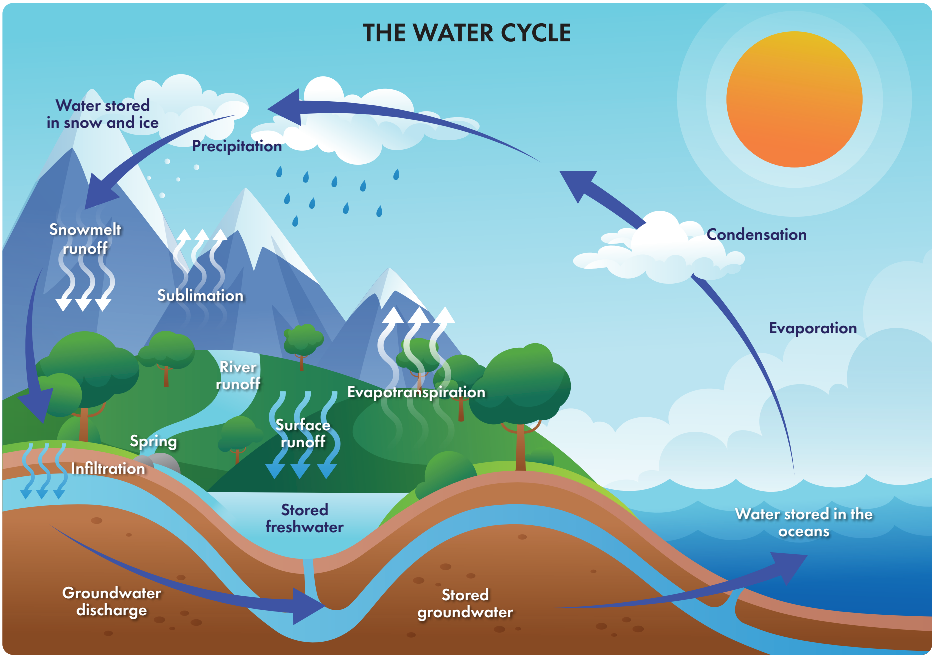

Figure 14 – Water cycle[100]

The hydrological cycle describes the continuous movement of water on the Earth's surface, above and below it. This cycle is vital for maintaining ecological balance and replenishing groundwater reservoirs, which are essential for the availability of potable water. Water is an important resource for humankind, but it is also an indispensable element of the planet's extensive web of life. A broad view of the "water cycle" is therefore necessary, recognising the ways in which it interacts with the atmosphere, soils and biotic communities in general, particularly human beings.

However, pressure on the hydrological cycle has been increasing, with growing consequences. There are multiple examples of this phenomenon. We can highlight the negligent approach to the so-called 'green water', that is, water existing in soils and vegetation, which ultimately circulates through the atmosphere and generates about half of the planet's precipitation, but which is neither valued by science nor economics and is ignored by public policies.

100. Figure prepared following a template adopted on the EPAL website: https://www.epal.pt/EPAL/menu/epal/comunica%C3%A7%C3%A3o-ambiental/ciclo-da-%C3%A1gua Graphic design by Pedro Daniel.

We must also recognise the seriousness of the degradation affecting freshwater ecosystems, including the loss of soil moisture. This loss is both a consequence of climate change and a driver of it, further intensifying the decline in biodiversity.

As previously noted, investment in water technologies can help alleviate current pressure on the hydrological cycle and should be considered within the broader framework of water management and governance as a key component of sustainability. Nevertheless, it is important to acknowledge that their implementation entails specific ethical risks, which must be identified to prevent or mitigate their negative impacts. In this way, we may also uphold the contemporary ethical imperative of regarding the water cycle as a global common good[101] and drinking water as a universal human right.

5.1. Some ethical challenges to consider when implementing water technologies

The main goals of innovative water technologies are to maximise the volume of available water (particularly drinking water) and to improve access to it, thereby promoting environmental and social values that also translate into economic benefits. Water is nowadays widely recognised as a global public asset and a human right, and the full realisation of this right can benefit significantly from the use of new technologies. For this reason, the development and implementation of water technologies should be supported and their use encouraged.

