

BEST PRACTICES ON DROUGHT AND FLOOD MANAGEMENT: ENGINEER'S CONTRIBUTION

World Federation of Engineers Organizations

Working Group on Water

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1 Introduction

1.1 Framework

The Working Group on Water (WGoW) of the World Federation of Engineering Organizations (WFEO) covers water engineering initiatives and its relations with United Nations' bodies and agencies, primarily with UN-Water and UNESCO, showing the contribution of engineering to the accomplishment of United Nations' Sustainable Development Goals (SDG).

WFEO's WGoW was created by its Executive Council at the meeting held in October 2018 in London on the occasion of the Global Engineering Congress. This Working Group was jointly proposed by Spain's Instituto de la Ingeniería de España and Portugal's Ordem dos Engenheiros. IIE'S representative and World Council of Civil Engineers' Past President, Mr. Tomás Sancho, was appointed WGoW's Chair, Mr. Joaquim Poças, Portugal's Ordem dos Engenheiros representative as Deputy Chair, and Mr. Teodoro Estrela, current Chair of WCCE's Standing Committee on Water Commission as WGoW's Secretary.

Such Working Group on Water has committed to deliver three monographs during its 2019-2021 three-year mandate regarding the following topics: Best practices on Drought and flood management: Engineer's contribution, 2019; Achieving SDG 6 on Water: Engineer's contribution, 2020 and Adaptation to climate change - Water: Engineer's contribution, 2021. This monograph addresses the first topic regarding best practices on Drought and flood management and engineer's contribution to such practices and builds upon both the mentioned reference documents and contributions provided by WFEO member organizations listed in the authorship section of this report.

1.2 Objectives

Extreme hydrological events - droughts and floods - have become current global topics regarding water issues, as reflected in the United Nations' 2030 Agenda (UN). In particular, Sustainable Development Goal - SDG No. 6 addresses water and aims to ensure the availability and sustainable management of water and sanitation for all people. Related to it is SDG No. 11, whose target 11.4 intends to reduce significantly the number of lives lost, victims and economic losses caused by water-related disasters.

The goal of this monograph is to describe the best practices for the risk management of droughts and floods, highlighting the engineer's contribution to such practices.

1.3 Summary

According to the United Nations' Office for Disaster Risk Reduction (UNDRR), the major climate-related disasters by number disasters are floods, followed closely by storms, and droughts and heat waves at a distance.

The economic impacts caused by extreme hydrological events - floods and droughts - have been increasing worldwide. These events pose serious threats to human life and the well-being of society and represent a burden and a serious challenge for the country governments, responsible for maintaining both economic development and the environment, on which society relies.

Climate change affects negatively the availability of resources and increases the frequency of extreme hydrological events, such as droughts and floods. OECD argues that investing in water security is a necessary condition for sustainable growth and development. Risk management related to extreme events requires policy coherence in all sectors, such as adaptation to climate change, water management and disaster risk reduction.

Traditionally, extreme hydrological events have managed as emergency or crisis situations addressed by mobilizing extraordinary resources, usually by way of urgency. This crisis-based approach is a reactive approach as it includes measures and actions that are triggered after the extreme event has begun. Such approach often results in inefficient technical and economic solutions, because actions take with little time to evaluate the optimal alternatives and stakeholder participation is very limited. In recent years, these policies are changing around the world, moving from a crisis management approach to another based on risk management or adaptive management.

The risk management approach is becoming an increasingly widespread practice in many fields of science and engineering, not just droughts and floods. Disaster risk reduction seeks to prevent new potential risks, reduce existing risks and manage residual risk. Addressing the risks of these extreme phenomena in a planned way allows studying, analysing and agreeing on measures with all stakeholders, and managing the corresponding risks in advance, assessing their consequences from all points of view. In recent years, evaluation

and management plans for flood and drought risks have developed in many regions of the world.

Engineering plays a very important role in estimating the time of occurrence of the natural phenomena, the affected areas, the risks and potential damages, the definition of any adaptation actions, the best evacuation options to non-affected areas, to guarantee the essential uses of water and limit the impact in droughts, and to develop risk management plans for flood and drought episodes.

Addressing these extreme phenomena requires combining a whole series of measures, where the role of engineering in its design and implementation is essential but is also necessary to coordinate the different stakeholders involved, reinforcing the need to previously implement such risk management plans through stakeholder participation, so that they are acknowledged and assumed by all the agents involved.

It is engineer's task to apply at earliest convenience the innovations and technological advances that allow a better management of both floods and droughts, improving prevention and alert systems and their reliability, applying decision support systems, making decisions such as flooding areas in a controlled manner, overexploiting temporary aquifers to cope with droughts or distribution of the available resources to ensure water security in a context of drought, among many others.

2 General framework

Droughts and floods are extreme hydrological events that bear many similarities, but also show characteristics that differentiate them.

Floods are probably one of the natural disasters that causes the most damage on our planet, as is reflected in the large bibliography issued by different international, regional and national organizations. In these reports, there is a high consensus that the number of people at risk by floods and its frequency will increase in the coming years. It is also foreseeable that global mega trends, such as climate change, population growth and urbanization will increase the frequency, intensity and impact of floods.

The Organization for Economic Cooperation and Development - OECD estimates that the number of people at risk will increase from 1.2 to 1.6 billion people by 2050. This represents

approximately 20% of the world's population. In 2016, 23.5 million people migrated due to weather-related disasters, of which the majority were associated with floods or storms. Between 1998 and 2017, floods accounted for about a quarter of economic losses due to natural disasters (OECD, 2019).

According to the United Nations Office for Disaster Risk Reduction (UNDRR), the greatest number of weather-related disasters is due to flooding, followed closely by storms. Then, although at a considerable distance in number, there are droughts and heat waves.

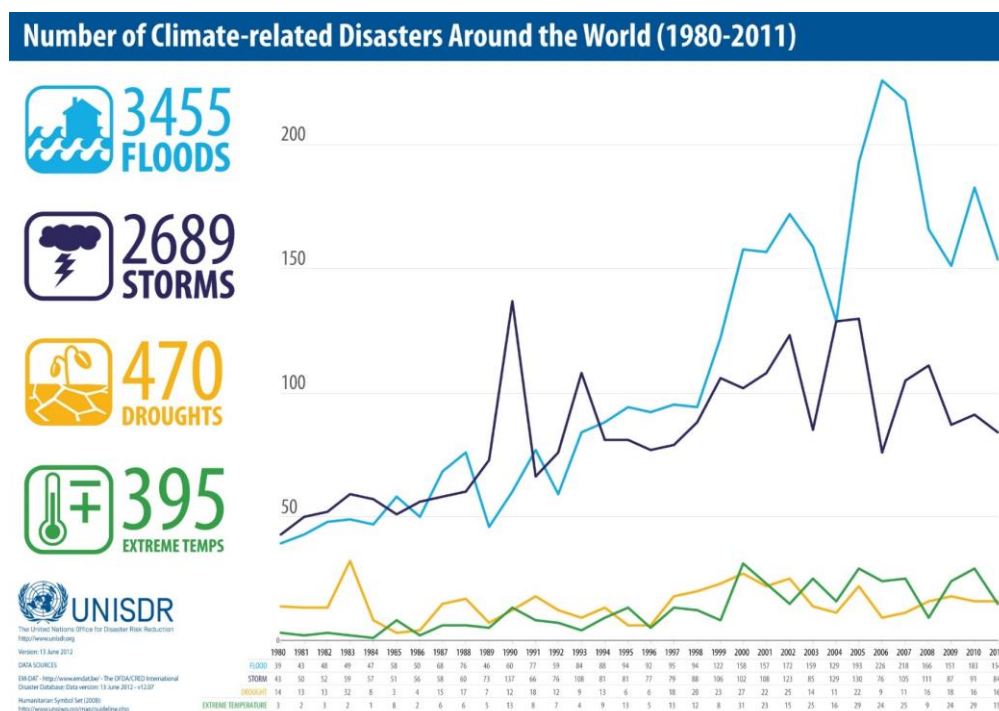


Figure 1. Number of climate-related disasters in the world (1980-2011). Draft figure taken from UNISDR

Floods are a natural phenomenon that, in general, responds to the behaviour of the hydrological cycle when large rainfall occurs leading to the overflow of rivers, ravines, streams and rambles. Under natural conditions, the effects are not, in general, harmful. Furthermore, flooding is necessary for rivers to develop their natural processes and maintain an adequate ecological status, with important benefits to nature, such as the fertilization of flood areas, improved infiltration capacity, increased levels of groundwater, and river bed clearing. Although the main cause of flooding are extreme rains, flooding can also occur due to other causes such as sea flooding, snow melting, dam breaks, landslides or roadway obstructions.

Damages caused by floods are due to the use of the watershed for several human activities: buildings, homes, transport routes, energy production, crops, etc., which sometimes are not compatible with the river's natural regimes, limiting the available space to evacuate the circulating flows.

The total elimination of the risk of flooding is not possible, no matter how many population protection measures are implemented. Therefore, it is necessary to promote awareness of self-protection in citizens. Administrations, meanwhile, must define the levels of security they must provide in each case. For example, the reconstruction of the levees of the city of New Orleans after Hurricane Katrina in 2005 carried out with levees of similar height to those previously existing, since substantially increasing the levees' height would lead to unacceptable costs.

Unlike floods, droughts are an extreme hydrological phenomenon of low water availability, which take place slowly and imperceptibly and that sometimes when detected, is too late and can cause very high social, economic and environmental impacts. Although drought by itself does not constitute a disaster, it can be a disaster depending on its impact on society and the environment. The temporal and spatial limits of droughts are uncertain and there is great difficulty in predicting or identifying cycles or periods. Thus, traditionally mitigation measures have not been applied until the crisis has arisen.

Extreme hydrological events - droughts and floods - have become current global topics regarding water issues, as reflected in the United Nations' 2030 Agenda (UN). In particular, SDG 6 refers to water and sanitation and aims to ensure the availability and sustainable management of water and sanitation for all people. Among the goals of SDG 6 related to scarcity and droughts, is to increase the efficient use of water resources and ensure the sustainability of the withdrawals to address the shortage and implement the integrated water resources management. Related to SDG 6, and specifically to extreme hydrological events, is SDG 11 and in particular goal 11.4 aiming to significantly reduce the number of deaths, the number of people affected and economic losses due to water-related disasters. SDG 2, which aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture or SDG 13 that seeks to take urgent measures to combat climate change and their effects, are deeply intertwined with extreme episodes' management.

To fight and mitigate water-related disasters, the United Nations (UN) provides regulatory support, data collection and analysis, capacity building and technical assistance, policy advice and support in its global and regional implementation. Thus, the activities carried out by the United Nations include regulatory and follow-up support for the Sendai Framework, which establishes the framework for disaster risk reduction in the 2015-2030 period, capacity building and policy instruments for member states to reduce disaster losses and enhance resilience, campaigns to support disaster risk reduction, provision of WASH (Water, Sanitation and Hygiene) services in responses of emergency, the protection of migrants, the improvement and application of forecast systems for flash floods and support to countries and exchange of best practices (UN-Water, 2019).

Within the regulatory support activities, United Nations Office for Disaster Risk Reduction (UNDRR) has developed the Words into Action (WiA) publication series, thematic guides developed for the implementation of the Sendai Framework and the integration of disaster risk management in specific areas (UNDDR, 2019). WiA guides help communities get involved in disaster risk reduction by facilitating access to straight forward practical information that is easily applicable for global, local and field use (UN-Water, 2019). Other international organizations, such as the World Meteorological Organization (WMO) have also developed manuals and guides on Flood Forecasting and Warning (WMO, 2011).

Within the Sendai Framework for Disaster Risk Reduction, UNDDR has the task of and promoting integration, coordination and synergies within the 2030 Agenda, in particular in disaster risk reduction and developing a new Sendai Framework monitoring system. (UN-Water, 2019).

2.1 Floods and droughts in the world

The economic impacts caused by extreme hydrological events - floods and droughts - have been increasing around the world. These events pose serious threats to human life and the well-being of society and represent a burden and in turn, a serious challenge for the States, responsible for maintaining economic development and maintaining the ecosystem services, on which society depends. It has been shown worldwide that reducing the risk of hydrological disasters improves human security, in any of its categories (Kundzewicz and Matczak, 2015).

The largest known floods in modern history have occurred in China, which has suffered heavy losses of human lives and property damage, with annual damage estimated, on average, at 1% of the country's gross domestic product. The flooding caused by the Yangtze, Amarillo and Huai rivers in Central China in 1931 resulted in a multitude of casualties, estimated by various sources between a few hundred thousand and nearly 4 million people. In the summer of 1931, snow melting, torrential rains and several cyclonic storms, combined to produce the most devastating flood in Chinese history. Only in the month of July, central China was flooded with the rainfall, which normally occurred in one and a half years. In August, the flows of Yangtze and Huai rivers caused the collapse of protection dikes flooding huge surface areas. Thousands of people died drowned during the initial phase of the flood, but many more followed due to widespread famine and disease outbreaks, such as cholera, typhoid and dysentery.

A case of large flooding largely reported is the great flood of the Mississippi River of 1927 in USA. It is remembered as the most destructive flood in the history of the United States discharging 65,000 m³/s. During the summer of 1926, heavy rains were witnessed in the central part of the Mississippi River, and for Christmas day the water level of the Cumberland River rose over 17 meters, a record that remains today. The river exceeded its levels in 145 areas, flooding over 70,000 km² with a water level of 10 meters, causing \$ 400 million in damage and killing 246 people. In addition, although it has not been one of the deadliest floods, the destruction is still a record for the United States, not even broken by the 2010 floods in the same area.

The 1966 flood on the Arno River in Italy had devastating effects on the cultural heritage of the city of Florence. The flood began on November 4, when a period of heavy rains caused the Arno River to overflow. Thousands of homes and businesses destroyed, but the water also reached several art galleries and libraries that contained priceless relics from the Renaissance era. Some 1.5 million books submerged in the Nazionale Library. Although countless works of art were rescued, the restoration process has, in many cases, taken decades.

On two successive occasions, between 1993 and 1995, European rivers Rhine and Meuse suffered experienced major water rises that caused severe flooding in the surrounding areas. The devastation caused by these floods pushed motivated the creation of a

transnational prevention program among the affected countries: Belgium, France, Luxembourg, Germany, and Switzerland and the Netherlands.

In addition to this, the great floods occurred between 1998 and 2004 in Central European rivers inspired the European Commission's 2004 Communication to the European Council, Parliament, Economic and Social Committee and the Committee of the Regions on flood risk management, communication that initiated the discussion finalized in October 23rd, 2007, with the approval by the European Parliament of Directive 2007/60 / EC on the assessment and management of flood risks.

More recently, in December 2015, vast areas of Paraguay, Argentina, Uruguay and Brazil were affected by the worst floods in the region in 50 years, which forced the evacuation of more than 150,000 people. The days of heavy rain caused by the El Niño weather phenomenon caused three major rivers to overflow. The state of emergency was declared in Paraguay, the most affected nation, where 130,000 people were displaced. In northern Argentina, some 20,000 people also left their homes.

Droughts have also caused serious damage worldwide. Australia recently suffered the worst drought in its history, the so-called Millennium Drought, which began in 1997 and officially ended in 2012. In general, the country survived the effects of this drought demonstrating the importance of innovation and planning of those situations. Actions were implemented in Australia's four largest cities in: Sydney, Melbourne, Brisbane (and the surrounding region of south-eastern Queensland) and Perth, where special attention was paid to the role of demand management measures to reducing the impact of drought. It can be said that the "silent achievement" of this drought was the improvements in urban water efficiency, saving more water at a lower cost and faster than other supply side alternatives¹.

In France, the 2003 drought intensified public authorities' awareness of this phenomenon. In metropolitan France, the prefects of 77 departments took measures to limit the use of water, an unprecedented action. Several deficiencies were identified, highlighting the need to improve the organization and implementation of the drought management system. In a context of global warming, the French authorities contemplated the possible influence of

¹ https://www.researchgate.net/publication/297723736_Managing_Drought_Learning_from_Australia.

climate change not only on the frequency of occurrence of the drought but also on its duration, since the concatenation of several years followed by crisis forced to increase their means of observation and detailed study of these hydrological phenomena.

2.2 Social, economic and environmental impacts

Extreme hydrological events, both drought situations and floods, have been causing high social, economic and environmental impacts.

In the case of droughts, their impacts can vary greatly between countries. While in those that lack water storage infrastructures and water supply depends primarily on precipitation, a decrease in rainfall over a few months may become a drought, whereas in other countries with significant reservoir capacity, the largest impacts occur when water deficits extend over several consecutive years. In the United Kingdom, where the number of reservoirs is reduced, the lack of rainfall for several consecutive months can cause drought situations, while in Spain, where there are more than 1,200 large dams with a reservoir capacity of more than 50,000 hm³, there are watersheds where the effects of the drought do not become effective until after 2 or 3 years after its beginning.

Knowledge of drought's environmental impacts require the prior study of the relationships between the parameters that define the state of water bodies and drought indicators. Assessing droughts' socioeconomic impact, the influence of drought periods estimates through metrics variables such as area affected, production and yield reduction, economic value and economic performance. On the other hand, socio-economic impact in urban water supply and hydroelectric power generation sectors assesses by contrasting, respectively, guarantees and power outputs in normal and drought periods.

Among the intangible impacts, we can mention the loss of soil due to the non-occurrence of the ground cover, the decrease in the quality of life in cities due to the loss of parks, population displacement (important in developing countries) and mortality. A well-known example of forced migration is that of Lake Chad in sub-Saharan Africa.

The most ignored crisis in the world: Lake Chad has lost more than 90% of its original surface in four decades.

Such has been called the great environmental and humanitarian crisis caused by the effective disappearance of Lake Chad, which in the 1960s - with 25,000 km² of surface -, ranked sixth largest lake in the world. Only two decades later, in the 80s, lake Chad's surface reduced to just 2,500 km², that is, 10% of its original dimension. By 2013, the lake recovered slightly, because of an exceptional increase in rainfall, which returned its surface to 5,000 km², only 20% of its former surface, currently reduced to an immense set of loosely connected ponds, surrounded by a great desert.

The current situation affects around 40 million people, who depended on the lake to obtain drinking water, fish and cultivate the nearby lands, and who now migrate massively southwards to Guinea's savannah, search for better life conditions. United Nations estimates that almost 11 million people need humanitarian assistance because of this situation. The cause lies in a situation of prolonged drought, because of the general decrease in rainfall. Concurrent to this cause, other factors such as the guerrilla war affecting these 4 countries (Niger, Nigeria, Chad and Cameroon) and an unsustainable increase in water withdrawals for different uses contribute to worsen such crisis.

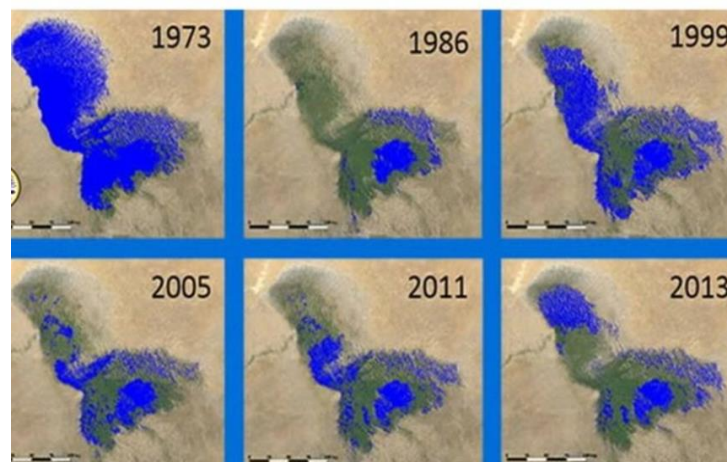


Figure 2. Evolution of water Surface in the Lake Chad ²

The impacts of droughts can be classified as tangible, easily determined, and intangible, which are much harder to quantify. Tangible impacts are normally classified as direct and

² <http://documents.worldbank.org/curated/en/489801468186879029/pdf/102851-v2-WP-P149275-Box394847B-PU-BLIC-v2-main-report-Lake-Chad-Development-and-Action-Plan-English.pdf>

indirect. Among the direct impacts are the environmental deterioration, agricultural and derived industries losses, decrease in hydroelectric power output, losses in the tourism sector or the deterioration of garden areas. Indirect impacts include the loss of market share of agricultural products, the increase in unemployment or any extra financial costs incurred from reduced turnover.

