FIRST RISK-BASED SCREENING ON A SPANISH PORTFOLIO OF 20 DAMS OWNED BY THE DUERO RIVER AUTHORITY

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ABSTRACT

Society is constantly evolving and the fact of the matter is that demand for transparency in decision-making has turned out to be a highly topical reality. It is in this context where the growing complexity that involves dam safety management can be found out.

Due to historical and technical reasons, dam safety has traditionally been based on the so called traditional standards-based approach, where risk is tackled by following recognised defensive design measures, taking extreme values for the loads, conservatively safe values for resistance variables and applying safety coefficients.

However, in a climate of growing public scrutiny, the traditional standards-based approach, by itself, is becoming increasingly limited to handle a single dam or a portfolio of dams in allocating limited resources for their operation.

A qualitative application (screening level) has been carried out by first time on a Spanish portfolio of 20 dams, owned and operated by the Duero River Authority (Confederacion Hidrografica del Duero). In a very simplified manner, the analysis involves potential failure modes, load scenarios, probabilities related to the system response and consideration of life loss and economic consequences.

Results show the importance of developing a Dam Safety Program based upon risk analysis and failure mode thinking in the realm of Spanish current dam safety practice.

Introduction

The article describes the risk analysis methodology, at screening level, as it has been customized and applied to a portfolio of 20 dams owned and operated by the Duero River Basin Authority (CHD) in Spain.

In particular, the procedure of USBR (5) has been adapted and complemented with some of the works of the *eDams* group at Universidad Politecnica de Valencia (Spain), who collaborates with the engineering firm OFITECO, SA in the development of the contract entitled *Redaccion de Planes de Emergencia e Informes de Seguridad de las presas de Camporredondo, Compuerto, Requejada, Cervera y Aguilar de Campoo*.

First part of the article leads with the contextualization of the methodology in a more general risk assessment framework as applied to dam safety. Second part is devoted to specific objectives and fundamentals of the screening procedure. Finally, the results of the particular application to the portfolio of dams are given and analyzed.

Contextualization

The need to implement a risk assessment technique as a decision support tool for dam safety management emerged in the early nineties in some of the most developed countries in the world, such as those described in ANCOLD (1), Bedford et al (2), Bowles et al (3), USBR (6), FERC (7), G.Membrillera et al (8), Hartford et al (10) or ICOLD (11). Some of the main reasons for this need are listed below:

a) Aging of dam structures (majority of dams being older than 30 years and a great percentage over 50 years in operation) including a gap between present-day good practice and the one followed when many existing dams were designed and constructed.

b) An increasing demand for safety for populations and properties located downstream.

c) A growing request for better justification of funding all aspects of dam safety programs.

d) Shifts to risk management approaches in business and regulation rather than an exclusive reliance on traditional engineering standards.

e) A growing backlog of dam safety improvements and the need to prioritise them to achieve the fastest rate of risk reduction.

