VALUTAZIONE DEL RISCHIO IDRAULICO A VALLE DELLE DIGHE

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RISK MANAGEMENT IN VALLEYS WITH DAMS, CONCEPTS AND PRACTICE (IN PORTUGAL)

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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.*

New concepts and procedures are now being developed in order to increase the safety level along the valleys against abnormal floods caused by dam accidents.

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)" were involved in a NATO Project (Science for Stability Program) from 1994 to 2000.

This paper presents some concepts about dam and valley risk management and describes the main developments achieved recently in Portugal.

Keywords*: Dam, risk, safety, valley, management.*

1 Introduction

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, Almeida et al., 2000 and Almeida and Viseu, 1997).

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 integrated safety and risk concept is based on a set of basic operational principles:

- Dam and reservoir and downstream valley are considered as a system for safety and risk management.

- Zero-risk is not possible and a shared risk strategy, including the acceptance and the responsibility of its management need to be developed between dam owners, safety authorities and public.

- Structural and non-structural measures need to be considered in order to control the expected risk along the dam lifetime.

These new concepts pose the question of the public risk perception and communication. To accept a certain risk level and to manage the valley life and safety according to that reality is a real challenge. Another challenge and a matter of controversy are the risk control techniques based on structural and non-structural measures. The former measures are well accepted by the dam engineers and the safety authorities (dam reinforcement and instrumentation among others). However, the reliability of mitigation measures based on human organisations is not so well understood or accepted.

In Portugal there are 150 large dams (ICOLD criteria) and more than 1500 medium and small dams. Dams incidents and failure of very small dams are registered in Portugal but no large dam failure occurred so far. Dam safety has a very high priority and a very qualified technical assistance (LNEC).

In what concerns the valley safety management in Portugal, there are two different situations: before 90's risk and disaster were not officially assumed. Risk analysis was not well accepted and the inundation map was reserved or even secret. There were no valley emergency plans; in the last decade a new paradigm began based on the public participation and the media power. New concepts and new values (responsibility-liability) force a new model and the dam safety regulation and the concept of the integrated dam and valley risk management began to be implemented in Portugal. For this new situation, the NATO project "Dam Break Flood Risk Management in Portugal" (1994-2000).

2 Safety of valleys with dams

2.1.1 Integrated safety and risk concepts

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 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 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 needs to include the human feelings and values in order to understand 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.

2.1.2 Conceptual risk framework

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.

For each potential event or hazard E_i acting on the dam system, the formal mathematical risk, R_i, can be considered split 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, $P(Q_P \mid E_i)$ = conditional probability of occurrence of an abnormal flood with maximum peak discharge Q_P induced by the dam response to hazard E_i and $P(N \mid Q_P)$ = 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 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.

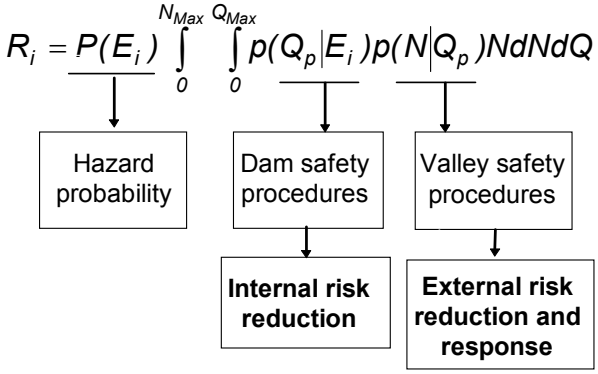

Figure 1 - Formal mathematical dam risk concept due to an hazard *Ei*.

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 assessment process we need to consider the hazard determination and the risk analysis. Both tasks are at the core of the process. They should identify the dangerous events and damages that can occur and to assign a probability for each event and consequence.

The risk assessment implies some form of action in of uncertainty and provides a basis for making decisions concerning the need for risk control measures. These actions will be based in a certain level of acceptance of potential catastrophic events. These arise an ethical component to the process. In the risk mitigation process two main set of actions can also 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.

