DAM RISK MANAGEMENT AT DOWNSTREAM VALLEYS
THE PORTUGUESE NATO INTEGRATED PROJECT

A. Betâmio de Almeida[1]

Professor at Technical University of Lisbon

Director of NATO PO-FLOODRISK Project

Abstract

One of the concerns about future and existing 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. Contemporary safety legislation and technical guidelines impose the consideration of dam failure scenarios and the valley inundation maps, zoning and the preparation of civil protection procedures, namely emergency plans, warning systems and exercises.

In open societies, where public information and participation is increasing, this concern is very important. In fact despite the increasing safety of dams due to better knowledge and engineering quality, a full non-risk guarantee is not possible and an accident can occur due to abnormal environmental factors, inadequate operation, change of hydrologic conditions or just because the dam is loosing strength capacity due to its age.

In order to develop an integrated and advanced technology 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 also involves the participation 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 were 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 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 lifetime;
- 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 organized in five sub-projects that were developed in order to reach the objectives. The work was based on theoretical and applied works for a case study: Arade valley at Algarve, in the south of Portugal, where two dams are in operation just upstream two cities.

The paper briefly describe the main concepts and developments achieved by this NATO project including the preliminary conclusions obtained so far.

1- Project Context

[1] Phone: 351 – 01 – 841 81 58
Fax: 351 – 01 – 684 81 50
email: aba@civil.ist.utl.pt

Effective dam risk management and mitigation have become an high priority of organizations concerned with dam and valley safety as well as with civil protection procedures.

For this particular type of risk, dam structural safety has been the focus of almost all mitigation actions. However, most of the potential damages and losses will occur along the downstream valleys. Past events show this evidence and recent dam safety legislation includes some procedures related to the downstream effects of a dam failure.

An effective mitigation of possible hazards due to a dam accident or incident clearly imposes an integrated risk management including both the dam risk control and the valley or external protection.

The success of such an integrated methodology is based on a set of methods and techniques:

- computational modeling 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 organization. The five year project began in 1994. The research institutions are the "Laboratório Nacional de Engenharia Civil" (LNEC) and the "Instituto Superior Técnico" (IST) of Lisbon, Portugal. The project is also supported by three portuguese organizations strongly related to dam safety and civil protection:

- "Instituto da Água" (INAG), the portuguese dam safety authority;
- "Electricidade de Portugal" (EDP), the main portuguese electricity utility and dam owner;
- "Serviço Nacional de Protecção Civil" (SNPC), the portuguese authority and organization of civil protection.

This NATO project pretend to develop some new integrated methodologies in order to improve in Portugal the dam-break flood simulation and inundation risk zoning, the emergency response, the land-use planning and the knowledge of risk social perception.

2- Safety of Valleys With Dams

2.1- Integrated Safety and Risk Concept The concentrated water (and energy) behind each dam can be considered as a major risk factor to downstream valley especially in what concerns potential abnormal and catastrophic floods induced by a dam accident. The advances in science and in engineering have dramatically diminished the expected rate of failure of new dams. However, the incremental risk induced by dams are differently perceived by engineers and laymen. Two radical behaviours or paradigms can be detected: an extreme confidence on dam safety, because all aspects were considered during the project (a typical specialist position) or because there is a blind faith in technological power (a typical position from a believer in absolute engineering efficacy), and a strong suspicion and fear by the uncertain consequences of a new technological environment or constraint. 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 need to be negotiated and implemented: the valley risk management process need to include the human feelings and values in order to understand potential conflicts and to find equity between individual interest and public good.

Protection against natural or controlled floods need 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 and the valley risk management should be an active and dynamic tool not only for crisis situation but also for regional and local decision-makers.

2.2- Conceptual framework Each dam, with its reservoir, can be considered as a system. An abnormal and dangerous response of this system can be provoked by different causes of disturbances (abnormal inflows, geotechnical disturbances, earthquakes, structural failure, operation error or acts of war or sabotage) and can induce a potential threat to the downstream-valley system including the river, the land and the people with its social organisation and infrastructures. Life, economic, cultural and environmental losses are, among others, the result of the valley system vulnerability facing a flood.

For each potential event or hazard E_i acting on the dam system, the formal mathematical risk, R_i, can be considered splitted in two kinds of risk: the internal dam risk and the external or downstream valley risk. In Figure 1 this formal risk concept is presented, where $P(E_i)$ = hazard occurrence probability, $P(Q_P|E_i)$ = conditional probability of occurrence of an abnormal flood with maximum peak discharge Q_P induced by the dam response to hazard E_i and $P(N|Q_P)$ = conditional probability of N losses along the valley due to the induced dam-break flood.

Dam-safety procedures will contribute directly to the **internal risk reduction** and the valley safety procedures will contribute directly to the **external risk reduction**. The 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 physically justified.