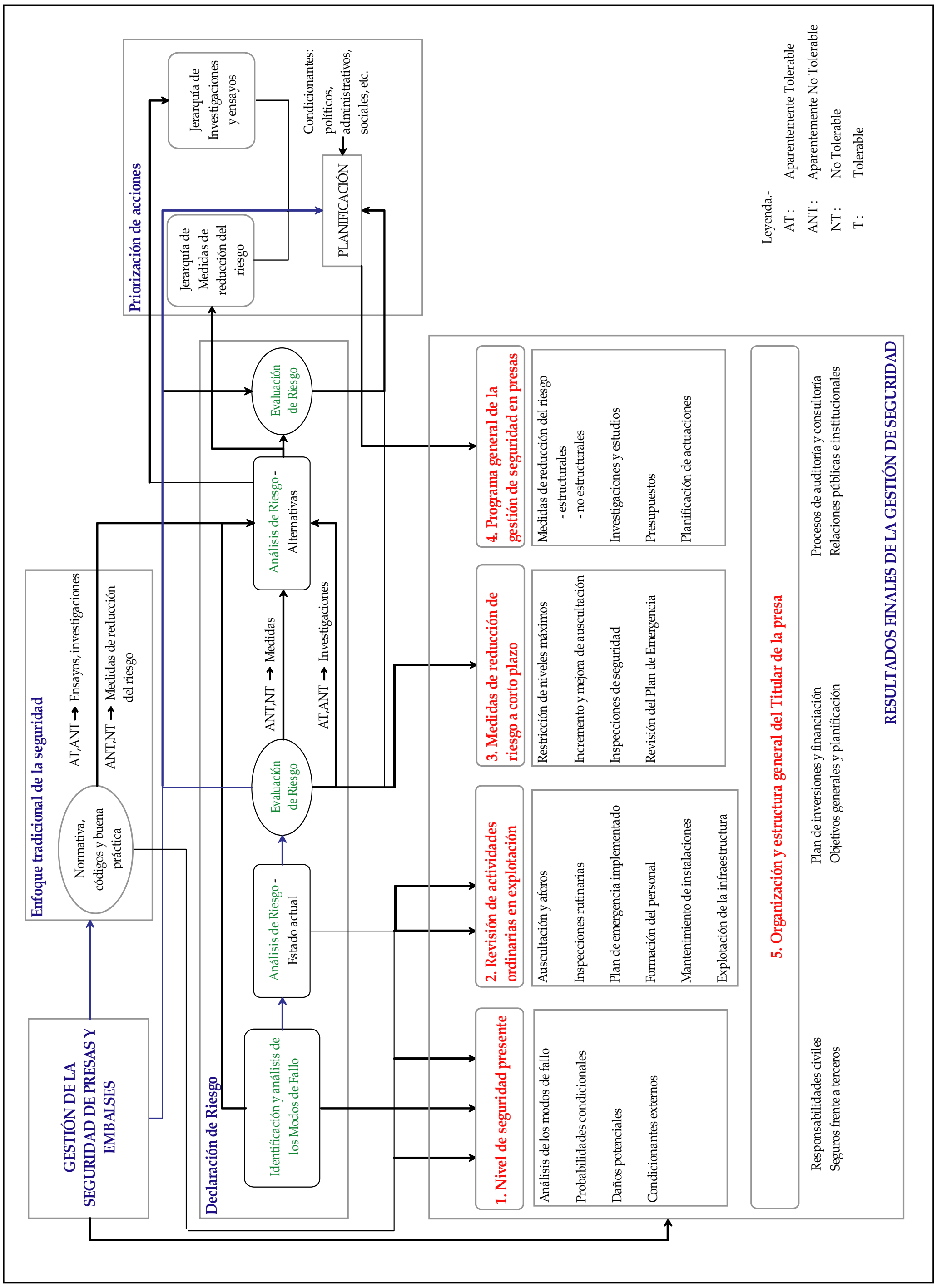
f) The difficulties in constructing new dams due to environmental and social factors.

g) The need to optimize water resources system management as well as to increase storage capacity in response to a continuously growing water supply demand and an apparent increase in extreme meteorological events (such as severe droughts and floods).

In this context of dam maintenance requirements, improving operating procedures and increasing regulation, estimating different types of risk (structural, operational, etc.) becomes a crucial need. Even more, the identification of tolerable risk levels (both related to the dam-reservoir system and water supply) should be an available tool for decision makers.

Figure 1 shows a general framework of a risk based dam safety program.

Figure 1. General scheme for Risk Assessment and Management activities. Adapted from D.S.Bowles in G.Membrillera (9).



Nowadays in Spain, classical dam safety calculations based on a pseudo-probabilistic load hypothesis and partial safety factors cannot satisfy these goals.

The above-mentioned pseudo-probabilistic analysis implies that, for both flood and earthquake loads, a deterministic assumption is made about the water level that is used in dam safety calculations. Thus, even though the occurrence of floods and earthquakes are recognised as random processes, this is not taken into account when applying this approach. In addition, partial safety factors lead to acceptance/non acceptance criteria but cannot directly be related to a probability of failure.

