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Sustainable water use in Europe

Part 3: Extreme hydrological events: floods and droughts

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Preface

This report presents an overview of the main natural and artificial causes and impacts of extreme hydrological events, such as floods and droughts, in European countries. It also gives an overview on policy responses to prevent such events and reduce their damage. The report has been produced by the European Topic Centre on Inland Waters (ETC/IW) on behalf of the European Environment Agency (EEA). The project was led by the Centro de Estúdios y Experimentacíon de Obras Públicas (CEDEX, Spain) with the assistance of the Institute of Hydrology (IH, UK), the Austrian Working Group on Water (AWW, Austria), the International Office for Water (IOW, France), the National Environmental Research Institute (NERI, Denmark) and the Phare Topic Link on Inland Waters (PTL/IW).

One of the main contributions of this report is the identification of driving forces, pressures, state, impacts and responses concerning floods and droughts. In this respect, data compilation of extreme events in EEA member countries and in some other central and east European countries has been made. In addition, maps have been produced with climatic data in order to show the state and impacts of these extreme events across Europe.

The report provides information on policy responses in different countries, describing national strategies in case of the occurrence of a flood or drought in an area. In the particular case of floods, an annex describing alleviation schemes in several European countries has been included. Thus, this report aims to help policy- and decision-makers in their work on preventing and managing extreme events, as well as the European Commission's work in the field of civil protection activities.

The report offers information based on the current knowledge of floods and droughts. In addition, it compiles descriptions of some major events provided by individual countries. These cases give a more detailed insight into the pressures and impacts of such events and the measures taken to alleviate them.

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Executive summary

The European Environment Agency (EEA) and its Topic Centre on Inland Waters (ETC/IW) are undertaking an assessment of the sustainable use of water in Europe. This report describes the third part of that assessment and considers the importance and impact of extreme hydrological events, in particular floods and droughts, in relation to Europe's water resources. There are many pressures on water resources including those arising from agriculture, industry, urban areas, households and tourism. These driving forces on the need for water are intimately linked with national and international social and economic policies. Additional driving forces arise from the natural variability in water availability (rainfall) and changes in Europe's climate. Recent history has demonstrated that extreme hydrological events such as floods and droughts can create additional stress on water supplies essential for human and ecosystem health. The prudent and efficient use of water is thus an important issue in Europe and a number of policies and mechanisms are being formulated or are being used to ensure sustainable use of water in the long term. Information for this report has largely been collected from EU Member States, though some information has also been obtained from some central and east European countries. Section A deals with floods and Section B with droughts.

Floods

Floods in a general sense can be described as situations of extreme water run-off during which human lives, property and infrastructure are threatened. Floods are the most common natural disasters in Europe and, in terms of economic damage, the most costly ones. Over a 25-year period (1971–95), there were 154 major floods in Europe, and in 1996 alone there were 9 flooding events. The cost of flood damage in Europe between 1991 and 1995 has been estimated at EUR 99 billion. The main areas prone to frequent floods include the Mediterranean coast, the dyked areas of the Netherlands, the Shannon callows in central Ireland, the north German coastal plains, the Rhine, Seine and Loire valleys, some coastal areas of Portugal, the Alpine valleys, the Po valley in Italy, and the Danube and Tisza valleys in Hungary.

Flooding and its impacts are often influenced by a combination of natural factors and human interference. The main driving forces (pressures) that induce or intensify floods and their impacts include climate change, land sealing, changes in the catchment and in the flood-plain land use, population growth, urbanisation and increasing settlement, roads and railways, and hydraulic engineering measures.

The water storage capacity of soil and vegetation cover can have major effects on the nature and duration of floods. For example, the storage and retention of floodwater on flat plains reduce the peak discharges and influence the temporal evolution of the flood, mainly increasing its duration. Vegetation cover has a very important effect on the attenuation of small and medium-sized floods. Human interference or alterations to soil and vegetation within catchments can thus have serious effects on the risk and impacts of floods.

Climate change can cause a change of precipitation patterns, which can lead to changes in the distribution, intensity and duration of extreme rainfall events and a higher frequency of heavy precipitation.

Urbanisation increases the frequency of high-flow discharges and reduces the time to reach peak discharges because of soil sealing and increased run-off. Between 1991 and 1995, the areas with the greatest increase in urbanisation tended to match those more prone to floods (e.g. the Mediterranean coast and Rhine catchment).

The direct impacts of floods include loss of human life and damage to property. There are also indirect impacts such as increased vulnerability of survivors to other hazards, disruption of traffic and trade, and reduced public confidence in the area. Indirect impacts are often equally or even more important than direct impacts, but they are more difficult to quantify.

Two types of measures are used to acquire the desired level of protection against floods: structural measures for flood control and non-structural measures to control the impact of floods. However, the risk of flooding can never be wholly eliminated by structural and non-structural measures.

The main structural measures are flood control reservoirs, areas for controlled flooding, soil protection and reforestation, river channelisation, protection dykes, the protection and cleaning of riverbeds, road and railway culverts, bridges, and the re-establishment of meanders and riparian zones.

At present, the application of non-structural measures against floods is increasing in Europe, partly because it has been realised that structural measures stimulate the development of communities in areas that are still at some risk of flooding (e.g. flood plains), because of the false sense of security that the measures provide. The main non-structural measures are the construction of flood protection aspects into buildings, the restriction of development on flood plains through controlled land-use planning, and early warning and flood forecasting systems.

A recent study has indicated that the tolerated level of residual risk to society of flooding after the application of flood protection measures varies across EU countries. For urban protection, the designed risk of a flood varies between one flood per 50 years and one per 200 years. The protection of agricultural areas is generally at a lower level.

Droughts

Although drought is a phenomenon which is apparently easy to recognise, there is no general agreement among experts regarding its definition. Large areas of Europe have been affected by drought over the past 50 years. Although events differ in character and severity, the frequency of occurrence demonstrates that drought is a normal, recurrent feature of the European climate. It is not restricted to Mediterranean regions but can occur in high- as well as low-rainfall areas and in any season. Recent severe and prolonged droughts have highlighted Europe's vulnerability to this natural hazard and alerted the public, governments, and operational agencies to the many problems of water shortage and the need for drought mitigation measures.

Drought results from a combination of meteorological, physical and human factors. The primary cause of any drought is a deficiency in rainfall and, in particular, the timing, distribution and intensity of this deficiency in relation to existing storage, demand and water use. Temperature and evapotranspiration may act in combination with rainfall to aggravate the severity and duration of the event. Both rainfall and temperature are in turn driven by the atmospheric circulation pattern. Human factors include demand for water in relation to socioeconomic factors such as population growth and agricultural practices, and modification in land use which directly influence the storage conditions and hydrological responses of a catchment and thus its vulnerability to drought.

Recent research on climate change impacts in Europe suggests that annual rainfall will increase in northern Europe by 2050, and decrease by about 10 % elsewhere; temperatures will rise everywhere and potential evaporation will generally increase. The general tendency is therefore for an increase or stabilisation in annual average run-off in northern Europe and a decrease in the south, with changes in the 30-year mean run-off by the 2050s of over 30 % in some areas. The greatest sensitivity to change was found in the drier regions of southern and eastern Europe with low flows tending to become more extreme across most of Europe.

The demand for European water resources increased from 100 km^3/year in 1950 to 550 km^3/year in 1990 with forecasts that this will increase to 660 km^3/year by the end of the 20th century. As the pressure on water resources continues to grow, Europe is becoming increasingly vulnerable to the effects of meteorological droughts.

Land use determines how much rainfall is lost through evapotranspiration and the balance between surface run-off and infiltration. In Europe as a whole, forest cover has increased by about 10 % over the past 30 years and it is calculated that 2 % of agricultural land is lost to urbanisation each decade. Both these changes will have a significant effect on the hydrology of the local area. This leads to drier soils, reduced recharge and a greater vulnerability to drought than if the land use was grass or a short crop.

The main impacts of droughts include water supply problems, shortages and deterioration of quality, salination of soil and groundwater, loss of crops and cattle, increased pollution of freshwater ecosystems and regional extinction of animal species. These have led to important economic impacts in parts of Europe.

To reach the goal of sustainable water management, a balance has to be achieved between the abstractive uses of water (e.g. abstraction for public water supply, irrigation and industrial use), the in-stream uses (e.g. recreation, ecosystem maintenance), the discharge of effluents and the impact of diffuse sources. In this sense, quantity and quality must be taken into account. Potential measures for improvement can be divided into those that aim to improve the performance of water distribution systems and those that aim to improve water-use efficiency at the user level.

During droughts, aquifers play a vital role in meeting water demand, not only as regards water quality and quantity, but also in relation to space and time distribution. In semi-arid areas, groundwater resources frequently constitute a vital element of water supply systems, due to their capacity for forming natural reservoirs and the fact that in most cases they are the only possible source of supply. The joint use of surface waters and groundwater presents opportunities to make use of the natural buffering capacity of aquifers in dry periods, and to ensure recharge when water is abundantly available. Non-conventional sources such as water reuse or seawater desalination are being applied, mainly in areas where no other sources of supply are available at competitive costs. One of the fundamental advantages of water reuse is the fact that in many cases the resource employed is available in the vicinity of its prospective new use, i.e. urban agglomerations and industrial sites. The limiting factor for water reuse can in many circumstances be the quality of the water available and potential hazards for secondary users. The potential of seawater desalination as a viable option for the future depends primarily on advances in desalination technology, evolution of the costs of energy and the cost of water from alternative sources.

The use of storage reservoirs helps overcome the uneven distribution of natural water resources over time. Run-off in the wet season can be held back and used in the dry season (seasonal regulation), while water available in wet years can be stored and used in dry years (inter-annual regulation). In addition, the construction of inter-basin transfers can be an efficient and cost-effective means of satisfying water demand in hydraulically deficient regions or drought periods. What needs to be assured in all cases is environmental sustainability, on the one hand, and economic viability, on the other.

In most cases, droughts are identified as such too late, and emergency measures are taken which will no longer be effective. Clear and consistent criteria for drought identification need to be established in order to allow, in a crisis, time to look for a suitable response in the management of the water resource system. The state of the art as regards climatic and hydrological modelling does not permit the exact prediction of a drought event. A suitable response to a drought largely depends upon adequate management of the water resource system. At present, hardly any technical guidance exists for water management in drought situations. Further work is needed in this area.

1. Introduction

1.1. Background

The European Environment Agency (EEA) aims to support sustainable development and to help achieve significant and measurable improvement in Europe's environment through the provision of timely, targeted, relevant and reliable information to policy-making agents and the public. The EEA and its Topic Centre on Inland Waters are undertaking a series of studies on the sustainable use of Europe's water resources. Water is a finite resource in many parts of Europe and must be managed in a sustainable way meeting human as well as environmental needs. The first report in the series assessed the use of water across Europe, and the second analysed the role of demand management in overall water management strategies.

The sustainable use of water is becoming increasingly important and prominent in the legislative agenda of Europe. For example, the purpose of the recently adopted Water Framework Directive 2000/60/EC is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which (amongst other purposes) promotes sustainable water use based on long-term protection of available water resources. It should also contribute to mitigating the effects of floods and droughts. The directive should thus contribute to the provision of sufficient supply of good quality surface water and groundwater as needed for sustainable, balanced and equitable water use.

The basis of EEA reporting and assessment is the DPSIR assessment framework. Thus information and indicators are required on the **D**riving forces resulting in **P**ressures on the environment that affect its **S**tate and potentially cause an **I**mpact (degradation). **R**esponses would include measures and policies to reduce the pressures and hence improve state and reduce impact. There are many pressures on water resources including those arising from agriculture, industry, urban areas, households and tourism. These driving forces on the need for water are intimately linked with national and international social and economic policies. Additional driving forces arise from natural variability in water availability (rainfall) and changes in Europe's climate. Recent history has demonstrated that extreme hydrological events such as floods and droughts can create additional stress on water supplies essential for human and ecosystem health. The prudent and efficient use of water is thus an important issue in Europe and a number of policies and mechanisms are being used or are being formulated to ensure sustainable use of water in the long term. Information for this report has largely been collected from western Europe though some information has also been obtained from some central and east European countries. Section A deals with floods and Section B with droughts.

1.2. Floods

Seasonal fluctuations in water levels and discharges as well as the flooding of riparian areas are natural features of running waters. Extreme weather events with the resulting large volume water flows can, however, cause enormous damage to lives and property, especially where flood plains are occupied and flooding interferes with human land-use activities. Floods can be generally described as situations of extreme water run-off during which human lives, property and infrastructure are threatened.

In Europe, floods are the most common natural disaster and, in terms of economic damage, the most costly. In recent years, floods have received much media and public attention within Europe. Serious examples of recent floods in Europe are the Vaison-la-Romaine flood of 1992, the Rhine and Meuse floods of 1993–94 and 1995, the Oder flood of 1997, and the floods of 1996 and 1997 in Biescas and in Badajoz, as well as those in Sarno and Quindici in 1998.

The main areas in Europe prone to frequent flooding episodes are the Mediterranean coast, the dyked areas of the Netherlands, the Shannon callows in central Ireland, the north German coastal plains, the Rhine, Seine and Loire valleys, some coastal areas of Portugal, the Alpine valleys, the Po valley in Italy, and the Danube and Tisza valleys in Hungary (Figure 1.1). These areas are among the economic heartland of the European Union and are rich in assets and production capacity.

Normally, the risk of flooding results from a combination of natural factors and human interference. In general terms, human actions can influence flooding either by affecting the run-off patterns (e.g. faster run-off through deforestation, urbanisation and river channelisation) or by increasing the possible impact of flooding (e.g. greater exposure of human populations through the occupation of flood plains).

Despite advances in the understanding of these cause–effect relationships, there are still insufficient results at experimental catchment scale, which relate flood events to soil distributions, land cover, hydrological variations and other factors to be able to quantify precisely these relations (Bourrelier et al., 1997).

Research on floods has been enhanced in Europe over the last two decades. Two projects of particular interest are the IRMA programme and Floodaware.

The IRMA (Interreg Rhine–Meuse activities) programme comprised a total of 153 projects funded by the European Commission. One of these projects is the so-called LaHoR project (quantification of the influence of the land surface conditions and river development on flood conditions in the Rhine catchment under special consideration of land use, vegetation cover and possible climate change). In particular, the role of the conditions of the land surface (i.e. the infiltration capacity) on the magnitude of flood generation and its comparison with the storage and discharge conditions of the large rivers and their retention areas is subject to investigation. First results were presented at the European Conference on Advances in Flood Research (see Bronstert et al., 2000).

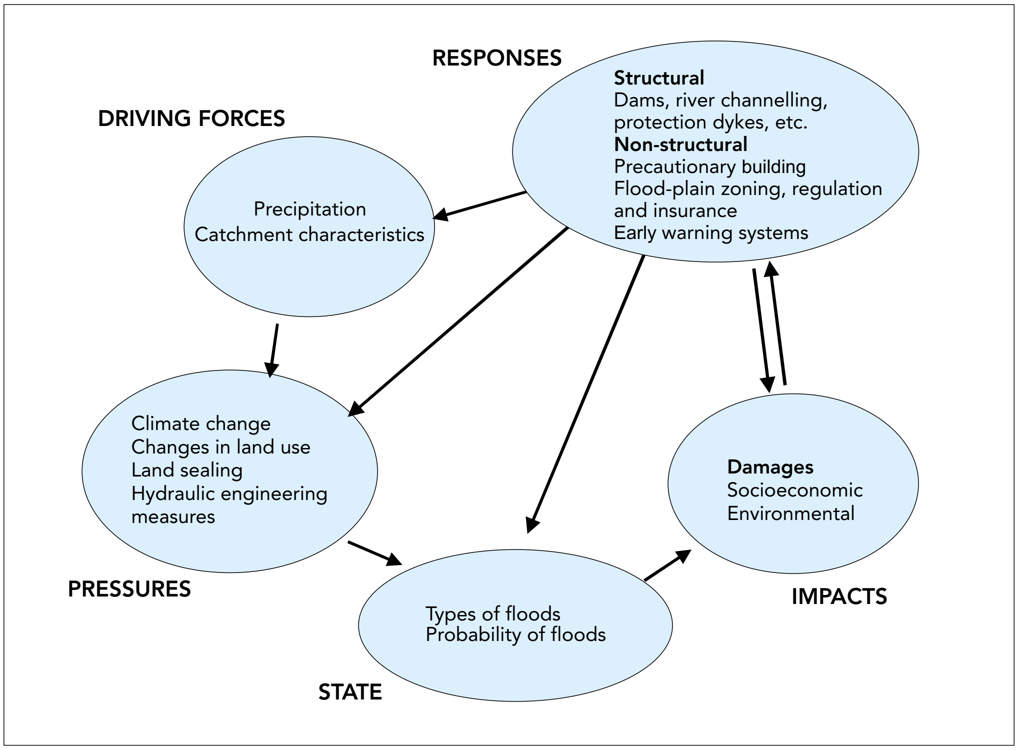
Floodaware is a project on prevention and forecasting of floods funded by the European Commission. It comprised three main parts: floodability, heuristic approximation and regionalisation. The first part focused on the concepts of floodability, vulnerability and risk, with the aim to make a standardisation of risk maps at European scale, jointly with an initial implementation of land management rules in flood plains. In the second part, it was intended to calibrate and apply different methodologies for calculating floods (i.e. statistical correlation based on already existing data, or the rational method), by heuristic approximation, in different geographical areas. The third part of the project related flood regionalisation, particularly in complex basins with large reservoirs (see European Commission, 1999).

Main areas in Europe prone to frequent flooding Figure 1.1.

Source: ETC/IW

Figure 1.2. **Factors related to the DPSIR framework for assessing floods**

Source: EEA



Section A of this report analyses the problems and features of floods using the DPSIR (driving forces, pressures, state, impacts and responses) assessment framework (Figure 1.2). The main driving forces affecting floods are intense precipitation and catchment and flood-plain characteristics as Section 2 describes. The pressures are the forces, which either induce or intensify floods and their impacts. Section 3 exposes the main pressures: climate change, land sealing, changes in the catchment and flood-plain land use, population growth, urbanisation and increasing settlement, roads and railways, and hydraulic engineering measures. State is determined by the type and by the probability of the occurrence of floods, as described in Section 4. Impacts can be defined as the socioeconomic and environmental effects, commonly expressed by damages caused by floods on the territory due to driving forces and pressures, as Section 5 shows. Responses are the measures used to control the floods (structural) and their impacts (non-structural) and they are described in Section 6.

1.3. Droughts

Although drought is a phenomenon which is apparently easy to recognise, there is no general agreement among experts regarding its definition. Droughts are normally described in terms of precipitation or run-off during a certain period of time, or in terms of reserves available, with the obvious limitations of all these interpretations. Drought is frequently confused with concepts that are related to it, such as aridity or lack of water. However, the main characteristic, which distinguishes a drought, is its abnormality, the fact that the water shortage is unusual. At the same time, the characterisation of droughts includes concepts, which are not strictly meteorological or hydrological, such as social, economic or agricultural considerations.

Large areas of Europe have been affected by drought over the past 50 years. Recent severe and prolonged droughts have highlighted Europe's vulnerability to this natural hazard and alerted the public, governments and operational agencies to the many problems of water shortage and the need for drought mitigation measures. As the pressure on existing water resources increases, the effects of a drought will be more keenly felt.

Droughts are characterised by a decrease in water availability in a particular period and over a particular area (Beran and Rodier, 1985). Because drought affects so many economic, social and environmental sectors, this general definition can be applied to a wide range of situations.

Of all the different types of drought that will be discussed in Section B, this study focuses on hydrological drought. While low flows have been extensively studied at the pan-European scale (Gustard et al., 1989), European studies of drought have been hampered by the lack of a universal and objective definition. As yet, no pan-European comparison of droughts according to consistent criteria exists. Droughts are complex, varying in character and intensity, in time and across wide geographic areas. They can accumulate slowly and extend beyond the meteorological conditions that initiated the drought.

As for floods, droughts have been assessed using the DPSIR framework based on published sources of information. Section 8 identifies the main driving forces (causes) of hydrological droughts in Europe, while Section 9 examines those factors that add pressure and exacerbate the severity, or increase the frequency, of droughts in Europe. Clearly in such a heterogeneous region as Europe, the relative importance of each of these driving forces and pressures will vary locally. Section 10 describes the state of droughts through a summary of some recent drought events and Section 11 describes the impacts through general information and regional examples. The assessment of these impacts provides information for setting targets for future research and policies. The potential responses are shown in Section 12.

Research in the field of droughts has been carried out in recent years. One project of particular interest is ARIDE ('Assessment of the regional impact of droughts in Europe'), which is funded by the European Commission. Its objectives are to improve the knowledge of the processes that create droughts across Europe, to develop methodologies for the estimation of spatial distribution of droughts at European scale, and to work out techniques for forecasting the impact of climate change on droughts (see ARIDE, 2000).

SECTION A: FLOODS
2. Driving forces

2.1. Precipitation

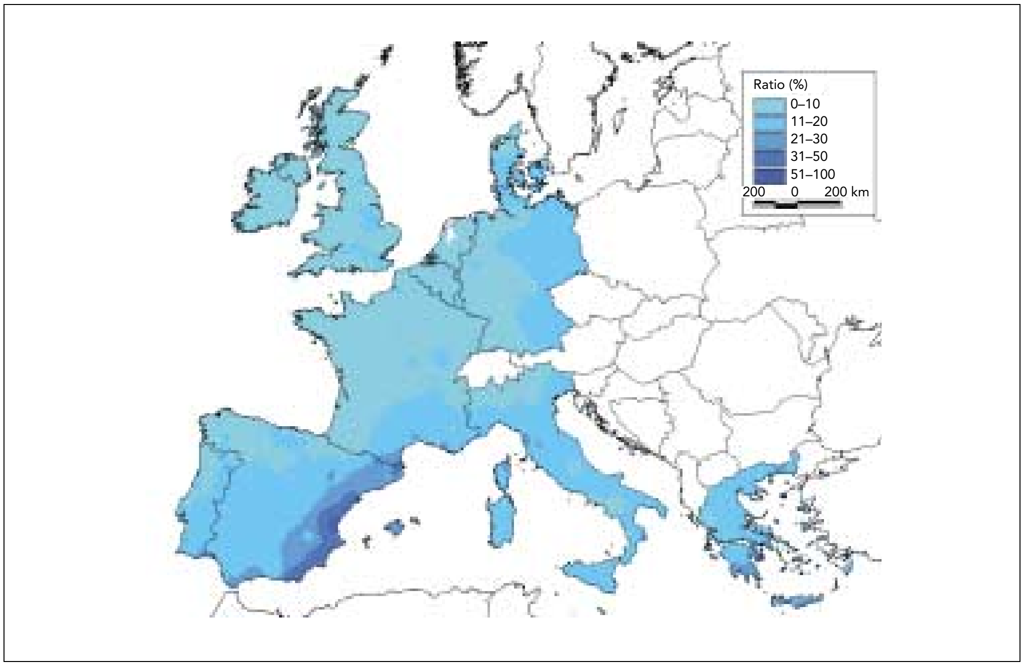
River flooding can be caused by continuous precipitation over several days, or by a very intense rainfall in a very short time in the catchment area. In the former case, rainfall reaches the stream by direct inflow and by soil or subsurface or groundwater infiltration, this latter with some delay after the rainfall. If short but intense rainfall occurs, the infiltration capacity of the soil may not be effective because of the short duration of the event and water that has not been absorbed by the soil becomes surface run-off leading to a quick rise in the water level in rivers and an increased danger of flooding. This risk can be enhanced by snowmelt or frozen soils, although the effect of soil frost conditions has not been clearly shown (Lindström and Löfvenius, 2000).

In large and medium-sized river basins situated in north and central Europe, wide-ranging and continuous precipitation is commonly the main factor in flood generation. Also, floods arising simultaneously from snowmelt and heavy rainfall can represent the same danger as floods arising only from rainfall.

Intense precipitation falling on small catchments is the main cause of floods in the Mediterranean area. These short but extremely intense rainfall events take place at the end of summer and in autumn. Figure 2.1 gives an illustrative example of the high temporal concentration of these rainfall events, and it can be seen that in some areas along the Mediterranean coast the recorded maximum daily rainfall is close to the mean annual rainfall.

Figure 2.1. **Ratio (%) between maximum daily precipitation and mean annual precipitation (period 1940/41–1995/96)**

Source: CEDEX with data from Eurostat.



2.2. Catchment characteristics

Along with the temporal and spatial distribution of precipitation, the effects of vegetation, soil, ground surface retention and drainage network in the catchment are of vital importance in determining the response in water flow and flood generation.

2.2.1. Vegetation and soils

Vegetation effectively intercepts and stores water when precipitation starts. Interception values between 2 and 5 mm of run-off are common. After the rain, the water on the plants evaporates thus allowing repeated use of this water storage by vegetation when precipitation occurs several times in succession.

The soil stores water very effectively and can store up to 100 times the quantity of water held by vegetation. The key elements of soil storage are porosity and depth of the soil. Vegetation secures the soil in steep locations and supports the absorption of water in the soil by means of root penetration. During a flood, the available water-absorption capacity of the soil is limited by the amount of water already stored. The soil behaves like a sponge; at first it can absorb a lot of water, but if precipitation continues, it absorbs less and less.

Forests often play a vital protective role with regard to water erosion in regions with fragile soils. This is particularly the case in south European countries such as Cyprus, Greece and Spain where protection against erosion and flooding is one of the primary roles of forests. Forests also contribute to the protection of mountain areas against floods (EEA, 1995).

2.2.2. Ground surface retention and drainage network

Steep land offers little surface retention and allows run-off to converge quickly. Very little surface retention is available in mountainous areas. By contrast, more water is stored in flat areas. Vegetation and certain types of land management aid surface retention. Dense vegetation, land divided into small parcels and land use along slopes increase the surface retention. Values of up to 10 mm of surface retention are common.

Water storage within the drainage network is greatest on level land and in extensive flood meadows. It influences the timing of floods and, thus, the time at which the water in the main river and its tributaries converge.

2.2.3. Flood plains and low-lying areas

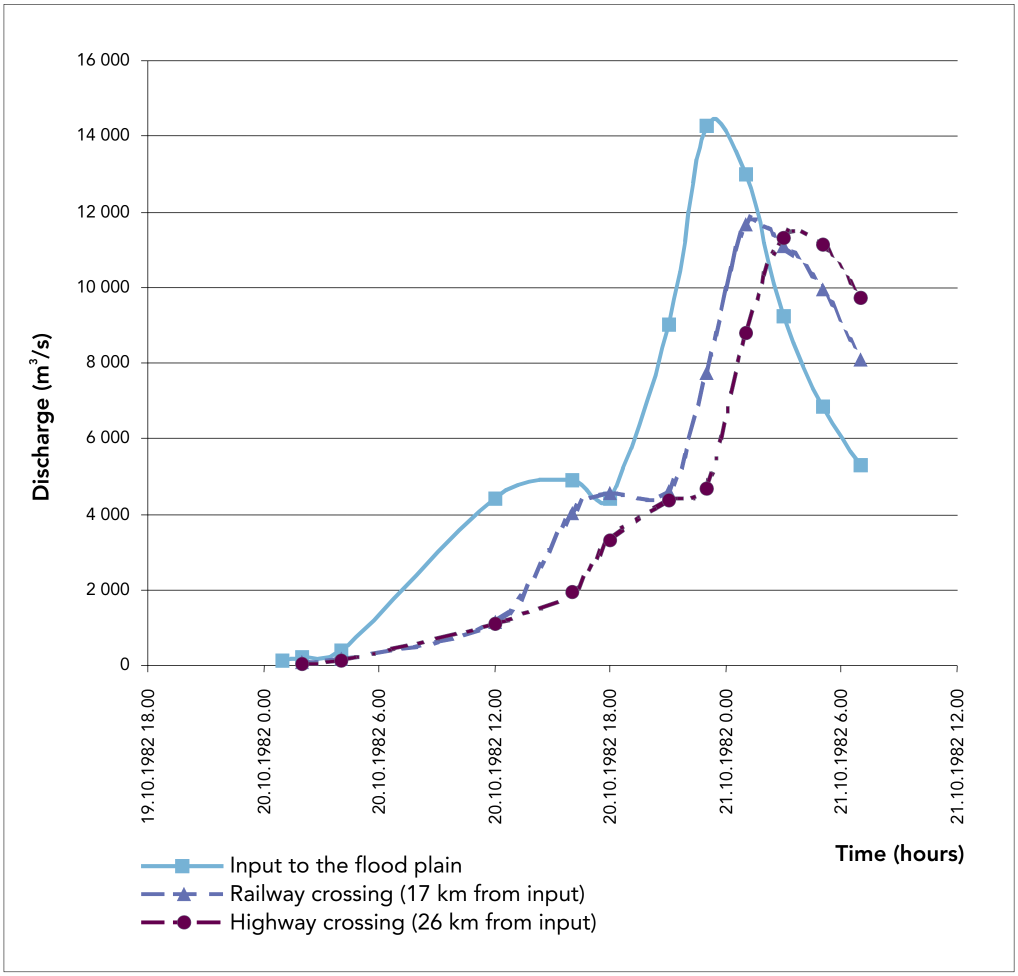
When flow discharges exceed the capacity of the river channel, waters overflow onto the flood plain. The storage and retention of water on flood plains reduce the peak discharge and influence the temporal evolution of the flood, mainly increasing its duration.