In this process, however, it is necessary to clearly identify the negative impacts that have been observed because of the application of certain water technologies, and to anticipate other potential impacts that must be prevented and/or mitigated. Moreover, in the latter case, it is important to put in place accompanying measures that mitigate any unintended consequences, whilst also reinforcing the positive aspects. In fact, innovative technologies in the area of access, retrieval and management cannot be assessed solely from a technical perspective or on the basis of their efficiency; they must also, and necessarily, be considered from environmental, social and economic perspec-

101. It is currently possible to distinguish three types of water. 'Blue water' is found in lakes, rivers and reservoirs, and in wetlands, or is pumped from aquifers beneath the surface. Available blue water is used for many purposes, including human consumption. It may be used in homes and by businesses – such as beverage manufacturers. This water is also used for agricultural irrigation, while 'green water' is available in the soil for plants and microorganisms. It is the water that, once absorbed by roots and used by plants, is released and returns to the atmosphere through the process of transpiration. Green water can also leave the soil through evaporation or subsurface runoff, but it is considered productive only when it is used for plant transpiration. 'Grey water' is water that has already been used and may therefore contain impurities. It consists of wastewater, which is normally treated and discharged. Grey water has been used in towns and cities, by households and industries. Nature produces blue and green water. Humans produce – and have learned to reuse – grey water. What are blue, green, and grey water? 17-Jan-2022 8:00 AM EST, by https://www.newswise.com/institutions/newsroom/1622/

tives, with a view to achieving this required triple sustainability, alongside citizens' autonomy, privacy and social justice.

Throughout this text, it has been pointed out that there are a number of key ethical issues specific to the water technologies under consideration. It is, however, worth taking a broader view of the issue at hand by considering a wide range of cross-cutting themes.

The first and foremost is, naturally, scientific excellence and technical reliability. This is a basic ethical requirement. This mainly refers to the quality of the water supplied, alongside the assessment of chemical and microbiological risks and its continuous monitoring, which is particularly important in the case of reused water. If the technology in question fails to meet these requirements, it falls short of its purpose and misleads its users, leading to public mistrust of technological solutions and, consequently, reducing the public's uptake of innovation.

This technological innovation, including water-related developments, requires significant financial investment, at least in the initial phase of its implementation. In the case of industries or businesses, i.e. economic activities in general, investment is incorporated into production costs and calculated in advance in terms of economic profitability or the fulfilment of social responsibility, and is written off over time; in the case of private consumers, the investment – whether their own or that of others, such as local authorities – is reflected in the monthly bill, causing increased difficulties for economically vulnerable groups, and may even prevent them from adopting new water technologies. From an ethical standpoint, these should not be seen as factors that exacerbate inequality or even discrimination, but rather as an opportunity to achieve greater equity in access to water. Therefore, to tackle social impacts such as inequalities in access – affecting 2.3 billion people without safe drinking water – and the marginalisation of smallholder farmers by Agriculture 4.0, it is important to adopt concrete measures such as social tariffs, subsidies for efficient equipment (e.g. low-flow showerheads and smart meters) and participatory governance.

A third set of considerations relates to the environmental and energy sustainability of the new technologies themselves, thereby touching on their very raison d'être and purpose. As a matter of fact, some water-related technologies involve high energy consumption and can also affect the balance of various ecosystems. In this context, they should not be implemented without a thorough prior assessment of the associated costs and benefits, which must be overwhelmingly positive.

As we move towards the use of water technologies, many of which are likely to be powered by artificial intelligence, ethical concerns focus on the possibility of the mass and continuous collection of consumer data, its storage and access, as well as its processing and the purposes for which it is used. Going digital in the water sector puts a strain on information security and privacy protection, requiring informed consent and a clear limitation of purpose.

Overall, it is critical that those responsible for both the development and adoption of water technologies maintain good communication with the various user groups and with communities that may be affected by their installation. This implies providing objective, transparent and clear information about the environmental, social and economic impacts of the technologies in question, as well as about the best way to use them.

The key issues highlighted here, which we consider to be essential, all point to the need for robust regulation of the implementation and use of water technologies, to promote their benefits and prevent the risks they entail.

To sum up, the design, development, implementation and use of water technologies to improve access to, recovery and management of water require the consideration of multiple factors and the coordination of efforts by various stakeholders. Nevertheless, they are an important contribution to the preservation of freshwater ecosystems as a common good.

5.2. From water as a common good to its recognition as a universal right

On the one hand, the idea of water as a global common good stem from its recognition as a vital resource for all living beings and for the planet itself. On the other hand, it implies a commitment to ensuring universal access. United Nations Resolution A/RES/64/292 of 2010[102] already defines water as a global common good. A similar position is taken by UNESCO in *The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water*, which presents water as a global common good on the grounds that it is essential to life, sustainable development and the environment. Indeed, it was UNESCO which, in 20018, in its report *Water Ethics: Ocean, Freshwater, Coastal Areas*, prepared by the Commission on the Ethics of Scientific Knowledge and Technology (COMEST)[103], gave significant impetus to ethical reflection on water. The report identified several fundamental concerns relating to the use of freshwater, namely security, human rights, the common good, justice and sustainable development[104].

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102. Mazzucato, M., Okonjo-Iweala, N., Rockström, J., & Shanmugaratnam, T. (2024). The economics of water: valuing the hydrological cycle as a global common good.