In the case of flooding, there is also a difference between tangible impacts, which characterize by being able to be quantified and intangibles, which are much more difficult to quantify (see attached figure). Tangible impacts classify into direct and indirect. Direct impacts include physical damage to property, the costs of emergency measures, or the costs of cleaning streets and homes. While indirect impacts include losses from paralysis of economic activity, the disappearance of jobs, financial cost overruns or devaluation suffered by flooded land. Intangible impacts include the loss of human life, damage to monuments and archaeological remains, or changes in the landscape.

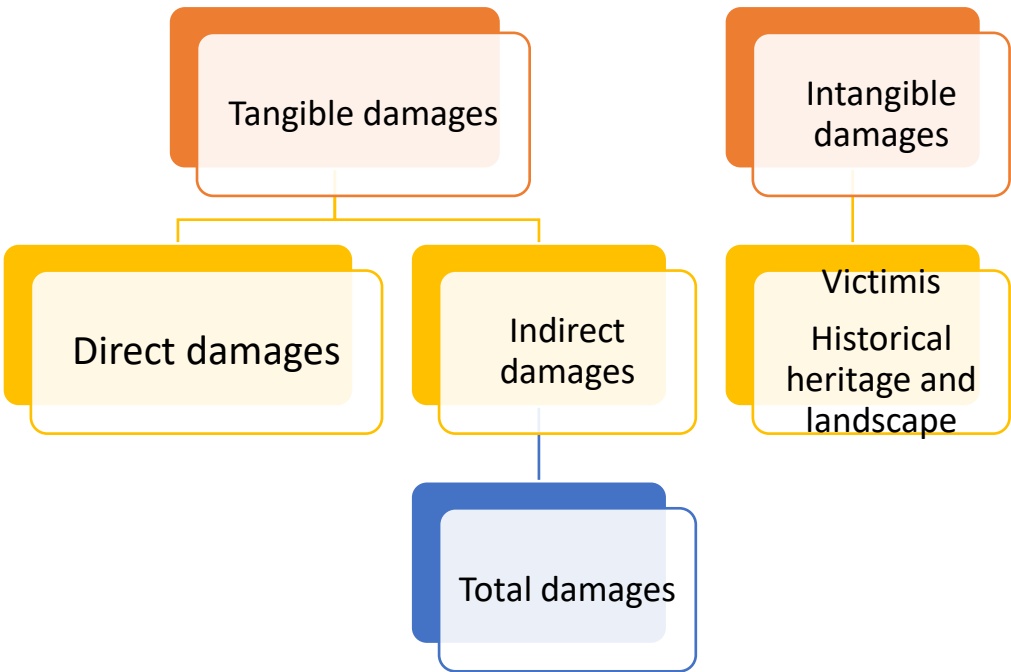


Figure 3. Type of damages due to floods

Economic appraisals on the value of life are made in order to be able to comparatively assess the effects of floods, bearing mind that the value of any life is infinite.

The assessment of human life loss in the European Climate Adapt SUFRI project

Climate Adapt's Sustainable Strategies of Urban Flood Risk Management with non-structural measures to cope with residual risk - SUFRI project aims to improve flood risk management in the event of disaster flooding, especially addressing non-structural measures. Flood analysis has shown that structural flood protection measures have limited applicability, especially in urban areas, and that full protection is not achievable.

Under the SUFRI project³, a method has been developed to calculate the number of possible victims due to floods, in which the estimation of mortality rates depends, among other factors, on the severity of the flood, the prior warning time to the population, the type of dam break (if such happens) and the time of occurrence (day / night).

This project was developed by several technological universities from 4 different European countries: Graz University of Technology (Austria), Dresden University of Technology (Germany), University of Pavia (Italy), Polytechnic University of Valencia (Spain); Polytechnic University of Catalonia (Spain) and University of Graz (Austria).

2.3 Effects of climate change

As a whole, the world suffers from low water availability, making difficult the match of the available natural resources and the use of water for socio-economic development, avoiding depopulation and facing climate change with better resilience. Climate change is part of other global changes of greater scope, which causes negative effects on the availability of resources and the frequency of presentation of extreme hydrological events, such as droughts and floods (Intergovernmental Panel on Climate Change, 2014).

The results of International Panel of Experts on Climate Change's 5th Assessment Report ⁴, show that the main runoff reductions are expected in regions such as the southern United States of America, Central and Southern Europe, North Africa or the Western part of Australia (see attached figure).

³ <https://climate-adapt.eea.europa.eu/metadata/projects/sustainable-strategies-of-urban-flood-risk-management-with-non-structural-measures-to-cope-with-the-residual-risk.se>

⁴ <http://www.climatechange2013.org/>

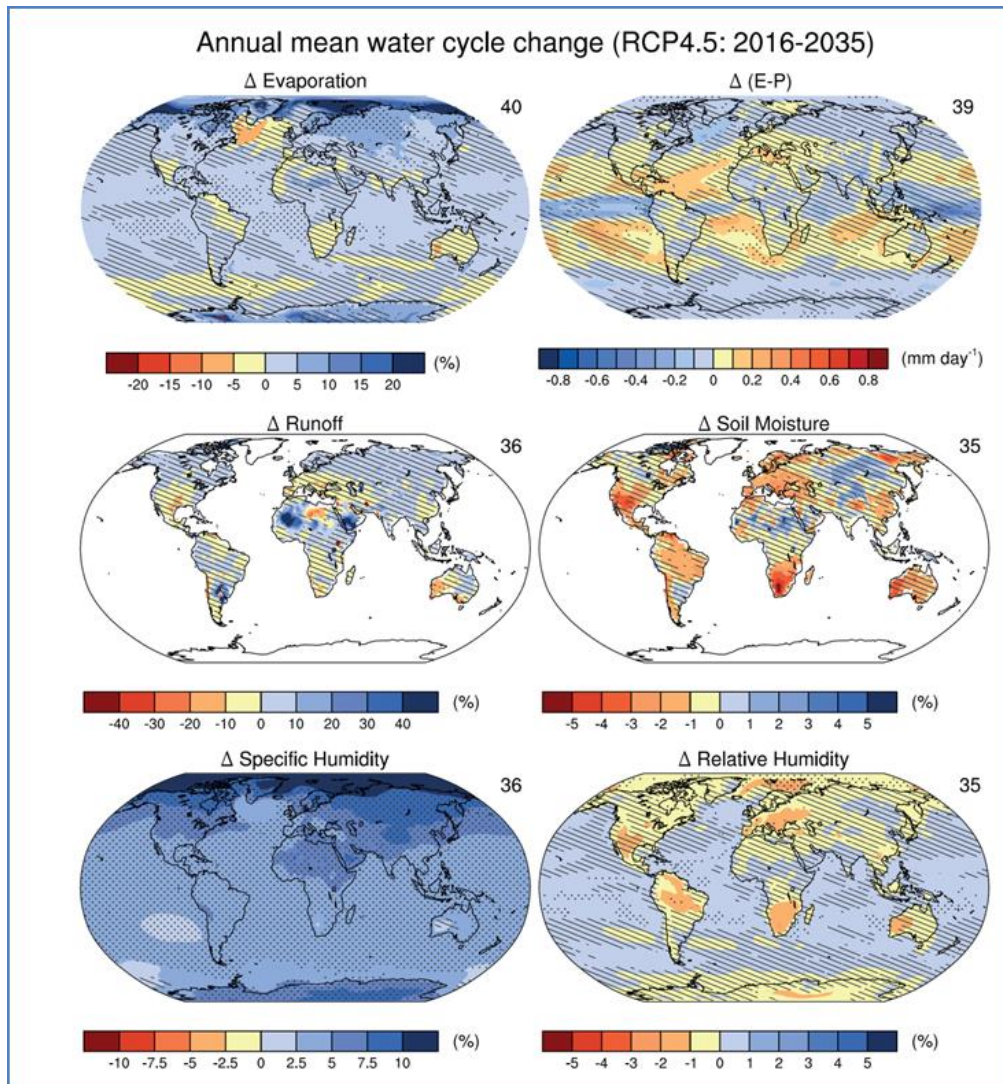


Figure 4. Estimated changes for the 2016-2031 period in: evaporation (%), evaporation minus precipitation (mm/day), total runoff (%), soil moisture in the top 10 cm (%), relative change in specific humidity (%) and absolute change in relative humidity (%). The number in the upper right of the image indicates the number of averaged models. Source: Kirtman et al (2013).

The effects of droughts can be aggravated when they occur in regions where water resources are scarce, where there are already existing imbalances between available resources and water demands (Estrela et al, 2102; European Environment Agency, 2001), as is the case in Southern Europe. Thus, the PESETA project (European Commission, 2014), EU's Joint Research Center - JRC has assessed the climate impacts in the 2071-2100 period compared to the reference period (1961-1990), studying five major regions of the Southern Europe: Spain, Portugal, Italy, Greece and Bulgaria. The simulations run forecast a temperature rise of between 2.3 and 3.7 ° C for Southern Europe. In parallel to such temperature rise, rainfall will reduce by around 6.5% in the region. Another study, this one carried out by Spain's

Center for Hydrographic Studies (CEH, 2017), estimates that, in general, droughts in Spain will become more frequent as the 21st century progresses, with the consequent increase in water scarcity due to the reduction of water resources.

There are currently a large number of climate scenarios in accordance to the different emission scenarios (Representative Concentration Pathway - CPRs of the International Panel of Experts on Climate Change and to the different climate simulation models existing in the world. In Europe, within the EC's Copernicus Climate-Water Program, two Decision Support Systems have been developed, EDGE and SWICCA, which, in addition to facilitating the visualization and analysis of climate data, have generated hydrological scenarios using hydrological models whose input are such climatic scenarios. Engineering has played an important role in the development of these systems and the models they incorporate.

The EDGE project combines a set of state-of-the-art climate and hydrological models to obtain a series of climate impact indicators and seasonal predictions that have been jointly agreed with stakeholders from the public and private water sectors in three European countries (Kingdom United, Spain and Norway). EDGE's final product is an information system implemented through a web application. The underlying framework of the EDGE modelling procedure comprises four phases: 1) climate data processing, 2) hydrological modelling, 3) co-design with the help of stakeholders and 4) assessments of the uncertainty and capabilities of the system (Samaniego et al, 2019). Within the EDGE project, tools have been developed to visualize and analyse seasonal predictions of meteorological and hydrological variables with a 6 months horizon, information that can be very useful for drought's risk management, especially in relation to irrigation farming.

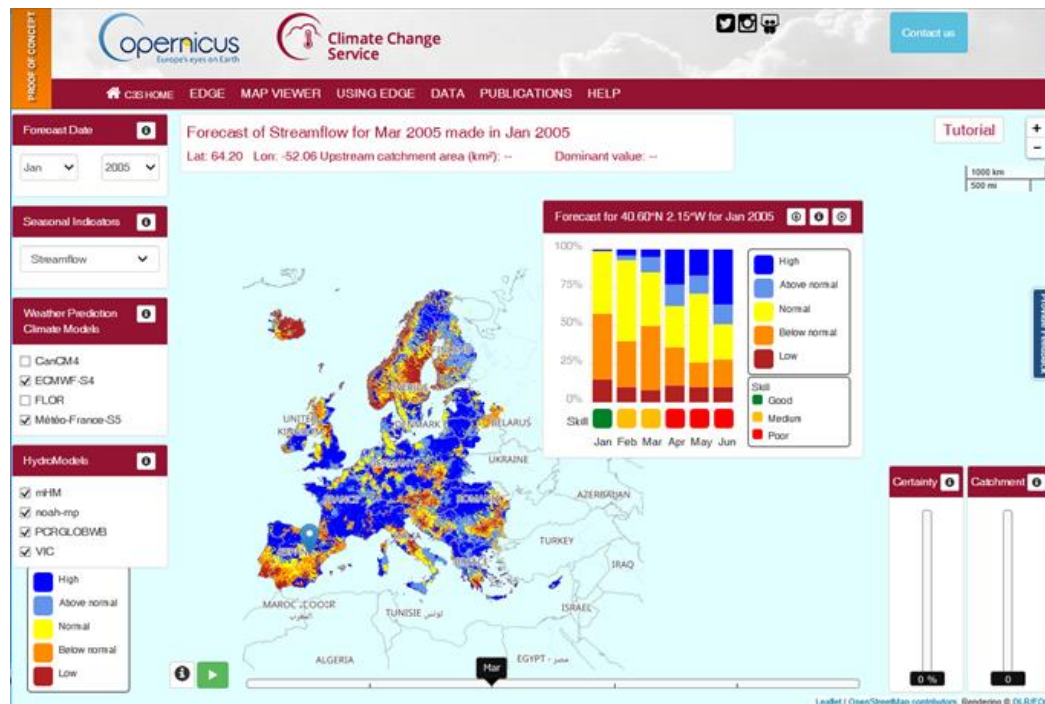


Figure 5. Copernicus Clima EDGE project demonstrator.

In addition to the previous examples, engineering can actively collaborate to the reduction of Greenhouse Gases (GHG) within various sectors improving the weather resistance of infrastructures to resist climate impacts, increasing their reliability and lifespan while exposed to extreme weather events, and the achievement of the United Nations Sustainable Development Goals (SDGs).

In particular, hydraulic works projects, especially dams, must incorporate the effects of climate change in their design, since they are infrastructures with a large lifespan which require large investments and impact territory, ecosystems and the landscape.

3 Evolution of water policies to manage extreme hydrological events

3.1 Traditional approaches

Traditionally, extreme hydrological events managed as emergency or crises addressed by mobilizing extraordinary resources, usually by way of urgency. This crisis-based approach is a reactive approach as it includes measures and actions that are only triggered after the extreme event has occurred. Such approach often results in inefficient technical and economic solutions, because actions are taken with little time to evaluate the optimal alternatives and hindering stakeholder participation. In recent years, these policies are

changing around the world, moving from a crisis management approach to another based on risk management or adaptive management.

3.2 Approaches based on risk reduction

The disaster risk caused by an extreme hydrological event is defined as the potential loss of life and material damage that could occur to a system, society or community during a specific period of time, probabilistically determined as a function of the hazard itself, exposure and vulnerability to such event. Disaster risk reduction is the objective of risk management and seeks to prevent new risks, reduce existing risks and manage residual risk, all of which contributes to enhance resilience. A comprehensive approach to disaster risk management can contribute to climate change mitigation, adaptation and future sustainable development.

The relationships between disaster risk management, climate change and sustainable development show in the attached table. Prospective risk management includes activities that address avoiding the risk of new disasters, corrective management refers activities that address and seek to eliminate or reduce the of existing disasters' risks and compensatory management refers activities that strengthen the social and economic resilience of people and societies in the face of residual risk that cannot be effectively reduced or avoided (UNDDR, 2019).

	Prospective	Corrective	Compensation
Disaster risk management	Avoid the risk	Reduce/mitigate risk	Enhance resilience to disaster (economic and social)
Climate change	Climate change mitigation	Climate change adaptation	Enhance resilience to extreme events associated to climate change.
Sustainable Development	Contribute to future sustainable development	Enhance the sustainability of the current development framework	Enhance resilience to all common risks.

Table 1. Relationships between disaster risk management, climate change and sustainable development. Source:

UNDDR, 2019

Among the extreme hydrological events, droughts are phenomena of slow evolution but unpredictable in time, whose risk management requires long-term preparedness through prevention (strategies to reduce risk and the effects of uncertainty), mitigation (measures taken to limit its adverse impacts) and preparation, through proactive management that develops planned actions in advance.

Researchers and scientists, such as Wilhite et al (2014), indicate that it is necessary to adopt new approaches to reduce drought risk, given the increasing impacts and trends regarding the increase of frequency and duration of such associated drought events due to climate change. On such grounds, the European Union (EU), has developed relevant political instruments in recent years, to address drought's negative impacts. Some examples of these regulations are the Water Framework Directive 2000/60 / EC, the European Commission communication "Addressing the challenge of water scarcity and droughts in the European Union" (EC, 2007b), the "Blueprint to Safeguard Europe's Water Resources " (EC, 2012) or the European Commission Communication "An EU strategy on adaptation to climate change"(EC, 2013). Table 1 summarizes European Union's evolution from traditional approaches to drought risk management since the adoption of EU's Water Framework Directive in 2000 (Estrela and Sancho, 2016).

Action	Year	Relationship with drought management
Water Framework Directive 2000/60/EC (European Parliament and Council of European Union, 2000)	2000	The protection of water bodies must contribute to mitigate the effects of droughts.
Communication on "Addressing the challenge of water scarcity and droughts in the European Union" COM(2007) 414 final (EC, 2007b)	2007	Highlights that water saving must become the priority, improving water efficiency prior to increasing supply. States that policy-making should promote participatory processes. Recommends the development of drought management plans.
Drought Management Plan Report, Including agricultural, drought indicators and climate change aspects, Technical report 2008–023 (EC, 2007a)	2007	General, non-binding guidelines for the development of Drought Management Plans elaborated jointly by EC and some leading EU countries (Spain, France and Italy).
European Commission Follow-up reports to the COM(2007) 414 [COM(2008) 875 final (EC, 2008), COM(2010) 228 final (EC, 2010) and COM(2011) 133 final (EC, 2011a)]	2008, 2010 and 2011	Reporting on progress made by Member States with regard to addressing the challenge of water scarcity and droughts.
European Drought Observatory (EDO) developed by Joint Research Centre of European Commission	2011	EDO enhances the knowledge of droughts using efficient alert systems which are an essential tool for risk management.
Blueprint to Safeguard Europe's Water Resources (EC, 2012)	2012	Outlines actions focusing on better implementation of current water regulations, the integration of water policy objectives into other policies, and bridging the gaps in particular as regards to water quantity and efficiency.
Development of water scarcity and droughts indicators by Member States.	2013-2016	These studies are being incorporated into the Policy Review of the Strategy for Water Scarcity and Droughts.

Table 2. Relevant milestones in the management of droughts in the European Union since the beginning of the 21st century (modified and updated by Estrela and Sancho, 2016)

In other regions such as Mexico, the PRONACOSE National Drought Program (Korenfeld et al, 2014) has focused on reducing vulnerability through the implementation of preventive action planned under a comprehensive and participatory approach.

Nowadays, drought management policies around the world are based on four fundamental pillars: the promotion of policies based on risk management, the promotion of preparedness

and mitigation measures, drought planning and the consideration of assistance financing instruments (Iglesias et al., 2009). The promotion of transparent processes of public participation, agreements between stakeholders, collaboration between water administrations, as well as the active participation of stakeholders, are essential elements in drought risk management.

Managing Droughts in Portugal: participatory approaches

The importance of the extreme 2005 drought event in Portugal resulted in the creation of a Drought Commission by Governmental initiative to monitor the progress of the drought event and to assist in mitigating its effects. This was the first drought to have an institutional framework to manage the event and related water scarcity, with a drought Commission. Four drought severity levels were established and several measures were planned and put to place during the drought.

The next drought occurring in Portugal in 2012 was followed by a political Commission, whereas a Working Group was constituted to deal with technical and operational aspects. The working group included institutions related with the environment and urban water supply, agriculture, food production, nature protection, human health, civil protection, energy, territory planning, internal administration, work and social security, and financing.

