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A RISK-INFORMED JOURNEY TOWARDS IMPROVED DAM SAFETY GOVERNANCE IN SPAIN

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Abstract. *The world has evolved significantly in last decades in the way of understanding floods and dam and other critical infrastructure protection. Modern societies depend on the correct and efficient behavior and operation of these infrastructures. In addition, there is an increasing social demand for higher safety levels, then requiring the integration of design, construction and operation of dams on a risk management framework that allows to mitigate both natural and manmade threats.*
In this context, the application of risk analysis techniques has emerged as a paradigm shift, enhancing dam safety and flood risk assessment and management.
The dam safety management context in Spain is evolving as a result of new regulation, guidelines and state-of-the-practice at national and international level. This paper presents an overview of this changing context and how Risk Analysis arises as a tool to guide dam owners towards an integrated dam safety management and governance. Successful pilot cases can be found for which the benefits of applying risk analysis techniques have been proved, supporting prioritization of risk reduction measures and improving dam knowledge, operation and maintenance. These pilot cases represent the first steps of a journey for dam owners, aiming at achieving efficient, transparent and robust dam safety governance.

1 INTRODUCTION

The world has evolved significantly in last decades in the way of understanding floods and critical infrastructure protection (including dams). Modern societies depend on the correct and efficient behavior and operation of these infrastructures.

Society demands higher levels of safety and reliability of critical infrastructures, then requiring the integration of design, construction and operation of dams on a risk management framework that allows to mitigate both natural and manmade threats in an efficient and effective way. This concept of integrated risk management has acquired importance in recent years and current dam safety management strategies require incorporating aspects such as sustainability, resilience and public participation.

In this context, the application of risk analysis techniques has emerged as a paradigm shift, enhancing dam safety and flood risk assessment and management. The European Flood Directive 2007 (2007/60/EC) and the European Directive on Critical Infrastructure Protection 2008 (2008/114/EC) are examples of such change. Both directives remark the need for

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identifying, characterizing and analyzing risk for establishing strategies for flood risk and critical infrastructure management.

In the United States, following the journey initiated by the United States Bureau of Reclamation in the nineties, the United States Army Corps of Engineers (USACE) and the Federal Emergency Regulatory Commission (FERC) have implemented risk-based dam safety management processes. At the European level, France enacted specific regulation in 2008 to develop the process at national level.

The state-of-the-practice worldwide recognizes the benefits of Risk Analysis as a tool for supporting decisionmaking for critical infrastructure management, encouraging other improvements in operation and maintenance, surveillance or emergency preparedness.

In Spain, national regulation includes since 2008 the need for considering risk management as a key driver for establishing dam safety strategies, following the example of other countries. Therefore, in recent years there has emerged a new perspective for dam safety management which incorporates Risk Analysis, which aims at combining both the traditional (essentially deterministic) and the risk-informed dam safety approach, focusing on all risk components associated with a potential dam failure or uncontrolled release.

In this paper, an overview of the dam safety management framework in Spain is provided (including actors and legislation), emphasizing the paradigm shift that has arisen in recent years with the application of risk analysis techniques to support dam safety management and governance.

2 DAM SAFETY MANAGEMENT IN SPAIN

2.1. Context

Spain is geographically located in the Southwest of Europe, with an area of 505,182 km² and a population of roughly 47 million inhabitants. Spain´s total water resources are estimated in 112 km³ per year, resulting in about 2,700 m³/per person/year[1] (the average of European Union countries is 3,200 m³/per person/year). Nevertheless, these water resources are highly irregular in time and an uneven geographic distribution (Figure 1a).

