The role of dams in Spain

L. Berga and J.C. de Cea, Spanish National Committee on Large Dams, Spain

The evolution of dam construction in Spain, with particular emphasis on trends in recent years, is presented here. The critical role which the reservoirs created by Spanish dams have played in the social welfare of the country is very clear.

Spain has a surface area of 505 182 km^2, and has a population of about 44 million, which corresponds to an average population density of 87 people per km^2. The GDP is around 830 billion, and the income per capita is about 19 000.

Spain lies in the southwest of Europe, and the Iberian Peninsula forms a bioclimatic bridge between Europe and Africa. The country's peninsular position means that the climate is very varied. It is exposed to the Atlantic fronts, to the Mediterranean disturbances, to the hot air masses arriving from North Africa and to the cold air masses coming from Northern and Central Europe. Such a varied climate gives rise to rainfall patterns and river flow regimes which are highly irregular in time, and their geographical distribution is also very uneven.

The irregularity in time not only causes major variations from one year to the next, with long spells of drought, but also major seasonal fluctuations with low discharges during the summer months. The uneven geographical distribution means that Northern Spain has abundant water resources, in sharp contrast to the scarcity which affects the basin in the Mediterranean watershed.

The mean annual rainfall in Spain is 685 mm/year, which yields natural water resources of 112 km^3/year, see Fig. 1 [Ministry of Environment, 2003[1]].

These natural resources yield 2600 m^3 per person per year of water resources. Although this figure indicates that the country is relatively self-sufficient as far as water resources are concerned, the percentage is about 20 per cent lower than the average for the European Union (which is 3200 m^3/per person/year), and this per capita volume puts Spain in 117th position of a total of 180 countries worldwide, in per capita water resources rankings. Furthermore, the distribution of the per capita water resources (see Table 1) shows a major geographical disparity. On mainland Spain, from a hydrological perspective, the internal basins of Catalonia are classified as a zone of absolute water scarcity (with less than 500 m^3 per person/per year of renewable resources), and the Segura and Júcar basins are defined as water scarcity zones (with some renewable resources ranging from 500 to 1000 m^3/per person/year), whereas the South and Guadalquivir Basins are classified as hydraulic stress zones (with values ranging from 1000 to 1700 m^3/per person/year).

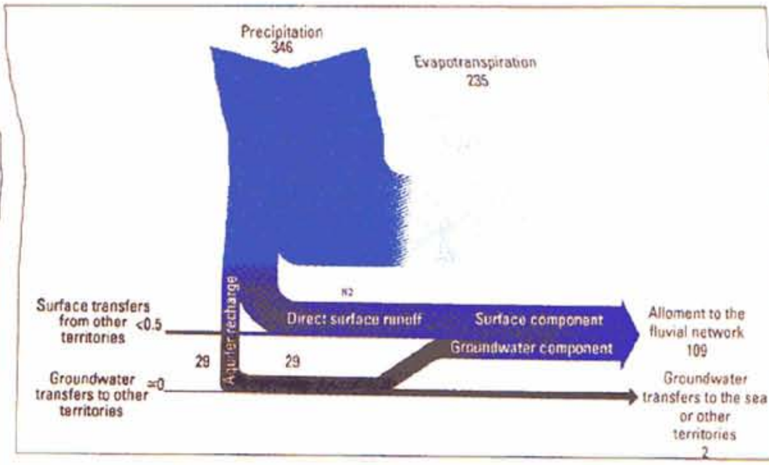


Fig.1. The water resources of Spain.

Furthermore, the hydrological regimes of the rivers are highly irregular in time, which leads to low water resource availability levels in the natural regime, with a total of only 9190 × 10^6 m^3/year (8.3 per cent of the renewable resources), which would yield average per capita availabilities of only 240 m^3 per person/per year, when compared with the 1000 m^3 per person/per year considered to be the basic on a world level to cater for water use requirements, see Table 2 [Berga et. al, 2000[2]].

These basic characteristics of the renewable water resources, together with the particular characteristics of water demands (about 80 per cent being allocated to irrigation), are clear indicators of the water situation in Spain and the problems that the country faces.

