7. IMPACTS ON HYDRIC RESOURCES

Alfredo Iglesias, Teodoro Estrela and Francesc Gallart

Contributing Authors

J. Andreu Alvarez, L. Hernández Barrios, M. A. Pérez Martín

Reviewers

E. Custodio Gimena, F. Ayala Carcedo, V. Fabregat Ventura, O. Llorens García

ABSTRACT

Climate change involving temperature rises and, in Spain, reduced rainfall, will cause a decrease in water yields and increased demand for irrigation systems.

The impacts of climate change on water resources will not only depend on the yields of each hydrological cycle, conditioned by land use and cover, temperature and the temporal structure of rainfall; the water resources system and the way this is managed are also a determinant factor of water sufficiency or scarcity in relation to global human needs.

Water resources are very sensitive to temperature increase and reduced rainfall, precisely in areas with high mean temperatures and low rainfall. The most critical areas are semiarid ones, where reduced yields can reach 50% of the area's potential resources.

Temporality in the distribution of rainfall and temperatures often has a greater influence on the generation of water resources than the mean values of these two climatic parameters.

For the 2030 horizon, considering two scenarios, one with a 1ºC increase in annual mean temperature and another with a 5% reduction of annual mean rainfall and a 1ºC temperature increase, decreases can be expected in mean water yields in natural regime in Spain, of between 5 and 14%. The Guadiana, Canary Isles, Segura, Júcar, Guadalquivir, Sur and Balearic Isles catchments are where the impact on water resources will be most severe.

For the 2060 horizon, with a scenario of a 2,5 ºC temperature rise and an 8% decrease in rainfall, global reduction of water resources is predicted of 17% on average for the Peninsula, along with an increase in the interannual variability thereof. These changes will be greater in southern Spain.

In an extreme scenario (unlikely) involving a 15% decrease in annual mean rainfall and a 4ºC temperature rise, total yield will range from 5% on the coast of Galicia 22% in Guadiana II 20% in the Júcar catchment, and 20% in the internal catchments of Catalonia.

The main mitigation options are aimed at optimising water use (demand management), improving the water resources system and the management thereof, in particular groundwater, and increasing unconventional resources, catchment of rain or dew water, transfers between catchments, desalinisation and reuse.

Variation in water resources resulting from climate change is conditioned by the influence of other sectors also affected by the changes. Changes in water resources, in turn, have a great effect on many other sectors, particularly on aquatic and continental ecosystems, on animal and plant biodiversity, the agriculture, forestry, energy and tourism sectors, on human health and on natural risks of climatic origin.

In estimating water resources in relation to climate change, there are uncertainties inherent both to databases and to the process of resource generation, the former being of greater relative importance. Among these uncertainties we can highlight foreseeable scenarios, spatial and temporal distribution of rainfall, the behaviour of land use and cover, aquifer recharge and the limitations of simulation models.

The change in water resources can be seen in the measures established in Spain involving control systems, which in some cases are well implemented or are being improved, and in others should be implemented in a more generalised way. Among the latter, we should

recommend the design and implementation of water use control networks, in relation both to surface and groundwater, and metering networks in springs and sources.

The decrease in water resources affects many sectors, the regulation of which is based on the definition of specific policies. The change would involve the necessary re-modelling and redefinition of new policies, related to science and technology, water, energy, agriculture, environment and land planning.

Climate change calls for the research needed to improve predictions of rainfall and temperatures, as well as the spatial and temporal distribution thereof, and research aimed at defining methods for generating climate data series based on scenarios, and at providing better and more reliable methods of evaluation of evaporation and evapotranspiration, the operation of groundwater in the soil, the interception and reserve of water that can be used by plants, and research aimed at establishing more reliable aquifer recharge processes and developing models for computerising yield calculation and catchment management models.

7.1. INTRODUCTION

7.1.1. General consideration of the impacts of CC on hydric resources

The origin of the hydric resources available to humanity is found in an imbalance between continents, between the rainwater that falls and that which evaporates or evapotranspires, the former clearly constituting a surplus. In the oceans, the phenomenon is the opposite; they are deficient and evaporation is approximately 10% greater than rainfall. The surplus of the continents flows to the sea by the rivers, compensating the deficit in the oceans (Figure 7.1).

The potential hydric resources available to humankind to satisfy all of our needs depends precisely on these surpluses on the continents, between rainwater and that which returns to the atmosphere.

The water that exists is nature is constant, as a result of the principle of conservation of mass, which constitutes a cycle that continuously changes from a liquid or solid state to vapour, and vice versa. Climate governs this cycle, and climatic changes will therefore necessarily give rise to changes in the time and space of available water resources.

Changes in rainfall directly condition the water falling upon the continents and changes in temperature modify evaporation and evapotranspiration values, and alter the amount and characteristics of runoff waters.

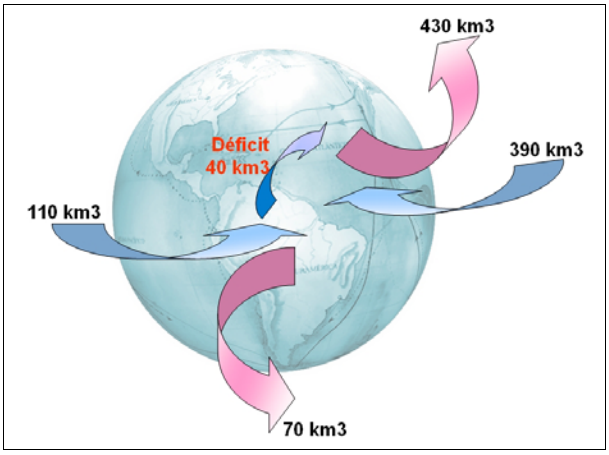


Fig. 7.1. *Global water balance (thousands of km^3)*

Given that runoff only occurs when the soil presents surpluses, or when rainfall intensity is greater than infiltration capacity, it is clear that temporal distribution and rainfall regime will affect the generation of runoff as much, or more, than the volume of rainfall itself.

Climate Change consequently has a direct and vitally important effect Hydric Resources. The impacts on these resources will be seen not only in variations in amounts, but also in a change in quality and in temporal distribution.

A lower volume of available water would worsen the quality thereof (National Climate Programme, MOPTMA – public works, transport and environment ministry – 1995) and phenomena such as the rise in sea level associated with global warming, and the fall in piezometric levels in aquifers hydraulically connected to the sea would favour pollution phenomena due to marine intrusion.

Water yields, considered to be the total volume of annually accountable water at one point of a catchment in natural regime, are initially conditioned by rainfall, temperature, land use and soil cover and the characteristics of the soil and subsoil.

Hydric resources, in the correct sense of the term, understood as volumes of water capable of satisfying water needs with regard to quantity and quality, time and space, are in turn conditioned by exploitation, temporal structure of demand, the available water resource systems (surface water and groundwater) and the operational rules defined for the system or the management rules thereof.

In short, it is the effort related to the regulation, supply, transport, distribution and quality protection by the Water Resources Systems, for both surface and subterranean waters, which constitutes the final stage, or group of factors, that condition the truly useable water resources.

Consequently, there are two groups of factors directly affecting the quantity and quality of available water resources, both endogenous and exogenous (Figure 7.2).

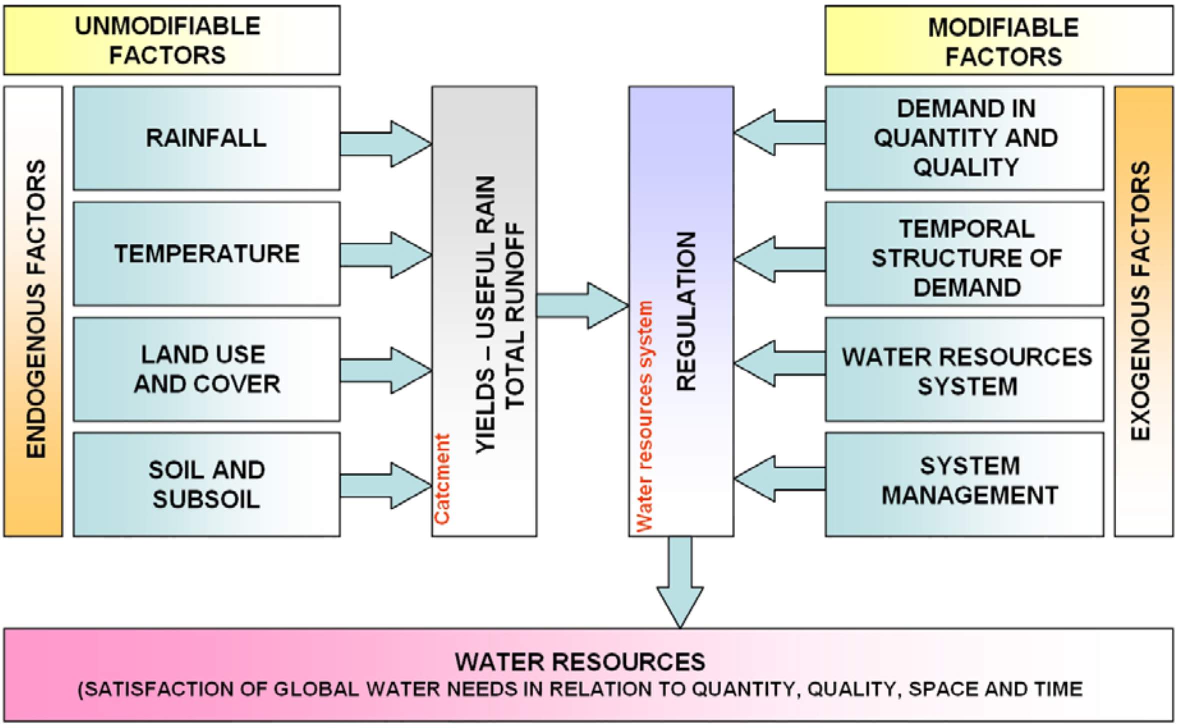


Fig. 7.2. *Table of factors intervening in the generation of water resources*
** Factors conditioned by land management, not usually integrated into water resources management.*

The first ones cannot be modified by human action and consequently, they are directly responsible for variation in yields in the hydric cycle. The only exception is land use and cover, factors which clearly condition the yields (Bosch and Hewlett 1982), but the management of which is usually independent from hydric resources management. These yields adjust to demand and the structure of this, making use of the water resource systems (surface and groundwater), which are suitably managed through management rules that are frequently designed with the support of management models.

Climate change with temperature increases, and in Spain, with reduced rainfall, will essentially cause a decrease in water yields and increased demand for irrigation systems. The real impact, however, will depend on the available water resources system and the way this is managed.

Demand and structure thereof, system and the management of this, are the exogenous and modifiable factors that can allow correction or adjustment in relation to the impact caused.

With regard to demand and its structure, there exist actions related to the optimisation of water use.

In relation to the system and the management thereof, there are options for modifying or expanding the system, or for improving management by means of operations backed by management tools (Figure 7.3).

Besides, there is always the option, frequently more costly, of increasing available resources by means of transfer between basin catchments, desalinisation of brackish waters or seawater and re-utilisation of resources with all the necessary precautions.

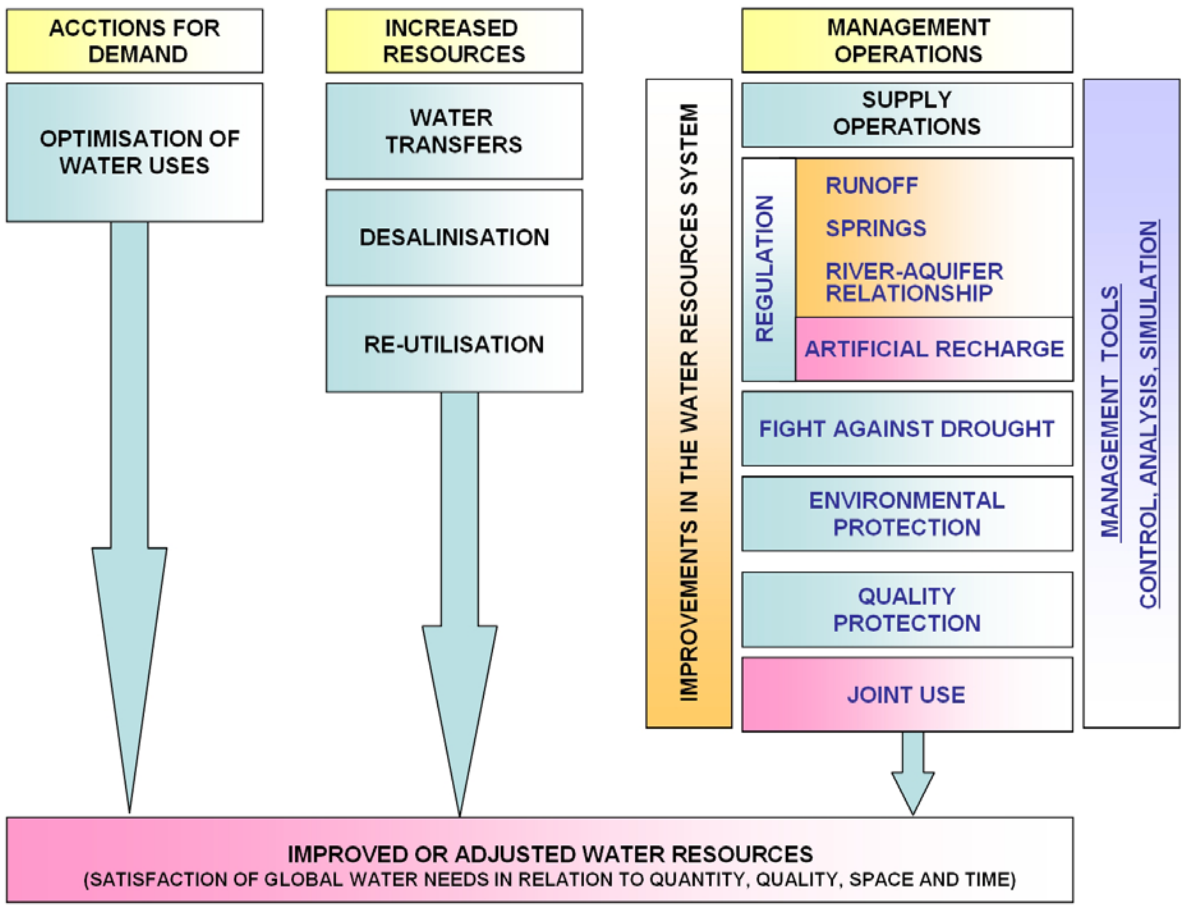


Fig. 7.3. *Table of possible corrective measures based on management*

One clear conclusion in relation to the impacts of climate change on water resources is that we are dealing with a system with a high degree of uncertainty. Resources do not only depend on the yields provided by the hydrological cycle, which are conditioned by the amount and temporal structure of rainfall, temperature and land use and cover, whereas demand depends not only on climate, but also on the technical and socioeconomic changes that will take place in the future. Finally, it is the system of available water resources and the way this is managed which fundamentally conditions the sufficiency or scarcity of water in relation to demand.

The conclusions of the ACACIA project in Europe (Parry 2000) with regard to water management are not exactly encouraging: In the water sector, the major policy implication of climate change is that it is no longer possible to assume that the future hydrological resource base will be similar to that of the present. This is important in the context of sustainable water management. Water managers, at all levels, therefore need to (a) develop methodological procedures for adopting a scenario-based approach to strategy or scheme assessment, and (b) develop adaptive techniques that allow incremental adjustments over time. A second major implication is that the amount of climate change might make it more difficult to move to more sustainable management of water resources, particularly in southern of Europe.

One clear conclusion with regard to the impacts of climate change on hydric resources is that these do not only depend on the yields from the hydrological cycle, which are conditioned by the soil, temperature and the temporal structure of rainfall, but also on the system of available water resources and the way this is managed. This constitutes the set of factors that basically conditions the sufficiency or scarcity of water in relation to global human needs.

7.1.2. Water resources in Spain. Surface water and groundwater

In Spain, yields by rivers to the sea have been well gauged throughout time, due to the high degree of development of the Water Resources System and to the importance of water availability in the national economy. The gauging network, however, was not designed to establish the hydrological response of natural systems, but rather, it is clearly oriented to the operational management of surface resources.

Taking into consideration the high level of water use in Spain, it is not easy to calculate the yields of rivers in natural regime, given that the flows measured therein will be altered by extractions for the different water uses and applications. Evaluations in natural regime are not based on gauging data, but rather make use of rainfall-runoff models.

The White Paper on Water (MIMAM 1998) contains data on evaluations made since 1967, Table 7.1, in which the scant differences between those made for each year can be appreciated, which makes them reliable and consistent.

These figures represent total runoffs, including surface waters and groundwater, and it must be understood that of these figures, one part would be strictly surface runoff and the other groundwater.

Several studies, however, indicate a significant decrease in yields from the main rivers during the second half of the XX century (figure 7.4), some of which cannot be justified by increased consumption (Prieto 1996; Flores-Montoya *et al*. 2003; García-Vera *et al*. 2003).

Table 7.1. *Estimation of total in natural regime.*

Sphere of planning	1967 (a)	1980 (b)	1993 (c)	1998 (d)	1998 (e)
Norte	37.500	38.700	42.088	42.258	44.157
Duero	13.200	15.900	15.168	15.168	13.660
Tajo	8.920	10.250	12.858	12.230	10.883
Guadiana	4.895	5.100	6.155	6.168	5.475
Guadalquivir	7.300	9.400	7.771	7.978	8.601
Sur	2.150	2.690	2.418	2.483	2.351
Segura	884	960	1.000	1.000	803
Júcar	2.950	5.100	4.142	4.142	3.432
Ebro	17.396	18.950	18.198	18.217	17.967
C.I. Catalonia	1.700	3.250	2.780	2.780	2.787
Total Península	**96.895**	**110.300**	**112.588**	**112.424**	**110.116**
Balearic Isles	-	690	745	562	661
Canary Isles	-	965	965	826	409
Total Spain	**-**	**111.955**	**114.298**	**113.812**	**111.186**

(a) PG (1967). Water resources. II Economic and Social Development Plan. Presidency of the Government.
(b) MOPU –public works ministry (1980). Water in Spain. CEH (hydrographic studies centre), DGOH (waterworks dept.) . Also in Heras (1977).
(c) MOPTMA-public works, transport and environment ministry- (1993b). Draft Report of the PHN (national hydrological plan) Law.
(d) 1998 Data on Catchment Management Plans.
(e) 1998 Data on the evaluation contained in the White Paper on Water.
Note: The figure in the Ebro Catchment Plan (column d) does not include the resources of Garona or Gallocanta.