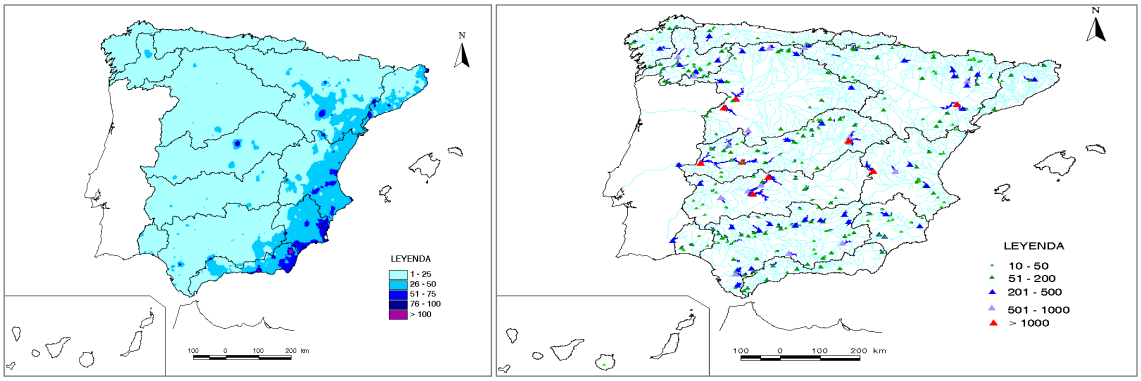

Figure 1: (a) Registered maximum daily rainfall vs. average yearly rainfall; (b) Dams in Spain and storage capacity in hm³. Source: MAGRAMA, 2015.

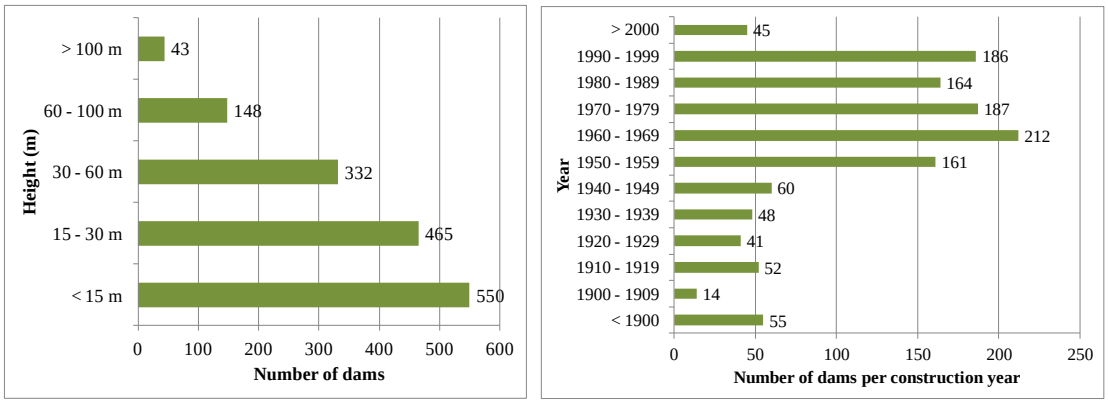

Figure 2: (a) Classification of dams in Spain based on dam height; (b) Number of dams in Spain per year of construction. Source: MAGRAMA, 2015.

Spain has a large tradition on dam construction. According to ICOLD (International Commission on Large Dams), Spain ranks ninth in the world in terms of number of large dams (the ICOLD Register of dams includes dams above 15 m high or ranging from 5 to 15 m high with a storage capacity above 3 hm^3), where the registered numbered of large dams is of 1082.

The total number of dams in Spain rises to 1225 (Figure 2a), most of them built in the last 60 years (Figure 2b).

Dams have played an important role in Spain regarding flood protection, hydroelectric production and water resources management over decades. Dams have been built across the whole country in both upstream and downstream areas of river catchments basins, aiming to cope with highly irregular water inputs, frequent drought events, and floods that usually take place in a short period of time (e.g. ratios between registered maximum daily rainfall and the average yearly rainfall above 100% are found in eastern areas, Figure 1a).

2.2. Actors

Given the aforementioned facts, it is undeniable that there exist a large number of dam owners in Spain, including public and private holders. Around one third of the total Spanish large dams are owned and operated by Spanish Ministry on Food, Agriculture and Environment (MAGRAMA), through the surrogated authorities given to the River Basin Authorities (RBAs) which, in addition, hold the authority to enforce and develop integrated water resources planning and management, flood control and environmental protection, among other activities. In accordance with the Water Framework Directive (WFD), 18 River Basin Districts have been defined in Spain (Figure 3). River Basin Authorities are public entities with autonomy of action and their own legal personality. Two types of them can be distinguished: inter-regional basins (e.g. Jucar River Basin) and intra-regional basins (e.g. Catalonia Intra-regional Basins).

