

Flood risk management in valleys with dams

A. Betâmio de Almeida

Professor at IST, Technical University of Lisbon, Portugal

ABSTRACT

New large dams projects are under the public fears and the critics from environmental groups; old dams and densely populated valleys are a growing threat. Environment, safety and public opinion about dams are now a major factor of decision and pressure all over the world: the open society and the media power have changed the decision-making methodologies. Benefits from technological progress are now less obvious and seems to be more risky for the common citizen.

One of the concerns about dams is its safety and the possibility of serious accidents including the dam failure. This concern is particularly important for people living along the valley downstream the dam.

In order to develop an integrated and advanced methodology to solve problems related to valley risk management and dam safety, the “Laboratório Nacional de Engenharia Civil (LNEC)” and the “Technical University of Lisbon (UTL-IST)” are being working in a NATO Project (Science for Stability Program) since 1994.

This paper presents some concepts about dam and valley risk management and describes the structure and the main developments achieved by the NATO project including the preliminary conclusions of a sociological field study on dam break risk perception. In another paper presented by Armanda Rodrigues to this conference, the decision support system developed within the project framework is described.

1. Introduction

Dams and reservoirs have a main positive role within the water management strategies and can give a strong contribution to the society life quality improvement. Dams are also a potential danger for downstream valleys:

whatever the cause and the probability of occurrence, a failure in the water retaining capability is always possible. An integrated operational methodology need to be developed and implemented in order to achieve the best balance between risk and safety management in flood plains and valleys in general.

A new integrated dam-valley safety management includes a broader spectrum of problems and methodologies. Emergent new problems and new solutions to overcome them are a challenge for those involved in dam and valley safety (Almeida, 2000 and Almeida *et al.*, 2000).

In order to develop an integrated methodology to solve problems related to valley risk management and dam safety, the "Laboratório Nacional de Engenharia Civil (LNEC)" and the "Technical University of Lisbon (UTL-IST)" are being working in a NATO Project (Science for Stability Program) since 1994. The NATO project has also the support of the Portuguese Water Authority (INAG), the National Civil Protection Service (SPNC) and the most important portuguese company of hydro-electricity, "Electricidade de Portugal (EDP)". The main objectives of the project are the following ones:

- to improve the computational capacity to simulate dam-break floods (one and two-dimensional models), including validation procedures based on physical and experimental models;
- to improve the portuguese dam safety legislation in what concerns downstream valleys;
- to introduce the applied social sciences in risk management methodologies, specially in what concerns risk public risk perception and information and the land-use management during dam life-time;
- to develop new decision tools to aid dam and valley risk management based on advanced computer technologies (SIG and multimedia databases);
- to develop a guideline for valley emergency plans and a full scale exercise.

The project was organised in sub-projects and the work was based on a theoretical and applied studies for a case study: Arade valley at Algarve, in the south of Portugal, where two dams are in operation upstream two cities (Silves and Portimão). Among the different results and products of this project, this presents with more detail the concept of valley vulnerability is one of the most important.

2. Integrated Safety and Risk Concept

Two radical behaviours or paradigms can be detected: an extreme confidence on dam safety or is a blind faith in technological power and a strong suspicion and fear by the uncertain consequences of a any technological or constraint and the changing environmental conditions. Meanwhile, millions of people live along valleys with dams, often with a very dense land occupation. Valley safety, in this context, can not be completely dependent on dam structural and operational reliability. In fact, valley safety need to be considered as an integrated concept closely involving both the dams and reservoirs as well as the downstream valley system comprising the people, the land and the economic occupancy.

A shared risk responsibility need to be negotiated and implemented: the valley risk management process need to include the human feelings and values in order to under-stand potential conflicts and to find equity between individual interest and public goods (Almeida et al, 1997).

Protection against natural or controlled floods needs also to be considered in the integrated safety and risk concept. Flood risk should be a factor to be taken in consideration by land-use and urban planning as well as insurance policies. The valley risk management needs to be an active and dynamic tool not only for crisis situation but also for the routine activity of regional and local decision-makers.

