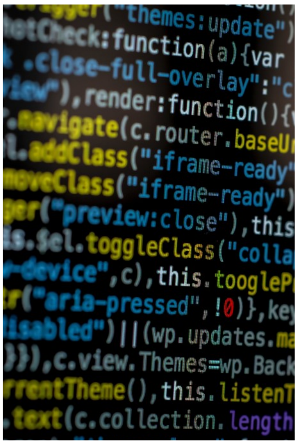
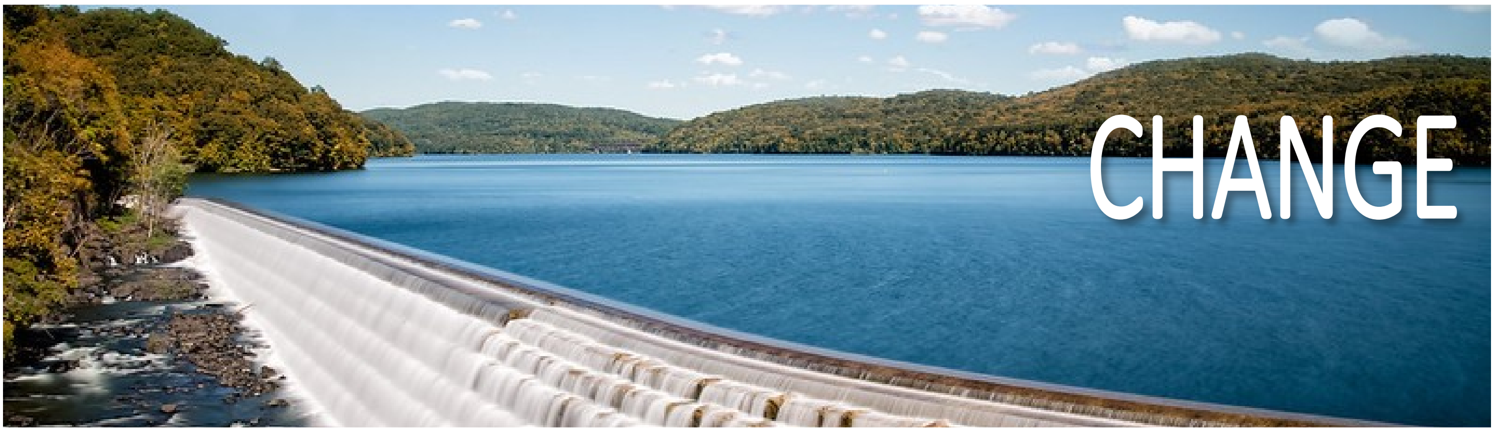
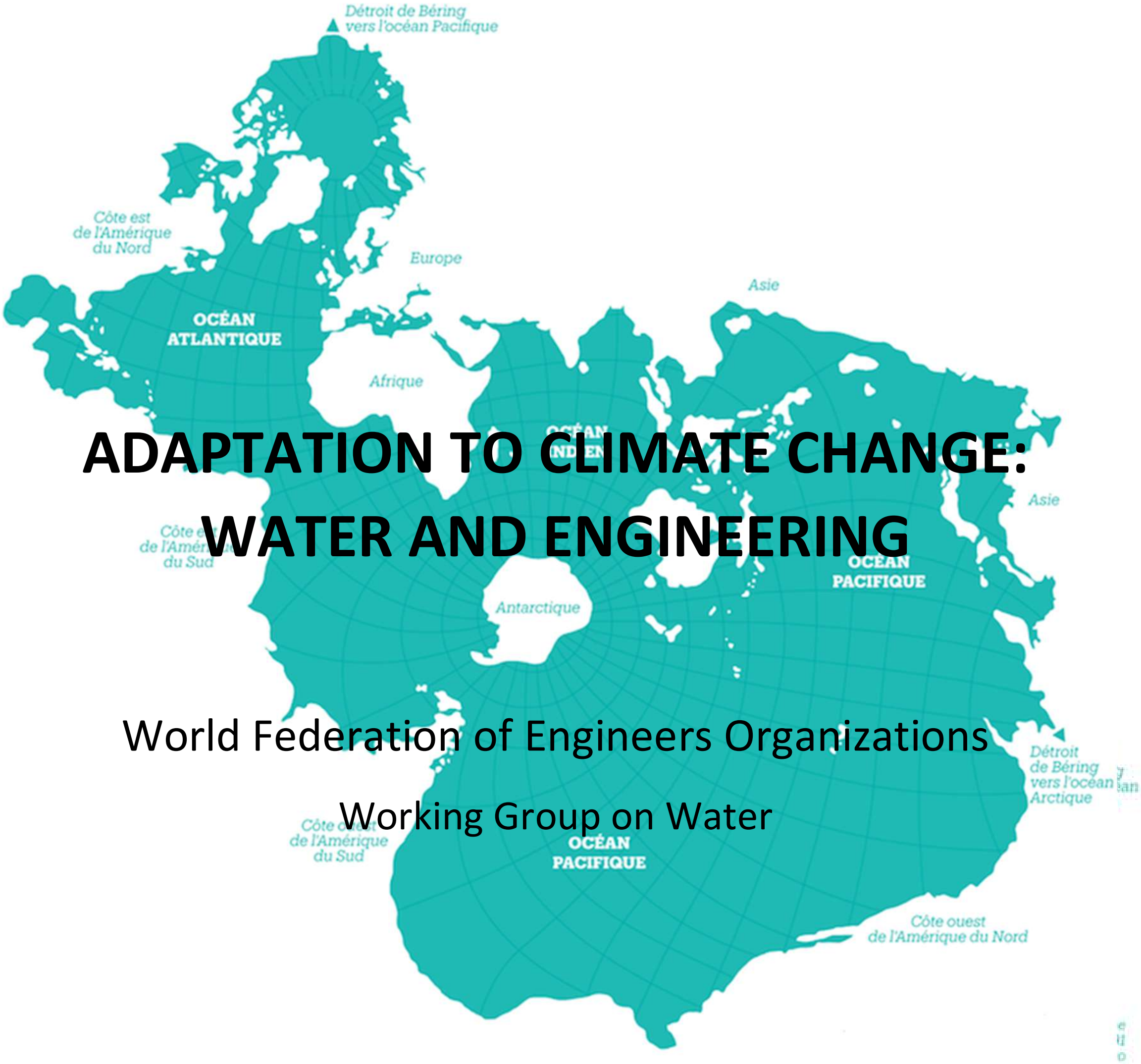
ADAPTATION TO CLIMATE CHANGE

Water and Engineering







ADAPTATION TO CLIMATE CHANGE: WATER AND ENGINEERING

World Federation of Engineers Organizations

Working Group on Water

WFEO / FMOI

LEAVE NO ONE BEHIND

August, 2021

ACKNOWLEDGMENTS

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1 Introduction.

1.1 The Working Group on Water of the World Federation of Engineering Organizations.

Given the growing importance of water in the global agenda and its cross-cutting nature to all the United Nations Sustainable Development Goals, the World Federation of Engineering Organizations (WFEO) approved in 2018, coinciding with the celebration of its fiftieth anniversary, the creation of the Working Group on Water (WGoW).

This Working Group, jointly sponsored by the "Instituto de la Ingeniería de España" and the "Ordem dos Engenheiros" of Portugal, covers all WFEO initiatives in the water engineering field and its relations with United Nations bodies and agencies, mainly with UN-Water and UNESCO. Its activity is framed within the scope of the contribution of engineering to the Sustainable Development Goals.

The Working Group's work covers the triennium 2019-2021, with a commitment to release three thematic papers. Two of them have already been delivered: "Best practices on Drought and Flood Management: Engineer’s Contribution" (2019) and " Achieving SDG 6 (Water goals): Contribution from engineering" (2021).

This work ends the Working Group on Water commitment, having achieved the objectives initially foreseen.

1.2 Objectives.

Water is a universal good indispensable for life, and its quantity and quality affect many sectors, giving this resource a social, environmental, and economic dimension. It is a good that knows no borders.

The water cycle is an essential part of the climate, understood as the set of atmospheric conditions that characterize a region. Any climate change has consequences on the water cycle and vice versa. Water conveys many of the impacts of climate change to society.

On a large scale, current climate change forecasts indicate an increase in the earth's temperature, leading to a greater water vapor present in the atmosphere and, consequently, an increase in global average annual precipitation. Extreme weather events will increase in frequency, duration, and intensity. Freshwater will be affected not only in quantity but also in quality.

Climate change also affects the cryosphere and sea level, which will rise mainly due to expanding its volume caused by thermal expansion and glaciers' melting.

Climate trends and their indicated effects at the global scale have a higher degree of uncertainty when we downscale to a regional, local, or basin level.

The different climate change scenarios foreseen affect all living beings and, more directly, human beings, especially their current way of life. This situation will be aggravated by the expected growth of the world population. It is not a matter of saving the earth but saving ourselves, other living beings, and our lifestyle.

This task entails, among others, the adoption of mitigation and adaptation measures in which engineers and engineering play an important role.

This document's objective is, precisely, to identify those alternatives for adaptation to climate change that engineers and engineering can contribute in the field of water. These actions will make it possible to cooperate in achieving the 2030 Agenda for Sustainable Development. Development that must be not only sustainable but also intelligent and inclusive.

The first chapter of the book "Water, a cross-cutting resource" analyzes the cross-cutting nature of water resources, describing the synergies and conflicts of Sustainable Development Goal "6 - Water and Sanitation" with the rest of the goals and also its relationship with engineering.

Before covering adaptation measures, it is necessary to know the change scenarios we are facing. For this reason, in the section "Water and climate change" it has been considered appropriate to summarize the main effects of climate change that have a direct or indirect impact on water.

The main adaptation measures are listed in the chapter "Water, adaptation, and engineering", having been grouped into three categories: adaptation measures related to water supply-demand, extreme weather events, and those related to sea-level rise. Throughout this section, experiences, examples, and good practices of adaptation that engineering has provided in the field of water are also described.

2 Water, a cross-cutting resource.

Water is one of the most important natural resources for life, the formation of different landscapes and ecosystems, and development. Therefore, only effective and efficient management of this resource can make it possible to achieve the goals of the three dimensions of sustainable development (social, environmental, and economic).

Sustainable Development Goal "6 - Water and sanitation" (SDG6) is interlinked with the entire 2030 agenda. The linkages between this SDG and the other SDGs can produce positive synergies but also generate conflicts. However, most of the relationships of SDG6 with the rest of the SDGs are positive because achieving its targets makes it possible to achieve those of the other goals.

How these linkages interact is not static but can vary between regions, countries, or even from one river basin to another.

Integrated planning and management of water resources and territory are the meeting point for these relationships between the different objectives and goals and the framework for resolving potential conflicts through all stakeholders' participation.

Figure 2-1: Relationship between Sustainable Development Goals and Dimensions. Illustration prepared by the author, based on information published by UN-Water (UN-Water, 2016).

The social dimension of water is most significant in the poverty and hunger eradication goals. However, there are also close links between SDG6 and the rest of sustainable development's social dimensions (UN-Water, 2016).

Ensuring access to WASH (water, sanitation, and hygiene) services, sustainable and quality water resources, and integrated water resources management is central to this social dimension. Investment in water and sanitation also yields significant social and economic returns. The benefits exceed the cost of intervention by 3 to 6 times. The World Health Organization (WHO) and the World Bank indicate that the global economic return on sanitation expenditure is US$5.50 for every US$1.00 invested (UN-Water, 2015).

Extreme weather events, such as droughts or floods, heat or cold waves, and cyclones, increase societies and economies' vulnerability.

Access to water is fundamental to global economic activity. The goods and services produced generate a water footprint, and their exchange or trade produces a virtual water market between different territories, regions, or countries.

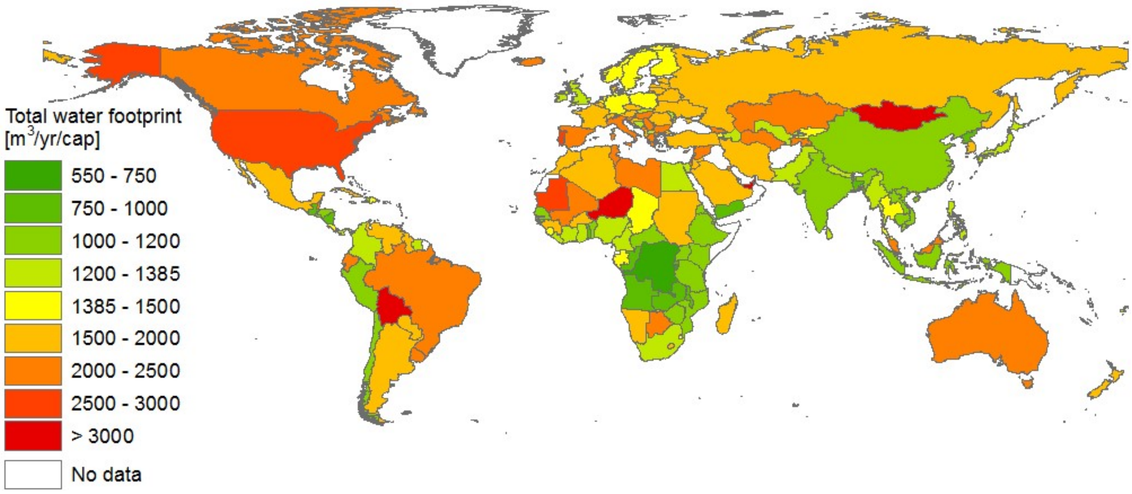


Figure 2-2: The total consumption water footprint per country (m^3/year per capita). Countries shown in green have a smaller water footprint than the world average; countries shown in yellow-red have a larger water footprint than the world average (Mekonnen & Hoekstra, 2011).

Consumers and producers can have a major impact on water quantity and quality.

Approximately one-fifth of the global water footprint is for export. Industrialized countries have water footprints in the range of 1,250-2,850 m^3⁄y per capita while developing countries show a much larger range of 550-3,800 m^3⁄y per capita (Mekonnen & Hoekstra, 2011).

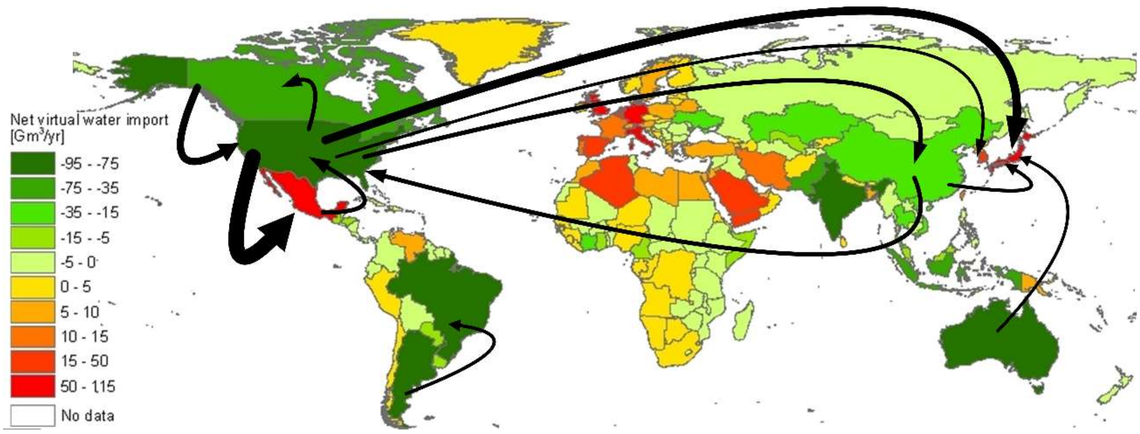


Figure 2-3: Virtual water balance by country and direction of gross virtual water flows related to agricultural and industrial trade during 1996-2005. Only the largest gross flows (> 15 Gm3/yr) are shown; the fatter the arrow, the larger the virtual water flows (Mekonnen & Hoekstra, 2011).

To achieve sustainable social and economic development, it is essential to decouple this development from environmental degradation and its natural resources. Therefore, the goals of economic productivity, growth, industrialization, and urbanization must be achieved in an integrated manner with other goals of these objectives and those of other sectors to avoid any potential conflict with the goals of water and aquatic ecosystems.

The interrelations between SDG6 and the environmental dimension of the 2030 Agenda is, together with the social dimension, the most visible of all.

Ecosystems are the final receptors of wastewater from cities, industries, and runoff from agriculture and urban areas. Therefore, special care must be taken to protect them so that these ecosystems can perform their function.

From all the relationships between goals and targets mentioned above, it is clear that water is a multiplier of opportunities in the achievement of the 2030 Agenda. Still, it is also a multiplier of risks. The increase in world population and development implies a greater access to basic services and other goods and services by society. This must be done sustainably so that water pollution and ecosystem contamination do not increase. Furthermore, extreme weather events have economic and social consequences, but these events' management affects water resources quality and quantity. These scenarios will be amplified by the effects of climate change since water, being a cross-cutting resource, is the agent that conveys many of the impacts of climate change to society.

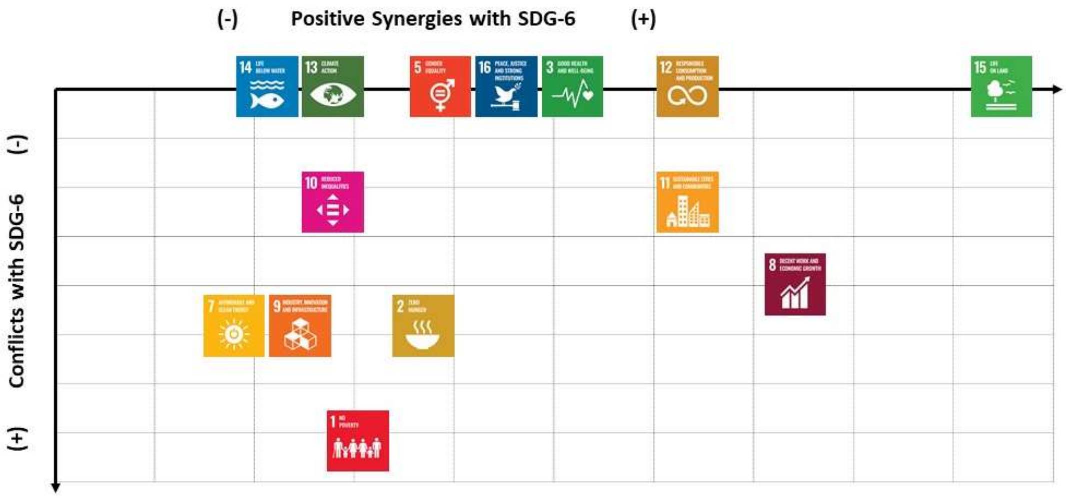


Figure 2-4: Positive and negative synergies (conflicts) of the SDGs with SDG-6. The horizontal axis shows positive synergies (synergies increase from left to right), and the vertical axis shows negative synergies/conflicts (conflicts increase from top to bottom). Illustration prepared by the author, based on information from UN-Water (UN-Water, 2016).