With more than 1400 dams (including also small dams and ponds), functions and responsibilities of dam owners regarding dam safety management have evolved as a result of a changing dam safety regulation framework. The current national dam safety regulation framework is presented in next subsection.

1.3 Legislation and other instruments

Regulation on Water and Flood Risk is strongly connected to Dam Safety Management. Overarching national and European legislation influencing, one way or another, dam safety management, include the Water Act of 1985 (and subsequent

upgrades), the National Hydrological Plan Act of 2011 (and subsequent upgrades) and the Water Framework Directive (WFD) of 2000 and its transposition to Spanish Legislation.

More related to Dam Safety Issues are the more recent European Directives on Floods and Critical Infrastructure, as well as their transposition to the Spanish Legislation:

- European Directive 2007/60/EC[2] on the assessment and management of flood risks (so-called EU Flood Directive).
- European Directive 2008/114/EC[3] on the identification and designation of European critical infrastructures and assessment of the need to improve their safety levels.

Directive 2007/60/CE acknowledges and explicitly requires that risk analysis must be used as a tool for flood risk reduction, through the development of flood risk management plans at river basin level and conducting flood risk analyses including dam failure.

More particularly, the history of dam safety regulation in Spain has been influenced by two dam failure events: the failure of Ribadelago dam (Zamora, Spain) in 1959 and the failure of Tous dam (Valencia, Spain) in 1982. Both failures were landmark events in the national dam safety regulation framework.

The current dam safety regulation context in Spain includes mainly two standards:

- the "Instruction for the Design, Construction and Operation of Large Dams" (*Instrucción para el Proyecto, Construcción y Explotación de Grandes Presas*) published in 1967, and,
- the "Technical Regulation for Dam and Reservoir Safety" (*Reglamento Técnico sobre Seguridad de Presas y Embalses*) published in 1996.

The approval of the 1996 Technical Regulation did not imply the revoke of the 1967 Instruction. This fact has been one of the problems more intensely discussed by the Spanish dam community and both standards remain applicable up to now.

The 1996 Technical Regulation included concepts and dam safety criteria that had evolved significantly since the publication of the Instruction of 1967 and it is applicable to all publicly owned dams and to all private dams constructed after 1996. This Technical Regulation affects more specifically on dam safety issues and has a partial but progressive implementation.

The Technical Regulation was approved one year after the adoption of the Basic Directive of Civil Protection Planning against Flood Risk (1995). Up to this point, dam safety management had focused almost exclusively on the infrastructure; however, the 1995 Civil Protection Directive incorporates the consideration of both flood risk components (probability and consequences). Therefore, the 1995 Civil Protection Directive represents a milestone in the dam safety regulatory framework so far, requiring the implementation of Dam Emergency Action Plans (DEAPs) for those that have previously been classified as Category A or B based on its potential risk (considering the possibility of adverse potential consequences in case of failure or uncontrolled dam release). This classification was defined by the 1996 Technical Regulation.

Table 1 shows the number of dams in Spain classified by potential risk in A, B or C.

Category	Number	Owner (public/private)
A	718	400/318
B	103	43/60
C	629	208/421
Total	1450	651/799

Table 1: Number of dams per category based on potential consequences in case of failure (potential risk). Source: MAGRAMA, 2013.

Considering A and B dams, 301 out of 821 required DEAPs have already been approved (Table 2). Before being approved, DEAPs are evaluated by MAGRAMA and the Spanish Civil Protection Department.

EAP	Number	Owner (public/private)
Approved	301	194/107
In evaluation by MAGRAMA	203	121/82
In evaluation by Civil Protection	42	28/14
Total	546	343/203

Table 2: Number of approved EAPs. Source: MAGRAMA, 2013.

