JUSTIFICATION FOR AN OPERATING RESTRICTION IN SPAIN INCORPORATING ANCOLD GUIDELINES ON RISK ASSESSMENT

Manuel G. de Membrillera[1], Ignacio Escuder[2], David Bowles[3], Eduardo Triana[4], Luis Altarejos[5]

ABSTRACT

The work herein presented is an application of the risk assessment process to retroactively estimate the justification of an operating restriction implemented on a Spanish Dam. Since the risk approach is not yet an established practice in Spain, the main objective of this case study is to show, the utility that risk assessment can have as a decision support tool for decisions on dam safety risk reduction investments.

An operating restriction has been imposed at this dam since its first impoundment. All studies, analysis and documents related to the safety of the dam and reservoir have been completed, as required by the Technical Regulation on Dam and Reservoir Safety (Spanish legislation, 1996). In addition, the structural corrective actions recommended in these evaluations are being implemented, so it is expected that the operating restriction can be removed in the near future.

In this context, the problem that has been formulated and solved comprises an evaluation, after more than 30 years since construction, of the operating restriction justification in terms of risk mitigation. In order to achieve the objective of the work, ANCOLD guidelines on Risk Assessment (2003) have been followed in addition to tolerable risk guidelines from several other countries and organizations.

1. INTRODUCTION

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. 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.

[1] PhD Researcher, Department of Hydraulic Engineering and Environment, Universidad Politécnica de Valencia. Camino de Vera S/N. 46022 Valencia, Spain. Assistant Professor, Universidad de Castilla La Mancha, Avda. Camilo J. Cela S/N. 13071 Ciudad Real, Spain. magode@hma.upv.es

[2] Professor and Vice-Dean, Department of Hydraulic Engineering and Environment, Universidad Politécnica de Valencia. Camino de Vera S/N. 46022 Valencia, Spain. iescuder@hma.upv.es

[3] Professor of Civil and Environmental Engineering and Director, Institute for Dam Safety Risk Management, Utah State University, Logan, Utah 84322-8200. Principal, RAC Engineers & Economists. David.Bowles@usu.edu

[4] PhD Researcher, Department of Hydraulic Engineering and Environment, Universidad Politécnica de Valencia. Camino de Vera S/N. 46022 Valencia, Spain. jortrmo@doctor.upv.es

[5] PhD Researcher, Department of Hydraulic Engineering and Environment, Universidad Politécnica de Valencia. Camino de Vera S/N. 46022 Valencia, Spain. luialgar@doctor.upv.es

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.

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.

By the mid-nineties, based in part on previous works published by Bowles et al ("Comparison of Hazard Criteria with Acceptable Risk Criteria", ASDSO 1995) and others, several dam safety agencies in the world started to develop risk assessment methodologies to estimate risks and make dam safety investment decisions based on the tolerability of such risks.

Some of the most important working groups since then are located in the USA (Utah State University and U.S. Bureau of Reclamation), Australia (University of New South Wales and ANCOLD) and Canada (BC Hydro and CDA).

Once Spain has reached a socio-economic level similar to the one attained years ago by the USA, Canada or Australia, it is widely accepted that government and private dam owners should undertake analyses to estimate the real impact of dam safety investment programs on risk reduction and their economic efficiency (Membrillera et at, 2005).

The International Week on Risk Analysis Applied to Dam Safety celebrated in Valencia in March 2005, organized by the Water Resources Engineering Group of the Polytechnical University of Valencia, was the first event on this topic celebrated in Spain, and the starting point for a collaboration with the Institute for Dam Safety Risk Management, Utah State University, to help to develop this practice in the Spanish context.

2. DAM AND RESERVOIR SAFETY LEGISLATION IN SPAIN

The increasing number of dams and the growth of the size of populations at risk and economic interests, together with some incidents and human losses and damages associated with dam failures, have demonstrated the necessity for paying attention to dam safety and considering it as a priority in all stages of the lifetime of a dam.

There exists in Spain a long tradition of dam safety control, which is reflected in the "Instructions on the Design, Construction and Operation of Large Dams" published in March 1967. These instructions require that every dam in operation should have a dam safety program including inspections, surveillance, procedures for maintenance of the flow control devices, outlets, access and communications.

As a result of some catastrophic floods, which affected the north and east of Spain in the early–eighties, and which even lead to the failure of Tous Dam, the former General

Direction of Hydraulic Works set out a program for dam safety in 1983, which was required for all state-operated dams. This program required operating rules and inspection reports, which are compendiums about design, construction and operation including monitoring data.

The Basic Directive for Civil Protection due to Flood Risk was published in 1995. It established the obligation to classify all Spanish dams according to their hazard potential into the three categories: A, B or C. CATEGORY A corresponds to dams whose failure or malfunction could seriously affect urban areas or essential services and infrastructures, or produce important property or environmental damages. CATEGORY B corresponds to dams whose failure or malfunction could cause important property or environmental damages, or affect a small number of residences[6]. Finally, CATEGORY C corresponds to dams whose failure or malfunction could produce damages of moderate importance and just incidentally loss of human life. The 1995 Directive also required that owners of both category A and B dams developed an Emergency Plan

The "Technical Regulation on Dam and Reservoir Safety", approved in 1996 by the former Ministry of Public Works, Transport and Environment, established a series of additional obligations for state-owned dams. The most important requirements referring to monitoring and inspection are as follows:

a) Develop and apply a coordinated plan to monitor and conduct periodic inspections of the dam and the reservoir, focused on the verification of its safety and functional state. The plan must define both the scope and frequency of the inspections as well as the composition of the installed equipment for recording monitoring data, indicating the record frequency of each sensor, specifications referred to information collection and processing, and its interpretation method.

b) Prepare an annual report based on the inspection and monitoring results, an analysis of observed deficiencies, and proposals for adequate remedial measures. This report must be prepared by the responsible dam operation engineer.

c) Carry out a detailed inspection of the dam and appurtenances, including access and communication, after an extraordinary incident such as an earthquake, an abrupt change of reservoir level, important discharges, landslides in the reservoir, etc.

d) Conduct periodic checking and general analysis of the dam and reservoir safety. This work must be performed by technical specialists from outside the reservoir operation team. The intervals for general reports are 5 year for category A dams and 10 years for category B and C dams.

In addition to the 1996 regulation, the Comité Nacional Español de Grandes Presas (Spanish National Committee on Large Dams, SPANCOLD) and the Dirección General de Obras Hidráulicas y Calidad de Aguas (an Office of the Spanish Ministry on Environment and Water) have developed a set of recommendations called Technical Guides These Technical Guides comprise guidance on how to apply the 1996 Regulation. This is important because while the 1967 Instructions are quite prescriptive and contain very rigid calculation criteria, the 1996 Regulations are quite general.

One of the Guides, Technical Guideline Number 1, refers to "Dam Safety", but it only includes some conceptual references to risk assessment and risk management.

As a result of the experience gained by applying these Guides, a number of debates on safety levels that can be reasonably imposed to such structures have been on-going. Most discussions have taken place in SPANCOLD and SEPREM (Spanish Society on Dams and Reservoirs) Congresses and other Technical Meetings (Valencia, 1996; Barcelona, 1998; Málaga, 1999; Zaragoza, 2002; Madrid, 2002; and Valencia 2005) with the result that a new

[6] The Basic Directive for Civil Protection (the latter being the Spanish state agency in charge of emergency management) does not give a specific figure, but subsequent guidelines consider the existence of serious urban damage when more than five residences are affected, whereas essential services and infrastructures are assumed to be used by a minimum of 10,000 people.

integral Law on Dam Safety has been proposed. Such a law is now being studied by the Ministerio de Medio Ambiente (Ministry of Environment; MMA).

3. STATEMENT OF THE PROBLEM

The work presented herein is an application of risk assessment to estimate the justification for an increase in freeboard (operating restriction) as a dam safety corrective action for a Spanish Dam.

The main objective of this paper is to demonstrate, for the study dam, the utility of risk assessment as a decision support tool to evaluate the justification for implementing dam safety risk reduction investments. For an example of a risk-based evaluation of an operating restriction to reduce the risk of earthquake-induced dam failure see Bowles et al (2006).

The structure is a 57.5 m high concrete gravity multipurpose dam (irrigation, urban water supply and flood protection). The crest is 8 m wide and the length of the dam is 198 m. The four-span gated spillway is mechanically operated from the dam site. Figures 1 to 4 show the dam and reservoir, the main spillway, the limestone layers in the foundation, and the downstream face of the dam, respectively.

The dam has been subjected to an operating restriction since its first impoundment about 30 years ago due to excessive seepage through the right abutment, between limestone layers and is likely eroding the silty and clayey material filling the joints. The storage capacity has been restricted to a water level of 309.54 m.a.s.l., corresponding to a storage volume of 40.7 Hm^3, while its maximum normal level is 320 m.a.s.l., corresponding to a 73.2 Hm^3stored volume.

All studies, analyses and documents related to the safety of the dam and reservoir have been completed in compliance with the Technical Regulation on Dam and Reservoir Safety (Spanish legislation, 1996).