As mentioned above, only an inclusive and participatory integrated planning and management of water resources and territory will allow for a fair, efficient, and sustainable allocation of water resources among all sectors, including ecosystems. Additionally, they will also reduce risks and enable the prioritization of actions that will make it possible to achieve the goals of the 2030 Agenda. Appropriate water resources management also takes into consideration the effects of climate change on water resources.

Engineers and engineering provide knowledge, goods, and basic infrastructures for both society and the environment, providing growth and sustainable development.

Figure 2-5: Indicative table of different topics in which engineers and engineering can contribute to achieving sustainable development and their relationship with the SDGs. Illustration prepared by the author, based on information obtained from the World Engineers Convention 2019.

The World Federation of Engineering Organizations (WFEO) has various committees and working groups committed to the responsibility of action that engineers have, both personally and professionally, to achieve the Sustainable Development Goals. This commitment is reflected in the document "WFEO Engineering 2030. A Plan to advance the achievement of the UN Sustainable Development Goals through engineering" (World Federation of Engineering Organizations; Division of Science Policy and Capacity Building - Natural Sciences Sector, 2018).

On the occasion of the World Engineering Day for Sustainable Development 2021, WFEO has participated in the recent UNESCO report "Engineering for Sustainable Development" (United Nations Educational, Scientific and Cultural Organization, and International Center for Engineering Education, 2021).

3 Water and climate change.

Climate is the set of atmospheric conditions that characterize a region, with the water cycle being an essential part of it and a climatic connector. Water is part of climate and, therefore, of its change; thus, there is an overlap between water and climate challenges.

Based on existing evidence, it is likely that human influence has impacted the global water cycle since 1960 (Stocker, et al., 2013).

Although the total amount of water (the sum of solid, liquid, and gaseous states) has remained constant over millions of years, climate change will alter its current distribution in physical, spatial, and temporal terms.

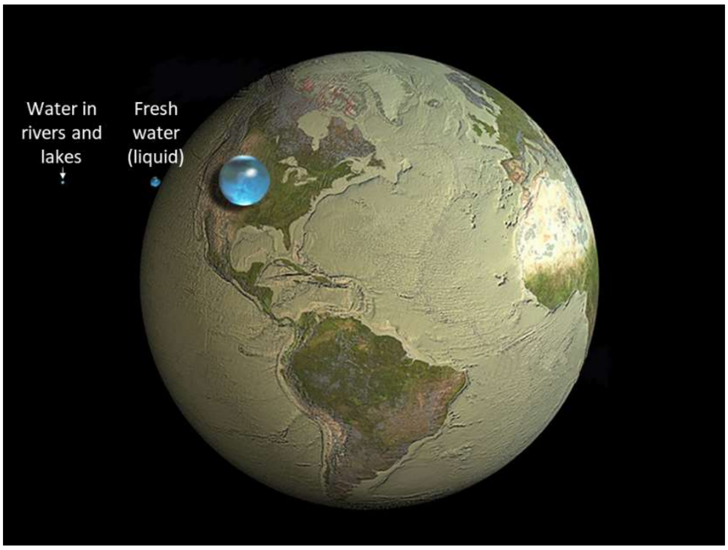


Figure 3-1: The blue spheres represent the relative amounts of terrestrial water compared to Earth's size. The largest sphere's volume represents the total amount of water in, on, and above the Earth (1,385 km in diameter). The freshwater (liquid) sphere represents groundwater, swamps, rivers, and lakes (272.8 km in diameter). The smaller sphere represents water from rivers and lakes (56.2 km in diameter). Image-based on an illustration from the U. S. Geological Survey (Perlman, Cook, Hole, Woods, & Nieman., 2016).

The earth has been warming due to an increased energy balance (incoming energy minus outgoing energy). The heat/energy added to the planet has been absorbed by the oceans (93% considering the entire ocean depth and about 64% considering only the upper layer -0 to 700 m-), ice melting (3%), continental warming (3%) and atmospheric warming (1%).

This has caused the Earth's surface's global average temperature to increase since the end of the 19th century, 0.89 °C during the period 1901-2012. The area of the atmosphere where meteorological and climatic processes take place (troposphere) has also warmed, producing an increase in the amount of water vapor in it. Specific humidity has increased both over land and over the oceans. With each additional degree of air temperature, the atmosphere can hold about 7% more water vapor. Considering this, the predicted increase in the average amount of water vapor in the atmosphere is between 5% and 25% by the end of the 21st century (Stocker, et al., 2013).

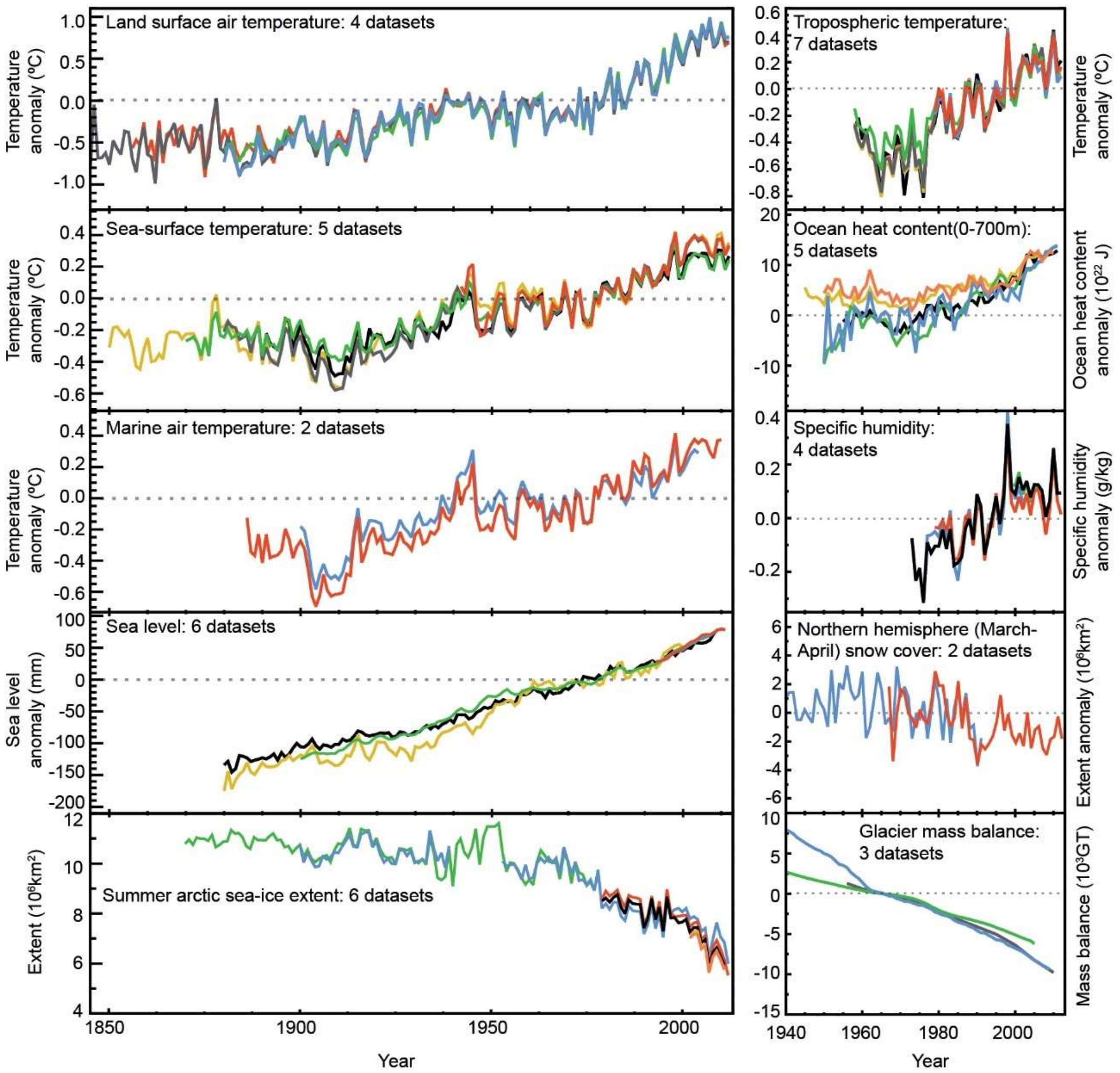


Figure 3-2: Indicators of a changing global climate. Illustration from IPCC 2013 report (Stocker, et al., 2013).

Higher temperature will raise atmospheric humidity and lead in the long term to an increase in global precipitation. This increase will be between 1 to 3% for every °C (Stocker, et al., 2013).

In general, precipitations will be more intense and frequent, generating more floods; however, there will be longer dry periods between rainfall events, leading to more droughts.

The spatial variation of precipitation will be significant, with some regions experiencing increased rainfall, some decreasing, and others no significant change.

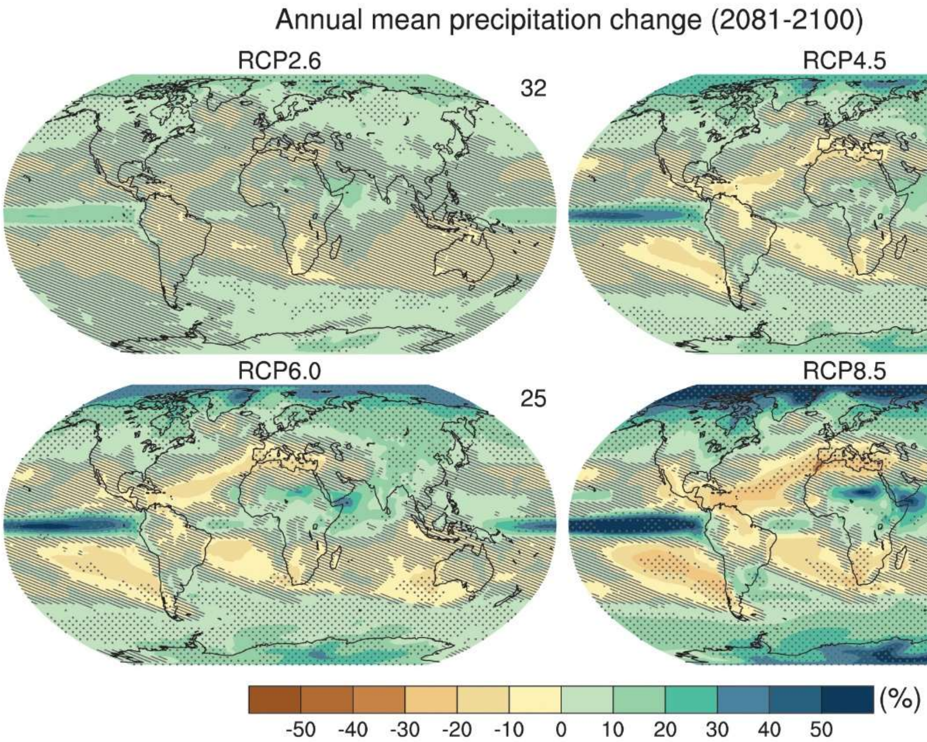


Figure 3-3: Maps of multiple model results for RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios in 2081-2100 of the mean precipitation percentage change. Changes are shown relative to 1986-2005. Illustration from IPCC 2013 report (Stocker, et al., 2013).

Extreme weather events, such as droughts and floods, will increase in frequency, duration, and intensity. Freshwater will be affected not only in quantity but also in quality.

Climate change also affects the cryosphere and sea level, which will rise mainly due to an increase in sea volume because of thermal expansion and melting glaciers (the latter is currently the main cause of sea-level rise). The contribution of thermal expansion to sea level rise is 30% to 50% of the total and glaciers 15% to 35% (Stocker, et al., 2013).

The thermal expansion of the ocean can be between 0.2 to 0.6 m per ^{o}C. Because of the slow heat transfer from the ocean surface to the deep water, ocean warming will continue to occur for centuries. By the end of the 21st century, 50% of the energy is expected to be absorbed in the first 700 meters of depth and 85% in the first 2000 meters. In contrast, the contribution of glacier melt (the current equivalent volume is 0.43 m of sea level) to sea-level rise will decrease over time as their volume decreases (Stocker, et al., 2013).

The most pessimistic of the scenarios considered in figure 3-4 means that living beings would have to increase their adaptation speed to these new situations compared to the most optimistic. For many species, change may be faster than their speed of adaptation, and even for humans, for example, the maximum limit of heat stress to which they can adapt has been called into question with an increase of 7 °C.

Figure 3-4: "Likely range" projections of global mean surface air temperature and global mean sea level rise for the mid (2046-2065) and late (2081-2100) 21st century, relative to the 1986-2005 reference period. Graph made based on data from the IPCC 2013 report (Stocker, et al., 2013).

The "likely range" scenarios shown in figure 3-4 are global averages, so the trends may be more attenuated or pronounced (figures 3-5 and 3-6).

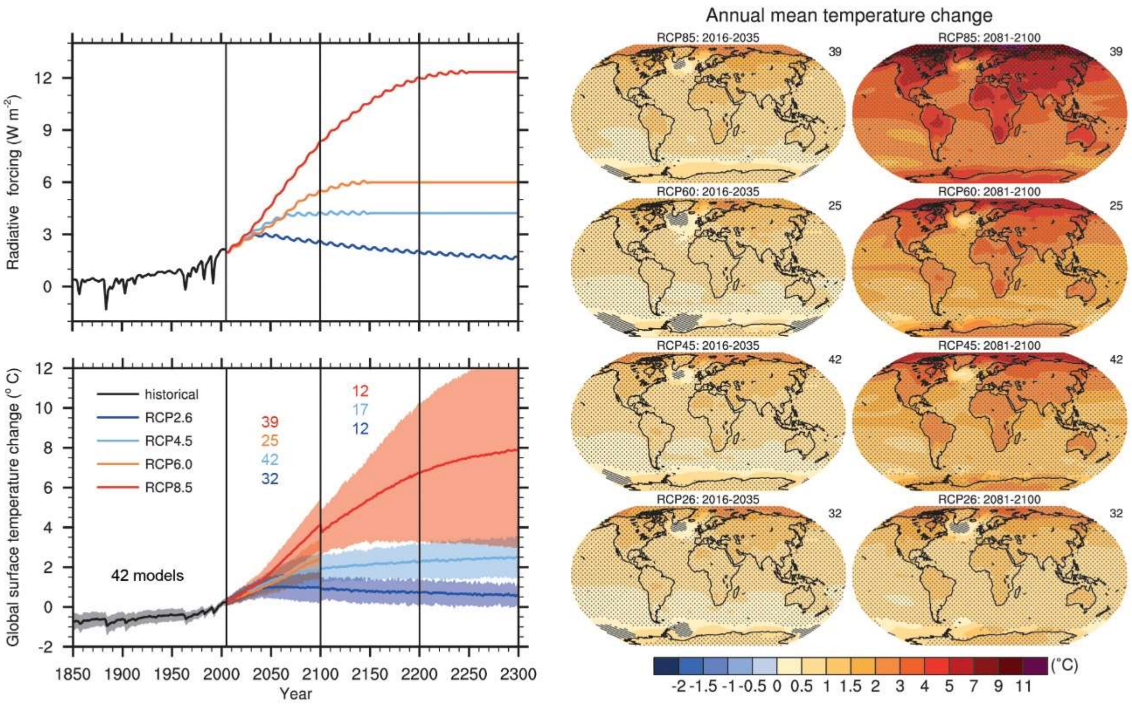


Figure 3-5: (Top left) Total global mean radiative forcing for the four RCP scenarios based on the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) energy balance model. (Bottom left) Time series of global annual mean surface air temperature anomalies (relative to 1986–2005). Maps: Multi-model ensemble average of annual mean surface air temperature change (compared to 1986–2005 base period) for 2016–2035 and 2081–2100, for RCP2.6, 4.5, 6.0 and 8.5. Illustration from IPCC report, 2013 (Stocker, et al., 2013).

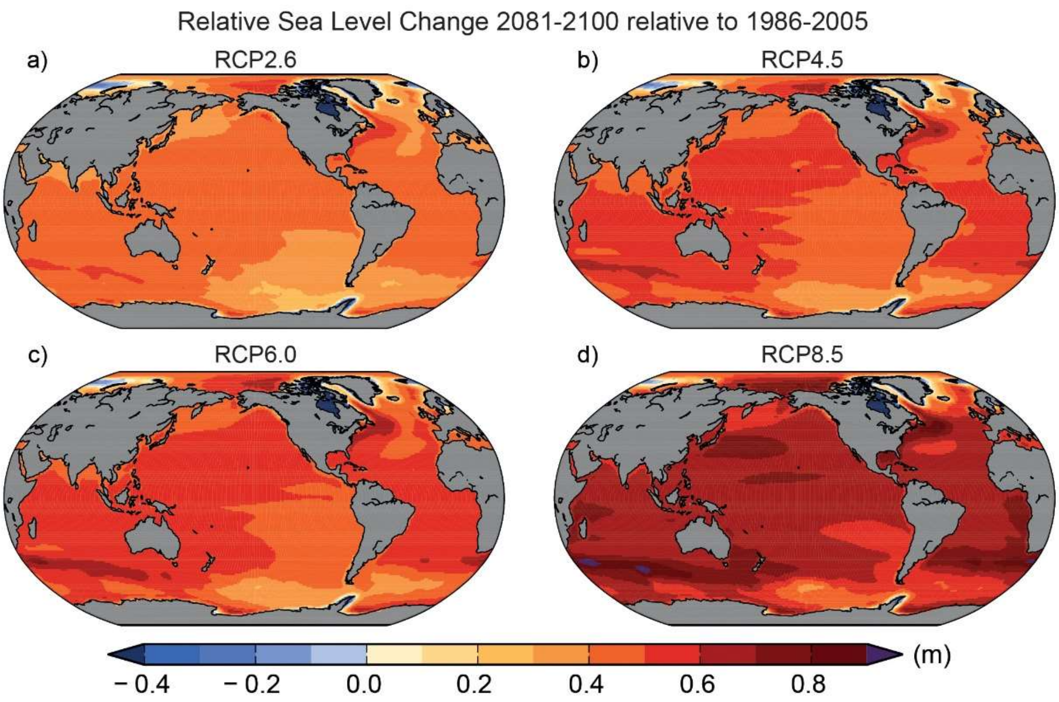


Figure 3-6: Ensemble mean net regional relative sea level change (metres) evaluated from 21 CMIP5 models for the RCP scenarios (a) 2.6, (b) 4.5, (c) 6.0 and (d) 8.5 between 1986–2005 and 2081–2100. Illustration from IPCC report, 2013. Illustration from IPCC report, 2013 (Stocker, et al., 2013).

The climate system components related to the water cycle, which are expected to change and the direction of their variation in a warmer planet, are shown in Table 3-1.