A dam-break flood intensity (peak discharge, volume and flood hydrograph) will depend on several factors, as, among others, dam and reservoir general characteristics and the dam breach characteristics. The valley damages will depend on the valley vulnerability to dam-induced floods. This vulnerability will be a function of several other factors: flood intensity along the valley, warning system and flood time of arrival, land socio-economic occupancy and characteristics on flood prone areas and people survival capability. In fact, the valley risk will strongly depend on dam safety or response to hazards and on valley capability to cope and to survive to those induced floods. An integrated safety and risk management is justified by physical reasons.

An integrated dam-valley risk management system can be conceptually composed by two parts: the risk assessment process, in which an approximate quantitative risk estimation and evaluation is made for dangerous situations; it includes the hazard identification and characterisation as well as the dam risk analysis; and the risk mitigation process, in which actions to reduce the risk will be identified and implemented.

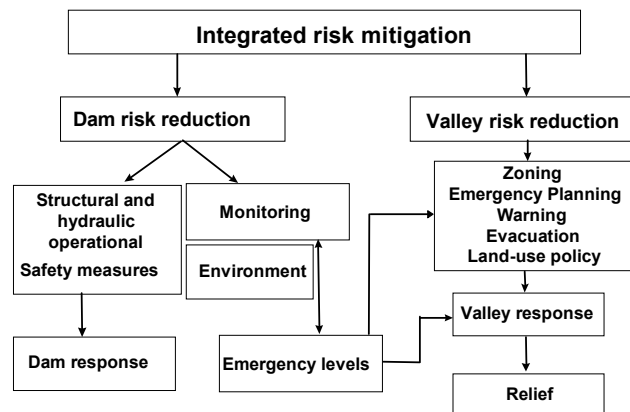


Figure 1. Integrated dam-valley risk mitigation.

In the risk mitigation process two main set of actions can be considered (Figure 1):

- risk control and reduction, including the actions to be taken, in different operational phases and situations of the dam-valley systems, in order to reduce the response probability functions referred in Figure 1. These actions include the operational safety of each dam during all its lifetime especially in what concerns the routine monitoring and inspection procedures and the safety procedures during an emergency situation, it also includes the actions to face a potential accident (early warning systems, emergency action plans, preparedness training and land-use restrictions or risk zoning).

- risk response, including the actions to be taken in order to develop and implement the crisis valley response plan should a disaster occur, caused by a dam incident or failure; it includes the civil protection actions for short-term assistance, evacuation and survival planning for both emergency and post-emergency phases.

In valleys and flood plains downstream dams the engineering paradigm based in structural defences against floods can not be considered due to the abnormal dam-break flood characteristics. Non-structural alternatives, such as land zoning, dam monitoring and hazard forecasting, warning and evacuation planning as well as the consideration of the behaviour of those involved (managers and residents) in the floodplain emergency planning (behavioural paradigm – Smith & Ward 1998) need to be implemented.

Two main benefits can be identified from this integrated concept:

- a more rational safety and risk analysis and evaluation including a real damage reduction that can be considered by the society (e.g. improving the expected damage estimations made by insurance companies, including a more realistic framework for price evaluation);

- a shared risk responsibility (Figure 2) can be developed between dam owners, safety authorities and public, due to a better consideration and as open analysis and characterisation of the dam benefits and risks as well as the mitigation or control action to protect the valley according to an accepted societal risk level.

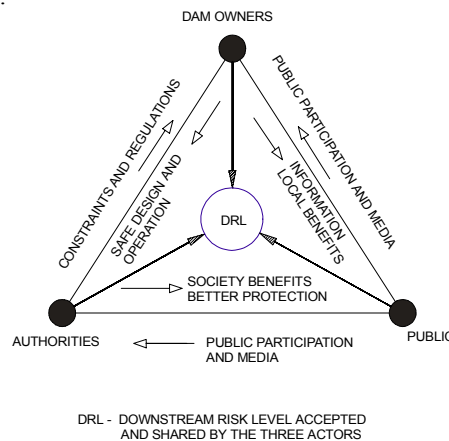


Figure 2 - Dam risk sharing between dam owners, public and authorities.