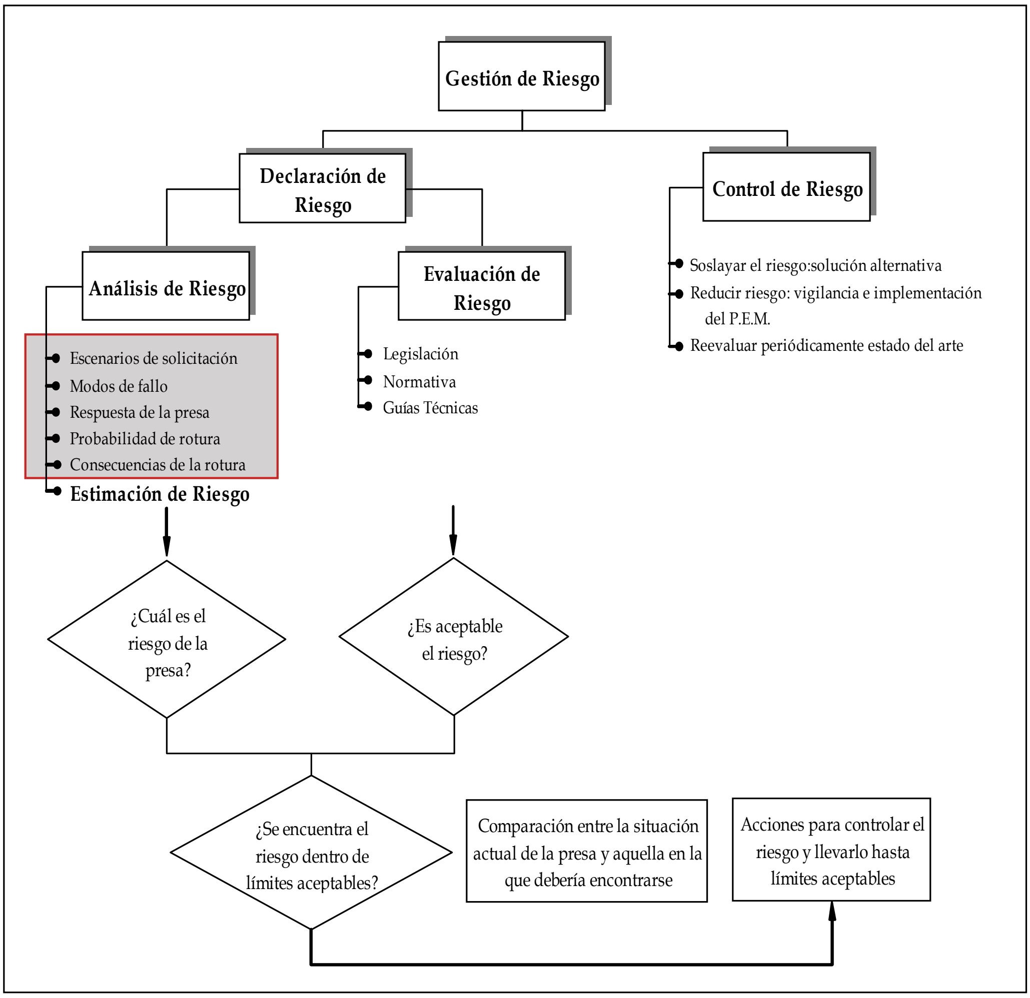
Recognizing all the above mentioned limitations, the CHD decided to develop a risk based complementary safety program that, as shown in the flowchart of Figure 1, incorporates the information coming from the normal activities in any dam safety program such as inspections, instrumentation, emergency plans etc. and provides an added value by dealing explicitly with risk. First step in such development consisted in a screening level analysis for a portfolio of 20 dams.

Risk analysis at screening level

As mentioned in the precedent chapter, risk based dam safety programs have the main objective of identifying is current risk are tolerable and, in any case, select the appropriate risk control measures. The assessment of such tolerability is accomplished by means of the so called Risk Analysis and Risk Evaluation activities, as shown in Figure 2.

More in detail, the screening level deals only with a number of the risk analysis tasks (shadowed in **Figure 2**), namely the load scenarios, failure modes, system response, failure probability and failure consequences.

Figure 2. Screening contextualization on the global risk management framework (shadowed). From: G.Membrillera (9).



Main objectives

The screening analysis is aimed to score a portfolio of dams, in a general and simplified manner, in terms of their potential failure risk. Consequently, the final goal is provide an objective information to help in the organization, planning and resource assignment to dam safety programs by identifying those dams with a higher level of risk.

It is however essential that, despite the simplicity of the procedure, a relevant mistake (such as not accounting a significant risk) is not made as it may imply that the dam would not receive the due attention and its safety can be jeopardized.

Input data and other requeriments

The input data should be collected from information gathered in safety related normal activities such as past visual inspections, field investigations or instrumentation records. In the case of Spain, mandatory documents according to the current legislation (14) such as the Operating Rules, Emergency Action Plan and Dam Safety Review reports are of great help to complete all needed data. Nevertheless, to properly complete the score of all dams, engineering judgment from an experience technician is unavoidable.

In order to evaluate the required resources for any organization to complete a screening analysis, according to the acquired experience by CHD, the activity that consumes most of the time is collecting the proper information. If such information is provided by previous documented works, and experience engineer should be able to complete the score in no more than few hours per dam.

Theoretical fundamentals

Taking into an account that the screening analysis main objective is to make a homogeneous comparison on potential risks associated to a portfolio of dams, "risk" should be herein properly defined. Risk (CSA, 1997 Hartford et al (10) and ICOLD(11)) "is a measure of the probability and severity of an adverse effect to life, health, property or environment".

In the general case, risk is estimated by the combined impact of all triplets of scenario, probability of occurrence and the associated consequence. In the special case, average risk is estimated by the mathematical expectation of the consequences of an adverse event occurring. Expressing this in terms of an equation:

$$R \approx \sum[P(\text{solicitaciones}) \cdot P(\text{rotura}|\text{solicitaciones})\ P(\text{consecuencias}|\text{rotura},\text{solicitaciones})] \quad \text{(ec. 1)}$$

where *R* is risk, *P(X)* the conditional probability estimated for the event *X*, and the expression *P(X|Y)* is the probability of the event *X* given the event *Y*.