In addition, the corrective actions recommended in these documents are being implemented; namely, a new grout and drainage curtain in the right abutment and a major repair of the outlet conduits and valves, so it is expected that the water level can be raised to its maximum normal level in the near future.

Therefore this is a retroactive evaluation of the operating restriction.

4. RISK ASSESSMENT

The Risk Assessment process started off by reviewing all existing documents and previous works on the dam, and bringing about an engineering assessment summary based on current practice, standards and guidelines following a procedure developed by Bowles et al (2003) (Figure 5). A site inspection was made by the Official State Engineer and the research team, and immediately following the inspection a report was prepared.

4.1 RISK ANALYSIS

After potential failure modes were identified, the loading domains, states and scenarios were determined accounting for:

- The historic record of inflows and reservoir pool levels.
- Operating rules and existing demands.
- Seismic characterization according to the Spanish guidelines (Figure 6).
- Number and state of spillway gates.

For the flood and flood internal loading domain, separate reservoir level versus AEP relationships were developed for each gate operating reliability state (Figures 7 and 8).

Thus, the probability of being at a certain water level was analysed for the Base Case making use of historical series and assigning the maximum storage capacity to the three reservoirs of the water resources system, while accounting for seasonal variations in freeboards.

The Operating Restriction Case was simulated with a limited storage capability at the dam, whereas the cost of the restriction was estimated as the cost of additional pumping needed to avoid the water deficits identified by the water resources simulation model.

Potential failure modes for dam system components were identified. For the dam and the foundation these included internal failure modes, such as those of the dam body or instabilities in the contact with the foundation. However, since levels associated with severe floods are required to provide enough loading for internal failure modes to occur, they were included in the flood event tree[7].

The Risk Model comprised the flood and earthquake event trees shown in summary form in Figures 9 and 10, respectively. The event tree approach results in a graphical depiction of the dam physical system and, to all intents and purposes, a belief structure that represents the lines of reasoning from the initiating events to all of the possible outcomes. These trees set out a framework for characterising knowledge and uncertainties, and let us analyse the connotations of those uncertainties (Hartford et al, 2004).

The estimation of probabilities related to the system responses was carried out using reliability models and elicitation of expert judgement (Bedford and Cooke, 2001). For instance, to estimate the probability of sliding failure at the contact between the dam and the foundation and the stability of the right abutment, sub-trees were used as a tool to disaggregate the failure process. Expert opinions were applied on some branches and mechanistic models were used for others, using probability density functions for friction angle and cohesion. Then, several Monte Carlo simulations[8] of 10,000 iterations were checked against Mohr Coulomb sliding criteria and a numerical FLAC model was used to check out how "real" stresses were influencing the Mohr-Coulomb sliding criteria versus the "rigid solid" stress distribution in the dam foundation initially assumed in the limit state equation.

Both the flood and earthquake event trees included a common cause adjustment of system response probabilities according to Bowles et al (2001).

Loss of life and economic consequences were estimated for each branch of the event trees, making initial use of a coarse model based on the approach followed in the Emergency Action Plan and then an improved approach was used as shown in Figure 11.

Estimates of life loss and economic damages were based on dam breach-inundation modelling results and information from Census and other GIS data bases. These were used to estimate population at risk (PARs), agricultural areas inundated, and damaged structures.

Life loss was estimated using the Graham or USBR (1999) method, which considers PAR, flood severity and flood severity understanding categories, and warning times. Some adjustments were needed to the one-dimensional transient hydraulic model, such as implementing the so called "quasi bi-dimensional" logic (DHI, 2003), to obtain a reasonable representation of the flood plain and the estimated flood wave travel times and hence the expected warning times.

To estimate the consequences of dam failure on the water resources system, in addition to downstream life loss and property damages, the system was modelled using the Aquatool software (Universidad Politécnica de Valencia; Andreu et al, 1992). The model simulates complex water resources systems, incorporating groundwater flows, links between groundwater and surface water sources, and losses due to seepage,

[7] Hence the use of the term "flood internal".

[8] In all cases, Latin Hypercube Sampling (LHS) was used in order to overcome the main disadvantage of the Monte Carlo method, which is the introduction of statistical noise or variance into the simulation. This variance is associated with the finite sample size and the goal of LHS is to spread out the sample points, so that low and high and moderate values of each variable are all contained in the sample.
The basis of LHS is a full stratification of the sampled distribution with a random selection inside each stratum. Sample values are randomly shuffled among different variables or dimensions and input samples of size n are generated based on the inverse transform method, given by:

$$xh_i = F^{-1}[(i-1+R_i)/n)] \text{ , } i=1,.., n \qquad (1)$$

Where R_i stands for an independent random uniform in [0,1] , i=1,.., n, and $F^{-1}(R)$, $R \in (0,1)$ is the inverse transform for the modeled input distribution.

evaporation, etc., as well a wide range of operating rules, storage capacities and supply prioritisation criteria. The model includes the three reservoirs in the system, 25 monthly urban demands (14 of which are fed from underground sources) with a total annual volume of 130.56Hm^3 and 10 agricultural demands with a total annual volume of 385.68Hm^3 (Triana et al, 2006).

Thus, in this risk analysis, contributions by the research team members are related to estimation of hydrological, hydraulic and structural risk model inputs, including a link to FLAC Numerical Model, water resources system management modelling for improved consequences estimation, and Monte Carlo analysis for several failure modes.

4.2 RISK EVALUATION

Once the risk analysis inputs were estimated for the existing base case and the operating restriction (actually implemented), risks were estimated using the risk model and then these estimates were evaluated against various risk-based criteria and tolerable risk guidelines to assess the significance of the estimated risks. The following guidelines were applied to represent a range of international practice in industry and dam safety:

- USBR (2003) Public Protection Guidelines,
- the Australian National Committee on Large Dams (ANCOLD 2003) Guidelines on Risk Assessment,
- the UK Health and Safety Executive (HSE 2001),
- Risk Tolerability Criteria on Hazardous Installations according to The Netherlands, Denmark, Hong Kong and the UK (Vrijling et al, 2004),
- Criteria proposed in Germany for dams (Rettemeier et al, 2001).

As can be drawn from Figures 12 to 16, none of the tolerable life safety risk guidelines were estimated to be met by the Base Case or the Operating Restriction. In both cases, the total Annual Probability of Failure is estimated to be very high. In addition, since floods that impose a clear threat to the dam are quite large, they would fill the reservoir rapidly such that the effect of the operating restriction is very small for floods and only noticeable in the earthquake event (Figures 17 to 19).

Still, the restriction can be justified in terms of economic efficiency as shown by the estimates of the benefit/cost ratio of more than 2.5, as shown in Figure 20, and the Adjusted Cost per Statistical Life Saved, which by convention is set to zero when the benefit/cost ratio is greater than 1.0. In addition, Figure 21 shows the reduction in Probability of Failure versus Annualized Risk Cost.

A detailed summary of results is provided in Table 1.

5. CONCLUSION AND FURTHER NEEDS

The completed work for both the Base Case and the Operating Restriction Alternative includes the following: review and synthesis of all existing dam safety documents, Risk Model implementation, Risk Analysis and Risk Evaluation. Based on this work, three main conclusions are drawn:

a) The operating restriction can be justified in terms of the estimated cost and risk mitigation which yields a Benefit/Cost ratio greater than 1.0.

b) However, the operating restriction does not alone provide sufficient risk reduction to meet tolerable risk any of the guidelines that were considered.

c) Therefore, additional risk reduction measures are needed.

Since a thorough ALARP Evaluation is a key step in answering the question, “How safe is safe enough?” (Bowles 2003), the identification of other potential non-structural and structural risk reduction measures is being carried out now[9]. These measures will be

[9] In addition to the so called Operating Restriction Case, the other measures considered are:
- Grout and drain curtain in the foundation, the right abutment and the dam body itself.
- Implementation of the Emergency Plan, complying with the Spanish guidelines.
- Emergency Plan + Grout and drain curtain.

examined using risk assessment and an uncertainty analysis is planned to estimate the level of confidence in risk assessment outcomes following the approach by Chauhan and Bowles (2003). This and work on prioritisation of fixes are expected to be presented in future papers.

Finally, it is expected that the implemented Risk Model will be a useful tool that can be adapted for application to other dams in the future to evaluate, compare and prioritize dam and reservoir safety-related actions. Hopefully, this work will also be a developmental milestone for dam and reservoir safety in Spain.

6. ACKNOWLEDGEMENTS

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Figure 1. The study dam and reservoir.