Increase	Decrease
Sea surface temperatura.	The sea ice zone.
Sea air temperature.	Snow cover.
The air temperature in the lower kilometers (troposphere).	The volume of glaciers.
The heat content of the ocean.	
Sea-level.	
The amount of water vapor.	
Temperature over land.	

Table 3-1: Components of the climate system that are expected to change and the direction of their variation in a warmer planet.

These scenarios represent a threat to water resources management, an increased risk of climate-related events, and a clear impact on the quality of water and sanitation services worldwide.

Tables 3-2 and 3-3 summarize the main short- and long-term effects of climate change on water-related elements described in various Intergovernmental Panel on Climate Change (IPCC) publications. In the long-term, external forcings are more relevant, and in the short-term, the current inertias.

It should be noted that there are uncertainties in the estimations of these effects in these publications, both in the development scenarios and in the models and scale. Also, the interactions between energy, land, water, and biodiversity are increasingly complex. This means that climate trends and their effects, although clear at the global level, have a higher degree of uncertainty when downscaled to the regional, local, watershed, or micro level. Also, long-term certainty can lead to uncertainty in the short term. Therefore, the challenge lies in knowing how to manage uncertainty at the local level since it can affect the territories and populations differently. All this adds further complexity to the field of water resources management.

Temperature	The global mean surface temperature anomaly for 2016-2035 is in the range of 0.3 ºC to 0.7 ºC (relative to 1986-2005)	Likely/Medium confidence level.
	Increased frequency of warm days and nights in most regions.	Likely.
	A decrease in the frequency of cold days and nights in most regions.	Likely.
Water cycle	Increased evaporation in many regions.	Likely.
	Increases in specific humidity near the surface.	Very likely.
	Increased frequency and intensity of precipitation over land areas.	Likely.
	Increased zonal mean precipitation at high latitudes and in some mid-latitude areas.	Very likely.
	Decreased precipitation in subtropical areas.	More likely than unlikely.
	Referring to predictions of projected changes in soil moisture and surface runoff.	Low confidence level.
Atmospheric circulation	Short-term projections of northern hemisphere storm tracks and storm intensity.	Low confidence level.
	Basin-scale projections of changes in tropical cyclone intensity and frequency for all basins through the mid-21st century.	Low confidence level.

	Oceans	An increase in the global mean surface and vertically mean ocean temperatures.	Very likely
		Increasing salinity in the coming decades in tropical and, especially, subtropical areas of the Atlantic and decreasing salinity in the western Pacific.	Likely.
		Decrease in salinity in the western Pacific in the coming decades.	Likely.
		Reduction of the Atlantic meridional return circulation by 2050.	Likely.
	Cryosphere	During September, a situation of a virtually ice-free Arctic Ocean (a sea ice extent of fewer than 106 km^2 for at least five consecutive years) will occur before the middle of the 21st century.	Likely/Medium confidence level.
		The Arctic Sea ice cover will continue to shrink and reduce in thickness. The spring snowpack at high latitudes and near-surface permafrost will be reduced as global mean surface temperature increases.	Very likely.
		Short-term decreases in the extent and volume of Antarctic Sea ice.	Low confidence level.

Table 3-2: Summary of major short-term change projections (until the middle of the 21st century) concerning temperature, water cycle, atmospheric circulation, oceans, and cryosphere. The last column of the table indicates the probability/confidence level of the projections. The term "Very Likely" means a probability of 90-100%, "Likely" a probability of 66-100%, and "More Likely than Unlikely" >50-100%. The confidence level is related to the evidence and level of agreement (Stocker, et al., 2013).

	Temperature	Globally averaged changes over land areas will be greater than over the oceans by the end of the 21st century by a factor likely to be in the range of 1.4 to 1.7.	Very high confidence level.
		The Arctic will be the region that will experience the greatest warming.	Very high confidence level.
		As the global mean temperature increases, more frequent hot extremes and less frequent cold extremes will occur in most continental areas. These changes are predictable for episodes defined as extremes on daily and seasonal time scales.	Virtually certain.
		In most regions, the high-temperature episodes that currently occur every 20 years will become more frequent by the end of the 21st century (at least doubling in frequency, and in many regions becoming annual or biannual events), and the current low-temperature episodes every 20 years will become less and less frequent.	Likely.
	Water cycle	The increase in global mean surface temperature will lead to increased global precipitation in the long term.	Virtually certain.
		As global temperatures rise, the contrast in mean annual precipitation between dry and wet regions and the contrast between the wet and dry seasons in most parts of the world will become more pronounced.	High confidence level.
		By the end of the century, many arid and semi-arid regions in mid and subtropical latitudes will experience less precipitation.	Likely.
		In many humid mid-latitude regions, precipitation will increase.	Likely.
		Globally and for short-duration precipitation events, it is likely that as temperatures increase, more intense individual storms and fewer weak storms will occur.	Likely.
		The intensity of extreme precipitation events will increase with warming at a rate that far exceeds average precipitation.	High confidence level.
		Most mid-latitude land masses and in humid tropical regions, more intense and frequent extreme precipitation events will occur.	Very likely.
		By the end of the century, and in the RCP8.5 scenario, there will be reductions in annual runoff in areas of southern Europe, the Middle East, and southern Africa and increases in high latitudes in the northern hemisphere.	Likely.

Atmospheric circulation	In the RCP8.5 scenario, a poleward shift of mid-latitude currents of about 1 to 2 degrees is likely to occur in both hemispheres by the end of the 21st century (medium confidence level), with the shift in the Northern Hemisphere being smaller.	Likely/Low confidence level.
	There remain substantial uncertainties, thus a low level of confidence, in projections of storm tracks changes, especially in the North Atlantic basin.	Low confidence level.
Oceans	The average rate of global mean sea-level rise during the 21st century will exceed the rate observed during 1971-2010.	Very likely.
	Global mean sea level rise will continue after 2100.	Virtually certain.
	By the end of the 21st century, the sea-level change will exhibit a markedly regional pattern, which will dominate over variability. Many regions are likely to experience substantial deviations from global mean change.	Likely.
	Approximately 95% of the ocean will experience relative regional sea-level rise. Most of the regions experiencing sea level decline will be located near current or extinct glaciers and ice sheets.	Very likely.
	Local sea-level changes will deviate by more than 10% and 25% of the global mean projection to 30% and 9% of ocean areas, respectively, indicating that spatial variations may be significant.	Very likely.
	In the future, it is very likely that there will be a significant increase in the occurrence of extreme sea-level values and that, as for past observations, this increase will be mainly a consequence of a rise in mean sea level.	Likely.
	Projections indicate that approximately 70% of coastlines worldwide will experience a relative sea-level change of 20% relative to global mean sea-level change.	Very likely.
Cryosphere	Northern hemisphere snowpack will shrink globally as temperatures rise over the next century.	Very likely.
	Receding permafrost extent.	Virtually certain.
	Projections reflect that by the end of the 21st century, the area with near-surface permafrost will decrease by 37% (RCP2.6) to 81% (RCP8.5).	Average confidence level.
	By the year 2100, the RCP2.6 projection indicates the disappearance of 15% to 55% of the current volume of glaciers, and the RCP8.5 projection indicates 35% to 85%.	Average confidence level.
	The average reduction in Arctic Sea ice extent for 2081-2100 compared to 1986-2005, ranging from 8% for RCP6.2 to 34% for RCP8.5 in February, and 43% for RCP2.6 to 94% for RCP8.5 in September.	Average confidence level.
	The RCP8.5 scenario envisages conditions in which the Arctic Ocean will be nearly ice-free by mid-century (ice extent less than 106 km2 for at least 5 consecutive years) in September.	Average confidence level.
	In the Antarctic, the median projection points to a decrease in sea ice extent ranging from 16% for RCP2.6 to 67% for RCP8.5 in February and 8% for RCP2.6 to 30% RCP8.5 in September for the period 2081-2100 compared to the period 1986-2005.	Low confidence level.
	Projections of the area of spring snow cover in the Northern Hemisphere by the end of the 21st-century range from a decrease of 7% [3 to 10]% (RCP2.6) to 25% [18 to 32]% (RCP8.5).	Low confidence level

Table 3-3: Summary of major projections of long-term change (from the mid-21st century onwards) for temperature, water cycle, atmospheric circulation, oceans, and cryosphere. The last column of the table indicates the probability/confidence level of the projections. The term " Virtually certain " means a probability of 99-100%, "Very likely" a probability of 90-100%, and "Likely" a probability of 66-100%. In confidence level is related to the evidence and level of agreement (Stocker, et al., 2013).

Changes in atmospheric circulation are important for local climate change, as they could produce greater or lesser changes in a given region's climate than in other regions.

Some of the spatial variations in the water cycle shown in the tables above are reflected in figure 3-7.

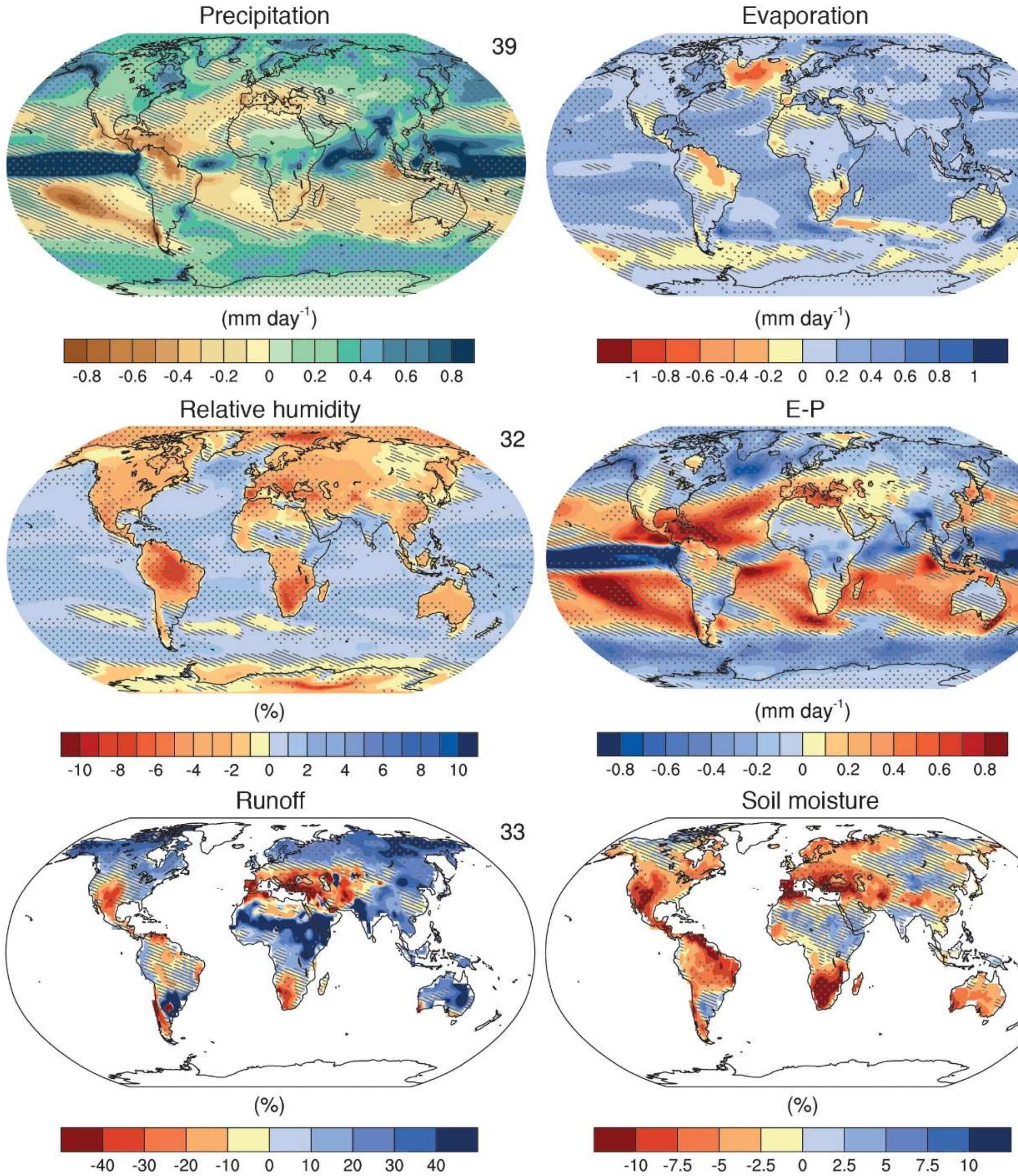


Figure 3-7: Annual mean changes in precipitation (P), evaporation (E), relative humidity, E – P, runoff and soil moisture for 2081–2100 relative to 1986–2005 under the Representative Concentration Pathway RCP8.5. Illustration from IPCC report, 2013 (Stocker, et al., 2013).

Concerning meteorological phenomena, it should be taken into account that an extreme climatic value varies depending on the location. With a significant alteration in the temporal and spatial patterns of precipitation, climate uncertainty will lead to an expected increase in droughts' risk, which will be more frequent, longer, and more intense, and of floods, with more frequent floods and higher peak flows.

Increase	Episodes of intense precipitation.	Decrease	Droughts in central North America and northwestern Australia.
	Droughts in the Mediterranean and West Africa.		
	Heat periods and heat waves		
	Hot days and nights.		Cold days and nights.
	More intense tropical cyclones in the North Atlantic.		

Table 3-4: Trends in the frequency (or intensity) of various weather extremes.

The above-described scenarios of increased temperatures and reduced flows will favor eutrophication processes and increased pollutant concentrations. The reduction of dissolved oxygen in the waters, due to the increase in temperature and eutrophication processes, will endanger numerous aquatic species' living conditions. Also, the increase in torrential rains will be accompanied by the dragging of sediments and pollutants. Additionally, the increase in sea level will favor saline intrusion processes in coastal areas (Ministry for Ecological Transition and the Demographic Challenge, 2020).

4 Water, adaptation, and engineering.

Climate change affects different sectors, but the water sector is a priority in undertaking adaptation measures. Most governments have identified water and its related sectors as key climate hazards and as priority adaptation options (UNFCCC, 2016).

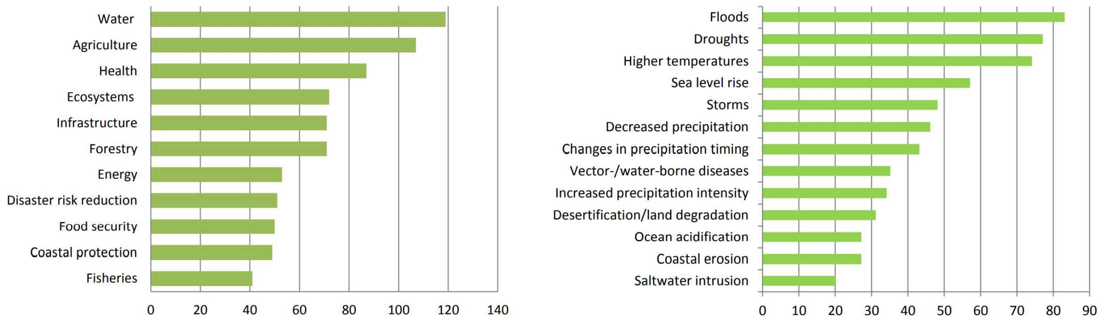


Figure 4-1: The graph on the left reflects the priority areas and sectors for adaptation actions identified by different countries in the adaptation component. The main sector is water, and the rest of the areas are indirectly related to water, except for disaster risk reduction, linked to water directly. The graph on the right shows the main climate risks identified in the adaptation component. Almost all of them are directly or indirectly related to water, except for high temperatures. Both graphs indicate the number of countries that refer to each sector. Source: (UNFCCC, 2016).

Likewise, the priority actions on water for adaptation proposed by different countries refer mainly to those related to management and governance (70%), infrastructure development (68%), water resources management (63%), and ecosystem and infrastructure conservation measures (51%) (Global Water Partnership, 2018).

This section presents different measures that engineering can provide to adapt to expected climate impacts on water. Moderating damages or taking advantage of beneficial opportunities. Some of the measures shown can also produce significant mitigation results.

Climate change will affect water resources in terms of availability, uses, water and ecosystem quality, and the probability of droughts and floods. However, other non-climatic factors have an impact on water.

The supply of fresh water will be affected by these changes, and adaptation measures will have to make it possible to meet strongly increasing demands, mainly due to population growth and the development model (factors included in climate change models).

Therefore, these measures must be approached from both supply (obtaining the resource) and demand (user of the resource). It is important to specify that the term "demand" refers to all living beings and their ecosystems, and not only human beings. Resource management must be carried out from a holistic and integrative viewpoint. It should not be forgotten that natural ecosystems are the basis of water supply.

The protection and regeneration of water resources must go hand in hand with protecting and restoration of biodiversity and the ecosystem services that water systems provide to society.

The balance between supply and demand can only be achieved through adequate integrated planning and management of water resources and territory that considers climate risks, effects, and vulnerabilities, thus enabling resilient systems and long-term adaptation strategies on water guarantees, environmental objectives, and hydraulic infrastructures. It must also involve all stakeholders, including those who do not have a voice, such as the environment and future generations.

Governance (and institutional strengthening) must facilitate the creation of management and governance structures and a regulatory framework to achieve this balance and, together with adequate funding, enable the planned measures to be undertaken, operated, and maintained. Although this paper focuses on the adaptation measures that engineering can provide, good governance and adequate financing availability are essential.

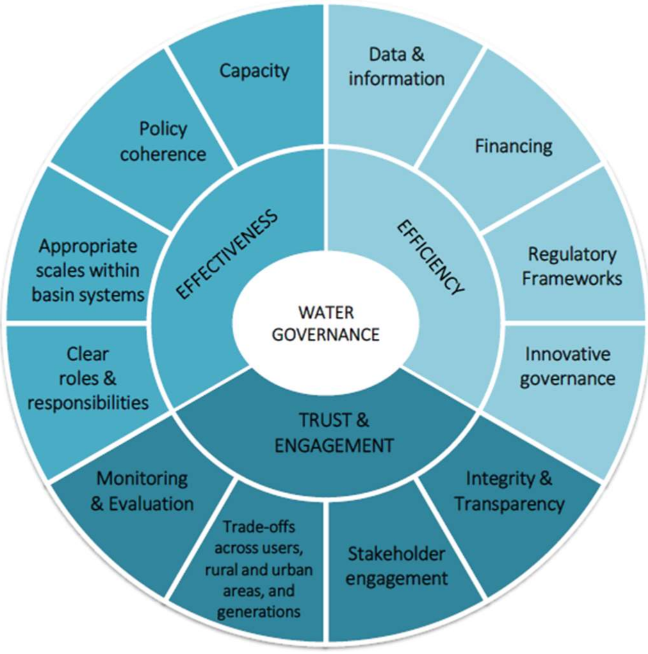


Figure 4-2: OECD Principles on Water Governance to contribute to the improvement of the "Water Governance Cycle", from policy design to implementation. Illustration from OECD (OECD, 2015).