The main objective of this integrated management is to improve the real safety of people and ecosystems along the valleys and its implementation should reduce the valley vulnerability. That can be achieved by a consistent dam-valley risk mitigation system.

$$R_i = P(E_i)\int_0^{N_{Max}}\int_0^{Q_{Max}} p(Q_p|E_i)\,p(N|Q_p)\,N\,dN\,dQ$$

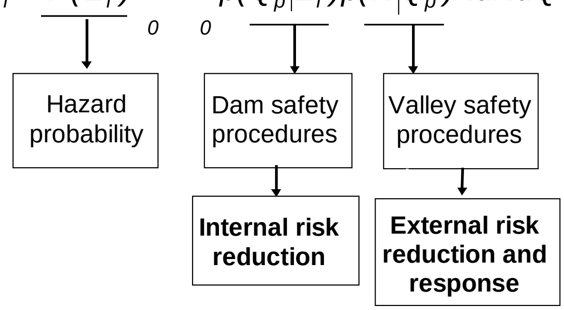

Figure 1 - Formal mathematical dam risk concept due to an hazard E_i.

In this context 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.

In the risk mitigation process two main set of actions can be considered (Figure 2):

- 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 (behavioral paradigm – Smith & Ward 1998) need to be implemented. So in this aspect of floodplain safety and risk management we need to consider the following strategies:

- The principle of **preventing accidents**, in what concerns the **internal risk** reduction management (in dam operation).
- The principle of **minimizing damage**, in what concerns the **external risk** reduction management (in valley management).

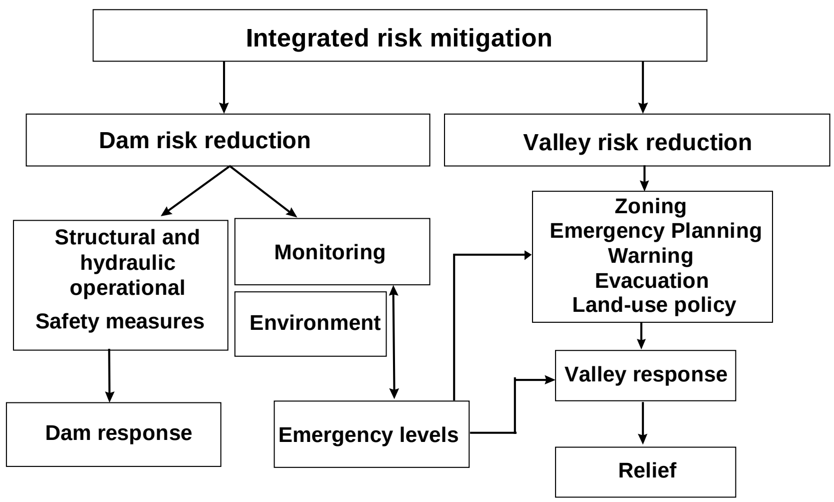

Figure 2 - Integrated dam-valley risk mitigation.

2.3- Operational difficulties Rare events with very low yearly probabilities are difficult to be accepted or understood. In fact, risk perception involves people's beliefs, attitudes, judgements and feelings, as well as the wider social or cultural values and dispositions people adopt toward dam hazards and benefits. Engineers are well trained to work with the physical truth or objective safety evaluation based on a quantitative analysis and on, as much as possible, "neutral" and rational decisions. However, in open and democratic societies, the public and the media are now a part of the decision process on what concerns dam impacts and flood mitigation. Typically, the individual doesn't easily accept a new uncertain risk or threat imposed to him and family by others. However, each individual may react in an opposite way should the risk decisions be from its own responsibility and for its own benefit. So, the benefits of project and the real dimensions of the potential induced threats need to be clearly presented and discussed in order to obtain public trust and acceptance to share future risks and to accept land-use restrictions for protection in flood-prone areas.

In order to conciliate the individuals and the groups of people under potential threat as a whole, social psychology and sociology are two social sciences that should be introduced in the interdisciplinary set of specialists involved in dam safety and valley risk assessment and management. Difficulties can arise from the fact that the consideration of social values in the design and decision-making process will impose, to all specialists, a better understanding of their role (including new ethical altitudes) and a strong confidence on the benefits of their work for the community. The following general principles should them be taken in consideration:

1) perceptions are the result of complex subjective and objective factors including emotional feeling and values. Public perception of rare events can be very different from what scientists or specialists feel;

2) public information, as an instrument for a better or unbiased judgement of risk management, need to be carefully prepared and to recognise public values and feelings in order that the message don't be distorted;

3) public participation within a framework of a shared risk and of an efficient non-structural valley risk management against floods and dam incidents or accidents;

4) ethical principles can not be neglected in this process and a moral dimension should also be considered in the accepted shared risk.

The consideration of both subjective (human response) and objective factors (inundation maps and evacuation plans), can improve the emergency response and also the real survival capability under limit or critical conditions. The integrated valley safety and risk management should also include abnormal floods and dam outflows.

Another very important category of difficulties, against a full integrated dam-valley safety and risk management, is the institutional one and especially the rigid separation between traditional roles in safety, civil protection and land-use policies.

Public information and participation is now a fundamental part of the decision-making process and must be considered as important as the engineering part of problem.