As shown in **Table 1**, adapted from USBR (5) and where the score system can be checked in full detail, the screening analysis deals with risk associated to three general load scenarios (hydrologic, seismic and normal operation), adding all three partial results to get an overall index. The obtained *Failure Index* combines scenarios with the two first components of the risk equation: loads at column A and system response at column B.

Table 1. Screening summary result table for every dam

Load Scenarios	A. Load Factor	B. Response Factor	C. Filure Index	D. Loss of Life Factor	E. Risk Index	F. Population at Risk	G. Socio-Economic Index	H. Consequence Factor
Static								
Hydrologic								
Seismic								
Operations, Maintenance, and Safety								
Totals								

Consistently with the definition of risk provided previously, the *failure index* is multiplied by a *Potential Life Loss Factor* that accounts for consequences of the dam failure, giving the *Risk Index* as final result.

In addition, a measure of potential social and economic impacts are reflected through use of the Socio-Economic Index. Also, for the purposes of the screening, the term “social” is assumed to grossly include cultural and environmental consequences.

Customized components

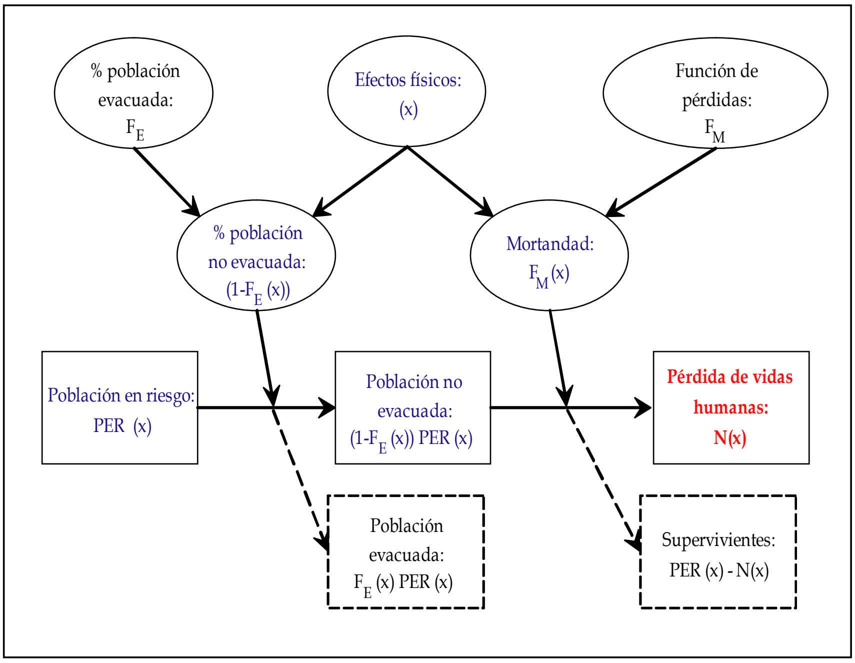
As properly referred before, the features of the scoring methodology can be fully checked at USBR (5). However, some remarks on particular customizations or specific recommendations suitable for the Spanish context are listed bellow:

- Concerning *the seismic load factor factor*, it is exclusively linked with the so called “Basic horizontal acceleration (a_b)” as referred in the current Spanish seismic code (13).

- Concerning Worksheet G (Operations, Maintenance, and Safety), the minimum discharge in absence of flood can be evaluated from “scenario A1” in the Spanish Emergency Action Plans.

- Concerning Worksheet H (Loss of Life Factor), a simplification from the McClelland and Graham methodology (4) was adopted, making use of the mandatory information that should be included in the Spanish Emergency Action Plans and some procedures implemented by Triana (15). **Figure 3** summarizes all factors involved in the procedure.

Figure 3. General scheme for potential loss of life estimation. Fuente: Jonkman et al (12).



Finally, a “Worksheet I” (Consequence Qualitative Index) has been added by the authors to the existing methodology so that a qualitative estimation of material damages can be incorporated to the over all judgment. These consequences can be classified as A (high), M (medium) or B (low) according to the reservoir uses (Flood Control, Water supply and irrigation, Hydropower Recreational and others) and the magnitude of the impact on population, economy and environment.

4. SCREENING APPLICATION TO A PORTFOLIO OF 20 DAMS

According to the previously described theoretical principles and practical procedures, the following graphs show the results of the screening application to a portfolio of 20 dams owned and operated by the CHD in Spain (**Figs. 4 to 8**).