More recently, during the drought of 2017 a permanent Commission was legally established to continuously prevent, monitor and follow the consequences of droughts in Portugal, including Government members from the following areas: environment and agriculture, that together coordinate the Commission, finances, internal administration, local administration, work, solidarity and social security, human health, economy and sea. The Commission is mandated to approve and monitor the implementation of the Drought Prevention, Monitoring and Contingency Plan and to define the political orientations in the context of the adverse climate phenomenon of drought. The permanent Commission is technically advised by a Drought Working Group that encompasses 21 public institutions. Other public institutions and civil society representatives can be invited to participate in the Working Group. In addition to the framework presented, the Reservoirs

Management Commission is also integrated in drought management, being mandated to resolve conflicts in the use of stored water.

Although the current framework for drought management and planning in Portugal is still based on a crisis management approach, drought and scarcity management plans are being prepared by the Water Authority. These plans will include a characterization of each River Basin and indicators to forecast and follow drought situations, and to assess economical, social and environmental impacts. Measures adapted to different drought levels will also be included. Overall, measures to address drought could include the increase in the use of treated water (The Legal Regime on Treated Water Reuse was recently published, Decree-Law n. 119/2019), and higher levels of efficiency in water use (namely with precision agriculture and reduction of water losses). In areas with severe scarcity, the economic viability of desalination of salted or brackish water could also be assessed.

Similar to what happens with droughts, flood risk management is the process of identifying, evaluating, selecting, implementing and monitoring the actions taken to mitigate risk levels. For this, scientifically sound measures must be taken to reduce the risks. In that process, social, cultural, ethical, environmental, political and legal considerations must also be taken into account (USA Army Corps, 2009).

Flood risk based approaches handle three fundamental concepts: hazard, vulnerability and impact or risk. The hazard represents the threat of a flood corresponding to a given frequency, expressed in the form of magnitude of the water levels, its speeds and / or its duration. Vulnerability is an internal risk factor of a system exposed to a threat. It depends on its features and the level of exposure it presents and its internal resilience to the event. It is the estimated degree of damage or loss of an element or group of exposed elements because of the occurrence of a phenomenon of a given magnitude and intensity. The impact or risk are the effects resulting from the effective occurrence of the risks on an individual or system and corresponds to the measurement of its effects (economic, environmental, etc.).

In the United States, since the enactment of the Flood Control Act of 1917, the Corps of Engineers has played an important role in flood risk management throughout the country.

This role has evolved over time, from flood relief to flood damage reduction and now, more recently, to flood risk management. In 2006, the Corps of Engineers established the National Flood Risk Management Program in order to advance the objectives of flood risk identification, communication, response and management services at all levels of government in order to save lives and reduce property damage caused by floods and coastal storms.

In the European Union, such types of approaches were introduced in all Member States with the approval of Directive 2007/60/EC of October 23rd, 2007 on flood risk assessment and risk management, whose main objectives are to gain adequate knowledge and evaluation of the risks associated with floods and to achieve a coordinated action of all public administrations and society to reduce its negative effects.

Main principles of the European Union Flood Directive

The main principles of the Flood Directive are: preliminary risk assessment, hazard and risk mapping, and flood risk management plans. The preliminary assessment of the flood risk is intended to determine those areas of the territory for which it has been concluded that there is a significant potential flood risk or in which the materialization of that risk may be considered probable. For areas with significant potential risk, hazard maps and risk maps are to be made at the most appropriate scale. Hazard maps represent, among others, for floods of different return periods, the following variables: floodwater levels (see following figure), flow rates and maximum speeds, wave and tide regimes.

For each of the above scenarios, risk maps are drawn up to include the number of potentially affected inhabitants, the type of potentially affected economic activity, facilities that may cause accidental pollution (IPPC and WWTP), protected areas for water catchment intended for human consumption or areas for the protection of habitats or species. Flood risk management plans in the European Union determine objectives to reduce damage to people, the environment, cultural heritage and economic activity. They cover all aspects of risk management, focusing on Prevention, Protection and Preparedness (3 P), including flood forecasting and early warning systems.

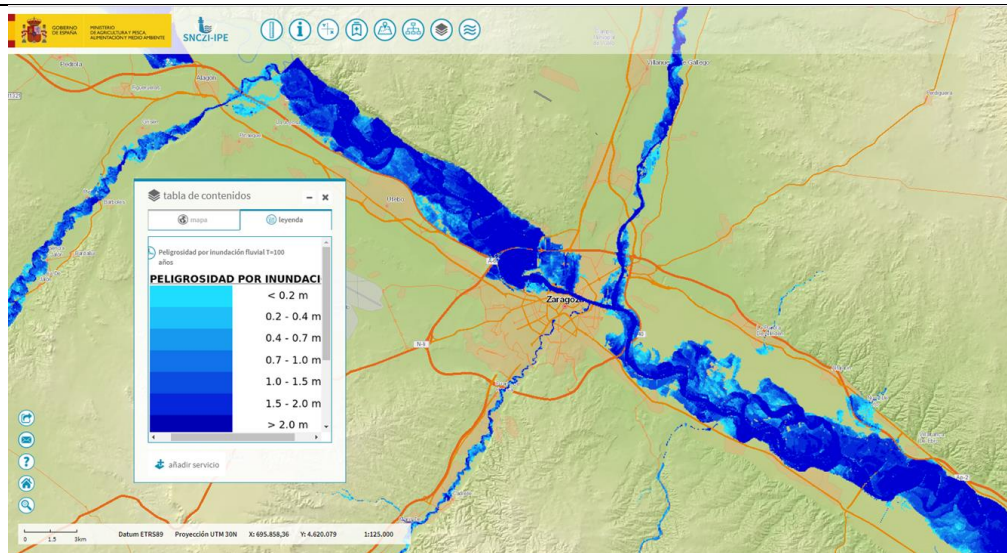


Figure 6. Hazard map of the Ebro river in Zaragoza (100 year return period flood)

3.3 Governance in the management of extreme hydrological events

Governance in the management of extreme hydrological events comprises the system of stakeholders, mechanisms, regulatory and legal frameworks that guide coordinate and supervise disaster risk reduction caused by extreme hydrological events.

OECD declares that investing in water security is a requirement for sustainable growth and development. Risk management related to extreme events requires policy coherence in all sectors, such as adaptation to climate change, water management and disaster risk reduction.

In relation to floods, OECD (2019) has recently published the report “Applying OECD Principles on Water Governance to Floods: A Checklist for Action (2019)”, where it states that good governance implies an improvement in design, implementation and impact of flood related policies. It also highlights the importance of including all stakeholders in decision-making and in the need for increased coordination among all policies, especially those of water, land management or climate change. Four years after the adoption of OECD’s Principles on Water Governance in 2015 and within the framework of the implementation strategy developed under the Water Governance Initiative, this OECD (2019) report applies its 12 principles of governance to analyze 27 specific cases of flood

management worldwide, including a cross-border strategic flood management plan, national policies and programs, regional, provincial and local flood management plans, as well as research projects at national or basin levels.

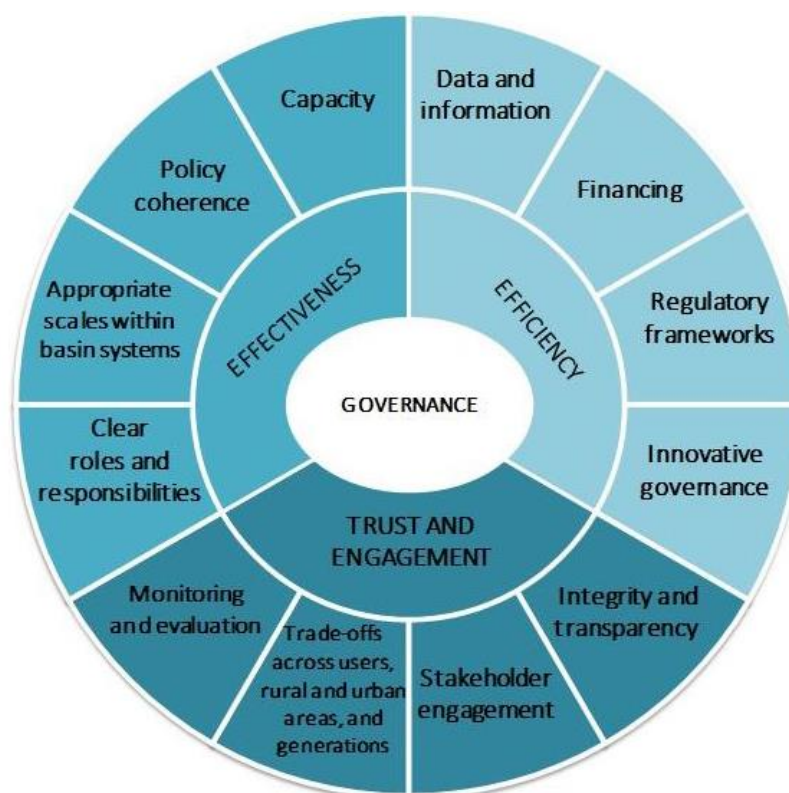


Figure 7. OECD Principles of water governance. Source: OECD (2015) and www.oecd.org/governance/oecd-principles-on-water-governance.htm

Below is a summary of the main results of the 2019 OECD report on the following aspects: fragmentation, policy coherence, scale, stakeholder engagement and insurance.

Fragmentation: flood management strategies often occur in institutional frameworks that present gaps, duplications, unnecessary delays, high transaction costs, irregular data and lack of information in decision making. The report notes that, in general, administrations and stakeholders share limited data. Only in 14 of the 27 case studies, information systems and databases are shared systematically.

Policy coherence: policies regarding topics such as climate change, land management, the environment, agriculture, urban development and infrastructure, have great influence on flood management and are not yet sufficiently coordinated. The report shows that 22 of the 27 case studies have included the consideration of other sectors (infrastructure,

environmental protection and land management) in their strategies, but in 19 of the 27 cases the inconsistencies of the sector policies led to increased costs, which could have been avoided with better coordination.

Scale: Floods take place through administrative, hydrological and political boundaries. Policy gaps are common in local and national frameworks, leading to an unclear assignment of roles and responsibilities and which, together with the limited coordination between different levels of government, makes difficult to apply integrated strategies to different territorial, urban and rural scales. For example, in Australia, the responsibility for territory and water management, and by extension, flood management, is regional. However, activities related to flood management are carried out by municipal or local governments.

Stakeholder engagement: stakeholder platforms are key to promoting long-term flood management plans and strategies. The participation of civil society can help bridge the gap that public administrations sometimes have to properly manage floods, as evidenced by the experience of Kampen, the Netherlands, where most stakeholders: governments, experts, users, owners and non-governmental organizations are generally involved in flood-related decisions. However, the report also reveals that only in some cases, representatives of groups such as women, the poorest local communities, indigenous populations, have been involved repeatedly in such decision-making processes.

Insurance: Public and private insurance systems are insufficient and fail to integrate a long-term vision to minimize the impacts of future floods. The lack of financial protection leaves homes and businesses - and ultimately governments - exposed to a significant risk of financial losses. An example that tries to close this gap is the German example "Floodlabel"⁵, "A smart tool for governance towards flood-resilient cities" developed by insurance companies and the German Flood Competition Centre (German Flood Competence Centre) that uses a long-term mitigation approach to support and also guide home and building owners to minimize the damage and harm caused by floods.

OECD's main recommendations in this report are: to conduct self-assessments of governance to identify what works, what doesn't, what needs to be improved and who can

⁵ <https://jpi-urbaneurope.eu/project/floodlabel/>

do what, promote multilevel governance to overcome fragmentation in flood management ; promote policy complementarity through sectoral policies; promote stakeholder participation to carry out inclusive policies, strategies and plans; improve coordination at local, regional, basin and national levels and promote financing mechanisms to facilitate flood management.

4 Knowledge, technology and innovation

4.1 Hydrological and hydraulic models

The hydrological and hydraulic models defined for the study of extreme events are constantly evolving. The increase in the computing capacity of computers occurred in recent decades makes hydrological and hydraulic processes more accurately simulated, in the latter enabling the use of three-dimensional (3D) models. In addition to the use of powerful Graphical User Interfaces (GUI), its integration with Geographic Information Systems (GIS) makes the models much friendlier than at the end of the last century, when they began to be developed.

In the study of floods, the problems become increasingly complex, with greater influence of environmental issues. In the European Union, since the beginning of the century, any infrastructure project requiring hydraulic studies has undergone a revolution to adapt to the objectives and principles of the Water Framework Directive and the Flood Risk Assessment and Management Directive.

Hydrological models allow estimating the evolution of flow rates over time, based primarily on rainfall data and the features and status of the basins. These flows constitute the main input to the hydraulic models. One of the applications of hydrological models is the real-time forecast of floods, which consists in estimating the future evolution of the flows in a certain forecast horizon. For this, deterministic and stochastic rain-flow models are usually applied. On the other hand, deterministic models require real-time flow and rainfall data and usually perform automatic calibration of the model parameters to adjust the calculated flows to those observed in successive time periods. The advances accomplished in short-term weather forecasts (hours, days, ...) in recent years have been spectacular and the use of radar has also been fundamental. Most national meteorological agencies have these prediction models available.

The hydraulic modelling aims to obtain the values of the flood's water levels and speeds of the rivers at the study points. One-dimensional hydraulic models are applicable in situations where the transverse component of the speed is zero or negligible. The use of 2D two-dimensional models is essential in areas where the speed field is such that both the component in the direction of flow and in the transverse direction have an important influence, and occurs in cases such as large alluvial plains or in areas in which lateral overflows may be relevant. Two-dimensional models solve the Saint-Venant equations in the nodes of a calculation mesh generated from the topography, according to the finite volume or the finite element methods. The model must be able to solve situations of change of hydraulic regime and to deal with internal boundary conditions, in particular in areas of lateral overflows in linear infrastructure embankments, bridges and weirs. Additionally, models should be able to import and export information from/to Geographic Information Systems (GIS).

In recent years, more and more 2D and 3D numerical models have been used, including new features such as mixed flow regime, sediment transport, etc. One of the best well known hydraulic models is the HEC-RAS model of the US Army Corps of Engineers. HEC-RAS is designed to develop one-dimensional and two-dimensional hydraulic calculations for a network of natural and artificial channels. It includes a user interface, hydraulic analysis modules, storage and data management tools and reporting modules for the preparation of graphs and reports.

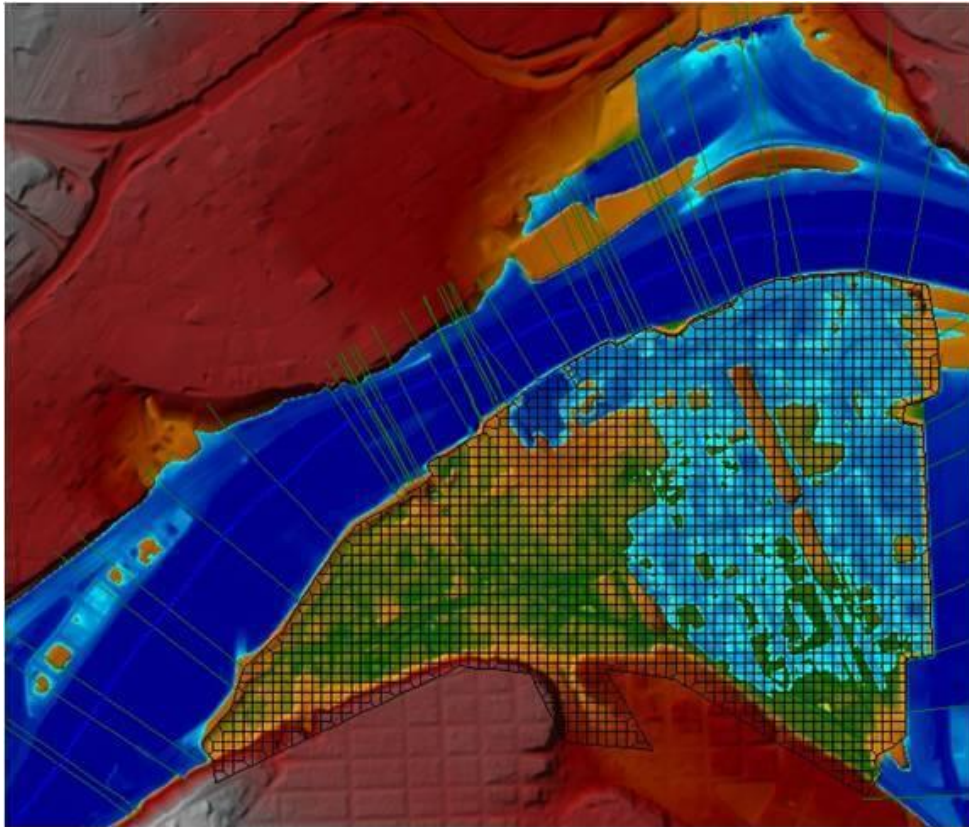


Figure 8. Flow simulation in variable regime in one and two dimensions with HEC-RAS

The main applications of hydraulic models in flood studies are: the development of mapping of flood areas (hazard and risk maps), the estimation of damage to the territory from the water levels and speeds, the dimensioning of the linear infrastructures' drainage works, storage development in flood areas and riverbed refitting.

These models, surely complex, require not only programming and computer skills for their elaboration, but also a thorough knowledge of the phenomena they represent, a selection of the variables and parameters that are required for their operation, and an adjustment and calibration agreement with the real experiences that are achieved through the participation of expert engineers. Damage assessment, for example, is based on damage curves that show the correlation between physical variables - such as the height of flood water - and the damage suffered by an infrastructure or an affected property. The difficulty lies both in assessing direct damages (tangible, of course, and intangible) and in assessing indirect damages, including (or not) the costs of suspending the services provided by the various affected assets, should these damage curves, obtained based on specific cases studied, are really representative. The hydrological and hydraulic models developed by the

USA Army Corps of Engineers are a good example of the important role that engineering has had in recent decades to the development and application of this type of models.

State of art on flood damage assessment

In recent years, with the conceptual shift from flood hazard control to flood risk management policies, flood damage assessment gained increased importance (Merz et al., 2010). Knowledge of expected or occurred damage in case of flood allows increasing the efficiency of flood risk mitigation strategies, by overcoming the traditional management approach based on established safety thresholds, and opening the doors to actions focused not only on the reduction of the hazard but also on the exposure and vulnerability components of risk (Plate, 2007).

In particular, before the occurrence of a flood, knowledge of expected damage is key to identify the most efficient and feasible risk mitigation strategies on the bases of reliable cost-benefit analyses, in which benefits can be identified as the expected avoided damage due to the implementation of the strategy (Merz et al., 2010; Shreve and Kelman, 2014; Mechler 2015). After the occurrence of a flood, a detailed survey of occurred damage is critical to support the recovery phase, by both allowing the identification of needs for recovery and reconstruction and as the basis of any compensation mechanism, be it conducted by public or private organisations. Damage data collected in the aftermath of floods are also needed to investigate flood damage mechanisms and their root causes, for better calibrating risk assessments before an event so as to support preventive measures (Ballio et al., 2015; De Groeve et al., 2013; De Groeve et al, 2014).

Next figure depicts the state of art of ex-ante damage assessment tools worldwide. Columns report the different steps required by a comprehensive estimation of flood damage: the evaluation of the elements exposed to risk, the estimation of their monetary value, the evaluation of the direct damage they can suffer and, finally, the evaluation of indirect damage due to the occurrence of direct one. Rows report instead the different elements exposed to flood risk for which an estimation of the expected damage is desirable. Dark green boxes indicate the existence of consolidated approaches, light green boxes mean that no consolidated approaches exist, white boxes refer to the existence of sporadic and preliminary studies or to the absence of approaches. The figure highlights

that most of consolidated tools refer to the estimation of direct damage to buildings structure, being residential or commercial/industrial buildings. Less attention has been paid to the estimation of exposure and direct damage to buildings contents, crops, roads, population, cultural and environmental heritage, and strategic buildings. Very few studies refer to the other exposed elements or to the estimation of indirect damage.

