RISK ASSESSMENT AND MANAGEMENT FOR 26 DAMS OPERATED BY THE DUERO RIVER AUTHORITY (SPAIN)

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Abstract. *The Spanish Regulations on Public Hydraulic Resources (Reglamento del Dominio Público Hidráulico, RD 16th January 2008) gathers the need for considering the risk management as a vital element in dam safety, following the example of some of the most developed countries in this field. In this context, the Duero River Authority (DRA) has promoted an ambitious program which complements the "state of the art" dam safety activities in Spain (Review Reports, Emergency Action Plans, etc.) with risk management.*

Specifically, an screening analysis was performed for this system of 26 state-owned dams, followed by a full quantitative analysis on two "pilot schemes" (Carrión' and 'Pisuerga' systems) and currently risk analysis is being adopted as a tool for dam safety management of the whole portfolio of Duero River Authority dams.

The paper deals with the different and concomitant activities that are being undertaking to achieve this goal. These activities include the analysis of 'Castrovido' dam, nowadays under construction, and integrates the maintenance and conservation contracts to provide the basic inputs for potential failure mode analysis (instrumentation, monitoring and surveillance tasks are thus efficiently integrated in the working framework).

From the set of the aforementioned activities, it is expected to obtain, among other results, a deeper knowledge of the portfolio of dams and their behaviour, to characterize the impact of operational activities in terms of risk management and to integrate a risk-informed supporting tool for decision making on dams and later on all infrastructures under Duero River Authority responsibility.

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1 INTRODUCTION

The Duero River Authority (DRA) is performing a series of additional tasks to its dam safety program based on risk analysis approaches, as it is being or has been developed by other international organizations, like the United States Bureau of Reclamation (USBR) or the United States Army Corps of Engineers (USACE).

Once a first phase or 'screening' was finished, a full quantitative analysis of the inherent risks on dam safety management of two systems ('Carrión' and 'Pisuerga') was performed. It included quantitative estimations of the probability of occurrence of different events, the identification of the potential failure modes, the probabilities of failure related to each event and the estimation of resulting consequences.

The abovementioned analysis, together with the evaluation of different risk-mitigation measures, provides to the operator a supporting tool for decision making on dam safety which makes it possible to prioritize the investment policies in accordance with technical, economical, social and environmental feasibility criteria, as encouraged by the current legislation.

Since 2009, the systematic framework developed by the DRA for integrating risk analysis and evaluation to the overall dam safety management is focused on the following three basic activities:

- Activity A: Risk analysis and evaluation for 'Castrovido' dam and its reservoir, now under construction (Sanz et ál, 2010).
- Activity B: Identification of the failure modes of each of the 26 dams as a part of the maintenance and conservation contracts for the systems under operation (Fernández Baños et ál, 2010).
- Activity C: Development of risk models of the 7 dam systems as a helping tool for the overall dam safety management (see next section).

Finally, several additional activities are being also integrated in the framework, regarding with the role of the different aspects of communication management and risk control. A series of preliminary ideas and objectives in this field are also provided in this article.

2 RISK MODELS AS SUPPORTING TOOL FOR DAM SAFETY

Understanding and recognizing all different risk components that are inherent in dam and reservoir safety management constitutes the conceptual basis to implement logic systems or models aimed to inform decision making.

Starting by day by day basic activities, many surveillance tasks such as visual inspections, monitoring of the behavior by means of instrumentation records or function tests on the electromechanical equipment are typically covered. In fact, if a failure mode has already started and is under progression, the capacity for detection and successful intervention relies on the efficacy of these activities.

Once any abnormal behaviour, thus affecting the safety of the facility, has been detected, intervention is focused both to overcome the deficiency and in terms of emergency management aimed to protect the downstream population. First of these actions would result in diminishing probability of failure and second in the potential adverse consequences mitigation, typically by means of conducting the activities included in an emergency action plan.

Another of the core activities of any dam safety program is the periodical safety review, where load scenarios and system response in terms of safety factors are typically analysed, together with other factors such as gate functionality, communication reliability, accessibility, etc.

In summary, all mentioned activities, studies and procedures linked to dam safety management that – according to Spanish regulations - are mandatory to document in the Operation Rules, Emergency Action Plans and Safety Review Reports, are linked to the different components of risk: loads, system response, and consequences.

Thus, if all processes involved in dam safety management are integrated in a logic system or risk models capable to aggregate all risk components inherent to these infrastructures, the resulting information will be of great value to help in decision making.

In order to achieve this value, the inputs to the risk model have to be converted into information to allow the identification, characterization and quantification of risk. The process that starts with gathering data and leads to risk quantification implies the consolidation of the existing knowledge on the facility and has to be guaranteed with procedures to properly store and update such data that will be integrated in a necessarily dynamic management tool.

Consistency, robustness, efficacy and efficiency of risk models in order to provide valuable information in decision-making are reinforced by different means. One of the most important aspects is exchanging information, debating on different procedures, etc. preferably in events such as workshops or conferences that are typically oriented to owners and dam safety professionals. However, it also becomes critical that all personnel involved in dam safety activities is trained and educated adequately to guarantee reliable results thus providing by itself a better safety condition of the dams.

In any case, the capacity and the way of communicating with the public (and particularly with downstream residents), together with a clear legislation that integrates design standards, safety requirements, risk management and legal responsibilities, are two of the main pillars necessary to implement a modern, transparent, efficient and socially accepted procedure for decision making in dam safety.

The following (Figure 1) conceptual scheme represents how risk models are linked to the contents of different legal documents (particularly in Spain but quite similar to many safety legislation over the world) and to scientific areas.