Table 1: Distribution of Spain's per capita natural water resources (1996)

Basin	Population (10^6)	Totals (10^6m^3/year)	Per capita (m^3/person/year)
North	6.75	42 088	6235
Duero	2.25	15 168	6741
Tagus	6.36	12 858	2022
Guadiana	1.66	6165	3714
Guadalquivir	4.9	7771	1586
South	2.07	2418	1168
Segura	1.36	1000	735
Jucar	4.19	4142	988
Ebro	2.76	18 198	6593
Internal basins of Catalonia	6.17	2780	450
Total for Spanish Peninsula	38.47	112 588	2927

Table 2: Water resources in the natural regime (1996)

Basin	Natural resources (10^6m^3)	Population in 1996 (10^6)	Per capita resources (m^3/person/year)
North	2550	6.75	378
Duero	840	2.25	373
Tagus	360	6.36	57
Guadiana	10	1.66	6
Guadalquivir	920	4.90	188
South	50	2.07	24
Segura	130	1.36	96
Jucar	710	4.19	169
Ebro	3460	2.76	1254
Internal basins of Catalonia	160	6.17	26
Total for Spanish Peninsula	9190	38.47	239

Fig.2. The evolution of large dams and reservoir capacity in Spain during the 20th century (1900 to 2000).

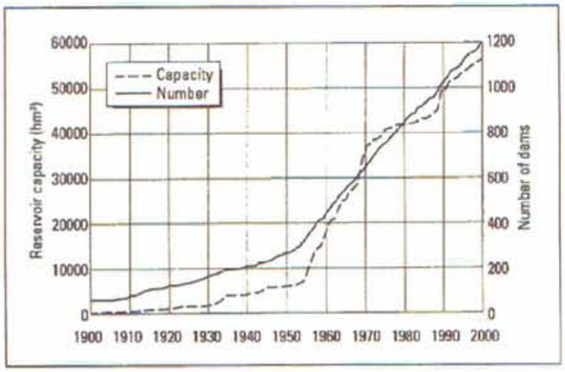


Table 3: Evolution of Spanish large dams (1950-2000)

Period	No. of large dams	Increase in average no. per year	Reservoir capacity ($10^6 m^3$)	Increase in mean capacity per year ($10^6 m^3$)
Before 1950	261	4	5945	115
1950-1960	426	17	15,551	960
1961-1970	644	22	34,949	1940
1971-1980	849	21	43,083	815
1981-1990	1046	20	50,511	745
1991-2000	1232	19	56,681	617
Mean for 1950-2000		19		1015

Therefore, for more than 2000 years, it has been necessary to construct major hydraulic works and a large number of dams and reservoirs.

1. The development of large dams in Spain

About 2000 years ago the Romans constructed the first large dams in Spain, mainly with a view to providing the water for the largest and most important cities; two of those ancient dams, Proserpina and Cornalvo, are still in operation today. Later, during the Arab rule, extensive irrigation systems were developed in the Mediterranean basins, which mainly used water from the rivers. The construction of large dams began again in the 16th and 17th centuries, to regulate the water resources. Examples of these works were the Tibi, Elche and Relleu dams [Smith, 1970[3]]. More information on some interesting historical aspects of the development of Spanish dam technology is given in the article on p53.

Fig. 2 shows how the number of large dams and reservoir capacity have evolved throughout the 20th Century.

At the end of 19th Century there were around 90 dams and diversion works, of which 52 are still in operation. The reservoirs created by these 52 dams had a total capacity of 108×10^6 m^3. During the first third of the 20th century, national hydrological plans were developed in Spain, and dam construction policies were encouraged to regulate the water resources for irrigation purposes. However, the Spanish Civil War virtually brought hydraulic development to a standstill. In 1950 there were 261 large dams, with a total storage capacity of 5945×10^6 m^3; this means that around four large dams were constructed per year until that time (see Table 3).

There was a sharp increase in dam construction in Spain during the second half of the century, mainly between 1955 and 1970, and this was largely because of the need to generate hydropower. The number of large dams increased by a factor of 2.4, and the storage capacity increased six-fold. From 1950 to 2000, the average annual increase in the number of dams remained almost constant at 19 dams per year, and the average increase in reservoir capacity was about 1000×10^6 m^3 per year, with a peak value of 2000×10^6 m^3 per year in the 1960s. In recent decades, the rate of dam construction has fallen considerably, as is the case in other developed countries. As an illustration of this, 91 dams were under construction in 1991, but the number of new dams currently under construction is only 23.

Spanish dam construction technology is among the most advanced in the world, and the country's experience is also among the greatest. For many years, various Spanish dams have held records as regards their typology or special characteristics. Furthermore, Spain pioneered the introduction of some new design types for dams, for example, roller compacted concrete (RCC) dams, and Spain is one of the leading countries in the world where the construction of these works is concerned [Berga, *et. al*, 2003[4]].