The content of a DEAP should include aspects such as dam safety analysis, dam break scenarios, flood mapping and identification of affected areas (usually consisting of a qualitative assessment of potential consequences), emergency procedures, and organizational schemes. The elaboration and implementation of DEAPs has constituted a complex process, requiring the development of guidelines by MAGRAMA to support the process.

The last update of the Spanish Public Water Regulation (16 January 2008) added a new chapter which deals with dam safety, including the need for considering risk management as a key aspect for dam safety, whose main objective is to unify all dam safety criteria to be applied to all dams. Consequently, three Technical Standards were published in 2011, but not approved so far, that will replace both the 1967 Instruction and 1996 Technical Regulation.

In addition to the aforementioned regulatory documents, a set of Technical Guidelines for Dam Safety has been published by the Spanish National Committee on Large Dams (SPANCOLD) of the International Commission on Large Dams (ICOLD).

These guidelines include the state of art in several dam safety aspects and provide recommendations for accomplishing current standards. Published in 2012, the Technical Guide on Dam Safety, Operation of dams and reservoirs, titled "Risk Analysis applied to Dam Safety Management" is a recent milestone in the Spanish context and describes the general process for implementing Risk Analysis in order to inform decision-making and prioritization of risk reduction measures for dam safety management. This guideline[4] can be considered a significant contribution towards integrated risk-informed dam safety management.

2.3. New paradigm: Risk-informed dam safety management

The application of risk analysis techniques to dam safety management has involved a paradigm shift, but dam safety risk analysis is not new. Following the failure of Teton dam in 1976, the U.S. Bureau of Reclamation (USBR) implemented a dam safety program in 1978, in accordance with national dam safety legislation. This program was in line with their mission “to protect, to the extent practicable, people from risks posed by dams.” It represented the first step in a journey toward dam safety risk-informed management.

Risk-based approaches for dam safety analysis were presented by the Australian National Committee on Large Dams (ANCOLD) in 1994, through the Dam Safety Management Guideline[5], which was later revised in 2003. Risk-based approaches were also introduced by the United States Society on Dams (USSD) in 2003, in a White Paper on Dam Safety Risk Assessment[6]. In addition, the International Commission on Large Dams (ICOLD) published its Bulletin 130 in 2005[7], including concepts such as the As-Low-As-Reasonably-Practicable (ALARP) criterion and the Cost-Per-Statistical-Life-Saved indicator (CPSLS).

Risk-informed dam safety management requires outcomes from risk analysis and assessment for supporting decisions. Risk analysis allows the dam owner, as well as the public, to understand the system and to document all information regarding contributions made to risk. Different risk analysis methods can be found. These methods may be partial or complete, if they analyze one or both risk components (probability and consequences). In addition, they may be classified as quantitative or qualitative, based on the nature of obtained risk outcomes. Among existing methodologies for dam safety risk analysis[8], several complete and quantitative examples can be found. At the Spanish context, the framework for risk-informed dam safety management published by the Spanish National Committee on Large Dams (SPANCOLD)[9] includes the analysis of all potential combinations of hazard events, system response and potential consequences that may result from dam failure or mission disruption through the application of risk modeling and the use of event tree analysis for risk calculation. Related work on risk assessment methods where event tree analysis has also been applied can be found in McGill et al. (2007)[10], Serrano-Lombillo et al. (2011)[11], and Castillo-Rodríguez et al. (2014)[12].

The publication of the SPANCOLD Technical Guideline emerged from the collaborative effort of several institutions and experts, incorporating results from research projects that had been developed in recent years. These projects resulted, among other outcomes, in tools for risk calculation, analysis and assessment, and prioritization of risk reduction measures (e.g. the software tool iPresas Calc[13] which allows risk calculation by means of event trees and influence diagrams, first developed at the Polytechnic University of Valencia and now being developed and upgraded by Ingeniería de iPresas SL, a UPV Spin-Off Company).