As a result of Ireland's configuration (saucer-shaped, with a high coastal rim and a flat, low central plain), many rivers that have their sources on the inland side of coastal mountains follow long circuitous courses to the sea with consequent sluggish flows. In times of heavy or prolonged rainfall, such slow-moving rivers are incapable of conveying the water, which can result in serious flooding over wide areas. For example, vast tracts of land along the River Shannon (the Shannon callows) are inundated annually, with extreme flooding in 1954, 1990 and 1995.

The River Júcar in Spain (Figure 2.2) is an example of flood propagation in the flood plain. The river flows in its natural channel until it reaches an open, low area where it spills over and inundates the flood plain. The 'input' in the figure means the hydrograph at the site where the river leaves its natural channel and enters the flood plain. When the flood advances downstream along the plain, the storage of water on it enhances the reduction of the peak discharge downstream and the increase of flood duration. Two hydrographs measured 17 and 26 km downstream of the input site show this effect of flood wave propagation.

Figure 2.2. **October 1982 flood at the River Júcar flood plain**

Source: CEDEX, 1998a.



On the contrary, in low-lying coastal areas, when high river flows are combined with high tides, floodwater cannot be fully discharged to the sea, causing a back-up of water behind the sluices and an increased risk of flooding. This is an important contributory factor to floods on the dyked areas of the Netherlands.

3. Pressures

Pressures induce or intensify floods and their impacts. Within the DPSIR framework, precipitation is the main driving force inducing floods, but the adverse effects of floods are intensified by some particular pressing human activities (Figure 1.2). The main pressures are climate change, land sealing, changes in catchment and flood-plain land use, population growth, urbanisation and increasing settlement, roads and railways, and hydraulic engineering measures.

3.1. Climate change

The most recent analysis of the causes of floods has increasingly included the possible effects of climate change. Scientific assessments indicate that the climate may be changing (e.g. IPCC, 1990). Expert opinion differs, however, with regard to the possible effects of this change. Climate change alters precipitation patterns resulting in changes in the distribution, intensity and duration of extreme rainfall events and a higher frequency of heavy precipitation.

In central Europe, a change in winter weather systems, and a shift towards mild and rainy winters, has already been observed in some catchments. Caspary and Bardossy (1995) postulate that a significant increase in winter precipitation due to this shift has brought about the increase in large flood events in the south-west of Germany over the last three decades. According to Kleeberg (1996), however, significant long-term trends cannot be derived from the time series available.

All of the scenarios consistently predict that air temperature would change substantially throughout the year and increments are predicted for winter months coinciding with increased precipitation. These conditions would result in a greater rate of winter snowmelt and a rise in the snowline, thus increasing the winter run-off and diminishing the spring and summer run-off due to the snowmelt.

Another important effect of climate change, apart from a change of precipitation patterns, is the impact of increasing temperature on the vegetation structure. A change of the vegetation structure in a catchment can affect soil properties and its retention capacity, and, as a consequence, the run-off.

3.2. Changes in catchment land use

Forests play an important role in water regulation and flood generation. Large-scale tree plantation or clear-cutting, fire and windfall can dramatically alter the water regulation dynamics of an area. Although there has been a 10 % increase in the forest cover of Europe over the last 30 years (EEA, 1995), damage to forests can locally be of great importance to water retention in an area.

Deforestation, and the loss of vegetation cover in headwater basins, mainly in the youngest mountainous areas, produces an increase in surface run-off. This vegetation cover has a very important effect on the attenuation of small and medium-sized floods, mainly in southern Europe. For a large flood, however, its effect is not so important in diminishing water flow, though it is extremely beneficial to the reduction of basin erosion and, consequently, on the amount of solids discharged.

Although deforestation is generally accepted to be a cause of increased flooding, more research is needed on the relationship between processes, factors and effects. The impact of forestry on peak flows can depend on the different stages of forest growth, the different forest types, the different climatic zones, the different soil types and the general land management practices, as the studies under the EU FAIR programme suggest.

A solution to this problem can be afforestation. It must be mentioned, however, that the impact of afforestation on climatic conditions in central Europe is not as significant as in southern Europe, because the land in deforested river basin areas is very quickly covered with plants and thus the soil is preserved. These results were, for instance, gained from long-term observations on experimental river basins in the Czech Republic.

3.3. Land sealing

The sealing of land leads to the direct run-off of precipitation into rivers (Händel and Verworn, 1982) which, in turn, enhances the risk of flooding at the regional level. One cause of major floods in Germany is the wide-scale sealing of the ground surface because of natural factors such as frost and saturation of the topsoil.

Artificial land sealing can result from the expansion of settlements and traffic networks. Also, agricultural activities can induce modifications in river basins. Water-retention areas on the flood plain are sometimes removed in order to gain arable land. Problems of soil compaction and soil erosion can occur if heavy machinery is used in agriculture and forestry.

In general terms, in Europe, land-use development is mainly characterised by a steady increase in the area occupied by settlements and traffic networks, and a decrease in agricultural land. For example, in Germany in 1993, the area occupied by settlements and traffic networks was 11.5 % of the total area with an increasing trend. Locally, the sealing of land can reach up to 75 % (Umweltbundesamt Berlin, 1998).

3.4. Urbanisation

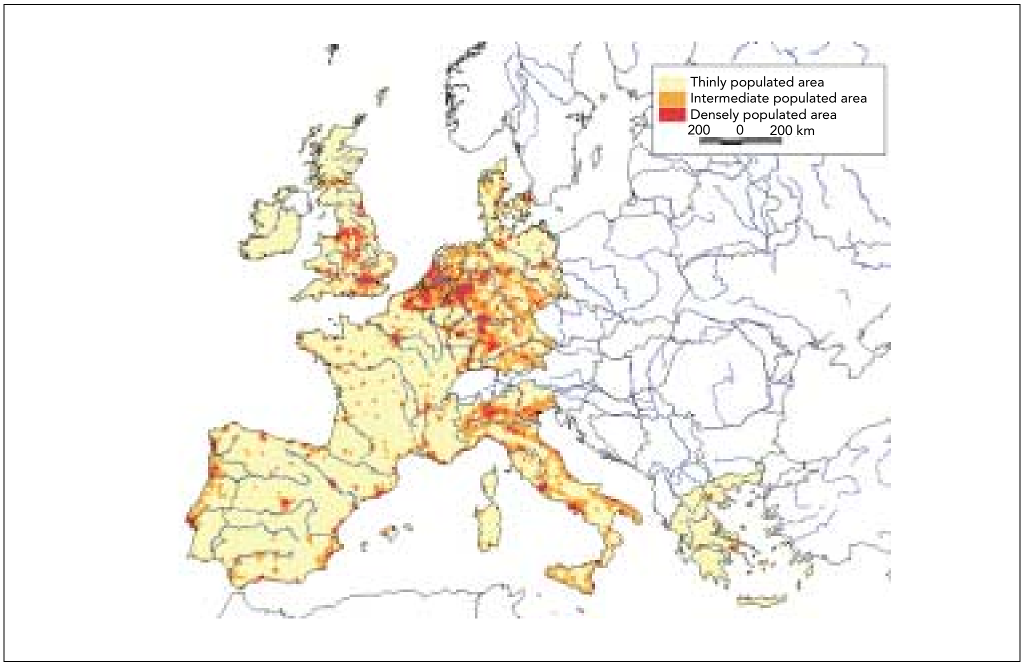
Alluvial areas close to rivers are usually flat and fertile and human activity has traditionally been located on them. In past centuries, floods were also catastrophic but their economic and social impact was relatively smaller than today.

An increase in population over recent decades has placed a greater demand on natural resources and space. The population of Europe reached about 680 million in 1990. Compared to other world regions, Europe (with the exception of the former USSR) is very densely populated (Figure 3.1). In Europe, more than two thirds of the population nowadays live in urban areas.

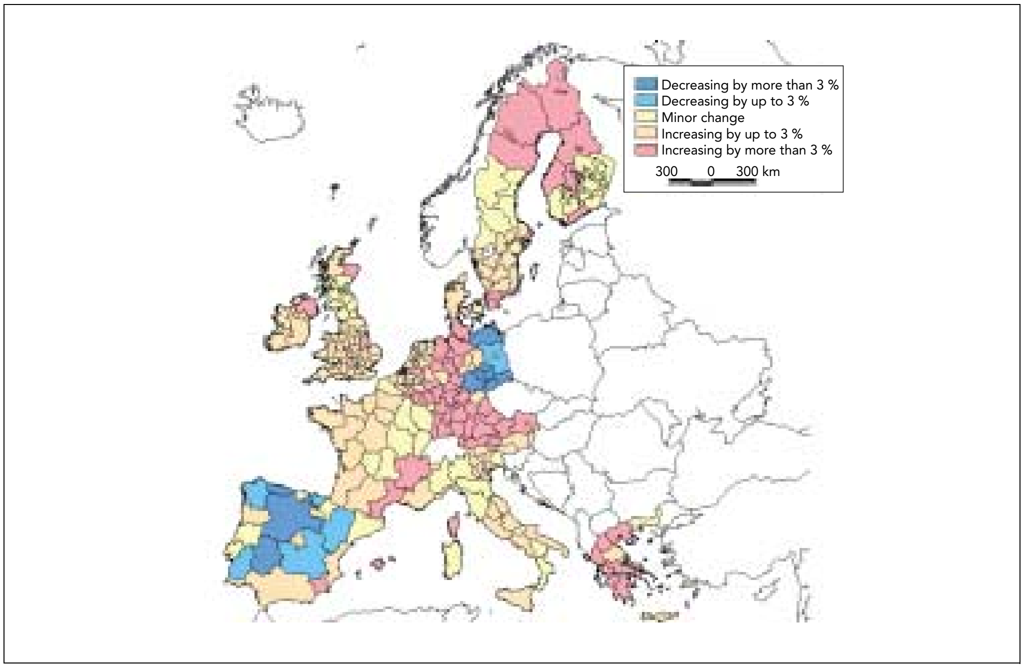
According to recent estimates, in Europe, 2 % of agricultural land is lost to urbanisation every 10 years. Rapid urbanisation is often the cause of enormous pressure from urban areas on rural and natural environments (EEA, 1995). Figure 3.2 shows the demographic development in Europe for the 1991–95 period. It can be seen how the areas with the most important increasing trend tend to match those that are more prone to floods, such as the Mediterranean coast and the River Rhine catchment.

Figure 3.1. **Degree of urbanisation and main rivers in Europe**

Source: Eurostat.



Demographic development for the period 1991–95 (Scotland 1991–94) Figure 3.2.



Source: Eurostat.

Urbanisation is often cited as one of the major human modifications to catchment hydrology in developed areas (Unesco, 1979). It has impacts (mainly negative) on the hydrological cycle regarding quantity as well as quality.

In general, urbanisation increases the frequency of high-flow discharges and reduces the time of rising discharges because of soil sealing and increased run-off, unless compensating measures are implemented.

A small proportion of towns are located in the higher parts of catchments, where urbanisation can lead to high discharges (e.g. Chambery in the French Alps), particularly if buffer zones, such as natural reservoirs or marshes, are eliminated. This is especially the case for winter sport stations which affect the plant cover and involve the creation of large car-parking areas with storm flow running off directly into mountain torrents. Similar problems are encountered in concentrated zones of coastal urbanisation (e.g. Nîmes and Marseilles) where flash floods are observed in small steep catchments leading directly from the mountains to the sea.

3.5. Roads and railways

Apart from an increase in population, a growing mobility and, consequently, an increase in transport infrastructure have been observed in Europe. Road and rail networks are often situated in river valleys and basins and their construction leads to faster run-off of precipitation via canalisation; in addition, the sealing of land reduces the water-retention capacity of a catchment.

The construction of road and rail networks can intensify floods and their catastrophic effects. Linear infrastructure with insufficient drainage works may divert flows to other areas or increase water levels upstream and, consequently, worsen the flood. However, it must be considered that the effect cannot be removed completely, and, in any case, it would not be desirable to make drainage works unnecessarily expensive. Furthermore, transport links are key in a flood situation for the evacuation of the population or access of emergency services.

3.6. Hydraulic engineering measures

In some cases, hydraulic engineering works that have been undertaken to mitigate the effects of floods in one area can worsen their effects in another. River channelisation works to protect a town can speed up the propagation of the flood wave and increase flood risk downstream. Channelisation generally changes a heterogeneous meandering river into a homogeneous straight channel with an increased bed slope, uniform flow conditions and less habitat diversity compared to the undisturbed situation. Bed and bank erosion, loss of riparian trees and damage to river-bank structures are frequently cited changes. Increased erosion and sedimentation reduce the capacity of stream channels, and thus flooding occurs where rivers previously would have remained within their banks.

Flood reservoirs constitute a very efficient method of protection against floods. However, exceptionally, they can aggravate the effects of a flood if, for example, the spillway is insufficient or incorrect sluice management is carried out.

Furthermore, it must be borne in mind that river channelisation and reservoir construction may eliminate small or medium-sized flood events but cannot always hold back large floods. Also, attention must be paid to the construction of hydraulic works in dry rivers and the consequent occupation of flood plains, partly because of the false feeling of safety that the new protection works bring to people.

River regulation has been undertaken to the largest extent in western and southern Europe (1). In countries such as Belgium, England and Wales, and Denmark, the percentage of river reaches that are still in a natural state is low, typically 0–20 %. By contrast, in countries such as Poland, Estonia and Norway, 70–100 % of the reaches of many rivers have remained in a natural state (EEA, 1995). River regulation works separate the rivers from their flood plains, while under natural conditions they closely interact with each other. With regard to flood events, undisturbed flood plains increase the water-retention capacity during flood periods. In almost all the European countries, the natural balance between rivers and their flood plains has been disturbed (EEA, 1995).

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(1) River regulation comprises the physical changes that people impose on watercourses, such as land drainage water abstraction, flood protection, inter-basin water transfer, reservoirs, wastewater discharge, weirs, dredging, channelisation and navigation.

4. State

4.1. Types of flood

Two main groups of meteorological events generating floods can be distinguished in Europe.

- In large river basins, flooding is usually frontal and seasonal. Hydrographs are normally broad-based and peak discharges may last a number of days.
- Flash floods are usually associated with isolated and localised very intense rainfall events occurring in small and medium-sized basins. Peak discharges are maintained only for hours or even minutes. Flash floods are common in Mediterranean rivers originating in mountains close to the sea.

4.1.1. Floods in large basins

Floods, at a given location in a river system, are a function of the hydrological processes in the catchment upstream of that location. The relationship between the flood behaviour in headwater catchments and the flood behaviour of the entire river basin is often complex and is not always perfectly understood. The downstream characteristics of the flood differ from the upstream characteristics because of lag, routeing effects, scale effects, and changes in geology, physiography and climate from headwaters to the outlet.

Severe overland floods in central and lowland parts of river basins are characterised by flooding of extensive areas and by slower responses to the cause of the flood, longer duration and lower specific discharge than the headwater flash floods. As rising water levels are relatively slow and response times are long, there are more chances for real-time forecasting and mitigation measures such as evacuation and flood protection. Nonetheless, their impact and the economic damage caused may be substantial because of the size of the flooded area and that on many occasions the exposed communities are not prepared for the flood risk.

A well-known example of a large basin flood is that of 1995 in the Rhine basin (basin surface area 190 000 km^2). The peak discharge approached 12 000 m^3/s; that is six times the average flow, and it lasted more than two weeks (Figure 4.1).

4.1.2. Flash floods

Flash floods are a sudden-onset flooding that can occur under a broad range of climatological and geographical conditions. Flash floods are associated with intense localised thunderstorm activity, mountainous areas where orographic uplift may intensify rainfall and where steep slopes may increase the potential for landslides, and, in exceptional situations, with failure of dams.

Flash floods tend to be mainly local or regional events. In spite of their usually much smaller geographical scale than floods in large basins, flash floods are the most considerable flood hazard regarding the number of fatalities, with recent examples at Biescas in Spain in 1996, and at Sarno and Quindici in Italy in 1998. This is because of their rapid onset characteristics, which limit warning procedures and emergency actions, and the high velocity of the flood flows and the associated debris load. A major risk factor is the occupation of potential flood areas through uncontrolled building and inadequate land-use planning. However, in many areas where they are frequent, the local communities are more or less adapted to the flood hazard, and the economic losses can be relatively low.

In Europe, the prevalent zones for flash floods are located in areas where basins have a short response time and are influenced by Mediterranean cyclones. These areas are the Côte d'Azur, east Pyrenees, Cevennes and Corsica in France, the north-western areas of Italy, and Catalonia and Valencia in Spain (Figure 4.2). Severe flash floods also occur where an orographic rise of the cold air masses of tropical origin takes place. These types of air mass have a marked instability manifested by upward movements resulting in heavy and very intense rains.

Figure 4.1. **Run-off during the 1995 Rhine flood**

Source: German Ministry of the Environment, 1996.

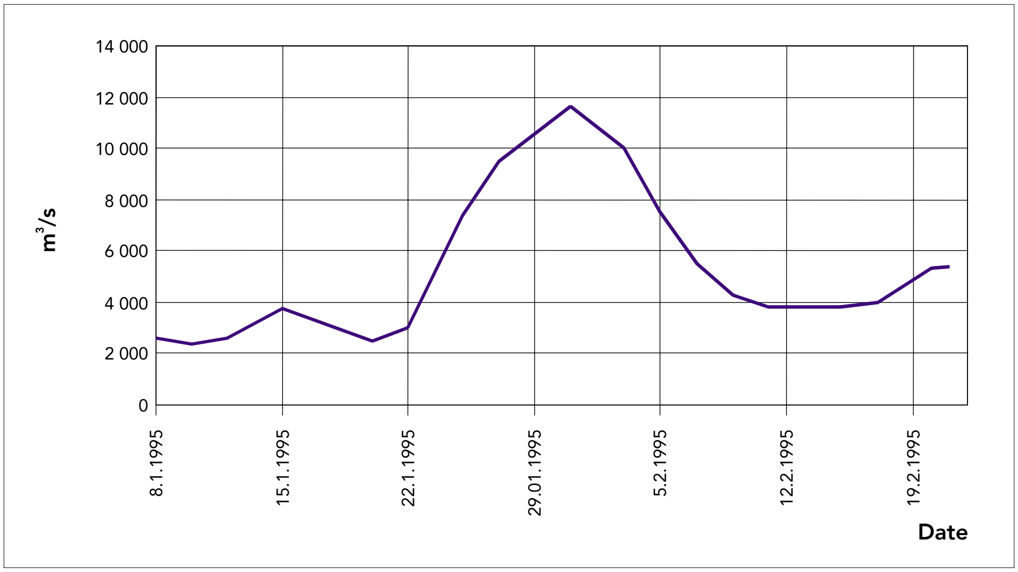
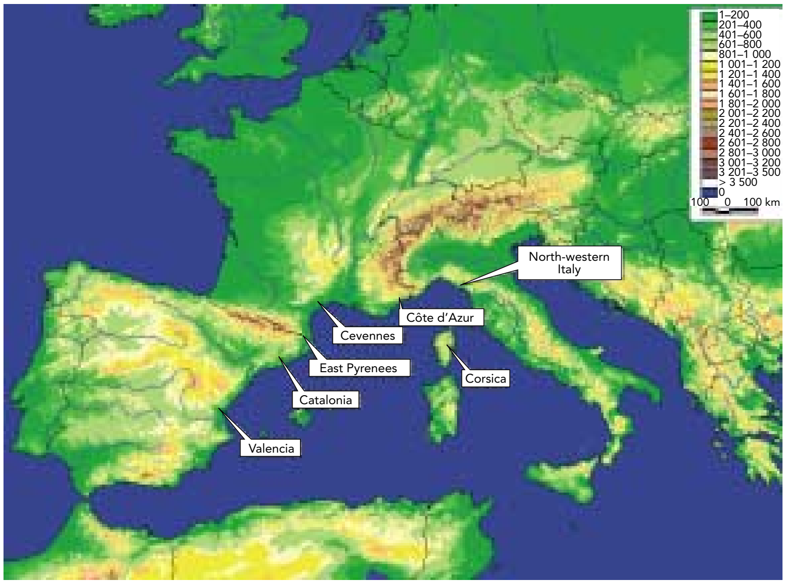
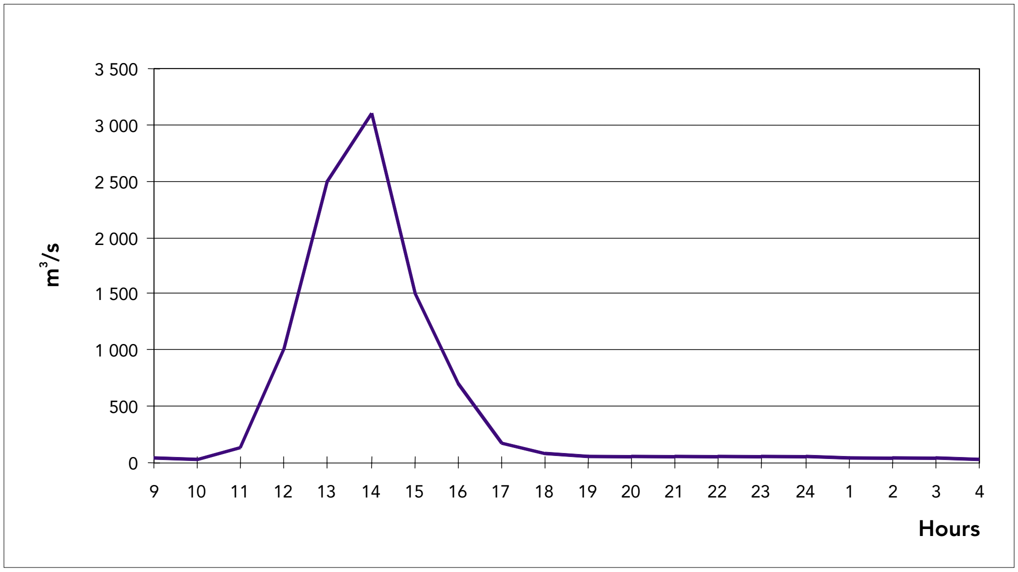


Figure 4.2. **Prevalent zones for flash floods in Europe (altitudes in metres above sea level)**



The 1973 flood of the River Almanzora, located on the south-eastern coast of Spain, was a classic flash flood event. With a drainage area of only 1 100 km^2, a peak discharge of 3 100 m^3/s was recorded, maintaining a discharge of more than 2 700 m^3/s over about one hour (Figure 4.3). A key aspect of flash floods like this is the disproportion between maximum discharges (which can be larger than 3 000 m^3/s) and mean annual flows of around 1 m^3/s.

Run-off during the Almanzora flood on 19 October 1973 Figure 4.3.



Source: MMA, 1999.

4.2. Probability of occurrence of floods

The analysis of the probability of the occurrence of a flood is traditionally based on the concepts of return period and the frequency law of maximum flow discharges. The return period associated with a defined flow is equal to the number of years between floods that exceed that flow. It is important to highlight that given the stochastic nature of floods, this number of years is only an average value.

The maximum discharge frequency law is formed by discharges corresponding to different return periods. Maximum discharge frequency laws corresponding to large basins and moderate hydrological regimes have usually a small growth rate (River Guadiana in Figure 4.4). On the contrary, in many Mediterranean basins, frequency laws are commonly composite, with a small growth rate for low return periods and a strong one for medium and high periods (River Júcar in Figure 4.4). This means that in practice medium-sized floods do not exist.

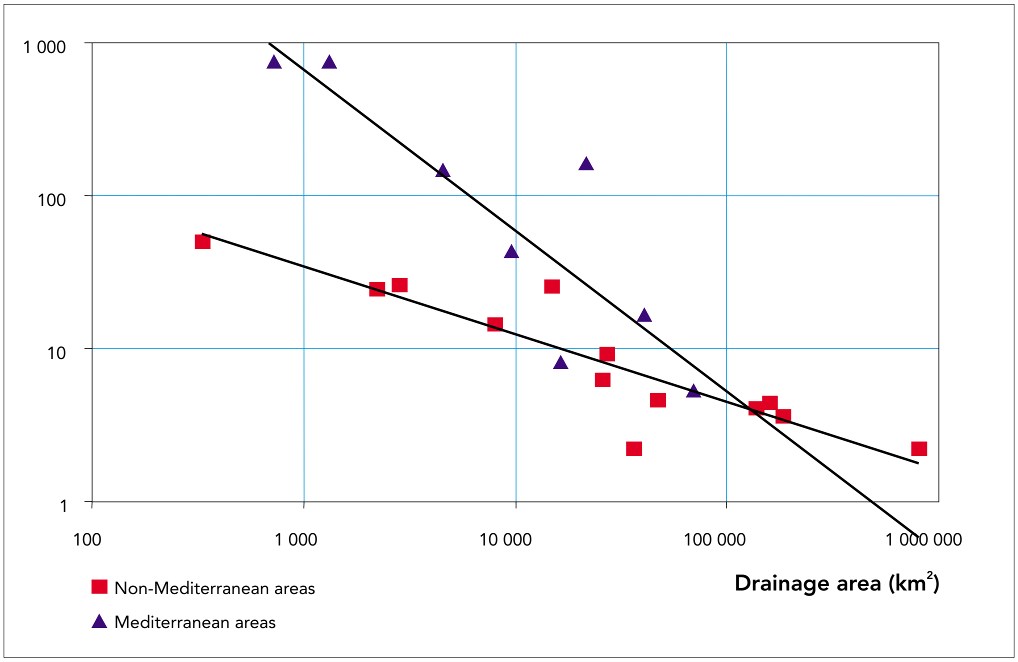
The ratio between the ordinary and extraordinary discharge of a river varies enormously depending on the meteorological regime and on the basin characteristics. In Table 4.1, average and maximum discharge values for different European rivers are shown. In Figure 4.5, values of this range from 2 to 1 000 for those rivers in Table 4.1. The ratios are smaller in large basins in northern and central Europe and larger for small Mediterranean basins.

Figure 4.4. **Maximum flow discharges at the Rivers Júcar and Guadiana in Spain**

Source: CEDEX, 1998a, 1998b.

Figure 4.5. **Ratio peak discharge/average annual discharge versus drainage areas in different regions**

Source: Stanescu and Matreata (1997), UNESCO (1993), Hydrological Data UK (1993, 1994), MMA (1999).



Average and maximum discharges in European rivers Table 4.1.

Source: Stanescu and Matreata, 1997; Unesco, 1993; Hydrological Data UK, 1993, 1994; MMA, 1999.