2. The main characteristics of Spanish dams and reservoirs

There are about 1270 large dams in Spain, according to ICOLD's World Register of Dams, of which 1250 are operational and 23 are under construction. This number of large dams means that Spain occupies the first position in Europe, and is 4th in the world ranking, after China, the USA, and India [ICOLD, 2003[5]].

The average height of Spanish dams is 32.7 m, which is relatively low. Of the total number of dams, 60 per cent are less than 30 m high, and only 14 per cent are more than 60 m high. There are 39 dams higher than 100 m, and 21 are more than 120 m high (see Table 4). The highest of all is the Almendra dam, constructed in 1970, which is 202 m high, see photograph [SPANCOLD, 2006[6]].

Table 4: Spanish dams > 120 m high

Dam	Year of completion	River	Type	Height (m)	Crest length (m)	Reservoir capacity ($10^6 m^3$)	Purpose reservoir
Almendra	1970	Tormes	VA	202	567.25	2648.7	H
Canales	1988	Genil	ER	157.5	340	71	I
Canelles	1960	Noguera Ribagorzana	VA	150	210	678	H
Portas, Las	1974	Camba	VA	141	476.7	535.7	H
Aldeadavila	1963	Duero	VA	139.5	250	114.3	H
Tous (new)	1966	Jucar	ER	135.5	1024	378.7	IS
Susqueda	1968	Ter	VA	135	510	233	HS
Atazar, El	1972	Lozoya	VA	134	484	425	IS
Beznar	1986	Izbor	VA	134	408	53.6	IH
Quentar	1975	Aguas Blancas	VA	133	200	13.6	SI
Belesar	1963	Miño	VA	132	500	654.1	H
Alcantara	1969	Tajo	CB	130	570	3162	H
Grado, El	1969	Cinca	PG	130	959	399	H
Rules	u/c	Guadalfeo	PG	130	531	117	ISH
Soria	1972	Soria	VA	130	248	32.8	I
Contreras	1974	Cabriel	PG	125	200	874	H
Escales	1955	Noguera Ribagorzana	PG	125	200	157.8	H
Salime	1956	Navia	PG	125	250	266.3	H
Itoiz	u/c	Irati	PG	122	525	418	ISH
Iznajar	1969	Genil	PG	122	407	1067	IH
Llosa del Cavall	1999	Cardoner	VA	122	330	80	S

The Almendra dam, completed in 1970, which at 202 m is Spain's highest dam.

Most Spanish dams (72 per cent), are concrete or masonry (64 per cent gravity, 5 per cent arch dams, and 3 per cent buttress), the remaining 28 per cent being embankment dams (17 per cent earth and 11 per cent rockfill) see Fig. 3. This is because not only are the characteristics of the foundations generally good, but also concrete dams are less vulnerable to the extreme floods which are so typical of many Spanish rivers.

With respect to the way in which dam types have evolved (see Fig. 4), it can be seen that until the 1970s, gravity dams were the most common type. In the 1980s there was a major increase in the number of embankment dams (earth and rockfill), mainly because embankment dams are more economical. However, as a result of dam accidents caused by floods during the 1980s, there was a reversal of this trend, and by the end of the 20th century, an equal number of both types were being built.

Spanish dams are relatively old, about 25 per cent of them having been constructed more than 50 years ago, and more than half (52 per cent) being more than 35 years old. Therefore, greater efforts will have to be made in the future as regards dam maintenance and rehabilitation.

Dams in Spain have created about 1150 reservoirs, with a total capacity of $56\,000 \times 10^6$ m^3. Fig. 5 shows the locations of the largest reservoirs, with a storage capacity of more than 10×10^6 m^3.

Spanish reservoirs have a relatively limited storage capacity, the average being 46×10^6 m^3 per reservoir. Furthermore, 98 per cent of the total reservoir capacity is stored in the 330 reservoirs the capacities of which are greater than 10×10^6 m^3.

Table 5 shows the reservoirs with a storage capacity greater than 1000×10^6 m^3. La Serena reservoir (see photograph), which was constructed in 1989, has the largest capacity, (3232×10^6 m^3). There are two other reservoirs with storage capacities greater than 2000×10^6 m^3 (José Mª Oriol-Alcantara, with 3162×10^6 m^3, and Almendra with 2649×10^6 m^3), as well as six reservoirs with storage capacities of between 1000 and 2000×10^6 m^3 (Buendía, Mequinenza, Cíjara, Valdecañas, Ricobayo and Alarcón).