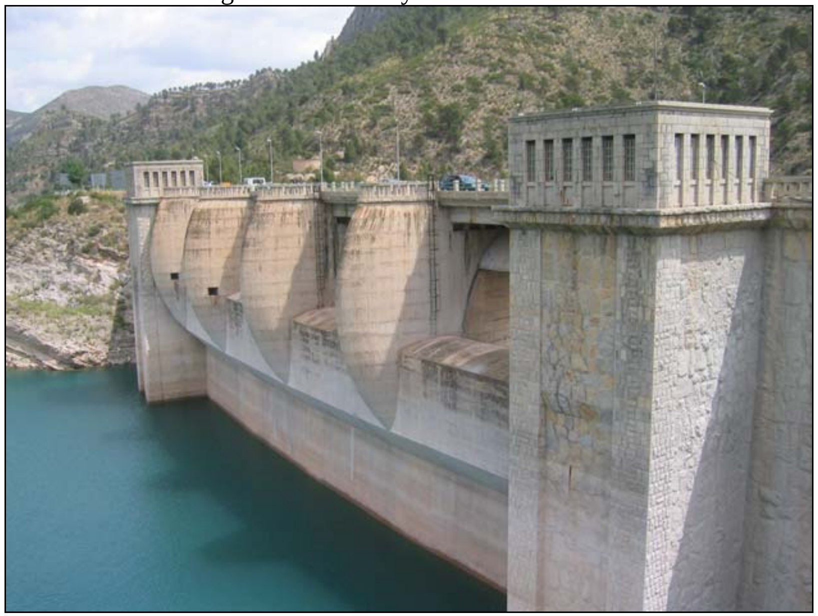

Figure 2. The main spillway from upstream.

Figure 3. Close up of the limestone foundation with thin layers of clayey marl.

Figure 4. The downstream face of the dam from the right abutment.

Flood event	Rating	Seismic event	Rating	Normal Operating Conditions	Rating
Concrete Gravity Section		**Concrete Gravity Section**		**Concrete Gravity Section**	
External stability	AP	External stability	AP	Foundation sliding	P
Internal stability	AP	Internal stability	AP	Foundation piping	P
Foundation piping	P	Abutments	ANP	Stresses within dam body	P
Abutments	ANP			External stability	P
Overall flood capacity				Abutments	ANP
Extreme Flood (5.000 yr)	P				
PMF	N/A				
Overtopping	P				
Spillway and stilling basin system		**Spillway and stilling basin system**		**Appurtenances**	
Structural Stability	AP	Structural Stability	AP	Electrical Systems and appurtenances	AP
Hydraulic capacity	AP	Gates - structural capacity	AP	Defects at buildings	AP
Walls - overtopping	ANP	Gate piers - structural capacity	AP	Elevator in the dam	**NP**
Gates - structural capacity	AP			Slope stability at access road	ANP
Gate piers - structural capacity	P				
Erodibility	AP			**General**	
Mechanical Systems	AP			Dam related documents (design, construction, etc	P
Electrical Systems	P			XYZT updated	P
Obstructions				Operating Rules updated	P
Drift and Debris	AP			Emergency Plan updated	P
Failed Slopes	AP			Emergency Plan implemented	**NP**
Sill	P			Maintenance staff and equipment	ANP
Outlet Works		**Outlet Works**		**Outlet Works**	
Piping	N/A	Stability		Outlet works piping	N/A
Electrical Systems	AP	Intake	AP	Outlet works gates	ANP
Mechanical Systems	**NP**	Tunnel/Conduit	AP		
Stability					
Intake	AP				
Tunnel/Conduit	AP				
Obstructions	AP				
Embankment		**Embankment**		**Embankment**	
Geotechnical issues		Liquefaction	N/A	Piping	N/A
Piping	N/A	Stability (includes excessive deformation)	N/A	Slope stability	N/A
Stability	N/A				
Toe erosion	N/A	**Foundation**		**Foundation**	
Wave action	N/A	Liquefaction	N/A	Liquefaction	N/A
Abutments	N/A	Stability	N/A	Stability	N/A
Foundation Piping	N/A	Fault movement	N/A		
Reservoir Rim		**Reservoir Rim**		**Reservoir Rim**	
Stability	AP	Stability	AP	Stability	AP
Loss Of Capacity	P	Loss Of Capacity	P		
Erodibility	P	Mining	N/A		
Mining	N/A				
Instrumentation	AP	**Instrumentation**	AP	**Instrumentation**	AP

Notes:

NP : NO PASS — AP : APPARENT PASS

ANP : APPARENT NO PASS — P : PASS

N/A : NOT AVAILABLE

Figure 5. Engineering assessment summary based on current practice, standards and guidelines

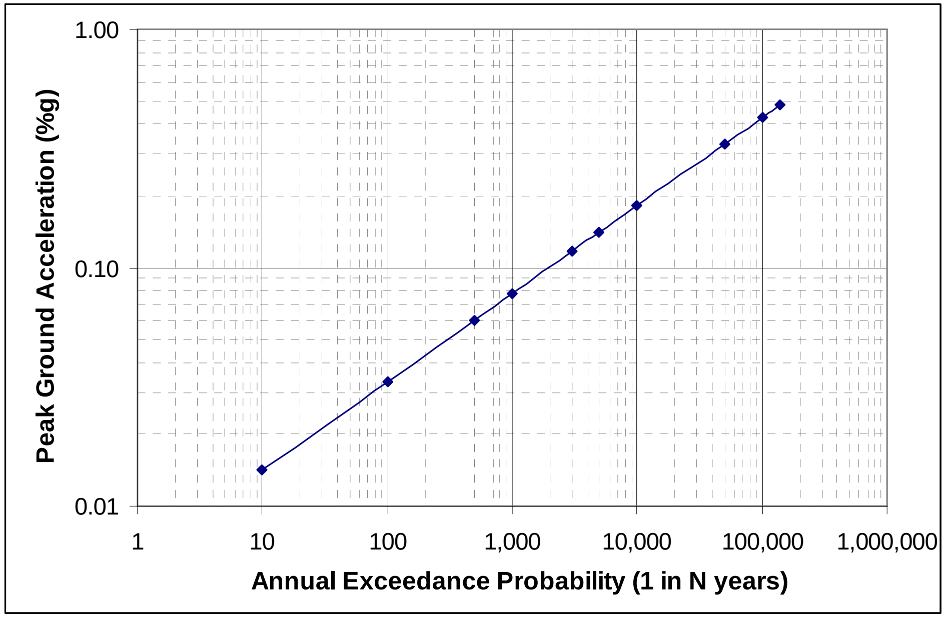

Figure 6. Earthquake loading (horizontal peak ground acceleration vs. AEP)

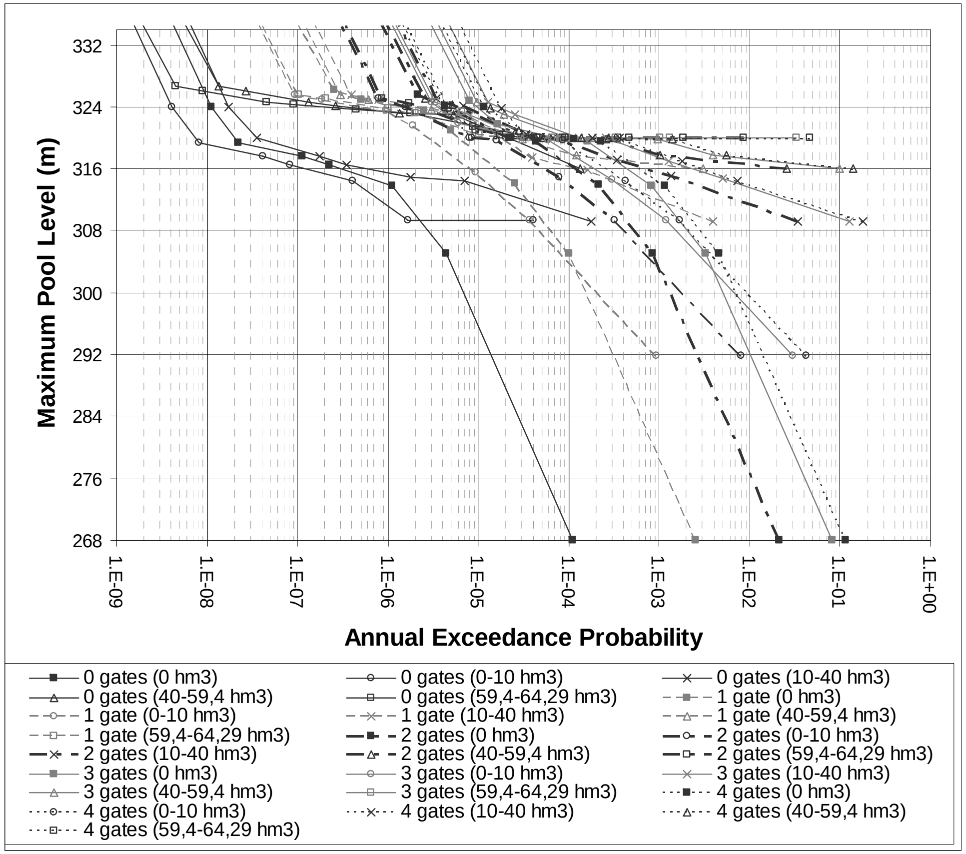

Figure 7. Flood and Flood Internal Loading (Peak Reservoir Stage – AEP) depending on spillway gate reliability and previous storage level.