Country	River	Location	Area (km^2)	Average flow (1) (m^3/s)	Peak flow (2) (m^3/s)	Date of flood event	Return period (years)	Period of data
Austria	Inn	Schärding	25 665	735	4 620	20.7.1981		1965–84
Bulgaria	Maritza	Plovdiv	7 981	51	730	16.4.1973		1965–79
Finland	Kymi	Pernoo	36 535	330	710	2.1.1924		1909–99
France	Seine	Paris		250	2 500			
France	Tech	Ceret	483		3 500	17.10.1940	100	
France	Reart	Mas Palegry	137		1 100	26.9.1992	100	
France	Var	Outlet	2 870		3 800	5–7.11.1994	100	
Germany	Danube	Hofkirchen	47 496	650	3 020	March 1988	15	
Germany	Mosel	Cochem	27 088	450	4 170	1993–94	80	
Germany	Rhine	Kaub	103 729		6 500	1993–94	40	
Germany	Rhine	Andernach	139 795		10 500	1993–94	65	
Germany	Rhine	Rees	159 683	2 500	11 000	1993–94	80	
Germany	Oder	Hohensaaten (3)	109 564	300	2 960	2.8.1997	150	
Germany	Danube	Kehlheim (4)	22 950	750	2 220	24.5.1999	300	
Hungary	Danube	Nagymaros	183 533	2 294	8 180	15.6.1965		1965–84
Hungary	Tisza	Szeged	138 408	944	3 825	31.5.1970		1965–84
Italy	Ambra	Mortozi	158		726	4.11.1966	100	
Italy	Po	Pontelagoscuro	70 000	1 550	8 200	2.11.1976		1965–79
Italy	Tevere	Rome	16 545	221	1 790	18.2.1979		1965–79
Italy	Sesia	Outle	2 300		3 000	November 1994	80–100	
Italy	Po	Ponte-Becca	36 800		11 300	November 1994	30–40	
Romania	Danube	Ceatal Izmail	807 000	7 011	15 540	25.5.1970		1965–84
Romania	Mures	Alba Iulia	17 964		2 450	May 1970	100	
Romania	Somes	Satu Mare	15 000	130	3 340	May 1970	125	
Romania	Potop	G. Foii	196		875	26.6.1979	200	
Spain	Albaida	Villanueva de Castellón	1 000	4	3 000			
Spain	Cinca	Fraga	9 612	85	3 700		100	
Spain	Ebro	Zaragoza	40 434	250	4 130	2.1.1961		1943–91
Spain	Guadalhorce	Puente del Rey	3 100		4 500		100	
Spain	Guadiana	Puente de Palmas	48 515	84				
Spain	Júcar	Huerto Mulet	21 497	37	6 000		100	
Spain	Llobregat	Martorell	4 561	19	2 820		100	
Spain	Noya	San Sadurni	726	2	1 510		100	
UK	Avon	Evesham	2 210	15	371	11.7.1968		1936–93
UK	Spey	Boat of Garten	2 861	64	1 675	17.8.1970		1952–93
UK	Oykel	Easter Turnaig	331	17	848	6.10.1978		1977–93
UK	Tay	Balathie	4 587		2 268	17.1.1993	70–80	
UK	Clay	Outlet	1 903		1 300	10.12.1994	20	

(1) Average annual discharge.
(2) Maximum discharge for a return period or period of data selected.
(3) Source: Das Oderhochwasser 1997, Internationale Kommission zum Schutz der Oder.
(4) Source: http://www.bayern.de/lfw/hnd/.

5. Impacts

5.1. Concepts

On average, the higher the water depth and the greater the flow velocity of a flood, the greater the damage. In addition, the high speed of onset or long flood duration exacerbates flood-related phenomena.

Water quality associated with a flood also impacts on natural ecosystems and human life. For example, almost all floods in urban areas will be contaminated with sewage potentially adversely affecting the health of people in the area.

Losses occurring during and immediately after the flood event, including loss of human life and damage to property, are called direct losses.

Indirect losses, such as increased vulnerability of survivors, disruption of traffic and trade, reduced public confidence in the area, and environmental consequences of flooding, are often equally or even more important, but they are more difficult to assess than the direct losses.

Factors associated with flood damage are different depending on land use. Flood duration, for instance, is an important factor in agricultural damage, but it is much less important for other land uses. The suspension of activities, as well as the interruption of electrical services or communications, can affect urban areas.

Flood risk can be analysed as two independent components, one based on the hydrologic and hydraulic regime, and the other based on the land use and the socioeconomic perception of risk.

The first factor is called hazard and depends only on the flow regime of the river (mainly maximum water levels, discharges and flood duration), independently of the land use on the flood plain.

The second factor is called vulnerability and it represents the sensitivity of land use to the flood. Consequently, it depends only on land use and the social perception of risk. For instance, it can be assumed that the same campsite has the same vulnerability wherever it is located, on a flood plain or on the top of the hill. The difference in the risk level is due to the occurrence of flooding, which is obviously different in the two situations.

5.2. Recent floods in Europe

In Europe, there is no common database for flood events, and data on floods are not collected by the different national authorities following common criteria. The International Federation of Red Cross and Red Crescent Societies (IFRC and RCS) operates a worldwide disaster database that provides information on flood events and related losses (http://www.ifrc.org/). Over a 25-year period (1971–95), 154 flooding events occurred in Europe, and in 1996 there were 9 flooding events. Over a five-year period (1991–95), the damage caused by flooding in Europe was estimated at EUR 99 billion. Table 5.1 shows the main floods that have occurred in recent years in Europe.

Significant flood events in Europe, 1992–98 Table 5.1.

Date (day/month/year)	Location	Fatalities (1)	Estimated damage (2)
21.7.1992	Bayer (D) Jura (CH)	8 5	USD 47 million
8–9.8.1992	South-Central (UK)	5	
22.9.1992	Vaison-la-Romaine (F) Savona (I)	35 2	USD 336 million
27–28.9.1992	Genoa (I)	2	USD 10 million
3–6.10.1992	Veneto (I)		USD 10 million
31.10.1992	Thyrrenian coasts Sicily (I)	3	USD 712 million
1992	Tazlau (RO)	107	USD 50 million
9–11.6.1993	Wales (UK)	3	USD 19 million
12–15.6.1993	Dublin (IRL)	3	USD 45 million
23.9.1993	Brig (CH)	2	USD 460 million
23.9.1993	Liguria (I)	2	ITL 100 billion
December 1993	Belgium		DEM 30 million
January 1994	Germany France Netherlands United Kingdom		DEM 180 million
1–4.4.1994	South-West (UK) Germany	7	
4.7.1994	Niedersachsen, Rheinland, Mittelgebirge (D)	5	USD 630 million
4–6.11.1994	Piedmont (I)	64	USD 13 billion
10–13.12.1994	Scotland (UK)	3	USD 155 million
1954, 1990, 1995	River Shannon (central Ireland) (3)		
January 1995	Germany Netherlands		
5–10.6.1995	Glomma (N)		USD 300 million
11.8.1995	La Ciotat (F)	30	
19.9.1995	Friuli (I)	2	
4–6.10.1995	Nimes (F), Liguria (I)	1	USD 10 million
19.6.1996	Versilia (I)	13	
7.8.1996	Biescas (E)	86	
8.10.1996	Emilia-Romagna, Calabria (I)	1	
14.10.1996	Crotone (I)	4	ITL 200 billion
3.11.1996	Scotland (UK)	6	
1997	Oder, Morava, Danube (PL, CZ, D)	105	USD 6.5 billion
1997	Badajoz (E)		
1998	Sarno and Quindici (I)	300	
9–10.4.1998	Central England and Wales	5	
23.7.1998	East Bohemia (CZ)	6	USD 60 million
20.7.1998	East Slovakia (SK)	50	USD 50 million
May 1999	Danube (4)	12 (5)	DEM 818 106

(1) Blank means no data.

(2) Million USD = 10^6 US dollars; million DEM = 10^6 Deutchmarks; billion USD = 10^9 US dollars; billion ITL = 10^9 lira.

(3) References: Rydell,1956; OPW, 1961; IFA, 1988.

(4) Source: http://www.bayern.de/lfw/hnd/

(5) Germany, Austria, Switzerland.

5.2.1. Sarno, Italy, 1998

During this flood, there were between 147 and 160 fatalities caused by a river of mud that destroyed an urban area with a great number of buildings (Thönissen, 1998). The river basin could not retain the great volume of mud and water because of the extensive urbanisation and the lack of vegetation and soil.

5.2.2. Biescas, Spain, 1996

This flood occurred on 7 August 1996 in Barranco de Aras, near the town of Biescas, in a small basin of 20 km^2 located in the Pyrenees. It had all the characteristics of a flash flood. A total of 86 people died as a consequence of the stream of water and mud that suddenly covered a campsite located near a channelised river. It was estimated that there was about 250 mm of rain in less than 24 hours, and the peak discharge was about 250 m^3/s, representing a most unlikely hydrological event (CEDEX, 1997). The storm quickly produced a powerful water stream, which was able to drag the largest boulders in the riverbed downstream. The boulders blocked the river channel, destroyed the flood protection works and caused flooding over the surrounding areas in a few minutes. The steep slope of the rivers and the intensity of the rainfall were the main causes of the high-speed stream of water and stones (Marcuello and Estrela, 1997).

In such a sudden event, where there is no time to alert the population, good coordination of civil protection forces is essential in order to evacuate the people affected.

5.2.3. Glomma, Norway, 1995

A major flood occurred in Østlandet in southern Norway in early June 1995 (NOU, 1996). Large volumes of snow and low temperatures in May were followed by high temperatures and precipitation which caused the largest flood this century in the central parts of the Glomma and Trysil river basins.

In the Glomma at Elverum, the flow increased within five days from 1 553 m^3/s (average annual maximum flow) to about 3 500 m^3/s. This flood was the largest observed since 1789.

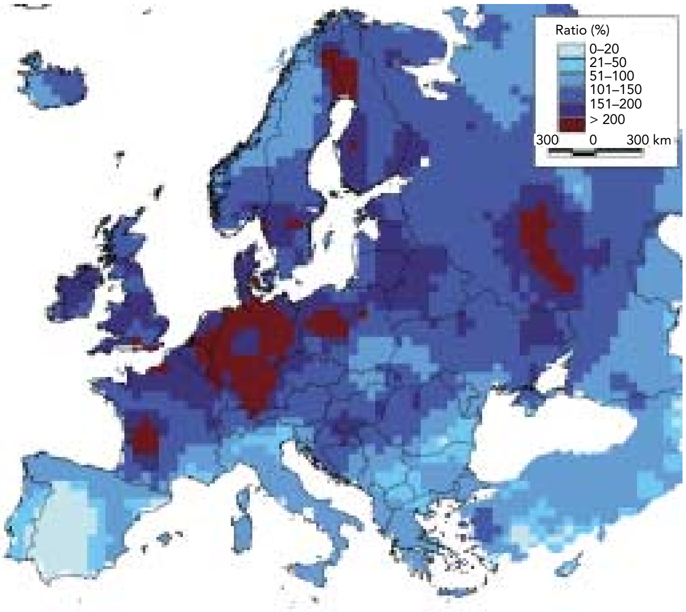
5.2.4. Rhine and Meuse, Germany and the Netherlands, 1993–94

In December 1993 and January 1994, a number of European countries experienced damaging flood events, which had been caused by persistent high precipitation. In a zone stretching from south-eastern UK, eastern France, the Benelux countries, Germany and Poland, the accumulated precipitation was more than double (Figure 5.1) the amount of the long-term average for December.

As a result of the high rainfall, a great number of rivers in the area overflowed their banks. In particular, the River Meuse, and on the middle and lower Rhine, a flood event which caused enormous damage attracted wide attention. It began around 19 December 1993 and ended in mid-January 1994. In some parts of the Rhine and Meuse basins, the estimated return period for the flood ranged between 50 and 100 years, which makes it a rare event.

According to initial estimates, damage on the Rivers Rhine and Meuse exceeded DEM 1 billion, while other European countries also suffered considerable damage. Ten people lost their lives in the affected countries. The total damage was later estimated at between USD 900 million for Belgium, Germany, France and the Netherlands, and USD 2 000 million if the UK was included (Bayrische Rückversicherung, 1996a).

Ratio (%) precipitation in December 1993/long-term average precipitation in December in Europe Figure 5.1.



Source: CEDEX with data from the Climate Research Unit (CRU, 1998).

5.2.5. Rhine and Meuse, Germany and the Netherlands, January 1995

Thirteen months later, in January 1995, intense rainfall (Figure 5.2) produced a new flood of similar characteristics to the Christmas flood of 1993–94. Figure 5.2 shows the 1993–94 and 1995 flood hydrographs recorded at the gauging station in Cologne. Similar peak discharges (11 000 m^3/s) were observed in both floods, though the 1993–94 flood had a second wave with a peak discharge close to 8 000 m^3/s. The particular significance of the January 1995 flood does not lie in the discharge peaks and water levels reached, but in the enormous discharge volumes occurring in the Rhine and Meuse catchment areas.

The total cost of damages in Germany from this flood was only half of that caused by the 1993–94 flood because people were aware of the risk and better prepared. Even though the January 1995 flood was certainly an exceptional event, it was not a 'flood of the century' (Bayrische Rückversicherung, 1996b).

Figure 5.2. **Ratio (%) precipitation in January 1995/long-term average precipitation in January in Europe**

Source: CEDEX with data from the Climate Research Unit (CRU, 1998).

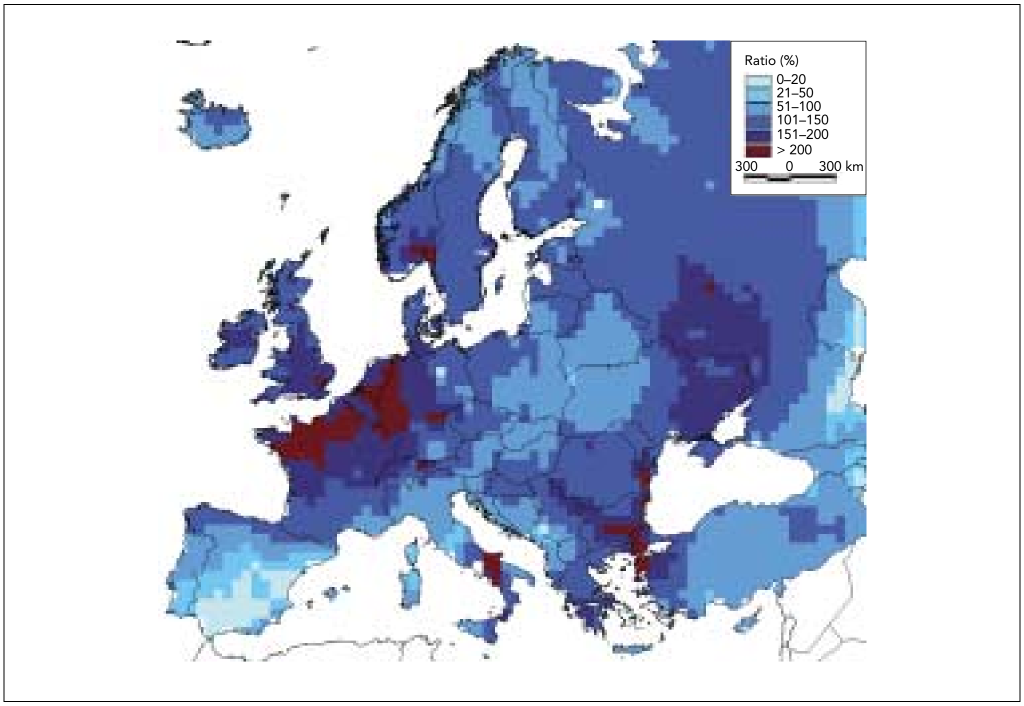
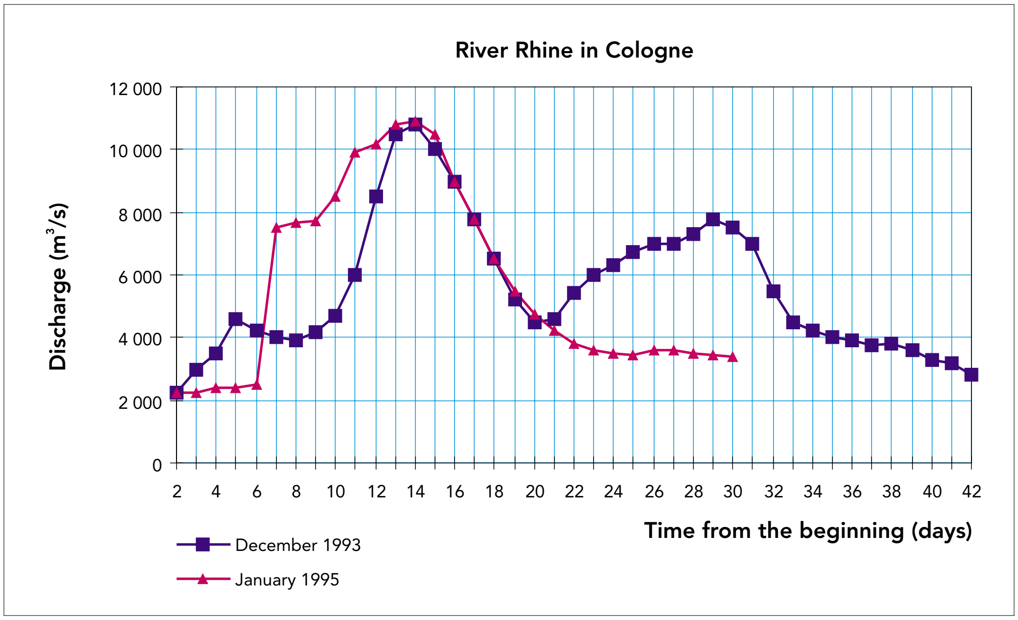


Figure 5.3. **Discharge of the River Rhine at Cologne — floods 1993–94 and 1995**

Source: Portman and Gerhard, 1996.



5.2.6. *Oder, Morava and Danube, Poland, Germany and the Czech Republic, 1997*

In July 1997, Europe experienced one of the most disastrous floods in its history. Vast areas of southern Poland, eastern Czech Republic and western Slovakia were flooded after exceptionally heavy rain. At the worst-hit locations, as much water fell in a few days as usually falls in an entire year. Many streams in the watersheds of the Oder, Elbe, Vistula and Morava Rivers flooded and overflowed their banks. The flood surges moved downstream, flooding communities and destroying houses and bridges. Industrial waste and sewage entered the floodwater, contaminating agricultural soils, stores, offices and homes.

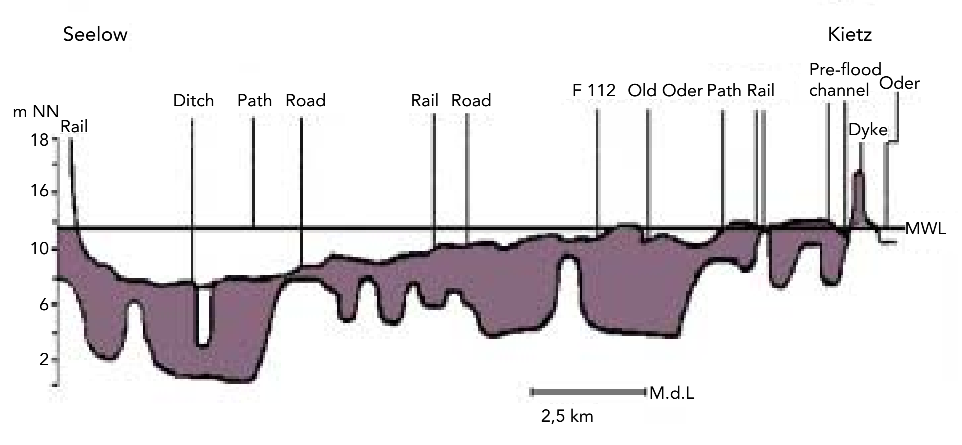
The flooding affected a quarter of Poland (an area populated by 4.5 million people) including nearly 1 400 towns and villages. In Poland, 400 000 ha of agricultural land were affected, 50 000 homes destroyed, 162 000 people evacuated and 55 people died. Infrastructural damage included 480 bridges, 3 177 km of road and 200 km of railway. The total damage in Poland was estimated at USD 4 billion. In the Czech Republic, the flood caused damage of USD 2.1 billion and 40 people lost their lives.

The ecological consequences included increased nutrient and pollutant concentrations in the Oder estuary. Heavy metals, mineral oils and organic trace substances were carried by the floodwater. The nitrogen concentration of the Oder was 6 to 8 times greater than the 1996 average, and phosphate 16 times the 1996 average.

The flood was caused by extremely heavy rain, but the effect was enlarged by human changes in the watersheds. In particular, the water-retention potential of several of the flooded watersheds had been reduced because of human action. The main cause of inundations is the drainage of the marshland which occurred in the 18th century. It was achieved essentially by redirecting the main river flow from its original course eastwards into an artificially created higher bed. The consequence of this main-flow diversion is that the water level of the Oder is up to 4 m above the level of the marshland area which is up to 15 km wide. Therefore, it was not only the districts located immediately beyond the dyke which were at special risk in case of breaching, but also the low-lying areas further away from the dyke (see Figure 5.4).

Destruction of forest and riverine wetlands, engineering of mountain streams and rivers, destruction of waterside vegetation, and removal of natural water-retention features (hedges, small forests and clumps of vegetation) have reduced water-absorption capacity. Straightening and shortening works in the Oder and Vistula over the past decades have made them more susceptible to floods. As a result, severe flooding has been an almost regular occurrence in the area for more than a decade.

Cross-section of the Oder marshland compared with the mean water level Figure 5.4.



(MWL = mean water Level on the Oder at the Kietz water gauge)

Source: According to the State Environmental Ministry Brandenburg.

5.2.7. Vaison-la-Romaine, September 1992

The tragic consequences of the disaster at Vaison-la-Romaine reflected the vulnerability of campsites and housing located too close to the river banks. The disaster was also exacerbated by the fact that it was not possible to provide a warning with sufficient time for evacuation (IFEN, 1994).

The review report on the flood (Conseil général des ponts et chaussées, 1992) concluded that the forecasts of an acceptable risk of flooding were based on a relatively limited analysis of the hydrology of the River Ouvèze. Insufficient consideration was given to the risk of higher flood discharges than those forecast in studies. In order to avoid disasters of this type in the future, global risk assessments are required which should be based not only on scientific calculations, but also on the economic, financial and social costs of prevention.

5.2.8. Extreme flood events in Hungary

There have been 75 significant floods along the Danube over the last nine centuries; 23 of them took place in the 18th century before extensive flood protection works started. Some of those are listed below.

1838 March	Icy-flood in Budapest, 153 victims, 10 100 houses collapsed along the Danube
1879 March	Flood disaster in Szeged, 158 victims
1888, 1919 Spring	Extreme floods in the Tisza valley, successful protection
1925 Christmas	Flood in the Körös valley, two dykes bursting, 21 000 ha flooded, 904 houses ruined
1932 Spring	Big flooding in the Tisza valley, successful protection
1941 February	Icy-flood at the Danube, dyke bursting at Apostag
1947 31 December	Icy-flood at the upper Tisza, 24 000 ha flooded
1954 July	Dyke bursting at Szigetköz, 20 600 ha flooded
1956 March	Icy-flood at the Danube, 58 dykes bursting downstream of Budapest, 70 000 ha flooded
1965 April–June	The biggest summer flood at the Danube until then, with great protection the disaster was prevented, 11 dykes bursting at the Rába valley
1966 February–April	Icy-flood at the Berettyó with dyke bursting, Szeghalom was threatened, dyke bursting at the Fehér-Körös in Romania, the Hungarian area between the Rivers Fehér-Köros and Fekete-Körös was flooded, altogether 12 600 ha
1970 May–July	The biggest Tisza valley flooding until then, 14 dykes bursting at the Romanian part of the Szamos, 3 at the Hungarian part of it, 57 000 ha flooded, 5 400 buildings destroyed; in other areas, the catastrophe was prevented by big protection effort; however, 96 000 inhabitants were relocated for safety reasons
1974 June	Flood in Körös valley, safety reservation at the area between the Rivers Fehér-Körös and Fekete-Körös, 7 100 ha flooded, 407 houses destroyed, 380 inhabitants relocated, Gyula, Gyulavári and Dénesmajor were threatened by flooding
1974 October	Very big flood in the valleys of the Ipoly, Zagyva-Tarna, Sajó, Hernád and Bodrog
1980 July	Flood in the Körös valley, two dykes bursting, 20 000 ha flooded, 4 100 inhabitants relocated
1981 March	Flood in the Körös valley, safety reservation at the area between the Rivers Fehér-Körös and Fekete-Körös at Mályvád, 3 400 ha flooded
1989 May	Extreme flood of Hernád, three settlements were flooded
1991 August	Danube flood with record high level in Szigetköz, dyke bursting in Szentendre Island at Surány; Szigetmonostor and Surány were threatened by floods

5.2.9. Some rare flood events in the UK between 1975 and 1998 (Faulkner, 1999)

Intense and prolonged rainfall over central England and Wales on 9 and 10 April 1998 together with the saturation of the ground led to rivers rising at rates about twice as fast as previously experienced, to levels which were the highest on record at many locations. Sudden and severe flooding over a wide area occurred, around 4 500 properties flooded and five people died.

In December 1994, nearly 700 homes were flooded in the area of Glasgow because of a five-day rainfall. Bridges were destroyed and three people were drowned.

Widespread flooding occurred in South Wales in December 1979. Four people drowned, thousands were evacuated and hundreds of homes flooded.

In West Yorkshire, a torrential, localised, two-hour thunderstorm with a small amount of hail occurred on 19 May 1989. Many properties were flooded in Halifax, with erosion and severe damage to river-retaining walls, mill foundations, culverts and sewers. A landslide was caused by a peat bog bursting. Cars and sheds were swept away and houses flooded to a depth of a metre at some sites.

In Hampstead, North London, an isolated and extremely severe thunderstorm that remained stationary for about 2 hours and 40 minutes caused severe flooding on 14 August 1975. Cars floated along streets, houses were damaged, subways filled and sewers burst. Two people drowned in basements and two were struck by lightning.

5.2.10.Extreme flood events in Finland

The highest well-recorded flood affecting large areas occurred in 1899. It was a typical Finnish high flood, resulting from both the melting of snow and heavy rain during the melting period and the peak period. The return period of the flood has been estimated to be once in 300 years. The flooded area totalled 144 000 ha, of which 60 000 ha were meadows, 46 000 ha forests and 38 000 ha fields. The total damage was estimated to be USD 22 million in present-day prices. It was a major disaster comprising 1.2 % of the GNP for 1899.

The second biggest flood occurred in 1924, having a return period of around once in 100 years. The reason was melting of snow combined with heavy rains during the melting period.

In northern rivers, there have been many very high floods caused by jamming of ice. During such floods, the water level can rise by several metres in a few hours.

6. Responses

6.1. Background

Measures taken in response to flooding are usually aimed at reducing flood damage. Some general points are made first, followed by discussion of measures taken in relation to floods.

Coordination: There is clearly a need for joint and coordinated actions between the different civil administrations involved (MMA, 1998). The importance of the role of regional and local administrations has been increasing compared to the role of central administrations.

Realism: The risk of flooding can never be wholly eliminated by structural and non-structural measures — there can only be a reduction in the risk (MMA, 1998).

Environmental considerations: Floods are important in the functioning of ecosystems. They are a basic element in the transport of sediments, and in the renovation of the physical substratum of the ecosystem. Furthermore, floods control the development of plants and animals in the fluvial ecosystem. For these reasons, controlled floods are increasingly being used in European countries as part of management policies. These re-establish the equilibrium of ecosystems that have been altered by flow regulation with reservoirs. The impact of any measures on fluvial ecosystems should thus be minimised and mitigated where possible.

Prevention: Problems arising from floods should be prevented before future interventions are needed. For example, the prevention of human occupation of flood plains and risk areas, and the development of towns in safer areas are the best ways to avoid those interventions (MMA, 1998). In developed countries, the problem of floods should be moved from infrastructure responses to land planning measures.

Transparency: An effort should be made to present the risks assumed in any measures taken, and to explain clearly the objectives of those adopted. For example, risk maps could be made available to the general public.

Integrated actions: Only the integrated application of a package of measures, such as natural water retention, structural flood protection, implementation of preventive actions against risks, raising the awareness of the remaining flood risk, and individual preventive measures, can lead to improved protection against floods.

6.2. Level of desired protection

The definition of the levels of desired and/or tolerated protection against floods is a difficult task without a unique answer. On the one hand, the adoption of a very high level of protection implies large investments, while, on the other hand, it is not desirable to suffer frequent flood damage.