103. Resolution A/RES/64/292 adopted by the General Assembly on 28 July 2010. The human right to water and sanitation. New York: UN. 3 Aug. 2010.

104. World Commission on the Ethics of Scientific Knowledge and Technology. (2018). Report of COMEST on “Water Ethics: Ocean, Freshwater, Coastal Areas”. https://unesdoc.unesco.org/ark:/48223/pf0000265449

This perspective makes it imperative that water resources be managed as a shared responsibility of humankind, rather than treated as a commodity subject to appropriation by a few, or merely as an economic asset[105].

Recognising water as a global common good necessarily entails affirming it as a universal human right. In turn, this establishes an obligation to ensure equitable access for all to sufficient, safe water of adequate quality, at affordable prices and in accordance with their needs.

In fact, even today water is not fully established as an autonomous and independent human right[106], although it is implicit in several other human rights. In this regard, reference should be made to United Nations General Assembly Resolution A/RES/64/292, which, for the first time in July 2010, formally recognised "the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights". This resolution calls on states and international organisations to provide financial resources, contribute to capacity building and transfer technologies in order to assist countries – particularly developing nations – in ensuring safe, clean, accessible and affordable drinking water and sanitation for all[107]. However, although this resolution represents a milestone in the recognition of the right to water, it is a soft law instrument. In other words, it does not create binding obligations for states, as it has no legally enforceable effect[108].

Nevertheless, there are some legally binding international instruments that refer to the right to water, albeit as a right that enables other primary rights (notably the rights to health, food and a basic quality of life). This therefore relegates it to a subsidiary or secondary position and does not recognise it as an autonomous right[109].

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105. ten Have, H., Patrão Neves, M. (2021). Water. In: Dictionary of Global Bioethics. Springer, Cham. https://doi.org/10.1007/978-3-030-54161-3_517

106. The United Nations World Water Development Report 2023: partnerships and cooperation for water. UNESCO 2023.

107. Sousa, M. (2017). O direito humano de acesso à água e ao saneamento: legitimado pelo costume internacional (The human right of access to water and sanitation: legitimised by international customary law). Temas de Direito da Água, pp. 9-38

108. Resolution A/RES/64/292 adopted by the General Assembly on 28 July 2010. The human right to water and sanitation. New York: UN. 3 Aug. 2010

109. Beyond this resolution, other resolutions of the United Nations related to access to water may also be noted: Resolution 68/157 of the United Nations General Assembly, dated 18 December 2013, entitled «The human right to safe drinking water and sanitation»; Resolution 45/8 of the United Nations Human Rights Council, dated 6 October 2020, entitled «The human rights to safe drinking water and sanitation»; Resolution 48/13 of the United Nations Human Rights Council, dated 8 October 2021, entitled «The human right to a clean, healthy and sustainable environment»; Resolution 71/222 of the United Nations General Assembly, dated 21 December 2016, entitled «International Decade for Action, "Water for Sustainable Development" 2018-2028»; Resolution 75/212 of the United Nations General Assembly, dated 21 December 2020, on the United Nations Conference on the Midterm Comprehensive Review of the Implementation of the Objectives of the International Decade for Action «Water for Sustainable Development» 2018-2028 (United Nations Water Conference 2023).

The best international instrument that has served as the basis for implementing the human right to water and sanitation is the Protocol on Water and Health to the 1999 Convention on the Protection and Use of Transboundary Watercourses and International Lakes of the United Nations Economic Commission for Europe (UNECE or ECE)[110]. The purpose of this protocol is to promote the protection of human health and well-being, at both individual and collective levels, within a sustainable development framework, by improving water management, including the protection of aquatic ecosystems and the prevention, control and reduction of water-related diseases.

It is also worth referring to the special report on obligations relating to human rights in respect of the enjoyment of a safe, clean, healthy and sustainable environment, published by the United Nations in 2018, which described how water pollution, water scarcity and water-related disasters have disproportionate effects on more vulnerable and marginalised groups[111]. This perspective is increasingly important, as the climate crisis, conflicts and situations such as the COVID-19 pandemic have heightened disparities in access among different groups[112].

The European Union has also pursued a path of promoting access to quality water, notably through the Right2Water[113] initiative. In the context of a public consultation exercise by the European Commission, it was concluded that certain areas could still be improved, in particular the list of parametric values based on quality, limited confidence in a risk-based approach, the lack of precision in provisions relating to consumer information, and the differences between systems for approving materials that come into contact with water intended for human consumption, as well as the consequences of such disparities for human health.

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110. In this context, the right to water may be referred to as a means of guaranteeing the enjoyment of adequate living conditions (Article 14(2)(h) of the 1979 Convention on the Elimination of All Forms of Discrimination against Women); as a means of fulfilling the right to health (Article 24(2)(c) of the Convention on the Rights of the Child); or as a means of guaranteeing a minimum standard of living and social protection (Article 28(2)(a) of the Convention on the Rights of Persons with Disabilities). A reference to the right to water also appears in the context of the Additional Protocols to the Geneva Conventions concerning persons deprived of their liberty.

111. Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes. 1999. United Nations Economic Commission for Europe (UNECE) AT: https://unece.org/DAM/env/water/publications/PWH_text/ECE_MP.WAT_17.pdf

112. Report A/73/188, adopted by the General Assembly of United Nations, 19 July 2018. Available at https://docs.un.org/en/A/73/188. This document has not been transposed into national law, either by formal transposition through a decree-law, a resolution of the Portuguese Parliament (Assembly of the Republic), or any other specific legislative instrument.

113. Right2Water was promoted through the European Citizens' Initiative process and launched in 2012 aiming at ensuring that water and basic sanitation would be recognised as human rights within the European Union, and that water distribution, as a common good, would remain a public service not subject to privatisation. This campaign gathered more than 1.8 million signatures and drove a political debate that resulted in the revision of the Drinking Water Directive and the strengthening of the European Union's commitment to universal access to quality water, particularly for more vulnerable groups (https://right2water.eu/)

It is in this context that we can understand 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 as a development of the previous Directive 98/83/EC. More comprehensive than its predecessor, this Directive lays down a set of minimum requirements, requiring Member States to adopt all necessary measures to ensure that water intended for human consumption contains no elements that constitute a potential risk to human health". This Directive was transposed into Portuguese domestic law by Decree-Law No. 69/2023 of 21 August 2023, establishing the legal framework for the quality of water intended for human consumption and aligning national legislation with European standards[114].

As a soft law instrument, i.e. a non-binding instrument, it is appropriate to highlight the resolution of the European Parliament of 5 October 2022 on access to water as a human right – the external dimension (2021/2187(INI))[115]. It underlines that the right to water constitutes a fundamental prerequisite for the exercise of other rights and, as such, should be guided by a logic of public interest and the common good. Despite its European scope, the importance of this resolution derives from its attempt to establish a binding and autonomous recognition of the right of access to water as a human right, which would pave the way for imposing consequences on those who infringe it.

5.3. From the universal right to water to the ethics of its management and use

The themes that have been developed can, from an axiological viewpoint, be translated into certain categories of values applicable to water, which relate to contemporary ethical reflection on the subject.

Using a simple example from the field of agriculture, such as irrigation, we can highlight the importance of these different values for direct decisions regarding water: Through a simple example in agriculture, namely irrigation, we can highlight the relevance of these different values for direct decisions about water: how the volume of water (governance) to be used for irrigation should be managed to facilitate agricultural investment (economic), ensure food production at affordable prices (social), preserve ecosystems (environmental) and respect the lived experiences of the communities involved (cultural). The ethical decision should pursue a balance between the

114. https://siwi.org/why-water/human-rights-and-water/

115. These minimum requirements are fundamentally based on the precautionary principle. Bearing this principle in mind, the revision of the legal framework focused on five pioneering objectives: (i) updating quality and monitoring standards, (ii) extending risk assessment and management across the entire supply chain, (iii) improving public access to information, (iv) introducing uniform standards for materials and products in contact with water, and (v) ensuring access to water (in Susana Rodrigues, *O novo regime legal da água: desafios ou oportunidades?*, in *Academia da Água: a construir o futuro*, 2024, pp. 85-88).

different values involved, potentially prioritising those that best protect the interests most at risk in the specific situation. In this context, the principle of proportionality is also respected, meaning the adoption of measures corresponding to the values at risk and the anticipation of both mitigating and compensatory actions in relation to potential harm.

Other associated questions may include which crops and agricultural practices should irrigation water preferentially support (governance and economic values)? Or alternatively: are pesticides affecting groundwater (environmental values) or drinking water (social values)?

The effects of actions taken, according to the values adopted, may have far-reaching implications in spatial and temporal terms. It is therefore important to set out the different values considered in decision-making processes so that decisions are optimal in environmental, social and economic terms and are ethically grounded. This perspective is required across a very wide range of water-related topics, from the construction of a dam and its impact on ecosystems, the landscape and the links between communities and their economic activities, to the simple act of brushing one's teeth and the different ways in which water is used, whether as a necessity or as waste. All the above represent forms of the relationship between humans and water, which broadly constitutes what is known as an "ethics of water" or an ethics applied to water management and use.