Efforts from a wide sector of the Spanish dam community are now allocated to enhance and promote risk-informed dam safety management through research and development, practical applications, training and communication. The aim is to achieve improved dam safety governance, based on efficiency, transparency, and sustainability principles. Risk-informed decisions may help to allocate funds more efficiently to protect the population downstream and to explain why actions are taken.

Some examples of further steps in this risk-informed journey are the publication of a simplified methodology[14] for the evaluation of hydrologic risk on dams and prioritization of risk mitigation measures or new advances for the incorporation of man-made threats into dam risk analysis[15].

3 CASE EXAMPLES AND LESSONS LEARNED

3.1 Pilot cases

Beyond the regulatory context and the aforementioned advances in risk analysis applied to dam safety management, a series of practical conditions have contributed to its application over the last years, including[9]:

- The need for analyzing existing risk due to the inclusion of dam owners' public responsibility in regulation, along with the social demand for higher safety levels and for justification of the use of private and public funds.
- The need for prioritizing corrective actions for risk reduction.
- The need for optimizing water resources management as well as to increase dam regulation capacity.
- The difficulty of building new dams, mainly due to social and environmental reasons, that will predictably make necessary to extend the dam operational phase.
- The ageing of existing dams (most of them are over 30 years old in Spain).

Several pilot cases have been conducted recently in Spain. These examples include dams from public and private owners, such as:

- Iberdrola [Private owner, Water supply and hydropower], 2010.
- Catalan Water Agency [Public owner, Water supply and irrigation] , 2010.
- Duero River Authority [Public owner, Portfolio of dams] , 2010-2013.
- *Gas Natural Fenosa* Engineering [Private owner, Hydropower and irrigation] , 2014-2015.
- *Canal Isabel II Gestión* [Public owner, Water supply], 2014-2015.
- Government of Extremadura [Public owner, Irrigation], 2014-2015.

These pilot cases have included dam risk analyses at small and large scale (e.g. at portfolio level). As an example, the work conducted by the Duero River Authority represents one of the most complete and documented international examples for a portfolio of dams in recent years[16]. The Duero River Authority promoted the analysis of 27 large dams located in the North-West region of Spain, with a broad variety of typologies and physical characteristics. It was the pilot case used by MAGRAMA to test on transition towards risk-informed decision making in dam safety management.

After analyzing risk for all dams and systems of dams within the portfolio, a set of more than 88 risk reduction measures was considered to analyze different scenarios and to establish the optimal strategy for dam safety management. The software tool iPresas Manager was used for analyzing risk outcomes for all dams and different scenarios, obtaining the optimal sequence of actions, taking into account equity and efficiency principles. Figure 3 shows a screenshot of the software tool for one step in the obtained prioritization sequence. In this graph, results for step 5 out of 88 are depicted. This type of risk representation allows to analyze how actions impact on societal risk (vertical axis) at portfolio level in the prioritization sequence (horizontal axis). After implementing the first five actions, societal risk shifts from 0.3 lives/year to 0.06 lives/year with a total cost of 3 M€. Economic risk would be reduced from 1.7 M€/year to 0.25 M€/year