Without these three pillars (planning and management of water resources and territory, governance, and financing), it will be difficult to guarantee water security for socio-economic activities and ecosystems or fairwater allocations. It is important that engineers and engineering are present, or at least represented, in these three pillars and not only in one of them.

In 2018, only 60% of countries (out of 172) acknowledged that they were at emerging stages of implementing an integrated water resources management approach.

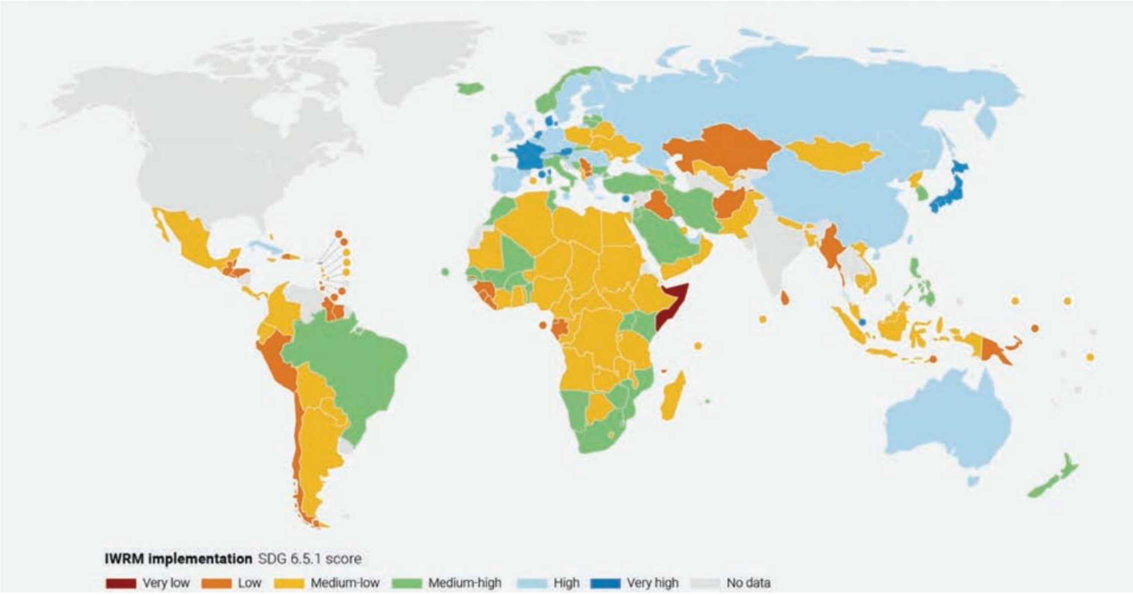


Figure 4-3: Levels of implementation of Integrated Water Resources Management in the countries. Illustration from GWP (Global Water Partnership, 2018).

Only one-quarter of countries planning water-related adaptation measures have adopted or prioritized an integrated water resources management approach (Global Water Partnership, 2018).

Considering that there are 263 transboundary lakes and river basins in 145 countries and approximately 300 transboundary aquifers (UN-Water, n.d.), governance over integrated management of these water resources becomes more complex, making cooperation between countries essential. This cooperation becomes especially essential in areas vulnerable to the impacts of climate change and where there is water scarcity. This is also the case of wetlands that extend along the borders and provide essential services.

Water scarcity may be due to source limitation, increased demand, lack of other types of resources, or institutional challenges. Also, increased precipitation does not necessarily mean increased water availability.

There are uncertainties at the local level about climate effects on the water cycle, although global trends are clear. In the uncertainty scenario, it seems reasonable to first undertake those actions independent of climate change or generate co-benefits or even implement adaptation measures in a staggered, gradual, or phased manner. These measures are referred to as "no regrets" or "low regrets" in some bibliographies. However, this terminology does not seem very appropriate since an action undertaken within the framework of adequate planning can never be considered "regrets". Uncertainty related to future scenarios means that every effort should be made to adopt flexible or resilient approaches, focusing on short-term, low-uncertainty actions.

As far as possible, adaptation measures should be subject to a cost-benefit analysis, with priority being given, in any case, to measures aimed at saving water and reducing consumption, diversification of resource sources, improvement of the status of water bodies and aquatic ecosystems, improvement of ecological connectivity, adaptation of hydraulic infrastructures to new scenarios and energy efficiency, incorporating renewable energies into the joint scheme of water and energy use, as a way to reduce operating costs of generating and transporting resources such as regenerated and desalinated water (Ministry for Ecological Transition and the Demographic Challenge, 2020).

It should be emphasized that adaptation strategies must also be based on knowledge (bigdata, etc.) to advance adequate decision-making.

In this paper, climate change adaptation measures that engineers and engineering can contribute to the water field have been grouped into three areas:

- Adaptation measures related to water supply-demand.
- Adaptation measures for extreme weather events.
- Adaptation measures due to sea-level rise.

Each of these measures, whether structural or non-structural, is described below. The physical measures indicated cover both the so-called, not very accurately, gray and green infrastructures. It is important to emphasize that the latter, also called nature-based solutions, are nothing more than traditional solutions, already applied previously by different disciplines of engineering, in which a greater technical and scientific knowledge of natural behaviors has allowed a better understanding of ecosystems and therefore of the functions they perform. This allows the design of more environmentally advantageous proposals with a greater degree of certainty about their effectiveness and efficiency, that is, a greater degree of certainty in their results. This type of solution works when environmental conditions are appropriate for a given ecosystem. Cross-cutting collaboration between different disciplines of engineering has facilitated the use of these solutions.

4.1 Adaptation measures related to water supply-demand.

Water supply is the quantity of this resource, provided by different sources, existing in a region or basin during a given period of time. Humans withdraw part of this water to meet their demand, both for supply and for the production of food, goods, and services (social and economic activities).

The water extracted (conventional and non-conventional resources) is stored, transported, treated, and distributed to the place of demand, although losses or leaks occur during this path and processes that return the water to the system, but not to its place of origin. Once consumed or used, the water may return to the system contaminated or be treated to return it to environmentally acceptable conditions even for later use (reuse). Figure 4-4 shows a diagram of the process described.

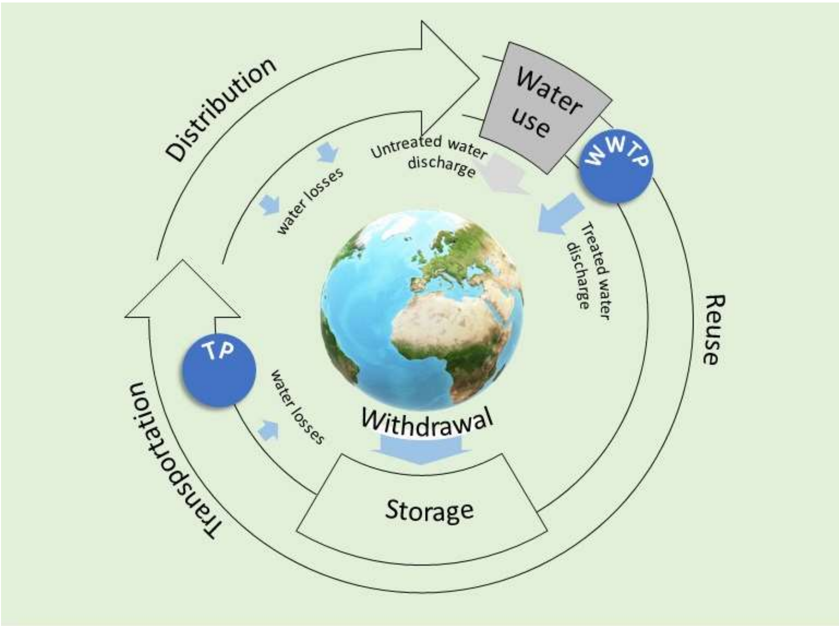


Figure 4-4: Cycle of human use of water resources from its extraction to its return to the environment (TP: Treatment Plant, WWTP: Wastewater Treatment Plant). Illustration prepared by the author.

In the different scenarios indicated in previous sections, climate change will affect water supply in terms of availability, quantity, and quality. Demand will be affected mainly by the increase in the world population and the current development model's consumption patterns. Water abstraction for domestic use has increased by more than 600% in the last 50 years, and the need for water in 2030 is expected to be 50% higher than at present.

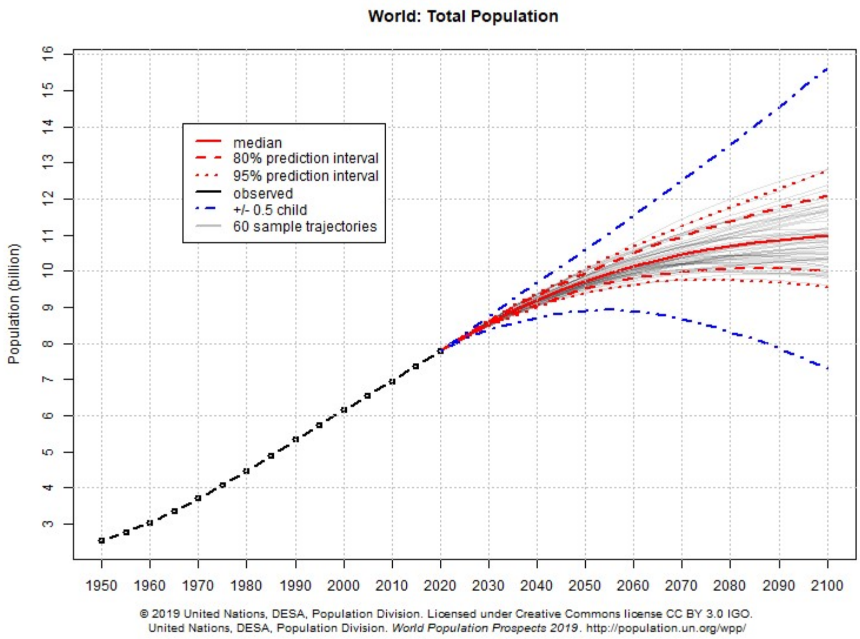


Figure 4-5: These charts show estimates and probabilistic projections of the total population for countries or areas, geographical aggregates and World Bank income groups as defined in Definition of Regions. The population projections are based on the probabilistic projections of total fertility and life expectancy at birth. These probabilistic projections of total fertility and life expectancy at birth were carried out with a Bayesian Hierarchical Model. The figures display the probabilistic median, and the 80 and 95 per cent prediction intervals of the probabilistic population projections, as well as the (deterministic) high and low variant (+/- 0.5 child). Source: United Nations, DESA (United Nations, 2019).

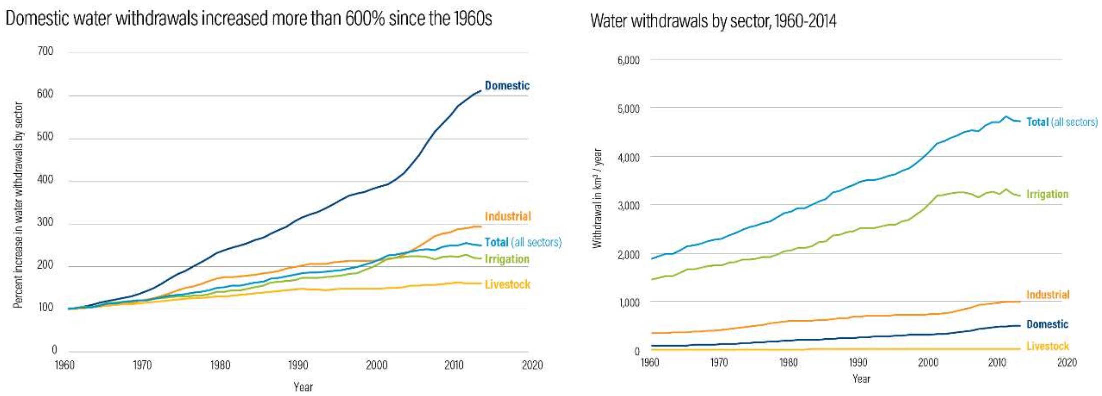


Figure 4-6: Evolution of water withdrawals by sector (domestic, industrial, livestock and irrigation). Sources: WRI-Aqueduct (World Resource Institute, 2020).

The balance between a reduced supply in terms of quantity and quality and an increasing demand can only be achieved through adequate planning and integrated water resources management and the territory.

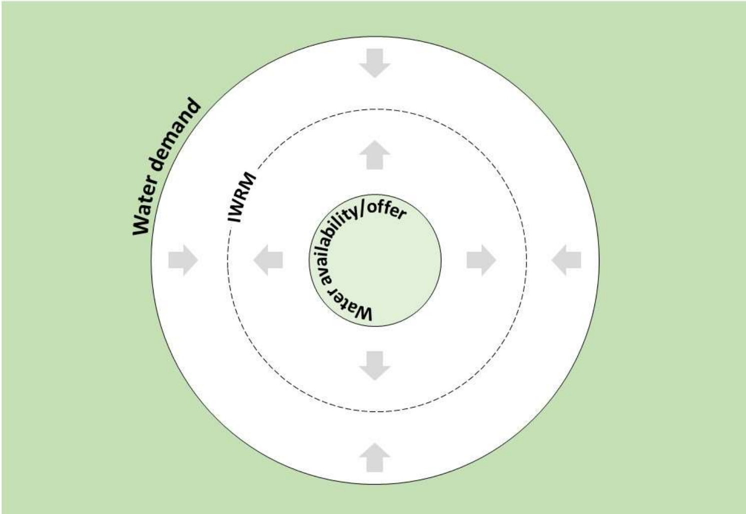


Figure 4-7: Only integrated water resources and land management that is participatory and considers the effects of climate change will optimize the supply of resources by prioritizing demand. Illustration prepared by the author.

Seven adaptation measures have been identified that engineers and engineering can provide to enable an increase in the amount of resources and improve their quality from the supply side. From the demand side, five adaptation measures focused on lower water consumption are proposed.

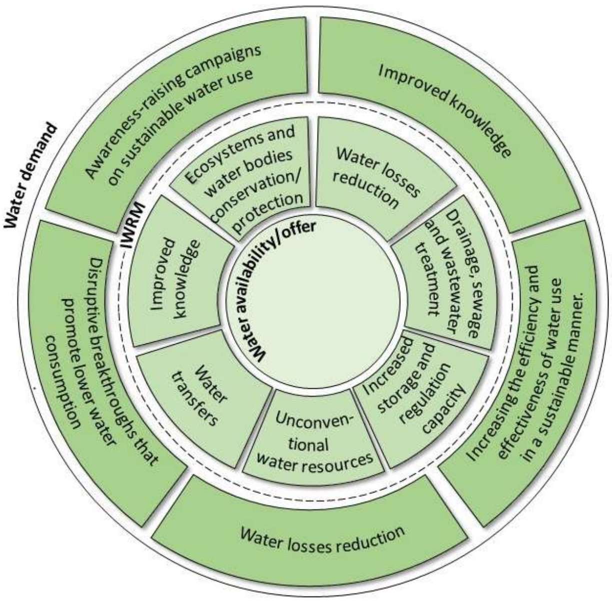


Figure 4-8: The balance point between water supply and demand is reached within an integrated water resource management. The adaptation measures that engineers and engineering can provide are a total of twelve. Seven correspond to measures focused on increasing resources (increasing supply), and five are aimed at promoting savings in water use (decreasing demand). Illustration prepared by the author.

Supply-side adaptation measures.

Increased knowledge and the protection and conservation of ecosystems and water bodies are two priority adaptation measures.

With information and analysis systems (satellite data, communication networks, big data analysis, artificial intelligence, etc.), greater knowledge contributes to better uncertainty management and decision-making. Improved meteorological data collection (satellites, weather stations, etc.) facilitates more accurate forecasts and greater precision of these predictions.

The data obtained by the satellites allow, among other things, environmental surveillance and monitoring, weather analysis and forecasting, climate research and predictions, global measurements of sea surface temperature, atmospheric temperature and humidity measurements, ocean dynamics, and vegetation analysis.

Water quality information systems, both surface and underground, facilitate water resources management and early decision-making in pollution episodes, overexploitation of aquifers, etc.

These networks are also important for monitoring climate change effects, especially in water bodies not altered by direct human action.

Figure 4-9: Information from satellites has become indispensable as a source of information for improving knowledge, establishing predictions, and making decisions (in the left image, the POES satellite -Polar Operational Environmental Satellite). Automatic water quality information systems (AWIS) provide valuable real-time assistance on surface water quality pollution, allowing immediate warning actions in the event of pollution episodes and having a deterrent effect on intentional discharges (in the image on the right, the AWIS system).

The hydrological models of the past are no longer accurate guides for the formulation of water policy, such as projections of annual availability and the frequency of droughts and floods. Improved knowledge of water uses (information on actual consumption, network losses, evaporation, irrigation returns, etc.) and the data provided by these information systems allow better analysis and formulation of new policies.

The water basin as a unit is best matched to surface and groundwater management, but new knowledge has brought to light "atmospheric basins", also known as "precipitation basins".

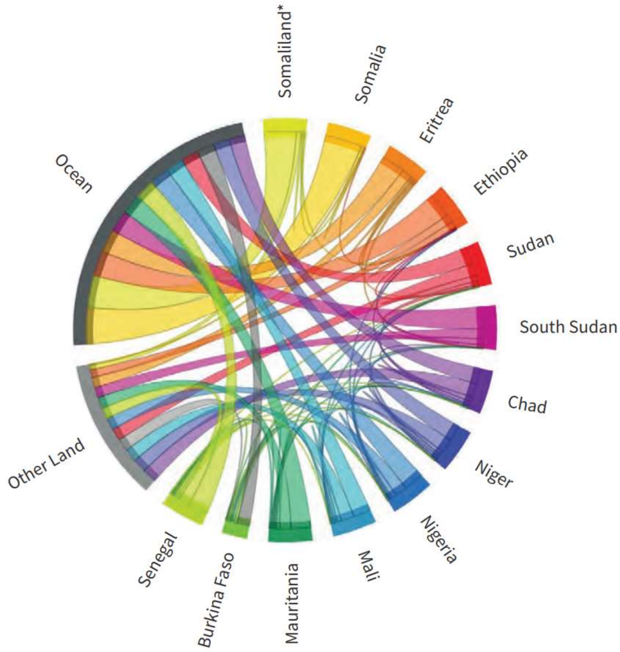


Figure 4-10: Precipitation sources or atmospheric basins for the Sahel region. The width of the flow corresponds to the fraction of precipitation received in the country/[territory]. The color of a flow corresponds to the country/[territory] in which that moisture flow falls as precipitation. When two countries/[territories] exchange moisture with one another, the color of that flow corresponds to the country with the larger (net) fraction received as rainfall. Starting from the ocean, countries/[territories] are listed clockwise from East to West. Illustration from WWDR (WWAP (United Nations World Water Assessment Programme)/UN-Water, 2018).