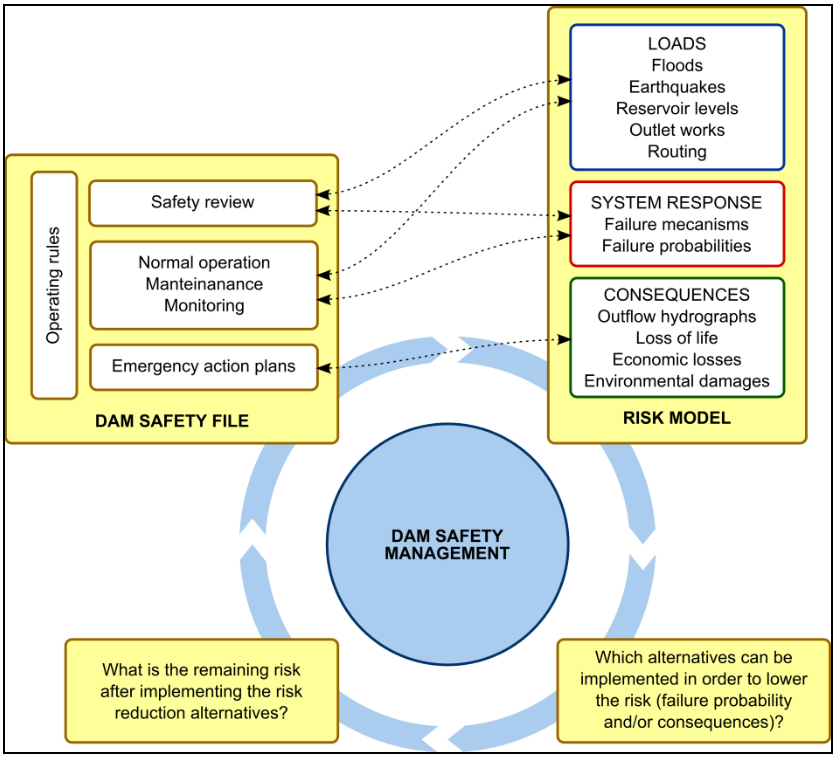

Figure 1: Risk model links to the contents of different legal documents and to scientific areas. Dynamics involved in using the risk models as tools to inform decision making.

As it is shown in Figure 1, the "state of the art" dam safety activities in Spain, provide the basis and necessary support for dam safety management, activity that may significantly benefit by using risk models. Next scheme (Figure 3) shows the structure of the main activities carried out by the DRA, described in the previous section, as a framework towards a risk-informed dam safety management procedure.

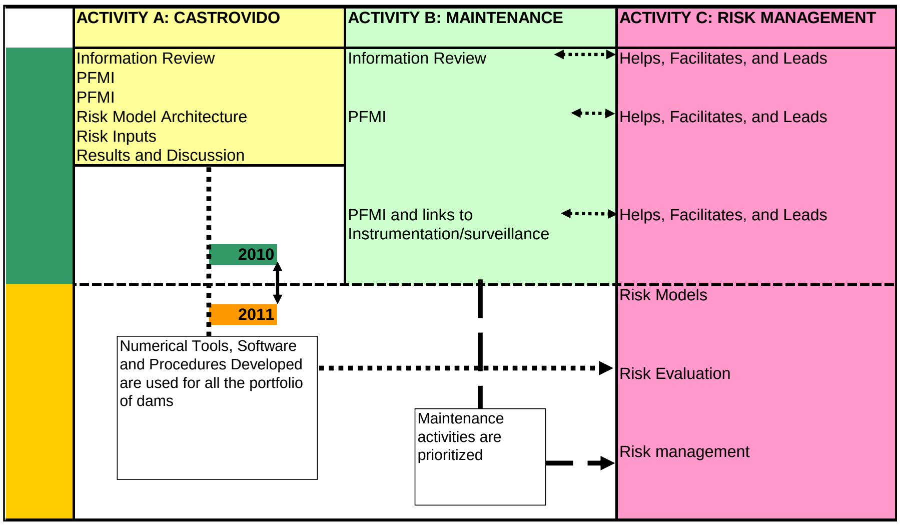

Figure 3: Framework and integration of the DRA activities towards a risk-informed management procedure.

In the next section, these activities are briefly explained.

3 ACTIVITY A: RISK ANALYSIS AND EVALUATION OF CASTROVIDO DAM AND RESERVOIR (UNDER CONSTRUCTION)

As it is described in Sanz et al[1], a model has been developed to analyze and evaluate risks of 'Castrovido' dam, currently under construction, so this model will be useful for the decision making, mainly, in the scope of the future operational phase of the dam.

A significant number of experts in design, construction and management of dams, have participated in the working sessions, with special focus on the Potential Failure Mode Identification session. Their names and affiliations are listed in Table 1.

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Liana Ardiles	Confederación Hidrográfica del Duero (DRA)
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Nuria Bueso	Confederación Hidrográfica del Duero (DRA)
Pedro Moreno	Confederación Hidrográfica del Duero (DRA)
Luis Alberto Franco	Confederación Hidrográfica del Duero (DRA)
Miguel Angel Méndez	Confederación Hidrográfica del Duero (DRA)
Julio Martín	FCC Construcción
Pedro Alvarez	FCC Construcción
Domingo Dos Santos	FCC Construcción
Miguel Polo	FCC Construcción
José Rodríguez	Intecsa-Inarsa
Raquel González	Intecsa-Inarsa
René Gómez	Confederación Hidrográfica del Ebro
Mario Andreu	Confederación Hidrográfica del Ebro
José Luis Nieto	Confederación Hidrográfica del Ebro
Francisco Hijós	Confederación Hidrográfica del Ebro
Carlos Barbero	Agencia Catalana del Agua
Arturo Gil	Iberdrola
Ricardo Fernández Cuevas	ATI
Jürgen Fleitz	Ofiteco
José Luis Lorenzo	Ofiteco
Oscar Pérez	Ofiteco
Angel Rodríguez	In Situ Testing
Carlos Granell	Jesús Granell Consultores
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Armando Serrano	Universidad Politécnica de Valencia (UPV)
Luis Altarejos	Universidad Politécnica de Valencia (UPV)
Manuel G. de Membrillera	Universidad Politécnica de Valencia (UPV)
Francisco Silva	External Reviewer

Table 1: Participants in the started activities (March 2010).

Working sessions have been prepared and facilitated by UPV personnel. The last author of the present paper served as Project Manager and divided the activities in those carried by the full group and those carried by a smaller group and later discussed and validated by the whole group.