3. Portuguese NATO FLOODRISK Project

An effective mitigation of possible hazards due to a dam accident or incident clearly imposes an integrated risk management as it was described before. The success of such an integrated methodology is based on a set of methods and techniques:

- computational modelling of dam breaches and dam-break floods;
- damage analysis based on inundation mapping and socio-economic land-use as well as on public risk perception and response;
- emergency planning including evacuation planning and public information and training;
- information management based on the new information technologies (e.g. GIS and database for decision support).

As a result of the importance of this problem in Portugal and in other countries of Europe a proposal for a development project on this topic was presented by two portuguese research institutions, in 1992, to NATO "Science for Stability" Program. The project was selected and partially funded by this organisation and began in 1994 and was finished in 2000. The involved research institutions are the "Laboratório Nacional de Engenharia Civil" (LNEC) and the "Instituto Superior Técnico" (IST) of Lisbon, Portugal.

The NATO Project was developed in the context of an integrated methodology for dam-break flood risk and safety management at downstream valleys and encompasses five sub-projects (Figure 3). Each sub-project is composed of several tasks with precise objectives: Sub-project 1 (Hydraulic Analysis and Computational Simulations) develops new computational models for a better dam-break flood prediction and zoning and will contribute for a better understanding of hydrodynamic problems related to transcritical flows with abrupt waves (bores); Sub-project 2 (Dam and Reservoir Safety Analysis) prepares design criteria for practical dam-break analysis, dam rupture scenarios, including initial hydrologic conditions, to satisfy dam safety legislation (Viseu and Martins, 1998); Sub-project 3 (Land-use, Safety Management and Civil Protection) develops re-search studies related to the social impact of dam failure risk and downstream land-use and risk management; Sub-project 4 (Computer Aided Decision Support System) implements an advanced decision support system (DSS) to be used in dam-break flood safety management; Sub-project 5 (Experimental Integrated Emergency System and Training) will prepare the final specific products on the project including final fields exercises and tests, the implementation, of a crisis management system and the actions for training and dissemination of knowledge.

The methodologies developed by the NATO project are being applied to a case study in Arade river valley in South of Portugal. In this valley there are two dams: 1) Funcho Dam, a concrete arch dam, built in 1991, with a height of 49 m and crest length of 165 m. The reservoir has a gross capacity of 43.4 hm³; 2) Arade Dam, an earthfill dam, built in 1955, with a height of 5.0 m and a crest length of 246 m. The reservoir has a gross capacity of 28 hm³. Two urban areas are placed downstream the dams: Silves and Portimão.

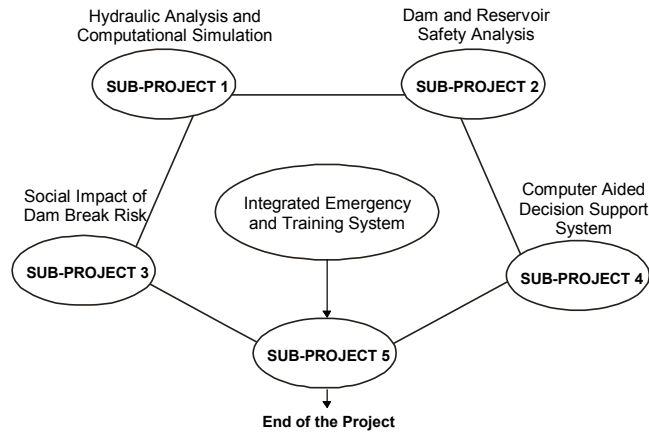


Figure 3 - NATO PO-FLOODRISK project structure.

4. Valley emergency planning and vulnerability

4.1 Valley vulnerability concept

The vulnerability concept when applied to valley risk management can be a very important one. This concept pretend to characterise the socio-economic, especially the human, tolerance of each valley to floods in this particular case. For natural floods the main attributes of vulnerability can be found in Penning-Rowsell & Fordham, 1994. For dam induced flood, contributions can be found in Almeida & Viseu 1997.