** Somaliland is an autonomous region of Somalia, subject to the Somali Federal Government.*

The protection and conservation of wetlands, meanders, riverbanks, surface and groundwater bodies (the latter indispensable in cases of droughts - drought wells), the elimination of non-native invasive vegetation, and the maintenance of all natural infrastructure at its source are fundamental (has repercussions) for better quality and quantity of the resource. These protection and conservation measures should be clearly incentivized to determine water prices (the polluter pays) and the strategic protection of land.

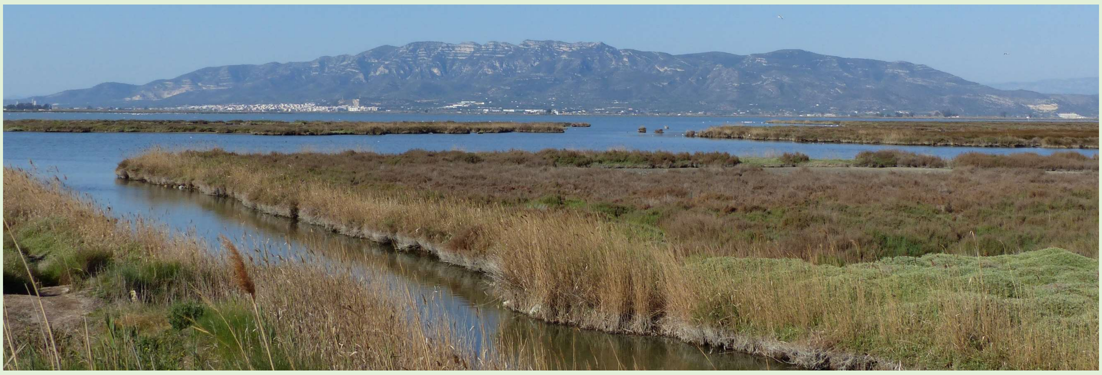
 

Figure 4-11: The protection and conservation of wetlands generate large co-benefits (the image on the left shows the wetlands of l'Albufera in Valencia, Spain). Despite their differences, all riparian zones have some similar ecological characteristics. They help control non-point source pollution. The trees and vegetation in these areas stabilize stream banks and reduce floodwater velocities (in the image on the right, the Nueces riverbanks in Texas-USA).

Box 4.1.a: **Artificial settling wetlands in the Ebro Delta, Tarragona, Spain.**

In the Ebro Delta, water from the river is used for extensive rice cultivation and then discharged into the lagoons and bays. During this process, the water incorporates a set of pollutants (nutrients, suspended matter, pesticides, etc.) that causes a decrease in the water quality of the receiving environments. This fact translates into effects on the existing natural ecosystems and on the economic activities that take place there.

The formation of purification wetlands involves applying systems that use soil, aquatic vegetation, and associated microorganisms to remove pollutants from the water.



These treatment systems are called "soft" because they do not have all the efficiency of traditional water purification treatments. However, their added value is creating areas of great ecological value, restoring areas of great potential for the establishment of fauna, and allowing their integration within visitor itineraries, thus promoting recreational and educational activities in the Natural Park area.

The construction of artificial wetlands in the Ebro Delta aims to improve the quality of the water circulating in the drains before it is discharged into the lagoon and its final outflow into the bays. Also, this construction is associated with the development of recreational areas and walkable dunes for the exclusive use of pedestrians and bicycles.

In the image above, scheme of operation of an artificial wetland/green filter: 1-Subsurface flow, 2-Surface flow and 3-Renaturalized lagoon.

Source: Ministry for Ecological Transition and the Demographic Challenge.

It has been previously mentioned that when there is uncertainty about the impact of climate change on water resources, it is convenient to implement measures that do not cause a subsequent "regret", that is, that achieve benefits regardless of climate change. These measures are the reduction of water losses, improvement of drainage, sanitation networks, and wastewater treatment. Reducing losses in storage (evaporation losses) and distribution systems (water leakage) will increase available resources.

Globally, water losses in drinking water supply networks amount to 130 km^3 per year. (International Water Association). Other agencies estimate losses in urban systems at 50 km^3 per year, which is lower but still extremely high (Kingdom, Liemberger, & Marin, 2006).

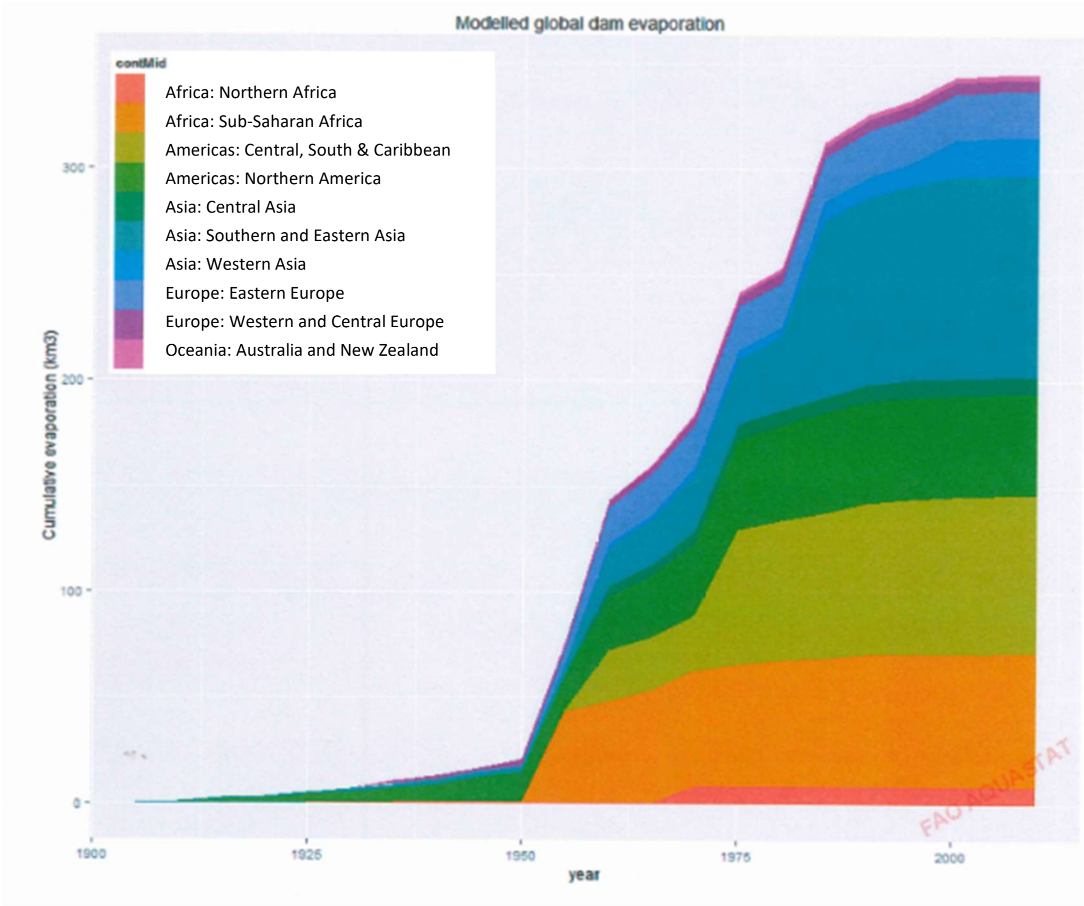


Figure 4-12: Estimation of evaporation in artificial lakes and reservoirs by region. Source: FAO-AQUASTAT.

Figure 4-13: Evaporation losses in lakes and reservoirs amount to more than 350 km³ per year. One possible solution is to cover part of the reservoir surface with solar panels, thus achieving a double function: reducing losses and energy production (Image of the floating photovoltaic plant in the Sierra Brava reservoir in Spain).

Measures to improve drainage and sanitation networks, together with wastewater treatment, allow water to be returned to the environment in an acceptable condition of quality. Sustainable urban drainage (green roofs, pervious pavements, etc.) allows, through evapotranspiration or infiltration, surface runoff reduction. Therefore, a reduction in water treatments, if incorporated into the sewage network, or less pollution if not treated.

Figure 4-14: The installation of vegetation on rooftops generates many co-benefits. In addition to reducing and slowing stormwater runoff in urban environments, they produce oxygen, provide shade, and reduce heat in cities (in the image on the left the Chicago City Hall, USA, and on the right ACROS-Fukuoka Prefectural International Hall, Japan).

Globally, about 60% of the population is connected to a sewerage system, 4.2 billion people lack safely managed sanitation, and about 80% of wastewater is discharged into the environment without adequate treatment (WWAP-United Nations World Water Assessment Programme-, 2017).

An estimated 380 km³ of wastewater is produced each year worldwide and is expected to increase to 470 km³ by 2030 and 575 km³ by 2050 (UN-Water, 2020).

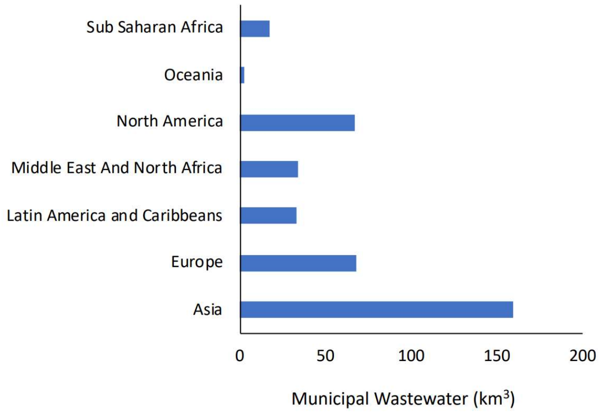


Figure 4-15: Estimated municipal wastewater production by region. An estimated 380 km^3 of wastewater is produced worldwide each year. Illustration from UN-Water (UN-Water, 2020).

The improvement of these services is independent of climate change. Only from the point of view of human health and the environment, this aspect is a priority. The decomposition of waste products accumulated in wastewater accounts for 1.3% of greenhouse gas emissions. Wastewater treatment is an adaptation measure and a mitigation measure, allowing energy to be generated in the process. Although the main source of diffuse (non-point) pollution is cultivated or industrial land, urban wastewater treatment is crucial. Improvements in sanitation systems must also be accompanied by measures to reduce the generation of wastewater by urban, industrial, and agricultural users.

Figure 4-16: The discharge of untreated wastewater is one of the most significant environmental problems that also reduce human well-being and social and economic development. This situation is aggravated by the deterioration in water quality caused by climate change, making sanitation systems a priority. Each country has a different approach to this challenge; the situation of undeveloped countries or some developing countries is not the same as developed countries. (In the image on the left "BAÑO" means "Toilet". Right image, the wastewater treatment plant in Morigasaki, Japan. Photo: World Bank / Monica Tijero).

Continuous monitoring of water quality in rivers upstream of the discharge points of wastewater treatment plants makes it possible to treat wastewater "à la carte" so that the quality of the treated water is adjusted at any time to the needs of the river.

Figure 4-17: Artificial wetlands/green filters are used as purification systems to improve water quality. Typically, wetlands are constructed to provide secondary and tertiary treatment of wastewater and improve local water quality

through the natural geochemical and biological processes inherent in a wetland ecosystem (left image, artificial wetland creation. Right image, artificial wetland in the Ebro Delta, Spain).

Increasing storage and regulation capacity is important to increase supply and make it available when demand requires it. Rainwater harvesting (micro-harvesting techniques, off-site harvesting, cultivation on terraces, roofs, other runoff areas, etc.), reservoirs, construction or restoration of wetlands, recharge of aquifers, and groundwater exploration and extraction are the main bases for this measure. Regarding reservoirs, some bibliographies indicate that they are an important source of greenhouse gas generation. This assertion should be analyzed on a case-by-case basis and not treated as a generality since it depends on the organic load present in the rivers, the vegetation removal measures that have been carried out before the reservoir's filling. Also, if it occurs, it occurs during the reservoir maturation period.

Figure 4-18: Climate change scenarios predict an increase in the temporal, spatial, and intensity variability of precipitation. Given this situation, there is a need to increase water harvesting and storage. This can be done through rainwater harvesting and storage (top left image -water retention with semicircular banks- and right image -rainwater harvesting-), reservoirs (middle left image -Plover Cove coastal reservoir in Hong Kong- and right image -Uzquiza dam in Spain-), creation of water retention areas (lower left image -water retention landscape of Tamera, Portugal-) and aquifer recharge (lower right image - aquifer recharge pond system in California-, USA).

Unconventional resources such as reuse, desalination of seawater or brackish water, or atmospheric water capture are becoming increasingly widespread in water scarcity regions. These new resources allow the release of other resources (not always economically quantified) and diversify sources. Water reuse and desalination have traditionally been expensive waters, mainly due to the energy consumption costs used in the process. This aspect has changed substantially in recent years, allowing more extended use of these new resources, including high value-added agriculture in the case of desalination (greenhouses, etc.).

Figure 4-19: Unconventional resources are essential in areas where water scarcity has become structural or necessary to release other water resources for environmental purposes. Fog water harvesting can provide between 2 to 10 l/m^2 per day (top left image - fog harvesting meshes in Chile-). Water reuse treatments make it possible to reuse the resource mainly for agriculture. However, in some countries, such as Namibia, it is used for water supply (top right image - water reuse plant in New Goreangab, Namibia.). Desalination by reverse osmosis has grown exponentially over the last few decades, mainly due to the drastic reduction in energy consumption (lower image - Torrevieja desalination plant -240,000 m^3/day-, Spain-).

Considering that more than 600 million people (about 10% of the world's population) live in coastal areas that are less than 10 meters above sea level and that almost 2.4 billion people (about 40% of the world's population) live less than 100 km (60 miles) away, it seems that desalination will continue to be an indispensable resource in the future (UN, 2017).

In addition to the above, there are also other types of unconventional resources, such as the reuse of agricultural drainage water, which consists of reusing saline water until it is unusable for any economic activity instead of its prior removal or discharge. Another resource is the harvesting of atmospheric humidity through cloud seeding, which is widespread in some countries. There are also several initiatives that are not feasible today and have not materialized, such as ballast water from ships or the collection of icebergs in arctic regions and transporting them to water scarcity areas (UN-Water, 2020).

Box 4.1.b: **Sponge city planning and construction in Xiamen (Fujian Province, China).**

Sponge city is a new concept of urban development first raised in China in 2013 and has been widely implemented especially in the field of urban water management. It draws on advanced concepts of water governance from overseas and accommodates the conditions in China. Sponge City champions the power of nature and advocates nature-based solutions (NBS). Its core concept is to allow rainwater to accumulate, infiltrate, and purify naturally. Xiamen is a coastal city in southeast China. It faces stern challenges of water stress, threatened water security, deteriorating water environment, and degraded aquatic ecosystem services. In recent years, Xiamen explores a sponge city-oriented development system that spans the mountains to streams and to coasts, eyeing for harmony in mixed ecosystems of mountains, rivers, forests, grassland, and lakes. The sponge city development efforts in Xiamen City mainly include pollution prevention and control, river-and-lake network connectivity, green landscaping, drainage and urban floods prevention, road transportation and sponge communities. Engineering measures with the functions of "infiltration, retention, storage, purification, recycling, and drainage" are applied, including small-scale infrastructure such as permeable pavements, rain gardens, vegetated swales and green roofs, and river-and-lake water systems. Non-engineering measures are also an integral part of the sponge city solution, including monitoring systems, rules, and regulations. The sponge city special planning for Xiamen is undertaken by a research team from China Institute of Water Resources and Hydropower Research. Five years into its operation, the sponge city planning has achieved good results in runoff control, ecological conservation, water source conservation, and urban floods control. The successful case of Xiamen provides scalable experiences for a wider sponge city development in China.

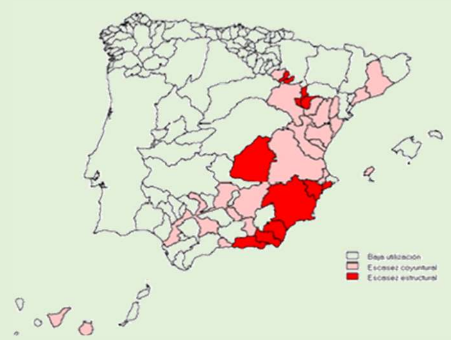
Source: China Institute of Water Resources and Hydropower Research.

The last of the seven supply-side adaptation measures is the transfer of resources between regions or basins. This measure is mainly implemented through water transfers from areas with water resources to areas with water scarcity.

The trend indicated by different models for predicting climate change shows the need for more regulation capacity and greater mobilization of water resources. Therefore, the need and opportunity for both regulations and basin connections will increase.

Box 4.1.c: **Desalination in the Mediterranean Coast, Spain.**

Spain has a wide variety of regional precipitation, which ranges from high averages of almost 2.000 mm in the north to less than 200 mm in the southeast areas (Mediterranean Regions). So, there are relevant water imbalances among regions. Thera are also prolonged droughts that will become more recurrent and severe throughout the next decades.

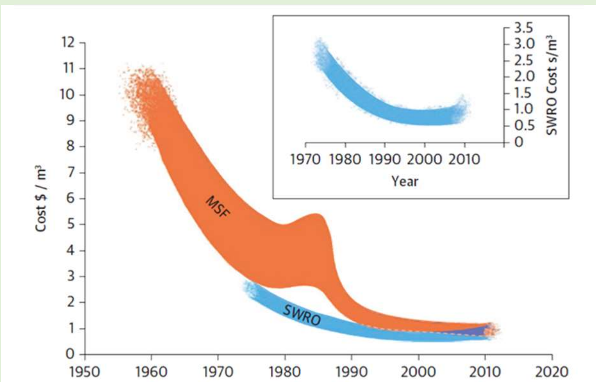


Areas of Spain with structural (in red) and temporary (in pink) water scarcity.

In regions with structural water scarcity (the southeastern Mediterranean area), non-conventional resources represent the way to match the supply-demand gap.

In Spain, the first desalination plant was built in the Canary Islands in 1964. The intense drought suffered in Spain in the mid-1990s caused desalination to make the leap from the islands to the peninsula, specifically to the Mediterranean area. This evolution in desalination has been possible thanks to governance, innovation, and technology.

The image shows the location of the most relevant desalination plants in Spain. The technology used is reverse osmosis (SWRO). Illustration prepared by the author.



Desalination costs (Sources: World Bank. 2019. "The Role of Desalination in an Increasingly Water-Scarce World." World Bank, Washington, DC.|Elimelech and Philip)

The cost of desalinated water has dropped significantly, from 3 or 4 €/m³ in the 1970s to less than a euro today.

Desalination, within the framework of an Integrated Water Resource Management, allows guaranteeing water supply and also a better risks management.