Table 2 provides the time framework and the contents of all the working sessions.

DATE	ACHIEVEMENTS
1/07/2009	Proposal of members to integrate the working group UPV provide main scientific references to be spread
09/11/2009	Analysis and discussion of the available information
10/11/2009	Site visit with special focus on foundation features
10/01/2010	Preliminary Potential Failure Modes Identification
11/01/2010	Site-visit to downstream main urban areas
21/02/2010	Potential Failure Modes Identification (PFMI)
22/02/2010	Potential Failure Modes Identification (PFMI)
23/02/2010	Review of procedures for the “steps ahead”
24/02/2010	Review of strong and weak points of the overall process
07/04/2010	iPresas software training and PFMI review
17/05/2010	Risk model architecture and discussion on the “inputs”
18/05/2010	Probability of failure elicitation
08/06/2010	Discussion on probability of failure results
09/06/2010	Second round for probability of failure elicitation
5/07/2010	Discussion on risk results, with emphasis on sharing numerical modeling procedures and consequence estimation. Proposal of structural and operating alternatives.
14/09/2010	Discussion on results with regard to the implementation of different alternatives
4/11/2010	Presentation and discussion on the overall results and focus on how to extend the procedures to the full DRA portfolio of dams.

Table 2: Fulfilled objectives and activities.

The following picture (Figure 4) shows the course of one of the group sessions.

Figure 4: Working group session.

Figure 5 illustrates the different phases of the 'process'.

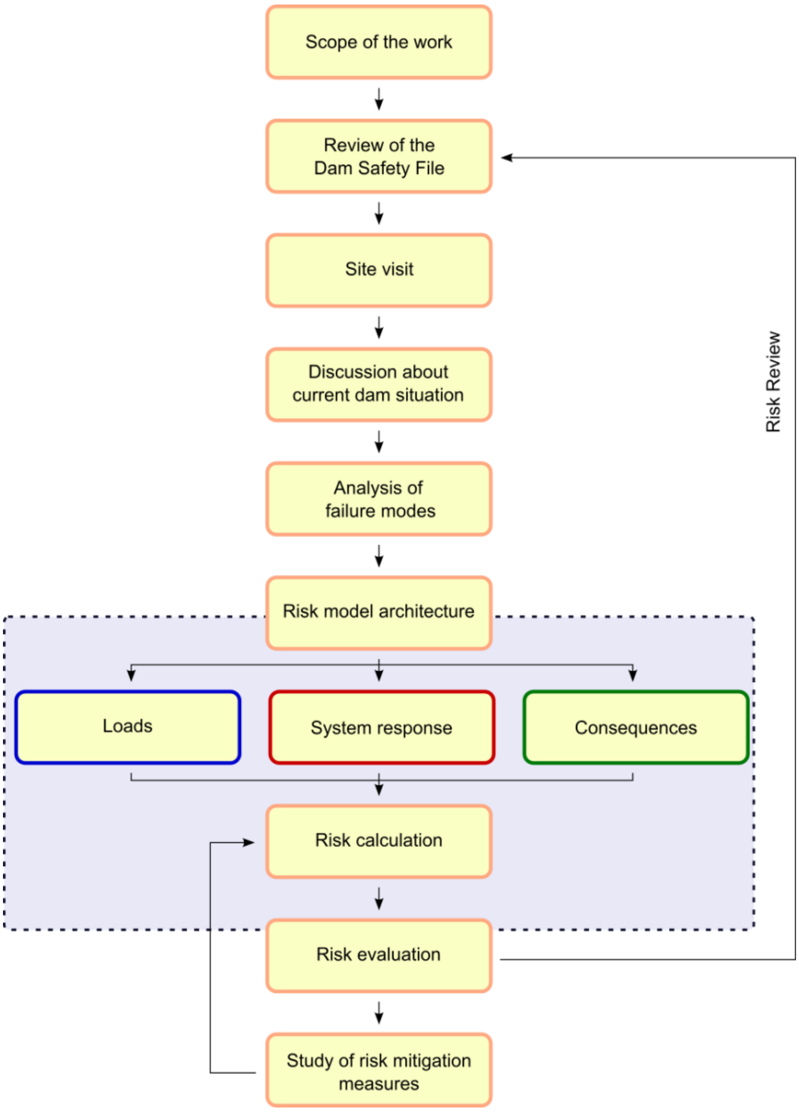

Figure 5: Phases of risk model development and structure for Castrovido dam.

The risk model structure has been implemented by the software iPresas[2], following the architecture shown in Figure 6. This Figure also incorporates the "procedures" used to obtain, calculate and/or estimate all the needed inputs for the hydrological risk model.