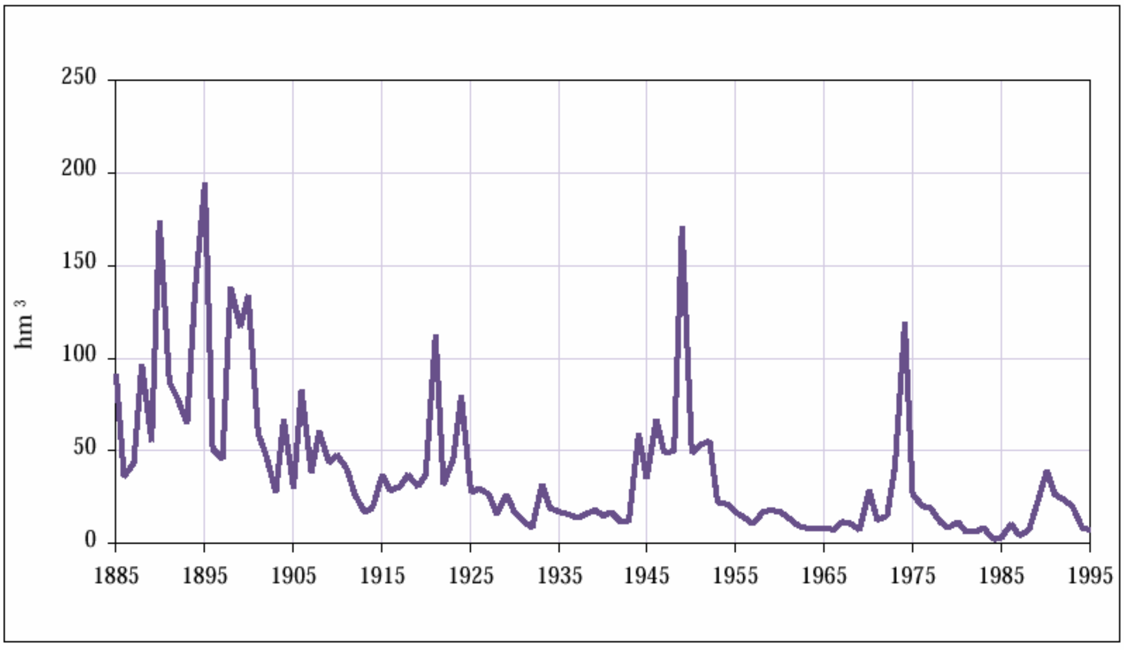


Fig. 7.4. *Series of annual yields of the river Guadalentín to the Puentes dam since (MMA Environment Ministry 1998)*

The values of groundwater flow have also been evaluated on multiple occasions with sufficient thoroughness, mainly in the regional studies of the National Groundwater Research Plan, IGME (geology and mining institute). Table 2 shows the values of the groundwater for the catchments of the large Spanish rivers, synthesised in the White Paper on Groundwater (MOPTMA (public works, transport and environment ministry)- MINER (industry and energy ministry) 1994)

Table 7.2. *Estimation of groundwater yields. Source: Catchment plans and White Paper on Groundwater (MOPTMA-MINER 1994).*

Sphere of Planning	Outcrop of permeable rocks. Area (km2)	Recharge by rain and flows (hm3/year)	Recharge by irrigation (hm3/year)
Norte	5.618	2.997	0
Duero	52.799	1.840	1
Tajo	17.475	1.565	0
Guadiana	14.754	787	20
Guadalquivir	15.140	2.573	16
Sur	5.305	865	69
Segura	6.958	674	83
Júcar	23.781	3.011	480
Ebro	17.057	4.433	586
C.I. Catalonia	6.616	938	45
Total Península	**165.503**	**19.683**	**1.300**
Balearic Isles	3.674	517	69
Canary Isles	7.384	681	0
Total Spain	**176.561**	**20.881**	**1.369**

In short, Spain's rivers in natural regime carry to the sea around 110,000 hm^3/year, of which around 90,000 hm^3 are strictly surface runoff and the other 20.000 hm^3 that have been transported through the aquifers are of subterranean origin, although the temporal stability of these yields has not been sufficiently studied.

7.1.3. Spatial and temporal heterogeneity of water resources in Spain

The heterogeneous spatial and temporal distribution of rainfall in Spain, much more evident than in other neighbouring countries, results in an extraordinary variability in yields over time and also in great variation in yields in the different catchments.

	TOTAL RUNOFF	TOTAL USES
NORTE CATCHMENT	39.000 hm^3/year	930 hm^3/year
SEGURA CATCHMENT	900 hm^3/year	1.300 hm^3/year

Fig. 7.5. *Comparisons between yields and water uses between catchments in "dry" and "humid" Spain.*

Figure 7.5 illustrates the needs and runoffs of two Spanish catchments; Norte and Segura, showing the difference between the two situations in order to deal with hydric demands. These differences are responsible for the existence of "dry" and "humid" Spain.

Taking as a reference the tables in the White paper of Water, MMA 1998, Figure 7.6 and Figure 7.7, the extraordinary differences can be seen between the runoffs of the different catchments and the variability in time of the yield.

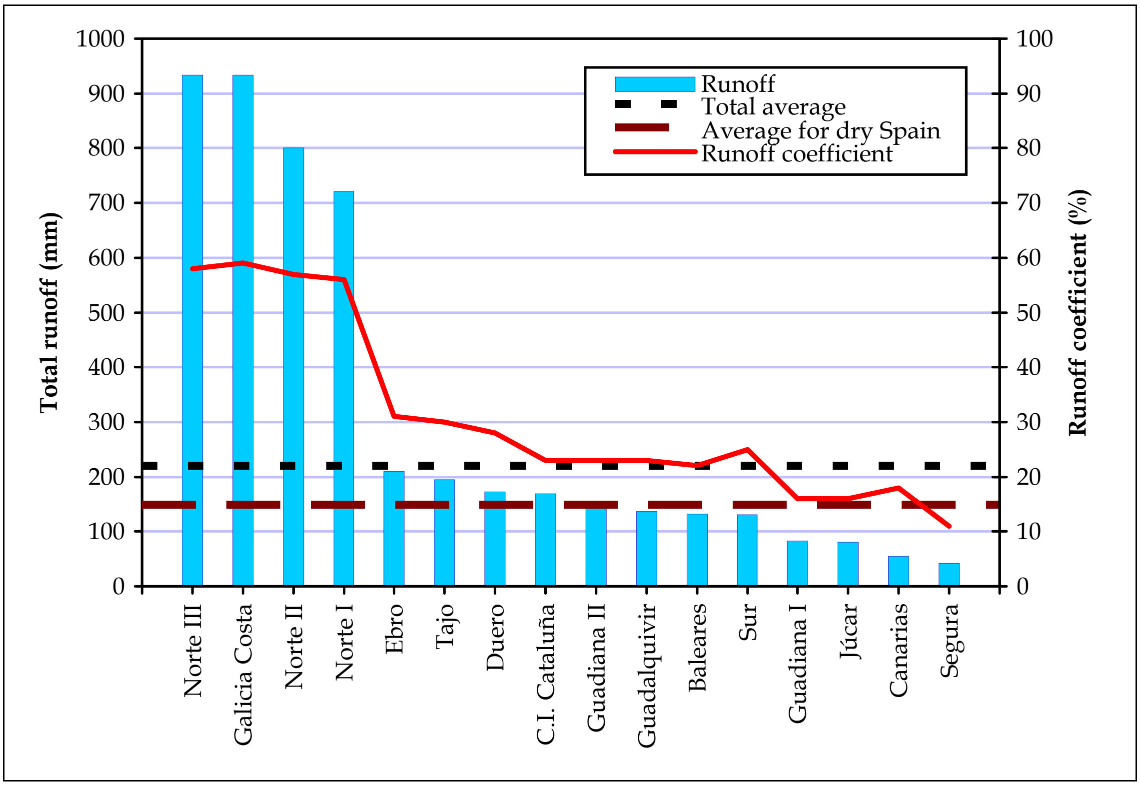


Fig. 7.6. *Annual total mean runoffs (mm) and runoff coefficients in natural regime in the different territorial spheres of the Catchment Management Plans. According to the White Paper on Water. MMA 1998*

The Norte catchments present excellent runoff values compared with the others, especially with those of Segura, Jucar, Canaries and Guadiana I. But it is precisely these catchments that present the highest consumption levels, mainly for irrigation.

Figure 7.7 shows runoff values in Spain, simulated in natural regime for the series 1940/41-1995/96, in which minimums of 50,000 hm^3/year and maximums of 220,000 hm^3/year can be seen, for an average of 110,000. This spatial heterogeneity, is another of the big problems of hydric resources in Spain; the amount that the hydrological cycle will provide is a factor of great uncertainty. These basic problems can only be approached by means of a large-scale and appropriately managed water resource system.

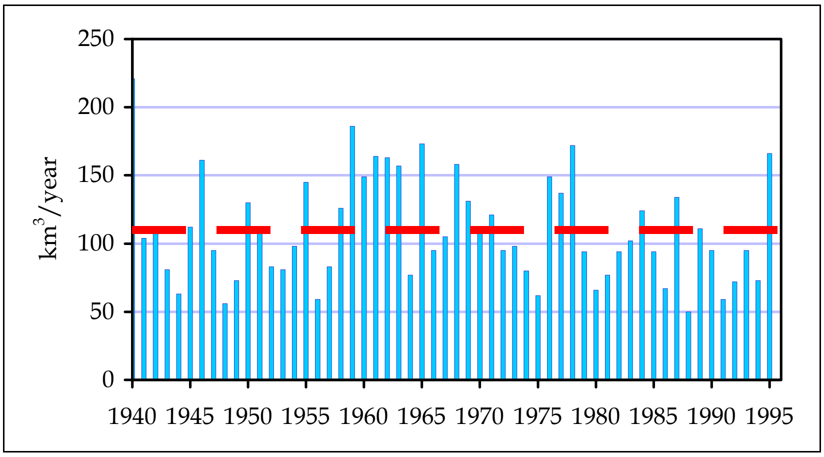


Fig. 7.7. *Series of total annual yields in natural regime on the Spanish Mainland (1940/41-1995/96 period)*

7.1.4. Water uses and applications in Spain

Spain has a long tradition of water uses. Mainly as a result of our well-developed agriculture and high potential for hydroelectricity, a large amount of reservoirs and groundwater captures have been built.

In many of the irrigation systems, vestiges of Roman construction can be found, and construction of these systems was probably started even earlier, but it was the hydrological systems of the Arabs that gave rise to the rich and fertile valleys of Granada, Valencia, Murcia and Aragón

The origin of the spectacular current development surely leads us to certain public figures of the last third of the XIX century, particularly Joaquín Costa and Macías Picavea, who promoted decisive action by the government aimed at regulating water yields and to extending irrigated areas, as a main objective of general economic policy.

Water use in Spain, however, has always been known to have problems, mainly due to the climate, partly semiarid, to the spatial and temporal heterogeneity of rainfall and certainly to the economic structure, with great involvement of agriculture, requiring large volumes of water precisely in summertime, when it is most lacking.

The table of Figure 7.8 synthesises some of the secular problems related to water use in Spain.

THE CLIMATE:	Development factor and aggression factor
RAINFALL:	Low and anarchic in time and space
ECONOMIC STRUCTURE:	Intense participation of agriculture and tourism
CROP REQUIREMENTS:	Hight
SUMMER RUNOFF:	Low
ECONOMIC DEVELOPMENT:	Fast
POWER:	Chaos, slowdown, confusion and "overexploitation"

Fig 7.8. *Table of secular problems related to water use in Spain*

Some very significant examples help us to understand the difficulty and complexity of water use in Spain, and especially, the huge volume of water needed on an annual basis.

Figure 7.9 presents these examples; in the first one, we can see (Moreno 1982) how in Spain, the irrigatable area which is actually irrigated, is double that of the world average. The need for water for irrigation is so widespread in our country that this doubles the global average.

	WORLD	SPAIN
FARMED AREA	4.000 M ha	21 M ha
IRRIGATABLE AREA	1.000 M ha	5 M ha
IRRIGATED AREA	250 M ha (25%)	2.5 M ha (55%)

	FRANCE	SPAIN
TOTAL USES (1975)	15 km³	25 km³
AGRICULTURAL USES	5.2 km³	21.5 km³
TOTAL RUNOFF	180 km³	110 km³
STORAGE CAPACITY	7 km³	40 km³

Fig. 7.9. *Comparisons of water uses in Spain and in France and frequency of Spanish irrigation, with some worldwide figures.*

In the second case, some very general global comparisons are made between water uses and yields in Spain and France.

France, with a larger surface area and more developed than Spain, present much lower total water uses, and the yields from French rivers, however, are substantially greater than those of Spanish ones.

In this context, France consumes 25% of the water used by Spain for irrigation, which is what is most difficult to satisfy, given that the demand for water occurs in summer, while the yields are generated at the humid times of year.

This means that Spain's water resources system is insufficient in certain years, with over 40 km^3 storage capacity, the French system is very sufficient, with only 7 km^3.

Table 7.3 provides details of the total annual yields, net consumption once returns have been discounted, and the relationship between net consumption and total yields.
The consumption of 20% of total renewable water resources is considered as the overexploitation limit of a system (Falkenmark and Lindh 1976). According to this criterion, and taking mean annual yields as total resources, most of the catchments surpass this overexploitation limit.

In short, it could be said that in Spain, water resources are overused in most of the catchments and that it is mainly the priority use of agriculture that not only requires very large volumes, but requires them at times of year in which the hydrological cycle does not provide them, and a well developed system of water resources is therefore needed to deal with these needs.

A country of these characteristics is very sensitive to possible decreases in water resources inherent to climate change.

Table 7.3. *Annual yields and consumption*

shpere	yields hm^3	consumption hm^3	relationship %
Norte III	5.614	98	2
Galicia Costa	12.245	479	4
Norte II	14.405	145	1
Norte I	13.147	403	3
Ebro	18.647	5.361	**29**
Tajo	11.371	(1) 2.328	**20**
Duero	14.175	2.929	**21**
C.I. Catalonia	2.728	493	18
Guadiana II	1.053	121	11
Guadalquivir	9.090	2.636	**29**
Balearic Isles	696	171	**25**
Sur	2.359	912	**39**
Guadiana I	4.624	1.756	**38**
Júcar	3.335	1.958	**59**
Canary Isles	394	244	**62**
Segura	(1) 1.411	1.350	**96**
Spain	113.998	20.613	18

(1) The nominal value of 600 hm^3 from the ATS was taken

Source: White paper on Water in Spain, Environment Ministry (1998)

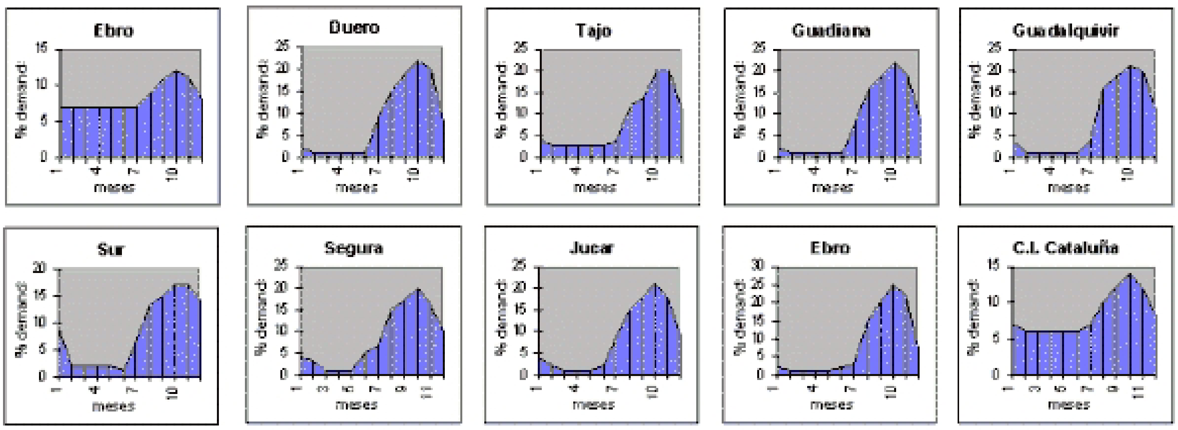
7.1.5. The resources-demands binomial; water resources regulation and systems

Satisfying water needs in relation to quantity, quality, space and time, involves availing of a water resources system, in order to adjust yields to demand structure. The temporal structure of these yields is conditioned by the hydrological cycle and demands, the structure of which is established by the different water uses and applications.

Hydric resources in Spain are generally low for the times of year in question. It should suffice to point out that, of the 110,000 hm^3 making up total annual runoff, only around 10,000 flow in rivers in the summer months, in which agricultural uses require over 24.000 hm^3.

Figure 7.10 represents the percentage distribution of demand, in the different Spanish catchments, along with the heterogeneity and lack of regularity of these.

Cuenca	Oct.	Nov.	Dic.	Ene.	Feb.	Mar.	Abr.	May.	Jun.	Jul.	Ago.	Sep.	
Norte	7	7	7	7	7	7	7	9	11	12	11	8	100
Duero	2	1	1	1	1	1	9	15	19	22	20	8	100
Tajo	4	3	3	3	3	3	4	12	14	20	20	11	100
Guadiana	2	1	1	1	1	1	8	16	19	22	19	9	100
Guadalquivir	4	1	1	1	1	1	4	16	19	21	20	11	100
Sur	9	2	2	2	2	1	6	13	15	17	17	14	100
Segura	4	3	1	1	1	5	7	15	17	20	16	10	100
Jucar	4	2	1	1	1	2	8	15	16	21	18	9	100
Ebro	2	1	1	1	1	2	3	15	20	25	22	7	100
C.I. Cataluña	7	6	6	6	6	6	7	10	12	14	12	8	100



* Meses de octubre a septiembre

Fig. 7.10. *Percentage distribution of demand in different Spanish catchments*

There are catchments such as Ebro, Guadalquivir and Guadiana 90% of whose needs are concentrated from May to September.