Desalination continues to face many challenges in different areas. However, it is expected to maintain its trend of growth and to play a more significant role in increasing the world's freshwater availability in the future.

Source: Ministry for Ecological Transition and the Demographic Challenge.

In certain situations, water transfers are essential because there is no other less costly alternative (economic, social, and environmental). However, they often generate conflicts between territories that are difficult to manage, causing a high social and political conflict. Environmental problems must be well evaluated in this type of solution.

This type of hydraulic infrastructure requires a long gestation period, and some of the lessons learned are the following:

- The socioeconomic context must be well understood previously.
- Political and user agreements are necessary, accords are made and have legal elements that provide security to the operation.
- It requires wisdom to estimate the capacity of the ceding basin and the effects on the catchment area. We do not endanger the ceding basin's future development or damage the socioeconomic or environmental balance and do not generate excessive expectations in the receiving basin.
- In general, it is recommended to transfer only a small percentage of the available resource.
- Development should be promoted in the ceding basin, not only in the receiving basin. At least, the ceding basin must be compensated for transferring resources.
- Once built, bodies and organizations are needed to manage these large infrastructures with good technical support and good management of the system.

Figure 4-20: South-north water transfer in Xichuan County, Nanyang, Henan, China.

Instinctively, water resource transfers are associated with water transfers because water is transported from one place to another directly and visibly. This transfer can also be carried out in many other ways through the import and export of products, goods, and services (virtual water). In some bibliographies, industries' relocation to other areas with more water resources is indicated as an adaptation measure. This alternative may be a solution on paper, but the social costs are extremely high.

Table 4-1 below summarizes the adaptation measures described from the supply side.

Supply-side adaptation	Improved knowledge (information systems and data analysis for improved decision making)	Systems for obtaining meteorological data to improve forecasts (satellites, etc.).
		Monitoring networks for the characterization and tracking of the quantitative and qualitative status of water bodies.
		Real-time hydrological information networks.

		Water sanitary quality information systems as a preventive measure for the health of the population.
		Improved understanding of natural processes and how they can improve water quality and quantity.
		Systems that allow the improvement of knowledge on water use.
		Networks for monitoring climate change effects on water bodies (especially those not altered by direct human action).
		Drinking and bathing water quality information systems.
		Systems that allow the management of uncertainties and risks.
	Protection and conservation of ecosystems and water bodies (they allow a quantitative and qualitative improvement of water by reducing post-treatment)	Protection of natural infrastructure at its source (sustainable agricultural practices).
		Protection and regeneration of wetlands and meanders.
		Removal of non-native invasive vegetation.
		Strategic land protection.
		Revegetation (including reforestation and forest conversion).
		Creation of riparian buffer zones.
		River and floodplain reconnection.
		Riverbank restoration (including riparian corridors)
	Reduction of water losses.	Systems to reduce evaporation losses in reservoirs.
		Waterway shading.
		Leak detection systems in water networks.
	Drainage, sanitation, and wastewater treatment improvement.	Providing households with basic sanitation facilities.
		Increasing improved sanitation systems.
		Construction and improvement of sewage networks.
		Implementation of sustainable drainage systems in cities (green roofs, draining pavements).
		Implement wastewater treatment facilities.
	Increased storage and regulation capacity	Bioretention or infiltration green spaces.
		Reservoirs.
		Construction of artificial wetlands (restoration or construction).
		Artificial recharge of aquifers (pumping or infiltration ponds, permeable pavements, etc.).
		Rainwater harvesting/collection.
		Increased regulation capacity through ponds and tanks.
		Groundwater exploration and extraction.
	Unconventional resources	Atmospheric humidity capture.
		Desalination.
		Reuse (of treated water or agricultural drainage water).
		Extraction of groundwater confined in deep geological formations on land or in marine aquifers.
		Increasing precipitation by cloud seeding.
	Transfer of resources	Water transfers.
		Virtual water (import/export).

Table 4-1: Main climate change adaptation measures from the point of view of water supply that engineers and engineering can provide to increase the amount of resources and improve their quality.

Box 4.1.d: **Urban Water Resilience in Africa: Kigali (Rwanda).**

The World Resources Institute (WRI) is undertaking a three-year program (2020-2022) to help advance urban water resilience in Africa. The overall objective of this work is to help cities address their water risks and vulnerabilities through research, technical assistance, knowledge sharing and partnerships for collective action. This is done in partnership with City of Kigali.

City leaders in Africa face three converging challenges: extending water and sanitation services for growing populations, managing watershed risks largely outside city jurisdictions, and designing for climate resilience. In order to survive and thrive, communities need access to reliable and affordable water as well as infrastructure that is adaptive and resilient to emerging climate risks.

The Africa Urban Water Resilience Initiative led by WRI will work with six cities on the continent to develop a new approach and strategy to overcome these barriers. This initiative is producing research and geospatial analysis to illuminate urban water resilience challenges and pathways; building partnerships with cities to develop urban water resilience action plans and provide technical assistance to advance design and implementation of priority actions; and improving enabling environments through aligned policy changes and enhanced investments from national governments and financial institutions.

Source: Institution of Engineers Rwanda and World Resources Institute.

Demand-side adaptation measures.

On the demand side, five adaptation measures have been identified, aiming to reduce water consumption.

The implementation of awareness campaigns on sustainable water use is a task in which engineers must actively participate. Especially in the promotion of water reduction practices for irrigation (modification of crop calendars, crop combinations, irrigation methods, etc.), more than 70% of water is used for this purpose.

As was the case with the measures indicated for water supply, increased knowledge is essential for decision-making regarding the opportunity (temporal, spatial, quantitative, and quantitative) of water consumption. The use of systems that detect the need for crop irrigation, soil erosion, or changes in land use, among others, can allow the establishment of highly professionalized crops.

Another measure for adapting demand is to increase water use's effectiveness and efficiency, both in industrial processes and in crops (modernization of irrigation, development of drought-, salt- and pest-resistant crops, etc.). This measure aims to increase the productivity of the resource. This also includes the reuse of water in industrial processes or even the exchange of water rights (water markets). The latter makes it possible to increase the resource's productivity through its use elsewhere, thus not conditioning socio-economic development. Reservoirs can store resources allocated over time that are not usable at the destination, and basin connections can carry water safely and efficiently from the ceding areas to the receiving areas. The exchange of water rights is a measure that also allows addressing drought situations.


Figure 4-21: Agriculture is the largest consumer of water (70% of the total). Drip irrigation systems (left image) and hydroponic crops (right image) are examples of more water-efficient agriculture systems.

The reduction of losses is also relevant, mainly in agriculture, by reducing evaporation in ponds and tanks and leaks in the distribution network. Loss reduction reduces the need for water catchment (pumping, etc.), treatment, and distribution.


Figure 4-22: Given many existing ponds, mainly for irrigation, covering them is essential to avoid evaporation losses, using continuous floating covers (left image) and discontinuous ones, such as floating balls (right image). These systems offer additional advantages: they prevent algae proliferation, extend the pond's useful life, and reduce water salinity.

The last measure, and perhaps the most important, are all those advances that make it possible to decouple development from water use or disruptive changes that promote less water consumption. These advances will release resources and ensure that water is not a limiting factor for development. Development that, with the expected increase in population, will require more food and goods. Examples of this type of progress include laboratory-grown foods (cloned meat, artificial egg-white, etc.). These types of disruptive changes are the ones that lead to an increase in the planet's biocapacity.

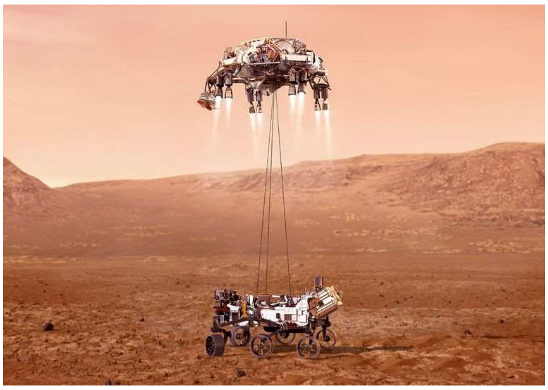



Figure 4-23: Only those disruptive advances that allow drastic water savings in production processes (industry, agriculture, and livestock) will really bring reductions in water consumption. An example of this is lab-grown meats. Global meat consumption in 2019 amounted to 325 million tons (OECD-FAO). If we consider that to produce just one kilo of beef, it is necessary to spend 15,000 liters of water; cultivated meat consumes 90% less water (in addition to needing 60% less energy and reduces the amount of land required 95%). In the top right image, the first artificial hamburger created in a laboratory from cow stem cells (the year 2013, 142 grams and cost 250 thousand euros). In 2020, Singapore authorized the consumption of synthetic chicken meat. The aerospace industry has used innovative systems to reuse 100% water for astronauts' stays in space and create new materials. Over time, these advances have been implemented in the water sector.

Table 4-2 below summarizes the adaptation measures described.

Demand-side adaptation measures	Awareness-raising campaigns on sustainable water use	Promoting sustainable practices in domestic water use.
		Promotion of indigenous practices for sustainable water use.
		Reduction in irrigation demand: through modifications of cropping calendars, crop combinations, irrigation methods, and planted areas.
		Sustainable agricultural practices.
	Improved knowledge	Systems that detect the need for crop irrigation (soil moisture measurement, etc.).
		Land erosion control.
		Changes in land use.
		Highly professionalized crops.
	Increasing the efficiency and effectiveness of water use sustainably.	Irrigation modernization.
		Greenhouse crops.
		Drought-, salt- and pest-resistant crops.
		Improvement of industrial processes (water recycling in industrial processes, reuse, etc.)..
		Measures to reduce the quantity of wastewater generated.
		Household equipment that promotes lower water consumption.
		Transfer/exchange of water rights to avoid limiting socioeconomic development.
	Reduction of water losses.	Reduction of evaporation losses in ponds and uncovered tanks.
		Reduction of water leaks in the distribution networks of users or industries.
	Disruptive breakthroughs that promote lower water consumption.	Laboratory-grown food.
		Measures that allow savings in water consumption in agriculture and that are sustainable.

Table 4-2: Main climate change adaptation measures from a water demand point of view that engineers and engineering can provide.

4.2 Adaptation measures for extreme weather events.

Climate extremes are mainly considered extreme temperatures, heatwaves and warm episodes, extreme precipitation values, and cyclones. In the case of some climatic extremes, such as droughts, floods, and heatwaves, several factors must combine to produce an extreme event (Stocker, et al., 2013).

Whether a meteorological phenomenon is catastrophic does not depend exclusively on the extreme value taken by the climatic element (precipitation, temperature, wind, pressure, etc.) but also on other factors such as the geomorphology of the affected area, population distribution, land use, inadequate practices and human interventions in the territory, the occupation of watercourses and flood plains, etc. Many of them, mostly caused by economic or social reasons, can condition the catastrophic nature of an extreme phenomenon of a certain frequency (Mata, 2001).

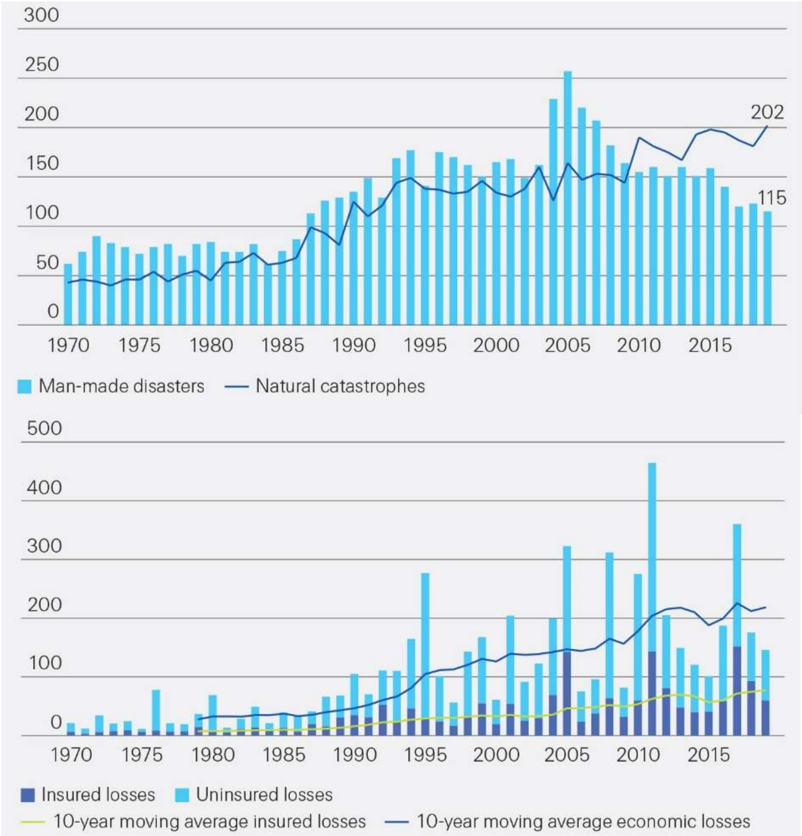


Figure 4-24: Number of catastrophic events occurring between 1970 and 2019 due to natural and human-made causes (top image) and cost of losses (USD billion, 2019 prices, bottom image). Source Swiss Re Institute (Bevere & Gloor, 2020).

Society, in carrying out all these interventions, must assume the risks that these phenomena cause in goods, services and people, either by improving infrastructures to resist extreme values of very low frequency or in a passive way by contracting insurance to cover the risks caused.

Adaptation measures for future extreme events, of greater intensity and frequency than the current ones, do not vary much with respect to the currently implemented measures.

Traditionally, these extreme events have been treated as an emergency or critical situation. At present, these policies are changing around the world, shifting from a crisis management approach to one based on risk management or adaptive management.

Engineering plays a significant role in estimating the time of occurrence of natural phenomena, affected areas, risks and potential damages, defining adaptation actions, the best options for evacuation to unaffected areas, as well as for guaranteeing essential water use and limiting the impact of droughts and developing risk management plans.

The Working Group on Water of the World Federation of Engineering Organizations drafted in 2019 the document "Best practices on Drought and Flood Management: Engineer's Contribution" (Estrela & Sancho, 2019). This document identifies several adaptation measures. As a summary, Table 4-3 lists the measures considered in this publication.

<table>
<tr><td rowspan="18">Flood risk measures</td><td rowspan="14">Structural measures</td><td>Dike and flood abatement dam and storm tanks.</td></tr>
<tr><td>Bypass channels.</td></tr>
<tr><td>Embankments and dikes.</td></tr>
<tr><td>Channel modification.</td></tr>
<tr><td>Drainage of linear infrastructures.</td></tr>
<tr><td>Sustainable drainage (green roofs and pervious pavements).</td></tr>
<tr><td>Green spaces (bioretention and infiltration).</td></tr>
<tr><td>Wetland conservation and restoration.</td></tr>
<tr><td>Construction of artificial wetlands.</td></tr>
<tr><td>Re/forestation and forest conservation.</td></tr>
<tr><td>Riparian buffer zones.</td></tr>
<tr><td>River and floodplain reconnection.</td></tr>
<tr><td>Establishment of flood diversions</td></tr>
<tr><td>Hydrological restoration and measures in flood zones.</td></tr>
<tr><td rowspan="4">Non-structural or management measures: prevention, warning, and response</td><td>Adaptation measures for potentially affected assets to mitigate damages.</td></tr>
<tr><td>Preventive measures: land management and urban planning.</td></tr>
<tr><td>Warning measures: flood warning systems.</td></tr>
<tr><td>Response measures: civil protection and flood insurance.</td></tr>
<tr><td rowspan="6">Measures to face drought risks</td><td colspan="2">Integrated water resources management</td></tr>
<tr><td colspan="2">Drought management plans</td></tr>
<tr><td colspan="2">Management and control measures: allocation of resources, water savings, and temporary transfer/exchange of water rights..</td></tr>
<tr><td colspan="2">Environmental measures</td></tr>
<tr><td colspan="2">Drought warning and monitoring system</td></tr>
<tr><td colspan="2">Agricultural insurance</td></tr>
</table>

Table 4-3: Summary of measures against flood and drought risks covered in the report of the World Federation of Engineering Organizations water group, " Best practices on Drought and Flood Management: Engineer's Contribution" (Estrela & Sancho, 2019).

One of the main uncertainties of these phenomena is the lack of knowledge of the future hydrometeorological scenario. Technology and innovation are essential in this, as well as for risk assessment and management.

Structural measures address the implementation of infrastructure works that affect the mechanisms of flood generation, action, and propagation, altering their hydrological or hydraulic characteristics. Among these are those that reduce the magnitude and frequency of floods, such as flood abatement dams or bypass channels to alternative waterways or the sea. Other measures modify flood levels, such as embankments and levees and protection walls or other actions on the channel section. Some modify the flood duration, such as drainage works, linear infrastructure works (roads, railroads, etc.).

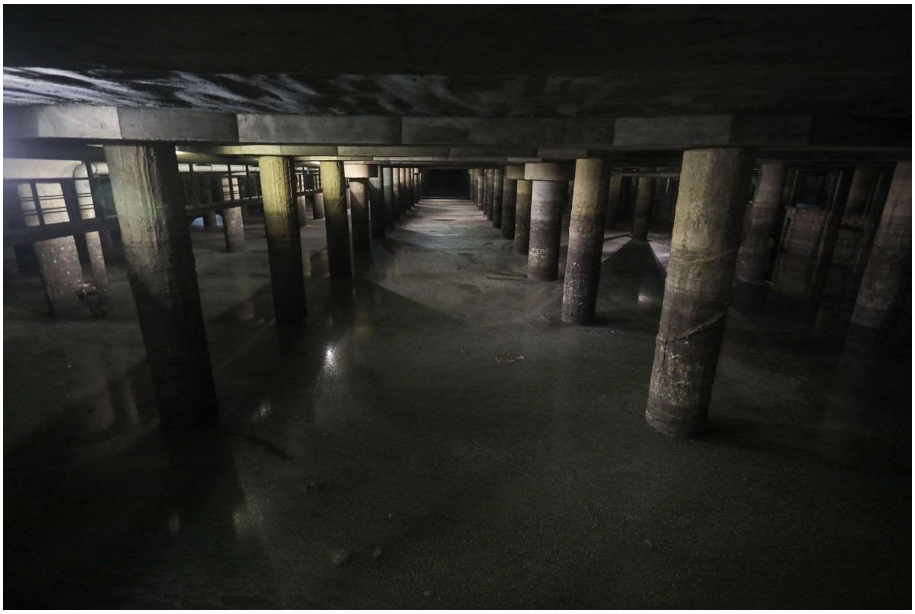


Figure 4-25: Storm tanks retain the first rainwater until the treatment plants have the capacity to treat it. Once treated, the water can be discharged back into the rivers in the best conditions without posing an ecological threat to the flow (in the picture, the 400,000 m^3 capacity storm tank of Arroyofresno, Madrid, Spain. Photo Kike Para).