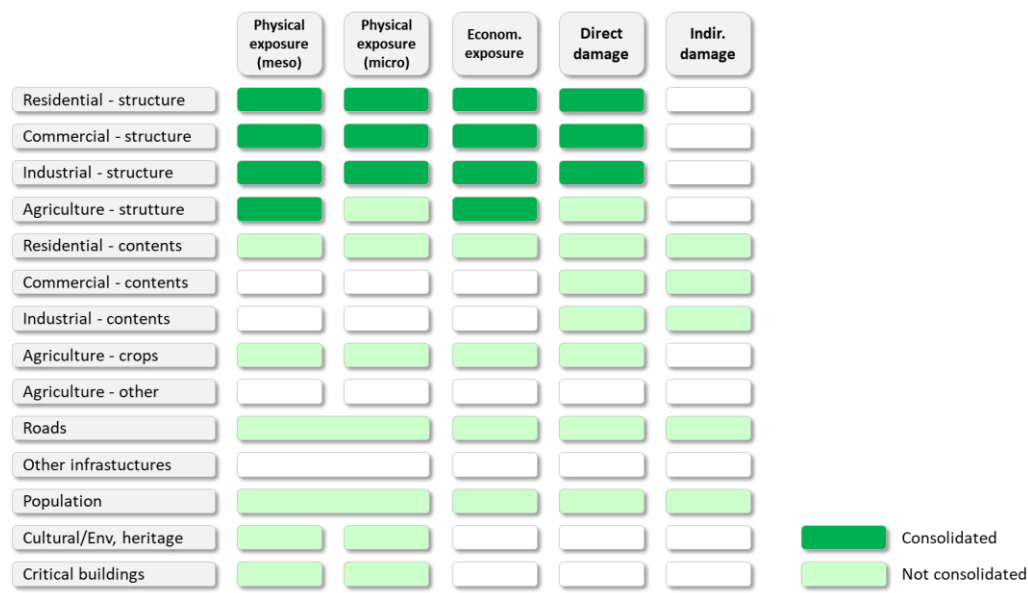


Figure 9. State of art of tools for ex-ante flood damage assessment worldwide

Above exposed elements, the residential sector is the one that received most of the attention by the research community. According to Gerl et al. (2016), almost half of the models developed for the estimation of flood damage in Europe rely on residential buildings. Still, no model can be considered as a standard, being damage models characterised by different levels of robustness and reliability. In such a context, the choice of the more suitable model(s) to be implemented in a specific context can be challenging, above all for non-expert users, and may imply significant errors in damage estimates if done without a critical knowledge of models’ limits and usability. A key question concerns the coherence between the scales of analysis. Damage models are usually developed and validated to be applied at a specific scale (e.g. micro, meso) and can be unreliable when implemented at different scales (see e.g. Jongman et al., 2012; Scorzini and Frank, 2017., Cammerer et al., 2013).

Regardless of which exposed element is considered, the lack of consistent and reliable (damage) data on past flood events is the main limit to the development of (new) robust

and reliable damage models, hampering both the calibration and the validation process of model development (Molinari et al., 2018). In fact, the standardising of flood damage data collection procedures has been constantly advocated by the scientific community (see e.g. Cammerer et al., 2013; Handmer, 2003; Rose, 2004; Downton and Pielke, 2005), in order to create complete and reliable databases, on the basis of which flood risks assessment and management can be effectively performed. Meanwhile, policy makers recognized the collection of loss data as one of the key actions that will help countries to increase their knowledge about natural risks, and to monitor their path towards risks mitigation objectives (see e.g. the Sendai Framework for Disaster Risk Reduction). Still, neither standards exist for loss data collection nor guidelines have been proposed for the effective use of flood damage data for risk mitigation objectives. Experiences and best practices of damage data collection, storage and analyses, at the worldwide level and with particular reference to floods, can be found in Molinari et al. (2017), as a first step towards standardization.

4.2 Hazard and flood risk maps

Hazard maps show information on flood water levels, flow rates and maximum speeds, wave and tidal regime, as well as areas exposed to erosive processes and trends in rising mean sea levels as a result of the change climate. This information is usually represented for different flood scenarios: those of high probability (return periods of 10 or 25 years), those of medium probability (return period of 100 years) and those of low probability or extreme event scenario (period of 500 year return period).

For each of the above scenarios, flood risk maps prepared in EU Member States compliant to the Floods Directive, must include the figures of the population and economic activity affected, any facilities that can cause accidental pollution (IPPC industries and Wastewater Treatment Plants, WWTP), protected areas for the collection of water intended for human consumption, bodies of water for recreational use and areas for the protection of habitats or species that may be affected , as well as any other relevant risk information, such as solid transport or sediment flows.

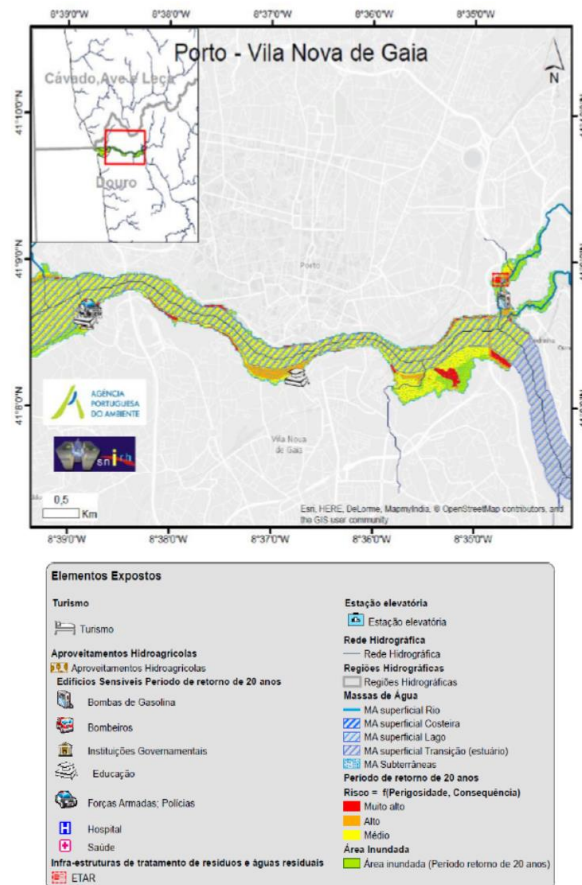


Figure 10. Example of an area with significant potential flood risk: Porto-Vila Nova de Gaia, Portugal

Flood mapping project for key areas of China

In 2013-2015, China first launched a large-scale flood mapping project, with a total investment of some 1.5 billion yuan from the central and local governments. With the aim of providing basic support for flood control decision making, flood control project planning, land use in flood control areas, flood impact assessment, enhance public awareness on flood risks and flood insurance mechanisms, the project developed maps for protected areas, flood areas, major cities and other types of areas identified in China's flood control plan. The maps were prepared at the provincial, basin and state levels to achieve systematic and integrated results.

The project completed the flood maps for a total of 574 units in China, including 227 flood control protected areas, 78 flood arrest basins, 26 flood plains on major rivers, 45 major cities, and 198 small river basins and medium, covering an area of 496,000 square kilometers, and representing 48% of the total area exposed to flood control in China. At

the same time, the project formulated more than 10 technical documents, which included detailed rules for the development of flood mapping and various regulatory documents related to management. In addition to this, a “software” was developed for flood analysis and its potential damage assessment. At present, China is working to apply the results of the flood maps to the planning, formulation and review of flood control plans, to support decision-making in flood management and control, to develop evacuation guidelines in flood situations, to the evaluation of the impact of floods, to enhance land management in flood areas, to foster public awareness of flood risks and to flood insurance.

4.3 Actions: technology and innovation

Technology and innovation are essential to the evaluation and management of risks due to extreme hydrological events.

In order to properly assess and manage the risks of droughts in recent years, Decision Support Systems (SAD) have been developed whose purpose is to simulate in a sufficiently detailed way the flows that run through rivers and canals, storage in reservoirs, the status of aquifers or the supply schemes to users that would occur for a future horizon, taking into account different hydro-meteorological scenarios, water demands and adopted measures.

One of the main uncertainties of the risk analysis is due to ignorance of the future hydro-meteorological scenario. Traditionally, in the absence of adequate forecasts, future hydro-meteorological scenarios used in drought management have consisted of the establishment of standard years (dry, normal, wet) or any year that could be relevant for the analysis, such as corresponding to the last important drought. The results obtained through these procedures have low reliability due to the ignorance of future hydrology. In recent years, important technological advances have allowed quantifying these uncertainties, such as the AQUATOOL Decision Support System developed in Spain.

Drought risk management through the AQUATOOL Decision Support System

The Department of Hydraulic and Environmental Engineering of the School of Civil Engineering of the Universitat Politècnica de València in Spain, has developed during the last decade models and Decision Support Systems (DSS), some of them through the

AQUATOOL environment (Andreu et al, 2009), which allow to simulate the behaviour of the basins and the management of their water resources operation systems incorporating all the complexities they have (available resources, water demands, infrastructure (reservoirs, canals, WWTPs, ...), returns of water uses, ...). These developments have been firstly applied to the Júcar river basin, but have also been applied to other Spanish basins.

Júcar basin authority provides a methodology that allows a thorough estimation of uncertainty and a probabilistic quantification of the evolution of the hydrological variables and metrics for any month of the future scenario such as, of probabilities of supply deficit in the supply of a certain amount at a certain demand, or the probability of exceeding a water storage threshold volume of water stored in a specific reservoir. This methodology, based on synthetic generation of flow series (Q) using stochastic ARMA models and multiple simulation models (Andreu et al, 2006), is incorporated into the AQUATOOL Decision Support System with a specific module (SIMRISK, SR) that performs all the risk assessment process, which was successfully applied during Júcar basin's 2005-2008 extreme drought, providing useful information for the meetings of the Permanent Drought Commission that was established for this task (Andreu et al., 2013).

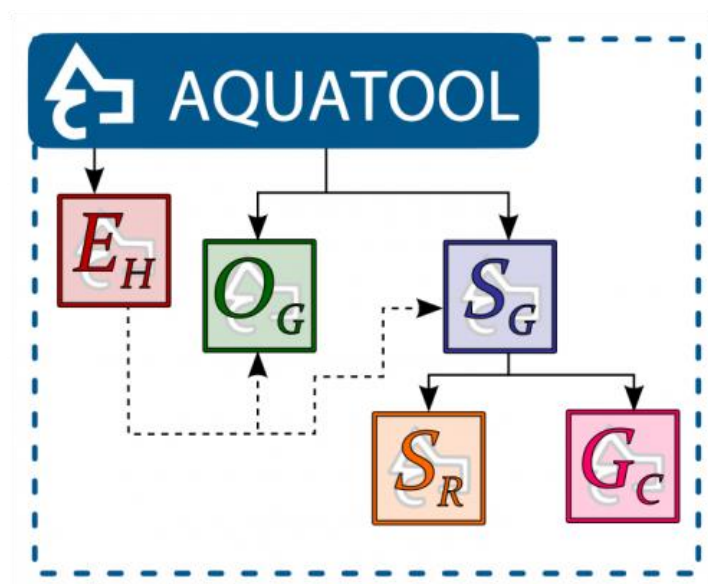


Figure 11. The AQUATOOL software⁶ developed at the Universitat Politècnica de València, Spain

⁶ <https://aquatool.webs.upv.es/aqt/aquatool/>

4.4 Advances in warning systems

Warning systems in the management of extreme hydrological events are a fundamental part of good risk management and governance. They have been evolving since the end of the last century, taking advantage of the greater capabilities of computer hardware, the development of friendly Graphical User Interfaces (GUIs), the increasing implementation of Geographic Information Systems (GIS) and remote sensing or the development of telecommunication systems increasingly reliable and at a lower cost. The advances in mathematical modelling of extreme hydrological events have also contributed to this evolution.

Flood warning systems are a set of elements that allow real-time rainfall monitoring, its transformation into runoff and eventual flooding that can be generated in the channels. Spain is a pioneer country in the implementation of Decision Support Systems such as the Spanish Automatic Hydrological Information System (SAIH) in all basins. SAIHs have been very effective in flood management at the basin level, since, providing real-time information on the flows that run through the rivers and the state of the reservoirs, decisions have been made, with sufficient time to mitigate its effects. To achieve this, management models are used at the basin level to anticipate the future situation in different parts of the basin, coordinating any necessary action with Civil Protection officials.

Drought warning and monitoring systems use different types of indicators depending on the type of drought (Ortega-Gómez et al, 2018). In meteorological droughts the most popular index worldwide is the Standard Precipitation Index (SPI), while in agricultural droughts the Palmer Drought Severity Index (PDSI) has been traditionally used, which is the result of the balance of moisture in the soil from precipitation, air temperature and local soil moisture, together with its background values. In recent years, indexes based on remote sensing are increasingly being used, such as the NDVI (Normalized Difference Vegetation Index). The reflectance for different spectral resolutions reflects the vigour of the vegetation, which is closely related to soil moisture. Other indexes are also used, such as percentiles for hydrological droughts or those that take into account the availability of resources and water demands to track operational droughts, which are those that affect water resource systems.

The incidence of drought in Europe during the twentieth century was studied by Lloyd-Hughes and Saunders (2002) on the basis of the monthly values of the Standardized Precipitation Index (SPI) calculated on a 0.5° cell resolution across Europe for the period 1901-99. More recently, other indexes such as the Reconnaissance Drought Index (RDI), based on precipitation and evapotranspiration, have been applied in Europe (Vangelis, H. et al., 2011). The drought indicators used in water resources management reflect whether it is possible to meet water demands in situations of reduced water availability and, at the same time, serve as an aid in decision-making related to water resources management in those situations.

In the world, different information and decision support systems have been developed that handle such indicators. Thus, in the European Union in 2011 the European Drought Observatory (EDO) was established by the Joint Research Center of the European Commission as part of its efforts to integrate droughts into water policy in the European Union. EDO's main objective⁷ is to improve knowledge of droughts using alert systems and properly prepare water authorities and managers for drought. Since 2011, EDO has been the main diffuser of relevant information on droughts in the EU, and as maps of drought-related indicators that use different data sources: rainfall, satellite measurements and simulations of soil moisture content, among others. EDO integrates such relevant data, drought monitoring indicators, information on detection and forecasting of droughts at different spatial scales, from local and regional to the general overview of the entire EU (Estrela and Sancho, 2016).

5 Experiences and best practices

5.1 Risk management plans: floods and droughts

5.1.1 Risk Management Approach

The risk approach has become an increasingly widespread practice in many fields of science and engineering, not just droughts and floods. Disaster risk reduction seeks to prevent new risks, reduce existing risks and manage residual risk. Addressing the risks of these extreme phenomena in a planned way allows studying, analysing and agreeing on measures with all

⁷ <https://edo.jrc.ec.europa.eu>

interested stakeholders, and managing the corresponding risk in advance, assessing their consequences from all points of view. In recent years, evaluation and management plans for flood and drought risks have been developed.

5.1.2 Flood risk management plans

The approach based on flood risk planning and management has spread worldwide in recent years. In the European Union, as a result of the application of the 2007 Floods Directive, flood risk management plans in river basin districts have been approved in 2015, covering all aspects of risk management, focusing in prevention, protection and preparation (what is known as the 3 Ps), including flood forecasting and the development of early warning systems. These plans may include the promotion of sustainable land use practices, hydrological-agroforestry restoration measures, improved water retention and controlled flooding. A fundamental element of these plans is to establish programs of measures that allow reducing the risk against floods based on the hazard and risk maps issued. Another relevant element introduced by the European Floods Directive is that structural measures require a prior cost-benefit analysis.

Elsewhere in the world, such as Japan, acknowledged to withstand several different types of natural disasters, flood risk management has also been extended. Japan's ability to manage urban flood risks has been greatly strengthened in the recent years, with an integrated management approach, which brings together all stakeholders and includes different measures to manage flood risks: regulations, plans, advanced infrastructure solutions and coordination and communication mechanisms. The main lessons derived from the experience of Japan are ⁸ : a) Risk assessment approaches must take into account the type of flood and basin features, reflecting the needs and objectives of all stakeholders and explaining the uncertainty due to climate change, b) National government plays an important role in supporting local governments in planning and prioritizing actions, although the latter have an important function of seeking consensus among all interested parties, c) Implementation of investments' measures, whenever possible, should include multifunctional systems that provide complementary other than managing flood risks and

⁸ <https://blogs.worldbank.org/sustainablecities/integrated-urban-flood-risk-management-learning-japanese-experience>

d) It is necessary to design and implement transparent governance mechanisms. Finally, the evaluation, control and monitoring of the measures is essential.

5.1.3 Drought Management Plans

Drought reduces water availability and makes it difficult to match demands and environmental objectives in bodies of water. Experience has shown that those who plan the response to drought events suffer less negative impacts than those who react when the disaster is upon them.

In the United States of America (USA), the National Drought Mitigation Center (NDMC) has developed guidelines that facilitate the development of drought management plans. According to these guidelines in the planning process, the first steps should try to ensure that the right people meet, that they know the objectives of the drought plan and that they are provided with adequate data to make fair and equitable decisions when formulating the plan. Next, an organizational structure must be developed to carry out the tasks required by the plan, which must always be understood as a process. During this step, a risk assessment should be carried out for key economic sectors, population groups, regions and communities. The last steps refer to the need for continuous research and coordination between scientists, managers and policy makers. Finally, the plan must be kept updated, being very important to evaluate its effectiveness in post-drought periods (NDMC, 1990).

In the USA, since the end of the 20th century to the present, drought management plans have been developed in most of the States of the Union, the most recent plans being those developed in 2018 in the States of Alabama, Colorado, Connecticut, Maryland, North Dakota, Pennsylvania and Washington ⁹.

In the European Union and within the Common Strategy for the Implementation of the Water Framework Directive, in 2007 the European Commission prepared the technical report “Drought Management Plan Report, including agricultural, drought indicators, and climate change aspects” (European Commission, 2007a), whose main objective is to serve as a useful tool to prepare drought management plans in the Member States of the

⁹ <https://drought.unl.edu/droughtplanning/Plans/StatePlans.aspx>

European Union, establishing general criteria and recommending the application of a battery of measures (Estrela and Vargas, 2012).

The development and implementation of drought management plans in the Member States of the European Union has not been extended to all river basin districts and this may have been due to the fact that there is no compulsory commitment to carry them out in the Water Framework Directive. There is only one recommendation for its development in the European's Commission Communication "Addressing the challenge of water scarcity and droughts in the European Union" (European Commission, 2007b), where drought management plans are identified as one of the main instruments of EU's Water policy to fight droughts.

Despite this, it can be said that the development of these plans is receiving increasing attention by the Member States. Hervás-Gómez and Delgado-Ramos (2019) indicate that 78 European River Basin Districts (42%) have implemented Drought Management Plans (DMP) (or similar tools) or have included them in the Program of Measures of its River Basin Management Plans, RBMP. For example, in Cyprus, DMPs are included as an annex to the RBMP, while in Spain the last approved DMPs have been developed as complementary documents to the RBMP. On the contrary, United Kingdom private water supply companies are obliged to develop Water Resources Management Plans and DMP. France and the Netherlands have their own operational drought management tools. Other countries have developed tools focused on emergency management or specific early warning systems.

Cooperation in the planning and management of droughts in the Iberian Peninsula

The planning and management of droughts in the Iberian Peninsula are compliant to the requirements of the EU's Water Framework Directive of the year 2000 and in the European Commission's Communication Shortage and Droughts (EC, 2007). Drought planning and management requires joint cooperation between Portugal and Spain, since the river basins shared between the two countries represent 45 percent of the territory of the Iberian Peninsula. The harmonization of drought policies of both countries is carried out through the existing bilateral agreement on the management of river basins, the Albufeira Covenant, signed in 1998. This agreement establishes the flows that must

circulate through the main rivers in periods of drought depending on the status of a series of indicators set in the agreement itself.