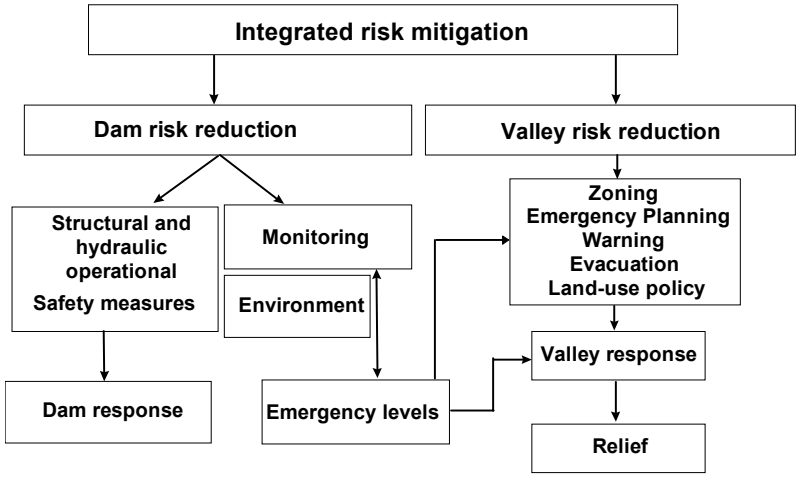

Fig.2. Integrated dam-valley risk mitigation.

In the risk mitigation process two main set of actions can be considered (Fig. 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 Fig. 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.

For 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).

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 need to be implemented.

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 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.

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 (Fig. 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.

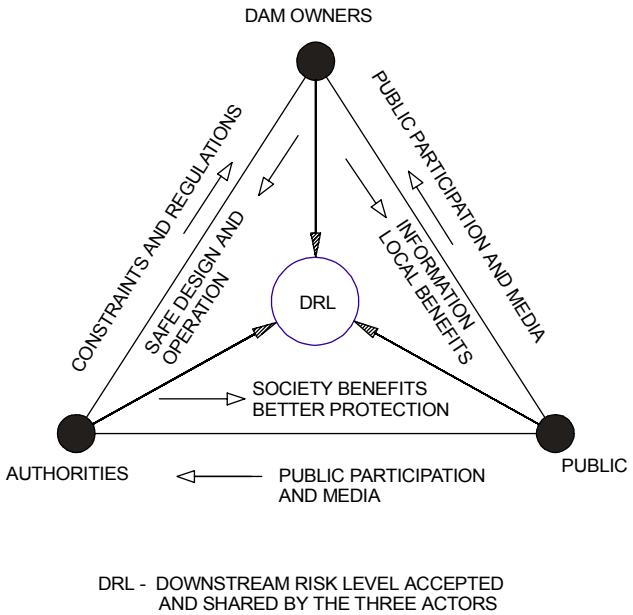

Fig.3. Dam risk sharing between dam owners, public and authorities.

3 The Portuguese experience

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 “Dam Break Flood Risk Management in Portugal” 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. 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 were 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 earth fill 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. The valley risk management in Portugal received a strong impulse from NATO project and special civil protection measures are being implemented (emergency planning).

4 NATO 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 presented. 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 life's 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 9 000 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 analysis covered the following aspects:

- 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.

According to a quantitative flood risk analysis, the compound overtopping risk probability (Arade dam) is around 10^{-7} that can be considered as “virtual impossible” following a verbal descriptor.

Residents 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. These 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 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 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 “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, a hazard impact as a dam-break flood. 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 operational efficiency, a methodology for quantitative description of the valley vulnerability should 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.

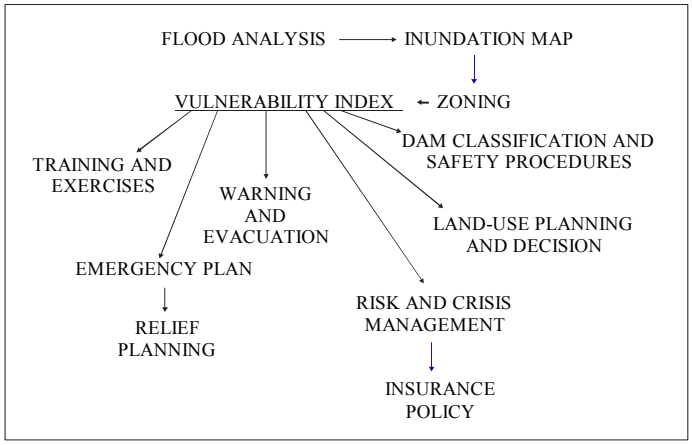

Figure 4 - Vulnerability index as a reference for valley risk management actions.

4.3.3 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).