The level of the tolerated residual risk to society from flooding (after preventive measures) varies across EU countries (European Commission, 1998). For example, in the UK, indicative standards of protection are set according to the damage potential (or vulnerability) of the land at risk (typically a risk of one flood occurring in 100 years for urban areas) where this defence standard can be justified through cost–benefit analysis. In the Netherlands, however, there is a statutory standard of defence to be provided (typically one flood in 1 000 years to 1 250 years) with a statutory periodic review procedure. In Germany, the channelisation of main rivers was designed to protect important towns against floods for a return period (2) ranging between 50 and 100 years. At present, it is planned to give protection for a return period of 200 years on the River Rhine. On 22 January 1998, the 12th Conference of Rhine Ministers adopted the action plan on flood defence in Rotterdam. This action plan aimed at the improvement of precautionary flood protection will be implemented within the next 20 years. Agricultural areas are protected for a low return period flood, variable between 5 and 25 years depending on the local legislation (UN, 1989). In Hungary, protection dykes constructed on

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(2) Return period: frequency at which a flood of a certain size is expected.

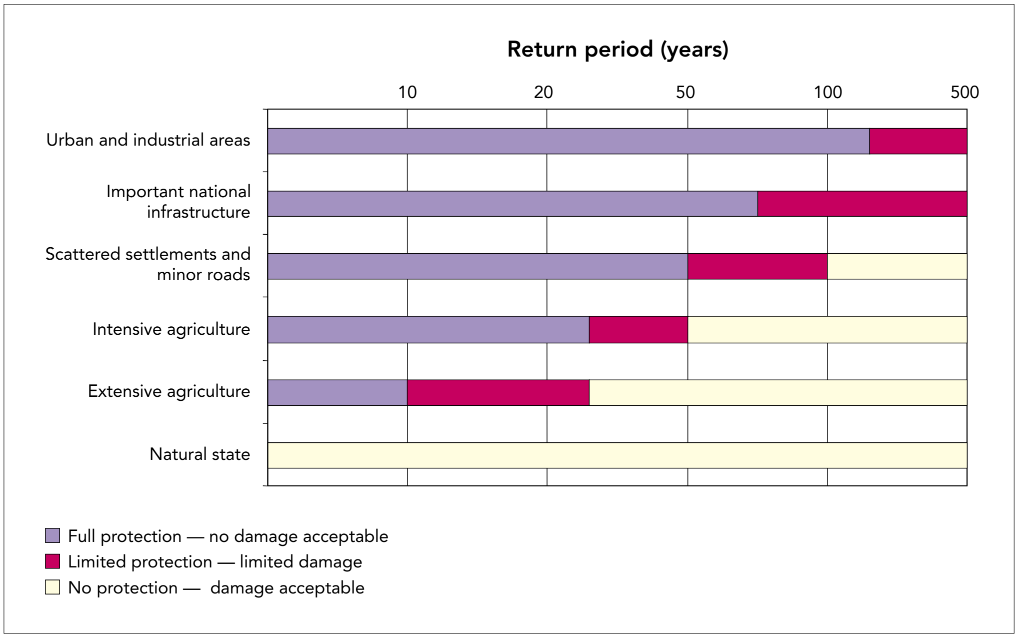
the Rivers Danube and Tisza have been designed for 100-year return period floods. In Finland, agricultural areas are protected against 20-year return period floods and residential areas against 50-year return period floods. A new recommendation from 1999 says that residential areas should be protected against 200-year return period floods both on inland shores and on the Baltic Sea shores.

A key European dimension to flood risk is that on transboundary rivers, such as the Rhine, the engineering of the river for flood protection, navigation, drainage, etc., in one country can affect the standard of flood defence in others.

There should be an agreed acceptable risk. Flood risk policies should relate to a certain level of tolerated damage (which has been collectively accepted) and to a certain level of desired protection (which has been collectively defined).

From the available information, there seems to be some degree of agreement on designing urban protection at between 50 and 200 years, and the protection of agricultural areas at a lower level. Figure 6.1 shows an example of the level of protection against floods as a function of the land use in the territory.

Example of level of protection against floods as a function of the land use Figure 6.1.



Source: Adapted from Saelthun and Tollan, 1996.

Two types of measures are mainly considered to achieve the level of protection desired or, at least, tolerated:

- structural measures for flood control;
- non-structural measures to control the impact of floods.

The choice is often dependent on the type of flood and the prevailing specific local circumstances.

6.3. Structural measures

Structural measures have been used for a long time to prevent floods and to mitigate their impacts, by controlling the development and propagation of floods, or by reducing the level of run-off or by protecting specific areas from flooding. Three main categories of structural measures can be distinguished:

- measures which reduce the peak run-off, such as flood control reservoirs, areas for controlled flooding, soil protection and afforestation;
- measures which reduce the level of flooding for a given run-off, such as river channelisation, protection dykes, protection and cleaning of riverbeds, etc.;
- measures which reduce the duration of flooding, such as road and railway culverts, bridges, etc.

Structural flood protection measures are expensive. The protection gained must justify the expense. This justification becomes ever more difficult, the higher the safety targets are set. At the same time, account must be taken of how the intervention will affect people living upstream and downstream.

6.3.1. Dams

Dams have largely been used as an efficient means of preventing flooding, either as pure flood protection reservoirs or in combination with other objectives. They normally produce relatively small impacts on a large stretch of the river, compared to river channelisation, and from an environmental point of view their impact is concentrated on a smaller part of the river ecosystem.

The effect of dam construction carried out since the beginning of the 20th century is widely seen across Europe, being, however, more evident in larger central European river basins than in Mediterranean rivers. The latter tend to be much shorter, carry more sediments and have higher ratios between peak discharges and average flows.

As an illustrative example, the IIBRBS (Institution interdépartementale des barrages réservoirs du bassin de la Seine) was set up after the severe flood of 1955 for the protection of the Paris region, and manages four sets of reservoirs upstream of Paris (Table 6.1 and Figure 6.2), which provide flood protection. The purpose of the reservoirs is to regulate the flow of the River Seine upstream of Paris. The highest flood flow observed in Paris was 2 500 m^3/s, while the mean annual discharge is 250 m^3/s (Nuñes Correia, 1998).

Table 6.1. **Dams managed by the IIBRBS**

Source: Nuñes Correia, 1998.

Dam	Completion date	Maximum capacity (million m^3)	Cities protected
Pannecière	1950	80	Auxerre, Sens, Montereau
Seine	1966	205	Troyes, Nogent-sur-Seine
Marne	1974	350	St Dizier, Vitry, Epernay, Meaux
Aube	1990	170	Nogent-sur-Seine

Figure 6.2. **Location of dams and reservoirs managed by the IIBRBS for the protection of Paris**

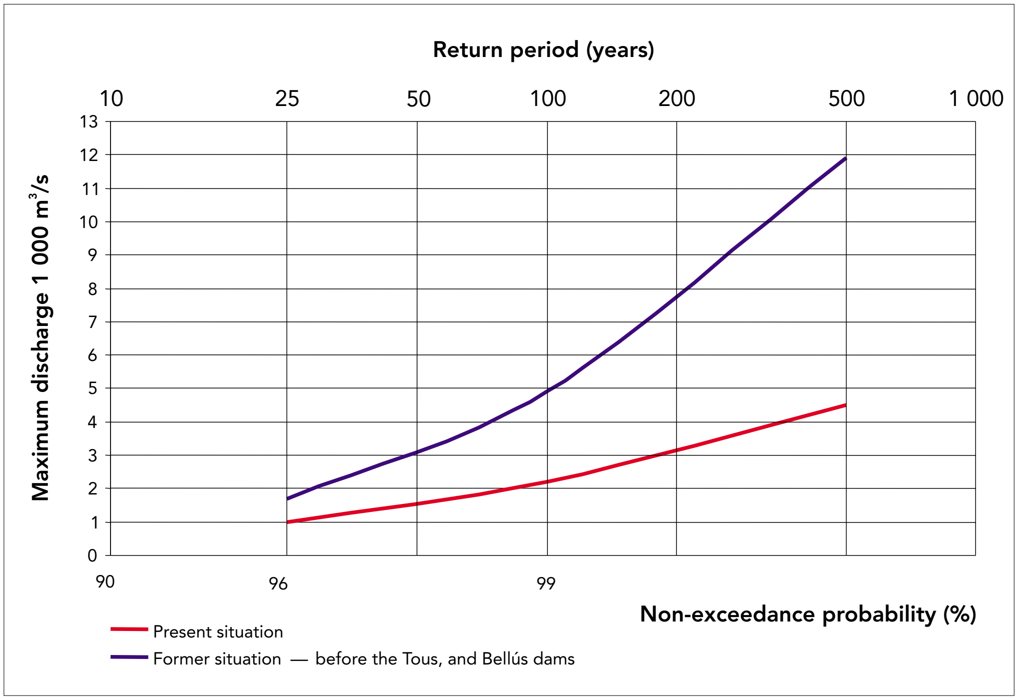
Source: Nuñes Correia, 1998.

In Spain, the Tous dam was constructed, and other different structural changes were made, in the basin of the River Júcar, following a catastrophic flood in October 1982 when rainfall was greater than 300 mm in four hours. Amongst the measures taken, three dams were constructed: the new Tous dam on the River Júcar, the Escalona dam on the River Escalona, and the Bellús dam on the River Albaida, one of the main tributaries of the River Júcar.

These structural works have contributed to a very important reduction in the frequency and magnitude of maximum peak discharges of the River Júcar, as illustrated in Figure 6.3.

In some northern flood-prone river basins, for example basins located in the west of Finland, several lakes have been regulated and multipurpose reservoirs have been constructed in cooperation with power companies. Normally, the lakes and reservoirs are for recreation and power production, but they are also an important part of flood protection schemes. The storage capacity is used to decrease flood peaks, resulting mainly from snow melting.

Effect of the new dams (Tous, Escalona and Bellús) on the maximum flow discharges of the River Júcar Figure 6.3.



Source: Estrela and Jiménez, 1999.

6.3.2. River channelisation and diversions

In many countries, river channelisation has traditionally been a means of protecting urban areas from flooding, although occasionally it has also been applied in agricultural areas. In Mediterranean rivers, it is frequently the only viable flood protection measure because of the difficulty in building dams on the steep slopes of coastal mountains.

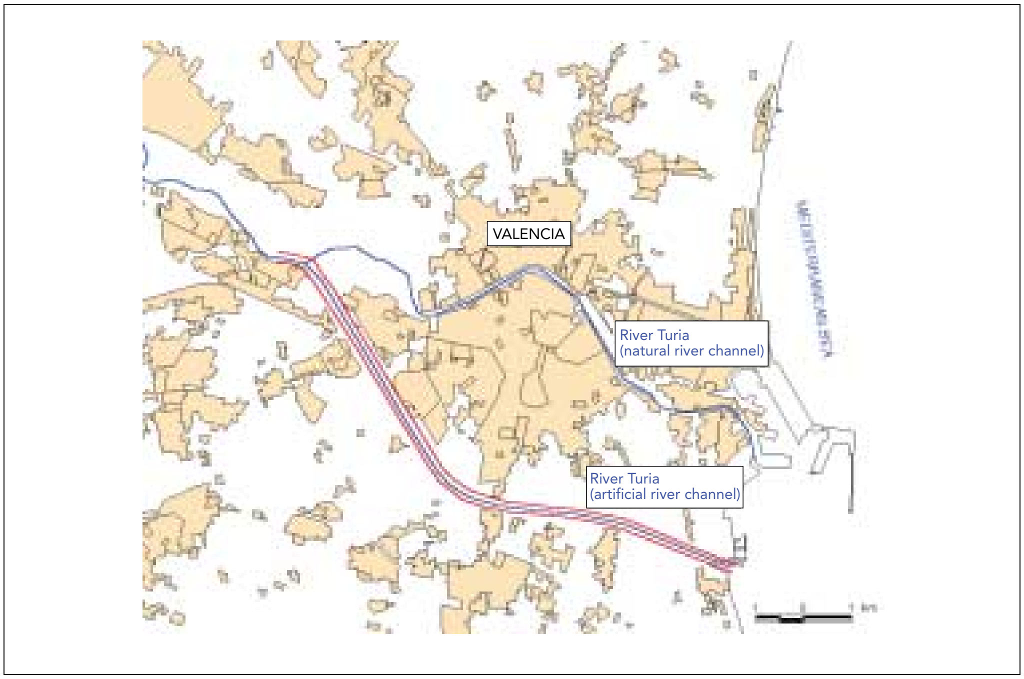
Another option is the diversion of peak discharges by the creation of artificial river channels or the removal of natural river meanders. This may lead to either an increase in flow velocity to prevent the flooding of adjacent areas or the re-routeing of water towards less vulnerable areas.

Figure 6.4 shows the artificial river channelisation made in Valencia, Spain. This artificial river channel diverts the waters of the River Turia towards the south of the town in an area where the land use is much less vulnerable than that around the natural river channel.

It has been shown that river channelisation and the loss of the natural water-retention capacity in river basins (loss of wetlands and natural vegetation etc.) can in some cases increase peak discharges significantly. For this reason, some measures, such as the removal of dykes and the creation of flood areas, have already been undertaken in some European countries (German Ministry of the Environment, 1996).

Figure 6.4. **River channelisation in the town of Valencia on the Mediterranean coast of Spain**

Source: CEDEX



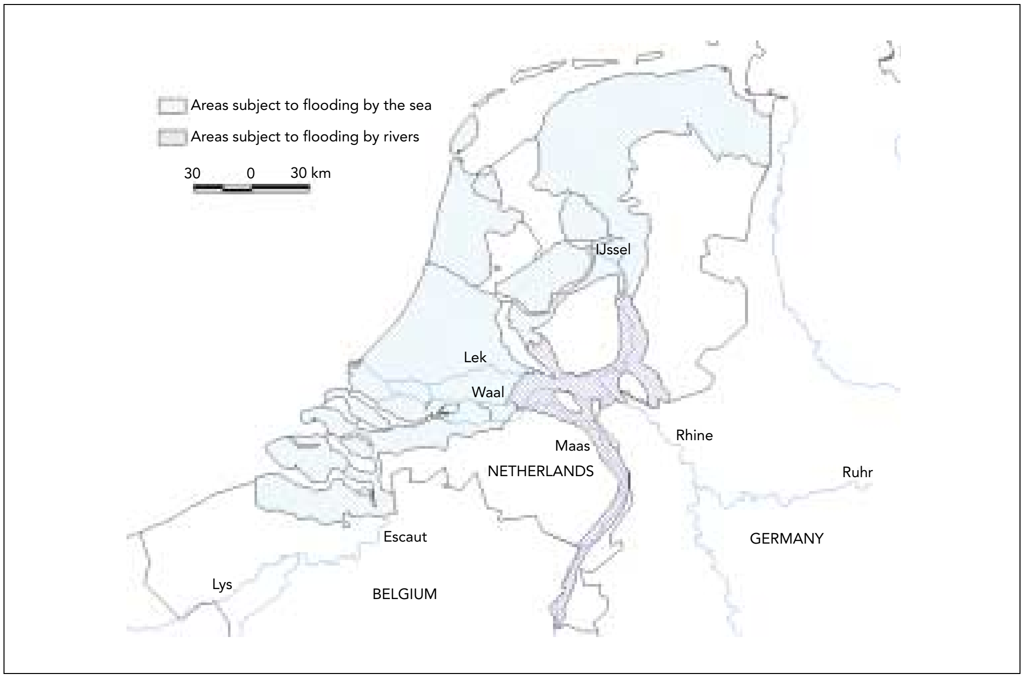
In the Finnish River Kyrönjoki, an artificial channel has been made to divert the waters from one of its main tributaries, the River Seinäjoki, to protect large agricultural flood areas located at the confluence of the two rivers. The diversion capacity is for floods with a return period of less than 20 years. The flood risk has been further reduced by improving the storage capacity of the Seinäjoki basin.

6.3.3. Protection dykes

Dykes were constructed in major river basins many centuries ago so that the flood plains could be used more effectively. However, when dykes are overtopped, the dyke material is eroded, leading to the dyke being breached in a very short time. The protected area behind the dyke is then quickly flooded. After every large-scale flood, the dykes are reinforced and made higher. It is essential that dykes be well maintained. It is a continuous task and, in the interest of safety, must not be neglected. But even if they are regularly maintained, basic repair is essential after a number of years of operation. The estimated cost for the maintenance of all the existing dykes on the River Rhine in Germany is over DEM 1 billion per year.

In Europe, there are many countries where the construction of dykes is essential for protection against floods. For example, if dykes had not been constructed in the Netherlands, approximately 60 % of the country would be permanently covered by water (Figure 6.5). Large parts of the areas surrounding the Rhine/Waal, Meuse/Maas and IYssel branches are protected by 570 km of dykes.

The effect of floods without dykes in the Netherlands Figure 6.5.



Source: Moll et al., 1996.

The areas protected against floods in Hungary are the most extensive in Europe. More than one fifth of the area of the country (occupied by 2.5 million people) is located on the flood plain. More than 4 000 km of dykes and water walls have been constructed to protect these areas.

In Finland, fields and residential areas have been protected by dykes along rivers, especially in coastal areas. Dykes have also been constructed on the shores of lakes and seas. The total length of dykes is 500 km and the protected area is 40 000 ha.

6.3.4. Artificial flooding areas

Another technique applied mainly in central Europe is the creation of artificial flooding areas and the opening of river dykes during floods. In a sense, this measure tends to recover some of the natural storage capacity of rivers that was present before channelisation.

6.3.5. Plant and habitat engineering

Vegetation planting and habitat engineering are used to stabilise river banks and to provide diverse habitats. Techniques include planting on bare soil and on steep rock embankments using stake-held roots, use of plant matter as a foundation, geotextile protection and plant anchorage.

6.4. Non-structural measures

Over recent decades, so-called non-structural measures have been gaining importance. These measures do not have such a direct effect on the flood discharge but try to reduce the damage caused by possible flood events by means of a management rather than a construction policy.

The application of non-structural measures in Europe is increasing in support of the structural measures already taken because it is apparent that the latter enhance the development of communities, which feel safer with these structures in place, close to rivers where flooding is, in any case, inevitable.

There are three groups of non-structural measures:

- measures which reduce the possible impact of a flood on existing structures, such as precautionary building, barricades, reinforcement of buildings, etc.;
- measures relating to land-use planning of potential flood plains, such as the identification of black spots, the definition of safety zones, the restriction of uncontrolled building, etc.;

- early warning systems and flood management measures, comprising, for example, real-time hydrological forecasting, hydraulic flood management rules, the development of flood evacuation and management plans.

6.4.1. Precautionary building

Precautionary building means adjusting modes of construction in areas susceptible to flooding so that they are able to cope with any flood which may arise.

An example would be the recommendation to construct buildings with at least two storeys, which would be less vulnerable to flood damage.

6.4.2. Flood-plain zoning, regulation and insurance

Flood-plain planning controls the use of land. This measure has not been widely used in Europe, in part due to the difficulty in coordinating the different administrations involved and also to the socioeconomic impacts resulting from its application.

The first step in flood-plain planning is to elaborate flood risk maps in which the main variables (water depth, flow velocity, flood duration, etc.) are defined, with the objective of informing the public about the flood risk derived from occupying a flood plain. Flood risk maps, corresponding to different flood magnitudes, are necessary for flood-plain planning. They provide a means of communicating the degree of flood risk to the authorities and the public, enabling an open debate on the most appropriate flood prevention and protection measures.

6.4.3. Forecasting and early warning systems

Forecasting and early warning systems are essential in order to reduce the risk to human life and to integrate the random nature of floods into policies.

In contrast to other elemental risks such as earthquakes, storms and hail, it is possible to estimate how floods are likely to develop over a particular period. It is, therefore, essential to increase the length of this period by improving forecasting techniques, and to use them more proactively than has been the case up to now.

Early warning systems incorporate tools to predict floods (Figure 6.6.) through the collection of relevant rainfall and river data, reservoir water levels and an assessment of that information. The approach to flood forecasting is dependent on catchment characteristics (Table 6.2.). As has already been mentioned, priority should be given to improve forecasting by means of applying well-tested models.

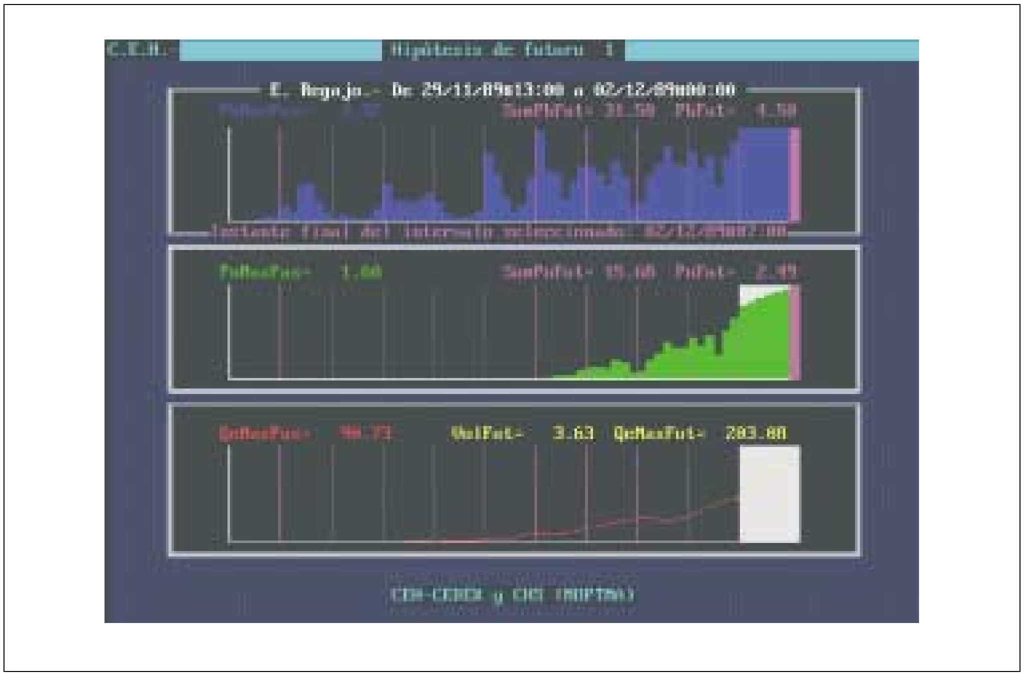
Table 6.2. **Examples of the forecasting approach as a function of the response time scale**

Source: Institute of Hydrology, 1984.

Response time scale	Forecasting approach
T_p (1) < 3 hours	Rainfall/run-off modelling plus quantitative precipitation forecast
3 < T_p < 9 hours	Rainfall/run-off modelling plus flood warning
T_p > 9 hours	Flood warning

(1) Time to peak discharge.

Flood forecasting CREM model used by river basin authorities in Spain Figure 6.6.



Source: CEDEX

6.5. Detailed examples of flood prevention and alleviation measures from selected European countries

Annex A to this report gives more detailed examples of flood prevention measures used across Europe. Cases from France, Germany, Hungary, Slovenia, Spain and Finland, and from the Rhine catchment are illustrated.

7. Conclusions

1. Flooding is the most common natural disaster in Europe and, in terms of economic damage, the most costly one. Flooding and its impact are often influenced by a combination of natural factors and human interference. The main areas prone to frequent floods include the Mediterranean coast, the dyked areas of the Netherlands, the Shannon callows in central Ireland, the north German coastal plains, the Rhine, Seine and Loire valleys, some coastal areas of Portugal, the Alpine valleys, the Po valley in Italy, and the Danube and Tisza valleys in Hungary.

2. Over a 25-year period (1971–95), 154 major floods occurred in Europe, and in 1996 alone there were 9 flooding events. The cost of flood damage in Europe between 1991 and 1995 has been estimated at EUR 99 billion.

3. Precipitation and catchment characteristics are the main driving forces leading to floods. Catchment characteristics such as vegetation and soil retention capacity and volume storage capacity of flood plains have the most influence in flooding.

4. In large and medium-sized river basins in northern and central Europe, wide-ranging and continuous precipitation is commonly the main factor in flood generation. Extremely intense precipitation over small catchments is the main cause of floods in the Mediterranean area. These short but extremely intense rainfall events usually occur at the end of summer and in autumn.

5. The main pressures that intensify floods and their impacts are climate change, land sealing, changes in the catchment and flood-plain land use, population growth, urbanisation and increasing settlement, roads and railways, and hydraulic engineering measures.

6. The effects of climate change on floods result from a change of precipitation patterns and increase in temperature. The former can lead to changes in the distribution, intensity and duration of extreme rainfall events and a higher frequency of heavy precipitation. A change of the vegetation structure in a catchment can affect soil properties and its retention capacity, and, as a consequence, the run-off.

7. Deforestation is a cause of increased flooding. However, the impact of forestry on peak flows depends on the different stages of forest growth, forest types, climatic zones, soil types and general land management practices. More research is needed to elucidate these dependencies.

8. Urbanisation increases the frequency of high-flow discharges and reduces the time to reach peak discharges because of soil sealing and increased run-off. The areas with the greatest increase in urbanisation tended to match those more prone to floods (e.g. the Mediterranean coast and Rhine catchment).

9. The construction of road and rail networks may contribute to the intensification of floods and their catastrophic effects. Linear infrastructure with insufficient drainage may divert flows to other areas, or increase water levels upstream, and, consequently, worsen the flood.

10. Hydraulic engineering works to lessen the impacts of floods in a particular zone can increase the impacts in another. For example, river channelisation to protect a town can speed up the propagation of the flood wave thus increasing flood risks downstream. River channelisation and reservoir construction may eliminate small or medium-sized flood events but cannot always hold back large floods.

11. Two main groups of meteorological events which cause floods can be distinguished in Europe. In large river basins, flooding is usually frontal and seasonal. Hydrographs are normally broad-based and peak discharges may last

a number of days. Flash floods are usually associated with isolated and localised very intense rainfall events occurring in small and medium-sized basins. Peak discharges are maintained only for hours or even minutes. Flash floods are common in Mediterranean rivers originating in mountains close to the sea.

12. The ratio between the ordinary and extraordinary discharge of a river varies enormously depending on the meteorological regime and on the basin characteristics, ranging from 2 to 1 000 for the most important rivers in Europe. The ratios are smaller in large basins in northern and central Europe and larger for small Mediterranean basins.

13. On average, the higher the water depth and the greater the flow velocity of a flood, the greater the damage. In addition, the high speed of onset or long flood duration exacerbates flood-related phenomena. Water quality associated with a flood also impacts on natural ecosystems and human life, for example sewer flooding in urban areas or large suspended and transported material along the river.

14. Measures taken in response to flooding are usually aimed at reducing flood damage. Some general points to be considered are as follows.

    - Coordination: Between central, regional and local administrations involved.
    - Realism: The risk of flooding can never be wholly eliminated by structural and non-structural measures. These are only responses to the reduction of risk.
    - Environmental considerations: Floods are important in the geomorphological and fluvial ecosystem development of rivers.
    - Prevention: Problems arising from floods should be prevented before future interventions are needed, such as the prevention of human occupation of flood plains and risk areas.
    - Transparency: This should come from the administrations involved in publishing assumed risks and measures taken.
    - Integrated actions: These are the only way to improved protection against floods.

15. Structural measures have been used for a long time to prevent floods and to mitigate their impacts. Three main categories of structural measures can be distinguished:

    - measures which reduce the peak run-off, such as flood control reservoirs, areas for controlled flooding, soil protection and afforestation;
    - measures which reduce the level of flooding for a given run-off, such as river channelisation, protection dykes, protection and cleaning of riverbeds;
    - measures which reduce the duration of flooding, such as road and railway culverts, and bridges.

16. The application of non-structural measures in Europe is increasing in support of the structural measures because they enhance the development of communities which are made safer with both measures in place, particularly in areas at higher risk of flooding. There are three groups of non-structural measures:

    - measures which reduce the possible impact of a flood on existing structures, such as precautionary building, barricades, reinforcement of buildings;
    - measures relating to land-use planning of potential flood plains, such as the identification of black spots, the definition of safety zones and the restriction of uncontrolled building;
    - early warning systems and flood management measures, comprising, for example, real-time hydrological forecasting, hydraulic flood management rules, the development of flood evacuation and management plans.