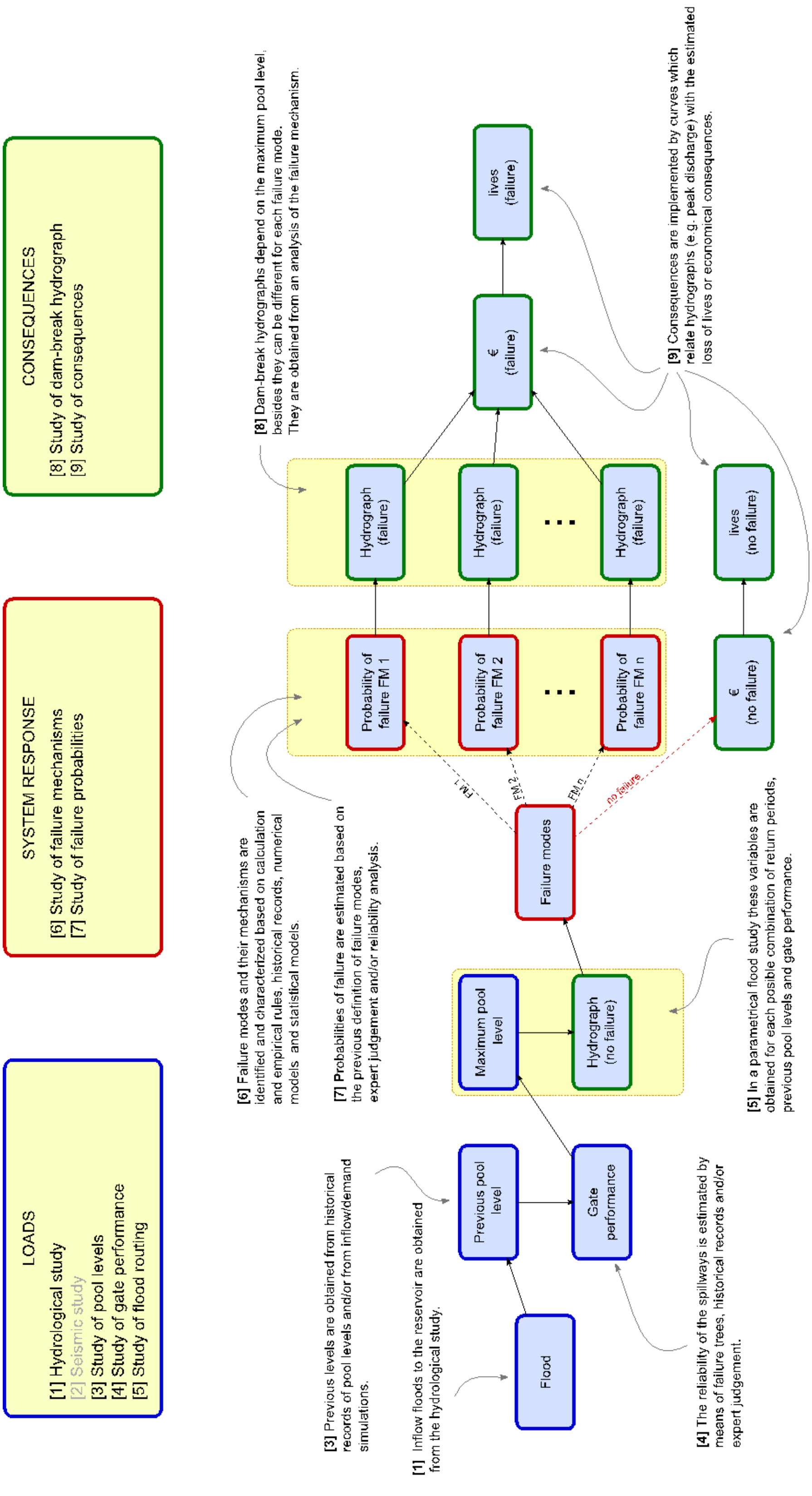

Figure 6: Overall hydrological model architecture and "procedures" for obtaining input data.

The model and the procedure itself have enabled a clear, defensible and robust framework to adopt and communicate decisions. Main advantages founded by undertaking this task during the dam-construction phase are:

- The possibility of structuring and incorporating the large amount of information to the model which is generated during the construction. Most of these data is incorporated in the reviews of information and the identification of failure modes.
- To identify and justify safety improvements in terms of reinforcing the ability of detection and intervention in case of any anomalous behaviour in the future, thus linked to surveillance activities.
- To evaluate the relevance in terms of risk of any future operational strategy, thus providing lot of insights for preparing the Operating Rules document.
- To evaluate the effectiveness of the different communication measures, warnings, etc., in emergency situations. In a similar manner, this analysis may introduce improvements in the Emergency Action Plan.

As an example of the type of results obtained to inform decision making, the following graphs (Figure 7 and Figure 8) are provided.

In particular, Figure 7 shows the risk estimated for the dam by means of an F-N curve (accumulated annual probability of exceedance vs potential loss of lives), plotted against USACE tolerability standards.

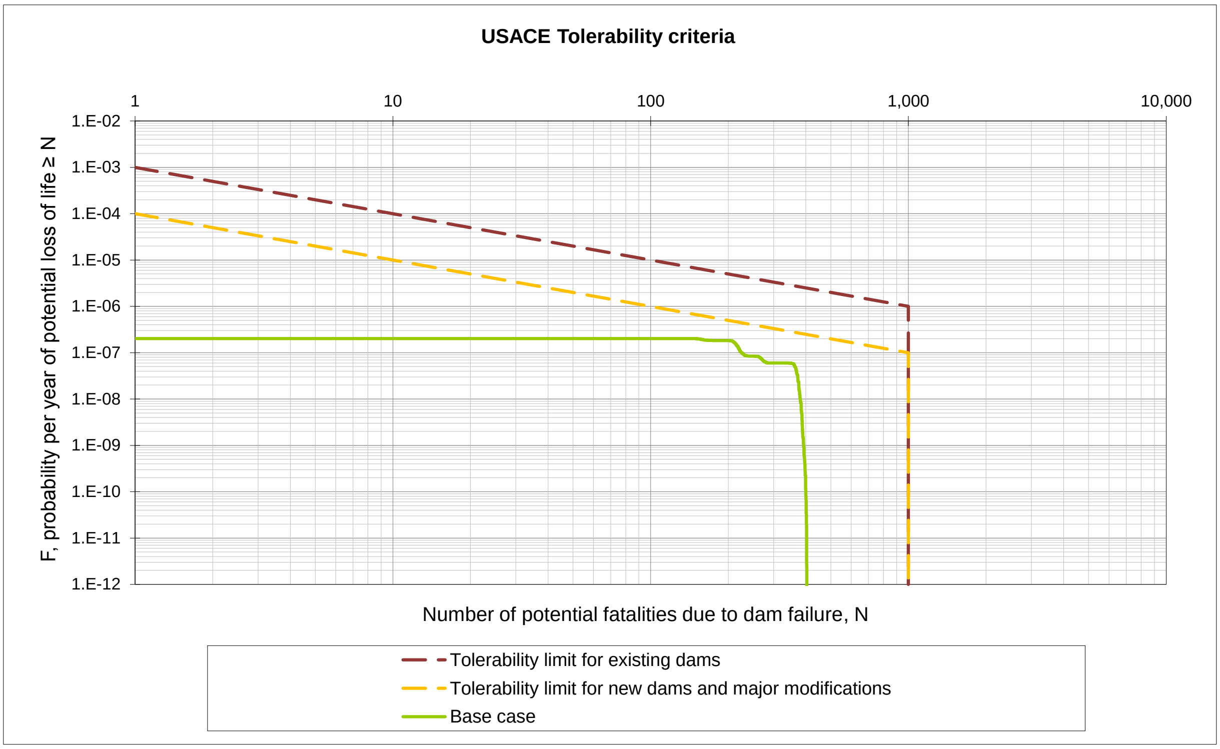

Figure 7: Estimated risk plotted against USACE F-N Standards.