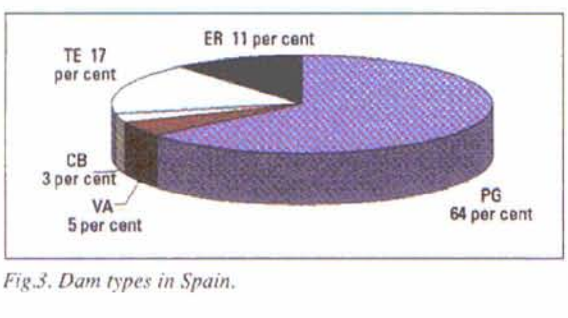


Fig.3. Dam types in Spain.

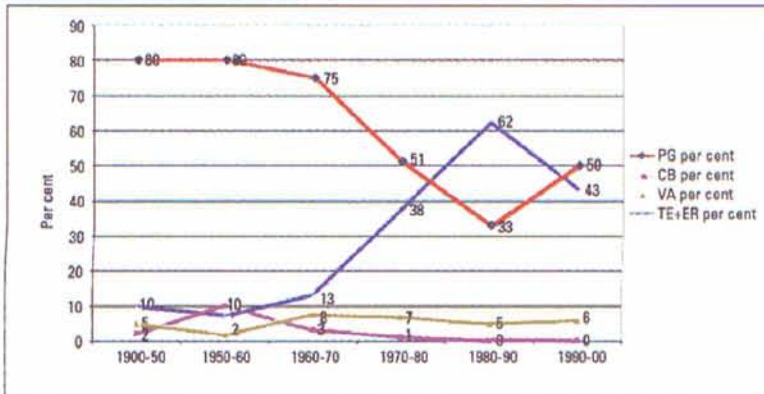
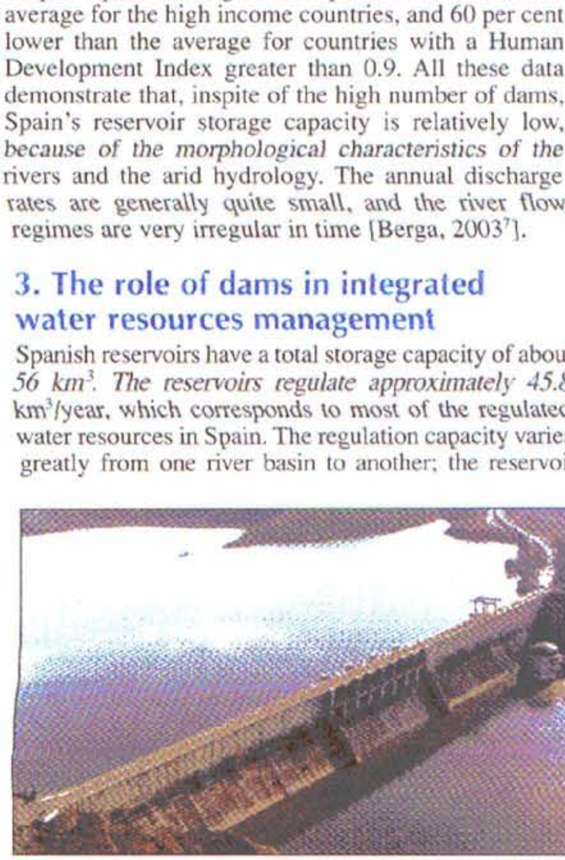


Fig. 4. Evolution of dam types in Spain.

As far as dam indicators are concerned, it should be pointed out that in Spain there are approximately 30 dams per million people, which puts the country at the upper limit of the most relevant countries in this respect. However, the value for the reservoir capacity per capita indicator is relatively low, with only 1430 m^3/per capita. This figure is 32 per cent lower than the average for the high income countries, and 60 per cent lower than the average for countries with a Human Development Index greater than 0.9. All these data demonstrate that, inspite of the high number of dams, Spain's reservoir storage capacity is relatively low, because of the morphological characteristics of the rivers and the arid hydrology. The annual discharge rates are generally quite small, and the river flow regimes are very irregular in time [Berga, 2003[7]].