SECTION B: DROUGHTS
8. Driving forces

Drought results from a combination of meteorological, physical and human factors. The primary cause of any drought is a deficiency in rainfall and, in particular, the timing, distribution and intensity of this deficiency in relation to existing storage, demand and water use. Temperature and evapotranspiration may act in combination with rainfall to aggravate the severity and duration of the event. Both rainfall and temperature are in turn driven by the atmospheric circulation pattern. The main meteorological driving forces are therefore:

- atmospheric circulation patterns;
- rainfall deficiency;
- temperature and evapotranspiration.

Additional human and physical driving factors within a given area are:

- degree of natural catchment storage;
- socioeconomic factors, controlling the demand for water.

Some hydrological droughts are not due to natural causes and can be entirely man-made through overabstraction or mismanagement of the available resource. These are outside the scope of this study.

8.1. Atmospheric circulation patterns

The atmospheric circulation pattern, particularly the location and persistence of high-pressure centres, has a major influence on rainfall and temperature across Europe. High-pressure systems are characterised by low precipitation. Western Europe has a largely temperate climate grading towards continental conditions in the east and a Mediterranean-type climate in the south. The climate of northern and western Europe is normally dominated by a strong mid-latitude westerly airflow as warm tropical air meets cold Arctic air along the Polar front. The jet stream developed along this convergence zone controls the movement of high- and low-pressure systems. In northern Europe, the recurrent stream of westerlies and surface fronts is broken largely by the development of surface high-pressure systems which either block or deflect the jet stream and westerly airflow. A normal feature of the climate is the development in summer of low pressure over Iceland and a high-pressure cell over the Azores, which builds northwards and in the Mediterranean lasts from March/April to October. During winter, an anticyclone is normally located over Siberia.

A change in the position, duration and intensity of these blocking anticyclones leads to changes in the circulation pattern and hence rainfall and temperature anomalies. A common feature of European droughts is the persistence of high-pressure systems. For instance, in 1995–96, high pressure in northern Scandinavia persisted for over 16 months and caused the jet stream to be deflected north towards Iceland with a branch south into the Mediterranean. This resulted in dry north and north-easterly winds over northern Europe and westerlies over Spain and east into northern Africa and the Middle East. This gave rise to a persistent drought and heatwave in the summer of 1995 across northern Europe, the warmest October temperatures since records began, and a long cold winter. In contrast, the 1995–96 winter in Spain was wetter than normal with abnormal rainfall patterns extending as far as North Africa and the Middle East.

Other persistent droughts, such as the 1988–92 drought in northern Europe (Marsh et al., 1994), the 1990–95 drought in Spain and droughts in central Europe, have all been linked to the persistence of high-pressure blocking zones. In 1988–89, the high pressure in the Azores continued abnormally in strength and northerly position well into the winter, resulting in depressions being deflected north over Scotland and Scandinavia with dry conditions over the rest of Europe.

8.2. Rainfall deficiency

Rainfall deficiency is the primary driving factor for drought and directly influences soil moisture, groundwater recharge and river flow, although the hydrological system will delay and smooth the effects. Rainfall is the most widely used indicator of drought conditions, as long-term rainfall records exist at many stations across Europe (some date back to the 17th century) and are easily available.

Rainfall deficit is expressed as rainfall over a selected period, usually a month, a season, or a natural or hydrological year, compared with the long-term mean over a standard period. A problem with this simple index is the choice of the threshold below which the deficit must fall to identify the onset of the drought, but 75 % is commonly adopted. From December 1975 to July 1976, rainfall was less than 40 % of normal over all of northern and western France and the upper Rhine and Rhône basins, and below 50 % of normal over parts of the UK. Care must be taken in interpretation of percentage rainfall deficits as annual average rainfall varies widely across Europe, from below 50 mm in inland Spain to over 3 000 mm in mountainous west-coast regions.

The severity of a drought is not simply a function of the size of the rainfall deficit but depends on the timing of the deficit. Rainfall deficiencies in summer and winter can have different hydrological impacts depending on the preceding levels of storage. Thomsen (1993), in an analysis of winter (October–February) and summer (May–September) rainfall at selected European stations from 1750–1989, showed that both types of drought occur in Europe and can cover large areas and persist for several years. Winter rainfall is critical for maintaining soil moisture storage and groundwater recharge, as evaporation losses are low thus resulting in more recharge. This can result in serious supply implications as groundwater has traditionally provided a local and least cost source of drinking water in Europe. In contrast, a summer drought, which is often accompanied by high temperatures and high rates of evapotranspiration, has a more immediate impact on surface water resources. As an example, the rainfall deficits in the summer of 1995 were the most severe ever recorded in the UK. Yet in many regions reliant on groundwater, supplies were unaffected, other regions reliant on reservoir supplies, such as Yorkshire, had severe water shortages and water had to be imported by tanker.

Droughts at other times of the year, for example in the growing season, can have serious implications for agriculture. For example, low April to September rainfall in 1994 in Bulgaria resulted in a serious loss of yield in corn production. A drought in spring would result in inadequate reservoir filling and possible supply problems if followed by a dry summer.

The duration of the deficit highly affects the severity of a drought and its impact. Drought conditions can prevail for several years (e.g. the 1988–92 and 1990–95 droughts), due to a clustering of dry winters and/or summers. The 1988–92 drought resulted from a sequence of dry mild winters. Winter rainfall in 1988–89 in Copenhagen was the second lowest in 40 years and was followed by three successive winters below the average rainfall. Marsh et al. (1994) compared n-month minimum rainfall totals with 1988–92 minima for a selection of long European rainfall series. They found that during the 1988–92 drought in Madrid rainfall minima were severe over all durations from 12–48 months, while in other parts of Europe rainfall deficits were most severe over shorter durations. Norway was unaffected by the drought. The rainfall at Bergen, over all durations, was the highest or second highest this century.

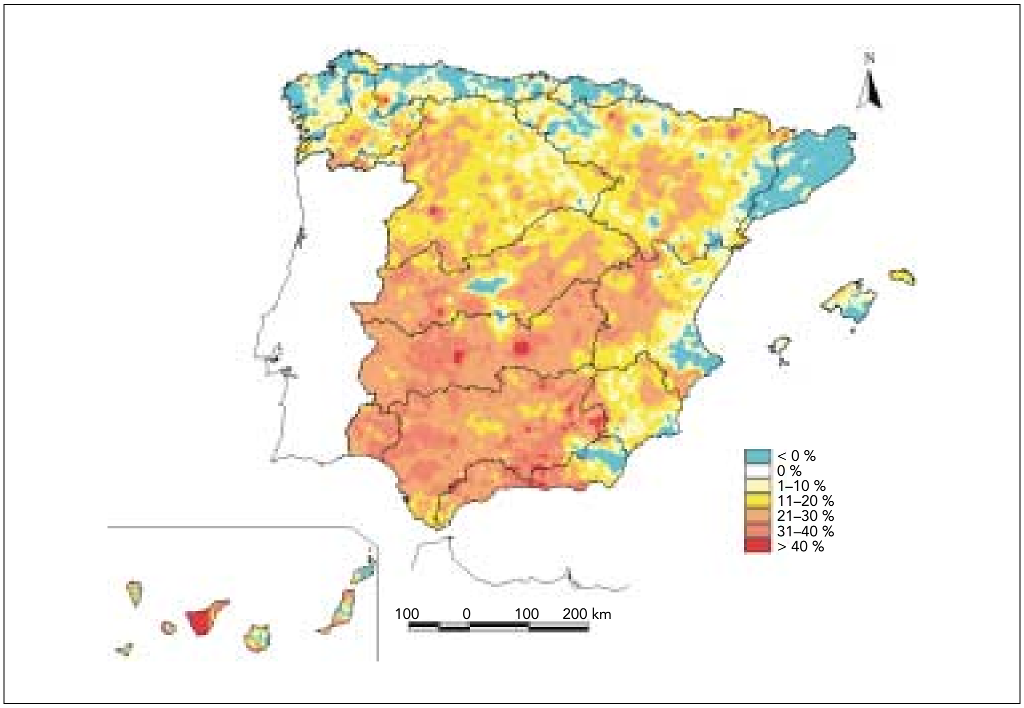
Batini and Benedini (1998) confirm that in Italy, as in other Mediterranean countries, it was not low rainfall in a single year which caused drought, but rather a sequence of years with very little precipitation. For Italy as a whole, the rainfall deficit in 1988, 1989 and 1990 was 21 %, 24 % and 16 % of annual rainfall, respectively, resulting in a total deficit for the 1988–90 period of 43 %. This situation was representative of the whole country, with particularly high deficits from September to March. Likewise, the 1992–95 drought in the Spanish area of Seville resulted from extremely low precipitation over four consecutive years.

The geographic extent of the rainfall deficit is also important in determining the severity and impacts of drought. Many recent European droughts have affected large areas. Rainfall deficiencies in the 1988–92 drought (Marsh et al., 1994) were experienced from Denmark southwards to the Mediterranean, although with large regional variations. Dijon (France) had only 50 % of average rainfall in the winter of 1988–89, and Madrid recorded just 20 % with no rain at all in some months. Similarly, the 1975–76 drought, at its height in August 1976, impacted on river flows across most of northern Europe. Despite the severity of the 1975–76 drought (one in 300-year return period in parts of the UK), rainfall totals for 1976 equalled the long-term average.

In Spain, the 1990–95 drought affected almost the entire territory as can be seen in Figure 8.1 in which the percentage deficit in precipitation during the drought is represented (3).

Figure 8.1. **Percentage deficit of precipitation in Spain during the 1990–95 drought**

Source: MMA, 1998.



Other droughts are more localised spatially. For instance, in 1990, the English lowlands experienced extreme rainfall deficiency and low river flows and groundwater levels, while statistics for the UK as a whole showed rainfall to be above average, with Scotland registering its wettest year on record.

8.3. Temperature

Temperature is an important driving force on drought in both summer and winter. Kašpárek and Novický (1997), using a physically based model to investigate the causal factors of drought in five hydrologically different catchments across Europe, found the annual pattern of air temperature to be a key factor in determining the type of drought in an area.

Winter droughts are caused by air temperature continuously below 0 °C. This results in precipitation being stored in the catchment in the form of snow and ice where it is unavailable to recharge rivers and aquifers until temperatures are raised and melting begins. These droughts receive less attention than summer droughts, but occur frequently in alpine and continental parts of Europe.

Summer droughts are normally associated with clear skies, sunshine, and high temperatures. This increases evapotranspiration to the extent that little or no summer rainfall is available for recharge. In 1976, evaporation rates in the UK were similar to those normally occurring in the Mediterranean. Many other recent European droughts have been of this type, including the 1992 drought in Bulgaria with air temperatures of 32–37 °C and the 1995 drought in the UK and Ireland with mean August temperatures in central England the second highest since 1659. Batini and Benedini (1998) note that the 1988–90 drought in Italy was characterised by an increase in average temperature, not only during the summer period. In the mountain regions of the Alps and Apennines, this resulted in less precipitation falling as snow and reduced snow storage.

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(3) ((mean precipitation during 1940–96 – mean precipitation during 1990–95)/mean precipitation during 1940–96) x 100.

Regional drought studies in Norway (Tallaksen and Hisdal, 1997), Germany (Demuth and Heinrich, 1997) and Poland (Gustard et al., 1997) differentiate between summer, winter and mixed (occurring at any time) droughts. An analysis of the spatial distribution of each type in Poland showed that winter droughts were most prevalent in the mountainous regions of southern Poland and the Tatra mountains, mixed droughts in upland basins, while lowland areas had the most severe droughts in summer. This clearly reflects temperature differences associated with altitude. Studies in Germany showed that, although winter droughts were more common, droughts in summer tended to be more severe with respect to duration.

High temperatures place ecosystems under additional stress at times of drought. Hot weather and dry soils will generate a heavy demand for water for irrigation, garden sprinkling, and domestic use for showers and recreational use. During a drought, competition for water between different users intensifies and conflicts arise between human demands and ecological needs. Restrictions on water use, such as hosepipe bans, and on abstractions by drought orders will tend to reduce this impact.

8.4. Natural catchment storage

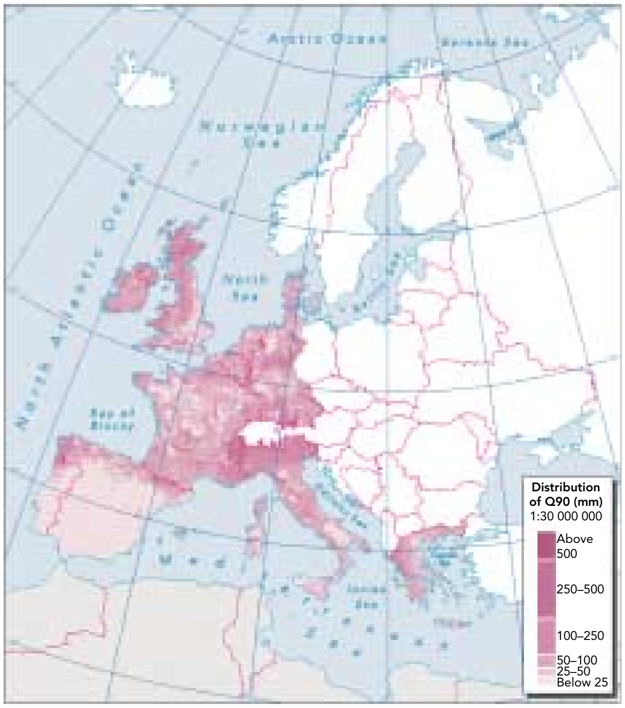
Water naturally stored in a catchment as soil moisture and in lakes, rivers, aquifers and wetlands helps determine the impact of any rainfall deficit. In times of sustained rainfall deficit (and no snowmelt), streamflow decreases until it consists entirely of groundwater flow. This baseflow has been shown to be strongly dependent on hydrogeology, with catchments of similar geology having a similar low-flow response. Relationships have been established in the UK between the low-flow characteristics of a river and a hydrological classification of soils (Gustard et al., 1992), while in Germany a hydrogeological index is used to estimate baseflow. Catchments with significant artificial storage in reservoirs or with groundwater recharge, river regulation or rivers with transboundary flows can withstand the impact of a drought for longer than an entirely natural catchment.

The preceding storage conditions are an important driving factor for drought. In the UK, the 1976 drought was severe in impact as a hot summer followed a dry winter. Similarly, the 1995 summer drought followed a dry spring. This resulted in few groundwater problems as aquifers had been replenished during a wet winter, but severe surface water supply problems as reservoirs were drawn down earlier than usual.

Even where there are sufficient long-term water resources in an area, the seasonal or inter-annual variation in the availability of the freshwater resource will, at times, induce problems of water stress. For water resource planners, decisions on water use are frequently based on the resource they can expect in periods of dry weather or low river flow. A valuable indicator of this is the 90th percentile flow (Q90), representing the freshwater resource which can be relied upon for an average of 328 days a year (i.e. 90 % of the time). Q90 may be used operationally to determine limits on the rates of abstraction from a river or for setting levels of minimum (ecological) flow. Figure 8.2. shows a Q90 general distribution in the EU-12 area. The values for the grid were calculated using observed flow data where available and regional characterisation methods for ungauged areas (Gustard et al., 1997).

Figure 8.2. **General distribution of Q90 (mm) across EU-12**

Source: EEA, 1998.



8.5. Socioeconomic factors controlling the demand for water

The most severe hydrological droughts do not always occur in areas with the lowest effective rainfall. They are driven in part by the demand for water. At the continental scale, Europe has abundant resources, but these are very unevenly distributed. Local demand, therefore, often exceeds local availability and problems of stress and overexploitation occur in areas of high population density and in regions where agricultural production is dependent on irrigation. Recent droughts have demonstrated how socioeconomic factors driving the demand for water have made even the wettest parts of Europe vulnerable to drought.

Changes in population, population distribution and density, and general standards of living are key factors influencing the demand for water resources. The population of the 15 EU Member States (EU-15) has increased by more than 72 million since 1960, with the highest rate of growth occurring between 1960 and 1980. The rate of increase stabilised in most countries from 1980 to 1990, but there are signs that it is increasing once more (EEA, 1999a). Despite apparently abundant water resources, more than half of the European countries can be classified as having low per capita water availability (EEA, 1998). This includes some north European countries (Denmark, Germany and the UK) with moderate rainfall but high population densities. The Czech Republic, Poland and Belgium all fall into the very low category. Further problems arise, since demand is not distributed evenly across the country but concentrated around the major urban centres. More than two thirds of the population of the European Union live in urban areas and in most countries the population in settlements of less than 2 000 inhabitants is decreasing. In France and Spain, there are clear trends of population migration, from inner parts of the country towards the Mediterranean coast in Spain, and to Paris and towards the south-east in France.

Agriculture, and particularly spray irrigation, is the most water-demanding sector in Mediterranean regions. It accounts for 80 % of total demand in Greece, more than 50 % in Italy, 68 % in Spain and 52 % in Portugal, compared with under 10 % in northern Europe. Whereas in northern and eastern Europe irrigation is used as a means to improve production, in southern Europe it is an essential part of agriculture.

The main uses of water in Europe are for public water supply (14 %), industry (10 %), agriculture (30 %), and cooling water (46 %) (EEA, 1999a). In two thirds of countries, 80 % of this demand is fulfilled by surface water abstractions with the remainder predominantly from groundwater. In individual countries, such as Denmark and Iceland, groundwater supplies over 90 % of demand. Until recently, resources have been developed to keep pace with increasing demand. Now the focus is on more efficient use of existing resources to improve and protect the water environment.

9. Pressures

In the aftermath of a major drought event, it is common to question whether droughts are becoming more frequent or more severe. Changes in land use, water demand, and climate will all influence the hydrological regime and alter the vulnerability of an area to drought. Although it is difficult to prove statistically, there is some evidence that these pressures may be increasing the impact and frequency of drought in parts of Europe. Some of the pressures, discussed individually below, include:

- climate change;
- water demand and water resource availability;
- land-use changes;
- environmental awareness.

9.1. Climate change

There is mounting evidence that the global climate is changing as a result of human activities. It is not possible to forecast precisely Europe's future climate, so estimates of the potential effect of climate change on hydrological flow regimes use feasible scenarios derived from output from global climate simulation models. In this way, the pressures on water resources can be assessed.

Recent research on climate change impacts in Europe, commissioned by the European Commission, using a consistent set of climate scenarios at the European, regional and catchment scale (Reynard et al., 1997) suggests that annual rainfall will increase in northern Europe by 2050, and decrease elsewhere, temperature will rise everywhere and potential evaporation will generally increase. The general tendency is, therefore, for an increase in the annual average run-off in northern Europe and a decrease in the south, with changes in the 30-year mean run-off by 2050 of over 30 % in some areas. The greatest sensitivity to change was found in the drier regions of southern and eastern Europe with low flows tending to become more extreme across most of Europe.

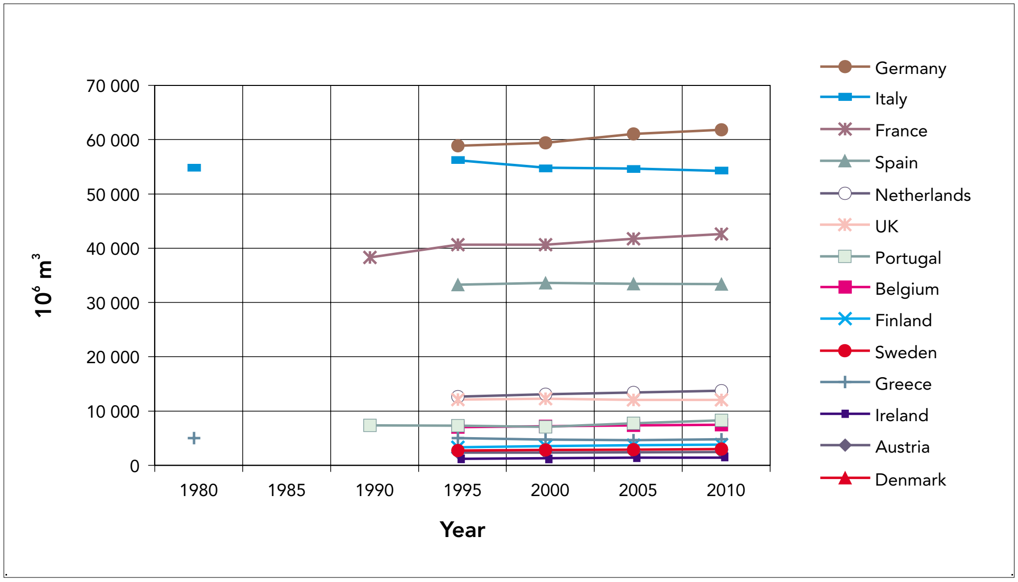
The results also suggest that over large areas of central and eastern Europe the seasonal distribution of run-off will also change. Higher temperatures will result in more winter precipitation falling as rain, rather than snow, with run-off occurring earlier in the year and a reduction/elimination of spring snowmelt peaks. In very cold parts of Europe, snowfall and hence snowmelt will be unchanged. In maritime regions, climate change tends to increase run-off variability with higher winter and lower summer flows.

The impact of climate change on the magnitude, duration and frequency of European droughts has not been studied directly, despite being of critical importance to European agriculture, water supply and industry. Studies, based on the Palmer drought severity index, suggest that the total area of Europe experiencing either extreme wet or dry conditions has increased notably in recent years. In Bulgaria, an increased number of dry spells and lower soil moisture levels have been noted during the last decade. Some researchers, for example the Medalus research group, also argue that rainfall across Europe has been progressively reducing since 1963 and the extended drought in Spain from 1990 to 1995 was only part of this long-term trend (Pearce, 1996). These observations have, however, yet to be proven statistically. Robson et al. (1998), for instance, found no statistically significant change in rainfall in long (40-year) time series of UK rainfall data.

9.2. Water demand and water resource availability

Recent assessments on trends and evolution of water demand in Europe have revealed that there is a clear stabilisation of demand. Abstractions from both surface water and groundwater sources rose steadily from 1980 to 1995, but recent demand management measures of reducing leakage, use of more water-efficient appliances, metering of supply and recycling are being more effective. Figure 9.1 shows the mentioned stabilising trend in total abstraction of surface waters and ground waters.

Evolution of total water abstracted in EU-15, 1980–2010 Figure 9.1.



Source: CEDEX, 1998c.

In northern Europe, it is public water supply that exerts the greatest pressure on water resources. Public water supply demand rose steadily from 1980 to 1990 in most countries driven by a rising population and increases in per capita consumption as a result of increased standards of living with increased use of water-using appliances. Since then, there are signs that this upward trend may be stabilising or even decreasing through the use of more water-efficient appliances, recycling, increased metering of domestic customers and reduced leakage. In southern Europe, the demand for irrigation exerts the greatest pressure on resources and at present the evolution of irrigated land is expected to increase, as is water demand for irrigation (CEDEX, 1998c).

This trend in demand is not that clear when looking into regional levels in countries. The seasonal water demand variability as well as the local variability in a country make some areas particularly vulnerable to the effects of a meteorological drought. These are the cases of demands not supplied because of water resource unavailability at local level and the pressure that tourism exerts in some regions.

Droughts can affect those areas where the annual demands are well supplied with the current water resource schemes but temporal pressures can unbalance the equilibrium between demand and supply in case of dry periods. This is the case of some regions in northern countries where a sharp decrease in water availability leads to restrictions on some uses, such as the bans on watering of gardens during the summer of 1995 in the UK. Some northern Spanish areas have difficulties and even restrictions on water supply in dry seasons because of a lack of regulation of their abundant natural resources.

Similar situations are found in Ireland, particularly in the Dublin area. Ireland has ample water to meet its demand for domestic, industrial and agricultural uses during droughts. However, the distribution of water resources in the country does not coincide with the population distribution and shortages do occur under extreme conditions, especially in the Dublin area. During the summers of 1975 and 1976, extreme droughts were experienced. In fact, the extreme drought occurring in 1976 in Ireland has become a standard against which to compare subsequent droughts.

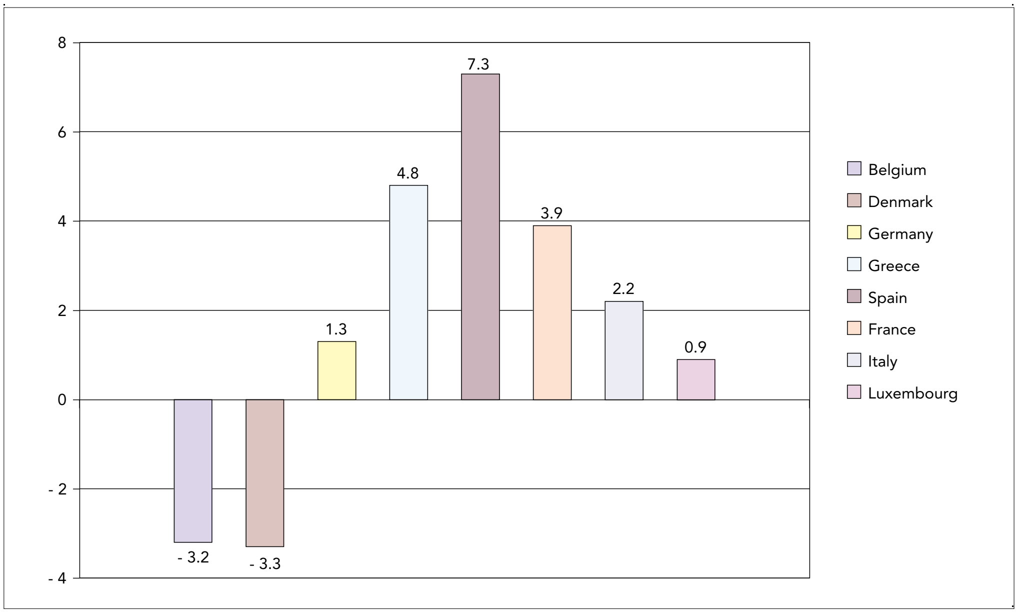
Tourism is undoubtedly the main pressure at local level, particularly in southern countries. According to Eurostat data, tourism makes an important contribution to the economies of most Mediterranean countries. Portugal, Spain, France and Greece recorded the highest international travel receipts in 1999 and an increasing trend is being recorded (see Figure 9.2). In terms of tourism activity, Portugal and Spain registered remarkable increases in 1998 of 8.8 and 7.3 % respectively, whereas the United Kingdom and Denmark showed a decrease (Eurostat, 1999).

The increase in water demand by tourism is an important pressure in the areas where it concentrates, particularly because these areas already have problems of water shortages. This is the case of the Mediterranean islands, the Canary Islands, and many coastal areas of southern countries.

Some of these areas face an added pressure from irrigation, which uses most of the water during the summer when the population doubles, thus enhancing the impact of a drought. There is expected to be an increase in irrigated area in southern Europe over the next 10 years (Figure 9.3.). Nevertheless, improved water resource management measures should lessen this pressure and not lead to the expected unsustainable increase. On the one hand, water restrictions in recent droughts make the public increasingly aware that water resources are not unlimited. On the other hand, the Food and Agriculture Organisation (FAO) has called for the promotion of water-saving irrigation techniques, such as drip irrigation. Scope also exists to improve the efficiency of irrigation systems and reduce leakage, and to cultivate more drought-resistant crops.

Figure 9.2. **Percentage change in nights spent in collective tourist accommodation between 1997 and 1998**

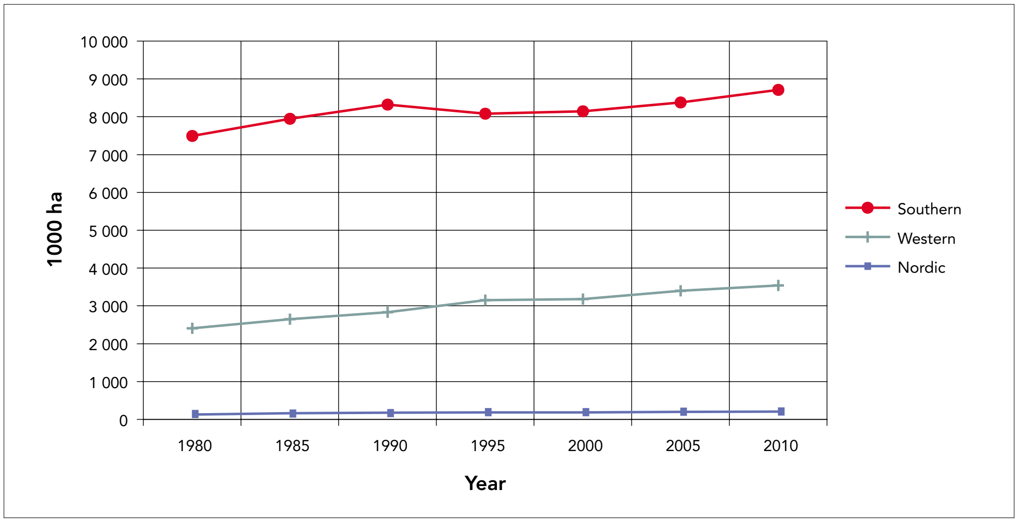
Source: Data from Eurostat, 1999.