Figure 4. Risk Index summary of results

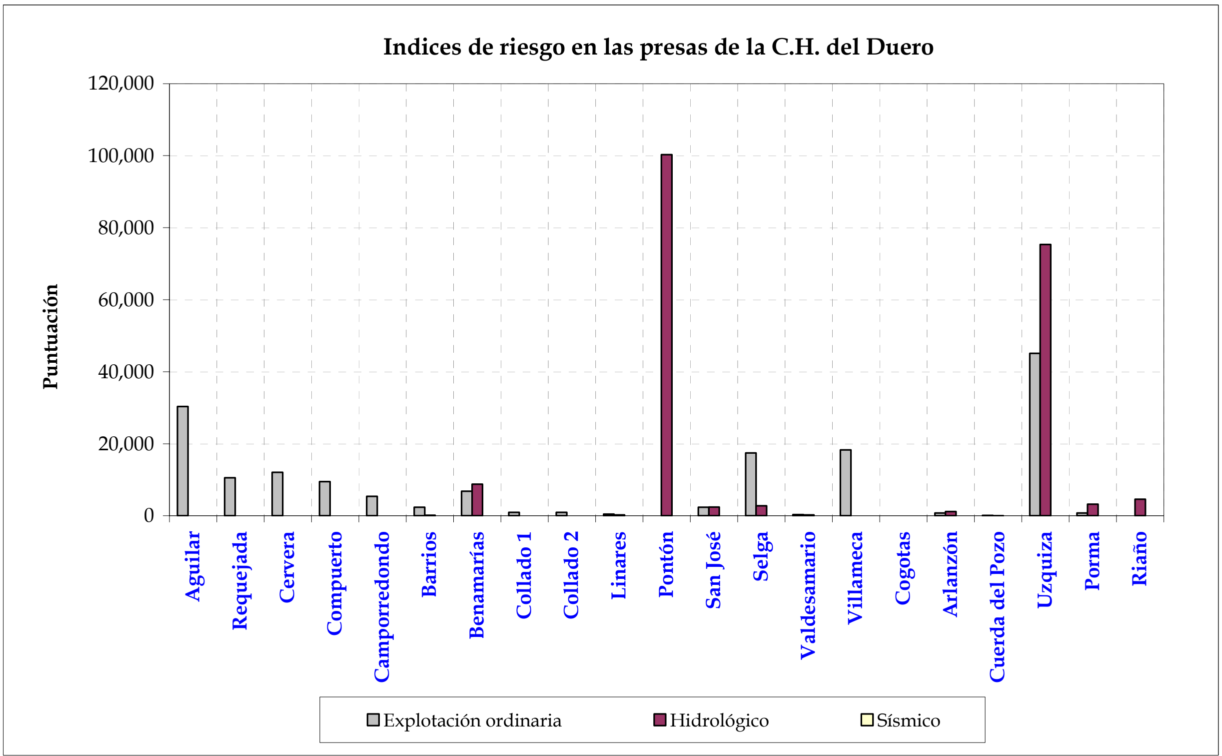


Figure 5. Failure index summary results