3. The role of dams in integrated water resources management

Spanish reservoirs have a total storage capacity of about 56 km^3. The reservoirs regulate approximately 45.8 km^3/year, which corresponds to most of the regulated water resources in Spain. The regulation capacity varies greatly from one river basin to another; the reservoir



View of La Serena dam, which has a reservoir capacity of 3232×10^6 m^3.

Table 5: Spanish reservoirs with a storage capacity >1000 × 10^{6}m^3

Reservoir	Year of comp-	River	Type	Height (m)	Crest length (m)	Reservoir capacity (10^{6}m^3)	Purpose reservoir
Serena, La	1989	Zucar	PG	91	580	3232	IH
Alcantara (Salto José Mª Oriol)	1969	Tagus	CB	130	570	3162	H
Almendra	1970	Tormes	VA	202	567	2649	H
Buendia	1958	Guadiela	PG	78.9	315	1638	IH
Mequinenza	1964	Ebro	PG	79	461	1530	H
Cijara	1956	Guadiana	PG	80	295	1505	IH
Valdecañas	1964	Tagus	VA	98	290	1446	IH
Ricobayo	1934	Esla	PG	99.4	270	1200	H
Alarcon	1955	Jucar	PG	67	317	1112	IH

Table 8: Dams under construction in Spain (February 2006)

Dam	River	Basin	Province	Type	Height (m)	Reservoir capacity (10^6m^3)	Purpose
Arenoso	Arenoso	Guadalquivir	Córdoba	ER	80	160	IS
Arroyo Montemayor	Montemayor	Ebro	Logroño	ER	29	0.4	S
Artajona	-	Ebro	Navarra	TE	45.5	2.0	I
Biscarrués	Gállego	Ebro	Huesca/Zaragoza	TE	84	192	I
Brandariz	Ulla	Norte	La Coruña	PG	37	2.4	H
Castrovido	Arlanza	Duero	Burgos	PG	95.5	82	ISC
Ceguilla	Ceguilla	Duero	Segovia	PG	40	1.0	S
Cigudosa-Valdeprado	Alhama	Ebro	Soria	RCC	65.5	41.8	IS
Colada, La	Guadalmatilla	Guadiana	Córdoba	PG	48.5	57.7	S
Enciso	Cidacos	Ebro	Logroño	RCC	103.5	48	IS
Ibiur	Ibiur	Norte	Guipuzcoa	PG	69.5	7.5	S
Laverné	-	Ebro	Zaragoza	TE	54.5	37.8	I
Lechago	Jiloca	Ebro	Zaragoza	TE	39	18.2	I
Loteta, La	Carrizal	Ebro	Zaragoza	TE	29	96.7	IS
Melonares	Viar	Guadalquivir	Sevilla	PG	50	180.4	IS
Monreal	Unciti	Ebro	Huesca	PG	21.9	0.57	I
Montearagón	Flumen	Ebro	Huesca	PG	78	51.5	IS
Mora de Rubielos	Tosquillas	Júcar	Teruel	ER	35	1.0	IS
Navas del Marqués	Valtravies	Duero	Ávila	PG	36	2.0	IS
Pareia, Dique	-	Tajo	Guadalajara	TE	19.0	1.0	R
Touro	Ulla	Norte	La Coruña	PG	40	1.4	H
Villalba do los Barros	Guadajira	Guadiana	Badajoz	TE	45.5	106	I
Villaveta	Arroyo Olleta	Ebro	Navarra	TE	44.3	5.3	I

per cent greater than the capacity of the new dams under construction [De Cea and Berga, 2004[10]].

There are also 17 recently completed large dams, which are at the first filling stage (see Table 10). These reservoirs will add a further storage capacity of 2235 $\times 10^6$ m^3, which will provide a 4 per cent increase in the current storage capacity.

As far as future prospects are concerned, it should be kept in mind that, in view of the arid hydrological characteristics in Spain, it has been considered necessary in all the rivers' hydrological plans prepared in recent decades to construct new dams and create new reservoirs, so that the country can achieve and maintain an acceptable level of available water resources. Thus, the 1993 Plan envisaged the construction of about 150 new large dams. In 2001 the National Hydrological Plan proposed the construction of 116 new large dams. The current National Hydrological Plan, approved in 2005, sets out plans to build about 100 new dams. The current assessments, taking into account environmental concerns, estimate the construction of about 70 new large dams over the next 10 years, which would mean an increase in water resources regulation of between 7 and 10 per cent [SPANCOLD, 2006[6]].