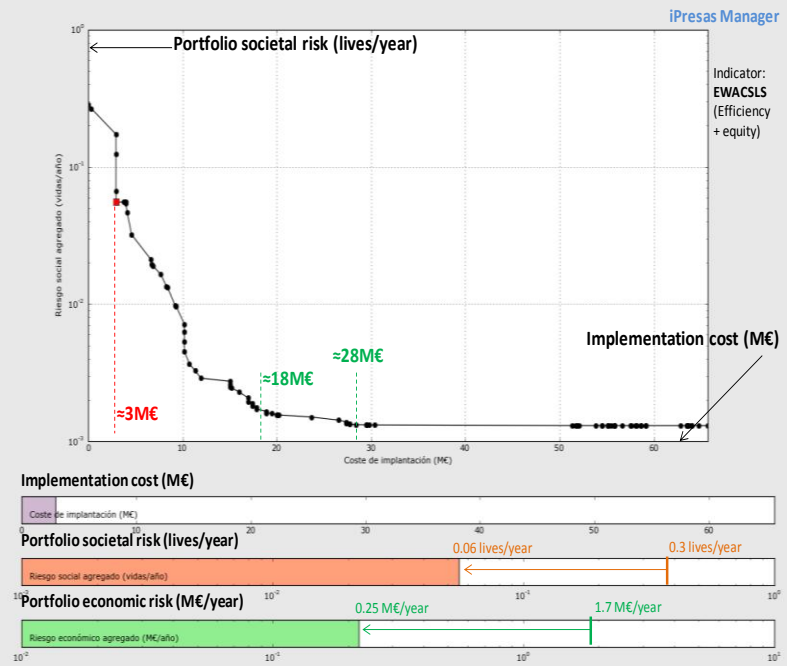

Figure 3: Portfolio societal risk (lives/year) in the prioritization sequence. Source: iPresas Manager.

Results from portfolio analysis shown that no risk reduction is provided further than measure 27 (approx. 28 M€), as risk reduction from applying next measures would become very marginal. This would represent one third of the total cost of implementing all measures (approx. 67M€).

Lessons learned from pilot cases conducted in Spain have revealed the benefits of

incorporating risk analysis techniques to dam safety management. These benefits include, among others:

- Improved understanding of the dam system (deeper knowledge of the dam, identification of knowledge gaps, uncertainty analysis, etc.).
- Improved decisions (prioritization of investments including efficiency and equity principles).
- Improved risk communication (for public education and awareness).
- Improved information for dam operation and maintenance.
- Improved emergency procedures and flood risk management plans.
- Good dam governance (decisions are justified, defensible and transparent).
- Business risks are known, enhancing business sustainability at mid and long term.

3.2 The value of integrating information for dam safety management

The application of risk analysis techniques provides a logical framework for better understanding the dam system itself. The added value of integrating all information regarding the dam system is inherent to any dam risk analysis, even in the case of purely qualitative analyses. Information from inspection and monitoring, operation and maintenance, operational rules, emergency action plans, etc. is reviewed, discussed, updated and, in a quantitative stage, incorporated to the risk model representing the system. Dam owners benefit from this process, gaining a better knowledge of the system.

The benefits of risk analysis and the added value of integrating information through risk analysis techniques go beyond the dam safety management discipline. As proposed in Castillo-Rodríguez et al.[12], risk analysis techniques allow to integrate also all information from multiple hazards for flood risk analysis and management. In this case, dam failure events and uncontrolled releases represent one of the possible sources of flood hazard.

Similarly to the overall process proposed for dam safety risk analysis by the SPANCOLD Technical Guideline, a generic risk model architecture is provided[14] for flood risk analysis from multiple hazards, as shown in Figure 4.