Although the two countries have been cooperating and working to achieve joint management of shared basins, they are currently at different stages in drought planning and management. According to Maia and Vicente-Serrano (2017), the drought management policy in Spain is based on a proactive and planned approach, while Portugal's drought management plans have not yet been approved.

Drought management plans in Spain

The heavy impact brought by the drought that struck Spain in the period 1991-1995 contributed to a paradigm shift in drought management. Then, it came clear to establish an instrument such as Special Drought Plans (PES), which allowed managing drought minimizing its socio-economic and environmental impacts, and which meant a change from the traditional approach of crisis management through emergencies (Estrela y Sancho, 2016).

Thus, Spanish Act 10/2001, of 5 July established through its National Hydrological Plan the basis for a planned drought management, indicating that: a) the Ministry of Environment would establish a global system of hydrological indicators to prevent drought situations that will serve as a general reference for its formal declaration, b) the Basin Organizations would develop special action plans to address eventual drought situations and c) the Public Administrations responsible for supplying populations over 20,000 inhabitants would develop emergency plans for drought situations.

Drought management plans in Spain are drafted by the River Basin Authorities and come into force when approved through ministerial order. These plans have been developed in all the State managed river basins. Recently, such plans have had its review updated in 2018 through ministerial order. With these special plans, a monthly series of hydrological indicators is set up which diagnoses the situation and specifies the result in a summary map published by the Ministry for Ecological Transition, through its web portal.

The basic contents of PES include the drought's features and diagnosis, the system of threshold indicators to establish scenarios of prolonged drought or temporary shortage, the measures and actions to be carried out in the different phases of drought and scarcity, drought monitoring and post-drought reporting, which would include the evaluation of socio-economic and environmental impacts and serve as a reference framework for the preparation of emergency supply plans.

In this regard, it should be noted that the Spanish Association of Supply and Sanitation (AEAS) has prepared a Guide (AEAS, 2019) to facilitate water supply utilities the review of their current emergency plans.

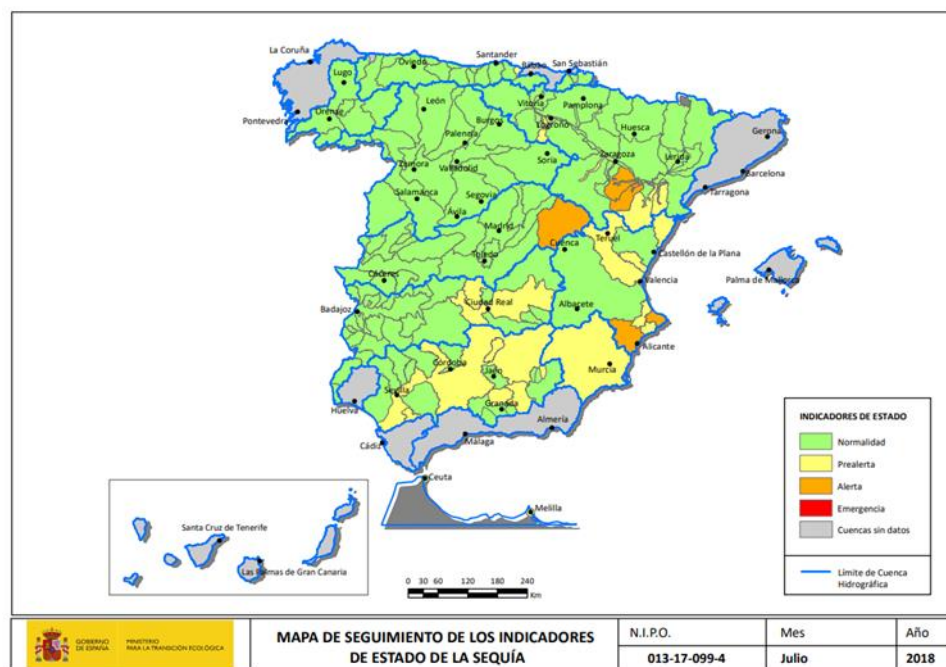


Figure 12. Drought Indicators Monitoring map in Spain, July 2018..

Lessons learnt so as not to repeat the same mistakes: La Paz Drought Management Special Plan in Bolivia

The water supply to the urban conglomerate La Paz - El Alto and nearby towns is provided by four hydraulic infrastructure systems: 1) Pampahasi system: its supply sources are the reservoir waters in two contiguous sub-basins, 2) El Alto system: its main supply source is Tuni dam's water reservoir, 3) Tilata system its supply source of supply is Pura Purani's

aquifer, located on Bolivia's plateau and 4) Achachicala system: its main supply source is the Milluni dam.

The water supply to La Paz - El Alto and adjacent towns went through a serious supply crisis during a period that began in November 2016, because of the low rainfall recorded in the preceding months. This situation caused supply restrictions, since the small available reserves did not guarantee the normal provision of this service. These restriction measures were accompanied by other emergency actions, such as interconnection works between different sections of the distribution network, transportation of water tanks, etc. The consequences of the unplanned management of a crisis of this nature were, among others, the sudden impact of its effects, the perplexity and lack of preparation of society to face it, the greater cost and inefficiency of the measures or the remaining situation of vulnerability to future episodes.

Bolivia's Ministry of Environment and Water, with the consultancy of the Spanish Agency for International Development Cooperation (AECID), considered the drafting of a Special Drought Management Plan, whose objective was the early preparation for future droughts, limiting its adverse impacts on the economy, social organization and the natural environment. This plan was established in accordance to the following procedure: a) definition of mechanisms for forecasting and detecting the occurrence of drought situations, through an adequate system of indicators, b) determination of threshold values for monitoring the evolution and intensity of drought, c) definition of the measures to achieve the specific objectives in each phase of the drought situations, depending on the status of each system: demand management measures, connection infrastructures of the Achachicala-El Alto systems and the Tilata-El systems Alto and new additional wells of the Purapurani aquifer and d) ensure transparency and public participation in the development of the plans.



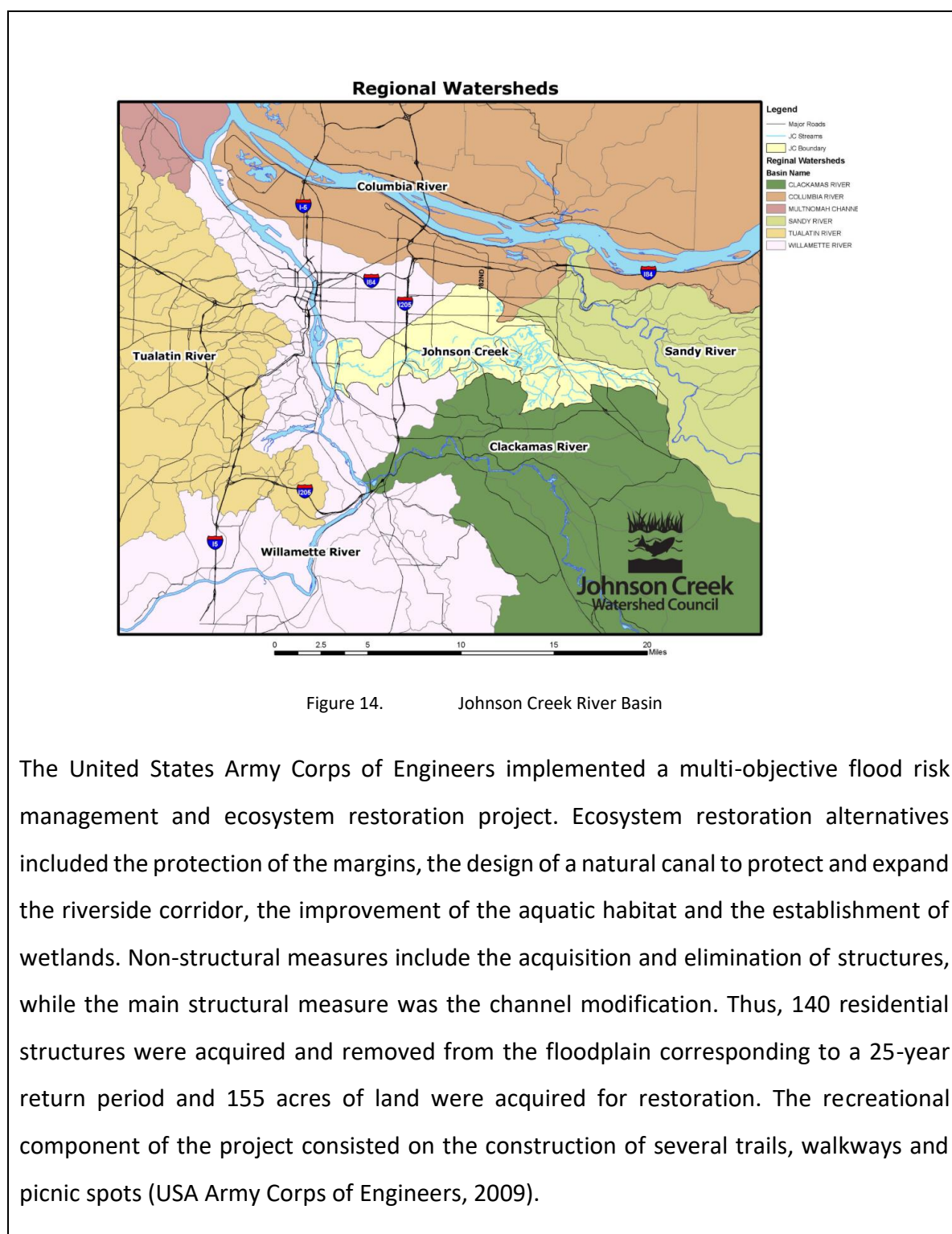
Figure 13. Tuni reservoir with a capacity of 21.55 Hm³. In operation since 1977

5.2 Measures to deal with flood risks

Measures to deal with flood risks must be identified, prioritized and implemented once the existing risk is well known and therefore, as already indicated, the development of hazard and risk maps becomes essential. There are a large number of measures, which classify into structural protection measures and management or non-structural measures. OECD (2019) recognizes that "hybrid" solutions combining structural and management measures are required to address in the most effective way the protection against floods and that contribute to achieving the good state of water bodies.

Flood risk management and ecosystem restoration at Johnson Creek in Arlington, Texas, USA

Johnson Creek has experienced a history of flooding, bed erosion and habitat degradation over the past 60 years, which led to different studies to reduce damage. Economic analysis showed that it was less expensive to restore flood plains along Johnson Creek, where homes and businesses were flooded every year, than to annually repair any damaged infrastructure.



5.2.1 Structural Protection Measures

Structural measures address the execution of infrastructure works which impact the mechanisms of generation, action and propagation of floods, altering their hydrological or hydraulic characteristics. Among the structural measures are those that reduce the

magnitude and frequency of flooding, such as flood rolling dams or diversion channels to alternative channels or to the sea. Other measures modify the level of flooding, such as embankments and dykes and protective walls or other actions on the channel section. There are also some other measures which modify the duration of the flood, such as the drainage works of the linear infrastructures (roads, railways, ...).

5.2.1.1 Flood control reservoirs

Flood control reservoirs hold part of the flood volume decreasing its peak flow rates. In many river basins, with very irregular regimes, reservoirs constitute a very effective protection against floods, through the management of seasonal safeguards to reduce peak flows. In this way, the danger and risk of flooding reduces, while maintaining the same vulnerability and exposure in all potentially affected assets downstream of these reservoirs.

Flood risk protection through reservoirs flow management. Case of the Ebro basin, Spain

In the Ebro river basin, numerous reservoirs contribute to the reduction of the danger of flooding episodes, through the management of existing reservoirs and the coordination of intakes and discharges so as not to overlap flood points. In this management, the engineers of the Ebro River Basin Authority (world's first basin authority) take advantage of the real-time data offered by the SAIH (Automatic Hydrological Information System) to adjust the discharges to the damage thresholds' reference flows of at significant points in the basin.

As an example, the operation of the Yesa and Itoiz reservoirs (in the Aragón rivers and its tributary the Irati, respectively) safeguards the city of Sangüesa, located at the confluence of both rivers, at another time hit by floods, contributing decisively to the protection of the city of Zaragoza, the capital of the Ebro, located downstream from Aragón river outtake to the Ebro river itself.

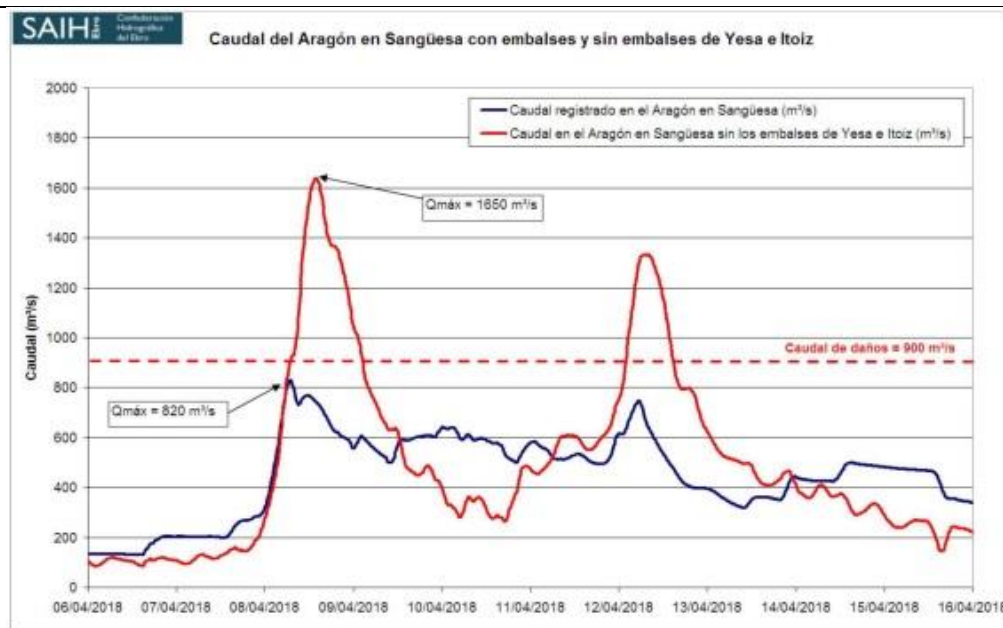


Figure 15. Rolling of the Aragón river flood as it passes through Sangüesa due to the water held in the Yesa and Itoiz reservoirs



Figure 16. Ebro river flood episode as it flows through the city of Zaragoza

5.2.1.2 Diversion channels

One alternative to reduce flood flows is to offer a different route for excess water by creating artificial channels which drive the flow to less vulnerable areas. Diversion channels are not carried out much in the present due to environmental considerations and the potential risk increase in the flow's diverted areas. A clear example of diversion channel can be observed

is the of river Turia's diversion channel to the sea in the city of Valencia, Spain, which was built in response to the Turia river 1957 floods. This man-made channel takes the flows of the Turia river to the South of the city, an area where land use is much less vulnerable than those on the banks of the natural channel (EEA, 2001).

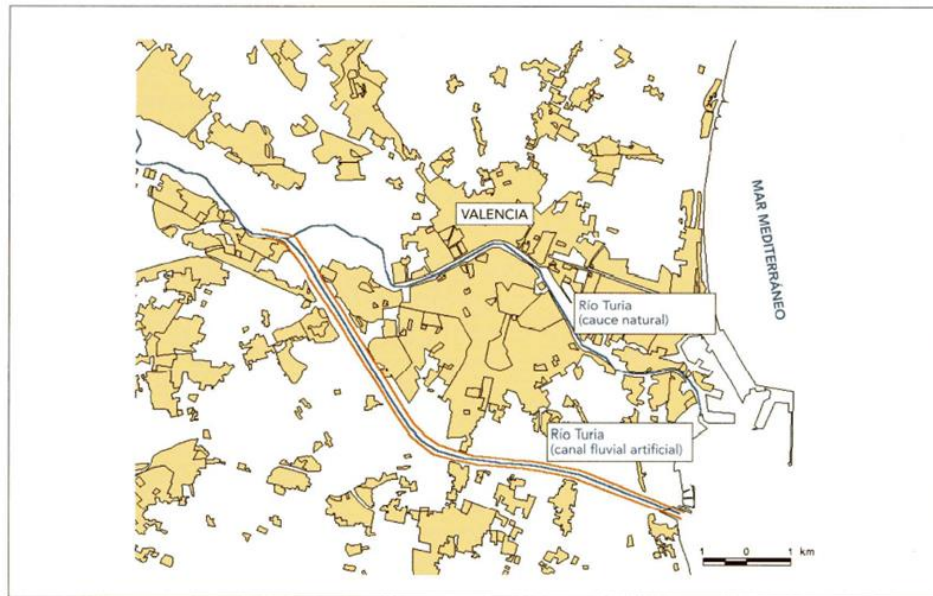


Figure 17. River Turia's diversion channel. Source: Sustainable water use in Europe. Part 3: Extreme hydrological events (EEA, 2001)

5.2.1.3 Embankments and dykes

Embankments are linear structures parallel to the main channel widely used to protect already consolidated urban areas. However, this type of action increases the level in the channel section and, consequently, the greater speed and water level in the embanked area infers a greater risk of flooding downstream. Embankments' other negative aspects are their frequent breaks (large length, lack of maintenance, regrowth, etc.) or their becoming an obstacle to tributaries and runoff drainage. In addition to this, any spill or break entails higher flood risk.

The first dikes reported were built in the Indus Valley (around 2600 BC), on which the agrarian life of its inhabitants was built upon. Also more than 3,000 years ago in ancient Egypt, a levee system was built along the left bank of the Nile River with more than 970 km, from Aswan to the Nile Delta in the Mediterranean. Mesopotamian civilizations and ancient China also built large levee systems. Much recent and important levee systems are those along the Mississippi and Sacramento rivers in the United States, and Po, Rhine, Meuse,

Rhone, Loire, Vistula and Danube rivers Europe, with special attention to the Rhine , Maas / Mosa and Scheldt delta in the Netherlands.

The Mississippi levee system represents one of the largest levee systems in the world, comprising over 5,600 km of dikes, with an average height of 7.5 m. Dike's break can happen due to multiple factors, including overflow, erosion, structural breaks or dike saturation. The most frequent and dangerous are dike break which would leave a large breach for water to flood the earth that would be be protected by the dike otherwise.



Figure 18. Sacramento River's dyke break

5.2.1.4 Channel modification

The modification of the channels' cross-section intends to improve its hydraulic capacity by an increase in the cross-section surface (increase in width and / or depth) or speed (greater slope: meander cuts, decrease in roughness). However, it has negative aspects, such as the increased risk of flooding downstream, impacts on the river ecosystem and changes to the geomorphological balance.

These actions, due to the drawbacks they present, are only really justified in already consolidated urban areas or in certain cases of river channels' affected by the construction of some transport infrastructure. However, in the past, such measure has also been used to protect arable land. As in the case of embankments and dikes, it is desirable that its design to be as natural as possible, with at least two different channel widths to address small and larger floods events.



Figure 19. Channeling the Ebro river in Castejón for its 5-year return period flow

5.2.1.5 Drainage of linear infrastructures

Transport infrastructures, due to their great length, affect numerous waterways, small or even intermittent, large rivers and very flat areas with diffuse natural drainage. All these factors are decisive when designing the transverse drainage of the infrastructure.

The purpose of transverse drainage is to restore the continuity of the natural drainage network of the land (troughs, channels, etc.), allowing the design flow to run through it. The importance of an adequate design of these works becomes more critical, since, during flood emergency situations, it is essential that transport infrastructures allow the evacuation and arrival of aid elements to mitigate their effect.

In the great channels, the main problem that usually occurs is that of the erosion of the river bed caused by the barrier effect to the flow of water generated by the bridges' piles and

abutments, in addition to the possible narrowing of the water depth during flood episodes if the abutments are not the out of the riverbed's core.