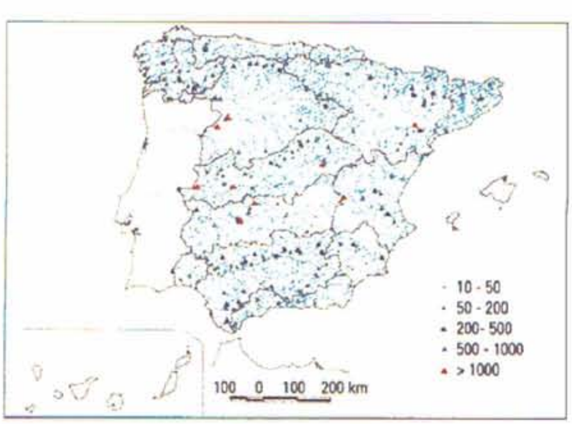


Fig.5. The location of the Spanish reservoirs with a capacity greater than 10×10^6 m^3.

Environmental issues are considered to be extremely important in Spain, and detailed analyses are made of the disturbance and impact caused by dams and reservoirs. In view of this, structural and management measures are taken as required to reduce any negative impact to an absolute minimum, so that the socio-economic/environmental balance is clearly positive. Dams and reservoirs must be constructed and operated taking into account any potential socio-economic or environmental effects, keeping in mind that Spain has great biodiversity and is a major biological bridge between Europe and Africa. There is considerable orographic and climatic diversity in the country, which gives rise to numerous bioclimatic areas. Dams in Spain are subjected to a process of environmental impact assessment (EIA), which has been regulated by a variety of European Directives since 1985: EU Directive 85/837EEC, Royal Decrees 1302/1986 and 1131/1988, EU Directive 97/11/CE, Royal Decree 9/2000, and Act 6/2001 concerning Environmental Impact Assessment.

Spanish dams thus co-exist harmoniously with the environment, and also provide shelter for many species of migrating birds (see Fig. 6). Furthermore, when constructing and operating dams and reservoirs in a country with one of the most varied biodiversities in Europe, it is necessary to conserve and preserve the natural habitats and the wild fauna and flora, so a host of preventive, corrective and compensatory measures have been applied to Spanish dams, some of which are

Table 9: Dam heightening projects in Spain

Dam	River	Basin	Province	Heightening (m)	Capacity increase (10^6m^3)	Purposes
La Breña II	Guadiano	Guadalquivir	Huelva	71	698	IS
Montoro	Montoro	Guadalquivir	Ciudad Real	60	67	IS
Yesa (under reappraisal)	Aragón	Ebro	Navarra	(38)	(1050)	ISH

Table 10: Dams at the first filling stage (November 2005)

Dam	River	Basin	Province	Type	Height (m)	Reservoir capacity (10^6m^3)	Purpose
Andévalo	Malagón	Guadiana	Huelva	ER	70	600	IS
Arroyo del Fresnillo	Arroyo del Fresnillo	Guadalquivir	Cádiz	PG	25.2	0.3	S
Casares de Arbas	Casares	Duero	León	PG	52	37	IS
Casasola	Campanilla	Guadalquivir	Málaga	PG	89	42	IS
Esparragal	Víar	Guadalquivir	Sevilla	RCC	21	4.5	IS
Gargantafría	Arroyo Gargantafría	Guadalquivir	Sevilla	PG	16.5	0.2	I
Giribaile	Guadalimar	Guadalquivir	Jaén	TE	89	475	IS
Irueña	Agueda	Duero	Salamanca	PG	68.5	122.5	IS
Itoiz	Iratí	Ebro	Navarra	PG	128	418	ISH
Rialb	Segre	Ebro	Lérida	RCC	101	402	IS
Risca, La	Alharabe	Segura	Murcia	PG	26.9	2.3	IC
Rules	Guadalfeo	Sur	Granada	PG	130	117.1	ISHC
Trapa, La	Barranco Val de Jaume	Ebro	Zaragoza	TE	15	1	IS
Ullibarri-Arrazúa	Arroyo Iturrichu	Ebro	Álava	TE	44	7.2	IS
Val Comuna	Barranco Val Comuna	Ebro	Zaragoza-Teruel	TE	35	2.2	IS
Yalde	Yalde	Ebro	Logroño	TE	55	3.6	I
Zorita de los Molinos	Adaja	Duero	Ávila	PG	22	2.0	I