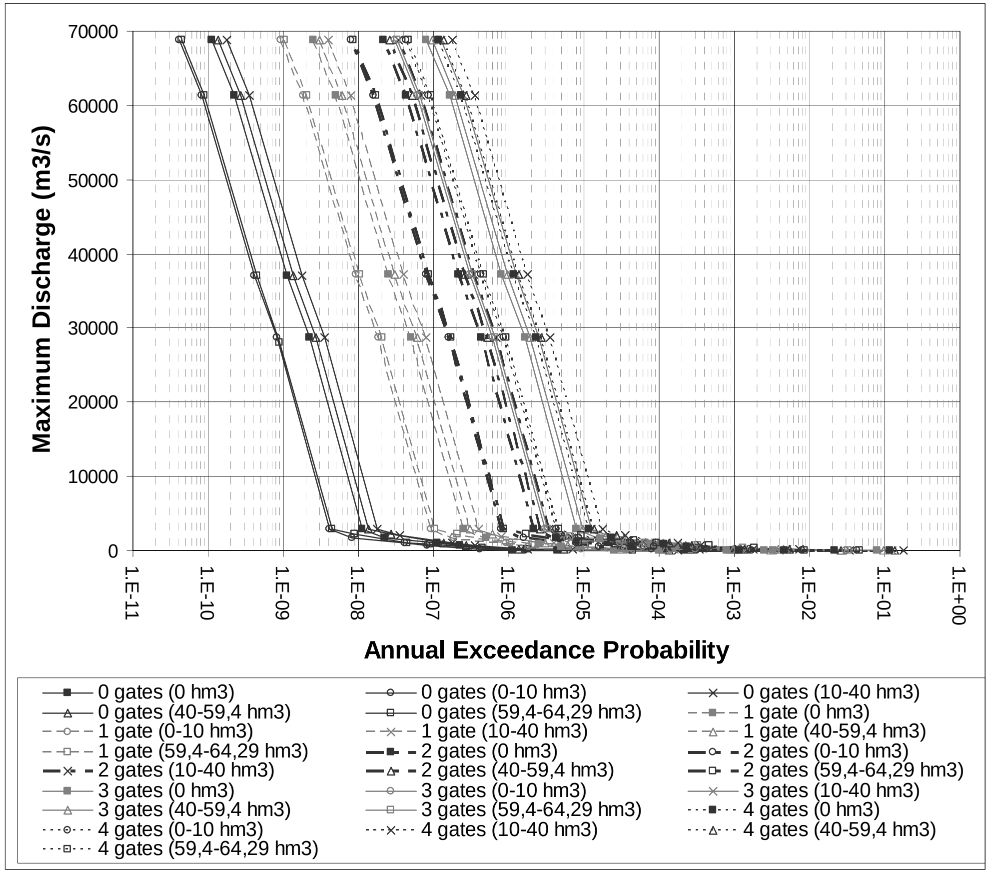

Figure 8. Flood and Flood Internal Loading (Peak Discharge – AEP) depending on spillway gate reliability and previous storage level.