> Ethics applied to water – or simply the "ethics of water" – reflects on the values and principles that determine how water is made available, managed and used, affirming it not only as an economic resource but as a global common good and a universal human right. In brief, the ethics of water aims to establish normative principles for individual and collective action that ensure people and communities, animals and other living beings, their future generations and ecosystems – in other words, the planet – have equitable and sustainable access to water, according to their differing needs.
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> Bioethics – Contemporary Issues | 1 National Council of Ethics for the Life Sciences, 2016

This aspiration requires consideration not only of the governance, environmental, social, economic and cultural aspects set out above, but also scientifically and technically grounded decisions, taken in an inclusive manner and communicated transparently. This means that it is ethically required for measures relating to water management and use to have a scientific basis, grounded in prior understanding of the outcomes, and a technical basis that makes use of the available means of intervention. It is also necessary for decision-making processes to involve stakeholders, not only because they are the most affected but also because it is important to consider the potential contributions they may bring. Finally, the decisions to be implemented must be publicised clearly and unequivocally, thereby fostering greater societal acceptance.

The ethical requirements of water encompass procedural dimensions associated with decision-making in matters of management, tariff setting, resource allocation priorities and mechanisms for conflict resolution. Good water governance is based on the assumption that institutions will be capable of designing coherent policies, systematically monitoring their results and correcting identified inequalities or injustices through structured communication processes with citizens and all relevant stakeholders. It also entails ensuring informed public participation in decisions on projects likely to affect access to water, in accordance with approaches grounded in human rights. It further requires effective access to reliable and up-to-date information on water quality, contamination risks, tariff structures and investments made, which is an indispensable requirement for democratic accountability and public scrutiny of adopted policies[116].

Recent reports from the UN-Water system stress that the equitable sharing of water-management benefits contributes to peace and conflict prevention, particularly in transboundary contexts, reinforcing the ethical and political dimension of water as a common good. In this sense, the ethics of water management and use involve not only individuals and communities but also states, which must cooperate to protect international watercourses and shared aquifers[117]. In a national context, this entails public policies that prioritise human supply and sanitation over less essential uses, and strict regulation of industrial and agricultural activities with a significant water footprint. Globally, it calls for international solidarity in the form of technical cooperation, knowledge transfer and financial support for countries facing chronic water scarcity, extreme events and fragile infrastructures, in line with the Sustainable Development Goals of the United Nations, in particular SDG 6: "Ensure availability and sustainable management of water and sanitation for all". We can systematise some ethical principles that underpin the guidelines of

116. Report A/80/117, adopted by the General Assembly of United Nations, 4 July 2025. Available at: https://docs.un.org/en/A/80/117

117. World Commission on the Ethics of Scientific Knowledge and Technology. (2018). Report of COMEST on" Water Ethics: Ocean, Freshwater, Coastal Areas".

the documents cited and that are explicitly formulated by some of them[118,119,120,121,122,123] as is the case of the aforementioned UNESCO report on Water Ethics: Ocean, Freshwater, Coastal Areas[124]:

a. Beneficence, actively promoting conditions of access to potable water, sanitation and adequate infrastructure, thereby contributing to public health and population well-being;

b. Non-maleficence, avoiding water-use practices that cause predictable harm to human health or ecosystems, including poor water management, contamination of aquifers, pollutant discharges and the overexploitation of groundwater reserves;

c. Justice and Equity, guaranteeing an equitable distribution of the benefits and burdens arising from sustainable water management, and preventing situations of exclusion, discrimination and "water injustice" that tend to affect primarily socio-economically disadvantaged groups;

d. Responsibility, in assuming duties to protect human dignity, One Health, and the sustainability of this global common good, preventing and remedying harm, and being accountable for decisions taken, including policies, in respect of global and intergenerational justice;

e. Water security and sustainable use, ensuring that water is available in sufficient quantity and quality for present and future generations, on a continuous basis and beyond the most immediate needs.

f. Integrity, in protecting the continuity of hydrological cycles, preventing their contamination, abusive appropriation or unjust division, and ensuring responsible uses that preserve the quality, quantity and availability of water for all communities and generations;

g. Solidarity, recognising the interdependence of people and communities,

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118. Araújo, J. (2011). Contributo da ética para um uso sustentável dos recursos hídricos (Contribution of ethics to the sustainable use of water resources). Ensaios de Bioética 2. Coord. Ana Sofia Carvalho, Walter Osswald. Instituto de Bioética da Universidade Católica Portuguesa (Bioethics Institute of the Portuguese Catholic University).

119. World Water Development Report (2003). *Water for People, Water for Life*. United Nations.

120. The United Nations world water development report 2019: leaving no one behind. UNESCO World Water Assessment Programme.

121. Schmidt, J. (2023). From integration to intersectionality: A review of water ethics. *Water Alternatives*.

122. McIntyre, O. (2024). Towards sustainability in transboundary water resources: The role of inter-state solidarity. *Environmental Policy and Law, 54*(4-6), 276-286.