The integrated dam-valley risk management has a definitive complementary role to the restricted dam safety concept only based on procedures related to dam works and operation. This concept pretends to embrace both the control of the main risk focus as well as the control of social-economic consequences external to dam and its near valley reach. Two main benefits can be identified from this 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 realostic framework for price evaluation).

- **a shared risk responsability** (Figure 3) can be developed between dam owners, safety authorities and public, due to a better consideration and as an open analysis and characterization of the dam benefits and risks as well as a mitigation or control action to protect the valley according to an accepted societal risk level (*e.g.* the integrated and shared risk management can be a positive way to consider during public discussions related to a new dam construction or safety reinforcement).

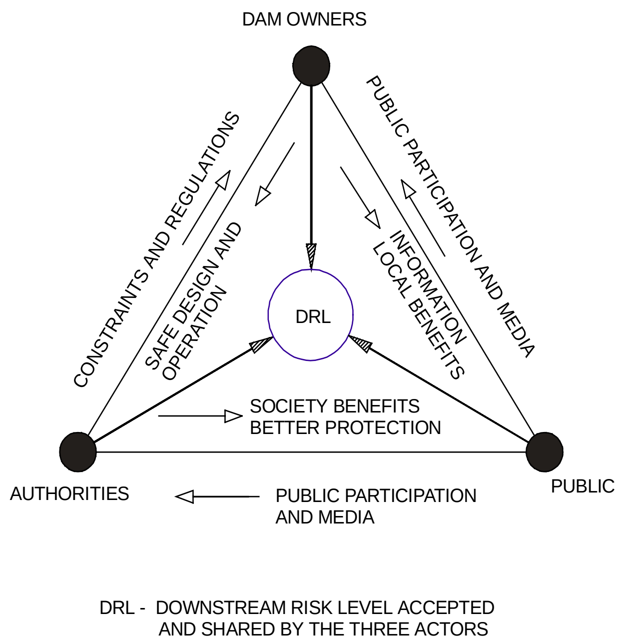

Figure 3 – Dam risk sharing between dam owners, public and authorities.

3- Project Structure

The NATO PO-FLOODRISK Project for Dam Risk Management at Downstream Valleys is organized in five sub-projects (Figure 4):

- Sub-project 1 - Hydraulic Analysis and Computational Simulation (B. Franco and T. Viseu);
- Sub-project 2 - Dam and Reservoir Safety Analysis (M. Ramos and R. Martins);
- Sub-project 3 - Social Impact of Dam Break Risk (D. Silva and P. Farrajota);
- Sub-project 4 - Computer Aided Decision Support System (A. Santos and M. Gamboa);
- Sub-project 5 - Integrated Emergency and Training System (all NATO project team and end users).

The main researchers of each sub-project are also referred. The project was coordinated by the author of this text as Director of the Project and by Matias Ramos as Sub-Director of the Project. Professor Erich Plate was the NATO consultant. At the end some references related to the project are presented (Almeida & Franco 1994, Almeida & Viseu 1997, Almeida *et al.* 1997, Lima *et al.* 1997, Viseu & Martins 1997, Almeida *et al.* 2000).

Each sub-project is composed of several tasks with precise objectives:

- Sub-project 1 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;
- Sub-project 2 prepares design criteria for practical dam-break analysis, dam rupture scenarios, including initial hydrologic conditions, to satisfy dam safety legislation;
- Sub-project 3 develops research studies related to the social impact of dam failure risk and downstream land-use and risk management;
- Sub-project 4 implements an advanced decision support system (DSS) to be used in dam-break flood safety management;

- Sub-project 5 prepares 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.

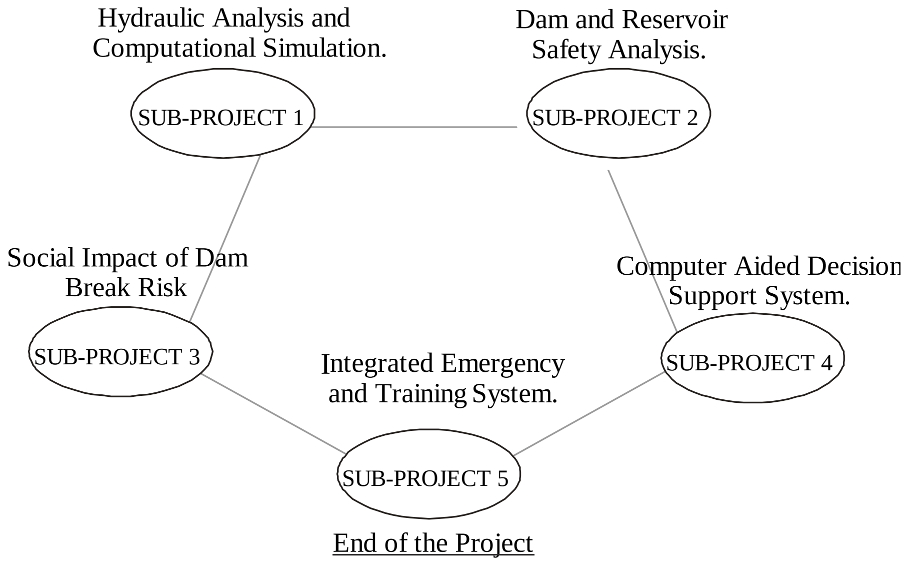

Figure 4 - NATO project structure.