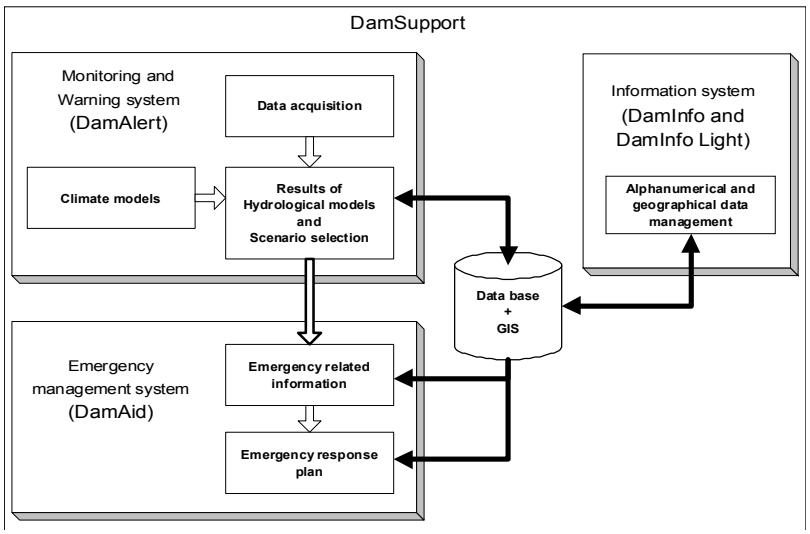

Figure 5 - Dam Support System (NATO project).

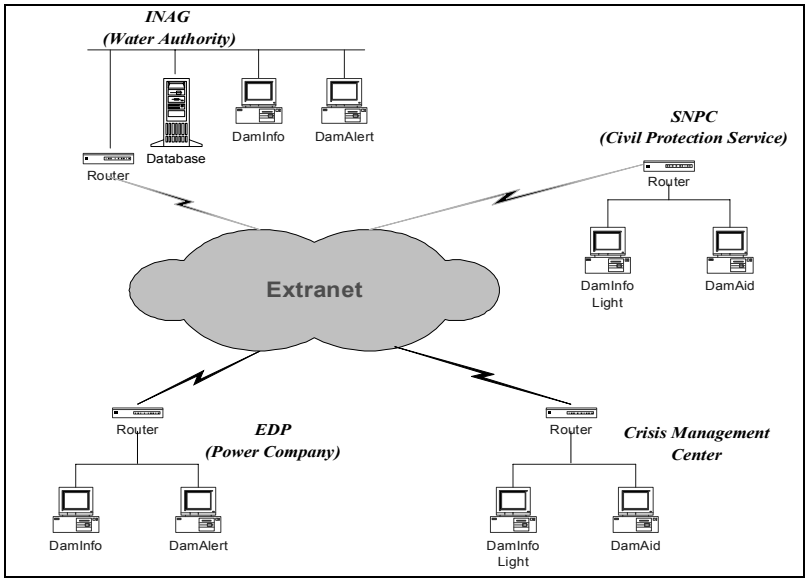

Figure 6 - DSS interconnection between end-users.

4.5 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.

Without any emergency plans and no warning system an expected 4300 LOL can be obtained (0.48 PAR) for the Arade valley. The civil protection measures can reduce the expected LOL for around 650. Emergency and risk 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). This case study was a like a prototype for the implementation of a valley risk management.

According to the conceptual risk framework already presented, two types of plans were 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.

As a prototype for Portugal, an emergency plan, including evacuation procedures and a warning system were 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 centre. The results of the project are now being implemented in the new Alqueva dam, one of the largest reservoirs of Europe.

5 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 9 000 inhabitants as population at risk, 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 according to different factors including the arrival time of the flood and to the dichotomy between rural and urban areas (Figure 7 and table 1).

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.

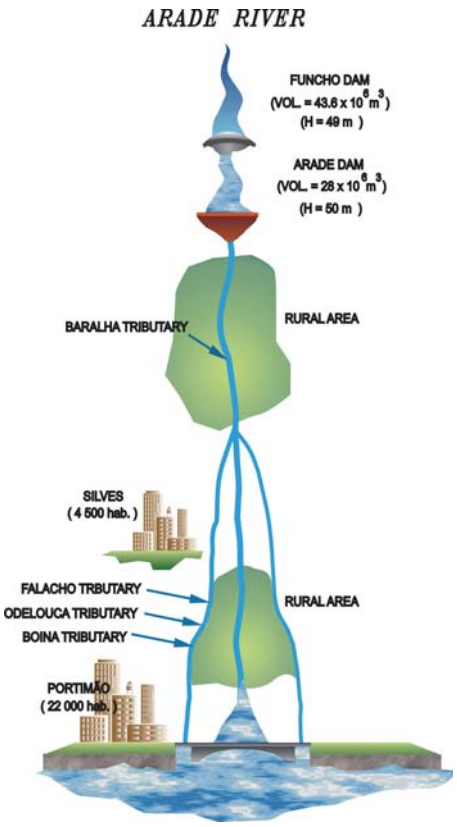

Figure 7 - Schematic definition of the river Arade valley.