For operational efficiency, a methodology for quantitative description of the valley vulnerability needs to be developed, like a vulnerability index. This would allow an approximate measure of the risk levels along each valley and between different valleys. This vulnerability index should be considered in risk management and emergency planning as an integrated concept combining both physical and tangible factors as well as social and intangible factors.

It can be a reference for the actions to be taken in valley risk and land-use management (Figure 4): the vulnerability index should not increase with the time. This index can also be a basis for insurance policies in floodplains.

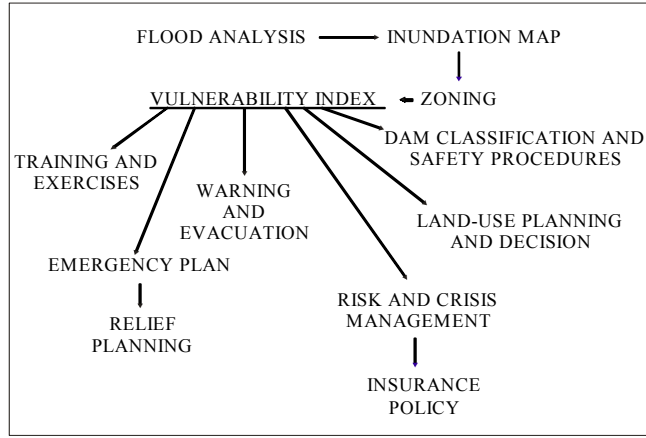


Figure 4. Vulnerability index as a reference for valley risk management actions.

4.2 Vulnerability index

The complete vulnerability index can be considered as a function of two main factors:

- The Agressivity Factor, related to the physical characteristic of the flood induced by the reference dam failure scenario;
- The Fragility Factor, related to both the social, economic and environmental characteristics of the valley, as well as the resistance (structural and non-structural) along the valley.

For each valley sub-zone j the complete vulnerability index $I_{v,j}$ can be defined by

$$I_{v,j} = I_{PV,J} \cdot I_{SV,J} \quad (1)$$

Where IPV,J is the agressivity or flood physical factor and ISV,J is the fragility or valley socio-economic factor.

The agressivity factor can be defined as a function of the main flood hydraulic characteristics in what concerns the impact on the downstream valley, among them: the maximum flood depth (DM), the maximum flow velocity x depth ($D \times V$) M , the flood arrival time after dam-break (TF) and the flood depth gradient (DD/DT).

These hydraulic quantities are related to the potential human and cattle survival capability as well as to building and other infra-structures damages. A general function can be defined:

$$I_{PV,J} = \left[\frac{F_1 (DV^\alpha)_M + F_2 (D_M) + F_3 (\Delta D/\Delta T)}{F_4 (T_F^\beta)} \right] \quad (2)$$

Where F_1 , F_2 , F_3 and F_4 are normalising and calibration functions and α , β are calibration parameters. Information about the effects of some of these quantities can be found in the literature (e.g. Suetsugi, 1998, TAW, 1990) and in

dam safety and emergency guidelines (e.g. Bureau of Reclamation or Spanish guidelines).

The fragility factor $I_{VS,J}$ can be based on the following components:

$$I_{VS,J} = \left[\frac{I_f + I_s + I_c + I_p}{4} \right] \quad (3)$$

- Physical environment (I_f), including habituated zones and people localisation, buildings, infrastructures, and ecosystems behaviour;
- Sociology (I_s), including the characterisation of people living downstream the dam as well as the public and strategic services;
- Economy (I_c), including the flood effects on economic life of the valley, employment and insurance;
- Preparedness (I_p), including the existence of emergency planning and the warning system, training and exercises and land-use restrictions.

And $I_{VS,J}$ can be obtained according to the following simple equation:

where each partial index has an integer value (0 to 3) according to specific guidelines (IST and LNEC, 2001).

The complete vulnerability index is non-dimensional and each factor need to be quantified by a panel according to the hierarchy of importance. The overall index need to be calibrated for consistency.

5. Computer support system

Taking all these aspects in consideration, the DamSupport system developed by the NATO project (to be tested in the Arade Valley) was designed to help dam safety managers and authorities as well as the civil protection services to manage a dam induced catastrophe or potential incident.