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 hm^3; 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 hm^3. Two urban areas are placed downstream the dams: Silves and Portimão.

4- Project developments

4.1- Sub-project 1 A good characterization of the floods induced by dam breaks is a fundamental requisite for the valley risk management. According to the project program the following tools were developed:

- computational flood simulation with fixed bed models (1-D and 2-D) for irregular valleys, based on a numerical technique with the capability to deal with flow discontinuities or shock waves (MacCormack - TVD technique);
- experiments in a special canal with different boundary conditions in order to validate the computational models. This canal was also used for CADAM tests;
- a physical model (scale 1/150) reproducing a reach of the Arade river 4 500 m long for model validation under real irregular conditions.

Dam-break floods, in real conditions, induce two-phase (solid-liquid) flows: the sediments in the reservoir are forced to move with the outflow and the downstream river bed will suffer erosions and strong modifications due to this kind of abnormal flood.

The NATO project also have promoted studies on this topic including analytical analysis and the coupled and non-coupled modeling of solid-liquid mixtures and experimental studies on a laboratory flume. At 1998 CADAM Munich Meeting some results were already presented (Ferreira and Leal).

In what concerns the Arade case study it was concluded that inundation maps based on 1-D and 2-D computational models presented very relevant differences both in what concerns the inundation area affected by the flood and in maximum flow depth and flood time arrival.

4.2- Sub-project 2 In this sub-project the dam safety legislation was discussed as well as the conditions to follow in dam-break flood studies as by example:

- dam failure scenarios for single and compound breaks (cascade dams along a river valley);
- hydrological conditions to consider in dam-break flood studies;
- outflow hydrographs due to a dam breach according to dam type and accident cause.

Another topic considered was the criteria for flood risk characterization based on the inundation maps obtained by computer simulations. The flood impact on human lifes and on buildings will depend on the hydrodynamic characteristics of the flow: maximum depth and flow velocity, depth gradient with time, time of flood arrival and flooding duration, among others. The flood severity characteristics should be the basis for a first or preliminary risk zoning.

4.3- Sub-project 3

4.3.1- Social perception research The NATO project made the first field inquiries in Portugal about dam risk social perception along the Arade valley. Downstream the two dams the valley has a length of about 14 km to the Atlantic Ocean and 8 200 inhabitants as population at risk (PAR), both in rural areas and urban areas (Silves town, 7 km downstream the Arade dam and Portimão town, 13 km downstream this dam).

The valley was divided in five sub-areas (Table 1) according to different factors including the arrival time of the flood and to the dichotomy between rural and urban areas.

A first a socio-demography analysis was made and special emphasis was given to the percentage of elderly people as well as of illiterate individuals.

Based on this social and demographic characterization of the risk area, four samples were extracted by random procedures. Data was collected by direct interviews using structured questionnaire. From that questionnaire data were analyzed in what concerns:

- subjective probability and awareness of negative consequences of a dam failure disaster;
- perceived risk of flood and dam failure;
- perceived benefits and perceived safety of dams;
- association of perceived risk with other social beliefs.

Table 1
Arade valley. Characteristics of the sub-areas

Inundation area			Population at risk			Buildings at risk	
	WT (min)	CS	PAR	O/Y rate (%)	Illiteracy (%)	CSS (%)	Low (%)
Area 1	< 15	Rural	674	113	28	43	100
Area 2	15 - 25	Rural	549	109	34	41	100
Area 3	25	Urban	3 694	40	16	58	89
Area 4	25 - 60	Rural	3 212	19	15	50	89
Area 5	60	Urban	905	114	15	21	79

Where

WT = time of flood arrival

CS = land occupation type

PAR = population at risk

O = old people (> 64)

Y = young people (< 14)

CSS = concrete structure buildings

LOW = low buildings (< 3 floors)

Samples near the dam perceive dam-break risks as more dread than people living for away. The accidents living near the dam have a great awareness of the consequences to their site in case of dam disaster, but those living near the coast don't.

Arade dam (earth fill dam) is perceived as safer than Funcho dam (concrete arch dam), specially by the residents near the dams. Judgments of dam safety are based on confidence in dam engineering and characteristics of the dam.

Older dams are considered as more trustable than younger ones, because they have already proved to be safe.

There results present some challenges in terms of risk communication strategy which need to be sensitive to the characteristics and feelings of the population at risk along the valley

The low frequency of accidents of this kind, or the low probability of occurrence associated with the high catastrophic potential have a strong influence on risk public perception. These aspects need to be considered when defining the risk communication strategy to be adopted in each case (Sub-project 5). This strategy is intended to dissipate feelings of apathy and public passivity and to motivate the community to prevention and supervising. The aim is also to avoid the triggering of overeactions of risk amplification conditioned by feelings like fear, anxiety or stress deriving from the consciousness of the catastrophic potential of the event.