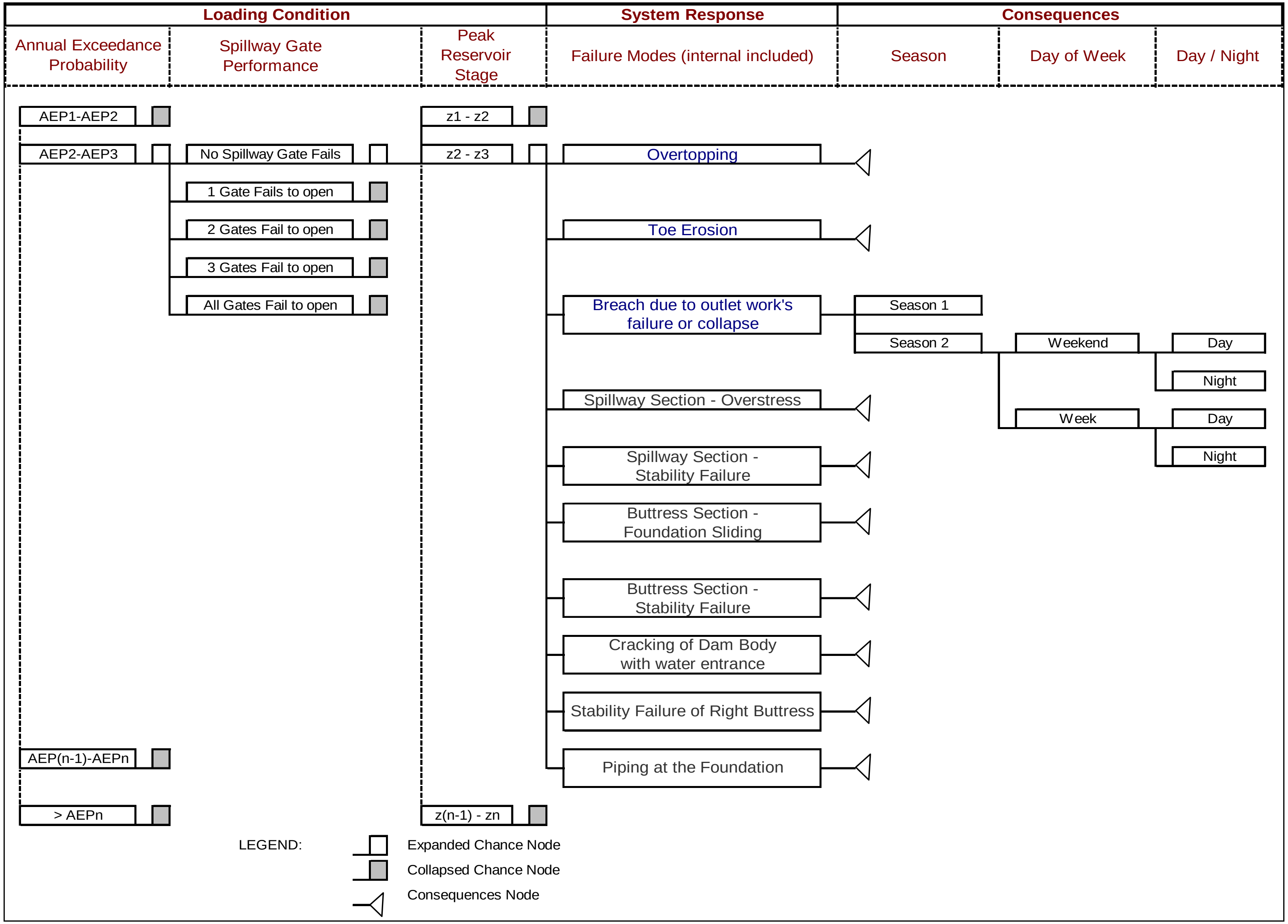

Figure 9. Event tree for flood scenarios including internal modes of failure

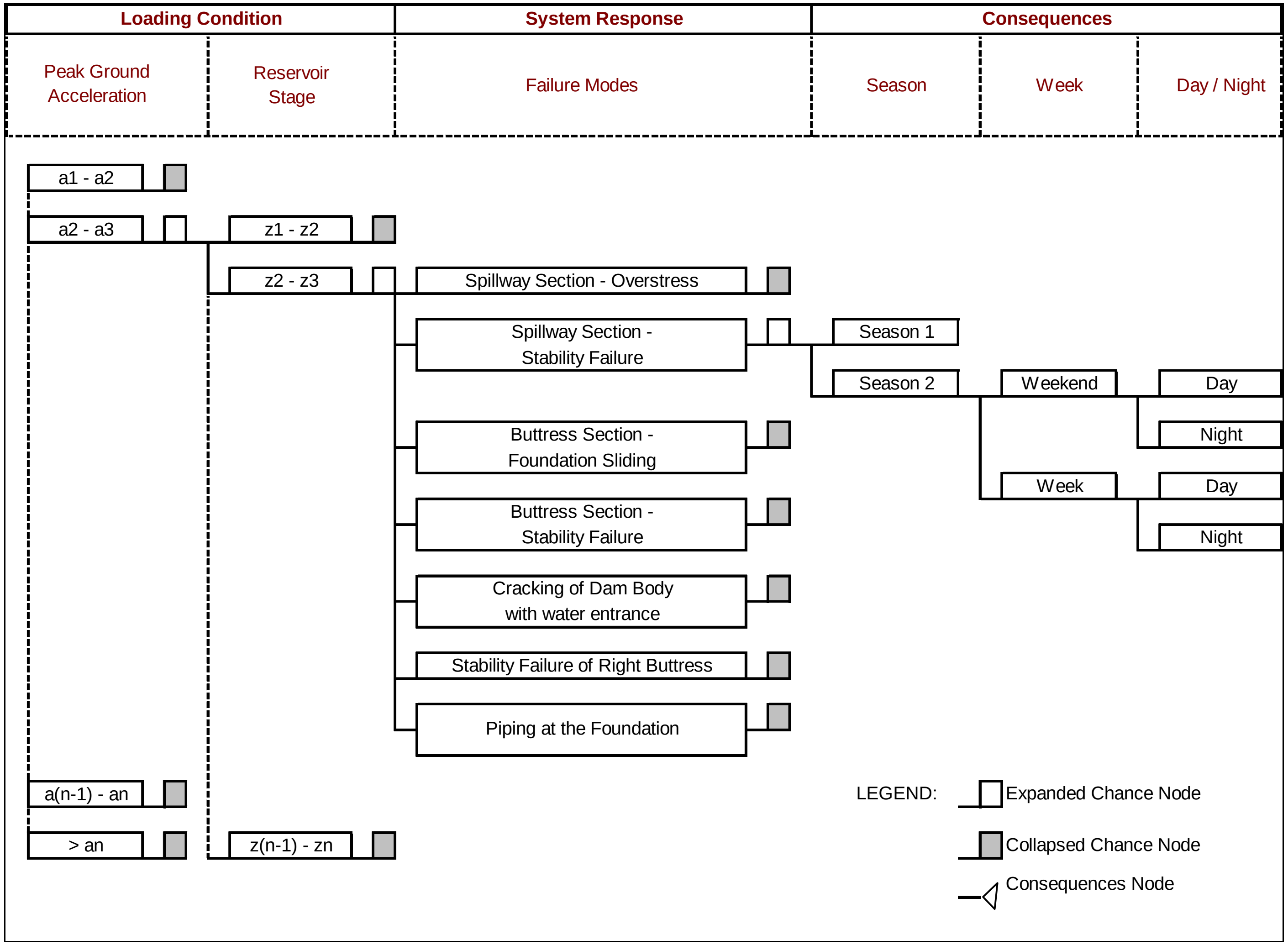

Figure 10. Event tree for earthquake scenarios.

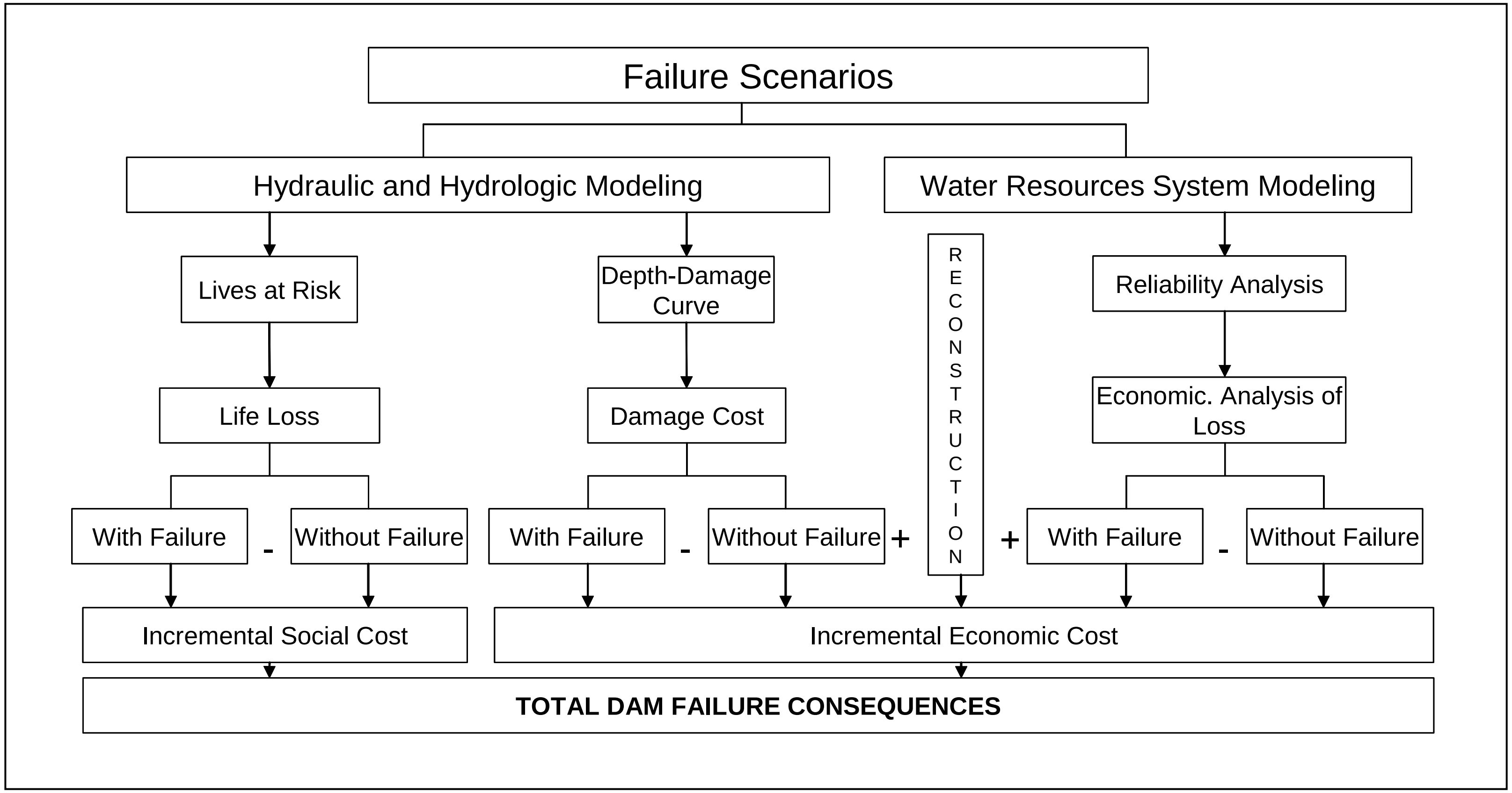

Figure 11. Flow chart for consequences calculation.

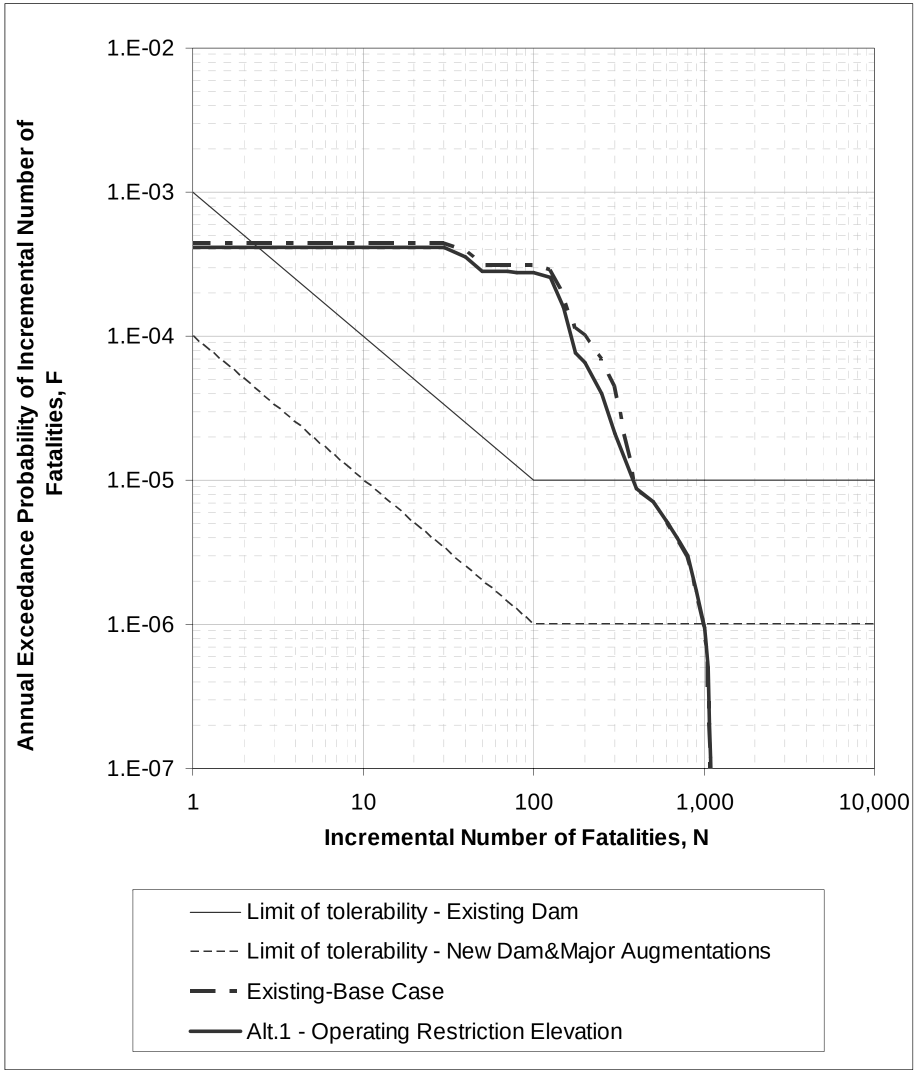

Figure 12. ANCOLD (2003)-Societal risk guidelines.