NB: Collective tourist accommodation includes hotels and similar establishments, campsites, holiday dwellings and other collective accommodation, for example youth hostels and group accommodation.

Annual evolution of irrigated land in EU regions

Figure 9.3.



Source: Data from CEDEX, 1998c.

NB: Southern countries are Greece, Spain, Italy and Portugal; western countries are Austria, Belgium, Denmark, Germany, France, Ireland, Luxembourg, the Netherlands and the UK; Nordic countries are Finland and Sweden.

There are numerous examples in Europe where the hydrological impact of a meteorological drought has been exacerbated by overexploitation of resources. This has happened particularly with groundwater resources leading to a lowering of the groundwater table, drying-up of springs and upper river reaches, reduction in river flows, destruction of wetlands and, in coastal areas, saline intrusion. It is estimated that 6 % of the area of aquifers suitable for abstraction are currently overexploited (EEA, 1995). Similarly, in the Guadiana basin, Spain, and in Greece intensive abstraction of groundwater for irrigation, especially during long periods of low rainfall, has led to a dramatic and dangerous decline in groundwater levels.

Overexploited sites are also found in or near large urban and industrial centres. It has been estimated that over 60 % of European cities with more than 100 000 inhabitants are located in or near areas of overexploitation of groundwater.

9.3. Land-use changes

The type of land cover directly influences the storage conditions and hydrological response of a catchment and thus its vulnerability to drought. Land-use changes, such as afforestation, land clearance, land drainage, and agricultural intensification, may therefore alter the vulnerability of a region to drought.

Most studies of the effect of land use on run-off have concentrated on floods and mean flows. Although the impact on low flows and droughts is less, the land use will determine how much rainfall is lost through evapotranspiration and the balance between surface run-off and infiltration. The rate of evapotranspiration depends on climate, the type of crop, density of planting, physiology, and the extent to which there is water available through irrigation.

It has been estimated that about 42 % of the total land area in Europe is farmland (comprising 24 % arable, 16 % permanent crops, and 2 % grassland), 33 % forest and 1 % urban (EEA, 1995). The European Community, as part of its reform of the common agricultural policy, is committed to a policy of increasing afforestation. In Europe as a whole, forest cover has increased by about 10 % over the past 30 years and it is calculated that each decade 2 % of agricultural land is lost to urbanisation. Both these changes will have a significant effect on the hydrology of the local area. It is generally accepted that afforestation of a catchment reduces mean run-off, through increased interception and evapotranspiration. This leads to drier soils, reduced recharge and greater vulnerability to drought than if the land use was grass or a short crop. The precise impact on the stream hydrograph will, however, vary, depending on the type of tree, density of planting and land management practice.

Urbanisation has been shown to lead to increased surface run-off, reduced infiltration and reduced baseflows locally. In Mediterranean regions, the semi-arid climate coupled with poor land and crop management can lead to desertification. It is estimated that about 44 % of Spain is affected by some kind of soil erosion. Soil erosion reduces the capacity for infiltration and increases the vulnerability of a region to drought.

9.4. Environmental awareness

Recent droughts have increased public awareness of the fragility of water resources in many areas and of the environmental as well as the supply consequences of a drought. Maintenance of river ecology is now viewed as an acceptable use for water and many abstraction licences are only granted with restrictions to protect this use at times of drought. This and other measures, such as the release of compensation water from reservoirs, will reduce the pressure on river flows and maintain baseflows for longer periods.

10. State

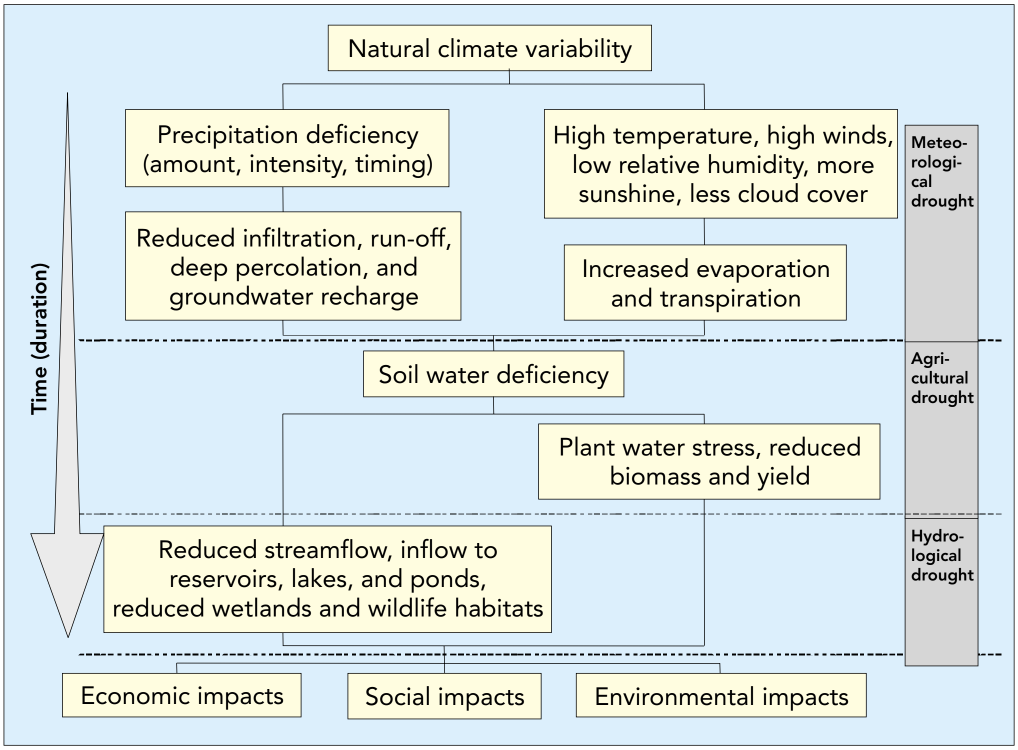
In general terms, a drought can be described as a 'decrease in water availability in a particular period over a particular area' (Beran and Rodier, 1985). A combination of meteorological factors, mainly precipitation and temperature, produces drought conditions. As yet, no universal and objective definition of a drought has been agreed.

Some of the main types of drought, characterised by a water deficiency and associated with a different level or type of impact, are listed below.

- **Meteorological:** Prolonged period with low rainfall. It is often defined by the number of days with less rainfall than some predetermined threshold.
- **Agricultural:** Insufficient soil moisture reserves to sustain crops or pasture.
- **Hydrological:** A shortage of water in rivers, lakes or aquifers.
- **Water resources:** Insufficient water to maintain supply. It can result entirely from a deficiency in rainfall, from poor resource management or from a combination of the two.

The different types grade into each other spatially as well as temporally as shown in Figure 10.1. Hydrological droughts are usually out of phase with the occurrence of meteorological and agricultural droughts. Sometimes, one type of drought can occur without the other types.

Gradation of drought severity and persistence Figure 10.1.



Source: National Drought Mitigation Center, USA, Drought Watch.

Some of the main drought events in Europe in the past 30 years are listed in Table 10.1. Although events differ in character and severity, the frequency of occurrence demonstrates that drought is a normal, recurrent feature of the European climate. It is not restricted to Mediterranean regions but can occur in high- as well as low-rainfall areas and in any season. In this respect, it differs from aridity, which is restricted to low-rainfall areas and is a permanent feature of the climate.

Table 10.1. **Summary of some recent drought events in Europe**

Source: Various, including Beran and Rodier, 1985.

Date	Region	Characteristics
1968	Hungary	Rainfall (February–July) 10 % of normal
1969	Denmark, Sweden, UK	Very dry summer; water rationing
1971	Most of Europe	Exceptionally dry year Lowest winter rainfall in Spain for 30 years Intensive summer drought in Poland Lowest levels on the Rhine since 1818
1972	USSR	Lowest river levels for 50–80 years
1973	Northern and eastern Europe	Very dry spring in eastern UK Low winter rain/snowfall in Austria, Germany and Czechoslovakia
1974	Scandinavia, France, the Netherlands, Austria	Dry spring in Norway (rainless April in some areas), Denmark, the Netherlands, Austria Nine-week spring drought in Sweden Low rainfall, April–August, in France
1975	Northern and eastern Europe	Dry winter in eastern Europe, low river levels February–August rainfall in Ireland and UK lowest this century Summer rainfall in Sweden lowest on record October rainfall in Belgium lowest on record
1976	Northern Europe (Scandinavia to France) Effects also spread to eastern Europe	Severe drought, especially in south-east England and northern France. Hot dry summer following a dry winter. Record rainfall deficits. Surface water and groundwater deficits UK: 16-month duration, unprecedented intensity. Very dry summer in Scotland, impact worst in south-east England with supply restrictions March–September rainfall in the Netherlands, Denmark, Norway, Sweden, Scotland and northern France lowest on record. Very low soil moisture deficits in Ireland
1976	UK	Dry summer from May to August Scotland (mid) — driest summer since 1868 Northern Ireland — seventh successive summer with below-average rainfall
1978	South-east UK	South-east England — driest autumn since 1752 Western France — driest October/November since records began
1984	Northern and eastern UK	Very dry spring and summer. Affected surface water sources only
1988–92	Most of Europe (southern England to Mediterranean and to Hungary)	Prolonged abnormal circulation pattern causing rainfall deficiency over wide geographic area interspersed with short wet periods. High summer temperatures and above-average winter temperatures with reduced snowfall. Timing and severity of maximum run-off deficit varied widely. Water resource problems across Europe exacerbated by increased demand, for example 3 000 rivers dried up in France in late 1990, irrigation restrictions. Severe summer drought in north-east Germany in 1992, with crop production reduced by 22 %
1990–95	Spain, Portugal	Prolonged drought across all of Spain except north coast. Most intense between September 1994 and August 1995 Hydroelectric stations forced to shut down
1992–93	Bulgaria, Hungary	Very hot dry summer in 1992. Continued with below-average rainfall to October 1993. Very low soil moisture in Bulgaria causing severe loss of agricultural production Worst drought in the USSR for 100 years
1995	Ireland and UK Norway, Sweden	Hot dry summer and autumn. Dry soil. Impact on surface water sources, not groundwater Low temperatures and little winter snow in Nordic countries
1996	Bulgaria	Hot dry summer across whole country
1997	Germany, France, Ireland, Portugal, UK	Very low rainfall
1999	Finland	Hot dry summer in southern Finland. Very low water levels both in rivers and groundwater formations

Some of the above drought events are characterised in the following maps by showing the percentage deficit in precipitation during the drought period (4). Negative percentages indicate a surplus of rainfall in the considered period.

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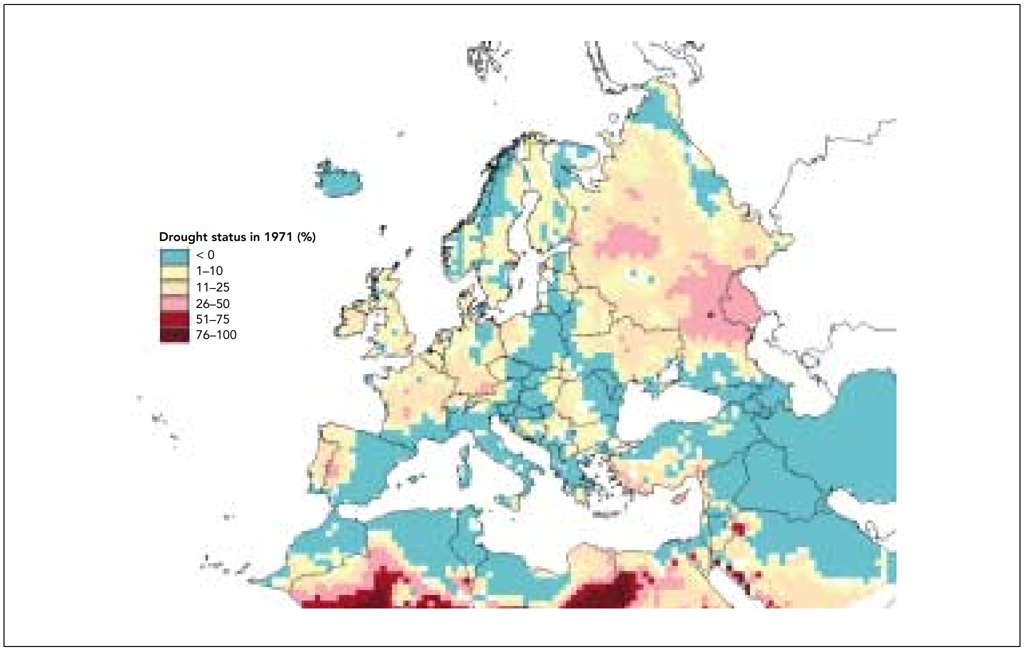
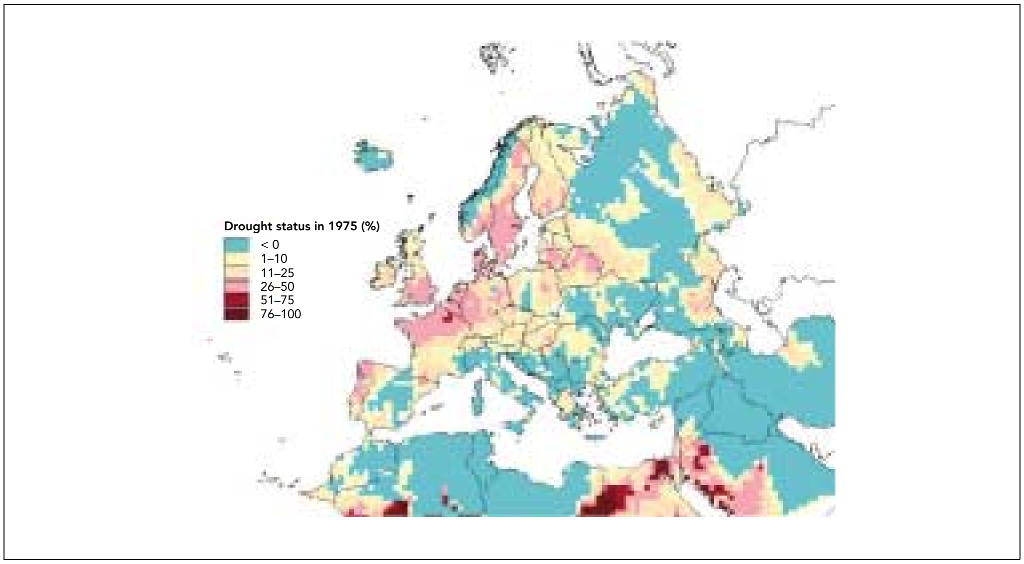
(4) (mean precipitation during 1900–96 — mean precipitation during period of drought)/mean precipitation during period of drought.

1971 percentage deficit in precipitation across Europe Figure 10.2.



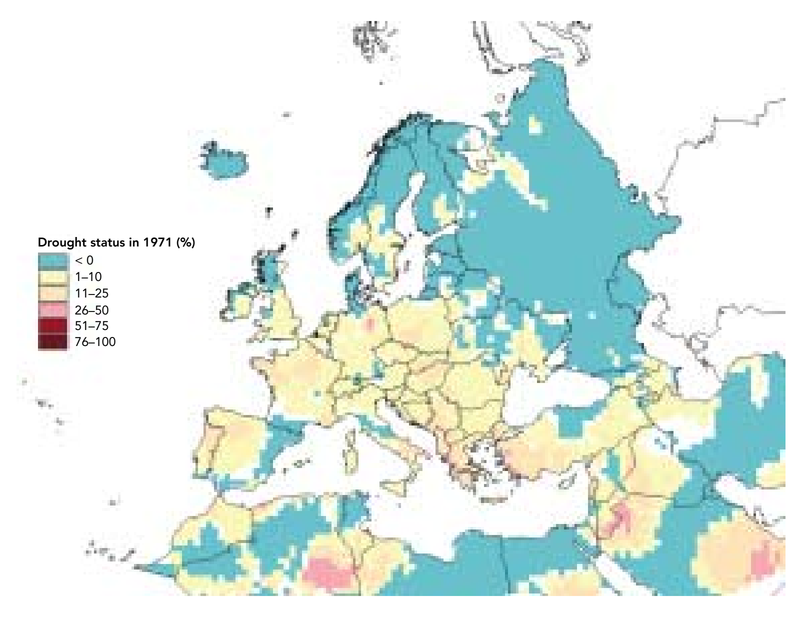
Source: CEDEX with data from the Climatic Research Unit (CRU, 1998).

1975 percentage deficit in precipitation across Europe Figure 10.3.



Source: CEDEX with data from the Climatic Research Unit (CRU, 1998).

Figure 10.4. **1988–92 percentage deficit in precipitation across Europe**



Source: CEDEX with data from the Climatic Research Unit (CRU, 1998).

11. Impacts

The low-flow regime of a river controls a wide range of natural and water resource issues. Low flows are critical for maintaining surface water abstractions for industrial, domestic and agricultural water supply, as well as for dilution of effluents, navigation, hydropower production and recreation. Low flows must also provide sufficient freshwater habitats for a wide range of flora and fauna. During a drought, the low-flow regime will be placed under even greater pressure with competition for water between different users. This will often result in abstractions for industry, agriculture or public supply being restricted or curtailed (a water resources drought) with attendant social and economic consequences and a deterioration, often severe and long-term, in the river ecology (an ecological drought). In fact, all parts of Europe experience droughts, and all countries are exposed to different impacts.

Some of the main impacts of droughts in Europe are described in the following sections.

11.1. Impacts on rivers, reservoirs and aquifers — water supply problems

When water resources experience a dramatic depletion, the main priority is drinking water supply of acceptable quality (see Section 12). River water entering a reservoir under low-flow conditions tends to be of lower quality because dilution of wastewater in the river is less than under normal-flow conditions. The main impact of a drought is the difficulty in facing urban demands under such circumstances. Poor water quality also affects agriculture, which is usually considered as the second priority after human supply.

The year 1976 was extremely dry in north-western Europe. The river flow of the Rhine and Meuse in the months April–September stayed for most of the time below the 10 % level in the flow frequency curve. In addition, the very low rainfall and high evaporation in the summer months generated a large demand for freshwater. From the climatological point of view, the return period of this event is 300 years. The flow in the Rhine in 1921 was lower than in 1976, whereas the flow in the Meuse in 1976 was the lowest of the century. The resulting decrease in water quality in the Meuse was greater than in the River Rhine. However, in general, the water quality was not a decisive factor in the operation of water intakes (e.g. closure), even though damage and production losses (because of salinity) in the greenhouse agricultural sector were reported. Saline water intrusion caused severe problems in specific areas.

At present, there are specific interactions between the impacts of a drought and some of the measures taken to alleviate them. This is particularly so because the warning systems that could prevent drought situations are lacking. The need for a quick response in order to keep water supply at a certain quantity and quality level means that impacts and some measures are interrelated.

In terms of supply-side management, water supply problems are often alleviated by adequate groundwater and reservoir storage. Water tanker supply is often used. In terms of demand-side management, bans on some uses and water cuts during the day are the most straightforward measures for combating water shortages. Some other emergency measures are taken if the impact of the drought continues over a long time or seriously affects the population's living standards. These measures mainly consist of water transfers from basins that do not experience drought at that moment, or, at least, not with the same intensity.

The following paragraphs describe the impacts on water supply of three cases of drought and the measures undertaken in each situation.

In France during the 1976 drought at the end of May, the Ministry of the Environment drew up a note addressed to local authorities, confirming the drought and setting out the problems that might arise and what actions should be taken. In June, the management committee of the Seine and Marne reservoirs, which are intended, in particular, to supply water to Paris, decided on an immediate water release to ensure water supplies and defined the reserves required to meet a prolonged shortage. Statutory measures in France were taken principally at departmental and commune level. They entail limiting usage apart from drinking water, which was considered to be a priority requirement, limiting if not banning certain uses and preventing pollution by requesting industry to limit discharges of wastewater. Emergency measures aimed at maintaining and ensuring a minimum water distribution service. They consisted of cutting off supply for several hours a day, setting up a tanker supply service run by the emergency services or certain army units, and interconnecting distribution networks.

It is well known from historical documents that Athens has suffered from water shortage since ancient times. In modern times, water demand has almost doubled every 10 years, except for the World War II period. Insufficiency of the local water resources inevitably led to the development and utilisation of remote water resources through the construction of the Iliki aqueduct in 1968 in the eastern Sterea Hellas water district and subsequently the Mornos reservoir and aqueduct in the western Sterea Hellas water district. The construction of all these works was always preceded by a period of crisis with a high risk of severe water shortage. In the severe drought that Greece suffered during the period 1987–88 to 1992–93, the mean annual water yield of the system was as low as 50 % of the normal yield. The six-year drought period included the two extremely dry years 1989–90 and 1991–92 whose yield was the lowest recorded in the century. The severe drought together with the prior overexploitation of the Mornos reservoir led the system to a particularly critical state that had to be remedied only by additional measures both in demand and resources.

In Italy during the 1989 drought, the priority given to drinking water use allowed the demand to be met with no significant shortfall. An exception to this was some urban agglomerations in the south and the larger islands, where the chronic scarcity was greatly aggravated. In some places, hit by unexpected shortage, the ultimate solution was to rely on water transported by tankers. This last measure was also taken in several small villages in Spain during the 1990–95 drought, whereas big cities in the south of the country suffered restrictions up to 10 hours a day.

Some aquifers, already highly depleted by urban or agricultural uses, experience an unusual lowering of the water table during droughts. The depletion can last long after the dry period is over, as after the 1989 drought in the northern flatlands of Italy. During the dry period, there is often an increase in average summer and other seasonal temperatures with the simultaneous reduction of the annual precipitation. In the Alpine and Apennine highlands, this contributed to a decrease in snowfall and its persistence on the ground in the 1989 drought. In central and southern regions, the yield of many springs greatly diminished.

11.2. Loss of crops and loss of livestock

Under drought conditions, animal water requirements cannot always be satisfied and stock must be slaughtered, as happened in France during the 1976 drought, particularly in the regions of Brittany and Normandy. During this drought, the transport of straw was organised with the assistance of the army (up to 15 000 men/day mobilised to transport 900 000 tonnes of forage) and milk yield was noticeably reduced (by between 15 and 25 %).

Agriculture is severely hit by droughts. All crops, whether irrigated or not, suffer a considerable reduction in yield. In particular, irrigation is dramatically affected due to the banning of it in some areas. During the 1989 drought in Italy, only a few plots out of the thousands of hectares could be irrigated in several districts of Sicily and Sardinia. Bans on irrigation from 1993 to 1995 affected half a million hectares in the Guadalquivir basin during the 1990–95 drought in Spain.

11.3. Water quality deterioration — impacts on ecosystems

Water quality deterioration affects not only drinking water supply, but also the natural ecosystems related to the water bodies affected as well as agricultural and livestock production. Abstraction from water bodies is particularly intensive in the absence of other resources. Low flow in a river means poor dilution of the discharged pollutants, and thus a risk of harming aquatic life. Sometimes, it can even pose a risk to human health. During the summer of 1989 (5), major blooms of toxic cyanobacteria were

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(5) As Table 10.1. shows, a drought was recorded in most of Europe in the years 1988–92.

reported in many reservoirs in the UK, Finland, Norway and Sweden (EEA, 1999b). This kind of impact can be very serious and persist long after the bloom has passed.

Aquatic life needs oxygen and other nutrients for its development. Some of these needs are altered during dry periods. For instance, maximum phosphorus concentration in rivers is expected during low-flow periods (EEA, 1999b). In Ireland, the Electricity Supply Board (ESB) is required to maintain minimum flows for some dam sites, for example the Inniscarra dam. The development of an algal bloom in the Inniscarra dam led to oxygen deficiencies in the water on the River Lee during low-flow periods. The ESB monitors dissolved oxygen in the water downstream of the dam and takes ameliorating actions, such as shutting down the turbines and releasing water over the spillway to ensure adequate dissolved oxygen for fish life. Provision is also made in the regulations for flushes of water from reservoirs to dilute waters downstream in the case of a serious pollution incident.

Thermal pollution must be taken into account in dry periods. When low-flow periods coincide with high air temperatures, water temperature may increase to a level for which the return flow to the river from the cooling water systems of the power plants is not acceptable for aquatic life. High-temperature water may endanger the aquatic environment.

11.4. Economic impacts of past drought events in European countries

In France, in the winter of 1975, the snowfall was insufficient to fill the large dams between March and September. In February 1976, measures were taken to use thermoelectric power stations to preserve minimum water levels in the reservoirs. During the drought, an additional 15 billion kWh were produced by thermoelectric power stations or bought from abroad (in particular from Spain and Italy). Despite this, the French Electricity Board had to reduce the distribution voltage by 5 %.

The drought in Italy in the period 1988–90 was evenly distributed over the entire territory and was particularly severe in the September to March periods. The flow recorded at the mouth of the Po was as low as 900 m^3/s on many occasions, i.e. close to the minimum values recorded. Low precipitation also had a strong effect on the Alpine lakes Como and Maggiore with levels lowered by 4.5 m and 7.5 m, respectively, and both reached their minimum recorded levels in 1989 and 1990. Lake Garda reached its minimum level in 1990 after a lowering of 2.2 m. Production of hydroelectricity was badly affected by the drought. Generating plants equipped with reservoirs were not only unable to store the required amount of water, but also suffered a reduction of power as a result of the lower head. Figures produced by the Italian State Electricity Board assessed the productivity of the entire national hydroelectric system, in terms of energy, as never exceeding 70 % of the total capacity during 1988. In northern Italy, the productivity was as low as 18 % during the spring. In such conditions, even pumped storage, characteristic of the most technologically advanced plants, was able to make only a very small contribution. The smallest plants suffered from a shortage of water and low levels in rivers, as did thermal plants, because of the unavailability of cooling water.

The drought of the early 1990s in the southern part of Spain had extremely severe consequences on the local community and economy. In the area of Seville, precipitation during the period 1992–95 decreased to around 70 % of the average (551 mm), with run-off during this period being less than 30 % of the normal volume. The drought of 1992–95 was especially severe, not only in terms of deviation of average annual rainfall and run-off, but also with regard to its duration. The fact that precipitation was extremely low during four consecutive years greatly affected the city's water management which relies heavily on storage in inter-annual reservoirs. A factor that aggravated the impact of the drought was the relatively high level of public water supply in 1991, with a per capita use of 400 l/person/day. The World Exposition of 1992, which was held in Seville, also affected water demand, although the water used in 1992 was less than 1991, thanks to public campaigns for water conservation. Nonetheless, due to low precipitation, the reserves of the municipal water company continuously decreased throughout 1992 and, by the beginning of 1993, reached the minimum level considered vital for secure supply. During the years 1992 and 1993, the authorities of Seville issued a series of decrees to promote water saving, ranging from calls for voluntary restrictions to supply cuts during the night, some lasting up to 12 hours/day over several months. As a result, savings of up to 35 % of normal supply were achieved. In addition, a variety of emergency measures were adopted to develop additional sources of supply: opening pump stations and river derivations, establishing the necessary links to incorporate additional water into the network, and introducing devices to purify water of inferior quality. The water supply situation in Seville had slightly improved by the end of 1993, thanks to higher precipitation, and emergency measures were lifted in November 1993. However, during the second half of 1994, the reserves again diminished and, in 1995, further emergency measures and supply cuts had to be imposed. The drought ended in the winter of 1995–96 when finally all restrictions were lifted.