123. Fanaian, S., Manero, A., Nguyen, N. M., & Grafton, R. Q. (2025). Beyond a Decade of Water Justice: Review, Directions, and Pathways to Achieve "Water for All". *Wiley Interdisciplinary Reviews: Water, 12*(6), e70043.

124. This report presents ten core ethical principles: Human dignity and human rights, solidarity, the common good, frugality, sustainability, justice, justice and international transboundary waters, gender equity, research integrity and the sharing of knowledge and technology. World Commission on the Ethics of Scientific Knowledge and Technology. (2018). Report of COMEST on" Water Ethics: Ocean, Freshwater, Coastal Areas".

requiring fair sharing of the resource, cooperation in management, support for vulnerable populations and shared global responsibility for protecting water as a common good essential to life.

Beyond the implementation of the various values associated with water, it should also be highlighted that water is frequently viewed as a resource, indicating the attribution of an instrumental value. However, water, as a vital good, a common good and a human right, represents an intrinsic value, insofar as it is indispensable and irreplaceable.

In summary, an ethics of water requires the assumption of responsibility in water management and use. It requires accountability through compliance with international law, national legislation and corresponding regulation in all sectors relating to water availability and use, and at the same time calls for legislation that is appropriate and tailored to each context, as well as regular monitoring. Moreover, this ethics requires moral responsibility, through the obligation to reflect on one's own behaviour in relation to water use, going beyond what is legally required, and which challenges everyone in proportion to their respective roles and capacities.

This responsibility therefore falls on each of us, as well as on humanity as a whole, in our duty to protect and preserve water[125] for the present and the future (sustainability), to make it universally accessible to all people and non-human entities (justice), and to invest in technological means that increase the volume of potable water available and distributable (responsibility). This is the only way to ensure that we achieve water governance, management and use that are environmentally sustainable, socially just and economically beneficial, today and tomorrow, for the planet and its inhabitants.

125. Postel, S. (2010). The missing link: a water ethic. in P Brown & J Schmidt (eds), *Water Ethics. Foundational Readings for Students and Professionals*, Island Press, Washington, DC, pp. 221–226.

6. SOME RECOMMENDATIONS AND IMPERATIVES FOR WATER ETHICS

The National Council of Ethics for the Life Sciences, highlighting that:

- the significant potential environmental, social and economic benefits from new water technologies
- the existence of ethical, environmental and social risks associated with some of these technologies recommends:

1. **That the central government, the autonomous regions and the local authorities to:**
   - take on the access, recovery and management of drinking water as an ethical, social and political duty, recognising it as a vital resource and a universal human right;
   - within the scope of their respective powers, establish favourable regulatory, financial and fiscal conditions to foster scientific research and investment, both public and private, in water technologies, as well as their uptake by domestic, business and other consumers;
   - promote the use of water technologies for the efficient production, economical use and recovery of drinking water;
   - engage domestic, business or other consumers in the decision-making processes leading to the adoption of new water technologies;
   - demand the submission of a specialised and independent environmental and social impact assessment prior to the implementation of water technologies, in such a way that the benefits far outweigh any potential harm caused by their application;
   - require the implementation of monitoring and intervention measures to mitigate harm and risks wherever these are foreseeable, in particular negative environmental and social impacts;
   - promote public training campaigns on sustainable water management and provide information on available water technologies, including those that enable the reduction of water losses and the reuse of treated wastewater, also with a view to achieving inclusive water governance;
   - continuously monitor the water cycle.

2. **That funding agencies and scientific research centres invest,** develop and participate in research in water technologies tailored to the geographical contexts and social activities for which they are intended, as well as to human and environmental needs, including re-

spect for human rights (data anonymisation and privacy protection), particularly in partnerships with local authorities and/or businesses.

3. **For industry and companies to**
   invest in scientific research and in implementing water technologies tailored to their economic activities, taking into account their environmental and community impact, alongside technical monitoring and environmental and social oversight measures, in order to prevent damage and mitigate risks, thereby fulfilling their social and environmental responsibilities.

4. **For civil society to keep**
   informed and adopt the water technologies that best suit its needs, whilst participating in the governance and decision-making processes relating to water resources.

Regarding water management and use, the National Council of Ethics for the Life Sciences considers it ethically imperative to recognise that:

Water is a vital and intrinsic value
Water is a vital value, the essence and foundation of life on the planet. Without water, life as we know it – the existence of any living being on Earth and the maintenance of the ecosystems that sustain it – would be impossible. As a vital resource, water is also an intrinsic value, a valuable in itself.

Water is a Global Common Good
Water is a natural heritage and should be universally recognised as a global common good (and not as a commodity), that is, as belonging to all living beings, without their availability and access being improperly exploited by private interests.

Water is a Human Right
Access to and availability of water, in sufficient quantity and potable quality, constitutes an inalienable human right (and not a privilege), to be upheld and respected by national law in each country and by international law.