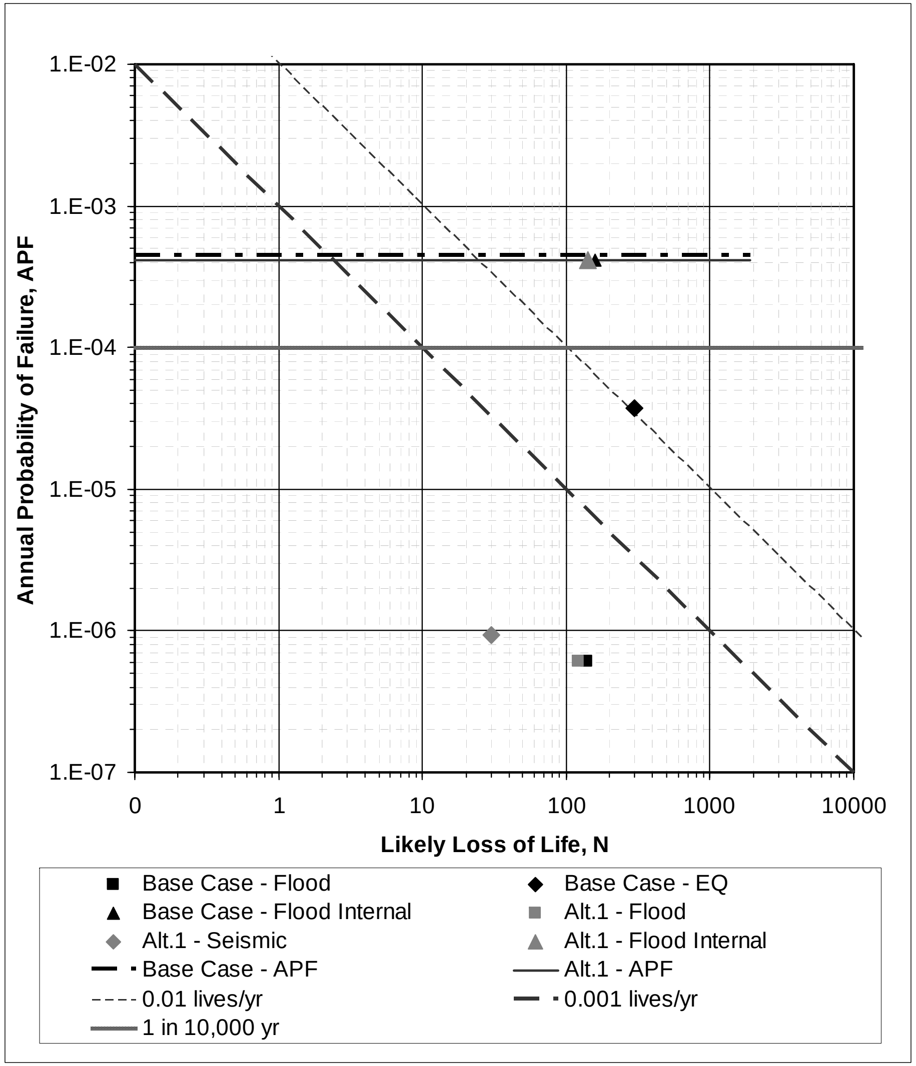

Figure 13. USBR-Portrayal of risks.

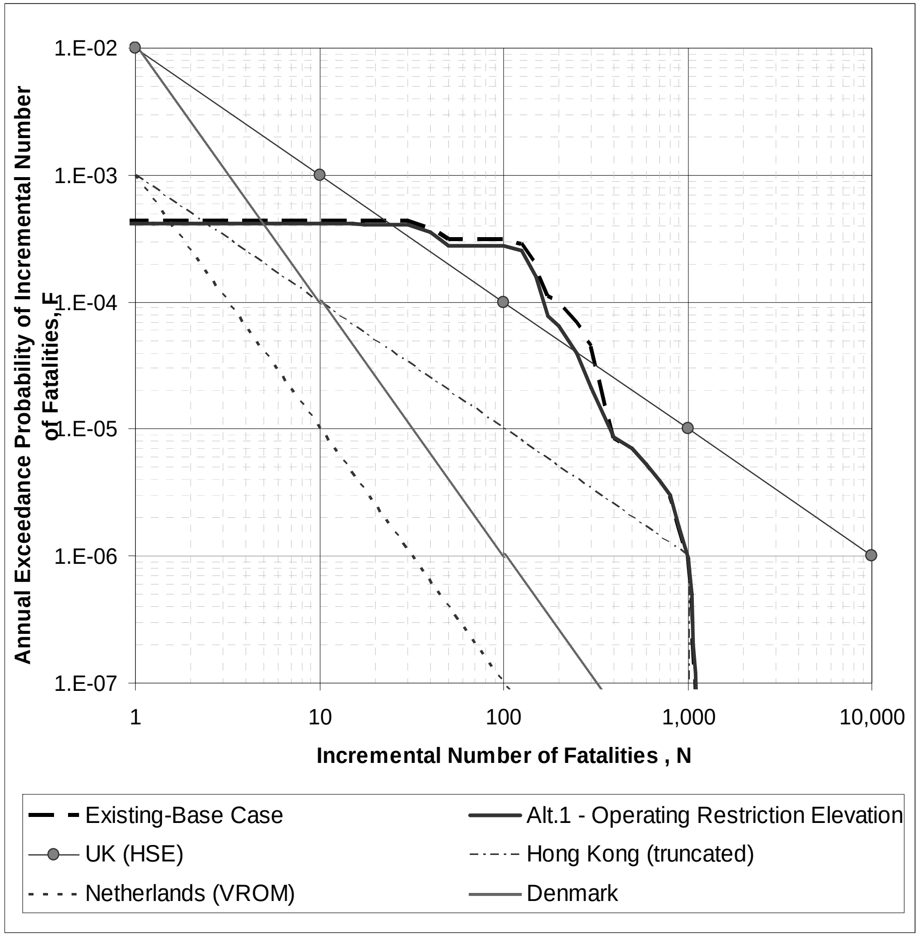

Figure 14. Risk tolerability criteria on Hazardous installations (Vrijling et al, 2004).

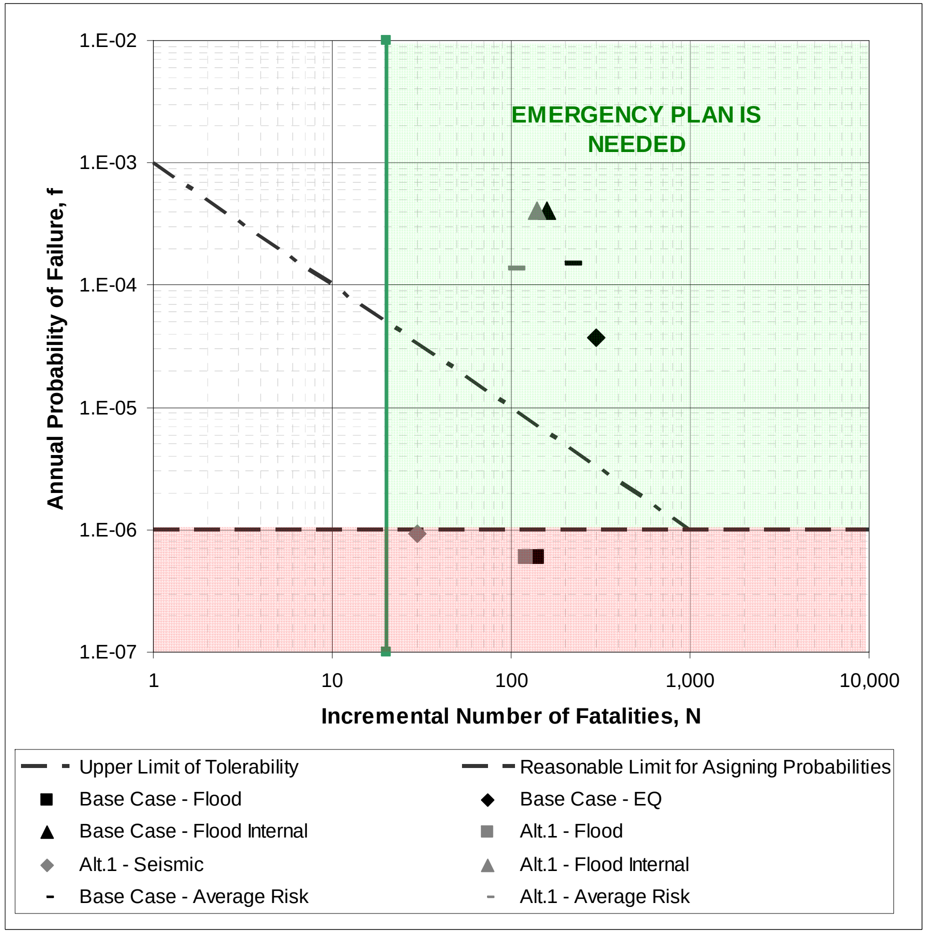

Figure 15. Criteria on Tolerable Societal Risk-Rettemeier et al 2001 (Germany).