It appears that this pattern of temporal heterogeneity can only be exacerbated in view of the heterogeneous distribution of rainfall presented with climate change.

In short, regulation in Spain aimed at satisfying hydric requirements is very difficult, and climate change is expected to worsen the situation.

7.2. SENSITIVITY TO THE PRESENT CLIMATE

7.2.1 Relationships between climate, soil, land uses and yield. Runoff rates

As has already been pointed out, the generation of yields is based on the relationship between the binomial climate and surface (soil and cover). The soil's capacity to retain water, and the capacity of this to be used by plants, involves rainfall, or part of it, being retained and evapotranspired by plants. The reserve of water that can be used by plants, which is a function of the field capacity, permanent wilting point, apparent density and mean root depth, incorporates rainfall and returns water to the atmosphere by evapotranspiration in a continuous manner, filling up and emptying, depending on whether inputs or outputs are greater, until a point is reached at which the soil does not absorb any more water, the reserve fills up and runoff or recharge of aquifers is generated by the surpluses. The characteristics of the vegetation also determine the exchanges of water and energy, not only as a result of root depth, but also of aerial biomass and aerodynamic roughness.

The runoff rate of a catchment, understood as the relationship between the yield or runoff measured in a catchment and the total volume of rainfall that has fallen therein, varies as a consequence, and is lower with less rainfall and greater potential evapotranspiration, inherent to a temperature increase. The runoff coefficient also increases, in the same climatic conditions, with certain characteristics of the soil or the vegetation, which reduce returns to the atmosphere, such as less soil's thickness, less field capacity, or also less mean root depth, aerial biomass or aerodynamic roughness.

7.2.2. Study of unitary sensitivity. Influence on the yield of the unitary variations of mean temperature and annual rainfall.

Purely for purposes for theoretical orientation, procedures can be sought for estimating the sensitivity of the yield to unitary variations in the parameters of climate change, rainfall and temperature.

This was used to calculate runoff, using the Turc method, for annual rainfall values of between 200 and 900 mm and annual mean daily temperature of between 10º C and 30º C.

The tables of figure 7.11 represent the percentage decreases in the yield between the aforementioned ranges of values of rainfall and temperature, for the following hypotheses:

Temperature increase by 1º C
Temperature increase by 2,5º C
Decrease in rainfall by 10%
Temperature increase by 1º C and decrease in rainfall by 10%

Simple analysis of the table shows that sensitivity is very high, precisely in the areas with high mean temperatures and low rainfall. That is to say, in the areas of Spain with higher rainfall and average temperatures, the decreases in yields in the scenarios proposed reach values almost always below 4% or 5%.

Decrease in yields in %. Hypothesis of 1ºC temperature increase

Rainfall

Temperature	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
10			37.6	16.3	11.9	9.9	8.6	7.7	7.0	6.4	5.9	5.4	5.1	4.7	4.4	4.1	3.9	3.7	3.5
11			53.7	17.4	12.2	10.0	8.6	7.7	7.0	6.4	5.9	5.5	5.1	4.7	4.4	4.2	3.9	3.7	3.5
12			100.0	19.0	12.6	10.1	8.7	7.7	7.0	6.4	5.9	5.5	5.1	4.8	4.5	4.2	4.0	3.7	3.5
13			100.0	21.2	13.1	10.3	8.8	7.8	7.0	6.4	5.9	5.5	5.1	4.8	4.5	4.2	4.0	3.8	3.6
14				24.3	13.7	10.5	8.9	7.8	7.0	6.4	5.9	5.5	5.1	4.8	4.5	4.2	4.0	3.8	3.6
15				29.2	14.5	10.8	9.0	7.9	7.1	6.4	5.9	5.5	5.1	4.8	4.5	4.3	4.0	3.8	3.6
16				37.4	15.5	11.1	9.1	7.9	7.1	6.5	6.0	5.5	5.2	4.8	4.5	4.3	4.0	3.8	3.6
17				54.6	16.8	11.5	9.3	8.0	7.1	6.5	6.0	5.5	5.2	4.8	4.6	4.3	4.1	3.8	3.7
18				109.7	18.5	11.9	9.4	8.1	7.2	6.5	6.0	5.5	5.2	4.9	4.6	4.3	4.1	3.9	3.7
19				100.0	20.9	12.5	9.7	8.2	7.2	6.5	6.0	5.6	5.2	4.9	4.6	4.3	4.1	3.9	3.7
20					24.4	13.2	9.9	8.3	7.3	6.6	6.0	5.6	5.2	4.9	4.6	4.3	4.1	3.9	3.7
21					29.8	14.1	10.3	8.5	7.4	6.6	6.0	5.6	5.2	4.9	4.6	4.3	4.1	3.9	3.7
22					39.2	15.3	10.6	8.6	7.5	6.7	6.1	5.6	5.2	4.9	4.6	4.4	4.1	3.9	3.7
23					59.6	16.7	11.1	8.8	7.6	6.7	6.1	5.6	5.2	4.9	4.6	4.4	4.1	3.9	3.7
24					100.0	18.7	11.6	9.1	7.7	6.8	6.1	5.7	5.3	4.9	4.6	4.4	4.1	3.9	3.8
25						21.4	12.3	9.3	7.8	6.9	6.2	5.7	5.3	4.9	4.6	4.4	4.2	4.0	3.8
26						25.3	13.1	9.6	8.0	6.9	6.2	5.7	5.3	5.0	4.7	4.4	4.2	4.0	3.8
27						31.6	14.1	10.0	8.1	7.0	6.3	5.8	5.3	5.0	4.7	4.4	4.2	4.0	3.8
28						43.3	15.4	10.4	8.3	7.1	6.4	5.8	5.4	5.0	4.7	4.4	4.2	4.0	3.8
29						71.3	17.1	11.0	8.6	7.3	6.4	5.8	5.4	5.0	4.7	4.4	4.2	4.0	3.8
30						100.0	19.3	11.6	8.8	7.4	6.5	5.9	5.4	5.0	4.7	4.4	4.2	4.0	3.8

Decrease in yields in %. Hypothesis of 2,5 ºC temperature increase

Rainfall

Temperature	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
10			86.5	37.6	27.6	23.0	20.2	18.1	16.5	15.2	14.1	13.1	12.2	11.4	10.7	10.1	9.5	9.0	8.6
11			100.0	40.4	28.4	23.3	20.3	18.2	16.6	15.2	14.1	13.1	12.2	11.5	10.8	10.2	9.6	9.1	8.6
12			100.0	44.1	29.4	23.7	20.5	18.3	16.6	15.3	14.1	13.1	12.3	11.5	10.8	10.2	9.6	9.1	8.7
13			100.0	49.3	30.6	24.1	20.6	18.4	16.6	15.3	14.1	13.2	12.3	11.6	10.9	10.3	9.7	9.2	8.7
14				56.7	32.1	24.7	20.9	18.5	16.7	15.3	14.2	13.2	12.3	11.6	10.9	10.3	9.7	9.2	8.8
15				68.0	34.0	25.3	21.2	18.6	16.8	15.4	14.2	13.2	12.4	11.6	11.0	10.3	9.8	9.3	8.8
16				87.5	36.4	26.1	21.5	18.8	16.9	15.4	14.2	13.3	12.4	11.7	11.0	10.4	9.8	9.3	8.9
17				100.0	39.5	27.0	21.9	18.9	17.0	15.5	14.3	13.3	12.4	11.7	11.0	10.4	9.9	9.4	8.9
18				100.0	43.6	28.2	22.4	19.2	17.1	15.5	14.3	13.3	12.5	11.7	11.0	10.4	9.9	9.4	9.0
19				100.0	49.3	29.6	22.9	19.4	17.2	15.6	14.4	13.4	12.5	11.7	11.1	10.5	9.9	9.4	9.0
20					57.5	31.3	23.6	19.7	17.4	15.7	14.4	13.4	12.5	11.8	11.1	10.5	10.0	9.5	9.0
21					70.2	33.4	24.3	20.1	17.6	15.8	14.5	13.4	12.6	11.8	11.1	10.5	10.0	9.5	9.1
22					92.5	36.1	25.3	20.5	17.8	15.9	14.6	13.5	12.6	11.8	11.1	10.6	10.0	9.5	9.1
23					100.0	39.6	26.3	21.0	18.0	16.1	14.7	13.5	12.6	11.9	11.2	10.6	10.0	9.6	9.1
24					100.0	44.3	27.7	21.6	18.3	16.2	14.7	13.6	12.7	11.9	11.2	10.6	10.1	9.6	9.1
25						50.7	29.2	22.2	18.6	16.4	14.9	13.7	12.7	11.9	11.2	10.6	10.1	9.6	9.2
26						60.2	31.2	23.0	19.0	16.6	15.0	13.7	12.8	12.0	11.3	10.7	10.1	9.6	9.2
27						75.3	33.6	23.9	19.5	16.9	15.1	13.8	12.8	12.0	11.3	10.7	10.1	9.7	9.2
28						103.0	36.7	24.9	20.0	17.1	15.3	13.9	12.9	12.0	11.3	10.7	10.2	9.7	9.2
29						100.0	40.7	26.2	20.5	17.4	15.5	14.1	13.0	12.1	11.4	10.7	10.2	9.7	9.3
30						100.0	46.1	27.7	21.2	17.8	15.7	14.2	13.1	12.2	11.4	10.8	10.2	9.7	9.3

Decrease in yields in %. Hypothesis of 10 ºC rainfall reduction

Rainfall

Temperature	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
10			82.3	35.8	26.3	21.9	19.2	17.2	15.7	14.4	13.3	12.4	11.6	10.8	10.2	9.6	9.0	8.5	8.1
11			100.0	39.8	28.0	23.0	20.0	17.9	16.3	15.0	13.9	12.9	12.1	11.3	10.6	10.0	9.5	8.9	8.5
12			100.0	45.1	30.0	24.2	20.9	18.7	17.0	15.6	14.4	13.4	12.6	11.8	11.1	10.5	9.9	9.4	8.9
13			100.0	52.1	32.3	25.5	21.9	19.4	17.6	16.2	15.0	14.0	13.1	12.3	11.5	10.9	10.3	9.8	9.3
14				61.9	35.1	27.0	22.8	20.2	18.3	16.8	15.6	14.5	13.6	12.7	12.0	11.3	10.7	10.2	9.7
15				76.7	38.3	28.5	23.9	21.0	19.0	17.4	16.1	15.0	14.0	13.2	12.4	11.8	11.1	10.6	10.0
16				100.0	42.3	30.3	25.0	21.9	19.7	18.0	16.7	15.5	14.5	13.7	12.9	12.2	11.5	11.0	10.4
17				100.0	47.2	32.4	26.2	22.7	20.4	18.6	17.2	16.0	15.0	14.1	13.3	12.6	12.0	11.4	10.8
18				100.0	53.7	34.7	27.6	23.7	21.1	19.2	17.8	16.5	15.5	14.6	13.8	13.0	12.4	11.7	11.2
19				100.0	62.3	37.4	29.0	24.7	21.9	19.9	18.3	17.0	16.0	15.0	14.2	13.4	12.8	12.1	11.6
20					74.7	40.7	30.7	25.7	22.7	20.5	18.9	17.6	16.4	15.5	14.6	13.8	13.1	12.5	11.9
21					93.6	44.6	32.5	26.9	23.5	21.2	19.5	18.1	16.9	15.9	15.0	14.3	13.5	12.9	12.3
22					100.0	49.4	34.6	28.2	24.4	21.9	20.1	18.6	17.4	16.4	15.5	14.7	13.9	13.3	12.7
23					100.0	55.5	37.0	29.5	25.4	22.7	20.7	19.2	17.9	16.8	15.9	15.1	14.3	13.6	13.0
24					100.0	63.5	39.7	31.0	26.4	23.5	21.3	19.7	18.4	17.3	16.3	15.5	14.7	14.0	13.4
25						74.5	43.0	32.7	27.5	24.3	22.0	20.3	18.9	17.7	16.7	15.9	15.1	14.4	13.7
26						90.3	46.9	34.6	28.7	25.1	22.7	20.9	19.4	18.2	17.2	16.3	15.5	14.7	14.1
27						100.0	51.7	36.8	30.0	26.1	23.4	21.5	19.9	18.7	17.6	16.7	15.9	15.1	14.4
28						100.0	57.6	39.2	31.4	27.0	24.2	22.1	20.5	19.1	18.0	17.1	16.2	15.5	14.8
29						100.0	65.2	42.0	33.0	28.1	25.0	22.7	21.0	19.6	18.5	17.5	16.6	15.8	15.1
30						100.0	75.4	45.3	34.7	29.2	25.8	23.4	21.6	20.1	18.9	17.9	17.0	16.2	15.5

Decrease in yields in %. Hypothesis of 10 ºC rainfall reduction
1º C temperature increase

Rainfall

Temperature	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
10			100.0	49.6	36.6	30.6	26.9	24.2	22.2	20.4	18.9	17.7	16.5	15.5	14.6	13.7	13.0	12.3	11.7
11			100.0	54.7	38.6	31.8	27.7	24.9	22.8	21.0	19.5	18.2	17.0	16.0	15.0	14.2	13.4	12.7	12.1
12			100.0	61.2	40.9	33.0	28.6	25.7	23.4	21.6	20.0	18.7	17.5	16.4	15.5	14.6	13.9	13.1	12.5
13			100.0	69.9	43.6	34.5	29.6	26.4	24.0	22.1	20.5	19.2	18.0	16.9	15.9	15.1	14.3	13.6	12.9
14				82.3	46.8	36.0	30.6	27.2	24.7	22.7	21.1	19.7	18.4	17.4	16.4	15.5	14.7	14.0	13.3
15				101.1	50.6	37.8	31.7	28.0	25.3	23.3	21.6	20.2	18.9	17.8	16.8	15.9	15.1	14.4	13.7
16				100.0	55.4	39.9	32.9	28.9	26.0	23.9	22.1	20.7	19.4	18.3	17.3	16.3	15.5	14.7	14.1
17				100.0	61.5	42.2	34.3	29.8	26.7	24.5	22.7	21.2	19.9	18.7	17.7	16.8	15.9	15.1	14.4
18				100.0	69.3	44.9	35.7	30.8	27.5	25.1	23.2	21.7	20.3	19.1	18.1	17.2	16.3	15.5	14.8
19				100.0	80.0	48.1	37.4	31.8	28.3	25.7	23.8	22.2	20.8	19.6	18.5	17.6	16.7	15.9	15.2
20					95.1	51.9	39.2	33.0	29.1	26.4	24.3	22.7	21.2	20.0	18.9	18.0	17.1	16.3	15.5
21					100.0	56.6	41.3	34.2	30.0	27.1	24.9	23.2	21.7	20.5	19.4	18.4	17.5	16.7	15.9
22					100.0	62.3	43.7	35.6	30.9	27.8	25.5	23.7	22.2	20.9	19.8	18.8	17.9	17.0	16.3
23					100.0	69.6	46.4	37.1	32.0	28.6	26.1	24.2	22.7	21.3	20.2	19.2	18.2	17.4	16.6
24					100.0	79.2	49.6	38.8	33.1	29.4	26.8	24.8	23.2	21.8	20.6	19.5	18.6	17.8	17.0
25						92.4	53.4	40.7	34.3	30.3	27.5	25.4	23.7	22.2	21.0	19.9	19.0	18.1	17.3
26						100.0	58.0	42.9	35.6	31.2	28.2	25.9	24.2	22.7	21.4	20.3	19.4	18.5	17.7
27						100.0	63.6	45.3	37.0	32.2	28.9	26.6	24.7	23.2	21.9	20.7	19.7	18.8	18.0
28						100.0	70.6	48.1	38.6	33.2	29.7	27.2	25.2	23.6	22.3	21.1	20.1	19.2	18.4
29						100.0	79.6	51.3	40.3	34.4	30.6	27.9	25.8	24.1	22.7	21.5	20.5	19.6	18.7
30						100.0	91.6	55.1	42.3	35.6	31.5	28.6	26.4	24.6	23.2	22.0	20.9	19.9	19.1

***Fig. 7. 11**. Decrease in yields with hypotheses of different of temperature increase and reduced rainfall*

In the most critical areas, however, which could be classified as semiarid, with rainfall between 200 and 400 mm and annual mean daily temperatures of between 18 and 20ºC, the decreases in yields may be so serious that they could reduce the potential resources of the area by half.

In Spain, there are many areas with scarce rainfall and high temperatures, which determines a high level of sensitivity, in general terms, to the climate changes studied.

This type of calculation is purely orientational, used for analysing sensitivity, but they can be very useful for considering different scenarios.

7.2.3 Sensitivity to seasonal variations in rainfall and temperature

Water resources are not generated at one specific moment in time, and neither are they regular throughout the year. There are periods in which generation is possible, depending on temperatures and rainfall, and on soil saturation, among other factors.

Thus, the temporality of rainfall and temperatures has a greater effect on the generation of water resources, on many occasions, than the values of these two climatic parameters themselves.

In general terms and for most of Spain, water resources are generated in the coldest months or during those with the highest rainfall, provided that temperatures have not risen excessively. That is to say, in summer with high temperatures and evapotranspiration rates, most of the water the ground can retain is used by plants. The soil is dry, with a low saturation level, and no significant recharge or runoff occurs. In the cold months, evapotranspiration is very low and demand for water by plants is also very low, whereas excess yields saturate the soil and surpluses occur.

If temperatures only increase in summer, the volume of runoff will probably not decrease appreciably, as there will be no runoff either before or after the possible climatic change. The same reasoning is valid if we consider decreases in rainfall, but only for the summer months; it would make no difference in relation to water generation, unless there was a more accentuated water deficit resulting from irrigation.