Basins that host numerous flood protection infrastructures have, in many cases, lost the connection between rivers and floodplains. Natural water retention measures attempt to achieve water management objectives by restoring nature and its functions. This type of infrastructure provides protection against floods and generates multiple benefits such as increased biodiversity, mitigation of greenhouse gases, etc. Among the measures used for flood control are the establishment of buffer strips, improvement of land cover through conservation and reforestation, erosion control through transverse levees, elimination of transverse barriers to flood flow, and sustainable urban drainage systems. Also, the creation of small levees or wetlands that function as water retention areas.

Figure 4-26: Rivers are increasingly artificially channeled, with rivers becoming disconnected from their floodplains. These land areas are essential in the management of flooding events. (left image, the Colville River's floodplain, Alaska -photo: Joel Sartore/National Geographic). Natural water retention measures reduce flood risk and store water for dry periods (right image, natural retention measure in Miętne, Poland).

Sustainable urban drainage systems (SUDS) are an alternative approach to urban drainage based on containing and storing runoff at the source (rooftops, impervious areas, gardens, squares, roads, etc.). These systems can complement conventional drainage networks and help control urban runoff using techniques that replicate nature's behavior. SUDS can achieve three objectives: reduce the total volume of runoff by infiltrating part of it, improve water quality by physically and biologically treating runoff, and attenuate and reduce peak flows, preventing flooding downstream.

Figure 4-27: Different sustainable urban drainage systems (SUDS).

Measures to address drought risks are based on integrated water resources management and the establishment of management plans and measures (resource allocation, water-saving, and temporary transfer/exchange of water rights), control, and drought warning systems. Environmental measures are also essential in drought situations.

More details on each of the above measures can be found in the World Federation of Engineering Organizations' Working Group on Water publication.

Box 4.2.a: **Adaptation to Climate Change: Water and Engineering in Myanmar.**

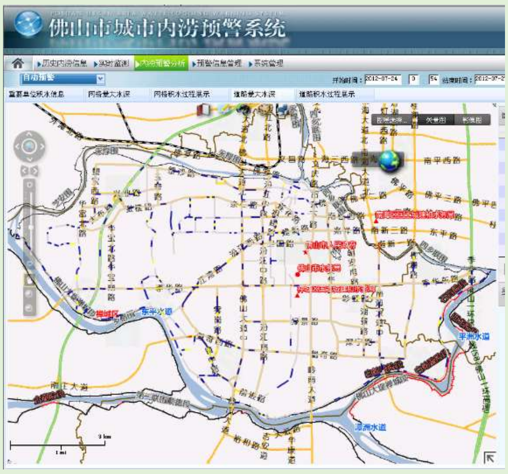
There are different projects related with Adaptation to Climate Change: Water and Engineering in Myanmar, such as for agricultural sector, flood protection, domestic water supply, urban flood protection, and upgrading of drainage system etc.

Due to the Climate Change, extreme weather conditions are experienced in recent years such as high temperature in summertime and high intensity of rainfall in rainy season. Urban flooding is one of the big problems in Yangon City since existing drainage system is not sufficient and major drainage canals are also aging since colonial period more than 100 years ago. Therefore, the Project to be implemented by Yangon City Development Committee (YCDC) is planning to review existing drainage network and redesign the carrying capacity of drainage canals accordingly with the intensity of rainfall affected by Climate Change. In addition, the project also includes the construction of sufficient pumping stations at the outlet of the main drains to the tidal river, as the flooding effect of urban flooding is more severe when high rainfall intensity coincides with high tide or spring tide.

Source: Federation of Myanmar Engineering Societies.

Box 4.2.b: **Water-logging monitoring and warning in Foshan (Guangdong Province, China): Enhancing the city's resilience against climate change.**

Foshan city is located in the center of the Pearl River Delta in China. Although the inter-weaved river network could increase the city's stormwater storage and regulation capacity by pre-drainage, this capacity is potentially weakened by inner river siltation, insufficient pumping capacity, drainage pipeline clogging as well as the low-lying terrain in certain localities. In case of local heavy rainfall, in particular, many parts of the city is inundated. The engineers at China Institute of Water Resources and Hydropower Research (IWHR) and Foshan Municipality have jointly developed the Foshan Urban Area Water-logging Warning System. It is a numerical model and warning system for water-logging prediction based on hydrology and hydraulics.



Water-logging early-warning system of Foshan city

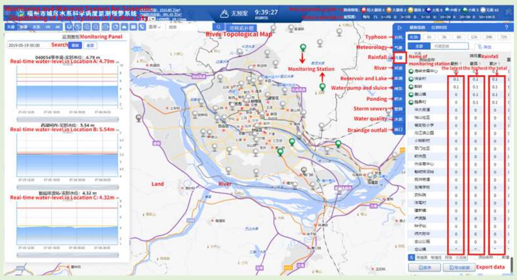
An outdoor warning display

With the simulation model as the core module, the system taps into GIS and database technologies by coupling with the radar-measured quantitative rainfall prediction data, correlating with the database of real-time automatic rainfall gauges, real-time river regime database and flood prevention and drainage project database. This system could realize the real-time analysis, calculation, and prediction of the possible water-log depth in low-lying areas, over- and under-passes, underground garages, and malls, etc. Since its operation in 2013, the Foshan Urban Area Water-logging Warning System has been used in the warning analysis of several large rainfall-induced water-logging events. It has issued 65 warning signals (4 orange, 19 yellow, and 42 blue). By virtue of this system, the hydrological department of Foshan Municipality can send warnings to Foshan municipal flood control department, traffic radio broadcast stations, residential communities, 110 hot-line and the people responsible for street block drainage through a notice platform. The messages are also displayed on outdoor screens to caution the public away from waterlogged areas. The subway management department gains the precious lead time to set up flood control facilities, and shields or sandbags can be stacked in advance to protect underground garages, etc. The early-warning messages effectively mobilize the society to adopt self-protection and self-rescue measures and minimize casualties and economic losses.

Source: China Institute of Water Resources and Hydropower Research.

Box 4.2.c: **Scientific Dispatching of the River System in Fuzhou City (Fujian Province, China).**

China is still in the process of accelerated urbanization and has formed ten urban agglomerations, especially in Southeast China. However, many mega-cities are under constant threat of extreme rainstorm events induced by rapid urbanization and climate change. In order to effectively regulate the urban drainage cycle, the Intelligent Drainage Management Platform (IDMP) has been developed based on Eyes-Brain-Hands theory. The Eyes are composed of intelligent monitoring and novel monitors on the water-IoT (Internet of Things) platform as well as big data technology They provide accurate data and contribute to a comprehensive perception of weather and water variables. The Brain refers to a multi-coupled urban drainage operation model that allows for predicting the tendency of future water regimes and informed emergency decision-making in real-time.



Monitoring and warning system of scientific dispatching of the river system in Fuzhou City (the Eyes)

Prediction system for scientific dispatching of the river system in Fuzhou City (the Brain)

The Hands serve as a unified command platform, on which various hydraulic structures including reservoirs, pumps and sluices can be remotely operated, and rescue forces and materials are efficiently coordinated and dispatched to stave off severe flooding. The three parts are linked to form a complete closed-loop system, enhancing the disaster prevention and mitigation capacity. Around two dozen of engineers from China Institute of Water Resources and Hydropower Research are responsible for the research and development of this system. Since 2017, this system has helped to formulate more than 100 emergency response plans based on water regime and urban water-logging prediction, real-time risk analysis, and the recommendation of dispatching decision-making scheme. It contributes to a significant improvement in the capacity of rainstorm emergency preparation and protects life and property. Its technologies have been successfully applied in Fuzhou, effectively helping to ease the waterlogging in the city.

Source: China Institute of Water Resources and Hydropower Research.

4.3 Adaptation measures due to sea-level rise.

The main risks caused by sea-level rise are flooding, increased coastal erosion, loss and change of coastal ecosystems, salinization of soils, aquifers and surface waters, and impeded drainage. These risks produce direct impacts on land and its uses, loss of coastal and marine ecosystem services, damage to people, human activities, goods, and services.

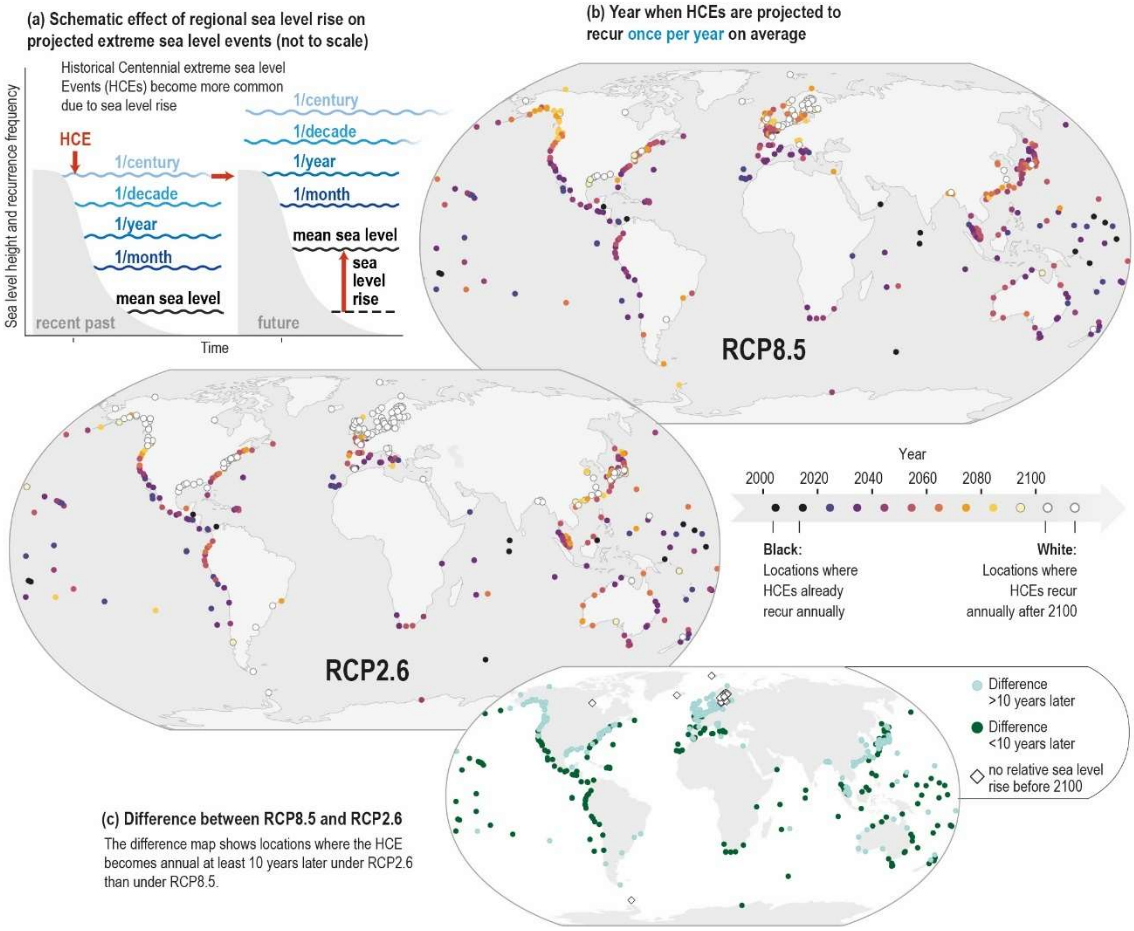


Figure 4-28: The effect of regional sea level rise on extreme sea level events at coastal locations. (a) Schematic illustration of extreme sea level events and their average recurrence in the recent past (1986–2005) and the future. As a consequence of mean sea level rise, local sea levels that historically occurred once per century (historical centennial events, HCEs) are projected to recur more frequently in the future. (b) The year in which HCEs are expected to recur once per year on average under RCP8.5 and RCP2.6, at the 439 individual coastal locations where the observational record is sufficient. The absence of a circle indicates an inability to perform an assessment due to a lack of data but does not indicate absence of exposure and risk. The darker the circle, the earlier this transition is expected. The likely range is ±10 years for locations where this transition is expected before 2100. White circles (33% of locations under RCP2.6 and 10% under RCP8.5) indicate that HCEs are not expected to recur once per year before 2100. (c) An indication at which locations this transition of HCEs to annual events is projected to occur more than 10 years later under RCP2.6 compared to RCP8.5. IPCC Illustration (Pörtner, et al., 2019).

Coastal ecosystems are affected by sea-level rise and other climate-related ocean changes, and the adverse effects of human activities in the ocean and land. Coastal megacities, urban atoll islands, densely populated deltas, and Arctic communities are examples of human pressure on ecosystems. At the same time, coastal protection is very efficient and cost-effective for cities, but not for less densely populated rural areas.

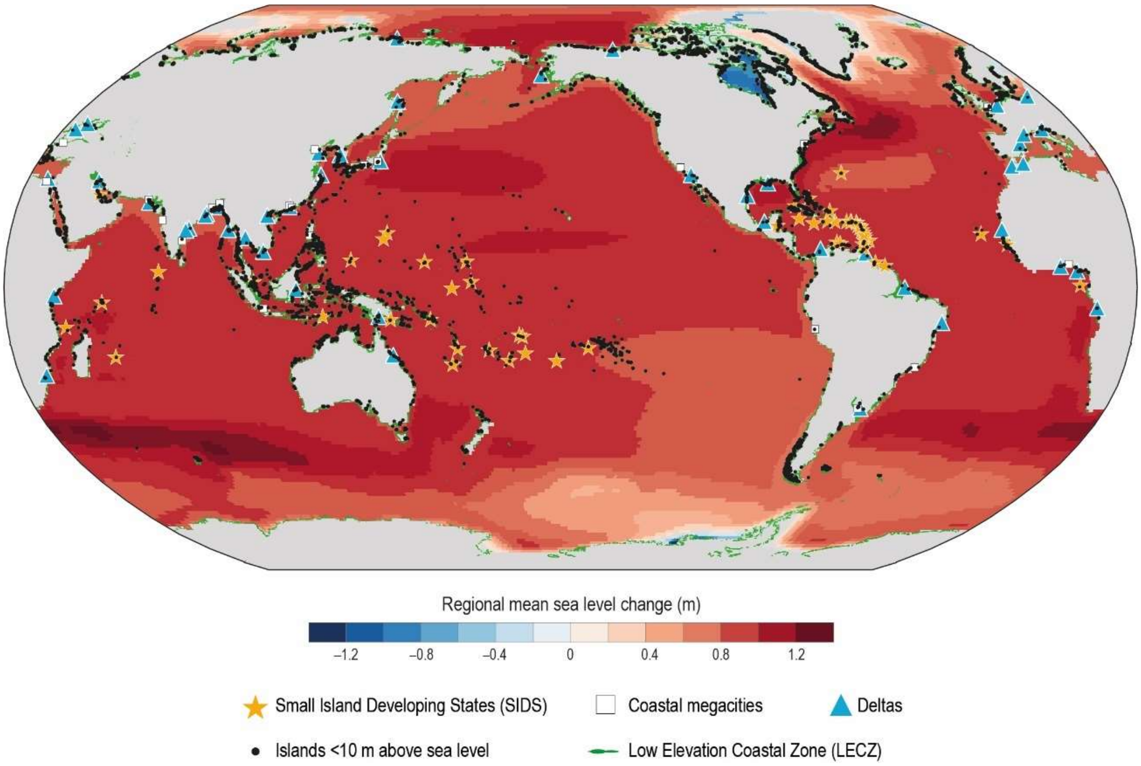


Figure 4-29: The global distribution of low-lying islands and coasts (LLIC) particularly at risk from sea level rise This map considers the Low Elevation Coastal, islands with a maximum elevation of 10 m above sea level, Small Island Developing States, coastal megacities (cities with more than 10 million inhabitants, within 100 km from coast, and maximum 50 m above sea level) and deltas. Regional sea level changes refer to projections under RCP8.5 (2081–2100). Illustration from IPCC (Pörtner, et al., 2019).

Given that sea level will continue to rise regardless of the mitigation measures undertaken, adaptation seems to be a priority. It should be noted that 10% of the world's population lives between 1 and 10 m above sea level.

Besides, morphological and ecological systems' ability to protect human settlements and infrastructure by attenuating sea level rise events and stabilizing shorelines is progressively lost due to coastal space reduction, pollution, habitat degradation, and fragmentation.

The main adaptation measures are coastal protection and advance, and accommodation or retreat (see table 4-4). All types of responses have important and synergistic roles in integrating and conserving natural resources.

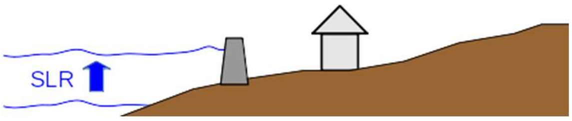
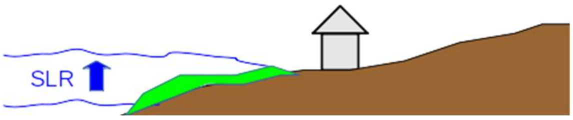
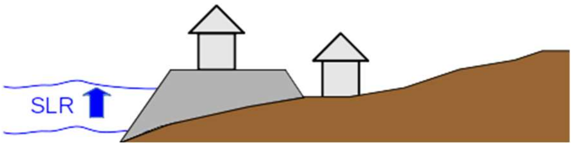
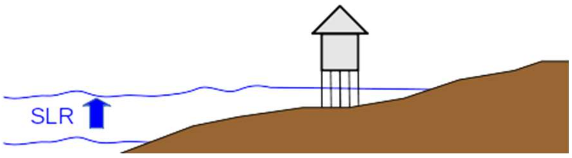
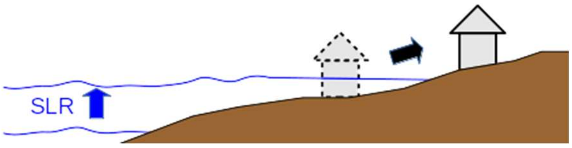
Adaptive responses to sea-level rise		
Coastal protection		
		• Hard protection, such as dikes, seawalls, breakwaters, barriers, and retaining dikes. • Sediment-based protection, such as beach and coastal regeneration.
		• Ecosystem-based protection: conservation or restoration of coastal ecosystems (dune systems, wetlands, reefs, marshes, and mangroves).
Coastal advance		
		• Gaining land from the sea by filling with sand, rock fill, or other material and planting vegetation to support soil's natural buildup.
Coastal adaptation		
		• New building codes and materials. • Drainage systems. • Changes in land use. • Planning, early warning and emergency systems. • Insurance.
Coastal retreat		
		

Table 4-4: Main adaptation responses to sea-level rise (Pörtner, et al., 2019).

Coastal protection measures prevent the inland flow of sea-level rise, reducing risk and impacts. This is also the case of coastal advance. Both measures may be cost-effective for cities but not affordable for rural and poorer areas.