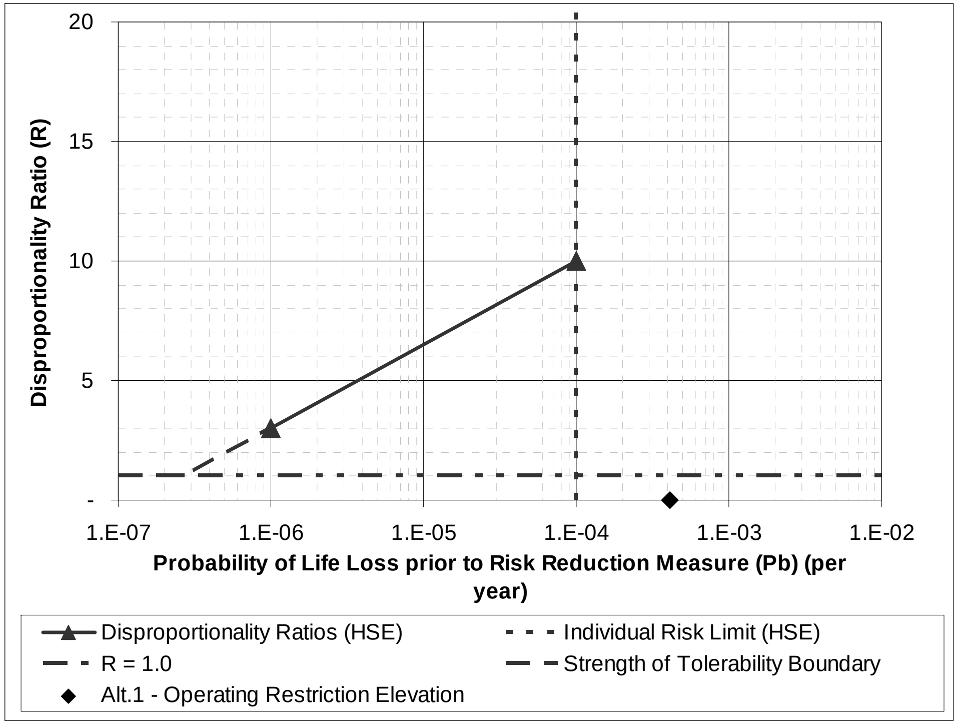

Figure 16. HSE Disproportionality ratios (Bowles 2003).

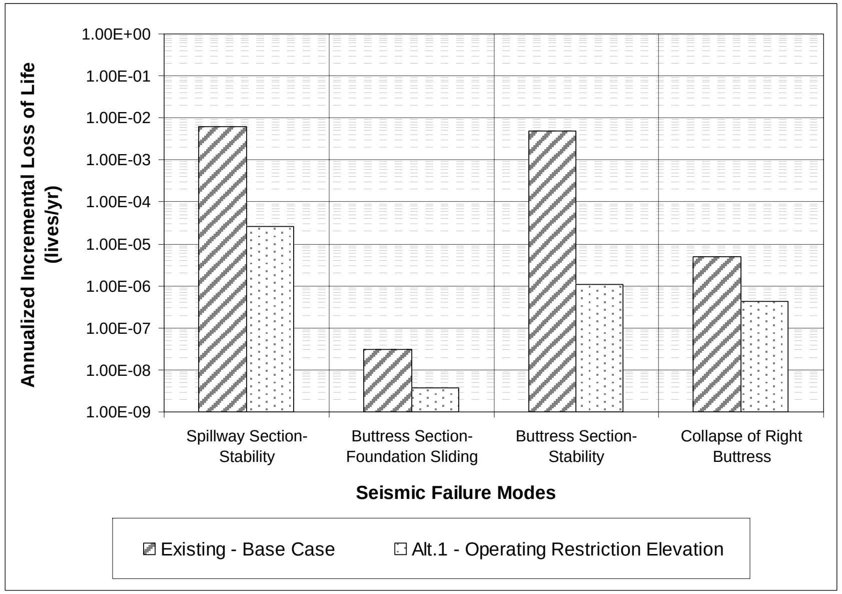

Figure 17. Annualized Incremental Loss of Life (lives/yr) - Seismic Event.

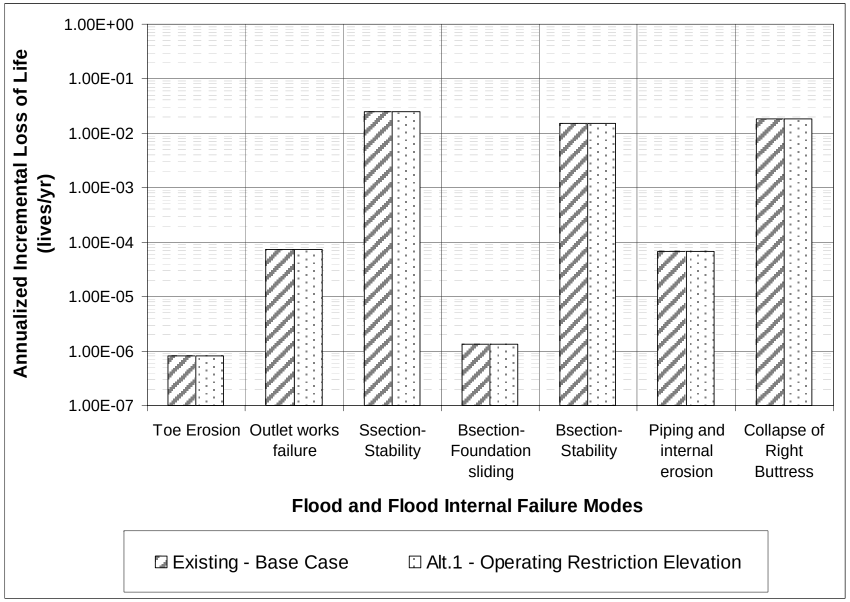

Figure 18. Annualized Incr. Loss of Life (lives/yr) – Flood and Flood Internal Events.

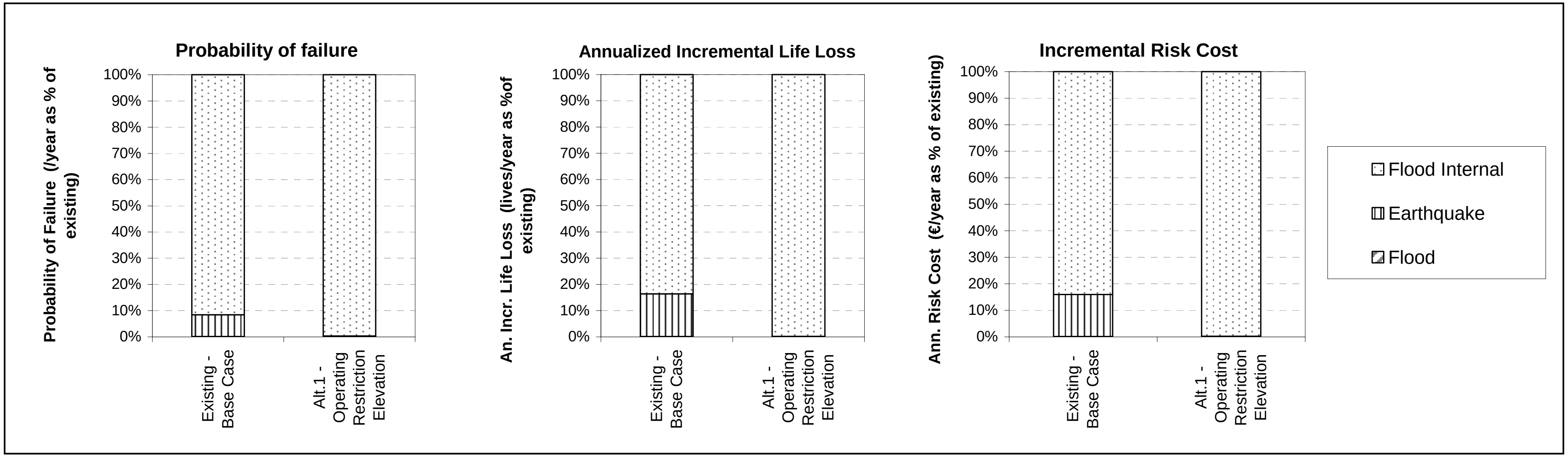

Figure 19. Probability of Failure, Annual Incremental Life Loss and Incremental Risk Cost as a percentage of existing.