The lack of knowledge of monthly distributions of rainfall and temperature prevents us from making orientational calculations. At a conceptual level, however, it could be said that the generation of water resources is qualitatively more sensitive to the way in which rainfall and temperatures are distributed throughout the year.

7.2.4 Sensitivity to external events; droughts and flooding

Assuming that changes in rainfall and in temperature were practically linear, an increase in temperature and a decrease in rainfall would combine to increase the frequency and severity of hydrological droughts. The increased demand for evapotranspiration related to warming would cause an increase in returns to the atmosphere, along with previous drier conditions of the soils during rainfall events, and a decrease in runoff and recharge of aquifers, along with reduced water quality, due to lower dilution. An increase in the frequency and severity of droughts in the last decade has been observed in some parts of the world, particularly in Africa and Asia. Furthermore, climatic models predict an increase in the frequency of drought for the near future, above all in medium-altitude areas (IPCC 2001).

Floods and inundations, however, do not follow this relatively simple pattern. A rise in temperature and a slight decrease in rainfall would have little influence on the frequency and magnitude of the floods. There is evidence, however, that extreme rainfall events have shown a slight increase in the last few decades in different parts of the world (IPCC 2001) and in particular in some sectors of the Pyrenees (Beguería 2003). Climate models are unsuitable for predicting inundations, as they are incapable of simulating the events at a suitable temporal scale. An increase in extreme rainfall events is believed to be very likely, as a result of accelerated climatic activity. Furthermore, in places where a significant part of the precipitation takes the form of snow, an advance in the melting season can be expected, as a consequence of global warming, which could lead to changes in the magnitude of the floods if the melting season coincides with a period of heavier rainfall.

Lastly, we should point out a few possible indirect effects of climate change on the generation of floods and soil erosion. In a scenario of global warming and increased summertime drought, degradation of the plant cover can be expected, along with increasingly frequent forest fires. These conditions could represent an increase in the frequency and severity of floods and of phenomena of soil erosion in small catchments.

7.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

7.3.1. Introduction to Climate-Hydrology

A modification of temperature or rainfall as a result of climate change would affect the hydric resources of a territory because, in the long term, the renewable resources of this are equal to the difference between rainfall and evapotranspiration.

If, in accordance with the climate models available for Spain, there is a slight decrease in annual rainfall and temperatures rise, there will be a future decrease in water resources.

Furthermore, the tendencies projected for Spain indicate greater temporal irregularity of precipitation, which would have negative consequences for the flood regime and for river regulation.

Not only are the quantitative aspects of water affected a change in climate, and a decrease in water quality can be accentuated along with a decrease in the amount of water. A lower volume of water available would cause water quality to fall and a drop in piezometic levels in aquifers, which would facilitate saltwater intrusion in coastal areas, which has also been favoured by the rise in sea level.

Some physical-chemical and biological processes in water depend on temperature, like, for example, blooms of algae, which would increase with temperature, thus producing greater oxygen consumption during decomposition. All of this can affect water quality in reservoirs, which would also be affected by the reduced oxygen concentrations and by reduced yields.

7.3.2. Definition of scenarios for defining impacts on water resources

7.3.2.1. Introduction

A scenario is defined as a plausible representation of a variable or set of variables in the future (world population, industrial activity, CO_2 emission, average sea level, temperature, precipitation, etc.), which can be based on different suppositions or on historic evolutions. Thus, a climate scenario is defined as a plausible representation of future climate (fundamentally related to the temperature and precipitation variables), which can also be based on other scenarios.

Given that there are numerous uncertainties related to the multiple factors regulating the behaviour of the climate system, it is not recommendable to use a climate scenario as if it were a short-term weather forecast. In this situation, it is advisable to represent future climate with the use of a range of projections covering a broad spectrum of uncertainties.

7.3.2.2. Types of scenarios

The climate scenarios used to evaluate the impact of a climate change on water resources are designed taking into account scocioeconomic aspects, and those related to land uses, environment or emissions, and they provide foreseeable changes in the variables intervening in the hydrological cycle. The ones most studied are temperature and rainfall, although other variables, such as solar radiation, wind speed or relative humidity can also be of great interest.

For evaluations of impacts on water resources, three different types of methodologies are used to define climate scenarios.

- *Incremental or synthetic scenarios* are simple adjustments of the reference climate (present climate), adapted to future climate changes on simples (increase by 1º or 5º in temperature, decrease by 5% or 10% in precipitation, etc…). These scenarios are occasionally based on the results of the scenarios produced by the *Modelos de Circulación General Acoplados Océano-Atmósfera* – ocean-atmosphere coupled general circulation models - (MCGA-OA).

- *Analogous scenarios* are the analogous representation of a climate that has undergone changes, based on previous records or on records from other regions.

- *The scenarios by the Ocean-Atmosphere Coupled General Circulation Models (OA-CGCM).* These are the most used ones at present and those that present the highest degree of reliability. They generate climate scenarios that indicate variations in relation to a reference climate, initially based on regional climate observations made by the Climate Research Unit, CRU, of the University of East Anglia in the United Kingdom, during the period 1961-1990. At present, these studies used for defining the reference climate have been extended to the 1900 – 1990 period.

7.3.2.3. Climate change scenarios for Spain

Figures 7.12 and 7.13 show the seasonal variations in temperature and rainfall obtained for Spain with 7 MCGA-OA models from different research institutes in different countries. For half way through the XXI century, these models project warming in Spain of between 1.0 and 5.0 °C and a decrease in rainfall of up to 40 mm in summer months.

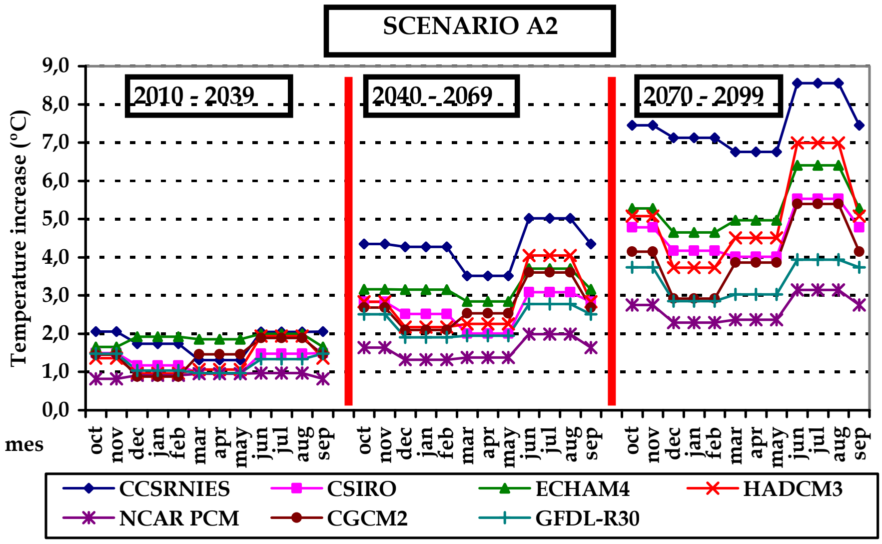


Fig. 7.12. *Temperature increase scenario A2 (IPPC).*

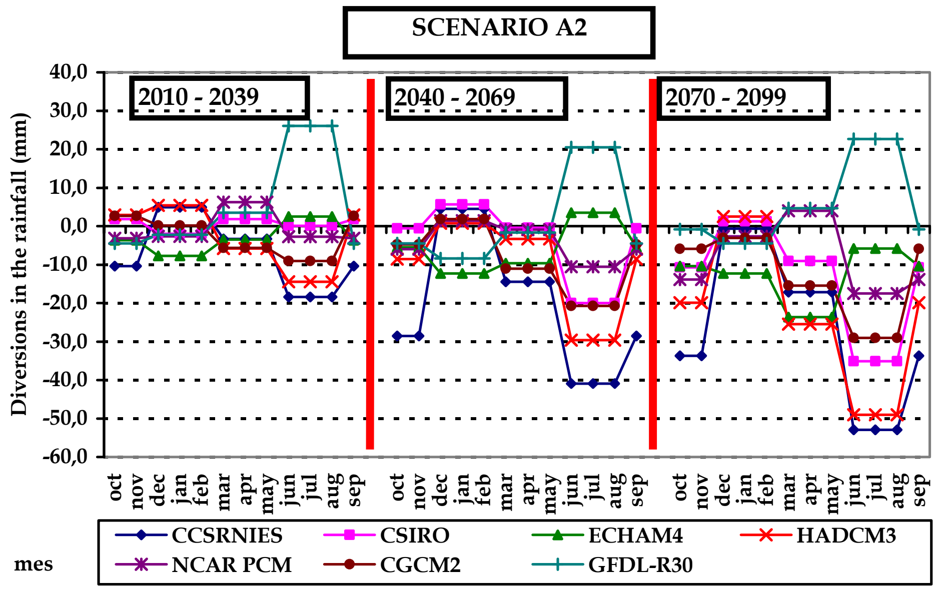


Fig. 7.13. *Variation in rainfall scenarios A2 (IPPC).*

The results of temperatures on the Iberian Peninsula, based on these global models, represent variations that are always positive, whereas in the case of rainfall, these variations are moderate and move in both directions.

One of the best known OA-CGCM models is model UKMO (United Kingdom Meteorological Model from the Hadley Centre for Climate Research in Bracknell, United Kingdom), which is a model that uses cells with a horizontal resolution of 2.5ºC x 3.75ºC in latitude-longitude (on the Iberian Peninsula it corresponds to cells of 280 km wide by 320 km high; see attached figure).

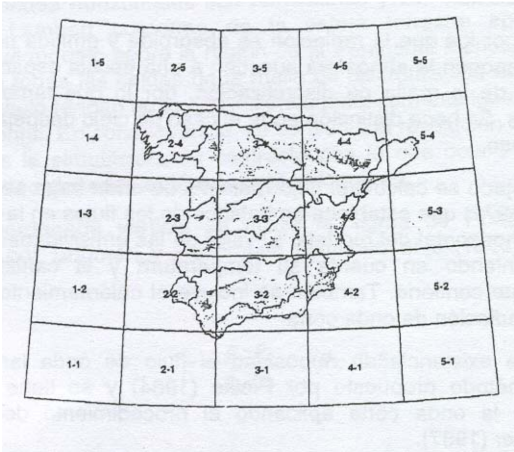


Fig. 7.14. *Diagram of the cells of UKMO model for Spain.*

The data used by this model come from two scenarios of future climate: the climate with the present CO_2 conditions ($1xCO_2$) and the equivalent climate with double CO_2 conditions ($2xCO_2$). In both cases, they belong to the same time interval, from 2040 to 2049, which correspond to the ten years after which the CO_2 doubles in the second scenario.

The outputs of the UKMO model consist of the monthly measurements of each year of maximum temperature (^oC), minimum temperature (^oC), rainfall (mm), wind speed (m s^{-1}) and relative humidity (%).

These climate scenarios are characterised in Spain by a temperature increase on doubling the concentration of atmospheric CO_2. Rainfall, however, increases in some cases and decreases in others, with seasonal differences, and there is generally a decrease in rainfall during summer months and an increase during the rest of the year (see table 7.4).

Table 7.4. *Summary of the results of the UKMO general circulation model for Spain.*

CELDA	TMAX		TMIN (ºC)		TMED (ºC)		PRECIP (mm)		SRAD(MJ/m2)	
	1xCO2	2xCO2	1xCO2	2xCO2	1xCO2	2xCO2	1xCO2	2xCO2	1xCO2	2xCO2
2-2	22,6	26,5	11,5	15,1	17,0	20,8	347,1	402,9	7360,6	7079,1
2-3	18,8	22,6	8,7	12,1	13,8	17,4	749,7	853,8	6198,5	6170,5
2-4	14,1	17,4	7,0	9,8	10,6	13,6	1502,1	1502,7	4254,2	4492,9
3-2	19,2	23,6	8,3	12,1	13,8	17,8	594,0	528,0	6638,2	6684,6
3-3	14,8	19,2	5,5	9,0	10,1	14,1	950,7	860,4	5205,0	5702,4
3-4	12,7	16,1	5,5	8,5	9,1	12,3	833,4	662,1	4356,0	4843,6
4-2	19,5	22,7	17,0	20,1	18,2	21,4	118,8	94,5	8872,0	8472,6
4-3	17,7	21,4	8,1	11,7	12,9	16,6	345,0	345,3	6665,4	6478,6
4-4	12,9	17,0	5,6	8,9	9,2	12,9	1043,7	892,2	4200,1	4786,0

Valores medios del período 2040-2049

CELDA	TMAX		TMIN (ºC)		TMED (ºC)		PRECIP (mm)		SRAD(MJ/m2)	
	F-A	F/A	F-A	F/A	F-A	F/A	F-A	F/A	F-A	F/A
2-2	3,9	117,3	3,6	131,3	3,8	122,4	55,8	116,1	-281,5	96,2
2-3	3,8	120,2	3,4	139,1	3,6	126,1	104,1	113,9	-28,0	99,5
2-4	3,3	123,4	2,8	140,0	3,0	128,3	0,6	100,0	238,7	105,6
3-2	4,4	122,9	3,8	145,8	4,0	129,0	-66,0	88,9	46,4	100,7
3-3	4,4	129,7	3,5	163,6	4,0	139,6	-90,3	90,5	497,4	109,6
3-4	3,4	126,8	3,0	154,5	3,2	135,2	-171,3	79,4	487,6	111,2
4-2	3,2	116,4	3,1	118,2	3,2	117,6	-24,3	79,5	-399,4	95,5
4-3	3,7	120,9	3,6	144,4	3,7	128,7	0,3	100,1	-186,8	97,2
4-4	4,1	131,8	3,3	158,9	3,7	140,2	-151,5	85,5	585,9	113,9

Diferencia (F-A) y relación (F/A) entre clima con doble (F) y simple (A) CO2

Although with the knowledge currently available, the OA-CGCM do not project a sufficiently accurate response of the climate systems to a variation in concentrations of atmospheric CO_2 and other GGs (greenhouse gasses), they are, however, the only tools available for obtaining patterns of climate response to different exogenous influences, and for this reason, increasingly accurate methods and processes are being developed in order to incorporate them into the existing ones. Most of these models solve similar equations, but there are differences with regard to temporal resolution, the physics of interconnections, treatment of clouds, representation of the ocean, etc., which accounts for some of the discrepancies in their results.

In order to answer questions about the impacts of a possible climate change on the water resources of a territory, increasingly greater temporal and spatial resolutions are needed, along with information on a higher number of variables (evapotranspiration, maximum and minimum temperatures, runoff, etc.), and it does not seem reasonable to demand this from the OA-CGCM. This is why regional climate models are being designed.

The PROMES model (Mesoscale Prognosis) is a regional model of primitive equations, hydrostatic and completely comprehensible. PROMES comes from the output fields of the GCM of the Hadley Centre for Climate Prediction and Research, known as HadCM2.

The basic objective of the regional climate model PROMES is to generate the necessary atmospheric fields to be uses as an input for the different models simulating hydric resources or for some other specific arda, both for current climate conditions (1xCO_2) and for a climate scenario considering a carbon dioxide concentration in the atmosphere which is double the existing one (2xCO_2).

The 1xCO_2 simulation took 10 years, which is a compromise between the convenience of 30-year simulations (time period considered ideal for characterising a climate) and available calculation resources.

The horizontal resolution used is uniform, and all the cells horizontal dimensions of $\Delta_x = \Delta_y =$ 50 km. The simulation region for Spain comprises 45x39 cells, including the border ones (figure 7.15).

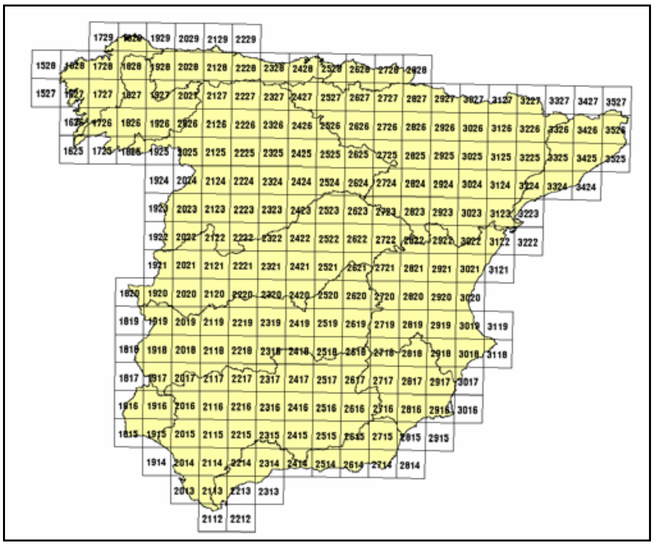


Fig. 7.15. *Calculation cells of the PROMES model.*

The CEDEX (1998) carried out a study to research the effects of climate change on water resources and water demand, in which the PROMES model was used to simulate climate scenarios. Figure 16 shows the mean daily temperatures in autumn simulated with PROMES for scenarios 1 x CO2 and 2 x CO2.