Figure 8 shows the impact in risk, represented in terms of average potential loss of lives and plotted against USBR tolerability standards of:

- Constructing an additional foundation reinforcement (Alt 2 in the Graph) and later elevating the maximum operating pool level ten more meters (Alt 1 in the Graph).
- Implementing a comprehensive strategy on communication, education and coordination with downstream population thus reinforcing the activities of the

Emergency Action Plan (Alt 3 in the Graph) and later elevating the maximum operating pool level ten more meters (Alt 1 in the Graph).

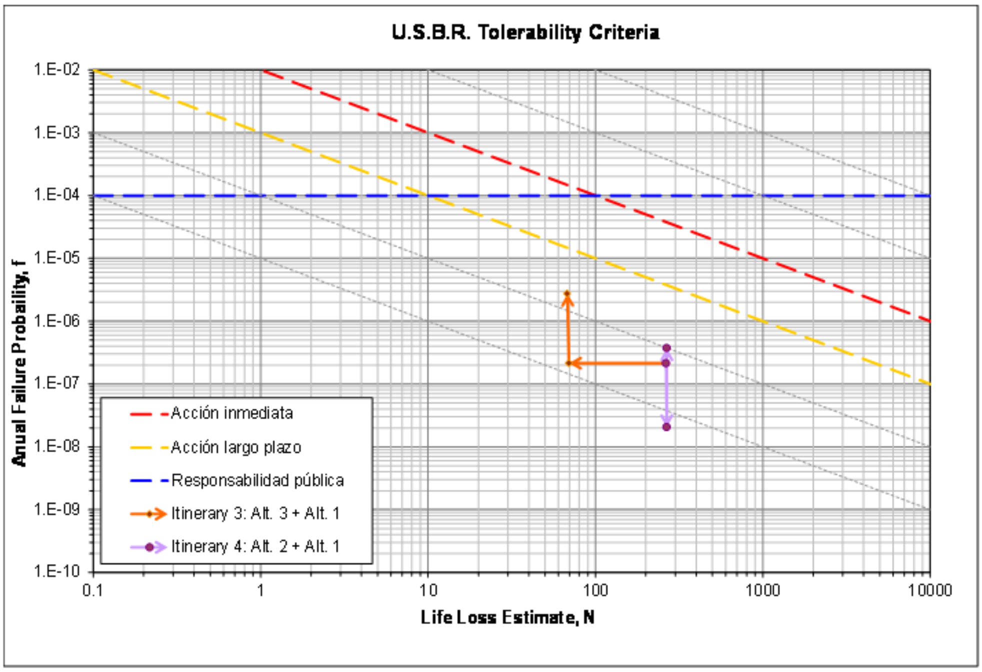

Figure 8: Impact of different sequences of actions in risk plotted against USBR standards.

4 ACTIVITY B: IDENTIFICATION OF FAILURE MODES FOR EACH DAM AS PART OF THE MAINTENANCE ACTIVITIES

As it is explained in *Fernández Baños et al*[3], the Duero River Authority has initiated, along 2009, the so called “maintenance contracts” of its dams. Dam maintenance was done before by staff of the public owner and recently has been outsourced to private companies.

Among the goals of these contracts, providing sound engineering knowledge for failure mode analysis has been prioritized for the current year.

The qualitative phase of identifying failure modes has been already performed for all 26 dams. As an example of on-going benefit, several improvements on inspections, surveillance and monitoring have been identified and are being implemented by means of these “maintenance contracts”.

Table 3 shows the detailed calendar followed for each of these dams (including the Castrovido Dam as well as the Carrion and Pisuerga systems, all them performed well in advance as Pilot cases).

After finishing all the identifications, dam by dam, a second round under “review mode” has been performed by a unique group, that included personnel from OFITECO who had been present in all the dam sessions and personnel from DRA and UPV that had been participating in the PILOT cases but not in the full portfolio of dams. Table 3 provides the list of dams and systems together with the time framework for all the working sessions.

SYSTEMS (Review of PFMI date)	**DAMS (Dam by Dam PFMI session date)**
Carrión (2008)	Camporredondo (14-16th May, 2008) and Compuerto (23-26th June, 2008)
Pisuerga (25th October, 2010)	Cervera, Aguilar de Campóo and Requejada (10-14th November, 2008)
Castrovido (April 2010)	Castrovido (January-February 2010)
Arlanzón (29th November, 2010)	Arlanzón (11th December, 2009) and Úzquiza (16th December, 2009, 25th June, 2010)
Alto Duero (29th November, 2010)	Cuerda del Pozo (10th December, 2009) and Campillo de Buitrago (13th January, 2010)
Porma (26th October, 2010)	Porma (18th February, 2010)
Riaño (26th October, 2010)	Riaño (17th February, 2010)
Tormes (29th November, 2010)	Santa Teresa (17th March, 24th June, 2010) and Azud de Villagonzalo (17th March, 24th June, 2010)
El Milagro (29th November, 2010)	El Milagro (17th March, 24th June, 2010)
Riolobos (29th November, 2010)	Azud de Riolobos (17th March, 24th June, 2010)
Pontón Alto (13-14th January, 2011)	Pontón Alto (30th April, 2010)
Linares del Arroyo (13-14th January, 2011)	Linares del Arroyo (23rd September, 2010)
Castro de las Cogotas (13-14th January, 2011)	Castro de las Cogotas (19th November, 2010)
San José (13-14th January, 2011)	San José (18th October, 2010)
Águeda (13-14th January, 2011)	Águeda (7th September, 2010) and Irueña (4th September, 2010)
Luna (8-9th November, 2010)	Barrios de Luna (21st July, 2010) and Selga de Ordás (21st July, 2010)
Valdesamario (8-9th November, 2010)	Valdesamario (22nd July, 2010)
Villameca (8-9th November, 2010)	Villameca (22nd July, 2010)
Benamarías (8-9th November, 2010)	Benamarías (22nd July, 2010)

Table 3: Potential Failure Mode Identification (PFMI) session framework.