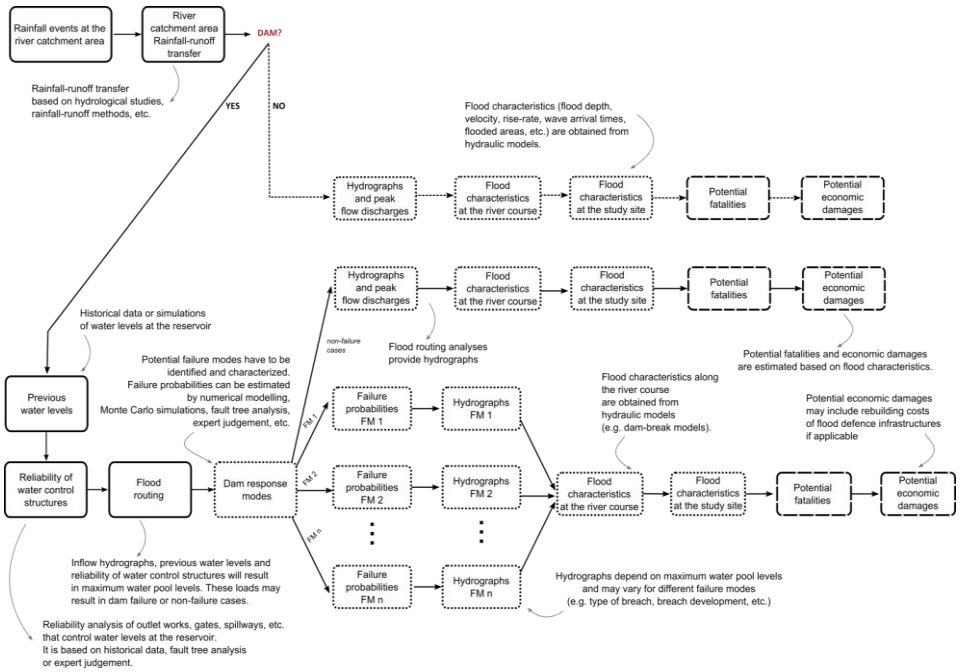

Figure 4: Generic risk model architecture for integrating multiple hazards for flood risk analysis and management. Source: Castillo-Rodríguez et al.[14]

This overall scheme integrates the analysis of pluvial flooding, river flooding and flooding from dam failure to provide better and more complete information to decisionmakers on flood risk management.

This integrative approach was applied to a case study in Spain (including flooding from failure a concrete gravity dam upstream the analyzed urban area). Risk outcomes, represented in a FN graph, are shown in Figure 5. Results show cumulative annual exceedance probabilities (vertical axis) for each level of potential consequences by integrating three sources of hazard: pluvial flooding, river flooding and flooding from dam failure. Three scenarios are depicted: the Base Case (current situation), the scenario after implementing the Dam Emergency Action Plan (DEAP) and a third case after implementing non-structural measures of improved emergency management and public risk awareness. A significant impact on flood risk reduction was found for DEAP-case and the scenario with non-structural measures ("high probability" flood events are reduced if compared with the Base Case).

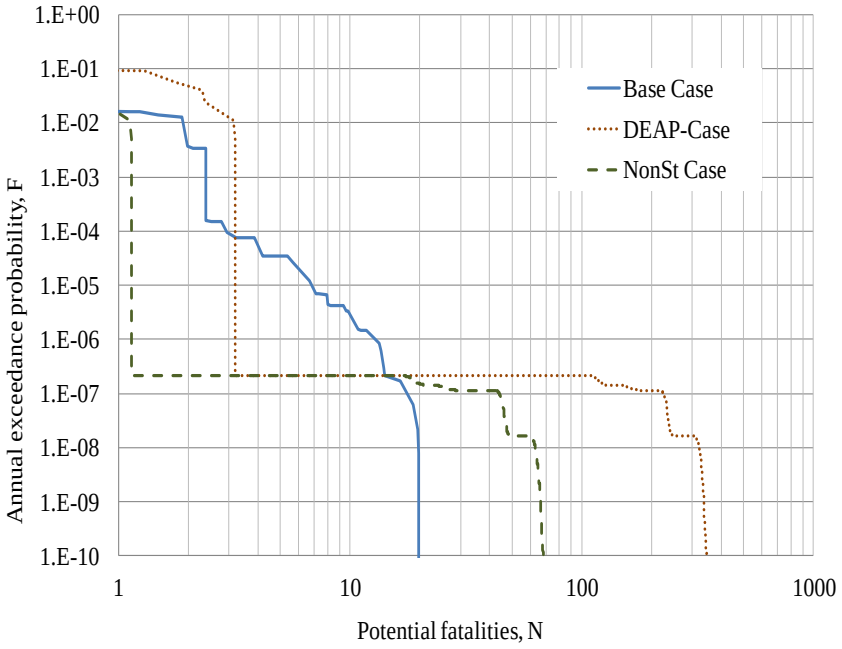

Figure 5: FN graph for a case example of integrated flood risk analysis including dam failure. Three scenarios: base-case, DEAP and non-structural measures. Source: Castillo-Rodríguez et al.[14]

4 CONCLUSIONS: FUTURE CHALLENGES AND STRATEGIES TOWARDS SMART DAM SAFETY GOVERNANCE

The dam safety management context in Spain is evolving as a result of new regulation and best practices. This paper has presented an overview of this changing context and how Risk Analysis arises as a tool to guide dam owners towards an integrated dam safety management and governance.