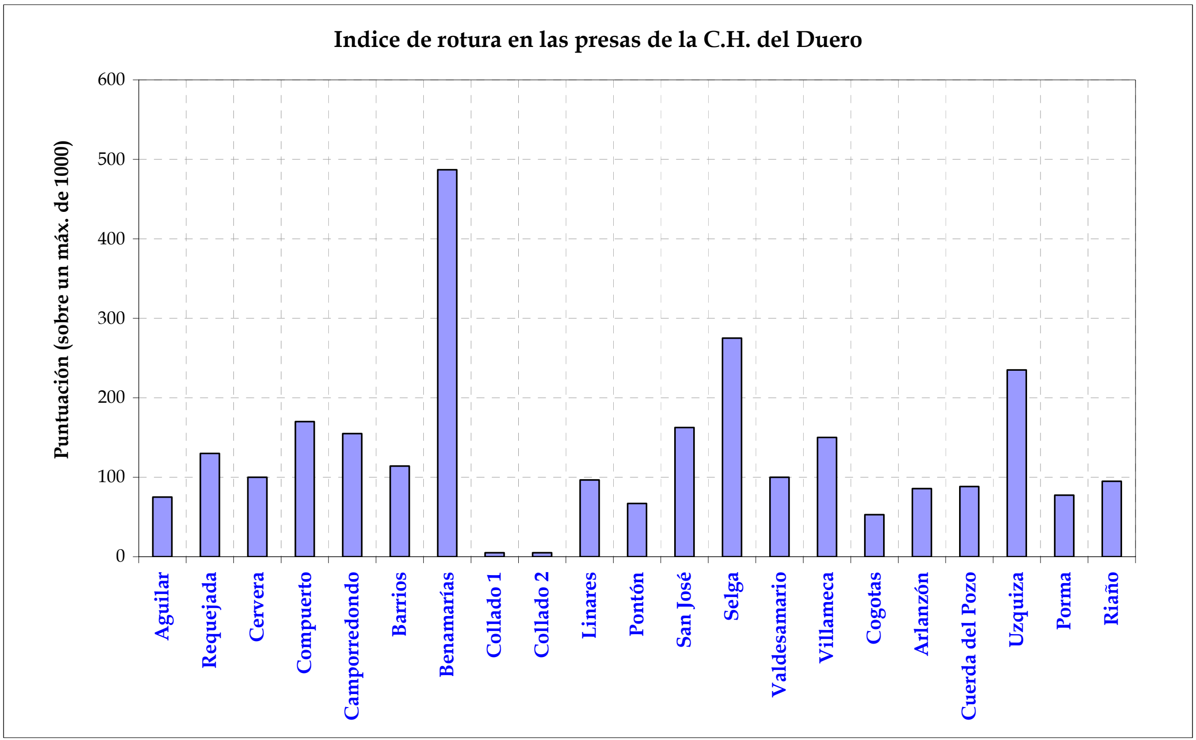


Figure 6. Loss of Life index summary results

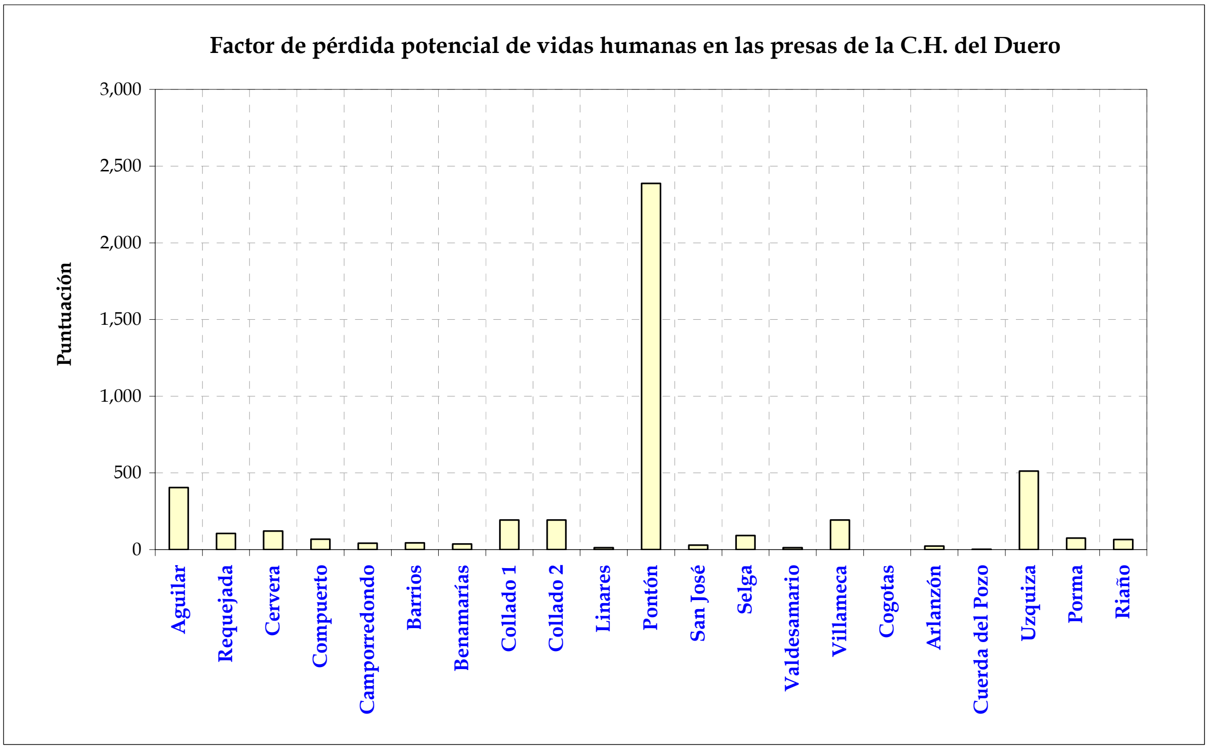