The results of this particular case study have also shown that people at risk have self--efficacy and control illusions (positive illusions) and need them for their well being when faced with dam failure risk day to day. For more details see contributions of Lima, Sousa e Silva, Silva & Lima and Campos & Farrajota 1997 and in "Dams and Safety Management at Downstream Valleys" (1997).

4.3.2- Valley vulnerability Valley socio-economic vulnerability towards each potential hazard is a major factor to be considered in risk management. Vulnerability reflects the potential weakness to react to, or recover from, an hazard impact as a dam-break flood.

In Chapter 4 details about the valley vulnerability concept are presented.

4.3.3- Land-use control The valley vulnerability will be closely linked to the probability of a certain number of human losses or other damages should a dam-break flood with special characteristics propagate along the valley.

Preventive procedures to be considered within an integrated valley risk management should include the land-use control according to high risk zoning. This control should avoid very vulnerable or strategic infra-structures or permanent people concentrations in areas prone to flooding.

This information is now easily considered and up-to-dated in a GIS interconnected through a special network (Sub-project 4).

4.4- Sub-project 4 The research group of the NATO project developed the Decision Support System (DSS) for the project team and also for future users (Dam Support). Basically, the following products were developed (Figure 5):

- a multimedia database oriented for dam safety as an inventory of all relevant information related to design, construction and exploration of each portuguese dam;
- Geographical Information System (ARCINF) linked to computational models and database by special interfaces;
- a database for crisis decision support including the valley emergency planning procedures (Dam Info and Dam Info Light);
- a monitoring and warning system (Dam Alert);
- and an emergency management support system including the emergency response plan (Dam Aid).

The DSS will be interconnected between the Water and Dam Safety Authority (INAG), the Civil Protection Service (SNPC), the EDP Power Company and a Crisis Management Center to be implemented at the end of the project (Figure 6).

For more details see Farrajota & Campos, Gamboa & Santos and Fernandes & Andrade in "Dams and Safety Management at Downstream Valleys" (1997).

3.5- Sub-project 5 At the end of the project the main goal is to have contributed for an effective improvement of valley safety and risk management in Portugal. This general objective is being obtained through the case study (Arade valley) where the developed methodologies and techniques are being applied. This work is composed by five stages including aspects like: flood computational simulations, inundation mappings, risk zoning, socio-economic characterization, regional and local hydrologic study (flood analysis), dam reservoir exploitation and land-use planning criteria.

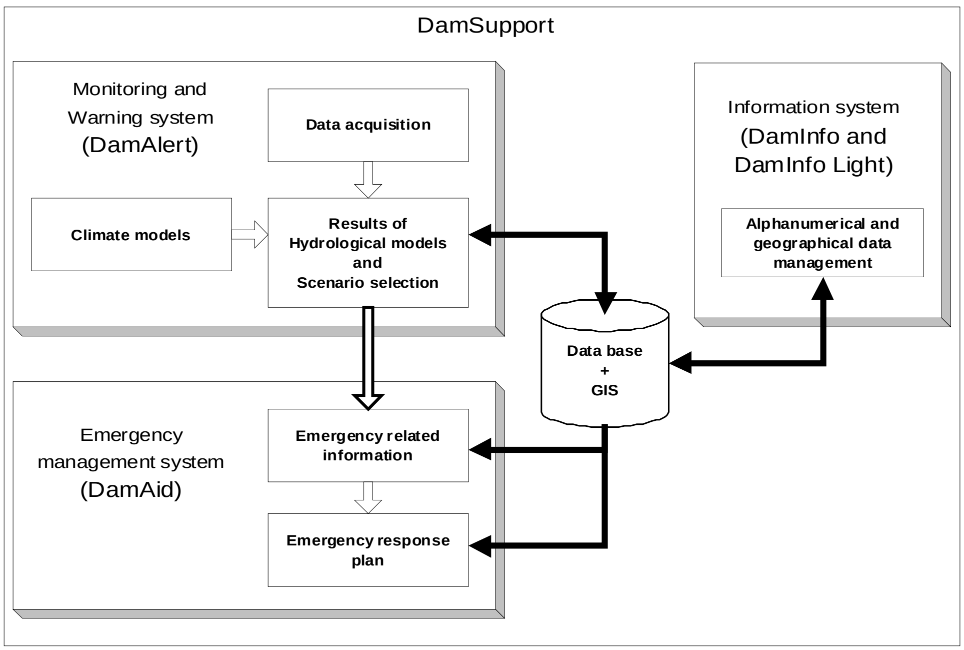

Figure 5 - Dam Support System (NATO project).