Figure 4-30: Conservation, restoration, or artificial creation of coastal ecosystems play an important role in adaptation to climate change (left image, a dune system. Right image, an artificial reef dike in Narrowneck, Australia).

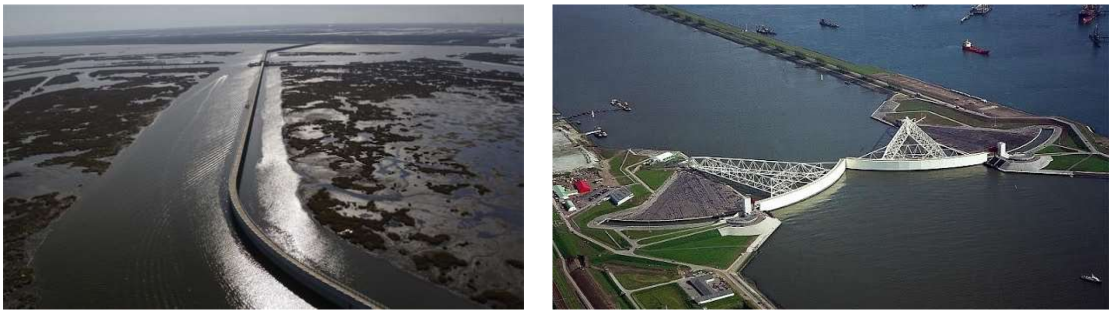


Figure 4-31: Protection measures through the construction of fixed and mobile barriers (left image, The Surge Barrier in Louisiana, New Orleans, USA. Right image, the Maeslant Kering Barrier, The Netherlands).

The main coastal advance problems are groundwater salinization, increased erosion and loss of coastal ecosystems and habitats, and the coastal floodplain's growth. Globally, an estimated 33,700 km^2 of land has been gained from the sea in the last 30 years (approximately 50% more than has been lost).

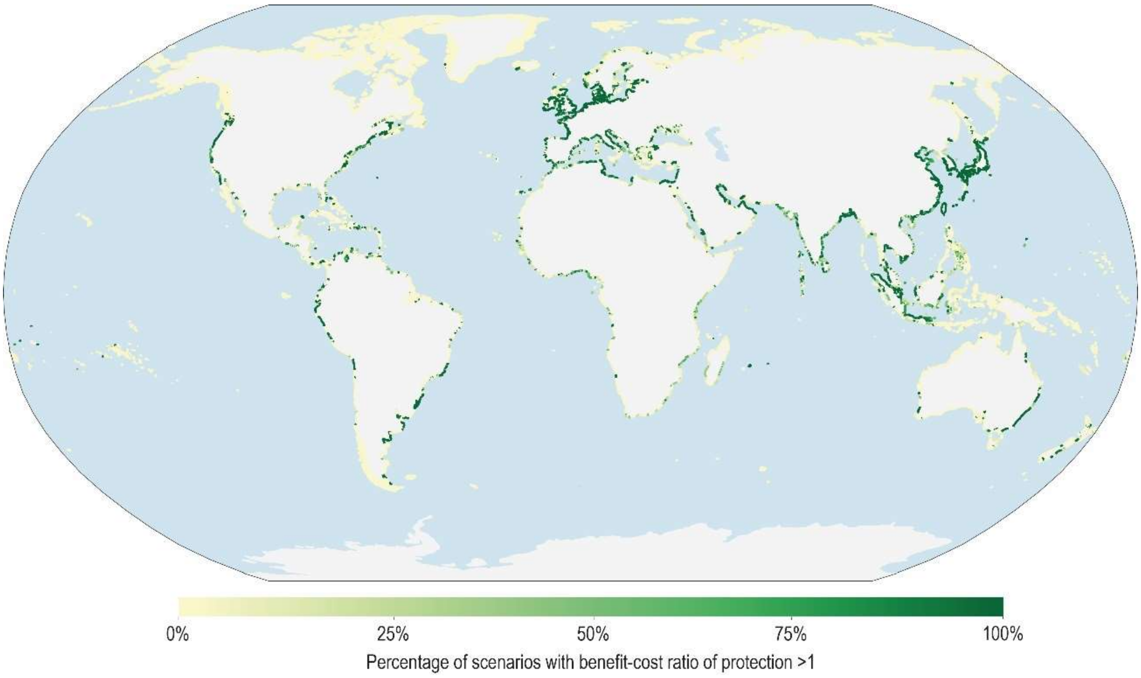


Figure 4-32: Economic robustness of coastal protection under sea level rise (SLR) scenarios from 0.3–2.0 m, the five Shared Socioeconomic Pathways (SSPs) and discount rates of up to 6%. Coastlines are colored according to the percentage of scenarios under which the benefit-cost ratio of protection (reduced flood risk divided by the cost of protection) are above 1. Source: Economically robust protection against 21st century sea-level rise (Lincke & Hinkel, 2019).

Ecosystem-based adaptation (EbA) responses provide a combination of protection and advancement benefits based on sustainable management, conservation, and ecosystem restoration. They can reduce coastal erosion and attenuate waves by acting as barriers and providing retaining space. These solutions work when environmental conditions are appropriate for a given ecosystem and require a larger surface area than traditional solutions. It should be noted that mangroves, salt marshes, and reefs are found along 40-50% of the world's coastlines.

Hybrid solutions, combining structural measures and EbA such as mangrove forests in front of levees, or building ecological improvements into engineered structures can provide an effective solution.

Adaptation or accommodation aims at the habitability (of the population, human activities, ecosystems, etc.) in coastal areas by reducing risks and vulnerabilities, despite the risks. The measures proposed are not only structural, but also those related to the establishment of new building codes, better planning, establishment of forecasting and early warning systems, etc.

Accommodation measures can be efficient in places where small rises in sea level are expected.

Figure 4-33: Coastal accommodation measures.

Coastal retreat avoids risk by moving people and property out of the hazard zone. This can be done permanently or temporarily, voluntarily or involuntarily (migration, displacement or relocation). This measure is an effective solution but has a serious social and political problem.

Adaptation measures due to sea-level rise must not only be physical and ecological, but also social, governance, economic and knowledge based. The latter must make it possible to manage uncertainty for decision-makers.

5 Conclusions.

Water is one of the most important natural resources for life, the formation of different types of landscapes and ecosystems, and for the development. It is a cross-cutting resource that affects sustainable development's three dimensions: social, environmental, and economical.

The different climate change scenarios expected pose a threat to water resource availability, both quantitatively and qualitatively. With a significant change in precipitation's temporal and spatial patterns, climate uncertainty will lead to a predictable increase in extreme weather events. The increase in global temperature will continue to raise sea levels due to thermal expansion and glaciers' melting.

Our water resources are threatened by climate change, but mainly by human activities. Population growth and current lifestyles are depleting the resources provided by the Earth, ecosystems, and biodiversity. The Living Planet Index shows an average rate of decline in species population size of 68% between 1970 and 2016. Thanks to changes in technology, land management practices, etc., global biocapacity has increased by approximately 28% in the last 60 years. However, to live, we still need 1.56 times more land than we have (WWF, 2020).

Protecting water sources at origin by maintaining natural infrastructure is essential for better water quality and quantity. Two-thirds of humanity depend on renewable water resources from forests and mountains, where 57% and 28% of the planet's surface water is generated, respectively. Healthy rivers, lakes, and wetlands provide many benefits to people worldwide: for agriculture, industry, drinking, and much more. And they are home to one in ten known animals. Despite this, the biodiversity of freshwater systems is declining at a faster rate than oceans and forests. The Living Planet Freshwater Index notes that there has been an 84% average decline in freshwater species since 1970, and one in three species is now at risk of extinction (WWF, 2020).

Engineers and engineering offer society and the environment different measures to adapt to these water-related changes. These range from providing new sources of information that facilitate knowledge for the formulation of new policies and improved decision making, to the implementation of infrastructures that allow the conservation and protection of water sources and the guarantee and security of supply. Also, treatment measures for the reuse of the resource or return of water to the environment under appropriate environmental conditions, as well as plans, warning systems or protection measures against extreme meteorological phenomena and sea level rise.

Engineering also provides increasingly effective and efficient solutions in the treatment and use of water and the maintenance, restoration, and conservation of natural infrastructure to improve the resource's quality and quantity. All these measures have contributed to the increase in the planet's biocapacity.

Climate trends at the global level are clear but have a higher degree of uncertainty at the regional or local scale. Long-term certainty can lead to uncertainty in the short term. Therefore, the challenge lies in knowing how to manage uncertainty at the local level since it can affect territories, ecosystems, and populations differently. In this complicated task, engineering has played and will continue to play an important role.

From a water supply and demand point of view, integrated planning and management of water resources and territory is a fundamental pillar to create resilient systems and long-term adaptation strategies on water guarantees, environmental objectives, and hydraulic infrastructures. Thus, guaranteeing water security and a fair distribution of the resource.

Any adaptation measure must be preceded by knowledge, by collecting and analyzing information (satellites, big data, artificial intelligence, etc.) to make appropriate decisions.

Governance must facilitate the creation of management and government structures and a regulatory framework that allows the development of planned measures, together with the existence of adequate financing. These two pillars, governance and financing, are also essential and engineers must be present, or at least represented, in both.

Considering that 60% of the world's freshwater flows cross national borders and that there are approximately 300 transboundary aquifers, governance over the integrated management of these water resources becomes more complex, making cooperation between countries essential.

Given the uncertainties at the regional or local scale of climate change action on water resources, it seems reasonable to first undertake those adaptation measures that generate co-benefits regardless of future climate patterns, or even implemented gradually or in phases. As mentioned above, climate change is one more factor that adds to the pressing current problems of the SDG6.

Some of these measures are the reduction of water pollution through wastewater treatment, reduction of water losses, protection and conservation of ecosystems and water bodies (wetlands, groundwater and surface water, etc.), improvement of irrigation, as well as reuse. All these actions can be considered both adaptation and mitigation actions.

The adaptation measure most closely identified with the circular water economy is reuse, which reduces the pressure to use water from other sources and, in coastal areas, results in a net increase in resource availability.

In addition to reuse, engineering provides other unconventional resources in areas of scarcity, such as capturing atmospheric water and the desalination of seawater or brackish water. Technological advances (reverse osmosis) have made desalination an increasingly affordable technique with less environmental impact. This has led its use to be extended beyond supply to agriculture. Considering that about 40% of the world's population lives within 100 km (60 miles) of the coast, it seems that seawater desalination will continue to be an indispensable resource in coastal areas with water scarcity.

The contribution of engineering to a greater technical and scientific knowledge of natural behaviors has allowed a better understanding of ecosystems and the functions they perform. Thus, when the environmental conditions are appropriate for a given ecosystem, new environmentally advantageous solutions with a higher degree of certainty about their effectiveness and efficiency are provided. These are artificial wetlands or green filters, sustainable urban drainage, green areas for bioretention or infiltration, among others.

Engineering is the guarantee of obtaining healthy water suitable for each of the different uses for which it is intended. Harvest, transport, and distribution infrastructures facilitate the resource's availability, and innovations in treatment systems guarantee a quality supply. Water transfers have also ensured that water is not a limiting factor in developing many regions, thus maintaining the population in the territory.

Extreme weather events will become increasingly intense and frequent because of climate change. However, the catastrophes they can cause do not depend exclusively on the extreme value of the climatic element (precipitation, temperature, wind, etc.) but also on other factors such as the geomorphology of the affected area, population distribution, land use, inadequate practices and human interventions in the territory, occupation of watercourses and flood plains, etc. Many of these factors, mostly caused by economic or social reasons, can condition the catastrophic nature of an extreme phenomenon of a certain frequency.

Addressing droughts and floods, engineering contributes with structural and non-structural adaptation solutions, from management plans and measures, warning and response systems to storage and retention elements (reservoirs, wetlands, reconnection of rivers to flood plains, flood bypasses, storm tanks, etc.).

Sea level rise causes flooding, increased coastal erosion, loss and change of coastal ecosystems, salinization of soils, aquifers and surface waters, and impeded drainage. These risks produce direct impacts on land and its uses, loss of coastal and marine ecosystem services, damage to people, human activities, goods, and services. It should not be forgotten that currently, 10% of the world's population lives between 1 and 10 m above sea level.

In this situation, engineering provides coastal protection, advance or accommodation measures. Coastal protection and advance prevent the inland propagation of sea-level rise, reducing risk and impacts. This protection can be based on ecosystems, sediments (beach, coastal, or dune regeneration), or sea walls. Accommodation aims at habitability (of the population, human activities, ecosystems, etc.) in coastal zones by reducing risks and vulnerabilities despite the existence of risks.

Climate change does not impact all places in the same way, nor do all countries have the same needs or development level. Facing these challenges, engineering can provide the best response to each specific case. The adaptation measures described are the result of the cross-cutting nature of different engineering disciplines, which have been able to adapt scientific knowledge to the needs of society and the environment. Thus, contributing to a sustainable, intelligent, and inclusive development.

6 References.

Abell, R. e. (2017). *Beyond the Source: The Environmental, Economic and Community Benefits of Source Water Protection.* Arlington, VA, USA: The Nature Conservancy.

Bevere, L., & Gloor, M. (2020). *Sigma 2/2020: Natural catastrophes in times of economic accumulation and climate change.* Swiss Re Institute.

Bill and Melinda Gates Fundation. (2021). *Gates Fundation*. Retrieved from Gates Fundation: https://www.gatesfoundation.org/

Browder, G., Ozment, S., Rehberger, I., Gartner, T., & Lange, G.-M. (2019). *Integrating green and grey.* Washington: World Resources Institute and World Bank Group.

Commission of the European Cummunities. (2007). *Green Book: Adapting to climate change in Europe: options for EU action.* Brussels: Commission of the European Cummunities.

CONAMA. (2019). *Water and Circular Economy.* Fundación Conama.

Estrela, T., & Sancho, T. (2019). *Best Practice on drought and flood management: Engineer's contribution.* World Federation of Engineers Organizations.

European Commission. (2016, November 22). *Sustainable development: EU announces its priorities:*. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/IP_16_3883

European Environment Agency. (2009). *Climate change and water adaptation issues.* Madrid: Ministry of the Environment and Rural and Marine Environment .

Global Water Partnership. (2018). *Preparing to Adapt: The Untold Story of Water in Climate Change Adaptation Processes.*

International Water Association. (2021). *World Water Loss Day*. Retrieved from World Water Loss Day: https://www.worldwaterlossday.org/

International Water Association. (n.d.). *World water loss day.* Retrieved from https://www.worldwaterlossday.org/

Kingdom, B., Liemberger, R., & Marin, P. (2006). *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries. How the Private Sector Can Help: A Look at Performance-Based Service Contracting.* Washington, DC: The International Bank for Reconstruction and Development/The World Bank.

Lincke, D., & Hinkel, J. (2019). Economically robust protection against 21st century sea-level rise. *Global Environmental Change*, 67-73.

Mata, C. A. (2001). Extreme weather events. *Física y Sociedad*.

Mekonnen, M., & Hoekstra, A. (2011). *National water footprint accounts: The green, blue and grey water footprint of production and consumption, Value of Water Research Report Series No. 50.* Delft: UNESCO-IHE Institute for Water Education .

Ministry for Ecological Transition and the Demographic Challenge. (2020). *National climate change adaptation plan.* Madrid.

OECD. (2015). *OECD Principles on Water Governance.*

OECD/The World Bank/UN Environment. (2018). *Financing Climate Futures: Rethinking Infrastructure.* Paris: OECD.

Perlman, H., Cook, J., Hole, Woods, & Nieman., A. (2016, July 16). *usgs.gov*. Retrieved from https://www.usgs.gov/special-topic/water-science-school/science/how-much-water-there-earth?qt-science_center_objects=0#qt-science_center_objects

Platform for adaptation to climate change in Spain: AdapteCCa. (n.d.). Retrieved from AdapteCCa: https://www.adaptecca.es/en/what-is-adaptecca

Pörtner, H.-O., Roberts, D., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., . . . (eds.), N. W. (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* IPCC.

PwC. (s.f.). *Water management in Spain.* Madrid: PwC.

Stocker, T., Qin, D., Plattne, G.-K., M. T., Allen, S., Boschung, J., . . . (eds.), P. M. (2013). *IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. ,* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Stocker, T.F., Qin, D., Plattner, G.-K., Alexander, L., Allen, S., . . . P. (2013). *Technical Summary. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA.: Cambridge University Press.

UN. (2017). The Ocean Conference., (pág. 7). New York.

UNESCO, UN-Water. (2020). *World Water Development Report 2020: Water and Climate Change.* Paris: UNESCO.

UNFCCC. (2016). *Aggregate effect of the intended nationally determined contributions: an update. United Nations Framework Convention on Climate Change.* New York.

United Nations. (2019). *United Nations: Department of Economic and Social Affairs: Population Dynamics*. Obtenido de United Nations: Department of Economic and Social Affairs: https://population.un.org/wpp/Graphs/Probabilistic/POP/TOT/900

United Nations. (2021). *UN-Water SDG 6 Data Portal*. Obtenido de UN-Water SDG 6 Data Portal: https://www.sdg6data.org/

United Nations Educational, Scientific and Cultural Organization, and International Center for Engineering Education. (2021). *Engineering for Sustainable Development.* Paris: UNESCO.

UN-Water. (2015). *Means of Implementation: A focus on Sustainable Development Goals 6 and 17.*

UN-Water. (2016). *Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development.* Geneva.

UN-Water. (2020). *UN-Water Analytical Brief on Unconventional Water Resources.* Geneva.

UN-Water. (n.d.). *Transboundary Waters*. Retrieved from UN-Water: https://www.unwater.org/water-facts/transboundary-waters/

World Bank Group. (2021). *Understanding poverty: water*. Retrieved from Understanding poverty: water: https://www.bancomundial.org/es/topic/water/overview

World Federation of Engineering Organizations. (n.d.). *Working Group on Water*. Retrieved from World Federation of Engineering Organizations. Web site: http://www.wfeo.org/working-group-on-water/

World Federation of Engineering Organizations; Division of Science Policy and Capacity Building - Natural Sciences Sector. (2018). *WFEO Engineering 2030. A Plan to advance the achievement of the UN Sustainable Development Goals through engineering.* Paris.

World Resource Institute. (2020, February 10). *Blog: Worl Resource Institute*. Retrieved from World Resource Institute: https://www.wri.org/blog/2020/02/growth-domestic-water-use

WWAP (United Nations World Water Assessment Programme)/UN-Water. (2018). *The United Nations World Water Development Report 2018: Nature-Based Solutions for Water.* Paris: UNESCO.

WWAP-United Nations World Water Assessment Programme-. (2017). *The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource.* Paris: UNESCO.

WWF. (2020). *LIVING PLANETREPORT 2020 - Bending the curve of biodiversity loss.* Gland, Switzerland: WWF.

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