Figure 7. Global consequences factor summary of results

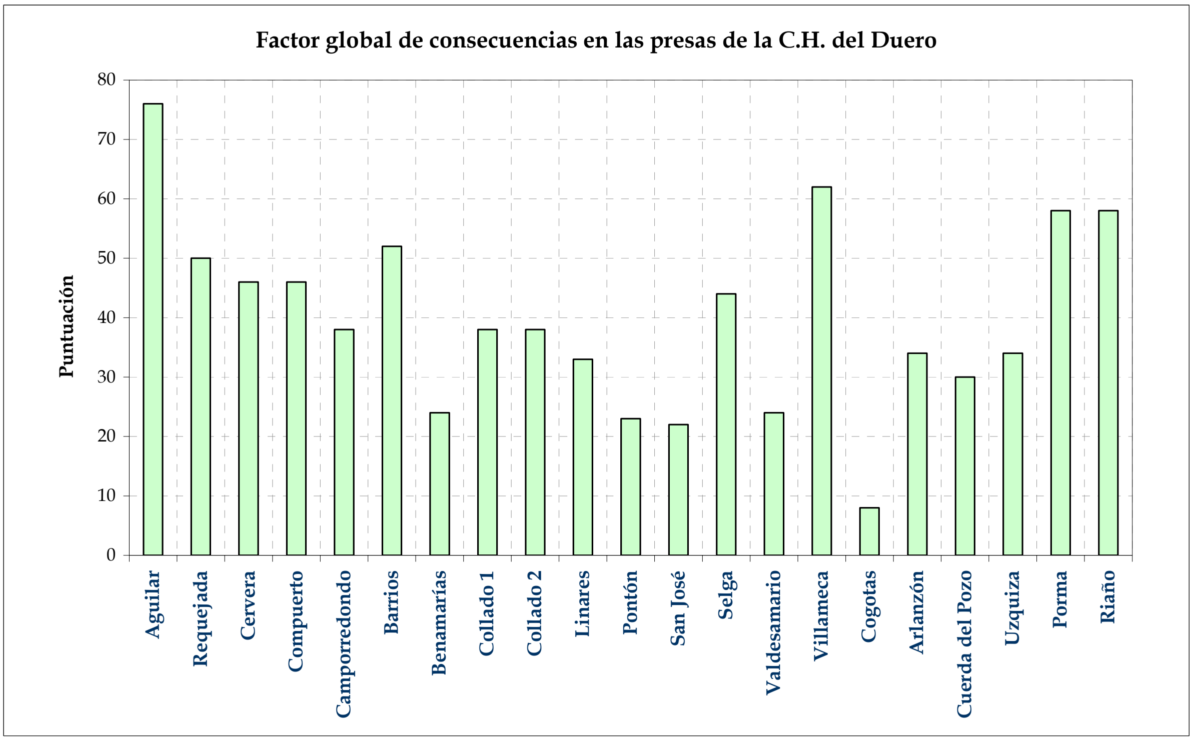
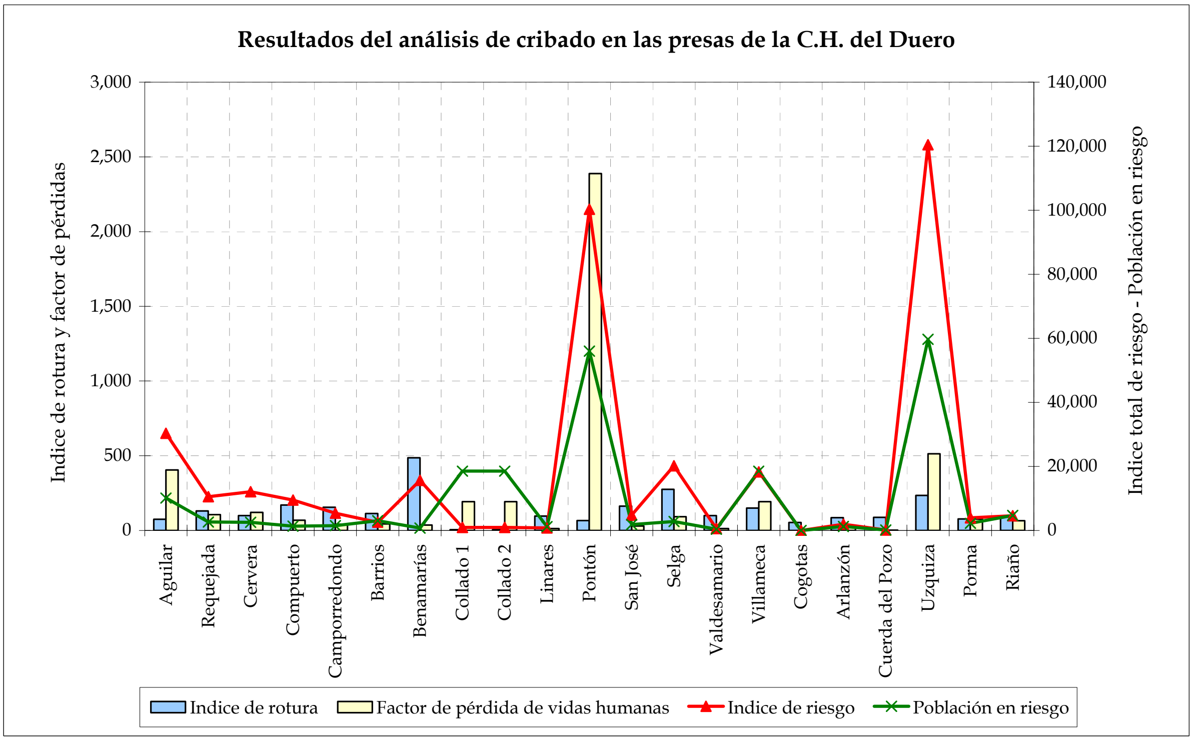