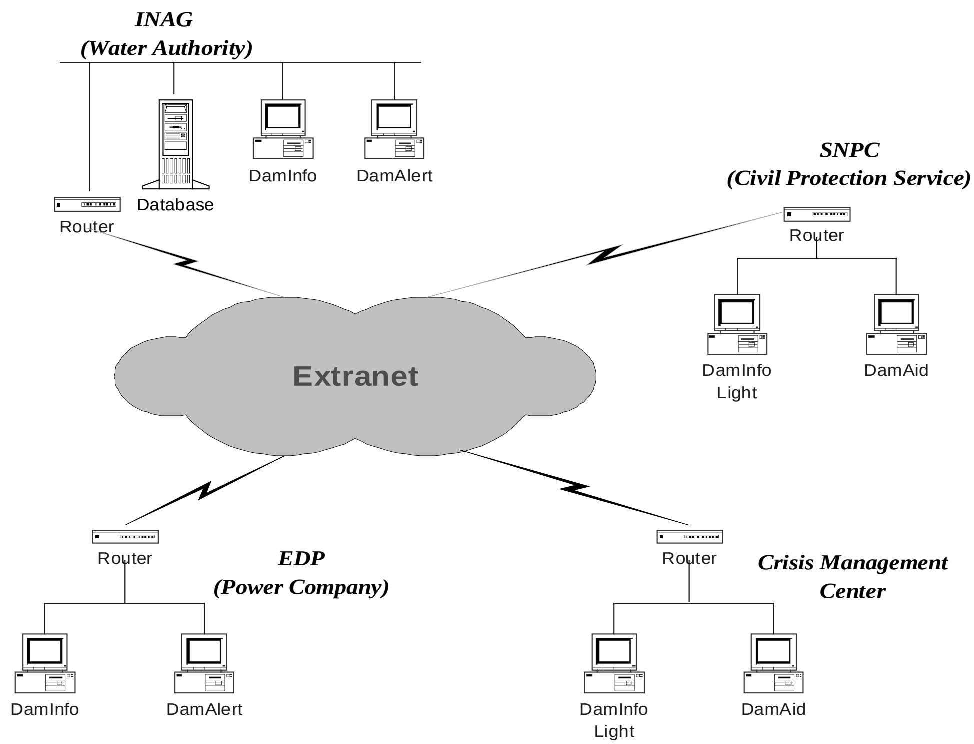

Figure 6 - DSS interconnection between end-users.

As a prototype for Portugal, an emergency plan, including evacuation procedures and a warning system is being developed by the NATO project in cooperation with the support institutions (INAG, EDP and SNPC). This system will include normal floods and dam discharges.

The DSS is being extended to a national level including an emergency or crisis center.

The implemented system will be tested by an exercise to be planned at the fall of 1999.

5- Valley Emergency Planning and Vulnerability

5.1- Emergency planning Emergency management aims at protecting life, minimising damage to property and alleviating suffering caused by a natural or man-made hazard. To achieve these goals, emergency management must act on four different stages: to understand the phenomena that may induce a failure and reduce its impact (mitigation); to prepare for effects of the hazard (preparedness); to respond in an effective way to the event, may it occur (response); to restore the systems to normal situation (recovery).

Emergency planning plays an important role in valley risk and crisis management and are adequate tools to guide the civil protection authorities to take an effective response. In fact, if a disaster can not be totally avoided, then having individuals and organisations need to be prepared for it. According to the conceptual risk framework already presented, two types of plans should be considered:

- the **Internal Emergency Plan**, that refers to the actions concerning the dam safety and operation; and;
- the **External Emergency Plan**, that should mainly be concerned with the actions in the valley.

The **Internal Emergency Plans** should include: 1) the characterisation of the water control infrastructure; 2) the identification of potential dangerous situations for the dam; 3) the definition of the safety levels in dam operation; 4) the methodology for hazard detection and decision-making; 5) the notification of dam safety and local authorities; 6) the notification and mobilisation of civil protection services.

The **External Emergency Plan** should include:

1) the characterisation of the downstream valley (population, infrastructures and equipment, routes and communication systems, military and paramilitary forces, medical care, economic activity);
2) the implementation of a the means of public warning and notification system;
3) the identification of the safety agents and their responsibilities;
4) a definition of the decision-making hierarchy;
5) the allocation of human and material resources;
6) the definition of shelter areas and the access routes (including alternate routes);
7) the identification of transportation material;
8) the identification of the communication systems.

Both types of emergency planning must consider different levels of action. Three levels are generally considered according to the crisis seriousness.

Public perception analysis is very important for emergency planning. A special communication or information strategy should be adopted based in this kind of analysis. This strategy is intended to dissipate feelings of apathy and public passivity and to motivate the community to prevention and supervising. The aim is also to avoid the triggering of overreactions of risk amplification conditioned by feelings like fear, anxiety or stress deriving from the consciousness of the catastrophic potential of the event.

The results of the Arade case study have also shown that people at risk have self-efficacy and control illusions (positive illusions) and need them for their well being when faced with dam failure risk day to day.