Water is essential to the health of living beings and the sustainability of ecosystems
Water is indispensable to the health of living beings and the planet, perfectly representing the inseparable dynamic interconnection between all, embodied in the concept of 'One Health'

Water is a factor in social and economic development
Water contributes to the development of various human communities, as

most of their activities – and particularly those with economic impact – depend on an adequate water supply for their operation.

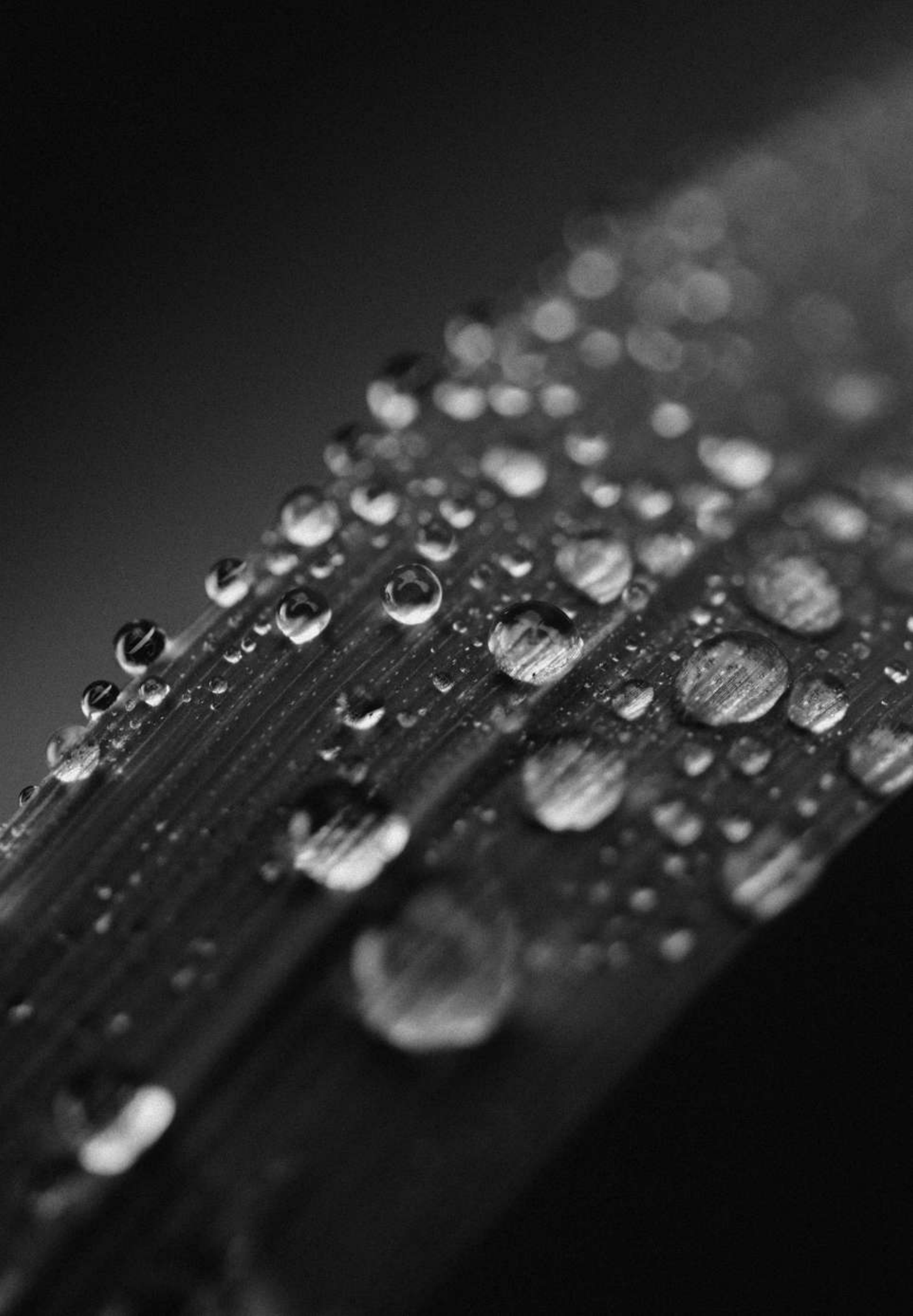
It is essential to ensure water security
The hydrological cycle is currently under unprecedented pressure, which has caused rising levels of water scarcity and poor water quality, with profoundly negative consequences for humans – individuals, populations, communities and countries – as well as for all living beings and ecosystems. The degradation of ecosystems, accompanied by a marked loss of biodiversity, also exacerbates the human situation. Given the dramatic consequences of the risk to access to the drinking water that is required, it is essential to ensure water security through concerted action by all those capable of contributing to it.