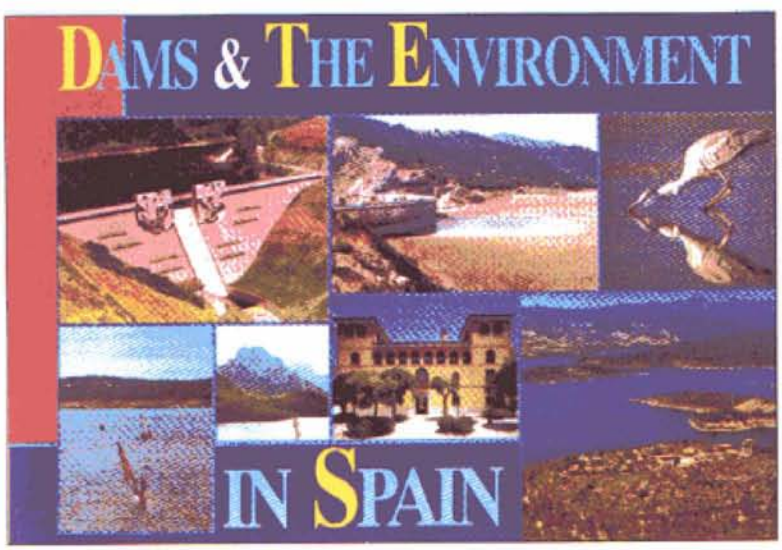
exemplary within the European context [SPANCOLD, 2006[6]; 1994[11]].

In conclusion, experience and technical capacity in the construction and operation of Spanish dams, together with the standards, regulations and laws of the country and the European Union, are sufficient to provide a framework for the construction of new dams, while at the same time complying with the basic implementation criteria within the context of integrated water resources management and sustainable development: technical economic and financial feasibility; compatibility with the environment (sustainability); and, political and social acceptance.

References

1. **Ministry of Environment,** "Water in Spain", White Paper on Water in Spain. Madrid, Spain; 2003.
2. **Berga, L., Yague, J., Cajete, J., Giron, F., and Mendiluce, J.Mª.,** "Benefits and concerns about dams in Spain. Q77, R36. Vol. II, 533-554", XX International Congress on Large Dams, Beijing, China; 2000.
3. **Smith, N.A.F.,** " The Heritage of Spanish Dams", Servicios de Publicaciones del Colegio de Ingenieros de Caminos, Canales y Puertos. Madrid, Spain; 1970.
4. **Berga, L., Buil, J.M., Jofre, C., and Shen Chonggang,** 'Roller Compacted Concrete Dams', (SPANCOLD) Ed. A.A. Balkema, Lisse; 2003.
5. **ICOLD,** 'World Register of Dams', International Commission on Large Dams, Paris, France; 2003.
6. **SPANCOLD,** "Dams in Spain". Servicio de Publicaciones del Colegio de Ingenieros de Caminos, Canales y Puertos, Madrid, Spain; 2006.
7. **Berga, L.,** "Economic evaluation of hydraulic projects including dams", General Report Q81, Vol. I, 671-737, XXI International Congress on Large Dams, Montreal, Canada; 2003.
8. **SPANCOLD,** *Proceedings*, International Symposium on Dams and Extreme Floods, Spanish National Committee on Large Dams, Granada, Spain; 1992.
9. **ICOLD,** "Dams and floods". Bulletin No. 125. International Commission on Large Dams, Paris, France; 2003.
10. **De Cea, J.C., and Berga, L.,** "Current dam engineering activities in Spain". *Hydropower and Dams*, No. 5, 2004.
11. **SPANCOLD,** "Dams and the environment in Spain", Spanish National Committee on Large Dams, Madrid, Spain; 2004.

Fig. 6 Spain's publication on Dams and the Environment.



Prof. Luis Berga Casafont is a Doctor of Civil Engineering, and is a Full Professor of Hydraulic Engineering at the Polytechnic University of Catalonia, Barcelona, Spain. He is **Chairman of International Commission on Large Dams (ICOLD)** (2006-2009) & **Chairman of the Spanish National Committee on Large Dams (SPANCOLD) .**

Dr. Juan Carlos de Cea is a Doctor of Civil Engineering. He has been working since 1999 in the Dam Safety Department of the Environment Ministry, and is also a Professor at the University of Madrid, Spain. He is currently **General Secretary of the Spanish National Committee on Large Dams (SPANCOLD) .**