It is important to point out that risk communication strategies must be part of an integrated dam (internal) and valley (external) risk management program, in which **valley vulnerability mitigation** and **emergency management practices** are stressed and developed. Risk communication by it self doesn't help and sometimes can worth things. If emergency planning is fragile, there's lay questions that may rest unanswered putting experts trust and credibility at risk. Past experiences on risk communication showed that trust in experts - something basic to the success of the strategy - once lost, is very difficult to achieve again.

The hard part (physical support) and soft part (messages and their meaning) of the warning system needs, once more, the cooperation of the engineering and the social psychology.

Public participation and inter-organisational involvement is very important, especially at local level: people tend to support plans that they help to create. Thinking that an emergency plan handbook is the only task is to make the plan fail. The plan needs to be supported by public acceptance and by an efficient information system.

5.2- Valley vulnerability concept The vulnerability concept when applied to valley risk management is a very important one. This concept pretend to characterise the socio-economic, especially the human, tolerance to valley hazards in general, and to floods in this particular case. For natural floods the main attributes of vulnerability can be found in Penning-Rocusell & 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 need 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 7): the vulnerability index should not increase with the time. This index can also be a basis for insurance policies in floodplains.

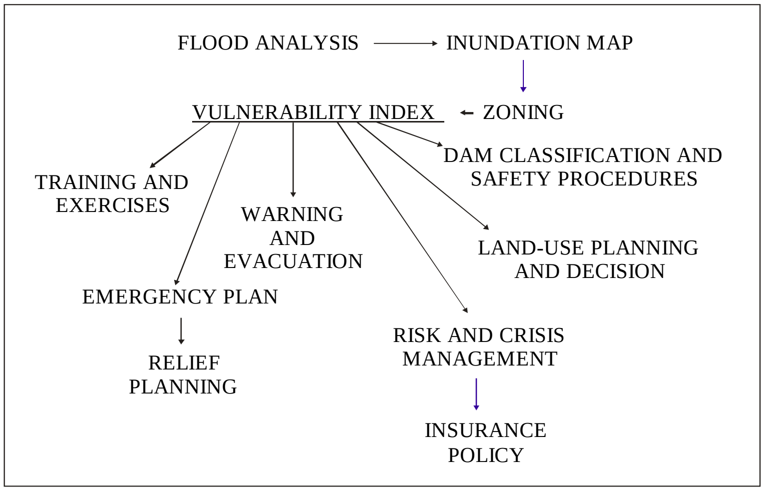

Figure 7 - Vulnerability index as a reference for valley risk management actions.

5.3- Vulnerability index The basis of a vulnerability index is the consideration of the valley vulnerability 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 proposed vulnerability index $I_{v,j}$ is defined by

$$I_{v,j} = I_{PV,J} \;.\; I_{SV,J} \qquad (1)$$

Where $I_{PV,J}$ is the agressivity or flood physical factor and $I_{SV,J}$ is the fragility or valley socio-economic factor.

The global valley vulnerability index, I_{VV}, can be obtained by the simple sum of all $I_{V,J}$ or by a weighted sum based on the distance of each sub-zone to the upstream dam.

5.4- Components of the vulnerability index

5.4.1- Agressivity or flood physical 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 (D_M), the maximum flow velocity $\times$ depth $(D \times V)_M$, the flood arrival time after dam-break (T_F) and the flood depth gradient ($\Delta D/\Delta T$).

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:

$$I_{PV,J} = \left[\frac{K_1 \left(DV^{\alpha}\right)_M + K_2 \left(D_M\right) + K_3 \left(\Delta D / \Delta T\right)}{K_4 \left(T_F^{\beta}\right)} \right] \qquad (2)$$

Where K_1, K_2, K_3 and K_4 are normalising and calibration factors 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).

5.4.2- Fragility or socio-economic factor The fragility factor $I_{VS,J}$ is based on the sum of several components:

$$I_{VS,J} = \left(H_V + ST_V + E_V + EN_V\right)_{,J} \qquad (3)$$

related to human vulnerability (H_V), structural-building vulnerability (ST_V), economic vulnerability (E_V) and environmental vulnerability (EN_V). The proposed operational structure is the following one:

$$H_V = H_{V1} \,.\, H_{V2} \,.\, H_{V3} \text{ where} \quad (4)$$

$$H_{V1} = (IPAR).(WS)(PIA)$$

being $IPAR$ the population at risk factor, *WS* the warning system factor and *PIA* the potential inundation area factor,

$$H_{V2} = 1 + PO + PYPI \qquad (5)$$

being *PO* the percentage of "elderly" people (> 64 years), *PY* the percentage of "young" people (< 14 years) and *P1* the percentage of illiteracy, all in the flood prone area, and H_{V3} is the emergency planning factor where a risk perception factor index is also considered.

$$ST_V = ST_{V1} \,.\, ST_{V2} \,.\, ST_{V3} \text{ where} (6)$$

ST_{V1} is the land occupation factor based on the main type related to the flood prone area (urban, rural or mixed),

$$ST_{V2} = (2 - CB)(0.5 + LB)) \quad (7)$$

being CB the percentage of concrete structure buildings and *LB* the percentage of low buildings (one or two stores), and ST_{V3} quantifies the important infra-structure in the flood prone area (no important, rather important or very important).

$$EV = AGR + IND + SER \text{ where} \qquad (8)$$

AGR, IND and SER are the factors that quantify the importance of the economic activities of the flood prone area: agriculture and cattle, industry and services, respectively which are considered as not important, with average importance or very important.