Dam Support System includes three sub-systems (Figure 5): 1) DamInfo - an information system, following the client/server paradigm, composed of a relational database, a geographic information system and an interface that allows the access to the two sets of data; DamInfo also includes emergency-related information; 2) DamAlert - includes a set of modules to monitor, simulate and forecast hydrological and hydraulic-related phenomena as well as to trigger the first alert, may an abnormal situation occur; 3) DamAid - that supports emergency management in what concerns warning the population as wells as supporting the authorities to activate and implement the external emergency plan and eventually to aid the victims.

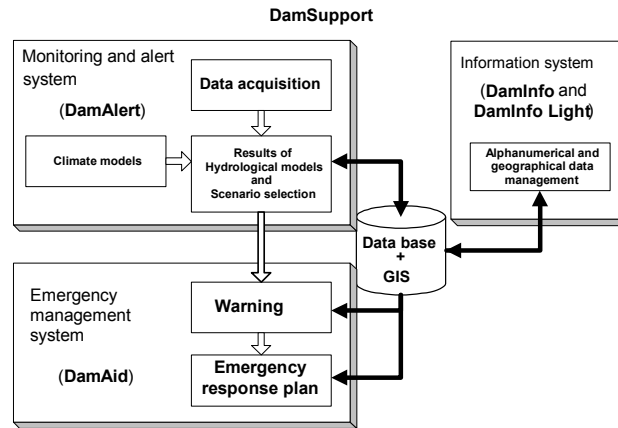


Figure 5 - Main components of the DamSupport System.

These sub-systems depend on a robust and efficient communications systems that should ensure reliable communication among the main agents involved: dam owner and operator, water authorities, local authorities, civil protection service, fire brigades, armed forces and others (red cross, voluntaries, ...). DamSupport also provides guide-lines for this system.

The system runs under Windows 95/98 or NT; Oracle server is the back-end server and Microsoft Visual Basic is the application tool used to develop both DamInfo and DamInfo Light interfaces; ARC/INFO, ArcView and MapObjects are the tools used to build, access and display geo-referenced data; TCP/IP is the network protocol used to distribute the system among the different agents involved (Figure 6).

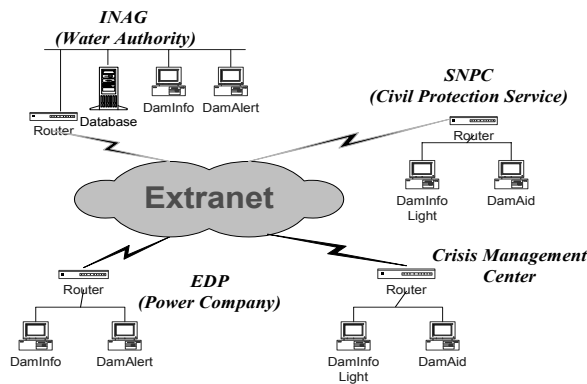


Figure 6 - DamSupport Architecture.

6. Conclusions

The products of the multidisciplinary research project funded, by NATO Science for Stability Program, developed in Portugal and concerning the integrated dam-valley are risk management are now being implemented. The project developed new methodologies for dam risk management in Portugal based on a cross-fertilisation between different engineering and social sciences techniques. The dam design practice and safety legislation can be improved as a result of the innovative proposals related to the accuracy of computational models and to an integrated land-use management, dam risk public perception and zoning as well as to decision support systems. These methodologies were applied to a real valley (Arade valley in Portugal), where the first social field re-search about dam risk perception was made in Portugal.

Acknowledgements

The author is very grateful to NATO and all other sponsor institutions, as well as to the NATO consultant Prof. Erich Plate, by the support given to PO-FLOODRISK Project. Main researchers of the project were: Sub-project 1 – A. Bento Franco and Teresa Viseu; Sub-project 2 – Matias Ramos and Rui Martins; Sub-project 3 – Delta Silva, Paula Farrajota and Alexandre Santos; Sub-project 4 – Alzira Santos and Miguel Gamboa. Mr. Matias Ramos was the sub-Director of the Project.

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