In Nordic countries, the consequences of droughts are not as severe as they are in many south European countries. For example, Finland has, under any circumstances, enough water to meet the needs for water supply. Dry spells can, however, cause some harm: a dry summer means problems for well owners, crop cultivation, cattle raising and even the water supply for industry. In a normal summer period, some 300–400 mm of water evaporate in southern and central Finland, and 400–500 mm in a hot summer. The latter value is about twice the precipitation of a normal summer. This means that, especially in dry summers, creeks may dry up, lake water levels fall sometimes by more than 1 m, and wells may dry up, especially in moraine-type soils. Another low-water period occurs in late winter, in March–April. During winter, the watercourses and the groundwater cannot store more water, as the snow accumulates on the surface of the ground. The dry spells have thus occurred predominantly in late summer. On the other hand, as recently as 1996, the waters were unusually low in southern and western Finland after a dry autumn and a long cold winter. The most important dry spells of this century in Finland occurred in the years 1940–42. In the Kallavesi and Päijanne lakes, the water level fell almost 1 m below the mean, while the Saimaa lake fell by 1.4 m. The rivers of Ostrobothnia had very little water in August 1968. In the 1990s, there were several hot and dry summers when the soil dried up and water levels were very low in many parts of Finland.

As Norwegian electricity production is almost completely based on hydropower, droughts have serious implications for electricity production and supply. A dry period lasting a year will reduce national electricity production, boost prices, increase energy import and, in extreme situations, necessitate emergency rationing situations, as the import potential is limited by transmission line capacity.

The drought of 1995–96 illustrates the special characteristics and impacts of droughts on Nordic hydrological regimes. A dry autumn caused low groundwater levels and in some places lower-than-normal reservoir levels at the start of the winter (normally groundwater and regulation reservoirs would be filled at this time). Severe and deep frost caused large problems with water supply in small surface water systems and single wells that typically supply farms and small communities. Many farms lost their water supply and farms with milk or meat production had problems in supplying their stock with drinking water. The low winter precipitation (a characteristic of a cold winter and also a cause of deep frost due to poor snow insulation) gave rise to small spring inflows to reservoirs. During the drought, Norway imported electricity at full transmission line capacity for most of the year and electricity prices increased.

12. Policy responses

Drought prevention relies on both technical and economic measures and requires a thorough inventory of available surface water and underground water resources. It also entails adopting technologies and management policies capable of making an appreciable impact on the whole economic system in which the water resource is located. In addition, to technical and economic measures, the willingness of the people involved is of fundamental importance, particularly to reduce water consumption.

12.1. Early warning systems (drought alert indicators)

In most cases, droughts are identified too late for emergency measures to be effective. Clear and consistent criteria for drought identification ought to be established, which would allow, in a crisis situation, adequate responses in the management of water resources to be implemented.

A wide variety of methods have been developed to define and monitor drought events. These are normally applied to the selected drought variable at a single station. The threshold (or truncation) method is now being used increasingly to express a drought in terms of its duration and severity (Institute of Hydrology, 1999). Other methods include calculating a cumulative precipitation deficit for the drought period or the use of physically based models (ICID, 1998).

The threshold method considers a time series (X_t) of a hydro-meteorological variable and a selected threshold value (y). A negative run (or deficit) occurs when the value of the variable is consecutively less than the threshold during one or more time intervals. Similarly, a positive run (or surplus) occurs when the value is consecutively greater than the threshold. A negative run can be determined by its length (l), its sum (d) or its intensity which are random variables, and, therefore, several runs result in a time series of a given threshold and sample size. The mean, the standard deviation and the maximum run length and run sum are important characteristics, describing the runs of a given time series and can be used to characterise droughts and for comparison purposes (Figure 12.1.).

As has been pointed in Section 9.2, a problem is the choice of the threshold below which the deficit must fall to identify the onset of the drought. In fact, the choice of a consistent threshold level may need to take account of multi-year droughts (longer than 365 days) and zero-drought years (flow never falls below the threshold level in a year), and to distinguish between winter and summer droughts (Institute of Hydrology, 1999).

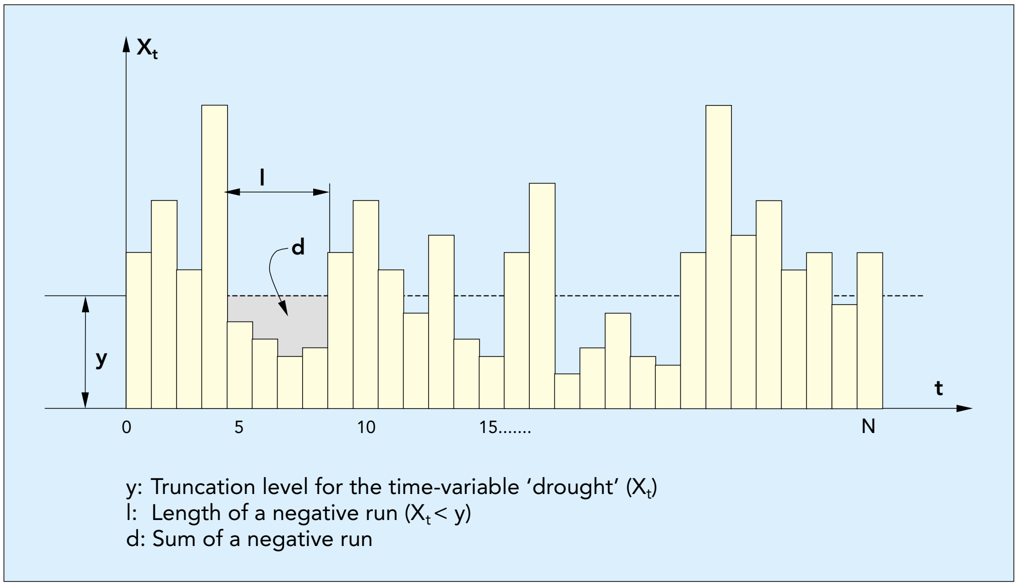
Other problems arise related to the identification of prolonged droughts. During a long dry period, flows may exceed the threshold for a short period effectively dividing a drought into a number of smaller droughts that, in fact, are mutually dependent. In this case, the moving average procedure can be applied to the time series to define an independent sequence of droughts.

A deficit in precipitation is commonly used as a measure of drought severity as long-term precipitation data are often widely available and as all other drought characteristics are, to a different degree, dependent on the temporal and spatial deficit in precipitation. Effective rainfall would be a more appropriate indicator but requires estimates of actual evaporation. Evapotranspiration has not been widely used as a drought severity indicator due to the lack of readily available data.

The threshold method has formed the basis for regional characterisation and identification of droughts from daily-recorded streamflow hydrographs in Norway (Tallaksen and Hisdal, 1997), Germany, and central Europe (Gustard and Cole, 1997). Traditional definitions use minimum annual n-day average discharge, with n often taken as seven days (Gustard et al., 1992).

Figure 12.1. **Threshold methodology**

Source: Institute of Hydrology (1999).



y: Truncation level for the time-variable 'drought' (X_t)
l: Length of a negative run ($X_t < y$)
d: Sum of a negative run

The Rivers Rhine and Meuse are key sources of water supply for most of the Netherlands in the dry season. Periods of prolonged low flow induce restrictions on water use and eventually lead to economic damage. The most critical year in this respect was 1976, when the low-flow situation lasted for six months, and substantial damages were recorded. A low-flow situation also occurred in 1991, but for a short period only. Low-flow bulletins are issued when river flows drop below specific levels. For the Rhine, a low-flow bulletin is issued if during the months of May to September the daily average flow at Lobith falls below 1 400 m^3/s (1 May) to 1 000 m^3/s (1 September). For the Meuse, at Maastricht a low-flow situation occurs when the flow averaged over three days drops below 25 m^3/s. The low-flow bulletin contains information on water intake values, water levels and chloride concentrations at key locations. This information is relevant for regional water managers. They eventually should decide on intakes or flushing operations for agriculture and natural conservation, and the operation of structures for navigation and salinity control. Also, the navigation sector needs this information for the optimal use of transport capacity with respect to available navigable depth. Drinking water companies use the low-flow bulletins to decide on water intakes and the use of storage facilities.

The most widely used drought indices allow a drought to be identified, but, in fact, do not forecast it. In some way, they consider the drought effects, but not their origins. Somehow, a notable breakthrough has been made in recent years as regards the development of general circulation models and the improvement in meteorological data analysis.

One observed fact is that the predominance of anticyclonic (or cyclonic) conditions within one region is usually compensated by the development of opposing anomalous conditions in another region. For example, the persistent area of high pressure across Europe during 1995–96 resulted in abnormally low rainfall across wide areas of western Europe, including Ireland, England and Wales, France, Belgium, Denmark, Portugal, southern Italy and Spain, whilst Greece, Bulgaria and the Rhine/Black Forest area had two to three times their normal average rainfall.

The physical causes of droughts have their origins in the natural fluctuations of the regional and global circulation systems and temporal and spatial variations in the interaction between oceans, atmosphere, biosphere and ice and land masses (Institute of Hydrology, 1999). The spatial and temporal patterns of droughts in Europe are related to patterns of anomalous climatic behaviour: the more severe droughts are often a regional phenomenon resulting from large-scale anomalies.

Persistent anticyclonic conditions are a common feature of European droughts

(Section 9.1). The position and relative magnitude of the Icelandic Low (IL) and Azores High (AH) affect the strength, position and extent of blocking anticyclones over Scandinavia and eastern Europe and the location, track and strength of rain-bearing westerlies. The difference between standardised pressure between the IL and AH is characterised by the North Atlantic oscillation index (NAOI). When the NAOI is low (i.e. when the pressure gradient is least), westerlies are weaker and penetrate less far into Europe, temperatures are influenced by cold high pressure located over Eurasia and precipitation is reduced. This has an influence on groundwater recharge and surface run-off during winter months.

12.2. Emergency plans

Anticipation of drought by using forecasting can result in conscious and systematic actions that may help in the alleviation of drought consequences. When an early warning system identifies a drought, the actions to be triggered can be classified into two main groups: demand- and supply-oriented, both described in more detail in the following sections. Careful planning of these actions is probably the only effective way of combating the effects of a drought.

To avoid confusion and inadequate action during a drought period, emergency plans should be ready which cover not only the actions triggered by the early warning system, but also the conditions for the implementation of measures (degrees of alert), the operation rules of water resource management systems and the allocation of resources between users.

A lack of water necessarily entails readjusting demands for all uses. As a quite general criterion, this measure could involve considerations concerning the economic and living conditions of the entire area affected by a drought. A shortage of available water leads, first of all, to increased conflict among the users, as the level of resource exploitation is very high in all the regions, and also in view of the severe constraints imposed by the deterioration in quality. Potable use comes first and claims the highest quality resources, but agriculture, in Mediterranean countries, demands the largest quantities.

In agriculture, activities switching from irrigated to dry crops could be an interesting issue, in particular in the Mediterranean region where reforestation of large areas should be considered at the expense of cultivating vegetables, which are not always competitive with similar products imported from other areas with more water. To change the cultivation pattern takes a long time, as it entails the transformation of entire economic sectors and has to cope with deep-rooted traditions of the populations concerned.

The establishment of a legal framework for emergency measures must be developed in advance. In Spain, the Water Act (1995) describes a water-use list, establishing the following priorities from the first to the last in importance: water supply in urban areas; irrigation; industrial uses for power generation; other industrial uses; fish farming; recreational uses; navigation. The Italian Galli Act No 36/1994 on water resources establishes that drinking water for human use is given first priority with respect to other uses and, after that, second priority is given to irrigation in case of drought or water resource scarcity. The Water Act 3/1992 in France also gives first priority to drinking water supply and, after that, agricultural use is mentioned.

In the Netherlands, the government policy with respect to water supply and distribution in drought situations is formulated in the so-called 'Third water management paper' of 1989: 'The policy is focused on the supply of sufficient water of adequate quality. This does, however, imply that not at all times and in all places all water demands can be satisfied.' In water management practice, particularly in dry periods, it may happen that it proves to be impossible to satisfy all water demands. Water managers have to take into account different interests, considering the actual situation and possibilities. Formal instructions on priorities have not been issued, but indicative guidelines were formulated.

- Water-level control in the low-lying part of the Netherlands, which is important to avoid irreversible land subsidence and to stabilise dykes and structures, has top priority. This expresses the view that safety has priority above, for instance, water quality in a situation where only water of inadequate quality (e.g. saline water) is available for water intake.
- Drinking water interests are considered essential for public health, and will get priority allocations, whereas optimal use will be made of the existing infrastructure

such as reservoirs and reductions in drinking water demands will be stimulated. This priority is also given to the greenhouse agricultural sector and industrial intakes in view of the limited possibilities to adapt production processes and in view of the subsequent economic and social damages.
- Lower priority is given to salinity control, cooling water supply for power plants and large industries, irrigation and navigation.

12.3. Demand management

The concept of 'water demand management' refers to all those activities that aim to render the greatest possible amount of services using the least possible volume of water (see *Sustainable water use in Europe — Part 2: Demand management,* EEA 2001).

To reach the goal of sustainable water management, a balance has to be achieved between the abstractive uses of water (e.g. abstraction for public water supply, irrigation and industrial use), the in-stream uses (e.g. recreation, and ecosystem maintenance), the discharge of effluents and the impact of diffuse sources. This goal requires that both quantity and quality are taken into account.

The command and control approach, based on a licensing system, has traditionally been applied to try to achieve the required balance between the different demands on the water environment. However, economic instruments are being applied increasingly to complement the licensing system as water resources of adequate quality become more and more scarce and water therefore becomes an important economic good. This is accelerated by the increasing value that people are putting on the aquatic environment in terms of minimum flow, quality and aesthetic appearance.

During drought, a wider range of policy instruments, including the application of special environmental charges and taxes, is often used. To be effective, the charges need to be set correctly. Thus, it is necessary to take into account the difficulties to assess the effect of water prices on water demand, since insufficient information is available on prices charged locally in different countries and their effect on demand.

Moreover, when using the pricing mechanism to reduce demand, the socioeconomic impact needs to be assessed to ensure that the pricing structure is equitable. In addition, in order to maintain the economic balance of the water supplier, the charges will normally have to be raised as consumption falls because of the high fixed costs. The overall benefit to consumers of saving money by saving water may therefore be small unless, of course, major infrastructure expenditure can be saved (e.g. the building of a new reservoir) which would otherwise have increased charges substantially.

Improvement programmes to be applied in industry are principally similar to the ones applicable in urban water supply. In the case of industries, the measures which promise most success in terms of demand reduction are those determining the legal and regulatory framework and all measures related to the economic cost of water use. Generally, the principle of internalisation of all direct and indirect costs associated with water use and emissions applies. Programmes aiming at the promotion of water substitution, reutilisation and especially recycling promise major saving rates. Also, the process of rationalisation of production in larger units tends to reduce the consumption of water per product unit.

Concerning agricultural production, some measures must be adopted during droughts. In Mediterranean countries, the lack of precipitation sometimes makes farmers change from arable land to irrigation land in order to keep their crop production. The consequence of this practice is an increase in water demand for irrigation, for which there are not enough resources, and a general decrease of non-irrigated crop production.

Potential measures for the improvement of water-use efficiency can be divided into those that aim to improve the performance of water distribution entities (public bodies and user associations) and those which aim to improve water-use efficiency at farm level. Measures can be further divided into those dealing with the improvement of existing infrastructure (e.g. concrete lining of canals, implementation of localised irrigation, levelling of fields and improved drainage) and those related to the non-structural aspects of irrigation (e.g. improvement of organisation and management, improvement of knowledge about water losses, establishment of information systems, improvement in determination of crop demand and adjustment of water allocations, optimisation of timing, promotion of user initiatives for improvements, and tariff systems).

In order to make the public more sensitive to drought and water conservation and the methods to mitigate impacts, educational or information campaigns must be adopted together with other policy instruments. As an example, in Athens (Greece) during the 1987–93 drought, significant reduction of consumption by 30 % was achieved by increasing the price of water, fining high users, and a broad campaign for keeping the public daily informed of the drought evolution. There was a reduction of other water uses, such as the irrigation of the Kopais plain from Iliki, which was reduced to a minimum, and the watering of parks and gardens in Athens either ceased or was done with water of lower quality.

12.4. Supply strategies

12.4.1. Additional sources of supply

During droughts, aquifers play a vital role in meeting water demand, not only as regards water quality and quantity, but also in relation to space and time distribution. Aquifers can be an efficient natural solution to water scarcity, being able to overcome a wide range of situations: supplying water under a variety of conditions, controlling abundant reserves and covering extensive areas, as well as transporting and distributing water. Aquifers are also important elements in the protection of water quality, providing quality reserves in areas where surface run-off in summer proves insufficient to maintain acceptable standards of water quality, and even when run-off is too low to maintain minimum ecological discharges.

However, the use of aquifers in semi-arid areas or in drought periods is dependent on annual recharge and requires effective management if sustainability is to be achieved. In some southern regions of the EEA area, aquifers have very limited annual recharge. Tourism and peak water demand in summer exert additional pressure on groundwater reserves. On the other hand, the climate in these areas frequently allows the growing of high-yield crops, which may require substantial amounts of water for irrigation during the whole year.

Intensive groundwater exploitation can give rise to overexploitation, depending on the balance between abstraction and renewable resources. In the semi-arid regions of Mediterranean Europe, the absence of abundant rainfall and run-off increasingly encourages the use of groundwater resources, frequently leading to excessive abstraction for irrigation and overexploitation. The resulting increase in productivity and changes in land use can initiate a cycle of non-sustainable socioeconomic development within an area. More and more resources are exploited to satisfy the increasing demand of population and agriculture, exacerbating the already threatened environment by reducing groundwater levels and, on some occasions, accelerating desertification. The lowering of water tables also damages natural wetlands and wetland ecosystems.

This scenario contrasts with central and northern Europe where overexploitation is mainly a consequence of the fact that groundwater resources historically have provided a low-cost, high-quality source of public water supply.

An increase in groundwater abstraction, therefore, faces certain limitations from an environmental point of view, given the problems of aquifer overexploitation and lowering of groundwater tables already observed, especially in southern areas of Europe. Also, in some aquifers, restrictions as regards water quality exist, limiting, in particular, their use for drinking water and increasing the costs of water treatment.

Nonetheless, it should be taken into consideration that particularly in semi-arid areas groundwater resources frequently constitute a vital element of water supply systems, due to their capacity for forming natural reservoirs and the fact that they are often the only possible source of supply. The joint use of surface waters and groundwater presents opportunities to make use of the natural buffer capacity of aquifers in dry periods, and to ensure recharge when water is abundantly available.

In Greece, during the 1987–93 drought, utilisation of groundwater for water supply with new works that included boreholes, pumping stations and pipe systems was increased. This system yielded about 160 million m^3 per year, out of which 110 million m^3 per year were allocated to the water supply of Athens.

In Spain, during the 1990–95 drought, the location and exploitation of groundwater reserves was carried out on a large scale. An example of this measure was the city of Granada, with a population of 300 000 inhabitants, and a demand of 34 million m^3 per year, where the water source was completely transformed, so that 100 % of the drinking water supply came from groundwater sources, whereas it had formerly been provided exclusively from surface resources.

Collecting 'all the available droplets of meteoric water' is a very common goal in some arid and semi-arid countries and now benefits from enhanced techniques. 'Water harvesting' has become synonymous with enhancing the possibility to capture the largest quantity of rainwater in dry lands during the short rainy season. This kind of experience is common in many parts of the world and, for instance, in the hilly areas of the central and southern regions of Italy there is already a long tradition of setting up very small ponds for irrigation with a storage capacity of a few thousand cubic metres. This old practice has tended to vanish in recent years for several reasons, primarily due to internal migration to the large urban agglomerations which has left hilly areas almost deserted. It should be stressed that certain technical and economic conditions could encourage the restoration of the practice of such ponds.

In the Netherlands, in the evaluation of the 1976 drought it was concluded that the construction of large water diversion systems was pointless. On the contrary, the construction of smaller works on a regional scale and agreements on operation and maintenance were recommended. So-called water agreements were introduced as a legal basis for regional water management.

12.4.2. Non-conventional sources

In Italy, initiatives have been taken to ascertain the feasibility of artificial precipitation. The opportunity to do this arose during investigations conducted in the Mediterranean and Middle East, in which attempts were made to produce artificial rain by seeding the clouds with suitable chemicals. These preliminary investigations confirmed that such a procedure can actually increase average annual precipitation. To this end, a massive research programme has been undertaken over an area of 25 000 km^2 in Apulia. Unfortunately, results have not so far been encouraging, particularly when the high costs are compared with the benefits obtained, the latter consisting simply of a few extra millimetres of rainfall. Very expensive equipment is required, which must be deployed at the right time and at the right place. The procedure obviously works only if there is already a large mass of vapour in the atmosphere and the air temperature is low enough to enhance vapour condensation. This favourable condition is very often absent during droughts, especially in inland areas far from the coast. The expected benefits are therefore limited to a small area, and so far there is no real chance in sight of increasing water resource availability in this way.

The practice of wastewater reuse is increasing greatly within the EU, mostly to alleviate the lack of water resources in certain regions or in certain drought periods, such as in south European countries, but also to protect the environment, especially in coastal waters by removing all discharges into fragile receiving waters. Article 12 of the Urban Wastewater Treatment Directive 91/271/EEC states that treated water shall be reused whenever appropriate. The largest application of this reuse, especially in droughts, is the irrigation of crops, golf courses and green areas. Somehow, the potential for water reuse and recycling has not yet been exploited in many areas. A decisive factor to achieve a higher percentage of water reuse is the establishment of effective incentives, which, in many instances, will be of either an economic or a regulatory nature. One of the fundamental advantages of water reuse is the fact that in many cases the resource employed is available in the vicinity of its prospective new use, i.e. urban agglomerations and industrial sites. The limiting factor for water reuse can in many circumstances be the quality of the water available and potential hazards for secondary users. To examine the economic viability of water reuse, a careful cost–benefit analysis for the various parties involved needs to be carried out.

At present, seawater desalination is being applied mainly in areas where no other sources of supply are available at competitive costs. The total volume of desalination in Europe is limited compared to other sources of supply. The essential factor which conditions the implementation of seawater desalination is the cost of water from desalination plants (presently of the order of EUR 0.7/m^3, including energy cost and depreciation). The potential of seawater desalination as a viable option for the future depends primarily on advances in desalination technology, evolution of the costs of energy and the cost of water from alternative sources. From an environmental viewpoint, a careful examination is required to clarify up to which point the use of primary energy for the production of water is environmentally sensible and economically viable.

Efforts have been made in recent years to ascertain the feasibility of using saline water for irrigation, taking into account the extensive availability of brackish water in the coastal areas. Saline water can affect irrigation in several ways, as high salt concentrations reduce both the capabilities of crops to take up water, and the soil infiltration capacity. Nevertheless, experiments conducted with different crops and water having different salt concentrations have given encouraging results. It is necessary that the watering procedures be performed according to the natural water characteristics, the crop species and the degree of soil permeability.

12.4.3. Fight against reduction of availability

The reader is referred here to *Sustainable water use in Europe — Part 2: Demand management* (EEA, 2001).

12.4.4. Increase of system flexibility

The use of storage reservoirs helps overcome the uneven distribution of natural water resources over time. Run-off in the wet season can be held back and used in the dry season (seasonal regulation), while water available in wet years can be stored and used in dry years (inter-annual regulation).

The construction of inter-basin transfers can certainly be an efficient and cost-effective means of satisfying water demand in hydraulically deficient regions or drought periods. What needs to be assured in all cases is environmental sustainability on the one hand and economic viability on the other. Especially in regions where either the evidence or the public perception of water shortage exists, attempts to carry water from one catchment to another can encounter fierce resistance from potential donors.

In Greece, during the 1987–93 drought, it was necessary to pump water from the dead volume of the reservoirs, which was accomplished through floating pumping stations. In Spain, during the 1990–95 drought, a variety of piping and channelling systems were installed with pumping stations, so that management could be made more flexible and more resources could be made available for water supply.

13. Conclusions

1. Although a drought is easy to recognise, there is no general agreement among experts regarding its definition.

2. Large areas of Europe have been affected by drought over the past 50 years. Although events differ in character and severity, the frequency of occurrence demonstrates that drought is a normal, recurrent feature of the European climate. It is not restricted to Mediterranean regions but can occur in high- as well as low-rainfall areas and in any season.

3. Drought results from a combination of meteorological, physical and human factors. The primary cause of any drought is a deficiency in rainfall and, in particular, the timing, distribution and intensity of this deficiency in relation to existing storage, demand and water use. Temperature and evapotranspiration may act in combination with rainfall to aggravate the severity and duration of the event. Both rainfall and temperature are, in turn, driven by the atmospheric circulation pattern. Human factors include demand for water in relation to socioeconomic factors such as population growth and agricultural practices, and modification in land use which directly influence the storage conditions and hydrological responses of a catchment and thus its vulnerability to drought.

4. The atmospheric circulation pattern, particularly the location and persistence of anticyclones (high-pressure centres), has a major influence on rainfall and temperature across Europe. A change in the position, duration or intensity of these anticyclones leads to changes in the circulation pattern and hence rainfall and temperature anomalies.

5. Rainfall deficiency is the primary driving factor for drought and directly influences soil moisture, groundwater recharge and river flow, although the hydrological system will delay and smooth the effects. The severity of a drought is not simply a function of the size of the rainfall deficit and will depend on the timing of the deficit and geographical extent.

6. Temperature is an important driving force on drought in both summer and winter. Summer droughts are normally associated with clear skies, sunshine, and high temperatures. These increase evapotranspiration to the extent that little or no summer rainfall is available for recharge. Winter droughts are caused by air temperature continuously below 0 °C. This results in precipitation being stored in the catchment in the form of snow and ice where it is unavailable to recharge rivers and aquifers until temperatures are raised and melting begins.

7. The presence and extent of natural catchment storage such as soil moisture and in lakes, rivers, aquifers and wetlands will help determine the impact of any rainfall deficit. Catchments with significant artificial storage in reservoirs or with groundwater recharge, river regulation or rivers with transboundary flows will be able to withstand the impact of a drought for longer than an entirely natural catchment. In times of sustained rainfall deficit (and no snowmelt), streamflow decreases until it consists entirely of groundwater flow. A valuable indicator is the 90th percentile flow (Q90), representing the freshwater resource which can be relied upon for an average of 328 days a year (i.e. 90 % of the time).

8. Recent droughts have demonstrated how socioeconomic factors driving the demand for water have made even the wettest parts of Europe vulnerable to drought. At the continental scale, Europe has abundant resources, but these are very unevenly distributed. Local demand therefore often exceeds local availability and problems of stress and overexploitation occur in areas of high population density and in regions where agricultural production is dependent on irrigation.

9. There is mounting evidence that the global climate is changing as a result of human activities. Recent research on climate change impacts in Europe suggests that annual rainfall will increase in northern Europe by 2050, and decrease by about 10 % elsewhere, temperatures will rise everywhere and potential evaporation will generally increase. The general tendency is therefore for an increase in annual average run-off in northern Europe and a decrease in the south, with changes in the 30-year mean run-off by 2050 of over 30 % in some areas and low flows tending to become more extreme across most of Europe. The greatest sensitivity to change was found in the drier regions of southern and eastern Europe.

10. The demand for European water resources increased from 100 km^3/year in 1950 to 550 km^3/year in 1990 with forecasts that this will increase to 660 km^3 by the end of the 20th century. As the pressure on water resources continues to grow, Europe is becoming increasingly vulnerable to the effects of meteorological droughts.

11. The land use will determine how much rainfall is lost through evapotranspiration and the balance between surface run-off and infiltration. In Europe as a whole, forest cover has increased by about 10 % over the past 30 years and it is calculated that each decade 2 % of agricultural land is lost to urbanisation. Both these changes will have a significant effect on the hydrology of the local area. This leads to drier soils, reduced recharge and a greater vulnerability to drought than if the land use was grass or a short crop.

12. Recent droughts have increased public awareness of the fragility of water resources in many areas and of the environmental as well as the supply consequences of a drought. Maintenance of river ecology is now viewed as an acceptable use for water and many abstraction licences are only granted with restrictions to protect this use at times of drought.

13. During a drought, the low-flow regime will be placed under even greater pressure with competition for water between different users. This will often result in abstractions for industry, agriculture or public supply being restricted or curtailed (a water resources drought) with attendant social and economic consequences and a deterioration, often severe and long-term, in the river ecology (an ecological drought).