In future years, dam owners will face challenges driven by a changing society, environment and regulatory context. The new risk paradigm provides dam owners with information that is essential to establish strategies for dam safety management for present and future scenarios.

In this context of highly dynamic and complex scenarios, it is worth to remark that increased capacity for effective risk governance will only be possible with the extensive and willing participation of all concerned actors, including international collaboration as a way of improving, validating and maximizing the benefits of enhanced risk governance.

Beyond dam safety, the risk paradigm is an integrative one. As stated before, examples of this integrative paradigm are considering different hazards for flood risk characterization.

Successful pilot cases can be found at national and international scale for which the benefits of applying risk analysis techniques have been proved, supporting prioritization of risk reduction measures and improving dam knowledge, operation and maintenance.

These pilot cases represent the first steps of a journey for dam owners, aiming at achieving efficient, transparent and robust dam safety governance.

REFERENCES

[1]. Dams in Spain, Spanish Professional Assoc. of Civ. Eng., ISBN-84-380-0318-4, 2006.

[2]. EC, Directive 2007/60/EC, Directive of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks, 2007.

[3]. EC, Directive 2008/114/EC, Council Directive of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection, Official Journal of the European Union, 2008.

[4]. SPANCOLD, Technical Guide on Dam Safety Nr. 8 "Risk Analysis applied to management of Dam Safety", Spanish National Committee on Large Dams (2012).

[5]. ANCOLD, Guidelines on Risk Assessment, Australian National Committee on Large Dams Inc., Australia, 2003.

[6]. USSD, Dam Safety Risk Assessment: What is it? Who's using it and why? And Where should we be going with it?, White Paper on Dam Safety Risk Assessment, 2003.

[7]. ICOLD, Bulletin 130, Risk Assessment in Dam Safety Management: A Reconnaissance of Benefits, Methods and Current Applications, International Commission on Large Dams, 2005.

[8]. Harrald, J. R., Renda-Tanali, I., Shaw, G.L., Rubin, C.B., Yeletaysi, S.,: Review of risk based prioritization/decision making methodologies for dams, USACE, Washington DC, USA, 2006.

[9]. SPANCOLD, Technical Guide N8 of Operation of Dams and Reservoirs., Vol.1: "Risk analysis applied to management of dam safety", Spanish National Committee on Large Dams, Madrid, Spain, 2012.

[10]. McGill W, Ayyub B, and Kaminskiy M., Risk analysis for critical asset protection. Risk Analysis, 27(5): 1265–1281., 2007.

[11]. A. Serrano-Lombillo, I. Escuder-Bueno, M. G. de Membrillera-Ortuño, and L. Altarejos-García, Methodology for the Calculation of Annualized Incremental Risks in Systems of Dams. Risk Analysis Journal, 2010.

[12]. J.T. Castillo-Rodríguez, I. Escuder-Bueno, L. Altarejos-García, and A. Serrano-Lombillo, The value of integrating information from multiple hazards for flood risk management, Nat. Hazards Earth Syst. Sci., doi:10.5194/nhessd-1-3305-2013, 2014.

[13]. A. Serrano-Lombillo, I. Escuder-Bueno, M. G. de Membrillera-Ortuño, and L. Altarejos-García, iPresas: Software for risk analysis. In 23rd International Congress on Large Dams, 2009.

[14]. I. Escuder-Bueno and J. González-Pérez, Metodología para la evaluación simplificada del riesgo hidrológico en presas, ISBN: 978-84-380-0465-4, Spanish Professional Association of Civil Engineers, 2014.

[15]. J.T. Castillo-Rodríguez and I. Escuder-Bueno, An approach for assessing the impact of manmade threats in dam risk management, Reliab. Eng. And Syst. Safety, In review process, 2015.

[16]. L. Ardiles, D. Sanz, P. Moreno, E. Jenaro, J. Fleitz, and I. Escuder, Risk assessment and management of 26 dams operated by the Duero River Authority in Spain, Dam engineering, ISSN: 0-617-00563-X, United Kingdom, 2011.