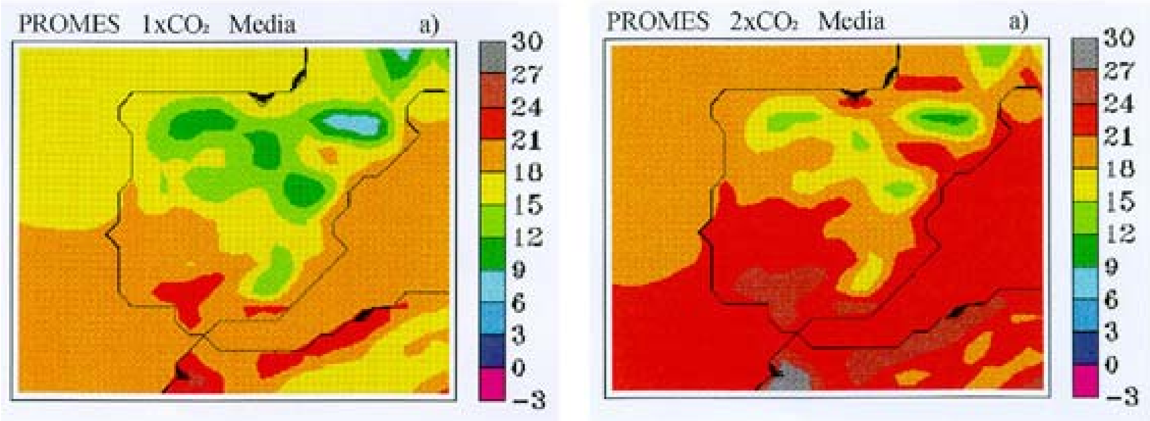


Fig. 7.16. *mean daily temperature at 2m in autumn: left). Simulation average 1 x CO2 PROMES, right). Simulation average 2 x CO2 PROMES (taken from CEDEX 1998).*

This study compared climate simulations generated by the PROMES model with those corresponding to the CRU climatology (Climate Research Unit) (Hulme et, al 1995), and concluded that the rainfall values of simulation 1xCO_2 (present situation) are generally higher than the results obtained for the CRU climatological unit (1998). The difference in rainfall, is more relevant in mountain areas. With regard to temperature in scenario 1xCO_2 in most regions of the Peninsula, these are higher than the results obtained by the CRU climatological unit (1998), varying from 1 to 3 degrees centigrade.

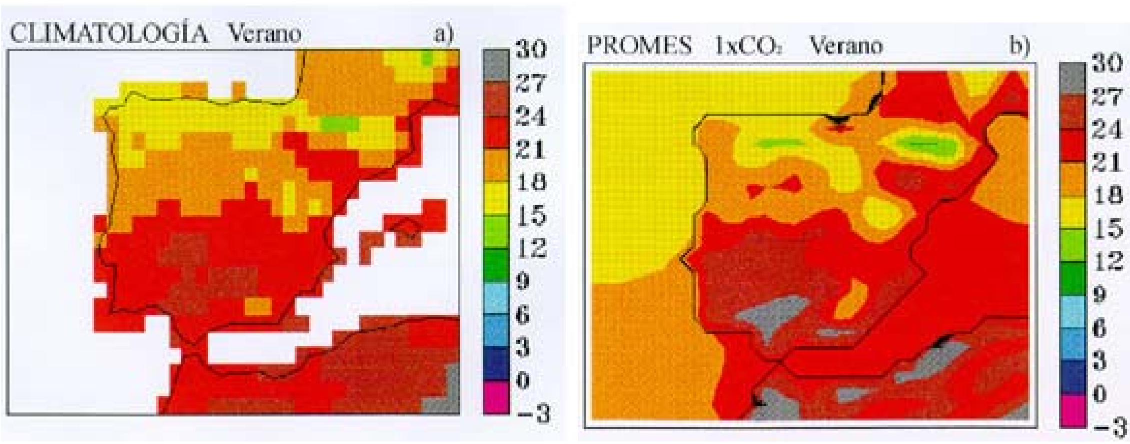


Fig. 7.17. Mean daily temperature at 2 m altitude in summer, a) CRU climatology, b) Simulation 1 x CO2 PROMES (taken from CEDEX 1998).

In general, PROMES overestimates both rainfall and temperature in the present situation, and the values for the future situation (2xCO_2) will probably also be overestimated. The remaining values used in the studies by the CEDEX, such as relative humidity, wind and radiation, were not contrasted, but there is evidence that greater uncertainty exists for these than for temperature and rainfall.

7.3.3. Evaluation of impacts on water resources in Spain

7.3.3.1. Introduction

The ACACIA Report by the European Commission on the Impacts of Climatic Change (1999) assumes for Europe that:

- The present and future pressures on water resources and on the management of these will be exacerbated by climate change (partly because the effects are uncertain). The risk of flooding will probably increase, and an increase in water scarcity is predicted, particularly in southern Europe. Climate change will probably exaggerate the differences in water resources between northern and southern Europe.
- In coastal areas, there will be a substantial increase in the risk of flooding, erosion and loss of wetlands, with implications for human colonisation, industry, tourism, agriculture and coastal natural habitats. Southern Europe seems to be more vulnerable to these changes.
- In mountain areas, the higher temperatures will cause the border between biotic and cryospheric zones to rise in altitude, thus disturbing the hydrological cycle. There will be a redistribution of species with risk of extinction in some cases

These conclusions by he ACACIA Report highlight the need to quantify the effects of climate change on water resources in Spain. The evaluation of these impacts in our country has followed different lines of work, in relation both to the temporal and spatial scale of the hydrological simulation and to the origin of the climate scenarios used. A description is now given of the different evaluations, arranged a lower to a higher degree of complexity of the modelling used.

7.3.3.2. Regional aggregated models

Given that an initial step involves long-term knowledge of the mean values of the main hydrological variables, application of regional laws expressing in annual averages rainfall, potential evapotranspiration (function of temperature) and total runoff, could provide a general view of the scope of the problem.

With this approach Ayala and Iglesias (Ayala-Carcedo et.al 2001), use an aggregated model for each of the big catchments into which Spain is divided, based on the use of annual regional laws. With regard to scenarios of climate change, they consider the predicted changes in relation to mean annual rainfall and temperature, provided by the National Meteorology Institute in 1995, based on the model Hadley Center (UK) from 1990, in which, on the 2060 horizon, mean annual temperature will rise by 2.5^0C and mean annual rainfall will decrease on the Peninsula by 8%.

These authors estimate that climate change will cause a global reduction of water resources by 17%, along with an increase in the interannual variability thereof, for the year 2060 (mean project horizon for big waterworks) and that these changes will be greater in the southern half of Spain. In order to obtain these values, a lumped conceptual model was applied, and the 1940-85 was used as a base.

7.3.3.3. Regional distributed models

Subsequently, the White Paper on Water in Spain (MIMAM 2000) maintained the approach related to the application of regional laws, but using a model distributed in space. Thus, a substantial improvement is attained of the results, on introducing the spatial variability of both rainfall and temperatures and of the physiographic features of the catchment.

The impact on the mean annual runoff derived from the different climate scenarios was estimated in MIMAM(2000) by means of the application, in a distributed fashion (1 km x 1 km cells), of Budyko's regional law (1961), which related runoff (A) with precipitation (P) and potential evapotranspiration (PET). This law had already been used in an experimental analysis applied to Spanish catchments with different climatic and hydrological features (Estrela *et al*. 1995). Previous to application, MIMAM (2000) contrasted the adjustment of this law to the data observed at 130 gauging points distributed throughout Spain (figure 7.18).

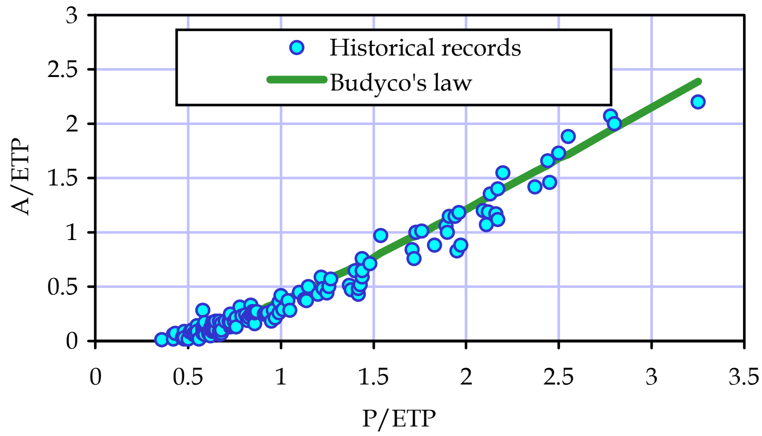


Fig. 7.18. *Relationships between yield, precipitation and PET at the gauging points (adapted from MIMAM 2000)*

The climate scenarios used in the White Paper on Water in Spain come from the climatic fields reflected in the document National Programme on Climate (MOPTMA 1995), which indicated that:

- A duplication of CO_2 could cause an increase in mean annual temperature, ranging from 1°C (analysis of response in transition) to 4°C (better estimate of the analysis of the response in balance), although these increases would be slightly greater in summer.
- There could be general decreases in the values of mean annual rainfall of between 5% and 15%, these being more likely in the southern half of the Peninsula. There may be a tendency towards temporal concentration of precipitation, along with greater annual and interannual variability.

Without ruling out the necessary precaution and uncertainties associated with the problem, the most likely evolution of the climate on the Spanish Peninsula, resulting from these analyses, was synthesised by MIMAM (2000) in the following temperature and precipitation scenarios, considered to be representative in the hypothesis of CO2 duplication, predicted for 2030.

1. Scenario 1. 1°C increase in mean annual temperature.
2. Scenario 2. 5% decrease in mean annual rainfall and a 1° C temperature increase.

3. Scenario 3. (unlikely extreme scenario) assuming a 15% decrease in mean annual rainfall and an extreme 4% temperature increase.

The most recent results related to rainfall on the Iberian Peninsula, based on global models, produce very moderate variations in precipitation, as our zone is situated in an area presenting a change of sign of the variation expected for precipitation, which means that in all the experiments, the line of zero change cuts across the Iberian Peninsula. This could imply more favourable hydrological conditions than the previously expounded ones.

From the analysis by MIMAM (2000) we can conclude that the catchments of Guadiana, Canarias, Segura, Júcar, Guadalquivir, Sur and Baleares (see figure 7.20), are those that would suffer the most severe impact on water resources. The climate scenarios (1 and 2) indicate an average decrease in water yields in Spain, in natural regime, of between 5 and 14%.

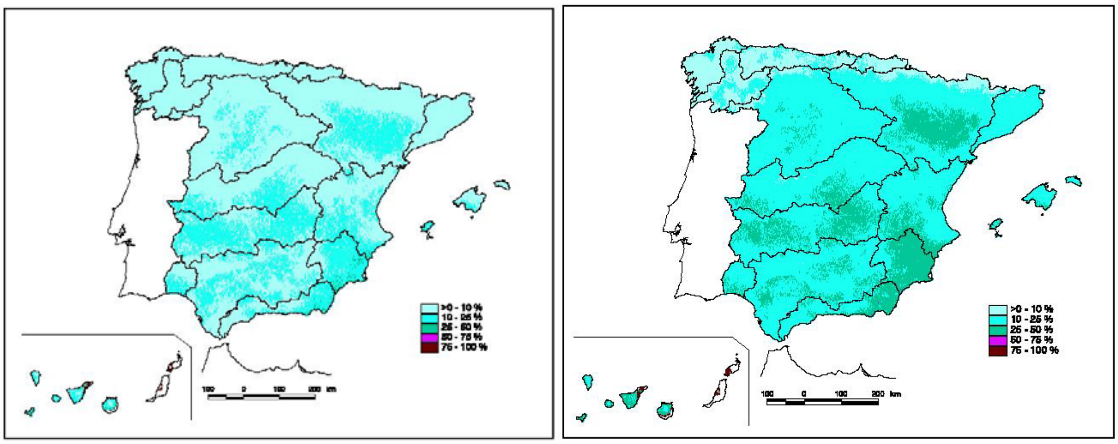


Fig. 7.19. *Map of percentage distribution of runoff for scenario 1 and in scenario 2*

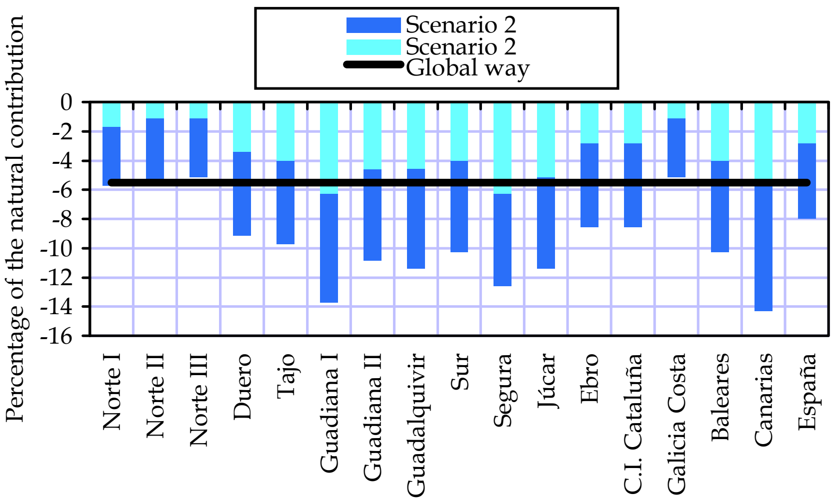


Fig. 7.20. *Percentages of decrease in total yields, for the climate scenarios considered, in long-term catchment management plans.*

7.3.3.4. Distributed models of simulation of the hydrological cycle

The distributed models of simulation of the hydrological cycle, such as the SIMPA model used in the White Paper on Water in Spain for the evaluation of hydric resources, establish hydric balances for the different processes taking place from the moment it rains until the waters runs off, whether on the surface or underground, and they estimate yields with the use of meteorological data (rainfall, potential evapotranspiration, etc.) and data on the physical characteristics of the territory (vegetation, hydrogeology, edaphology, etc.).

In this line of work, we should mention the studies carried out by the CEDEX's Centre of Hydrographic Studies (1998) or by Fernández (2002).

In the studies developed by the CEDEX in their "Study of the potential impact of climate change on water resources and demand for irrigation in determined regions of Spain" for the Environment Ministry (MIMAM 1998), three groups of climate scenarios were used for the hydrological simulations:

- Analysis of the sensitivity of climatic variations:
    - scenario 1. An increase by 1°C in mean annual temperature.
    - scenario 2. A decrease by 5% in mean annual rainfall and a 1° C temperature increase.
- General climate scenarios. From general circulation models, UKNMO model.
- Regional climate scenarios. Results of the PROMES regional climate model, considering increases in temperature and maintaining precipitation the same as at present.

Using the SIMPA (integrated system for modelling precipitation- yield) distribute rainfall-runoff model they obtained runoff maps for each scenario (see map corresponding to PROMES results in figure 7.21) and the percentage variables of runoff in relation to the present situation.

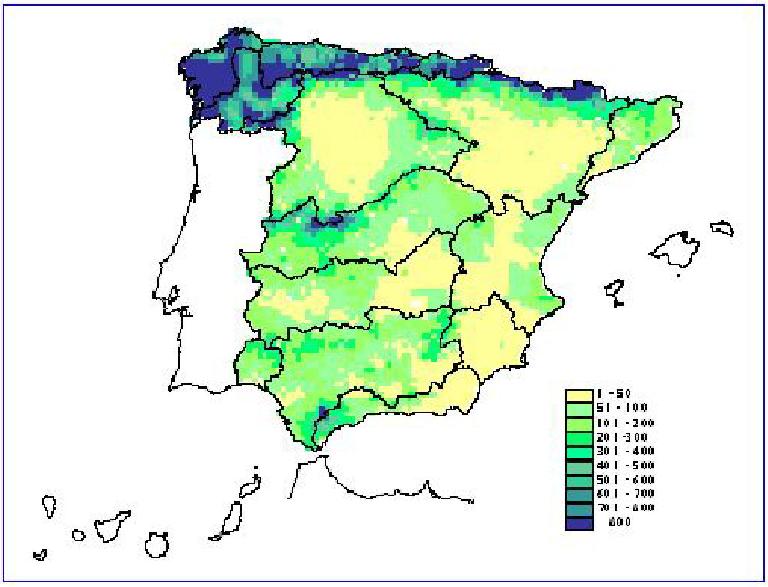


Fig. 7.21. *Map of total mean annual yield in mm, in the hypothesis of climate change resulting from the PROMES model.*

The analysis led to the following conclusions:

1) In Spain, there will be average decreases in total mean annual yield, ranging from 5% for scenario 1 to 14% for scenario 2 and regional scenario 3.
2) The Southeast of the Peninsula and the islands are the areas that will suffer the severest impacts on water resources. In scenario 1, the decrease in total yield will range from 2% (Galicia Costa and Norte I) and 11% (Guadiana and Segura), whereas in scenario 2, these percentages rise to 9% (Galicia Costa and Norte) and just over 25% (Canary Isles).
3) In the adopted regional scenario, total yield will range from 5% in Galicia Costa, and 22% in Guadiana II, with values similar to those of scenario 2, except in the Júcar catchment 15% compared with 20% for scenario 2, and the Catalonia internal catchments 20% compared with 15% for scenario 2.

The aforementioned study concludes that the results should not at all be taken as final, as these depend on the basic hypotheses adopted.

Fernández (2002), developed a methodological procedure to evaluate the impact on resources in Spain using hydrological modelling distributed at a monthly scale, together with the use of climatic fields created by regional models of climate change. He applied this procedure to 19 catchments distributed throughout Spain.

The future climate scenarios adopted were obtained by modifying the monthly precipitation and rainfall for the 1945 - 1995 period, with the difference in rainfall and temperature results obtained by the PROMES climate model in simulations 1xCO_2 and 2xCO_2 for the mean values of the 2040 – 2049 period.

This study also considers other simulations corresponding to different climate scenarios, such as those mentioned in MIMAM (2000) and others that they considered to be of interest. .A total of 15 hydrological simulations were made, presented in three main groups:

a) Nine annual simulations using Budyko's regional law (Schreiber *et al*. 1978) at annual scale.

b) Six monthly simulations using the distributed hydrological model SIMPA.

For the simulation at annual scale, use was made both of climatic fields (synthetic scenarios obtained by reducing precipitation in a set proportion and raising temperature by one or several degrees in relation to the base period) and scenarios generated by the PROMES model. In the simulations at monthly scale, climatic fields generated by the UKMO global climate model and by the PROMES regional climate model were used.

One of the important conclusions of this study lies in the significant differences obtained between the annual yields simulated with a model simulating monthly hydrological series over long time periods, such as SIMPA, and with the use of regional laws that only consider annual data or interannual averages, such as Budyko's. This discrepancy clearly shows that the simulations at annual scale are not appropriate for describing the variations in the yields caused by changes in rainfall and temperature, as they do not take into account the distribution of these throughout the year, a factor which, in the PROMES simulations used, has proven to be fundamental in the evaluation of the impact of climate change on water resources.