Figure 20. Viaduct over Chanza river

In small and intermittent channels, in addition to the previous considerations, it is important to take into account that their dimensions should allow the passage of trees and vegetation remains that flood flows carry usually. When the area affected by the infrastructure is very flat, without defined channels for water circulation, the problem becomes quite complex and almost the only solution is to determine the possible level that the water could reach with 2D hydraulic models and then define the level from the slope of the infrastructure and permeabilize as much as possible the entire linear infrastructure's route of the same, to create a kind of communicating vessels network between the areas in which the infrastructure divides the plain.



Figure 21. Small Drainage Work (SDW) on an embankment

5.2.1.6 Green infrastructure and natural water retention measures

Basins which host many flood protection infrastructures have, in many cases, lost the connection between rivers and floodplains, which has resulted in significant decreases in river productivity and biodiversity. As a matter of fact, species which are part of freshwater ecosystems are in greater danger of extinction than terrestrial or marine species, largely due to the fragmentation of habitats and changes in inflows caused by infrastructure.

Therefore, flood plains face two major challenges to achieve sustainable flood risk management: develop actions to reduce flood risk and at the same time maintain or restore connections between rivers and its flood plains (European Environment Agency, 2016). Although these objectives seem incompatible at first glance, the approach to flood risk management based on green infrastructures tries to make them compatible. Unlike classical engineering infrastructures for protection against floods, green infrastructures entails restoration or conservation of forests, wetlands, rivers and floodplains.

Natural water retention measures (NWRM) constitute an innovative approach to achieve water management objectives by restoring nature and its functions. NWRMs are not only means to produce a single benefit, such as flood protection, but they are accompanied by others, such as increased biodiversity, greenhouse gas mitigation, energy savings or opportunities for rural development, which affects many people whose well-being is directly and indirectly improved (European Commission, 2015).

Among the measures used for flood control are the establishment of buffer strips, the improvement of ground cover through conservation and reforestation, erosion control through transverse dikes, the elimination of transverse barriers to flood development and urban sustainable drainage systems (SUDS).

Many rivers in northern and western Europe have had its channels straightened to facilitate the flotation of logs or accelerate water runoff and control or limit horizontal movements of the riverbed. Channelling was also a way to obtain land for cultivation. River re-meandering consists in reconnecting formerly cut-off meanders, slowing down again the river flow. The new form of the river channel creates new flow conditions and very often also has a positive impact on sedimentation and biodiversity. The newly created or reconnected meanders also provide habitats for a wide range of aquatic and land species of plants and animals.



Figure 22. Before and after the restitution of meanders on the Morava river in Slovakia and the Czech Republic

In recent years, the territory associated with the middle and lower reaches of the Arga and Aragón rivers in Spain has suffered numerous management problems because of recurrent flooding. Such system holds a large flood plain, in which numerous intensive agricultural activities are developed, and in which several municipalities and numerous linear infrastructures are also located. At the same time, it is an area that supports various natural river enclaves protected by the regional environmental schemes and the European Natura 2000 network, due to the quality of their natural habitats and the important biological diversity it hosts.

The increase in the capacity of floods mitigation and temporary water storage was clear since the meander restitution from the reopening of the meander: several ordinary floods that occurred at the end of 2009 and beginning of 2010 showed that the functional reconnection of the meander had been achieved. Since then, the natural dynamics of the

Arga River have been configuring the morphology and eco-hydrological processes of the meander, progressively increasing the naturalness of the environment and its ability to retain water and to support numerous habitats and species of conservation interest.



Figure 23. Plantío meander on the Arga river in Spain

The creation of small dams / wetlands that perform as water retention areas and protected refuge for the European mink and for different aquatic and riparian species. The topographic and hydraulic modelling (from which the weir geometry follows) ensures the measures' effectiveness.



Figure 24. Temporary controlled flood area of Pradilla de Ebro on the Ebro river in Spain

Nature-based solutions to prevent urban flooding

Sustainable urban drainage systems (SUDS) are an alternative approach to urban drainage. These innovative systems can be considered as a supplement for conventional drainage networks, and they help to control urban runoff using techniques that replicate the nature behaviour (nature-based solutions) in the scenario prior to urban development, using elements that are harmonically integrated in the urban landscape.

SUDS should start being applied where the runoff is produced and before it starts to become an issue: roofs, impermeable areas, gardens, plazas, roads... The main principle of this approach is to contain and store the runoff at source, for example, infiltrating and storing stormwater in the public and private green areas. This way, SUDS are able to achieve three objectives: firstly, they can reduce overall runoff volume infiltrating part of it; additionally, they are able to improve water quality treating physically and biologically the runoff; and finally, they can attenuate and reduce peak flows, preventing downstream flooding.

Sustainable Development Goals (SDG) from the United Nations (UN) are seeking for a more sustainable world by 2030. As expected, many of these goals are water and environment related, and they aim to improve water quality or to optimize water resources. SUDS are a key tool to achieve these goals, as they are able to treat water and improve its quality, they can boost biodiversity and help to prevent flooding issues in cities.

In addition to the continuous growth of the cities, climate change is causing high temperatures and extreme rainfalls. These factors are increasing the risk of urban flooding, and sizing up existing networks is not a feasible solution from the economical, technical and environmental perspective.

In conclusion, SUDS constitute an interesting nature-based solution for urban drainage, being able to solve part of the problems on the existing drainage networks by attenuating and reducing the runoff volumes. 2018 World Water Day's slogan, "Nature for water", highlights the importance of replicating hydrological natural processes. As a nature-based solution, able to replicate infiltration, evapotranspiration or detention, SUDS constitute an innovative approach for urban drainage.

Although SUDS are a quite recent practice (few decades), there are already really good examples of SUDS utilisation in various cities around the world.

For example, in 2010 the Green Infrastructure Plan was approved in New York. The main goal of this plan was to capture and retain 25mm of rainfall using sustainable drainage systems, in at least 10% of the impermeable areas served by combined sewers (City of New York – DEP, 2016). By the end of 2015, more than 2,500 rain gardens able to store and treat runoff from footpaths and carriageways were already constructed, and there are several regeneration projects currently running that involve more than 250 public assets and 29 parks.

Also in the USA, in 2012 Washington DC's government prepared a plan to deal with climate change effects. One of the main goals of this programme was to reduce the impact of climate change on the existing drainage networks, preventing long-term urban flooding issues. To achieve this, by 2032 75% of the rainfall events should be captured for infiltration or storage for re-use (District of Columbia, 2013). Helping to reach these targets, government published Greening DC Streets: a design guidance for green infrastructures in the urban landscape (bio-retention strips, permeable paving, infiltration features), which contains sketches, specifications and O&M plans.



Figure 25. Bioretention planter with step-out zone in Washington DC. Source: Green Blue Management S.L.

SUDS are also appearing in Europe, Oceania and Asia. Between 2011 and 2014, several Chinese cities had flooding issues and as a consequence, Chinese government developed the Sponge City Programme, which aims to stir up urban drainage management, ensuring that the urban landscape is able to absorb, store, infiltrate and treat water for re-use. According to this programme, by 2020, 80% of the urban areas should be ready to store and re-use at least 70% of the rainfall (Dai, 2017). Wuhan was selected as one of the pilot cities due to the risk of flooding in this area, and the SCP has developed several projects around, including the Garden Expo Park, a very popular leisure area constructed on top of a landfill.

In the last decade, SUDS are also emerging in Spain. The Spanish civil engineering magazine “Revista de Obras Públicas” (edited by Colegio de Caminos, Canales y Puertos), on the March 2019 issue, contains more than 20 articles on sustainable drainage experiences. Cities like Madrid (where it is worth to highlight the Wanda Metropolitano stadium permeable parking), Barcelona (that created a SUDS commission within several city departments), Sevilla (that has a restriction on stormwater flows connecting to the municipal sewer system), Benaguasil (a 11,500 inhabitants town than holds the 2015 national award to the most sustainable city in water management), and others like Vitoria-Gasteiz, Santander or Valencia, count with a number of SUDS projects.

An example of these interventions can be found in the Barcelona Bon Pastor district, which incorporates SUDS to control urban runoff. As part of the plan, different SUDS were integrated in the urban landscape, being able to collect and treat runoff from the paved areas nearby and from the new buildings. Streets and pedestrian areas have incorporated bioretention areas, rain gardens, permeable paving, and structural soil along the tree alignments (Soto-Fernández and Perales-Momparler, 2018).



Figure 26. SUDS in Bon Pastor, Barcelona. Source: Soto-Fernández and Perales-Momparler, 2018

5.2.1.7 Hydrological restoration and flood zone measures

The measures for the hydrological-agroforestry restoration of basins try to reduce the solid load carried by the river flow, as well as to favour the rainfall infiltration.

5.2.2 Non-structural or management measures: prevention, alert and response

Non-structural or management measures are those that, without acting on the flood itself or on the action of the sea, modify the exposure of the flood zone to flood damage. In Europe, the Floods Directive has placed emphasis on prevention, forecasting, protection and non-structural measures. The main non-structural or management measures are the adaptation measures for potentially affected assets, the territorial and urban planning measures, the flood warning systems, the civil protection measures and the flood insurance promotion

5.2.2.1 Adaptation measures for potentially affected assets, for damage mitigation

The damages to flood affected assets and elements, and whose withdrawal is not feasible are to be identified, classified, studied, and promoted adaptation action. Its objective is to

improve their resilience, either by adapting or rearranging the facilities and their uses, or by adopting specific protection measures.

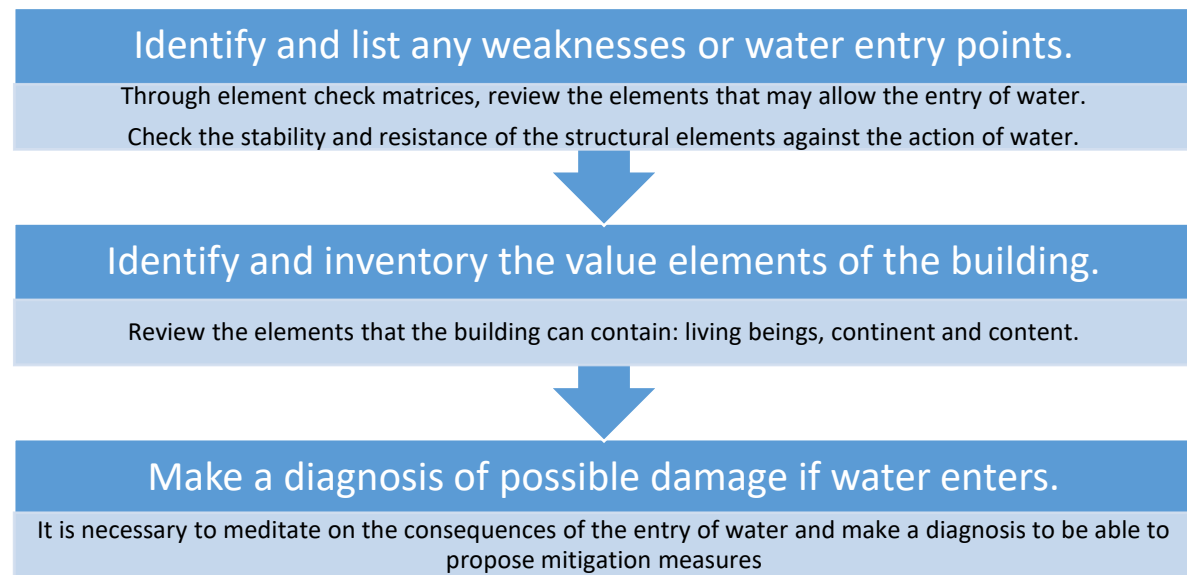
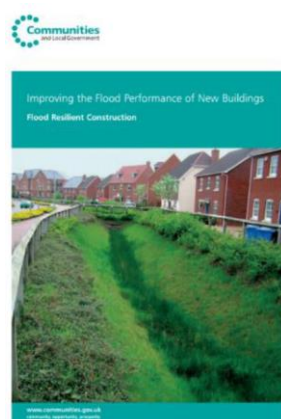
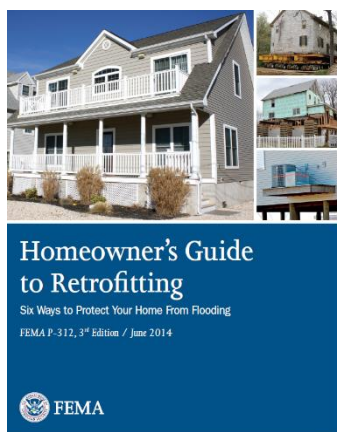
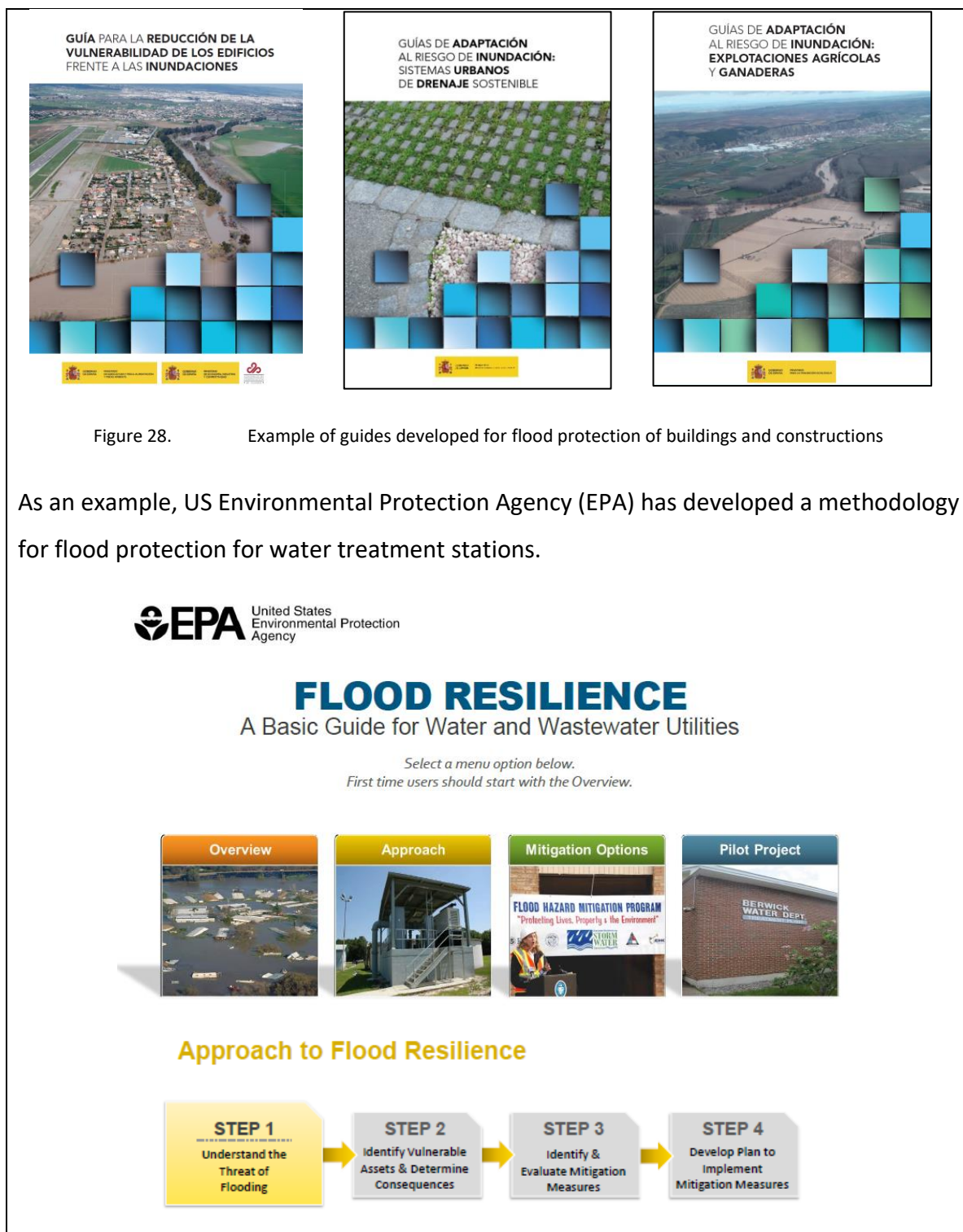


Figure 27. Damage assessment steps for flood protection

International experience in the protection of buildings and constructions

A general concern worldwide about the protection of buildings and constructions against floods has risen, which fostered the publication of several technical guides on the topic in developed countries such as the United States, United Kingdom, France or Spain.





Worksheet

STEP 1: Worksheet (page 1 of 2)

To better understand the threat of flooding, your utility should first examine historical flooding data and review Federal Emergency Management Agency (FEMA) Flood Maps. Below are instructions for evaluating the threat of flooding at your utility.

The tables below have sample data. Use the blank tables (double click icon) to input your utility's data.

1.1 Have you reviewed utility records of past flooding events? ☐ Yes ☐ No

If no, review how past flooding events have threatened your utility. Use various sources, including utility records, newspapers, websites and hazard mitigation experts, to collect previous flooding data. Enter your utility's past flooding information into Table 1.

EXAMPLE OF COMPLETED TABLE 1 - PAST FLOODING EVENTS

Event Information (e.g., Date, Name, Type*, Flood Elevation)	Description of Damage (Operational, Public Health and Economic Impacts)
April 2007, "Patriot's Day Storm," Nor'easter, 238.5 ft	Collapsed water storage tank and damage to pump stations and chemical storage. Operated on backup power generator. Soil water notice issued for several days. Financial impacts were roughly \$100,000.


* Tropical storm, hurricane, spring thaw/snowmelt, levee failure, etc.

1.2 What potential sources of flooding could impact your utility?

☐ Swollen rivers/streams ☐ Flash floods ☐ Levee/dam failure
☐ Spring thaw ☐ Coastal flooding ☐ Non-natural causes (e.g., main break)

1.3 Have you obtained FEMA Flood Maps? ☐ Yes ☐ No

If no, go to the [Map Service Center](#) to find FEMA Flood Maps, categorized by community. Flood Maps show areas that will be affected by both 100-year and 500-year floods. A "100-year flood" is a flood event that has a one percent chance of occurring in a given year. A "500-year flood" is a flood event that has a two tenths percent chance of occurring in a given year. Click on the icon to learn more about interpreting a Flood Map. If your Flood Map is not up to date, talk with your local community planning department or floodplain manager.



1.4 Identify which floodplains your utility systems are located within.

Locate your utility systems, such as intake, treatment, distribution, storage tank and pump stations, on your community's Flood Map to determine which floodplains they are located within. Summarize your findings in Table 2.

Worksheet

STEP 1: Worksheet (page 2 of 2)

EXAMPLE OF COMPLETED TABLE 2 - UTILITY SYSTEMS WITHIN FLOODPLAIN

Utility System	100-year Floodplain Flood Reaches Elevation (237 ft)	500-year Floodplain Flood Reaches Elevation (240 ft)
Intake (235 ft)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Treatment (238 ft)	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Distribution/Collection (237 ft)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Storage Tank (252 ft)	<input type="checkbox"/>	<input type="checkbox"/>
Pump Stations (238 ft)	<input type="checkbox"/>	<input checked="" type="checkbox"/>

Note: Changes in climate and land use can affect a utility's flooding threat. For a more advanced evaluation EPA's [Climate Resilience Evaluation and Awareness Tool \(CREAT\)](#) can provide data on projected changes extreme precipitation even and sea-level rise by location.

1.5 What flooding threat do you want to prepare for?

Using your utility's information from Table 2, decide which flood threat will be the focus for protecting your utility. Select the flooding level that you would like to address.

☐ 100-year flood Elevation _____ ft
☐ 500-year flood Elevation _____ ft
☐ Other: _____ Elevation _____ ft
 (e.g., add elevation for climate change impacts or freeboard¹ for local building requirements)

Note: A recent FEMA publication² recommended elevating critical infrastructures above the 500-year flood elevation. This level of protection may be necessary to obtain federal funding.

To illustrate how a utility might make this decision, below are three potential options based on the sample data in Table 2 above.