5 ACTIVITY C: DEVELOPMENT OF RISK MODELS FOR ALL DAM SYSTEMS

The development of risk models for the systems of dams operated by the Duero River Authority will be carried out during next year, as it was discussed before in the paper.

However, it is important to remark the crucial experience obtained in 2008 when a full quantitative analysis was carried out as a pilot experience for the 'Carrión' system ('Camporredondo' and 'Compuerto' dams) and, in a more simplified approach, for the 'Pisuerga' system ('Cervera', 'Requejada' and 'Aguilar de Campoo' dams). The aforementioned works have been described in several papers[4 5] and presented in different forums: Valladolid 2009, at the Technical Conference on Risk analysis and Evaluation, organized by the DRA; Brasilia 2009, at the 23rd ICOLD International Conference on Large Dams and, more recently, in Sacramento, in April, where it has been selected as one of the six Case Histories to be presented at the International Workshop of 'Case Histories in Dam Safety Risk Assessment', hosted by the United States Society on Dams (USSD).

Figure 9 illustrates, as an example, the risk model architecture of Camporredondo and Compuerto Dams.

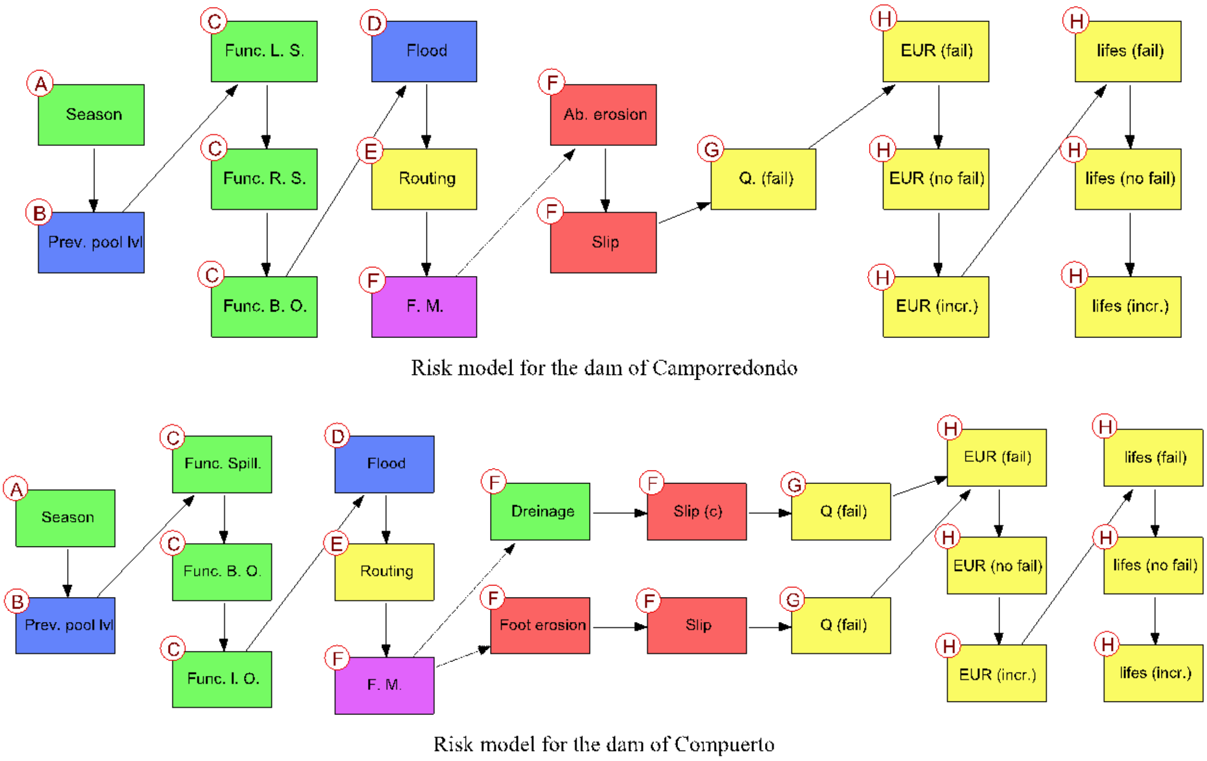

Figure 9: Risk model architecture for Camporredondo and Compuerto Dam.

As Figure 9 shows, the models have a similar structure. Both models represent the hydrologic scenario. The first node (A) determines the season. The second node (B) determines the previous level of the reservoir when the flood starts, which depends on the season. The following nodes (C) determine the functionality of each of the discharge devices. The next node (D) specifies the return period of the incoming flood for each branch. Then, the next one (E) determines the peak reservoir level, the peak outflow and the characteristics of the overspill (if any) as a function of the return period of the incoming flood and the variables of the previous nodes. Next, the nodes corresponding to the failure modes are shown (F). After them there is a node (G) for determining the peak flow if the dam fails and six more (H) for determining the consequences (consequences in lives and euros and consequences in the case of failure, non failure and incremental consequences).

Figure 10 illustrates the model of the Carrion System (integrated by Camporredondo and Compuerto Dams).