7.3.3.5. The impact of climate change on resources in catchment management.

Assessment studies of climate impact on water resources were not taken into account, in a specific manner, in the catchment management plans approved in Spain in the year 1998. The first time that this type of study was considered in certain detail was in the drafting of the Technical Documentation of the National Hydrological Plan (NHP). The complex question of water transfers between catchments required an evaluation of a possible decrease in water resources, due to climate change, in the catchments selected to yield resources.

The NHP considered the different reduction bounds in the yields obtained in the White Paper on Water (MIMAM 2000) for the different catchments, with an increase in the global recommended value, and the simultaneous introduction of an effect of greater irregularity in the values of the monthly series used. This was used for the possible catchments selected to yield resources, the Duero, Tajo and Ebro.

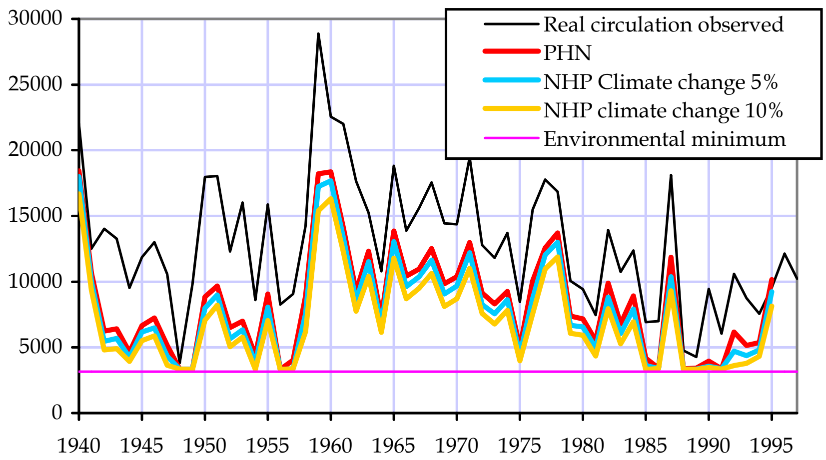


Fig. 7.22. *Circulation of annual flows (hm3) in the final section of the Ebro in suppositions of climate change.Hypothesis of 5 and 10% reduction. (taken from the DT of the NHP).*

In the case of the Ebro catchment, the bound corresponding to the two scenarios, according to the Spanish White Paper on Water, is between 3 and 9% of decreased yields.

Upon this basis, the analysis document of the Ebro system, drafted in the NHP, evaluated the annual flows in the lower section of the river in suppositions of 5 and 10% reductions of the water yields of the whole catchment.

As a result of this evaluation, figure 7.22, taken from the document *Systems Analysis* in the NHP, shows the circulation of annual flows really observed in the final section of the Ebro, together with the series of simulated circulation, adopted in the NHP, and the resulting circulations following a generalised 5 and 10% decrease in natural yields.

7.3.4. Integrated evaluation of the impacts of climate change on complex water resources systems

The methodological process for the integrated evaluation of the impacts of climate change on complex water resources systems requires the use of different sequentially nested simulation models. This is due to the high level of complexity and of interaction of the different elements making up the water resources systems, with regard to both their quantitative aspects and those related to the chemical and ecological quality of the water and to socioeconomic repercussions.

The sequential process is based on the selection of the results of the different climatological scenarios existing for Spain, both the ones provided by the Ocean-Atmosphere Coupled

General Circulation Models (OA-CGCM) and by the regional climate models providing these results with a higher degree of spatial detail. The climatological variables resulting from the models are the predicted variations in temperature and rainfall.

An important part of the evaluation of the impacts of climate change on water resources involves the selection of scenarios, among which are the incremental or synthetic ones, which can provide valuable information on the sensitivity of the system to future climate. The increments of these scenarios can sometimes be done taking as a guideline the results of the outputs of the General Circulation Models proposed by the IIPCC in its section on worldwide regionalisation, choosing those corresponding to Spain. Another way to evaluate water resources is using the scenarios of the regional models, whether these be HadCM2SUL, UKMO or PROMES, thus providing a wide range of scenarios, enabling the results of each one to be assessed at the precise moment, and permitting analysis of the results for different seasonal periods, in order to establish both global effects and those resulting from seasonal variations in rainfall and temperature and the possible effects of these on water resources.

Having selected the set of scenarios, the next methodological step involves simulating the hydrological cycle by means of a distributed rainfall-runoff model, encompassing the whole catchment at monthly temporal scale. This rainfall-runoff model would establish the place and proportion in which hydric resources would be reduced and to analyse how the different components and water storage would be affected, for instance, the piezometric levels of aquifers or the humidity of the soil in the upper layers (closely related to dry farming). Furthermore, if these models include the transport of certain chemical components dissolved in the water, it would be possible to evaluate the variations in chemical quality of the water resulting from climate change.

Having analysed the quantitative repercussions, and to a certain extent, the qualitative ones in catchments, the following process would consist of the simulation or optimisation of water resources management with the use of currently available models, such as SIMGES or OPTGES (Andreu *et al*. 1996). These models allow for the reproduction of water resources management and the evaluation of the guarantees or shortcomings occurring in urban and agricultural demand, and in ecological flows and environmental reserves set up within these systems. It is thus possible to establish the future effects of a decrease in hydric resources on the water resources system. Figure 7.23 shows the management simulation model for the Júcar system.

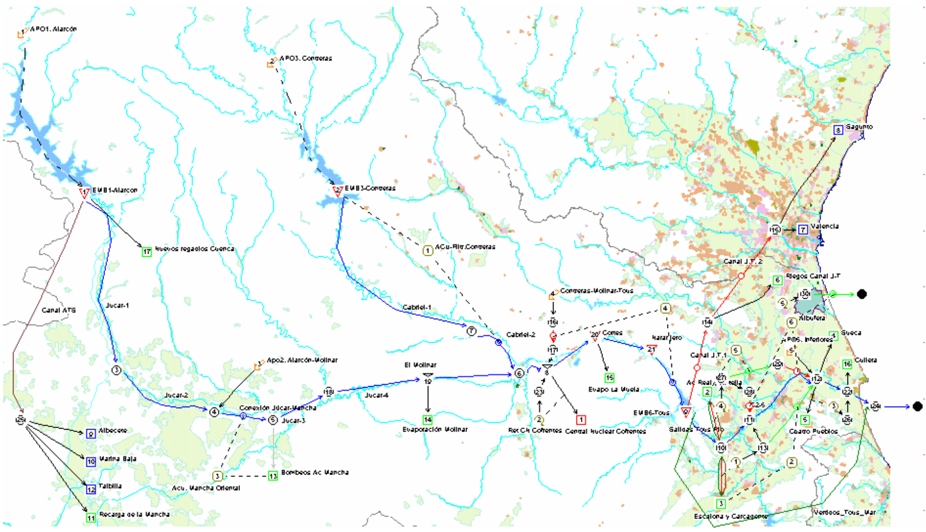


Fig. 7.23. *Management simulation model of the Júcar system.*

These models also incorporate an economic evaluation model, and a chemical and ecological quality management model, which include a model of dissolved oxygen, organic matter, conservative pollutants and of pollutants with first order decomposition. With the use of these models, the economic consequences can be established, along with the variations in water quality associated with the different management policies.

The integrated evaluation and detailed quantification of the impacts of climate change require the sequential use of different simulation models, which have been validated in recent years through day-to-day use in the spheres of both planning and management of catchments. Without the use of these tools, it is difficult to obtain objective detailed results, mainly due to the fact that the high number of simplifications necessary to deal with the problem could lead to unreal conclusions.

Garrote *et al*. (1999) evaluated the necessary increases in reservoir capacity resulting from the impacts of climate change. This study calculated the increased capacity needed in reservoirs to maintain the water resources system at the same level of current availability (1999), assuming scenarios involving a reduction of the series of yields caused by climate change.

These authors used the climate scenarios and the evaluation of water resources from the White Paper on Water in Spain. The climate scenarios used correspond to a mean annual temperature increase of between 1º C and 4º C and general decreases in mean annual rainfall values of between 5% and 15%.

Analysis of the necessary increase in regulation capacity in Spain was done with the use of the optimisation model of each one of the catchments in the spheres of planning on the Peninsula, using the OPTIGES programme. This model was used to estimate the maximum demand that can be satisfied at each node, fulfilling the following guarantee criterion, according to which, a failure is considered to exist in one of the following three situations:

1. Annual deficit of over 50% of annual demand.
2. Deficit for two consecutive years of over 75% of annual demand.
3. Deficit for 10 consecutive years of over 100% of annual demand.

In the scenario of moderate climate change, the reduction in yields on the Spanish Peninsula is by 5%, which is a reduction of 4% of the available resource. In the specific case of the Segura catchment, this decrease would reach 9%.

In the scenario of more severe change, the joint reduction of yields is 14%, with a decrease in the available resource of 11%. According to field of activity, Guadiana I is subjected to the greatest decrease in yields, with 24%. In the Segura catchment, however, there is a 22% decrease in yields, which constitutes the biggest decrease in available resources: 18%.

7.3.5. Impacts on the social and economic environment in relation to water resources.

Many of the Earth's systems sustaining human societies are sensitive to climate and to the conditions of water resources, and will therefore suffer the impacts of changes thereof. Impacts can be expected in the circulation of oceans, sea level, water cycle, carbon and nutrient cycles, the productivity of natural ecosystems, agricultural productivity, pastures and forests and the behaviour, abundance and survival of plant and animal species, etc.

The changes in these systems in response to variation in water resources will affect human wellbeing, both positively and negatively. The impacts on human wellbeing will be felt through changes in water supply and demand, changes in the opportunities for using the environment for recreational purposes and tourism, consumption aside, changes regarding the "non-use" of

the water environment in relation to culture or preservation, changes related to the loss of property and lives resulting from extreme hydrological events, and changes in human health.
The impacts of climate change on water resources will affect perspectives for sustainable development in different parts of the world, and may lead to an increase in existing inequalities, because, as a general rule, the more arid countries are the ones most affected by these changes.

In some contexts, the impacts of climate change can cause social strife, economic decline and population displacements which could affect people's health. There may be substantial impacts on health, related to population displacement resulting from desertification processes, natural disasters or from environmental degradation.

The negative impacts of climate change will generally affected the more vulnerable, lower-income populations, predominantly in tropical and subtropical countries.

There are many specific conventional and advanced techniques that can contribute to improving the ordination and planning of the water environment, including instruments based on the market, aimed at combating pollution, demand management, environmental impact assessment, strategic environment plans, environmental auditing procedures and reports on the state of the environment.

An increase in the frequency and magnitude of extreme events could have adverse effects on all sectors and regions. Agriculture and water resources can be particularly vulnerable to changes in hydrological extremes and temperature changes. Floods can lead to the spread of disease transmitted by water and by vectors, in particular in developing countries. Much damage and financial loss caused by extreme events will have repercussions for a wide range of finance institutions, from insurance and reinsurance companies to investors, banks and funds for disaster aid. Changes in the statistics of extreme events have consequences for the design criteria of technical applications, which are based on probabilistic estimates.

Climate change can reduce water availability in certain regions subjected to hydric stress and increase it in others. In the municipal and industrial sectors, certain factors that do not depend on climate will probably have a great effect on water demand. Irrigation, however, is more conditioned by climate, and an increase or decrease in a determined zone depends on changes in precipitation. If temperatures are higher, there will be a greater demand for crops, resulting from evapotranspiration.

7.4. MOST VULNERABLE AREAS

7.4.1 Concept and criteria of vulnerability

The vulnerability of a territory to variations in hydric resources is closely related to the uses occurring therein. One same geographic space is more vulnerable when its water needs are greater, as with the guarantees it requires. A territory will be much more vulnerable, in equal conditions with regard to demand volume, if this volume is used for urban supply, as opposed to for irrigation, because in the latter case, the guarantees of supply are less demanding.

In general terms, the territories with greater "hydric stress" should be considered the most vulnerable to possible variations in water resources.

There are many indicators of hydric stress, most of these related to water demand and to renewable hydric resources. The following section shows two indicators of hydric stress for the whole of Spain: the deficits between consumer demand and potential resources and the so-called consumer index, calculated as the quotient between consumer demand and potential resource.

7.4.2. Vulnerability to variations in hydric resources in Spain

An indicator of the vulnerability of the different territories in Spain can be obtained by establishing the balance between the maps of potential resources and consumer demand.

Potential resource is understood as the non-reserved part of natural resources plus the resources from the desalinisation of seawater and the existing transfers.

The map of consumer demand can be obtained by applying to the demand for irrigation 80% and for urban and industrial demand, 90%, along a 10 km stretch along the coast of the Peninsula, 80% along the same stretch of coast on the islands and 20% in the rest of the territory, thus reflecting the different possibilities for direct or indirect reuse of resources.

These criteria were applied in the drafting of the White Paper on Water in Spain (MIMAM 2000), and a map of balances was obtained in each one of the resources systems in Spain's catchments. The balance, aggregated according to resources systems, presupposes the full use of the potential resources generated throughout the whole territory. as well as, where pertinent, resources from the desalinisation of seawater and from transfers from other systems. This represents a maximum level of use, which requires a series of infrastructures, along with the necessary quality conditions. Figure 7.24 shows the water resources system with a deficit.

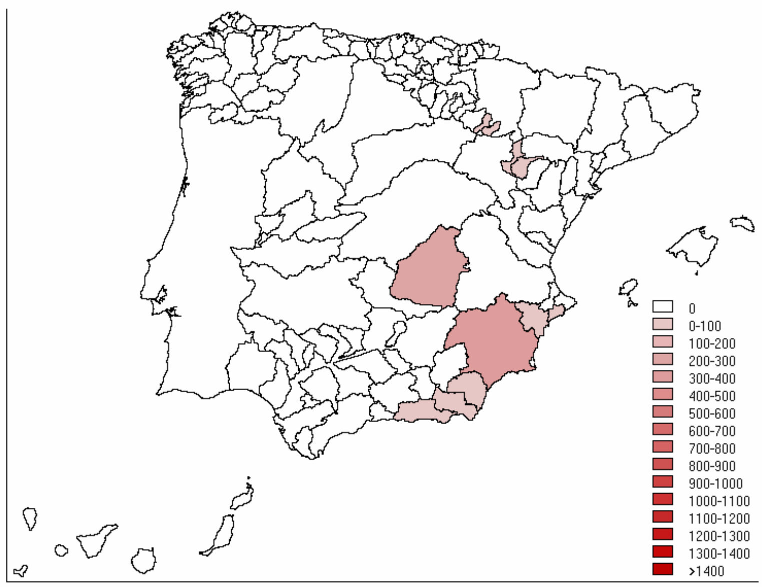


Fig. 7.24. *Deficit map (hm3/year) in the water resources system (taken from MIMAM 2000)*

The previous map shows that the deficits are located mainly in the Segura, the headwaters of the Guadiana, Vinalopó-Alacantí and Marina Baja in the Júcar, the east of the Sur catchment, together with other smaller systems on the right-hand bank of the Ebro. Although all these systems show a deficit, the magnitude of the problem is obviously very different, and the deficit of the systems on the right-hand bank of the Ebro, of great local importance, cannot be compared with that of the headwaters of the Guadiana or with the set of southern systems made up of the Júcar, the Segura and the eastern Sur systems, with a clearly greater territorial impact and dimension (MIMAM 2000).

This map can, however, give rise to erroneous interpretations, because, as we are dealing with absolute figures, these are conditioned by the size of the systems, which varies greatly from case to case. In order to avoid this, MIMAM (2000) designed the so-called consumption index, relating consumer demand to potential resources. This index is the basis of the following map of risk of scarcity, which could be a good indicator of the degree of vulnerability of the different water resource systems in Spain to variations in water resources. The most vulnerable ones are those classified as structurally scarce, followed to a lesser extent by those classified of momentary scarcity.

Figure 7.25 shows that the systems with a deficit suffer from a structural type of scarcity, that is to say, the potential resource, including reuse, desalinisation and transfers, is systematically lower than the consumption level to be reached. But there is also a series of systems which, although they present a surplus, run the risk of suffering a momentary type scarcity, due to the fact that their consumption levels are relatively close to the potential resource level. In these conditions, adverse hydrological sequences could cause supply problems due to insufficient resources.

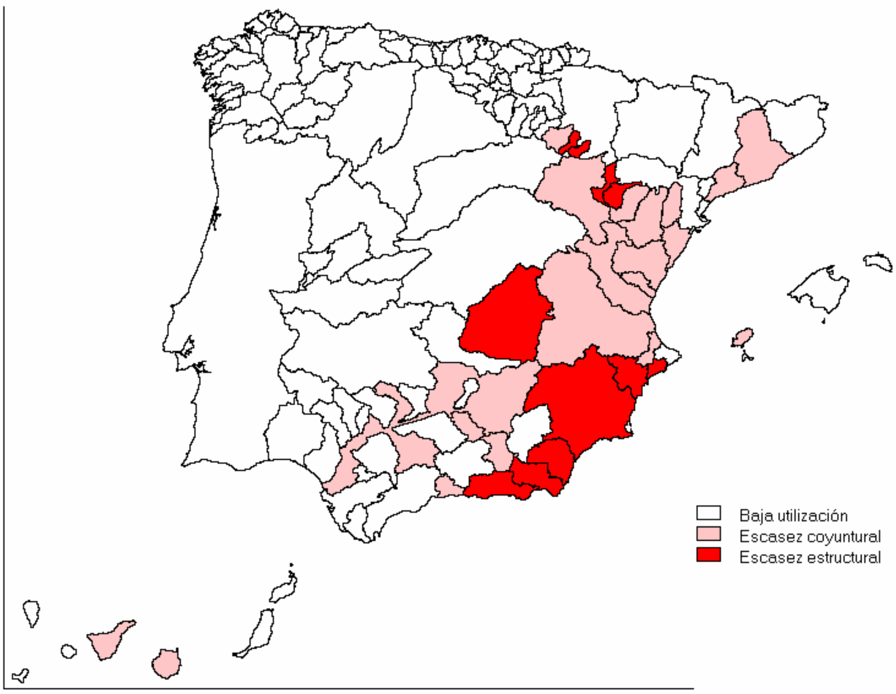


Fig. 7.25. *Map of risk of scarcity of the resource systems (taken from MIMAM 2000)*

As can be seen, a large part of the systems in the south-eastern half of the Peninsula, together with some systems on the right-hand bank of the Ebro, part of Catalonia and some islands, are subjected to a scarcity of resources of the structural or momentary type, even in the hypothetical case of maximum use of potential resources, including desalinisation and transfers and a maximum degree of reuse.