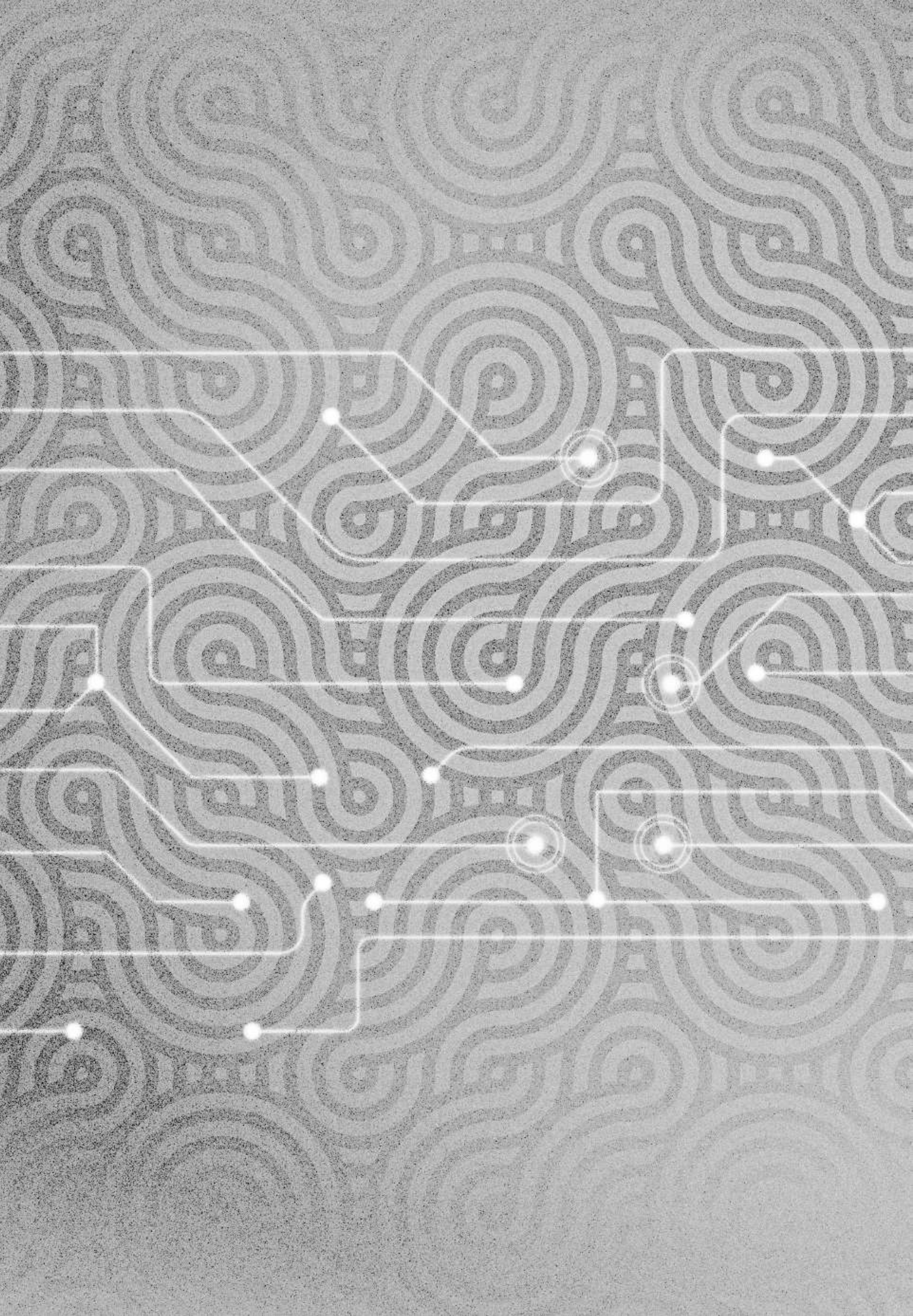
It is essential to provide scientific grounding for public water policies
The scientific grounding of public water policies is not just a technical requirement but an ethical one, insofar as it reduces arbitrariness, prevents avoidable harm and promotes informed choices that protect human life and ecosystems.

It is essential to implement integrated management
Integrated water management calls for a holistic perspective – one that takes into account all the natural elements involved, all living beings affected and all interests at stake – through planning, distribution and efficient use under multifaceted coordination that maximises availability and access with security and equity.

It is essential to promote sustainable governance
Sustainable water governance calls for a comprehensive and collaborative approach – encompassing policies, institutions, administrations, procedures and practices within a transparent decision-making process for public water policies and their implementation.

It is essential to ensure intergenerational responsibility
It is imperative to ensure that present choices regarding water management and use do not compromise its availability, quality and accessibility in the future, nor exacerbate social or economic inequalities.





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