- Option A:** Select 100-year flood. The utility is unwilling to tolerate a one percent probability of a flood that would damage its intake and distribution systems. The utility is not concerned about the more remote possibility of a 500-year flood at this time.
- Option B:** Select 500-year flood. Although the utility will have some impacts from a 100-year flood, the intake and distribution systems are generally well protected. However, the entire facility, including a new expensive treatment system, would be a total loss with a 500-year flood.
- Option C:** Select 100-year flood plus 2 feet. The facility has assets located along the coast and experienced two floods in the last 5 years that approached this elevation and caused significant disruption to service.

¹ Freeboard is a safety factor expressed in feet above a flood level for purposes of floodplain managers.
² "Reducing Flood Effects in Critical Facilities," FEMA RA-2 (accessed August 24, 2014).

Figure 29. Flood protection of water treatment stations. Source: USA Environmental Protection Agency

5.2.2.2 Prevention measures: land management and urban planning

Many experts around the world are convinced that unsustainable development contributes to an increase in flood damage. The design of mitigation strategies provides an adequate way to avoid or minimize such losses. The limitation of land use in flood prone areas is a clear example of these mitigation strategies. It is assumed by all that the risk of flooding cannot be completely eliminated and therefore there is a need to integrate flood risk into the urban and territorial planning process, bearing in mind that in many cases the most efficient measure to reduce the impact of floods is to avoid locating the most vulnerable uses in the most exposed areas.

The territorial and urban planning measures therefore should take into account the limitations to the land uses of the affected flood zones in its different hazard scenarios, the criteria used to consider the territory as non-developable, and construction criteria required for buildings located in flood zone, which must go beyond the requirements of standard building codes, in order to reduce the loss of life and property damage. Prevention measures may also include the possibility of removing existing buildings or facilities that pose serious risk.

60

5.2.2.3 Warning measures: flood warning systems

Since the end of the last century, forecast and early warning systems have been developed for real-time flood management. These systems usually include tools for visualization and analysis of real-time data (rainfall, river flows, levels in riverbeds and reservoirs, ...) as well as mathematical models of simulation and forecasting of flows and floods.

Flood warning systems in Spain

In Spain, the Sistema Automático de Información Hidrológica - Automatic Hydrological Information System - SAIH was initially launched in 1983 at the Júcar River Basin Authority (CHJ) as a consequence to river Júcar's flash floods, which caused Tous dam break in 1982. In following years, these systems were replicated in other basins.

SAIH is a real-time information system that provides data (within 5 minute intervals) of the main hydro meteorological and hydraulic variables in the basins for water resources management, flood management, flood alert and dam safety. Its operation is based on data collection at key monitoring points, its transmission to the basin authority control centers and the processing of such information and its analysis. Currently, SAIH has 1,462 rain gauges, 925 gauging sensors in rivers and 848 sensors deployed throughout Spain's reservoirs.



Figure 30. SAIH control centre at the Júcar River Basin Authority

The Mediterranean areas of Spain is especially exposed to the flash floods and cold drop phenomena, which cause intense rainfall in very short periods of time and, consequently, overflows in the channels and serious floods. The difficult predictability of these phenomena, the extraordinary virulence of rainfall and the vertiginous rapidity of flooding in rivers and ravines, makes the response time of the population and the means deployed

by Civil Protection Services very scarce. Such motivates the interest of Early Warning Systems, which trigger the specific warning and initiate the first phases of Flood Risk Civil Protection Plans, to be the most anticipating as possible. Taking into account the high speed of propagation of the hydrological process into the channels (intense rains in short space / large slopes / ...) the SAIH, in addition to using the real-time hydro meteorological information captured in sensors distributed throughout the basin, carry out alerts and forecasts hydrological from the information retrieved by meteorological radars.

China's sudden flood forecast and warning system

The disasters that cause floods in China are mostly sudden and difficult to predict and prevent, severe in terms of the destruction they produce and vary significantly during the seasons of the year and in the different regions. In the past, due to the failure of warning and evacuation systems, the annual average number of deaths caused by flash floods accounted for about 70% of total flood deaths. To address such disaster risks, the Chinese government implemented a national plan for the prevention of flash floods. Automatic monitoring facilities have been built which include automatic, water level, video (image) rain stations, as well as wireless transmission and communication terminals. China has already built 2,076 flash flood surveillance platforms at the county and state level and has extended them to 18,924 between municipalities and cities. Currently, China's flash flood monitoring and early warning system plays a very important role during the flood season every year. The number of victims has been greatly reduced and the benefits of flood control and disaster reduction are evident.

Distributed hydrological models and early warning indicators have also been developed for communities exposed to this type of flood. Through the use of modern information technologies, an information exchange network has been built at various administrative levels (state, provincial, municipal, county and municipality), which provides information services for the monitoring and control of floods, consultation of information on disasters, and the dissemination of information to the responsible persons.

5.2.2.4 Response measures: civil protection

Civil protection measures include coordination measures with existing civil protection plans, and protocols for the communication of information and hydrological predictions of the competent water bodies in the area to the civil protection authorities. They can also include the measures proposed for the elaboration of civil protection plans if they are not previously defined.

5.2.2.5 Response measures: flood insurance

This type of measures includes the promotion of flood insurance on people and property and, especially, agricultural insurance. Insurance policies require the existence of irrigation maps to determine insurance premiums. An example of insurance policies in the world is the USA National Flood Insurance Program (NFIP).

USA's National Flood Insurance Program (NFIP)

USA's National Flood Insurance Program - NFIP is a voluntary program that operates through a partnership between the Federal Government and the communities (cities, towns or villages). NFIP provides flood insurance, backed by the federal government, to the owners and tenants of the participating communities. In return, each community adopts and enforces NFIP floodplain management regulations. The creation of the NFIP was an important step in the evolution of floodplain management in the United States of America (USA). During the 1960s, Congress studied in depth the traditional approaches to deal with the damage caused by floods, concluding that: structural flood protection actions was costly and could not protect everyone; people continued to build in the floodplains and, therefore, remained at risk; disaster relief was inadequate and expensive; private insurance industry could not offer flood insurance at an affordable price because it was only acquired by those in an area exposed to significant risk; and federal flood control programs were funded by all taxpayers, but helped only those who lived in the floodplains.

In 1968, the US Congress of America passed the National Flood Insurance Act to correct some of the deficiencies of traditional flood control programs. The Act created the NFIP to guide the future development of settlements away from flood risk areas, demanding that new buildings should be able to withstand the damage caused by floods, provide

financial assistance after floods residents and owners in flood plains, especially after small and medium-sized floods that could not justify federal disaster assistance and transfer some of the costs of taxpayer flood losses to property owners located on floodplains through the use of flood insurance premiums.

In 1979, the FIA and the NFIP were transferred to the newly created Federal Emergency Management Agency (FEMA). Currently, the NFIP is administered by the Federal Insurance and Mitigation Administration (FIMA) within FEMA.

5.3 Measures to deal with drought risks

5.3.1 Integrated Water Resources Management

The Global Water Partnership - GWP defines Integrated Water Resources Management - IWRM as “a process that promotes the coordinated management and development of water, land and related resources, in order to maximize the resulting economic and social well-being in an equitable manner, without compromising the sustainability of vital ecosystems”.

IWRM is based on the principles defined and adopted by the international community since the Rio and Dublin Summit in 1992. These principles are summarized in: fresh water is a finite and vulnerable resource, essential for maintaining life, development and environment; water management must be based on a participatory approach that involves users, planners and politicians at all levels; Women have a central role in the provision, management and protection of water and water has economic value in all its uses, competitive with each other, and should be recognized as an economic asset. IWRM has been accepted worldwide as a basic instrument to face the great challenges that water offers today. OECD, in its Water Governance Initiative, considers IWRM as an essential principle at the river basin level.

Droughts are temporary situations of lack of availability of water resources to meet both water demands and environmental requirements. In drought situations, the coordinated development of water, land and resources which IWRM entails is especially necessary in arid and semi-arid territories with imbalances between water resources, demands and the environment. In these situations, all available resources must be mobilized, through

participatory approaches and keeping in mind the environmental, economic and social effects of any decisions taken.

5.3.2 Management and control measures: resource allocation, water savings and temporary transfer of rights

The measures to stand out as the most used management and control measures to manage drought situations are the changes to resource allocations between different sources and water savings and restrictions, especially in the agriculture sector. It is usual to establish savings and reductions in allocations depending on the stage of the drought in which is currently in, thus anticipating the most critical situations. Therefore, not only should these measures be applied in the emergency phases but also in previous phases, such as pre-alert or alert, where the phenomena lurks in. In summary, risk must be managed to reduce disaster risk.

In some countries, such as Chile, United States of America or Spain, it is also possible to temporarily reallocate water rights among users in order to achieve greater efficiency and rationality in the use of water.

Measures taken in Cyprus during the 1996-2000 drought period

During the 1996-2000 period, there was a period of low rainfall in Cyprus that placed the country in conditions of extreme drought, worsening the already existing structural mismatch between supply and demand. The drought caused significant socio-economic problems and various types of measures were deployed to address the situation: water supply restrictions, demand management measures and supply improvement measures (WDD, 2002).

Domestic urban supply was limited to several hours for two or three days a week. Irrigation water for seasonal crops was almost completely restricted and the water allocated to permanent crops was reduced to the absolute minimum necessary for their survival. Livestock and industry suffered a reduction in supply of about 28%. In general, water supply restrictions amounted to more than 20% for domestic uses and 30% to 70% for irrigation purposes.

Regarding demand management measures, aids for obtaining good quality resources were established for domestic urban supply, through the drilling of private wells. Subsidies were also provided for the installation of grey water recycling systems in homes, schools, etc. Other measures were the reduction of Non Revenue Water (NRW) in distribution systems and education and awareness campaigns on water saving needs.

Aids were established for irrigation to collect rainwater from the roofs of the greenhouses and for the improvement of irrigation systems, water quotas were applied for irrigation and penalization for excessive consumption, new irrigation areas were halted and the training of farmers for a better use of water and the adoption of new crops with lower water demand was promoted.

As for the measures to improve the supply, the existing desalination plant (in Dhekelia) was expanded from 25,000 to 40,000 m³ / day, the procurement process for a new desalination plant (west of Larnaca) with a capacity of 52,000 m³ / day was accelerated and reuse of recycled water was promoted for agriculture use.

5.3.3 Environmental measures

In drought periods it is common for impacts to occur on associated aquatic and terrestrial ecosystems. The integrated management of all available water resources to meet demands and environmental needs is of the essence. However, the resources' greater withdrawal, as is usually the case with those coming from groundwater, can affect the discharge areas of aquifers in rivers and wetlands. Thus, it is necessary to control the state of surface and underground water bodies, the fulfilment of the ecological flows established in the rivers and the water requirements of wetlands.

Liberating resources from the economic uses of water (agriculture and industry) for the environment is one of the environmental measures used in drought situations. In the area of the Júcar River Basin Authority in Spain, agreements have been reached for the temporary acquisition of rights (wells near the river) between Administration and users for environmental reasons, with the objective to ensure a minimum flow through the Júcar River to avoid its channel from drying out.

Reuse of urban water for wetland conservation in dry periods. The case of the Torre Guareto Reserve in Apulia, Italy.

Apulia and the coastal areas of Basilicata, in southern Italy, are exposed to frequent problems of water supply due to a historical problem of scarcity not well resolved. In recent decades, efforts have made to improve infrastructure and to build large dams to enhance water resource management, also increasing the extraction of groundwater, which has led to a critical situation its aquifer status. It has also endangered the survival of the Torre Guaceto Reserve, a wetland of international interest included in the Ramsar Convention, Special Protection Area (Directive 79/409 / EEC), marine reserve and Site of Community Importance LIC (Directive 92 / 43 / EEC).

The overexploitation of the aquifer constitutes the fundamental risk for the survival of the "Torre Guaceto Reserve". The very high concentration of salt in groundwater has led to the reduction and even the extinction of some very particular and rare macroinvertebrate species. This situation has become critical during drought periods. On such grounds, it was necessary to apply measures to prevent the deterioration of its current state during those episodes. The Wastewater Treatment Plant (WWTP) of Carovigno represented a potential source of unconventional water available in the agricultural area to replace groundwater during periods of drought.

5.3.4 Drought warning and monitoring system

Drought warning and monitoring systems are essential to drought management as environmental flows can be controlled, water availability be improved, and forecasts of discharges and demands, etc. can be assessed. The main advantages of these systems are the small investment required in contrast to the value of potential damages, the short term of implementation, the virtually zero environmental impact and their wide scope of application.

In the European Union, the Joint Research Center (JRC) of the European Commission established a European Drought Observatory - EDO, as part of efforts to integrate droughts into water policy. The main purpose of the EDO is to improve the knowledge of droughts through warning systems and prepare the competent authorities for drought. Since 2011,

EDO has been the main disseminator of information related to drought in the EU, drawing up maps of indicators derived from various data sources, also producing reports on drought events in the EU.

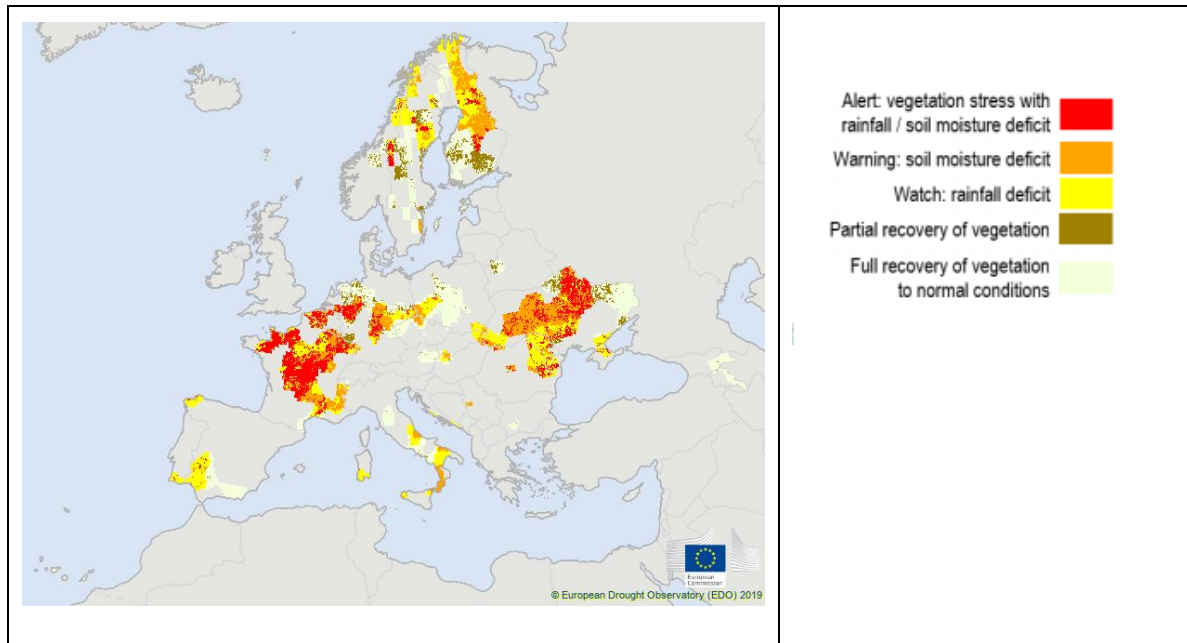


Figure 31. Situation of Combined Drought Indicator in Europe - 1st ten-day period of October 2019.

In the last years, a combined index for drought monitoring has been used in the USA, the US Drought Monitor, where drought intensity categories are defined through five key indicators, numerous complementary indicators including those of drought impact and in local reports from more than 350 experts around the country ¹⁰.

¹⁰ <https://droughtmonitor.unl.edu>

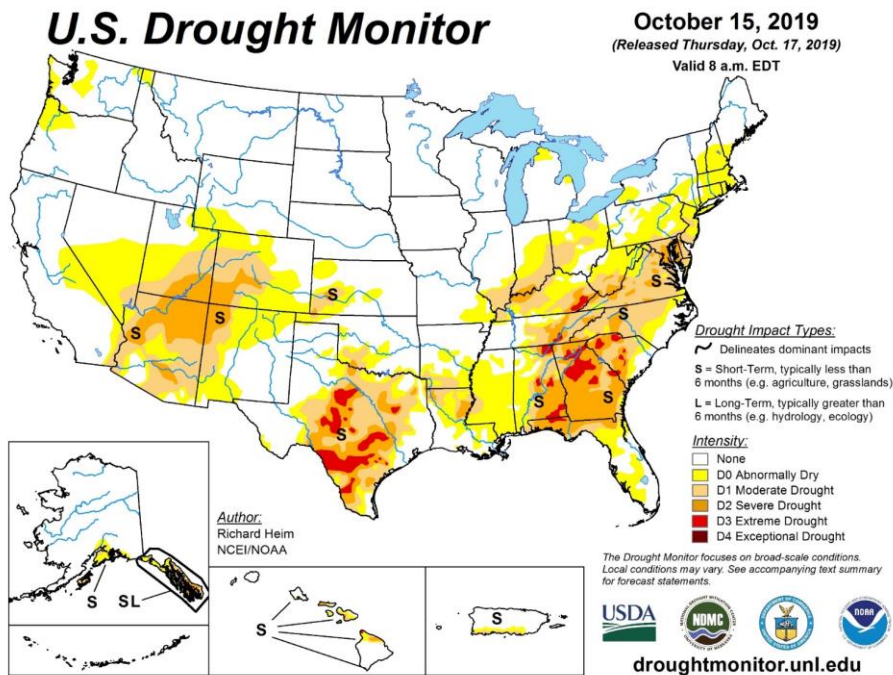


Figure 32. U.S.A. Drought Monitor Map, October 15, 2019.

5.3.5 Agricultural insurance

In order to face the risks of drought which extend more than one dry period and cause irreparable economic damage to small farms, agricultural insurance systems together with other complementary measures to mitigate damages not covered by insurance have become common. The development of these agricultural insurances must rely on the specific agro climatic conditions of each territory.

6 Lessons learnt

6.1 Importance of planning

The current approach in the management of extreme hydrological events is no longer reduced to accepting the consequences of the inevitable and acting to reduce its catastrophic effects. Addressing the risks of these phenomena in a planned way offers opportunities for study, reflection and participation of all relevant stakeholders to manage such risks.

It is highly recommended, therefore, to provide drought and flood management plans that are compatible and coordinated with the hydrological plans of the respective river basins, to anticipate the detection of these extraordinary situations, graduated at various levels, coordinate the different actions to can be taken, establish who should undertake them, and

define any necessary coordination. These plans must also include measures to monitor their implementation and their effectiveness. Such monitoring measures should be periodically reviewed, especially in a context of climate change that may alter the forecasts and any starting hydro meteorological axioms.

The scientific and technical knowledge, which enforces ensures the participation of engineers in its inception, development, implementation and monitoring is quite convenient and necessary, since only from this knowledge can reasonable, effective measures be studied, proposed and applied which optimize risk management with the due effectiveness.

6.2 Adaptative management

Nature has its laws, and it is a serious, sterile and fruitless mistake not to accept them. The application of engineering knowledge and methods cannot change these laws and thinking about reaching zero risk in the face of these extreme natural phenomena is delusional. Thus, engineer's commitment should embrace and encourage adaptive management, which allows the lower risks to reasonable, feasible and socially acceptable, admitting the natural function that droughts and floods also have. Adaptive management is staged by acting on exposure and vulnerability, not only on reducing the impact of events, on which engineering had traditionally focused. So that for similar intensities of a flood or a drought, adaptive management reduces the risks and damages caused, by adapting land use, buildings or facilities, or the timely evacuation of people and property (in case of flooding), or the adaptation of water use and mindful management of available water resources, in case of droughts.