7.5. MAIN ADAPTIVE OPTIONS

7.5.1. Concepts and classification of the mitigatory effects of the decrease in water resources.

From the previous sections, we can highlight three main impacts of climate change on hydrological cycles: 1) global warming will cause an increase in water demand by terrestrial ecosystems and by agriculture systems 2) climate change will most likely cause a reduction of available water resources in most of the catchments, and 3) extreme events will most likely become accentuated: droughts and flooding.

In order to deal with this increased pressure on water resources systems, which are already above the overexploitation levels in most of the catchments, three types of adaptive options can be proposed (see, for example, MMA 1998): increased supply, demand management and improved systems management.

The first one is based both on traditional actions (increased reservoir volumes, transfers) and on alternatives which have not yet been sufficiently developed (groundwater) and on the development of unconventional resources (rainwater catchment, desalinisation, reuse). The second one is based on reducing consumption by means of different procedures, such as policies related to tariffs or subsidies (canalisation, irrigation). The third one lies in improving knowledge of climate and hydrological systems and perfecting and applying instruments for resources management, particularly for extreme conditions (droughts).

In any case, it is important that the actions undertaken do not undermine the sustainability of the system, and, in particular, that they are compatible with the Framework Directive on Water (WFD). The options proposed should be applied regardless of climate change in order to reduce overexploitation levels, to increase the resistance of the systems to extreme situations, and to facilitate the recovery of good ecological conditions. Climate change, seen in one of the main conclusions of the project ACACIA (Parry 2000), constitutes a serious challenge for the establishment of sustainable management of water resources.

In view of the obvious limitations of this document, we will attempt to write a synthetic review, placing more emphasis on the advantages and disadvantages of each one of them than on details of a technical nature.

7.5.2. Options for increasing resources

Available resources can be increased through the implementation of very different options, from those based on ancient techniques (rainwater catchment), to the more characteristic ones from half way through the XX century (reservoirs), the harnessing of storm waters, to techniques making use of the latest technology (desalinisation). The following are the main types, together with a critical analysis.

Reforestation

It has traditionally been considered that an increase in the area and density of forests i) reduces soil erosion, ii) reduces the frequency and intensity of floods, iii) improves surface and subterranean resources, and iv) even increases rainfall. However, experience accumulated during the XX century throughout the world in different environments and at different scales, has refuted these assumptions, or has subjected them to certain conditions (see summary in Gallart and Llorens 2003): i) improving plant cover reduces soil erosion, but on many occasions, the destruction of the pre-existing vegetation, work with machines and opening up new trails have counteracted this effect; ii) forest cover clearly reduces small or medium-magnitude floods in small catchments, but does not big floods in medium or large-sized catchments; iii) establishing forest cover in catchments with the use of short vegetation determines a reduction of surface and subterranean resources. The problem is a complex one, the disappearance of trees leads to an increase in yields during the first 2 or 3 years. On one hand, it increases canopy interception, but on the other, it improves the soil's capacity for storage and reduces evaporation from the soil; iv) increased forest cover causes an increase in real evapotranspiration, so that it can represent an increase in rainfall, but this effect does not compensate for the increase in evapotranspiration and only occurs at continental scale.

There is no doubt that there are many areas of Spain in which, for different reasons (abandonment of rural activities, overgrazing, fires...), the plant cover has become degraded, and requires actions aimed at regeneration. Furthermore, some of the strategies aimed at mitigating climate change are based on reforestation as a means of carbon sequestration, which is contemplated in the Kyoto protocol. The design of these actions, however, should take into account that certain environmental advantages are gained at the expense of hydrology.

The maintenance could also be recommended of plant cover in a limited number of areas in which environmental problems such as the risk of erosion are not very serious, in comparison with the interest in minimising evapotranspiration (aquifer recharge zones, catchment areas).

Catchment of rainwater or dew.

Since ancient times, different systems have been used to harness rainwater for small farms or to supply isolated dwellings or small communities. Most of these devices have now been abandoned in Spain for different technical, economic or cultural reasons. In recent years, however, these technologies are being recovered in different parts of the world, due to their low economic and environmental cost and the ease with which they can be implemented in remote areas. In 1991 the *International Rainwater Catchment Systems Association* (http://www.ircsa.org/) was created, an international association for scientific, technical and educational development. The UNEP is also lending great support to these technologies (UNEP 1998).

The main limitation of these techniques is the low level of supply guarantee, but they may be of use for improving reforestation techniques and favouring aquifer recharge, and they could be used alternatively with underground resources for promoting the recharge of aquifers during wet spells.

Increased storage capacity, transfers between catchments

One of the traditional options for dealing with a foreseeable decrease in resources and increased temporal variability thereof, involves increasing storage capacity or transferring resources from one catchment to another. It has been shown, however, that in the last few decades, the high socioeconomic and environmental costs of these structures are rarely offset by the benefits they produce (MMA,1998; WCD 2000). Besides, in Spain there is a record number of dams, and most of the rivers are already over-regulated. Since the FDW was adopted, the legal and environmental requirements for the construction of new dams are very restrictive in Europe (Barreira 2004).

*Groundwate*r

Groundwater plays a very important role in Spain. These currently irrigate approximately one third of the irrigated area, but they produce more than half of the income. Groundwater is the main source of supply for small communities and is a strategic resource in the event of drought.

Until 1985 groundwaters were not regulated, and were rapidly exploited by private individuals, which led to many cases of overexploitation. At present, over 20% of the hydrogeological units are overexploited (pumping rate similar to or greater than recharge). Pollution by nitrates or by intrusion of the marine salt wedge are the main quality problems of groundwater. Since 1985, with the enactment of the Water Law, groundwater is of public domain, but he Administration, due to a lack of financial, human and technical means, has been incapable, except on very few occasions, of controlling the excessive exploitation of aquifers or of establishing a functional joint system of management of surface and surface waters and groundwater.

Certain options for the exploitation of groundwater may be of great interest with regard to Climate Change. In particular, *alternative use* (utilisation of surface resources during wet periods and of the groundwater ones in dry periods), artificial recharge during wet periods or temporal overexploitation of certain aquifers, in particular, coastal ones, during periods of drought, are some of these (MMA 1998).

Desalinisation

Desalinisation has long existed in Spain, as it was first implemented in the Canary Isles in 1969. Great advances have been made in recent years with regard to desalinisation, especially from the point of view of economic cost. These technologies currently enable water resources to be obtained from seawater of low-quality water at a price which allows these resources to be used for certain types of high-performance irrigation. The main disadvantages are the high energy costs and the elimination of the resulting brine. A sustainable option would be the use of renewable energy to support desalinisation. There has been much experience in the Canary Isles involving large-scale desalinisation using aeolic energy aimed at reducing energy costs. The *Instituto Tecnológico de Canarias* – Canary Isles Technology Institute- (ITC) has developed several applications for the implementation of this type of studies and some small-scale experiences of totally autonomous systems with aeolic or solar energy.

Reuse

Direct reuse is understood as the direct use of purified wastewater , with a greater or lesser degree of previous treatment, by transport to the second point of use through a specific duct, with no intermediate dumping into public waterways.

The possibilities for reuse are conditioned by the availability of treated wastewaters, by the quality of these, and by the quality requirements for second use. Most reused water is for irrigation, and to a much lesser degree, for recreational use and golf courses, municipal, environmental and industrial uses. Use for drinking water is forbidden by law.

Directives for the regulation of water reuse not only consider minimum quality parameters for each use, but also methodologies and quality control criteria applied to analyses, surveillance systems and certain safety regulations aimed at reducing risks, such as limitation applied to sprinkle irrigation and storage and labelling of undrinkable water. There is an urgent need for regulations and directives at European and National level.

The main problems involve the uncertainty regarding the potential risk to public health (in particular with regard to the long-term recharge of aquifers), the high cost of the more intense purifying processes, and the fact that purified water is not returned to the natural waterways, it being necessary to establish ecological channels aimed at avoiding serious environmental aggression in dry areas (AEMA 2002).

7.5.3. Options for optimisation of use. Demand management.

The need to reduce the pressure on hydrological systems in order not to compromise the sustainability, along with the growing unavailability of water of sufficient quality is leading the water planners to focus increasingly on the possibilities of reducing demand. Some of the demand management options are now summarised (MMA 1998; AEMA 2002).

Public information and the use of simple techniques, such as those applied to the discharge of toilet cisterns, can generate reductions of up to 40% of urban consumption. The water supply in many cities, however, is in the hands of private companies, and water saving clashes with their interests.

Even without considering earnings, water metering systems cause a 10 – 25% reduction in consumption. Losses in the distribution networks tend to be considerable (average of 28%, with extreme cases in Spain of 50%) and depend on the age of the network. Reducing losses is a costly process and has a technical limit of between 10% and 15%.

Pricing policies are also a mechanism for controlling demand, especially when excessive consumption is penalised. Although prices very greatly according to users (domestic, industrial, agricultural), experience has shown that a price rise reduces consumption.

The main water consumer in Spain is irrigation. The current consumption rate is unsustainable, as this had led to the overexploitation of most of the catchments and of a growing number of aquifers, and to a reduction of the quality of surface water and groundwaters, mainly caused by nitrates and salts from soil leaching. The estimates of the NHP, of the National Irrigation Plan, and of the different Catchment Plans are political figures, with no realistic sustainability criteria, and less so with regard to CC. It will therefore be necessary to reduce growth estimates, even those related to the current area irrigated. It will also be necessary to substitute certain crops with a high hydrological cost (rice, corn) by other, less costly ones, and to stop irrigation of unsuitable land. We must ensure that the subsidy policies for agriculture are favourable for hydrological sustainability. Improvement of irrigation techniques and of the efficiency of transport networks can lead to considerable savings, although the economic costs are high and some of the highly efficient hydrological techniques are unsustainable because they cause soil salinisation.

In the industrial sector, suitable pricing policies and legal provisions are needed, in order to favour low-consumption, clean water technologies. Efficient control is needed of direct extraction, especially of groundwater, and of spills.

7.5.4. Options for the improvement and management of the water resources system.

These are actions aimed at obtaining more information on water resources systems and tools for more efficient management.

The metering networks of precipitation, meteorology, snow blanket, flows and piezometric levels should be improved in order to obtain more suitable information on the hydrological cycle. In particular, precipitation and meteorology are observed mainly in population nuclei instead of in the headwater areas, more relevant for the generation of resources, and the metering network in catchments in natural regime is clearly insufficient.

The simulation models of yields in natural regime should be improved in order to reproduce the hydric balance in as physical a way as possible, considering groundwater and differentiating between intercepted water and the water transpired by vegetation. Time should be considered on a daily basis, and the uncertainty of predictions should be considered in an explicit manner. The simulation and optimisation models of the water resources systems should be integrated into Decision-taking Support Systems for unspecialised users.

The databases of resources, demand and water resources systems should be updated as soon as possible and new technologies should be made available.

The creation of Exchange Centres of Water Use Rights, provided for by the Water Law, could improve water management, especially in conditions of scarcity, on favouring users' perception of water as a scarce commodity and favouring the recovery of costs provided for in the FDW (Moral *et al*. 2003).

Resource management during periods of drought should be given special mention. Firstly, improved methods need to be developed for early detection, for which updated information is required on rainfall, climate, soil humidity, flows, piezometric levels of aquifers and reserves in reservoirs. The use of long-term weather predictions, along with the possible correlation of drought periods with global indicators such as the North Atlantic Oscillations or the Niño, in the Pacific, should be studied and implemented in the detection system. In second place, it is necessary to establish plans of action in order to clearly establish the regulations for the exploitation of the system, groundwater resources in particular, for the different levels of risk or severity of drought.

Lastly, sustainable catchment management requires integrated water and territorial management. Any decision related to the territory involves a decision regarding the quantity and quality of water (Falkenmark 2000).

7.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

7.6.1. Sectors of influence in the variation in water resources due to climate change

Variation in water resources as a consequence of possible climate change is conditioned by the influence of other sectors which are also affected by this change.

In theory, there are three sectors that affect or can affect water resources, and alterations in these sectors can therefore determine changes in the quantity and quality of water resources.

All sectors related to soil and plant cover can influence the generation of runoff, for example:

Forestry sector

An increase in forest masses reduces the intensity of floods and helps to establish greater temporal regularity in the generation of runoff.

Edaphic resources

The generation or destruction of soils conditions their retention capacity and therefore the amounts of water awaiting an evapotranspiration process. They also affect the intensity and temporal regularity of floods in the same way.

Plant biodiversity

Plant species, with their specific root depth, their water needs and the characteristics of the soils where they settle themselves, there determine the water balance and the generation of contributions

7.6.2. Repercussions of variation in water resources for other sectors

Changes in water resources in turn seriously affect many other sectors. There is a clear influence of water resources in the following eleven sectors:

Terrestrial ecosystems

The existence of flora, fauna and in general all living things is conditioned by the availability of water, of appropriate quality in each case. Variation in the quantity and quality of water resources and the spatial and temporal distribution of these, can condition the existence and development of terrestrial ecosystems.

Continental aquatic ecosystems

Humid areas contain a very rich and varied fauna in comparison with the surrounding areas, particularly in Spain. They depend on the bodies of water they are made up of and on the natural sources of supply of this. Spatial variability in the yield can also play an important role in relation to the movement of migratory birds.

Plant biodiversity

Plant biodiversity is governed by the presence of water, which is needed for the development of the different species of plants, and variations in yield can cause the disappearance of species or substitution by others with a better capacity for adaptation. This sector also has an influence on the generation of water resources.

Animal biodiversity

In an analogous way, animal biodiversity depends on the presence of water, which is needed to sustain the different animal species, and variations in yield can lead to the disappearance of species migration.

Agricultural sector

This sector is a vital one in Spain. Over 3 million ha are irrigated 2 with surface waters and 1 with groundwater. Irrigation is possible thanks to a generalised regulation process with reservoirs and aquifers. A decrease in rainfall would cause a reduction of resources for irrigation, which means that the use guarantee would be reduced. It would not be sufficient to improve regulation, given that this is already well developed and there is not much room for more improvement.

Forestry sector

This is another double input sector, affected by the amount and spatial distribution of the yield, and at the same time a conditioning factor of the generation process of water resources and very particularly of the amount and intensity of floods.

Natural risks of climatic origin

The spatial distribution of the foreseeably more heterogeneous yield resulting from climate change, and even the increased number and intensity of extreme events will probably exacerbate the problem of floods and will increase the frequency and intensity of landslides. This phenomenon, in spite of the great uncertainties involved, is of particular interest for study in Spain, given the secular nature of the risks for human life in floods and landslides.

Energy sector

The energy sector is conditioned by the existence of sufficient amounts of water, mainly for the production of hydroelectric energy, but also for covering the cooling needs of thermal and nuclear power plants. In spite of the existing high level of regulation, the hydroelectric sector will be affected by the foreseeable decrease in yields caused by climate change. Apart from these general aspects, it must be taken into account that a decrease in resources will require, for agriculture, a type of regulation adapted to its needs, with more irregular liberation of water of the reservoirs, which will affect the hydroelectric production subjected to more regularised demand.

Tourism sector

The tourism sector is governed by a very temporally heterogeneous type of demand, as with agriculture. The reduction of resources, and even more so, the worse distribution of these throughout the year, will be a factor affecting tourism. It is precisely in the Mediterranean areas, with little or no rain in summertime, those presenting the greatest demand for tourism, and these are the areas in which water resources can suffer the biggest percentage reductions as a result of climate change.

Human heath

The reduction of flows, much more accentuated in summer months, may affect parameters of water quality, with consequences for human health.

7.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

7.7.1. Analysis of uncertainties and the relative importance of these

In reference to the estimation of water resources in a possible climate change, we must consider both the uncertainties inherent in the estimation, by simulation, of temperature increases and reduced rainfall (in the case of Spain), and the uncertainties involved in the generation process of resources, which are influenced by soil and the plant cover, on one hand, and the water resources system and the way this is managed, on the other.

Of these two main groups of uncertainties, that is, databases and the runoff generation process, the former are of greater relevant importance, due to the fact that in calculations of resources generation, there are many methods that allow for appropriate contrasts of results.

7.7.2. Influence of databases. Scenarios.

The most relevant uncertainties refer to the projection of rainfall and temperature for the horizons of this century. These are the databases, and any calculation or estimate of runoff is based on this climatic parameters. It has also been seen that big variations in rainfall or temperature are not needed to cause big changes with regard to the reduction of runoff, especially with the semiarid climate type, unfortunately common in Spain.

Calculations of yields are made by means of sufficiently gauged hydrological studies, at least in Spain, and most specialists estimate that the admissible errors in a good study are 15%. However, to this end, reliable monthly data are needed, along with homogeneous and representative series and suitable distribution of the information at spatial level. The reliability of evaluations of resources in conditions of climate change will increase as the scenarios become more real, and provide more information on the temporal distribution of rainfall and temperature.

- Uncertainties in the databases
Increase in real temperature value
reduced rainfall
spatial distribution of both with the appropriate discretisation.

7.7.3 Spatial and temporal distribution of rainfall and temperature

The spatial discretisation of the simulation models is too gross to provide sufficiently accurate calculations for the precise information needs of Spain. One of the most frequent and conveniently detected errors in many hydrological studies in Spain involved evaluating reduced yields resulting from climate change carrying out calculation extended to basins (Ayala, F.J. and Iglesias, A. 2000) whereas calculations extended to sub-catchments or smaller units (Fernández Carrasco, P. 2002) tend to show a greater degree of reliability. This is true not only for studies of climate change, but also for most hydrological studies in Spain.