Figure 8. Comparison among failure index, loss of life factor, risk index and population at risk



Detailed numbers as obtained for each dam are given in the following summary table (**Table 2**):

Table 2. Numerical summary of results

	Presa						INDICES DE RIESGO				
		Indice de rotura	Factor de pérdida de vidas humanas	Indice de riesgo	Población en riesgo	Indice socio-económico	Explotación ordinaria	Hidrológico	Sísmico	Factor global de consecuencias	
1	Aguilar	75.00	404.64	30,346.81	10,117	760	30,346.81	0.00	0.00	76.00	M
2	Requejada	130.00	105.68	10,571.27	2,631	263	10,568.27	0.00	0.00	50.00	M
3	Cervera	100.00	120.76	12,098.56	2,530	255	12,098.56	0.00	0.00	46.00	B
4	Compuerto	170.00	67.85	9,502.18	1,341	188	9,499.18	0.00	0.00	46.00	B
5	Camporredondo	155.00	41.54	5,402.10	1,525	198	5,399.60	0.00	0.00	38.00	B
6	Barrios	114.00	43.44	2,568.43	3,068	181	2,389.18	173.76	0.00	52.00	M
7	Benamarías	487.00	36.67	15,663.08	751	321	6,856.85	8,800.23	0.00	24.00	B
8	Collado 1	5.00	192.74	963.72	18,517	93	963.72	0.00	0.00	38.00	B
9	Collado 2	5.00	192.74	963.72	18,517	93	963.72	0.00	0.00	38.00	B
10	Linares	96.70	12.31	763.32	1,196	74	492.59	267.23	0.00	33.00	B
11	Pontón	67.00	2387.92	100,294.98	56,000	2,352	0.00	100,292.48	0.00	23.00	B
12	San José	162.50	29.45	4,785.48	1,860	302	2,355.93	2,429.55	0.00	22.00	B
13	Selga	275.00	91.81	20,203.92	2,814	619	17,444.09	2,754.33	0.00	44.00	B
14	Valdesamario	100.00	12.94	588.01	369	17	323.62	258.89	0.00	24.00	B
15	Villameca	150.00	192.74	18,316.16	18,517	1,759	18,310.66	0.00	0.00	62.00	M
16	Cogotas	53.00	0.18	9.30	5	0	0.00	9.30	0.00	8.00	B
17	Arlanzón	85.75	22.63	1,940.93	1,225	105	792.22	1,148.71	0.00	34.00	B
18	Cuerda del Pozo	88.25	2.28	146.88	163	10	102.72	41.66	0.00	30.00	B
19	Uzquiza	235.05	512.50	120,464.13	59,691	14,030	45,100.38	75,363.75	0.00	34.00	B
20	Porma	77.50	75.51	3,966.63	2,236	117	755.07	3,209.06	0.00	58.00	M
21	Riaño	95.00	65.62	4,596.00	4,692	328	0.00	4,593.50	0.00	58.00	M

Conclusions

As mentioned in the very recent modification of the Spanish legislation on dam safety (January 2008), that states that "risk management should be a capital aspect on dam legislation of any advanced country", dealing explicitly with risks even in a very simplified and general manner, provides very significant information and added value to the classical way to deal with dam safety issues.

Main conclusions derived from the practical application of the customized screening process to a portfolio of 20 dams are:

- The analysis provides an homogeneous comparison of the level of safety among dams with very different circumstances.

- It also identifies those areas where particular effort is required in terms of monitoring, inspection and surveillance.

- It has been very important the consideration of all risk components, as previous existing assumptions where basically based only in the probability of failure, thus efforts where not aimed to provide and homogeneous risk level through the basin.

- Results are in any case qualitative and useful for the comparisson of the dams analyzed, but should not be directly compared with other groups of dams.

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