ENV is the factor that quantifies the environmental importance at risk of potential destruction due to a break dam flood in each area.

5.4.3- Calibration and evaluation The vulnerability index is non-dimensional and each factor above presented need to be quantified by a panel according to the hierarchy of importance. The overall index need to be calibrated for consistency. The index is now being calibrated in the framework of the Arade case study.

6- Concluding remarks

Dam safety legislation in several countries are now taking in consideration the potential effects or damages at downstream valleys should a dam-break occur regardless the probability of the event. These procedures introduce several problems to all organisations involved in dam exploitation as well as in dam and valley safety and, civil protection. An integrated dam-valley safety and risk management is proposed in this work.

Dam owners faces a responsibility towards society in what concerns the internal dam procedures that will avoid a dam-break or diminish the probability of a dam-break flood should an abnormal event or action occur (*e.g.* an extreme hydrological event or flood). Insurance premium related to dam failure consequences will also be in the future a serious factor to be considered by dam owners.

Civil protection authorities or valley safety authorities faces a responsibility to diminish the probability of human and economic losses should a dam-break event occur. To mitigate the risk along the valley, non-structural procedures should be implemented as land-use control according to flood risk zoning and emergency planning.

Emergency planning and effective warning systems are now mandatory by the portuguese dam safety regulation and all modern dam safety regulations. However, these procedures need to be implemented with the support of local authorities and with an adequate public information and participation according to the risk perception level of the population at risk. The emergency planning should also include the normal floods as another integration dimension. Evacuation planning need to be well prepared and trained and in almost all real cases the alarm need to be switch on as soon as a failure is predicted: before the failure inception time and the failure time, in order to be possible to evacuate a large number of inhabitants. This condition implies:

- advanced monitoring systems will real time capability to predict with more accuracy a dam failure scenario and the dam breach characteristics;
- good coordination between dam owners, dam safety authorities and civil protection authorities in order to be sure that emergency and evacuation planning's are effective;
- good public information in order to guarantee a good response to flood crisis.

The formal risk concept can be different perceived by the specialists and laymen. A new index was developed based on valley vulnerability, as it is presented in this work.

The results of the multidisciplinary research project funded, by NATO Science for Stability Program, developed in Portugal and concerning the integrated dam-valley risk management is 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 research about dam risk perception was made in Portugal.

The author is very grateful to all members of NATO project, and sponsor institutions, as well as to Prof. Erich Plate, by the support given to FLOODRISK Project.

References

ALMEIDA, A. B. & FRANCO, A. B. 1994. Modelling of Dam-Break Flow. In M. H. Chaudhry and L. W. Mays (ed.), Dordrecht: Computer Modelling of Free-Surface an Pressurised Flows, Kluwer Academia Publishers: 343-373.

ALMEIDA, A. B. & VISEU, T. 1997. Dams and Safety Management at Downstream Valleys, (eds), Rotterdam: Balkema.

ALMEIDA, A. B. *et al.* 1997. Dam-Break Flood Risk an Safety Management at Downstream Valleys: a Portuguese Integrated Research Project. Proceedings 19th ICOLD Congress, Florence, Italy, Vol IV, (Q. 75-R. 25): 331-347.

ALMEIDA, A. B. *et al.* 2000. Dam-Valley Risk Management. First Results of a Case Study in Portugal. Arade Valley. Proceedings 20th ICOLD Congress (to be published), Beijing, China.

LIMA, M. L. *et al.* 1997. From Risk Analysis to Risk Perception: Developing a Risk Communication Strategy for a Dam-Break Flood Risk. In C. Guedes Soares (ed.), Advances in safety and Reliability, Vol. 1, Oxford: Pergamon: 53-60.

PENNING-ROWSELL, E. & FORDHAM, M. 1994. Floods Across Europe. Flood Hazard Assessment, Modelling and Management. London: Middlesex University Press.

SMITH, K. & WARD, R. 1998. Floods. Physical Processes and Human Impacts. Chichester: John Wiley & Sons.

SUETSUGI, T. 1998. Control of Floodwater and Improvement of Evacuation System for Floodplain Management. In S. Fukuoka (ed.), Floodplain Risk Management. Rotterdam: Balkema: 191-207.

TAW 1990. Probabilistic Design of Flood Defences. Technical Advisory Committee on Water Defences. Centre for Civil Engineering Research and Codes (CUR), Rel 141. Gouda, Netherlands.

VISEU, T. & MARTINS, R. 1998. Safety Risks of Small Dams. In L. Berga (ed.), Dam Safety, Vol. 1. Rotterdam: Balkema: 283-288.