In both cases, engineering plays a very important role in estimating the occurrence of time the natural phenomena, the potential affected areas, the risks and potential damages, the definition of adaptation actions, the best evacuation alternatives to non-flood areas, the best options to guarantee the essential uses of water and limit socio-economic damages in droughts, and to establish previously appropriate guidelines and actions in flood and drought management plans.

6.3 Technology and improvement of results

The technology is facilitating a rapid improvement in the management of floods and droughts. Satellites have facilitated the reliability of weather forecasts, and the calibration

of the corresponding predictive models, allowing real-time monitoring of the evolution and forecasts' readjustment, together with a better knowledge of land uses, essential data to feed Geographic Information Systems - GIS, very useful auxiliary element for the necessary studies.

GIS have required, for their effectiveness, the development of automated sensor systems deployed in the field and the increased capability of transmitting, storing, processing and distributing these collected data, all of which would not have been possible without the contribution of Information and Communications Technologies - ICTs.

Digital Terrain Models - DTMs, have required the development of LIDAR technologies, without whose contribution the hydraulic models with which the potentially affected areas are estimated could not be reliably and quickly fed, according to the intensity of the extreme event that may occur. Hydraulic models have required, in order to study the effects of extreme hydrological phenomena, the best alternatives applicable and damage assessment. All these alternatives were the contribution of expert engineers in their inception, development and fine-tuning. Engineering contribution is also present in flow monitoring during flood events.

But, in addition to participating being in the development of such technologies, engineering is totally necessary for its correct use and to foster its improvement. As an example, it is engineering what drives and focuses the development of Decision Support Systems, both in floods, to decide the best management options based on the existing alternatives and in situations of droughts, to study and evaluate the most appropriate integrated resource management options to mitigate their effects.

6.4 Combination of measures

Although adaptive management has been embraced as a main strategic principle, it must be underscored that dealing with these extreme phenomena requires a proper combination of a series of measures, which must be executed by different stakeholders, which fosters the need to previously implement the management plans in a participatory manner.

High-level scientific and technical tools are being developed as part of the systems of analysis, prediction, monitoring, evaluation, adaptation and support for decision-making that contribute to the decision-making process. Focused on adaptive flood management,

where the objective is not its elimination but the best possible adaptation to them, changing measures of all kinds and involving all the actors co-ordinately.

This new approach continues to evolve. What does not change is the need to apply sound engineering to achieve satisfactory solutions. The following figure shows the different measures that can be combined to adequately manage flood risk, sorting those that relate with land occupation, infrastructure and those, which have a physical basis.

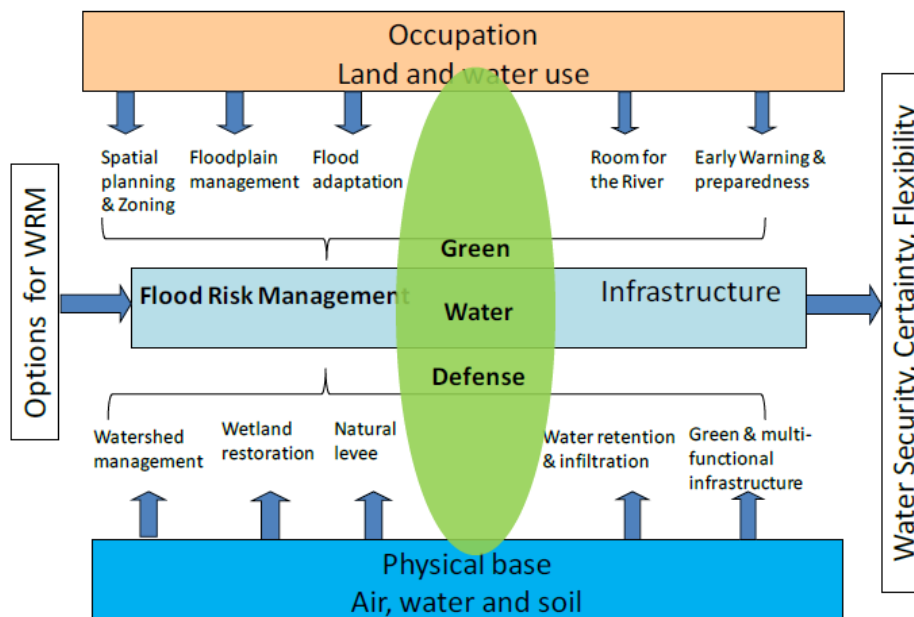


Figure 33. Combination of measures for flood risk management

7 Challenges for engineers

7.1 The current role

Engineers' professional profile has varied greatly throughout the years. First half 20th century engineers were generalists and self-sufficient. They developed many works, which they executed with few documents and calculations and had almost full control of the execution. Later on, during the second half of the century, engineers began to execute fewer works, although these were supported by a larger number of documents and calculations, while the control of the execution became no longer total. 21st century engineers are mostly specialists and reliant on other team members. They participate in few works and generate a large number of documents supported by many calculations, usually having a very limited control of the execution.

Current engineering practice has become increasingly collaborative, favouring specialization, undermining engineers' leadership roles formerly assumed by more broad-based generalist self-sufficient engineers. On the other hand, specialization provides high qualification for the operation of complex tools in the analysis of extreme events, such as Decision Support Systems (DSS) and Geographic Information Systems GIS for drought management and floods or mathematical models used in hydraulics studies and in the design of flood rolling dams and other infrastructures.

Another aspect increasingly present in current engineering is global practice and its corresponding demands: languages, knowledge of each region's "water culture" and adaptation to diverse local factors, as well as the cross-knowledge transfer between countries with different features and idiosyncrasies.

7.2 Professional practice indicators

There are no reliable indicators of the activity developed by engineers in this flood or drought management. Even worse, there is a huge void of global statistics regarding the number of engineering professionals dedicated to water issues. Professional engineering organizations through its global federations (World Federation of Engineering Organizations - WFEO, World Council of Civil Engineers - WCCE) are strongly recommended to establish a formal consultation with their member organizations in this regard, indicating not only that number, but also specifying to the engineer's specialty and field of activity.

Fields of activity can be classified through UNESCO's nomenclature for fields of science and technology accordingly. Other classification alternatives may define specialties in accordance to the following branches: civil (including hydraulics), industrial, Information and Communications Technologies (ICT), environmental and others. On the other hand, water related areas expertise can in turn be subdivided in: water planning, water management and administration, hydraulic engineering and consultancy, urban water cycle, universities and research centers, and others.

7.3 Innovation and technology

Since the end of the 18th century, engineering applications have been constantly applying innovation to technology. Thus, at the end of the 18th century, engineering produced the massive application of technology breakthroughs in hydraulic energy, mechanization,

textiles or commerce. The 19th century was the age of the steam engine, railroad or steel. 20th century's first half of the twentieth century progressed by breakthroughs on electricity, chemistry, internal combustion or engines. Its second half preyed on advances in petro chemistry, electronics, aviation, the space race and later in digital networks, biotechnology, software developments and information and communication technologies (ICT). The future will foreseeably bring the design of global systems, green chemistry, industrial ecology, renewable energy, and nanotechnology, all in the search for sustainability and many other unfathomable applications.

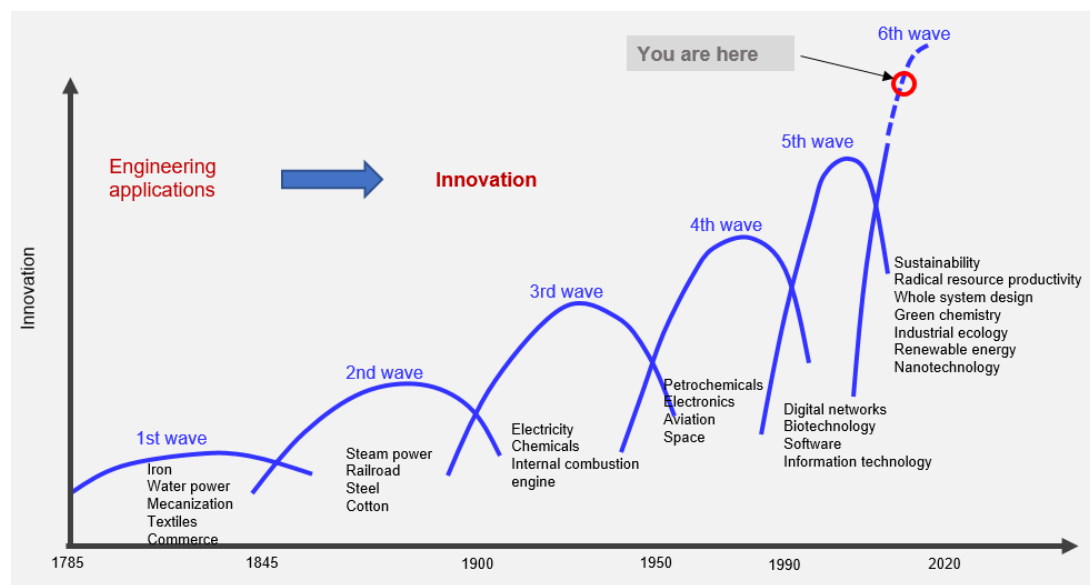


Figure 34. Historical evolution of engineering innovation. Source: Referred by Jose Vieira, Ode Portugal and President FEANI

Presently, the accepted definition of innovation entails the application of research results into better services and products to be marketed globally and thus generating growth and employment. The pillars of innovation today are institutions, human capital, business and the market, and infrastructure. The institutional pillar refers to the existence of a political and social fabric which fosters innovation; the pillar of human capital refers fundamentally to the quality of education and vocational training, the business and market pillars allow innovation to become a product or service and the infrastructure pillar is what facilitates production and delivery of such innovation to society, expanding its social and economic effects (Polimon, 2018).

Within the scope of extreme hydrological events, engineering can contribute to the development of better technologies, the construction of infrastructures and the design of resilient water resources systems, highly robust to hydrological disasters, participating in the situation management and aftermath response teams of such events.

7.3.1 Technology development

The market currently offers multiple available technologies capable of boosting innovation in the engineering sector regarding extreme hydrological events such as Building Information Modeling - BIM, 3D printing, IoT (internet of things) applied to infrastructure sensing, Big Data, Machine Learning, augmented reality or the use of drones, which allows the affordable inspection, maintenance and conservation of areas of difficult access (Urrecho, J., 2018). All these technologies are applicable to the field of droughts and floods. It is up to engineers not only to actively participate in the technology development, but also direct investigation topics and its development development towards the fields with more added value for engineers to contribute, boost new technologies' phases of innovation and application, facilitating collaboration between research and technology centers, and the corporations which undertake product development, finetune and validate innovations' effectiveness and and initiate a new innovation cycle returning real data feedback to research and technology centers.

An example of an international project that incorporates smart technologies is the Flood and Drought Management Portal¹¹, developed by the Global Environment Facility (GEF), the United Nations Environment Program (UNEP), the International Water Association (IWA) and the Danish Hydraulic Institute (DHI). The project incorporates real-time satellite data, seasonal climate forecasts and medium-term climate projections with the objective of assisting in the planning and management of droughts and floods, in the short, medium and long term, both at local or transnational scopes. The project was validated in three pilot basins: the Chao Phraya basin in Thailand, the Victoria Lake basin in East Africa and the Volta basin in West Africa¹².

¹¹ www.flooddroughtmonitor.com

¹² <http://www.iwa-network.org/projects/flood-and-drought-management-tools/>

7.3.2 Infrastructure construction and design of resilient systems

Engineers can help mitigate the impact of natural disasters, such as droughts and floods, by designing and building resilient systems and infrastructure, always keeping in mind that our role is to minimize life loss, property damage, and provide assistance for an effective emergency response.

One emerging engineering fields of practice is the incorporation of resilience criteria in the inception and design phases of new infrastructures or flood defense systems, and the adaptation of the existing in accordance to such resilience criteria. The latter entails an even more complex task: offer sophisticated feasible solutions which overrule radical simplistic alternatives like the decommissioning of affected elements or assets, either physically (from flood areas) or the permanent inhibition of water demands corresponding to certain uses, (to deal with the droughts). Engineering, regarding the environmental needs of water-related ecosystems, must consider and offer stakeholders, in the first place, and society in general, solutions that do not cause serious socio-economic consequences in the affected areas by floods and droughts.

Nature-based solutions, as a means of protection against floods, and SUDS (Urban Sustainable Drainage Systems), in the urban environment, show the mark a line of future evolution that has to be enhanced.

7.3.3 Extreme event management and restoration

Despite the approval of plans and the development of protective and preventive actions, when the extreme phenomena arises, an intense engineering activity must be developed to manage them and, once passed, proceed as soon as possible to restore any damages suffered.

Engineering's contribution to water-related extreme episodes management should include enhanced data collection to better adjust predictive models and decision support systems, improving potential damage assessment, and monitoring and avoided damages appraisals. Regarding to restoring action, studies should be undertaken to increase the system's overall resilience and adaptation to climate change, rather than just reinstating the former condition of the works and assets affected.

7.4 Social responsibility

Honouring society's mandate to create a sustainable world and improve human welfare globally, engineers must serve competently, collaboratively and ethically as expert:

- Planners, designers, builders and managers of society's economic and social engine, what is known as the built environment;
- Custodians of the natural environment advocating the efficient and proper use of the available resources;
- Innovators and integrators of ideas and technologies in academia and the public and private sectors;
- Managers of risks and uncertainties caused by natural events, accidents and other hazards under their area of expertise; and
- Trend-setters leading discussions and decisions that compose environmental and infrastructure public policies.

Nowadays, the scientific community declares that the climate is changing and will continue to change. In addition to this, evidence suggests that climate change has led to extreme weather changes such as heat waves, record temperatures and, in many regions, heavy rainfall over the past half century. Climate change, by diverting the climatic patterns of historical climate ranges, could negatively affect the robustness of the design, operation and management of engineering systems. There is a growing demand for engineers to incorporate design criteria based on future climate projections. It is the engineer's duty to take all reasonable measures to ensure that these systems are adapted to adequately anticipate the impact of changing weather conditions.

Engineers have responsibilities in the planning, design, construction, operation and maintenance of physical infrastructure. These facilities include all types of buildings, communication systems, power generation and distribution systems, industrial facilities, transportation networks, water resources services and urban water systems. Such physical infrastructure is expected to remain functional, sustainable and safe for its service lifespan, typically ranging from 50 to over 100 years, while exposed and potentially vulnerable to extreme weather effects such as droughts, floods, heat waves, high winds, storms, fires, and

ice and snow accumulation. Engineering standards and best practices must provide acceptably low risks of failures regarding performance, durability and safety over the service life of infrastructure systems and services.

Risk assessment and its mitigation is a key principle of engineering practice. Such principle imposes a responsible commitment to civil engineering professionals to adopt due to assess the effect of climate change on the works and the service they provide. This is reflected twofold. Firstly, engineers in charge of public facilities and infrastructure design and management will have to adapt to climate change at the local level to ensure public health and safety. Secondly, the growing level of awareness to this risk and the high visibility of the impacts derived from the most intense storms and extraordinary events raise accountability issues. Engineers who do not exercise due diligence regarding climate change, in short, may be considered personally or jointly liable for damages or failures arising from the impacts of climate change on engineering systems.

7.5 Emerging and future areas

Population concentration in urban areas and climate change, with its associated uncertainty, are circumstances, which influence the near future. Engineers must express their commitment, among other things, to:

- Promote engineering links with the society, encouraging participation and commitment to sustainable development and action against climate change.
- Support with innovative engineering technologies and practices COP-21's Climate Agreement and contribute to the achievement of UN's SDG 6: Ensure availability and sustainable management of water and sanitation for all and other connected SDGs.
- Promote R & D & I projects regarding risk management, sustainability and climate action, regarding the nexus between the actions on the territory with the use and conservation of natural resources and the protection of ecosystems.
- Host congresses, seminars, conferences and meetings in which engineering principles and commitments are encouraged and adapted to the different fields of engineering practice.

- Actively collaborate through our professional practice in achieving the reduction of GHG within various sectors, the improvement of weather resistance of various types of infrastructure to resist climate impacts, increasing their reliability and service life, and the achievement of engineering challenges for sustainable development, embodied in United Nations SDG 6 and other connected goals.

Regarding the adaptation of infrastructure to climate change, an increase in average sea levels is to be expected, together with the occurrence and / or increase in intensity and frequency of extreme events, such as droughts, floods or hurricanes. It is necessary to anticipate these phenomena, try to identify and assess them, ensuring corresponding infrastructure to be prepared for these scenarios: coastal defenses, greater capacity of reservoirs for prolonged droughts, hurricane resistance, etc. Naturally, the more critical an infrastructure is, the greater its resilience to extreme events should be. It is required in this regard to develop the following action:

- Identify and assess, if possible, the potential effects of climate change by geographic areas.
- Incorporate these effects in the infrastructure design standards.
- Evaluate the resilience of existing infrastructure to predictable changes and phenomena.
- Identify the need for new specific infrastructure.
- Prioritize and plan maintenance and adaptation actions of existing infrastructure.
- Proceed to build the infrastructure currently unavailable.

On the other hand, climate projections worldwide concur that the impact of climate change on water resources will entail reductions in water resources, sea level rise in coastal areas, as well as a possible increase in the frequency and magnitude of extreme events such as droughts and floods. In order to assess climate change and its adaptation strategies, the following actions are therefore required:

- Deepen studies of the effects of climate change on resources, the water environment, droughts and floods and water demands in order to improve their

consideration in planning and define and implement the most appropriate adaptation measures.

- Incorporate climate change measures into national policies, strategies and plans. The programs of measures of the hydrological plans should be consistent with climate change scenarios, making progress in adapting to this phenomena and guaranteeing the resilience of the planned infrastructure.
- Include climate change as one of the factors to consider in the design, operation and management for the safety of the new Critical Infrastructures, and for the adaptation of existing ones.

To achieve this goal, the following actions should be implemented:

- Develop joint initiatives between governments, universities, technology and research centers, and companies to develop projects within the innovation trends regarding the fields of Information, Planning, Engineering, Technology and Water Management.
- Join efforts and develop R & D & I projects that, applying the available technologies and instruments (mathematical models, measurement, telemetry, remote control or remote control, remote sensing, purification treatments, generation of unconventional resources through water regeneration or desalination, etc.) allow the improvement of water management.
- Establish technological innovation as a key development factor.
- Improve governance, invest in institutional capacity building and apply integrated, transparent and effective solutions in water management.

7.6 New roles and challenges

Traditionally, engineering has contributed to human welfare as a consequence of economic growth. Today, the goals and targets of the United Nations 2030 Agenda for Sustainable Development are closely interconnected and thus achieving or not, a specific goal will also enhance or undermine the accomplishment of other goals. For this reason, the 2030 Agenda states that the achievement of sustainable development in its three dimensions, economic,

environmental and social, must be addressed in an integrated and balanced manner. Thus, water is the Sustainable Development Goal 6 and, at European level, water is one of the sectoral policies which receives the most momentum and action following the approval of EU's 2000 Water Framework Directive, whose primary objective is to ensure the good state water bodies and their associated ecosystems, and the Flood Risk Assessment and Management Directive of 2007.

Access to water and sanitation, to affordable and non-polluting energy, to food security, sustainable growth, the ability to adapt to risks related to climate and natural disasters, such as droughts and floods, resilient infrastructure or international cooperation, are clear examples of interconnected issues. Today, engineers around the world are addressing global challenges, such as climate change, locally. Such means that when they carry out studies or project works they must take these global challenges into consideration.

On the other hand, engineers face decentralized teamwork often. Leading multidisciplinary teams in natural disaster management, such as droughts and floods, is a great challenges. Furthermore, increased globalization requires engineers to overcome any cultural bias in its professional practice, a skill that should be exercised.

Engineers must best practices worldwide such as 2013 WFEO's Codes of Best Practices for Sustainable Development and Environmental Protection "Think with a global vision and act with a local vision" (WFEO, 2013), and 2015 "Code of Good Practices: Principles of Adaptation to Climate Change for Engineers" (WFEO, 2015), expanded and adapted locally.

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