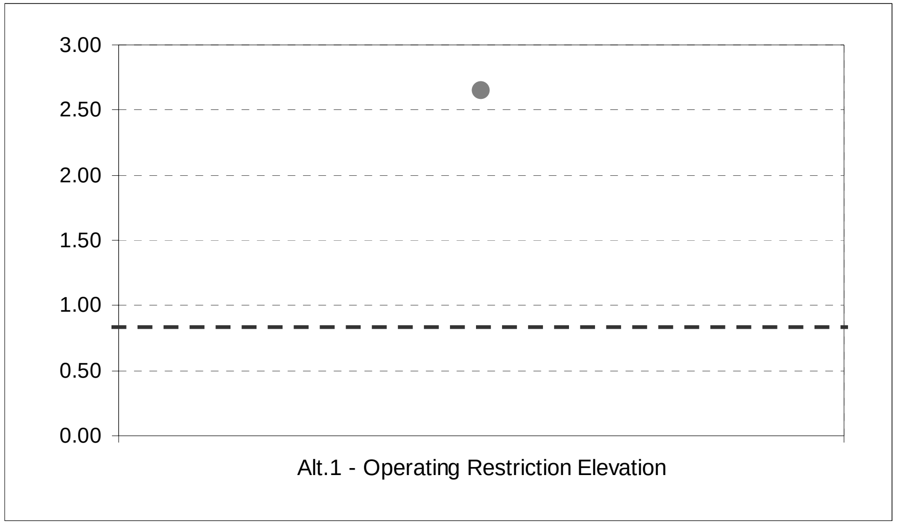

Figure 20. Benefit/Cost Ratio.

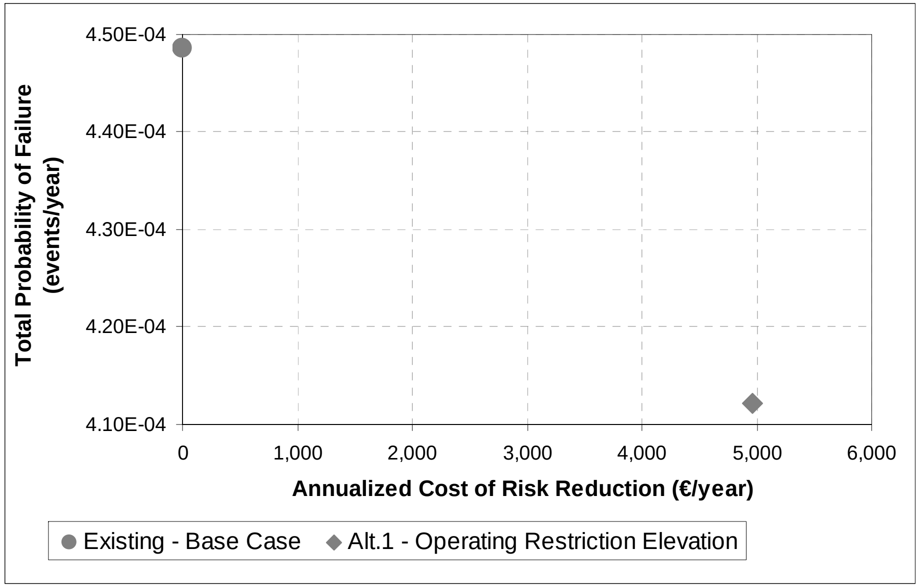

Figure 21. Reduction in Probability of Failure vs. Annualized Cost.

General Main Events	Probability of Failure		Incremental Risk Cost		Risk Reduction Benefit	Risk Reduction Cost	Total Economic Cost	Benefic/Cost Ratio	Annualized Incremental Life Loss		Adjusted Cost per Statistical Life Saved (ACSLS)
	(events/year)	%	(€/year)	%	(€/year)	(€/year)	(€/year)	(-)	(lives/year)	%	(€/life)
	Existing-Base Case										
Flood	**6.03E-07**	0%	**€ 94**	0%			**€ 94**		**7.27E-05**	0%	
Seismic	**3.74E-05**	8%	**€ 13,197**	16%			**€ 13,197**		1.12E-02	16%	
Flood Internal	4.11E-04	92%	**€ 69,887**	84%			**€ 69,887**		5.76E-02	84%	
Total	**4.49E-04**	100%	**€ 83,179**	100%			**€ 83,179**		**6.89E-02**	100%	
	Alt.1 - Operating Restriction Elevation										
Flood	**6.03E-07**	0%	**€ 94**	0%	**€ 0**				**7.27E-05**	0%	
Seismic	**9.35E-07**	0%	**€ 78**	0%	**€ 13,119**				**2.80E-05**	0%	
Flood Internal	4.11E-04	100%	**€ 69,846**	100%	**€ 42**				5.76E-02	100%	
Total	**4.12E-04**	100%	**€ 70,018**	100%	**€ 13,161**	**€ 4,962**	**€ 74,979**	2.653	**5.77E-02**	100%	

Failure Modes Break Down	Probability of Failure		Incremental Risk Cost		Risk Reduction Benefit	Risk Reduction Cost	Total Economic Cost	Benefic/Cost Ratio	Annualized Incremental Life Loss		Adjusted Cost per Statistical Life Saved (ACSLS)
	(events/year)	%	(€/year)	%	(€/year)	(€/year)	(€/year)	(-)	(lives/year)	%	(€/life)
	Existing-Base Case										
Flood	**6.03E-07**	**0.1%**	**€ 94**	**0.1%**			**€ 94**		**7.27E-05**	**0.1%**	
Toe erosion	1.38E-09	0.0%	€ 1	0.0%			€ 1		8.27E-07	0.0%	
Outlet works failure	6.02E-07	0.1%	€ 93	0.1%			€ 93		7.18E-05	0.1%	
Seismic	**3.74E-05**	**8.3%**	**€ 13,197**	**15.9%**			**€ 13,197**		**1.12E-02**	**16.3%**	
Spillway section-Stability	2.13E-05	4.7%	€ 7,433	8.9%			€ 7,433		6.32E-03	9.2%	
Buttress section-Foundation sliding	2.38E-10	0.0%	€ 0	0.0%			€ 0		3.07E-08	0.0%	
Buttress section-Stability	1.61E-05	3.6%	€ 5,757	6.9%			€ 5,757		4.92E-03	7.1%	
Collapse of right buttress	3.44E-08	0.0%	€ 7	0.0%			€ 7		4.88E-06	0.0%	
Flood Internal	**4.11E-04**	**91.5%**	**€ 69,887**	**84.0%**			**€ 69,887**		**5.76E-02**	**83.6%**	
Spillway section-Stability	1.87E-04	41.6%	€ 31,242	37.6%			€ 31,242		2.45E-02	35.6%	
Buttress section-Foundation sliding	1.20E-08	0.0%	€ 2	0.0%			€ 2		1.33E-06	0.0%	
Buttress section-Stability	7.61E-05	17.0%	€ 14,896	17.9%			€ 14,896		1.49E-02	21.7%	
Piping and internal erosion	6.71E-07	0.1%	€ 93	0.1%			€ 93		6.81E-05	0.1%	
Collapse of right buttress	1.47E-04	32.8%	€ 23,655	28.4%			€ 23,655		1.81E-02	26.2%	
Total	**4.49E-04**	**100%**	**€ 83,179**	**100%**			**€ 83,179**		**6.89E-02**	**100%**	
	Alt.1 - Operating Restriction Elevation										
Flood	**6.03E-07**	**0.1%**	**€ 94**	**0.1%**	**€ -**		**€ 94**		**7.27E-05**	**0.1%**	
Toe erosion	1.38E-09	0.0%	€ 1	0.0%	€ -				8.27E-07	0.0%	
Outlet works failure	6.02E-07	0.1%	€ 93	0.1%	€ -				7.18E-05	0.1%	
Seismic	**9.35E-07**	**0.2%**	**€ 78**	**0.1%**	**€ 13,119**		**€ 78**		**2.80E-05**	**0.0%**	
Spillway section-Stability	8.73E-07	0.2%	€ 73	0.1%	€ 7,360				2.65E-05	0.0%	
Buttress section-Foundation sliding	1.89E-10	0.0%	€ 0	0.0%	€ 0				3.75E-09	0.0%	
Buttress section-Stability	3.49E-08	0.0%	€ 3	0.0%	€ 5,754				1.06E-06	0.0%	
Collapse of right buttress	2.62E-08	0.0%	€ 2	0.0%	€ 5				4.30E-07	0.0%	
Flood Internal	**4.11E-04**	**99.6%**	**€ 69,846**	**99.8%**	**€ 42**		**€ 69,846**		**5.76E-02**	**99.8%**	
Spillway section-Stability	1.87E-04	45.3%	€ 31,223	44.6%	€ 19				2.45E-02	42.5%	
Buttress section-Foundation sliding	1.20E-08	0.0%	€ 2	0.0%	€ 0				1.33E-06	0.0%	
Buttress section-Stability	7.61E-05	18.5%	€ 14,888	21.3%	€ 8				1.49E-02	25.9%	
Piping and internal erosion	6.71E-07	0.2%	€ 93	0.1%	€ 0				6.81E-05	0.1%	
Collapse of right buttress	1.47E-04	35.7%	€ 23,640	33.8%	€ 15				1.81E-02	31.3%	
Total	**4.12E-04**	**100%**	**€ 70,018**	**100%**	**€ 13,161**	**€ 4,962**	**€ 70,018**	2.653	**5.77E-02**	**100%**	B/C > 1

Table 1. Summary of broken down results for the Existing-Base Case and the Risk Reduction Measure 1 (Operating Restriction Elevation).