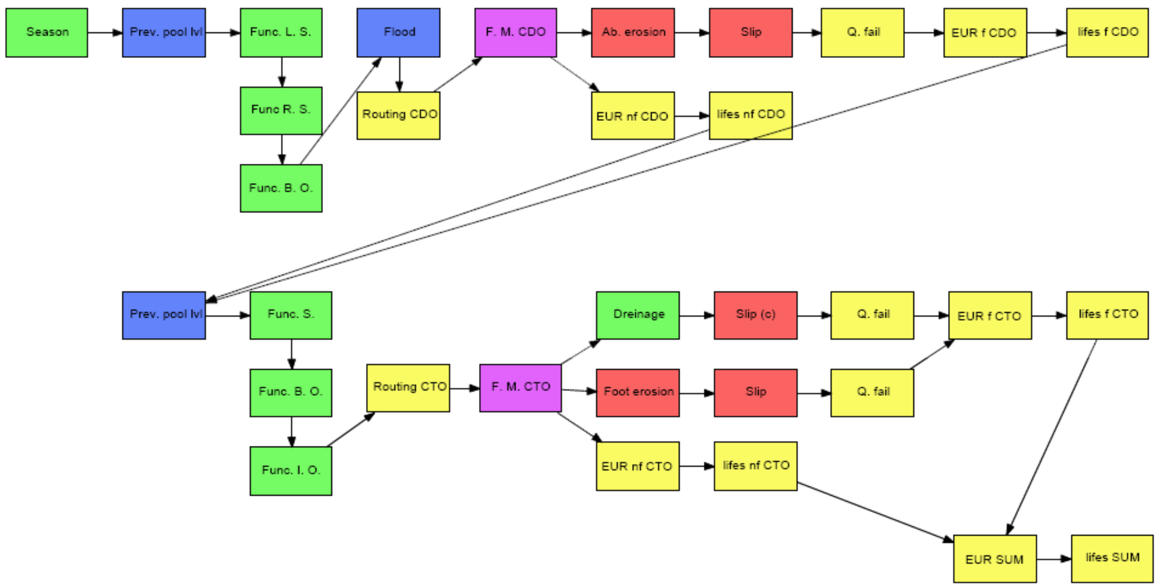

Figure 10: Risk model architecture of Carrión system.

In particular, for the Carrion system, several outcomes of the risk model where used for decision making:

- ➢ All measures that had been recommended in the Safety Review Reports were justified in terms of efficiency, although, results allowed to recommend how to prioritize them: the most efficient measure resulted in the rehabilitation of the drainage system in both dams, followed by the implementation of the Emergency Action Plan and rehabilitation of the electro-oil-hydraulic equipments.
- ➢ On the other hand, as a system, it was observed that there is allowance for risk transfer from ‘Compuerto’ to ‘Camporredondo’, dam whose risk is significantly lower than the first, and currently complies with all existing international tolerability criteria.

This example enables to advance some of the overall objective that is pursued through the development of risk models for the whole basin: to acquire a management tool to assist the decision-making process on new investments (basically, for planning and prioritizing actions) just as to make possible a continuous risk monitoring and control.

As an example of how results are compared to international risk standards, next graph (Figure 11) shows Camporredondo risk results plotted against the USBR Tolerability criteria.

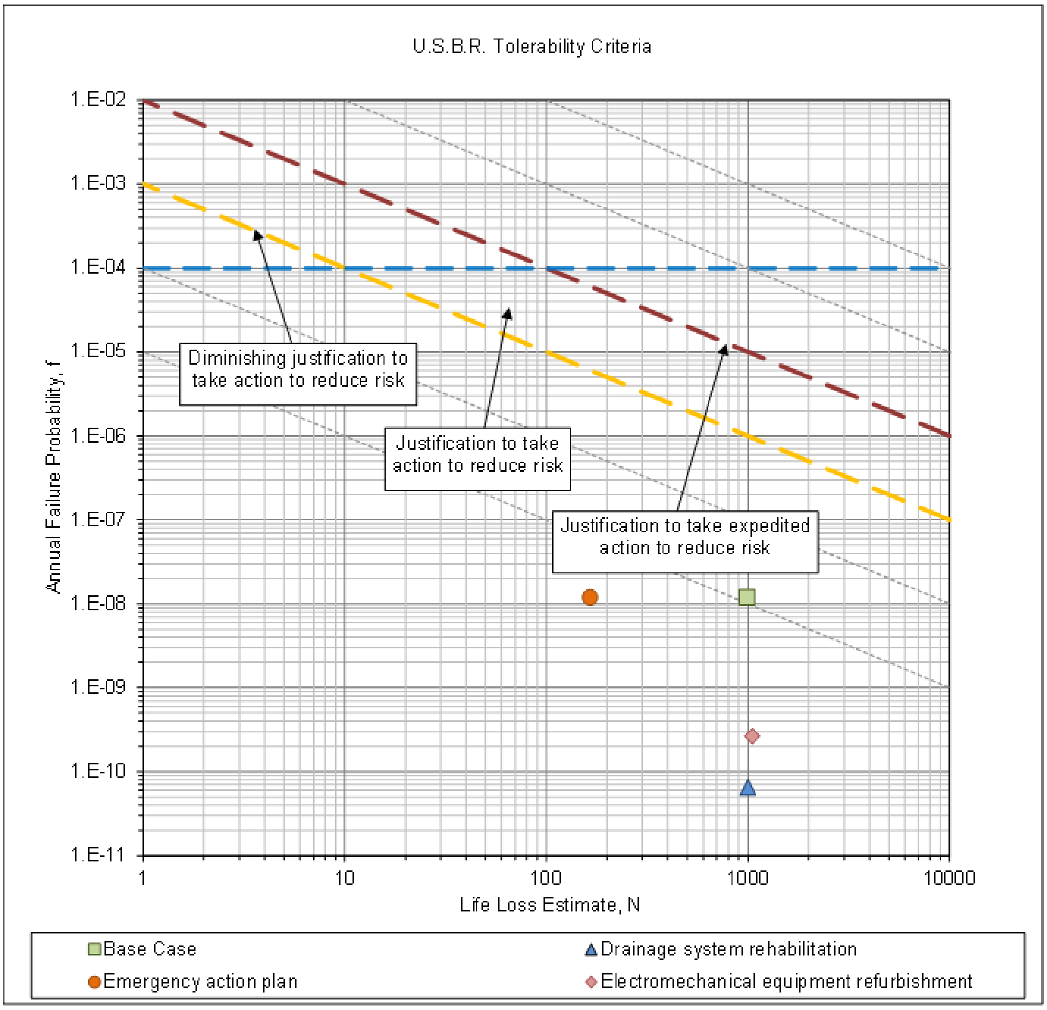

Figure 11: Camporredondo risk results plotted against the USBR tolerability criteria.