14. The main impacts of droughts include water supply problems, shortages and deterioration of quality, loss of crops and cattle, increased pollution of freshwater ecosystems and regional extinction of animal species. These have, in turn, led to important economic impacts in some parts of Europe.

15. Water demand management and water conservation should be implemented to achieve a reduction in demand during a drought period and also, in forward planning for potential droughts, to achieve a secure supply and to reduce the vulnerability of the system.

16. To reach the goal of sustainable water management, a balance has to be achieved between the abstractive uses of water (e.g. abstraction for public water supply, irrigation and industrial use), the in-stream uses (e.g. recreation, ecosystem maintenance), the discharge of effluents and the impact of diffuse sources. This goal requires that both quantity and quality are taken into account.

17. Potential measures for the improvement of water-use efficiency can be divided into those that aim to improve the performance of water distribution entities and those which aim to improve water-use efficiency at stakeholder level. Measures can be further divided into those dealing with the improvement of existing infrastructure and those related to the non-structural aspects of water demand (e.g. improvement of organisation and management, improvement of knowledge about water losses, establishment of information systems, improvement in determination of crop demand and adjustment of water allocations, optimisation of timing, promotion of user initiatives for improvements, and tariff systems).

18. During droughts, aquifers play a vital role in meeting water demand, not only as regards water quality and quantity, but also in relation to space and time

distribution. In semi-arid areas, groundwater resources frequently constitute a vital element of water supply systems, due to their capacity for forming natural reservoirs and the fact that often they are the only possible source of supply. The joint use of surface waters and groundwater presents opportunities to make use of the natural buffering capacity of aquifers in dry periods, and to ensure recharge when water is abundantly available. Non-conventional sources, such as water reuse or seawater desalination, are being applied mainly in areas where no other sources of supply are available at competitive costs. One of the fundamental advantages of water reuse is the fact that, in many cases, the resource employed is available in the vicinity of its prospective new use, i.e. urban agglomerations and industrial sites. The limiting factor for water reuse can in many circumstances be the quality of the water available and potential hazards for secondary users. The potential of seawater desalination as a viable option for the future depends primarily on advances in desalination technology, evolution of the costs of energy and the cost of water from alternative sources.

19. The use of storage reservoirs helps overcome the uneven distribution of natural water resources over time. Run-off in the wet season can be held back and used in the dry season (seasonal regulation), while water available in wet years can be stored and used in dry years (inter-annual regulation).

20. The construction of inter-basin transfers can certainly be an efficient and cost-effective means of satisfying water demand in hydraulically deficient regions or drought periods. What needs to be assured in all cases is environmental sustainability on the one hand and economic viability on the other.

21. In most cases, droughts are identified too late and emergency measures are taken which will not be sufficiently effective. Clear and consistent criteria for drought identification need to be established, which, in a crisis, would allow time to look for a suitable response in the management of the water resource system.

22. The state of the art as regards climatic and hydrological modelling does not permit the exact prediction of a drought event.

23. A suitable response to a drought largely depends on adequate management of the water resource system. At present, hardly any technical guidance exists for water management in drought situations. Further work is needed in this area.

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Annex A: Detailed examples of flood protection and alleviation measures applied in Europe

A.1. Measures against floods in France

For many years, plans of **submersible areas** were required in zones prone to flooding. The objective was to ensure free movement of water and to preserve flood plains. In 1987, a new law integrated these objectives into a requirement for producing risk exposure plans. These plans determined three zones: red (unbuildable), blue (buildable under constraints), and white, where the risk of flooding is no more than once in a century. Neither of these pieces of legislation results in an efficient flood risk policy.

The extensive flooding events in 1992–93 led to calls for a new **natural risk policy.** This was announced at an Interministerial Committee meeting (January 1994) and was transposed into national legislation in 1995. The new policy involves the production of a national 10-year plan to prevent natural disasters, and concentrates primarily on river management and protection against floods. It requires risk prevention plans (known as PPRs, which cover, in fact, all types of natural risk, including floods and forest fires) to be produced by all high-risk communes within five years.

Flooding risks are identified for approximately 30 % of all communes in France (IFEN, 1999). In 1998, approved PPR documents had been produced for only 10 % of the communes identified as being at risk of natural disaster, and many of the large cities have not yet been covered. There are many difficulties in producing this type of document: financial (cost of studies), technical (lack of specialists), institutional (poor definition of respective responsibilities of the State and local authorities) and political (consequences of defining risk zones on property values and building rights).

For flooding risks, the PPRs should include:

- identification of risk zones;
- prohibition of construction of new installations in the most exposed areas;
- reduction in the number of existing installations in these zones;
- reinforcement of flood forecasting and alert systems;
- river restoration and dam maintenance;
- setting-up of new financial and institutional budgets and procedures to aid the development of flood prevention programmes (including the definition of risk prevention plans) and provide indemnities for the removal of installations in risk zones.

In terms of budget, the river restoration actions in the risk prevention plans are significant, corresponding to approximately FRF 10.2 billion over 10 years, 40 % financed by the State. From 1994 to 1996, 1 300 river restoration projects (for a total cost of 27 % of the total 10-year budget) had already been launched.

A.1.1. Plan for a 'natural Loire'

In 1994, a new integrated 10-year policy for the River Loire was initiated (*Loire grandeur nature*), covering population safety, water supply and ecological protection.

Under this plan, the mapping of flood risk zones in the Loire valley was accelerated. Three thematic maps of each of the 17 different sectors of the Loire valley have been produced at a scale of 1:25 000 (IFEN, 1994):

- zones previously defined as **submersible areas** under the Public Fluvial Code and also the most important hydraulic control installations;
- extent of greatest historical floods (in particular, the great floods of 1856 and 1866 in the middle Loire valley);
- zones classed according to flood risk.

For these maps, water levels measured in particular areas were extrapolated to other areas where less data were available and velocity classes were defined for both rising and falling flood periods.

Another important aspect of the plan was to improve the understanding of flood processes in the middle Loire. A permanent multidisciplinary team was set up composed of ecologists, hydraulics experts, geographers, agricultural experts and economists. The work programme is intended to develop, advise and evaluate regional and local prevention strategies for the Loire and to run for 10 years. The study programme includes:

- hydraulic modelling of exceptional flood events, in order to provide information that enables local authorities to improve warning systems and evacuation plans, and also to provide an expert opinion on the flood protection need for a new dam on the Loire at Veurdre;
- morphological monitoring of the Loire, in order to be able to understand and predict impacts of particular developments on sensitive parts of the river;
- support programmes for the restoration of natural zones, through collection and analysis of multidisciplinary information concerning buildings, land cover, statistical data, ecological descriptions and cartographic information of the channel and flood plain based on aerial photographs.

The actions initiated during 1998 at Brive-Charensac (Haute-Loire, population 4 400), where eight people died in a flood on 21 September 1981, illustrate the types of measures being implemented in the context of the natural Loire plan. These actions (FRF 300 million) aim to provide the Loire with space to breathe and were given priority over the construction of a new dam at Serre-de-la-Fare (FRF 600–700 million) which would have had a significant environmental impact in an upstream valley according to ecologists.

The actions include:

- removal of sediment to provide a wider and deeper river channel;
- partial destruction of obstacles creating a barrier to flood flow (textile factory, two flour mills and natural rocky points);
- plant and habitat engineering along several reaches upstream and downstream of the town where the river flow is lower, in order to stabilise the river banks by deep rooting and to provide diverse habitats. This is the largest project of plant/habitat engineering ever envisaged in France; techniques include planting on bare soil and on steep rock embankments using stake-held roots, use of plant matter as foundation, geotextile protection and plant anchorage;
- modifications of a national road bridge (creation of additional channels), which had been constructed in the 1970s but tended to ‘plug’ floods;
- clearance of 10 ha of non-urban zones downstream of the town to create space for natural storage of floods;
- mobile weirs at three points along a 2 km section in the town which play an aesthetic role by producing areas of stored water;
- other urban improvements were also put in place such as cycle paths, viewing points, canoeing sites;
- flood-warning alert and evacuation system with several alert levels.

A.1.2. Flood forecasting and alert systems

Currently, 16 000 km of river in France are monitored by 54 flood alert services. During the 1980s, the flood alert systems were progressively modernised to improve the collection and interpretation of hydrological and meteorological data through automating monitoring stations, telemetry by radio or telephone and by programming the warning systems.

Over the past few years, the emphasis has been on shortening the lead time of forecasts and improving alert warnings using meteorological radar and forecast models. In particular, the radar images, currently available from 14 radar installations in the Aramis network operated by Météo-France, enable precipitation areas to be detected. An additional five radars will be installed in the south-east of France, where previous intense flooding incidents (the most difficult to forecast in real time) have caused much damage.

A.1.3. Action plan against Rhine floods

After the significant floods during 1993–94 and 1994–95, the International Commission for the Rhine decided that a new flood prevention plan (*hautes eaux*) should be adopted in order to lower the highest water levels (12th Interministerial Conference, 22 January 1998). The objective is to lower the highest flood level by 30 cm (relative to current levels) before 2005, and by 70 cm before 2020. Under the new agreement, the river channel and the flood zones of the Rhine will be enlarged and dykes shifted, so as to limit water levels rising: spatial planning should take greater account of flooding risks. The strategy is intended to contribute to the achievement of the ecological objectives defined by the Rhine action programme in 1987.

The participants are the ministers from Switzerland, France, Germany, Luxembourg, the Netherlands and the European Commission. The cost is FRF 80 million and the main objectives are:

- to reduce the risk of damage by 10 % by 2005 and 25 % by 2020;
- to reduce the water level by up to 30 cm by 2005 and by 70 cm by 2020 from the regulated area of the upper Rhine.

The action plan gives a new approach to the flood problem:

- the population has to learn to live with the flood risk (reinforcement of individual prevention for persons, industries and trade);
- it is necessary to take into account the flood risk in new developments (new buildings adapted to the risk in order to reduce damage).

The subventions from the EU are around FRF 900 million over the next four years.

A.2. Flood protection in Germany

In Germany, there are 400 000 km of watercourses. The length of the classified flood protection dykes and protection walls is 7 500 km. There are also 500 impounding dams and larger retention basins with a flood protection capacity of 1 billion m^3.

The Federal Water Act allows the definition of flood basins in order to ensure drainage of the floodwater. Flood basins are to be used only in such a way that the flood level is not changed with negative effects for people living upstream and downstream.

Flood alarm systems are in operation on most major rivers. They give warning times of between a few hours and several days, depending on the size of the river. Longer flood-warning times are less reliable, particularly if they are based on precipitation forecasts.

Protection from the dangers of floods is the responsibility of local emergency services or, if it extends to uncontrollable danger levels, the so-called disaster services.

Under German federal law, there is no obligation to protect the population against the dangers by building flood protection works. If such preventive regulations exist, they are based on provisions under the *Land* law which vary from *Land* to *Land*.

In all cases, these are preventive regulations under public law that are committed to the general well-being without there being an individual entitlement to flood protection. It is the personal responsibility of anyone who lives and works by, or on, the river to adapt his/her use of the water to objective flood risks.

A.3. Flood protection in Hungary

More than half of the area of Hungary situated in the Carpathian basin is flood-plain land. The total area of flood plains which can be flooded is 21 248 km^2; this is 23 % of the area of the country.

Statistically, on average, small or medium-sized floods can be expected every 2–3 years, significant floods every 5–6 years, and exceptional floods every 10–12 years. The duration of the significant flood waves along the upper parts of Hungarian rivers is 5–10 days, and at the middle and lower parts of the rivers it can even be 50–120 days. This phenomenon is not typical of other European rivers.

The upper part of the Hungarian tributaries of the River Tisza are particularly sensitive to rapid floods. Flooding occurs after a quick snowmelt or a large amount of rain on the Hungarian parts of the rivers. After one or two days, the water levels rise several metres within a short time. The tributaries of the upper Tisza and the Körös Rivers are especially dangerous in this respect, because within 28–36 hours after significant rainfall the water level can rise as much as 8–10 m at the border.

Some typical pressures and the value of flood impacts on the flood plain are listed below:

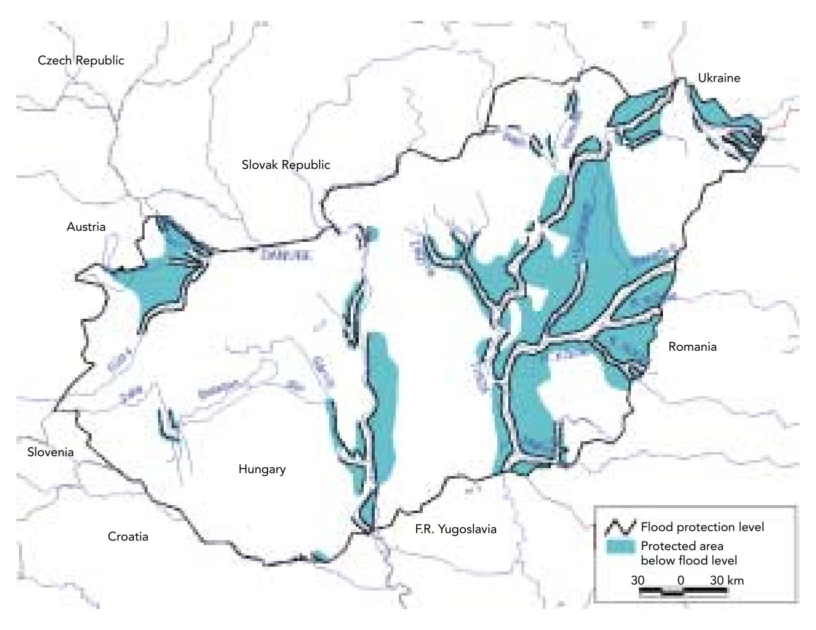
- one third of the arable land of Hungary is highly sensitive to damage; this is equivalent to 1.8 million ha of agricultural land where the value of the production is more than HUF 200 billion;

- 32 % of the railways and 15 % of the roads, the value of which together is HUF 270 billion, are subject to flood damage;
- there are more than 2 000 industries with a value of HUF 540 billion and production of HUF 1 143 billion on the flood plains;
- 2.5 million inhabitants in almost 700 settlements are threatened by flooding;
- the annual gross production of all the economic sectors at risk amounts to HUF 1 540 billion/year, which is 25 % of the yearly gross production of Hungary.

In Europe, the threat of floods in Hungary can only be compared to that of the Netherlands.

The existing system of flood protection was constructed in the middle of the last century. Several improvements in the system have been made since to meet the needs of flood defence throughout the decades (Figure A.1.). The national water management service is responsible for 4 128 km of the main flood defences (dykes, flood walls), while local authorities own and maintain the remaining 199 km. Only 65 % of these dykes were constructed for protection against a one in 100-year return period flood. One of the main problems of the water sector in Hungary is the need for flood protection constructions.

Figure A.1. **Areas protected against floods with the main levees in Hungary**



A.4. Flood protection in Slovenia

There is a strong tradition in Slovenia of applying flood protection measures. In Tables A.1. and A.2., some characteristics of flood protection and river regulation are given.

Table A.1. **Protection against floods in Slovenia**

Source: SIRS, 1998.

Year	Main embankments (km)	Flood protected area (ha)
1980	754	228 218
1985	857	232 313
1990	904	234 351
1994	946	238 997

Regulation of watercourses Table A.2.

Year	Regulated sections (km)	River-bank protection (km)	River-bank dams (km)	Meander cuts (km)	Alongside objects (km)	Other (km)
1980	—	456	—	408	163	8
1985	1 144	810	9	467	251	19
1990	1 463	1 005	10	511	2 700	31
1994	1 641	978	11	512	384	32

Source: SIRS, 1998.

It has been evaluated that civil engineering works carried out for flood protection have reduced the possibility of large-scale disastrous flooding in Slovenia. But floods are still occurring and causing great economic and social damage. Additionally, floods due to local storms still occur quite frequently. In the last 10 years, two national-scale floods occurred, in 1990 and 1998. Both have been evaluated as 100-year return period floods. The causes have been quite similar in both cases. They occurred in November where soil moisture content was high and the ground surface hardly permeable because of leaf cover. After a long period of modest rainfall, there was a storm causing an immediate increase in run-off. Flood damage was great in both cases (infrastructure, urban areas, industry and business units are situated in risk areas).

Although new concepts of flood protection behaviour are appearing among professionals, most people (and managers) still have technical measures as the only tool to prevent further damage by floods. Protection of flood areas, renaturalisation and reactivation of old flood areas are new concepts that are being developed through an integrated water management approach on a catchment level.

A.5. Flood protection in Spain

Traditionally, so-called structural measures have been used in flood prevention schemes in Spain, and these involve the construction of works that influence the mechanisms that cause flooding. In recent years, non-structural measures have been increasingly used.

(a) Structural measures

The main structural measures used in Spain have been the construction of reservoirs and river channelisation works.

- **Flood control reservoirs:** There are more than 1 000 large dams in Spain, many of which are used only for flood control or in combination with other uses (urban and agriculture demand, hydropower, etc.).
- **River channelisation works:** A great number have been constructed since the 1960s, mainly to protect towns against floods. In some cases, these works have constituted a new flood-way that substitutes or supplements the natural river channel.

(b) Non-structural measures: flood-plain zoning and regulation

Among the non-structural measures applied in Spain that should be mentioned, there are those regarding the management of the future development of the areas susceptible to flooding, for example the flood-plain planning (zoning and regulation of land use).

The Water Act and its regulations deal with the planning of river channels and banks. The concepts of restricted use, surveillance and flood risk zones are contained therein, and a series of general considerations are made, which are supplemented and defined in the hydrological plans for each basin. The aforementioned legislation provides the following zoning of channel and banks (Figure A.2), and the land-use restrictions in each zone (Estrela and Témez, 1993).

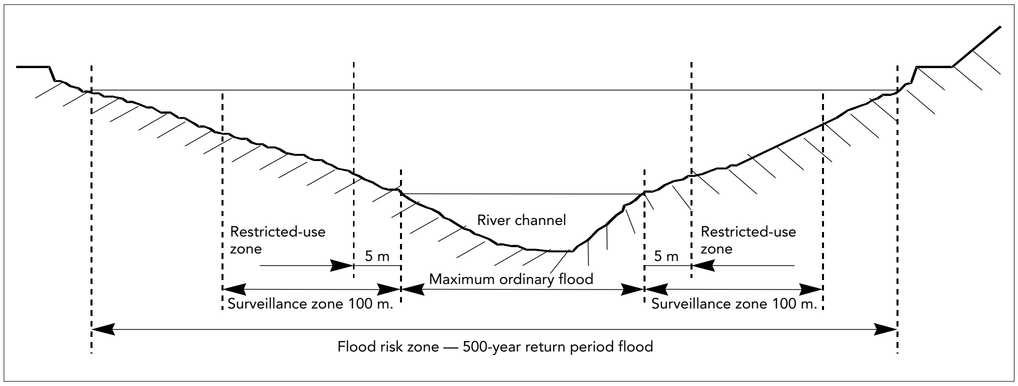
The restricted-use zone is generally a 5 m strip on either side of the channel. Specific authorisation is required from the river basin authority to plant trees and, above all, to construct, this latter activity being rarely allowed.

The surveillance zone is generally a 100 m width stretch on both sides of the channel. Here again, authorisation is required from all the administrative bodies for constructions of any kind and also if the relief is to be substantially altered, aggregates extracted or the current obstructed. The limits of this zone can be modified on the initiative of the regional, local or central administration, but it is the river basin authority that has the jurisdiction to carry it out.

The flood risk zone is defined by the theoretical levels that the water would reach during floods for the 500-year return period flood, unless the corresponding ministry defines it in another way.

Figure A.2. **Zoning of river channel and banks according to the Spanish Water Act and its regulations**

Source: CEDEX (1998a)



(c) Non-structural measures: flood forecasting and early warning system

The extensive flooding that took place in Mediterranean basins in 1982 produced a strong advance in the implementation of different responses against floods. One of the main measures was the creation of a nationwide flood forecasting and early warning system, the so-called automatic system of hydrological information (Sistema Automático de Información Hidrológica — SAIH).

The SAIH is a tool that provides hydrological and hydrometeorological information in real time and makes short-term discharge forecasting. The river basin authority manages this system in each basin. During a flood situation, the information produced by SAIH is supplied to Civil Protection, which is in charge of establishing the warning system.

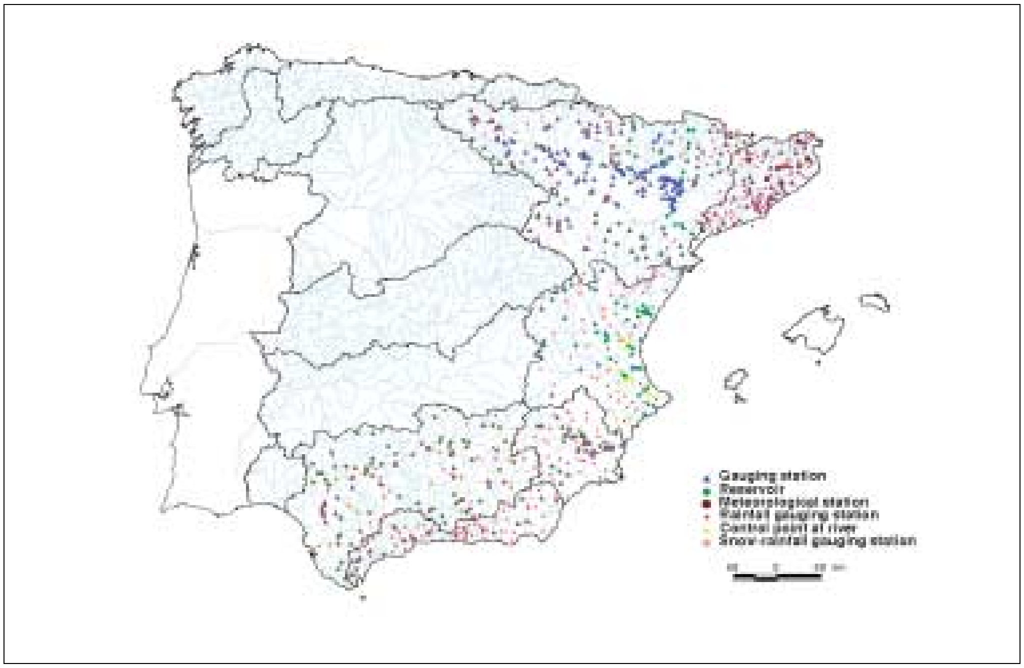
Hydrological information in real time is basically provided by the SAIH and includes data (Figure A.3.) on the precipitation recorded (about 700 rainfall gauging stations), sequences of water levels (about 700) at control sites (rivers and reservoirs) and forecasting about the flood evolution.

The structure of the SAIH operates on a three-level network:

- control sites, where data are recorded;
- concentration sites that govern specific zones, where information is received through their control sites;
- basin processing centre, which receives and elaborates all the data from the concentration sites and wherein decisions are taken.

At present, the SAIH network has been implemented in approximately 50 % of the total Spanish territory. Full implementation nationwide is one of the soon-to-be objectives.

Sites of the automatic system of hydrological information in real time in Spain (translated from MMA, 1998) Figure A.3.



Source: MMA (1998)

A.6. Flood protection in Finland

In Finland, there are about 220 regulated lakes or reservoirs. Flood protection is one of the main purposes in almost all of them. Floods are usually generated over a long period of time (weeks or months), and therefore regulation can have a significant effect in preventing flood damage.

In the coastal part of Finland, there are very few lakes, and therefore reservoirs have mainly been constructed in this area. In all, 500 km of dykes have also been constructed, and, thus, an area of 40 000 ha has been protected.

During extremely big floods, cooperation between authorities and other parties is of vital importance. Therefore, a flood response and emergency exercise was organised in 1999 in a major water system.

The economic damage caused by flooding to houses, agriculture, forestry and other property can be compensated by the State in Finland, if the flood is considered exceptional, which means a flood with a return period of at least 20 years. The compensation according to Finnish law is not automatic; it is considered separately in every flooding case. Every year, a certain amount of money is reserved for compensation in the State budget. If the amount of damage in the whole country is large, the rate of compensation is smaller. It has varied between 40 and 80 %, the latter being the maximum. Finnish insurance companies do not admit liability for flooding or droughts.

Flood problems caused by ice are typical in rivers in Scandinavia and Finland. During the ice break-up in springtime, ice jams can be formed in certain locations in the rivers causing a rise in water levels comparable to flash flooding. Damage is normally local, but water and moving ice floes may reach exceptional levels causing damage to property not located in an ordinary flood risk area. The ice break-up can be forecast by models and the jamming risk reduced by several methods. In Finland, the environmental authorities have used ice-sawing to weaken the ice cover before break-up in order to avoid ice jamming. In the early winter, if water is supercooled, frazil ice is formed in turbulent flows. Frazil ice can block the intakes of hydropower plants and cause flooding because of anchor-ice formation at the bottom of the river or by formation of frazil accumulations under the existing ice cover. By controlling the outflow from regulated lakes, the ice break-up can be delayed and the flow velocities lowered, if there is a risk of supercooling.

A.6.1. Hydrological forecasting and real-time monitoring in Finland: the watershed simulation and forecasting system (WSFS)

A real-time monitoring and forecasting system based on hydrological watershed models is widely used in Finland. The main operating part of the watershed simulation and forecasting system (WSFS) consists of 20 watershed models, which simulate the hydrological cycle using standard meteorological data. The watershed models cover 286 000 km^2 or 86 % of the area of Finland. Forecasts are made for 277 water-level and discharge observation points in lakes and rivers. Forecasts are usually daily.

The operation of a watershed model consists of meteorological and hydrological data collection, basic simulation runs, updating of model accuracy according to observations, model runs with different regulation rules for regulated lakes, forecasting runs with weather forecast and weather statistics and the delivery of the forecast to regional environment centres, other users and the Internet. Owing to the large number of forecasts carried out, the entire operating system is fully automatic. Forecast and simulation results are presented as graphs of discharges, water levels, water equivalent of snow, area precipitation, soil evaporation, lake evaporation and daily temperatures. The forecast covers up to six months.

The latest version of the watershed model utilises an elevation model to simulate area temperature, precipitation and snow cover. The simulation is made with a 1 km grid size. The user interface of the system is based on a web browser and can be operated over Internet. The user needs a browser and an Internet connection. Through the user interface, one can look at meteorological and hydrological observations and weather forecasts, and at simulated variables — snow, soil moisture, groundwater, run-off, water level and discharge — and forecasts of them, and simulate different regulation schemes for lakes. Forecasts to the Internet are delivered for over 100 lakes and rivers. Hydrological water-balance maps are presented in real time. Maps of water level, water equivalent of snow, daily snowmelt, run-off, soil moisture deficit and soil evaporation are available. The address of the home page of the WSFS is: http://www.vyh.fi/eng/environ/state/water/forecast/index.html. The forecast for different lakes and rivers can be chosen by clicking on the watershed of interest on the map of Finland.

The map-based user interface of the WSFS makes it possible to examine hydrological variables simulated by watershed models in 3 500 different sub-basins covering 50 % of Finland. At the user interface, it is possible to choose the watershed of interest to the user. Within this watershed, one can move between the first, second and third levels of watershed subdivisions. In each level, all the simulated daily data are available. The user interface also contains information on snow, soil moisture, discharge, run-off, temporary subsurface and groundwater storage, lake levels and inflows into lakes.

The WSFS is connected to a number of independent systems. These are the hydrological data register (HYDRO), the operative watershed management system (OPERA), the automatic real-time water level and discharge station net (Procol), synoptic weather stations of the Finnish Meteorological Institute (FMI) and weather forecasts from the European Centre of Medium-Range Weather Forecasts (ECMWF) via the FMI. Connections to different water quality models are being tested: INCA (nitrogen), different phosphorus models and the VEPS system for diffuse load simulations.

The different stages in watershed forecasting are:

- meteorological data transfer in real time from the FMI;
- automatic collection of hydrological data from registers;
- automatic watershed model updating according to water-level and discharge observations in real time;
- forecast runs by watershed models;
- distribution of forecasts through the data net to users;
- data updating for the map-based user interface of the WSFS;
- forecast and hydrological map updating to the Internet.