The temporal distribution of climatic parameters throughout the year, as was seen in point 1, completely conditions the generation of runoff. Heavy rainfall at very warm times of year does not generate yields which would be generated with lower rainfall during the winter months.

This is a particularly critical uncertainty, because it could have even more influence than the temperature increase value at annual scale.

It is also uncertain how the series will vary, not within the year, but at interannual scale. This information is unknown, and has not even been estimate, and only one attempt has been made to approach the subject, in the aforementioned article by Ayala, FJ. and Iglesias, A., which defined annual series that took as an average the average of the mean series deduced, and the standard deviation coincided with those of the present series. The mechanisms for generating series need to be improved in order to correct this uncertainty as much as possible.

- Uncertainties in the spatial distribution of rainfall and temperature.
Monthly distribution throughout the year of rainfall and temperature
Interannual distribution of rainfall and temperature (series)
Evaluation at the level of sub-catchments and small catchments

7.7.4. Soil behaviour and aquifer recharge

Uncertainties related to soil behaviour and the real factors conditioning recharge are very variable and range from uncertainties related to methods of calculation of potential evapotranspiration, leaf interception or the balance of water in the soil, to parameters that cause the useful part of rainwater recharging aquifers to be greater or lesser. Empirical methods have been validated for determined areas with given topographies and given climatic values, but the usefulness of these has not been validated in relation to different values inherent to climate change.

With regard to infiltration that is to become part of the aquifer recharge, it is known that this cannot take place while the soil does not present a surplus. That is to say, once the soil is saturated and continues to receive rainwater, surpluses appear, which constitute useful rainwater, part of which infiltrates to recharge the aquifer. The parameters that quantitatively define this division are unknown, but it is important to establish these, provided that if as,like seems, appears to level of hypothesis it depends on the time that the soil remains saturated every year and of the values of permeability of the subsoil, climate change might not affect groundwaters, or affect them intensely, in a positive or negative sense, depending on each case.

- Uncertainties related to the soil and aquifer recharge
Suitable methods for estimating possible evaporation and evapotranspiration
The specific phenomena of aquifer recharge
Calculations of useful rainwater under the new climate circumstances

7.7.5. Limitations of the simulation models

The models of numeric simulation and those based on empirical expressions have traditionally been used with good results, but some clarifications should be made. In theory, a model is as good as the data it is supplied with, but those that have been implemented or are being implemented undergo a process of fitting or calibration which gives them a particular validity with regard to use. Models for evaluating yields under specific circumstances of climate change, applied to determined scenarios, cannot be calibrated, because these series did not occur in reality and it is therefore impossible to what really took place with what has been calculated by a model.

Simulation models will have to be validated with the use of other current series which we will have to assume have been harmonised with others deriving from change. These are some of the basic limitations of the modelling process which needs to be developed and improved in order to partially eliminate these shortcomings and to make them reliable for the study of climate change.

7.8. DETECTING THE CHANGE

7.8.1. Continuous evaluation of hydric resources

The changes water resources are subjected to by climate foreseeable changes can be detected by means of the measurement and quantification systems being established in Spain. Changes in hydric resource are detected with the use of a plan for gauging river flows, the piezometry of groundwater, sample collection and analysis of surface waters and of groundwater catchment. All of this should be formalised by means of appropriate spatial distribution and frequency of sampling in order to make a follow-up of the evolution of the resources and of the quality thereof, with the necessary degree of reliability.

In Spain, there is a good metering network that could be improved, and which, in fact, is constantly being worked on. There is also a river-water quality network, and both of them can be used to implement a continuous follow-up in time and space of the evolution of surface yields, in quantity and quality.

There have also been reasonably complete networks for the control of aquifers, piezometry and quality, and a very precarious and deficient network for controlling yields from springs. The quality and frequency of the measurements taken by these networks has been declining, although plans currently exist aimed at improving these.

The disadvantage of data on flow measurement is that they do not reflect natural yields, but rather, they give values of surplus yields. The difference between these is basically the detractions made to satisfy water uses. This is why, together with the networks mentioned, another network is needed for measuring water uses, and this has bot yet been developed, and we recommend that it be carefully designed and implemented. These networks should also be complemented by networks for controlling extractions of groundwater.

7.8.2. Quantity and quality control systems. Surface and groundwater

The following is a synthesis of the control systems for the evaluation of water resources.

- Surface waters
Flow and yield metering networks
Flood control networks
Networks for the control of chemical and bacteriological quality in rivers
Quality control networks in lakes and reservoirs
Networks for controlling water uses and diversions

- Groundwater
Piezometric control networks in drilling and piezometers
General quality control networks
Specific quality control networks (salwater intrusion, nitrates, etc.)
Networks for water metering in springs and sources and differential water metering in rivers
Networks for controlling pumping in aquifers

These control systems are well established, or are being improved, in some cases, and in others, more generalised installation is recommended. With regard to the latter, it would be convenient to design, implement or clearly improve the control networks of surface and groundwater, along with the flow gauging networks in springs and sources.

7.9. IMPLICATIONS FOR POLICIES

Reduced hydric resources, as we have seen, affects a large number of sectors. Given that these sectors are regulated by means of specific policies, climate change affecting water resources will necessarily require the remodelled and redesigned policies.

- Science and technology policy
The science and technology policy will necessarily become involved, as a result of reduced water resources, an increase in investment and changes in priorization of criteria, and new research will have to be budgeted for, which could involve both resource generation methods (desalinisation) and methods for combating pollution, water purification and use optimisation.

- *Water policy*
Climate change, which will affect water availability, will lead to debates in the future on water policy, which will surely be more heated and in-depth than at present. Few policies will be so affected in such a continuous way.

One of the methods for correcting the impacts of climate change on water resources basically consists of using an improved and better-adapted water resources system and managing this according to a series of realistic rules related to the binomial resources-demand.

Water policy will be seriously influenced by variations in resources. The elements of regulation, supply, transport, distribution and quality protection of water resources, the interdependence of these, along with management regulations, will need to be adapted to political directives which should give priority to uses and establish stronger compromised related to interregional solidarity.

- *Energy policy*
This is another policy hat will be clearly influenced by a decrease in resources. It will be affected in three fundamental aspects – reduced energy production based on the use of water, obviously affected by shortened resources, an increase in energy consumption resulting from desalinisation operations and pumping in water transfers and from groundwater aimed at mitigating the new hydric deficits.

Resources will be reduced even more by changes in the temporal distribution of liberation of water of the reservoirs aimed at dealing with other uses, which are given more priority than hydroelectric energy, mainly agricultural ones. All of this should be considered and included in successive water policies.

- *Agricultural policy.*
Agricultural policy will have to be redefined as a result of scarcity of available water resources for irrigation. Irrigation methods aimed at water saving will be promoted, along with crops that require less water. More relaxed irrigation guarantees may be accepted, and on some occasions, irrigation may have to give way to more priority uses, such as human supply or livestock farming. Agriculture policy will have to give more consideration to the reuse of waters, mainly of urban origin.

- *Environmental policy*
Water has a double implication in environmental policy. On one hand, it is a transmitter, *par excellence,* of pollutants to the geosphere, and on the other, a priority element pollutant dilution.

In conditions of reduced ecological flows, environmental policy will have to spills and pollution levels.

- *Land planning*
The planning of water and land uses will have to consider a possible decrease in water resources resulting from climate change.

Land planning will have to adjust to definitions of land uses based more on the real possibilities of resources. In certain cases, we could even expect changes from high-consumption land uses to other, more efficient ones.

7.10. MAIN RESEARCH NEEDS

7.10.1. Analysis and enumeration of the parameters involved

Runoff generation and the subsequent generation of water resources, are affect by a large number of factors, which make evaluation of the impact of climate change therein very complicated. The following are the parameters considered to be most significant, although, as has already been seen, not all of them have the same degree of influence.

- Reduced rainfall
- Temperature increase
- Distribution of rainfall and temperature in discrete spaces (with spatial sufficiently low discretisation).
- Temporal distribution throughout the year of rainfall and temperature.
- Type of treatment given to these data and how the series intervening in calculations are generated.
- EV values and the variability of these, with climatic and topographic parameters.
- PET values and the variability of these, with climatic and topographic parameters and latitude.
- Canopy interception
- Soil retention
- Water reserve for plants
- Surplus management
- Infiltration of groundwater
- Surface and groundwater resources system
- Regulations for system management
- Irrigation methods
- Water uses

The parameters of incidence are divided into three main groups; those depending on climate change and the spatial and temporal distribution thereof, which is the mystery *par excellence*, and the way these are to be treated, those relating to the generation of runoff itself, where soil processes come into play, and lastly, the parameters of incidence deriving from the system of available water resources and the way this is managed.

7.10.2. Quantitative evaluation of confidence levels

Quantitative evaluation of the reliability of the data and processes related to the generation of water resources, all of which revolves around foreseeable climate change, is a task that lies within the realms of hypothesis, and not based on validated facts, as required by science. We can therefore assume that the only levels of reliability are based on ideas that will vary in time and, above all, depending on how analysis is focussed.

In relation to currently available databases needed to calculated predicted decreases in water resources, rainfall and temperatures and the spatial distribution of these, the confidence level can be considered **Low (**)**. The databases present very low high variations in medium and long-term estimates, which requires the use of scenarios which differ greatly and which overdiversify the results of runoff predictions.

The second group of parameters of incidence, refers to the available knowledge of the process of runoff generation and whether this knowledge has been suitable adjusted for application to big variations in climatic parameters. It should be pointed out that this process has had a **High** (****) confidence level, but this was due to the possibility to contrast the empirical methods with the integration of the hydrograph obtained from real measurements in rivers. The unavailability of effective contrasts of resources, estimated with the use of methods based on the role of water in the soil, reduces, to say the least, the confidence level, and the level thereof, in the parameters of incidence included with the group constituted by the runoff generation process, is therefore considered to be **Medium (***)**. Within this group, there are aspects with a higher confidence level compared with certain others, but this classification extends to the whole group as an average.

Finally, the confidence level existing in the water resources system and the way this is managed should be considered **High (****)**. In this groups of incidence, what is assessed is the degree of reliability in the calculation of water resources based on pre-established runoff rates and on an existing water resources system or one that can be designed included in the management regulations. There is a significantly high degree of knowledge and a great deal of experience in this respect in Spain, with regard to both the development of systems and to the use of numerical management models aimed at supporting the adoption of regulations for the use of these systems.

7.10.3. Definition of research needs

There are many needs for research, as surely occurs in all the sectors influenced by climate change, but if we follow an established order in the parameters of incidence, we can consider the following ones to be important:

Research aimed at improving and consolidating the estimates of predictable rainfall and temperature values, with the appropriate spatial and temporal distribution of these for the different horizons of this century.

Research aimed at defining methods for the generation of series of climatic data based on the scenarios considered.

Research for the evaluation of evaporation and evapotranspiration, according to topography, latitude and climatic parameters distributed in time and space.

Research into the role of water in the soil, interception, water reserve for plants, etc., in order to improve the empirical methods for calculating useful rainwater.

Research aimed at establishing more reliable knowledge of phenomena of aquifer recharge from the soil, which at present are only estimated through the decomposition of the recession curve of the hydrograph.

Research for the development of a standard numerical model or for the analysis and adaptation of existing ones, in order to computerise the calculation of surface and groundwater yields, and for use as a model for comparing the different hypotheses of successive studies. (The designed or selected model should include all the parameters of incidence and the representative physical indices of the catchment.

Lastly, we ought to continue researching and designing methods and models for backing decisions related to the design of water resource systems and the way these are managed.

7.11. BIBLIOGRAPHY

ACACIA. 1999. Valoración de los efectos potenciales del cambio climático en Europa. Informe ACACIA. Parry M., Parry C. and Livermore M. (eds.).

AEMA. 2002. Uso sostenible del agua en Europa. Gestión de la demanda. Ministerio de Medio Ambiente, Madrid. 94 pgs.

Andreu J., Capilla J. and Sanchis E. 1996. AQUATOOL, A Generalized Decision-Support System for Water-Resources Planning and Operational Management. Journal of Hydrology 177 : 269-291.

Ayala-Carcedo F.J. and Iglesias López A. 2001. Impactos del Cambio Climático sobre los recursos hídricos, el diseño y la planificación hidrológica en la España peninsular. Instituto Tecnológico y Geominero de España.

Ayala-Carcedo F.J. and Iglesias López A. 1996. Impactos del Cambio Climático sobre los recursos hídricos, el diseño y la planificación hidrológica en la España peninsular. Instituto Tecnológico y Geominero de España.

Balairon Ruiz L. 1998. Escenarios Climáticos. Energía y cambio climático. Ministerio de Medio Ambiente.

Barreira A. 2004. Dams in Europe, The Water Framework Directive and the World Commission on Dams Recommendations: A Legal and Policy Analysis. WWF. http://www.panda.org/news_facts/publications/freshwater/index.cfm?uPage=2

BBVA. 2000. El cambio climatico. El campo de las ciencias y las artes. Servicio de estudios nº 137.

Beguería S. 2003. Identficación y características de las fuentes de sedimento en áreas de montaña: erosión y transferencia de sedimento en la cuenca alta del río Aragón. Tesis Doctoral, Universidad de Zaragoza.

Bosch J.M. and Hewlett J.D. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55: 3-23.

Budyko M.I. and Zubenok 1961. The determination of evaporation from the lands surface. Izv. Akad, Nauk SSSR, Ser. Geogr. 6: 3-17.

CEDEX 1998. Estudio Sobre el Impacto Potencial del Cambio Climático en los Recursos Hídricos y Demandas de Agua de Riego en Determinadas Regiones de España. Informe técnico para el Ministerio de medio Ambiente de España. Madrid.

CRU 1998. Representing twentieth century space-time climate variability. II Development of 1901-96 monthly grids of terrestrial surface climate. *In:* New M., Hulme M. and Jones P. Climate Research Unit. School of Enviromental Sciences, University of East Anglia. Norwich, NR4 7TJ. Reino Unido.

Estrela T. and Quintas L. 1996. El sistema integrado de modelización precipitación-aportación SIMPA. Revista de Ingeniería Civil, no. 104. CEDEX-Ministerio de Fomento.

Estrela T., Ferrer M. and Ardiles L. 1995. Estimación of pre-cipitation-runoff regional laws and runoff maps in Spain using a Geographical Information System. International Hydrological Programme (IHP). UNESCO FRIEND AMHY. Thessaloniki, Greece.

Falkenmark M. 2000. No Freshwater Security Without Major Shift in Thinking. Ten-Year Message from the Stockholm Water Symposia. Stockholm International Water Institute, Stockholm.

Falkenmark M. and Lindh G. 1976. Water for a Starving World. Westview Press, Boulder, CO.

Fernández Carrasco P. 2002. Estudio del Impacto del Cambio Climático Sobre los Recursos Hídricos. Aplicación en diecinueve cuencas en España. Tesis Doctoral. E.T.S de Ingenieros de Caminos, Canales y Puertos. Universidad Politécnica de Madrid.

Flores-Montoya F., Garrote L.M. and Martín-Carrasco F.J. 2003. The hydrologic regime of the Tagus river in the last 60 years. XI World Water Congress, IWRA, CEDEX, Madrid (CD).

Frisk T., Bilaletdin Ä., Kallio K. and Saura M. 1997. Modelling the effects of climatic change on lake eutrophication. Boreal Environment Research 2 : 53–67.

Gallart F. and Llorens P. 2003. Catchment management under Environmental Change: Impact of Land Cover Change on Water Resources. Water International 28(3): 334-340.

García-Vera M.A., Coch-Flotats A., Gallart F., LLorens P. and Pintor M.C. 2003. Evaluación preliminar de los efectos de la forestación sobre la escorrentía del Ebro. XI World Water Congress, IWRA, CEDEX, Madrid (CD).

Garrote L., Rodríguez I.C. and Estrada F. 1999. Una evaluación de la capacidad de regulación de las cuencas de la España peninsular. VI Jornadas Españolas de Presas. Vol.2, Málaga. Pgs. 645-656.

Iglesias López A. 1985. Usos y aplicaciones del agua en España. Boletín Geológico y Minero T XCVI-V :(512-540). Pgs. 44-72

IPCC. 2001. Working Group II. The Third Assessment Report of the Intergovernmental Panel on Climate Change. Impacts, Adaptation, and Vulnerability. WMO.UNEP.

IPCC. 2003. Future climate in world regions: and intercoparation of model-based projections for the new IPCC emissions scenarios.

MIMAM. 1998. El Libro Blanco del Agua en España. Ministerio del Medio Ambiente

MOPTMA. 1995. Programa Nacional del Clima.

MOPTMA- MINER. 1994. Libro Blanco de las Aguas Subterráneas

Moral L. del, Werff P. van der, Bakker K. and Handmer J. 2003. Global trends and water policy in Spain. Water International 28(3): 358-366.

Moreno Torres A. 1982. Los usos del agua. Ponencia al cursillo monográfico sobre conservación del patrimonio hídrico. Madrid.

Parry M.L. (ed.). 2000. Assessment of Potential Effects and Adaptations for Climate Change in Europe: Summary and Conclusions. Jackson Environment Institute, University of East Anglia, Norwich, UK. 24 pgs.

Pilgrim J.M., Fang X., Stefan H.G. 1998. Stream temperature correlations with air temperatures in Minnesota: implications for climate warming. Journal of the American Water Resources Association 34: 1109–1121.

Prieto C. 1996. La evolución de los recursos hídricos en España. 2ª Conferencia Internacional de Hidrología Mediterránea. Los recursos hídricos en los países Mediterráneos. Iberdrola Instituto Tecnológico, Bilbao. Pgs. 257-288.

WWW. 1999. Escenarios de Cambio Climático para la Península Ibérica. WWW.

UNEP. 1998. Sourcebook of Alternative Technologies for Freshwater Augmentation in Africa. UNEP, Technical Publication Series, 8. (http://www.unep.or.jp/ietc/Publications /TechPublications/TechPub-8a/index.asp)

WCD. 2000. Represas y Desarrollo. El reporte final de la comisión mundial de represas. Un nuevo marco para la toma de decisiones. Comisión Mundial de Represas, http://www.dams.org/docs/report/wcd_sp.pdf