6 ADDITIONAL ACTIVITIES: COMMUNICATION ASPECTS

As an additional aspect in this first phase, the DRA is working on establishing the impact that communication has as a non-structural measure for risk-reduction and risk management, together with the need for establishing proper communication procedures to advice the population during but not only in emergencies, thus trying to avoid an increase with time on the risk level due to a lack of involvement or awareness to the public.

In fact, an efficient communication system with the public will reduce risk if, being used continuously, in each phase of the risk management, credibility arises from the authorities to the potentially affected population.

Moreover, communication will generate credibility if the given information is clear, together with an appropriate documentation, and also if it explains the procedures in a natural manner, with empathy, and it is carried out continuously. The openness demands a Communication Plan with well-defined aims, by identifying the affected public properly, with suitable strategies to accomplish the objectives, and simple and clearly-defined messages, using an appropriate language for each group of population.

As an example of the concepts and aspects which are being considered, risk reduction focused on diminishing loss of human life in case of flooding, depends on the correct application of the Dam Emergency Action Plan by authorities and operators and the proper behaviour of the population. In addition to this, sufficient accomplishment depends on the efficiency and performance of the Communication Plan, enclosed in the Emergency Action Plan, and again, success relies on an effective application and credibility of the authorities who are responsible of putting into practice the Communication Plan.

7 TOWARDS AN OVERALL MANAGEMENT ON SAFETY INFRAESTRUCTURE OF THE DUERO RIVER AUTHORITY

The set of started activities in the framework of overall management on dam safety in the Duero River Authority (DRA) has the overall aim of improving dam safety decision making so that:

- The corrective measures and investments will be justified in terms of efficiency on risk reduction.
- The processes for justifying decisions will be clear, defensible and socially validated
- Best possible decisions should be taken, particularly when high investments are considered.

In any case, the 'work-planning' defined by the DRA transcends the scope of risk models, or any of the other described activities in this paper, and implies a new role for the DRA. This significance is partly linked to the process itself, which goes beyond the adopted methodology for making risk models or the tolerability risk criteria to be applied or developed ex profeso for the Duero basin or, even, for the Spanish context.

As an example of these implications on the process, the DRA has clear responsibilities with regard to 'structural' actions, either in terms of execution of new defence structures or to ensure the integrity of the existing structures. However, when considering non-structural actions, such as warning systems, urban evacuation or planning, responsibilities are generally shared or exclusive, in some cases, of other organizations or authorities: Civil Defence, Regional Governments, Councils, etc.

Therefore, one of the challenges of developing processes like those currently undertaken by the DRA is building consensus while improving the identification and implementation, in collaboration with other involved organizations, of those measures, that in a more efficient way, are used for risk control and mitigation in the surrounding areas of our river beds.

Finally, Figure 12 shows the time framework of all the DRA activities:

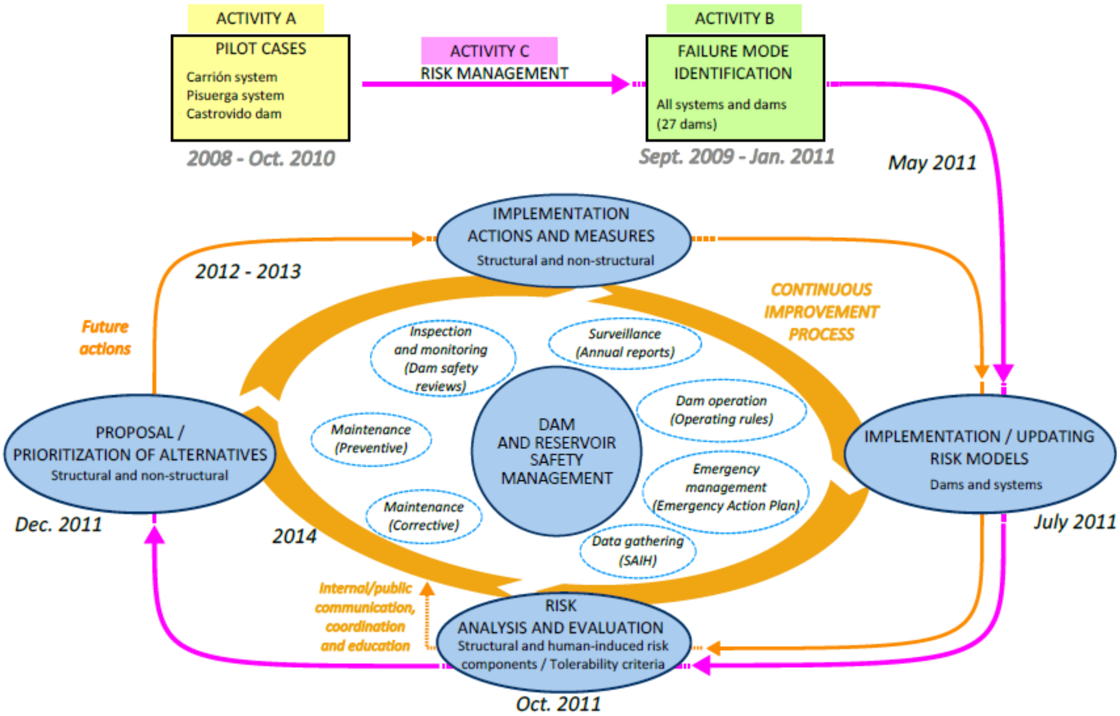

Figure 12: Towards an overall management on infrastructure safety of the Duero River Authority.

As it is illustrated by the previous scheme, once all risk models are available by the end of 2011, all maintenance activities, improvements on predictions provided by the SAIH (Automated System for Hydrological Data Collecting), performance characterization through monitoring improvements, implementation of the Emergency Action Plan, communication activities or recommendations of the dam safety reports, will be evaluated in terms of their contribution to risk reduction and, in cases of budget limitations, prioritized in terms of efficiency. After 2014, it is also planned to extend this framework to the whole group of different infrastructures operated by Duero River Authority.

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