Table 1 - Description of the population and buildings at risk by inundation sub-area

	Inundation area		Population at risk			Buildings at risk	
	WT (min)	LO	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	3694	40	16	58	89
Area 4	25-60	Rural	3212	19	15	50	89
Area 5	60	Urban	905	114	15	21	79

PAR - Population at risk
O - Old (>64)
Y - Young (<19)
LO - Land occupation
Low - % of buildings with one or two floors
CSS - % of buildings with concrete support structure

%O	%Y
24.0	13.2
20.6	8.4
11.5	19.37
6.42	4.7
22.3	11.4

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 analysed 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.

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.

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.

Here we presented a short summary of this social perception research (NATO PO-FLOODRISK Final Report-Draft edition – 2002).

• Perceived dams benefits

- The two dams are generally seen as highly beneficial facilities (Arade dam is subject to higher approval). The agriculture and the formers are considered as the main beneficiaries. Flood control and flood risk abetment are also perceived as benefits.
- The social component of the paradigms of the research work. Due to the potential importance for future developments in risk management a resume of the research results are have presented.
- The benefits perception is more salient in the area closer to the dams.

• Perceived dams break risk

- The break of the dams is perceived as a low probability event: forest fires, earthquakes, "natural floods", house fires and bridges accidents are considered as more probable events in the region.
- The analysis indicates that residents in areas nearer to the dams make lower risk estimates (a cognitive strategy for adaptation to threats).

- Individuals living between Arade dam and the city of Silves, revealed some awareness of the potential area where the effects of any dam breaking (Arade and/or Funcho dams break) would be more devastating.
- 27% of the interviewees living immediately downstream from dams believed that their home/shop would not be damaged.
- Dam break risk is generally perceived as something dread and catastrophic. For some individuals it is something that can be controlled by the authorities while for others is uncontrollable. More than a half of subjects perceive dam break risk like this last case.
- Approximately 20% of the individuals living in the localities nearest to the dams state that the possibility of the Arade and/or Funcho dams bursting does not frighten them, despite the fact that they admit that such a disaster would be a catastrophe – a consequence of a mixture of disbelief in the possibility of a real dam break accident, combined with a positive perception of a kind of individual invulnerability towards this kind of risk. The disbelief appears to be fuelled by denial and risk minimisation.

• Perceived dams safety

- What prevails in the nearest areas to the dams is the perception of those facilities as safe structures, particularly Arade dam (on earth fill dam). Many of the interviewed stated to feel this dam as safer then Funcho dam.
- The lack of any perception increases along the valley, from the dams to the sea.
- The factors behind the different safety perception related to Funcho dam (a concrete arch dam) and Arade dam (an earth fill dam) are the following ones:

<u>Dam's age</u>

- Arade dam was built 55 years age and there is confidence in safety and good performance of the dam. Funcho dam is a relatively new dam (five years old and has not proved its safety).

<u>Type of dam</u>

- Earth seems to be a more safe more material and the "thickness of the (concrete arch) dam" seems to inspire less confidence.

<u>Belief in regular inspection and confidence in experts</u>

- The safety perception is also sustained by the belief that both dams are subject to regular maintenance and inspections routines. Confidence in local operators and engineers is also a reason for a good safety perception.

• Practical implications

- Some demographic traits can be seen as vulnerabilities of the population towards flood risk and effects. Rural and urban areas, individual or dispersed population, different education levels and age are factors that need to be considered in a future warning system and evacuation plan.
- In was found a sort of local wisdom about dam safety immediately downstream Funcho and Arade dams. Despite this tendency, there is a series of biased beliefs that permit a more relaxed daily interaction with the environmental stressor: the dams. However, not believing that a certain risk effectively reveal itself in the form of disaster can discourage any plans of prevention and jeopardise part of the valley preparedness efforts.
- This local wisdom should not be considered as “irrational” by the safety experts. Local knowledge can be an important tool of adjustment for the type of language in communicating risk and safety topics.
- Two-way risk communication is the type of strategy considered to be the most appropriate in this case study. The physical meeting of experts and laymen has several advantages: Lay individuals can express their opinions, perceptions, worries as well as their suggestions.
- However, one-way methodologies should not be completely removed. The two types of communication strategies are complementary and they should be combined. It is very important to avoid any undesirable resonance in individuals provoked by one way risk communication.
- Risk denial attitudes or risk ignorance may cause a lack of safety motivation and resistance to public involvement or even a resistance to public response. To ignore warning messages can also be a consequence of these attitudes.
- The length of time that populations are exposed to the flood.
- The problem of the belief in risk is not an exclusively lay problem. Experts and organisations also have internal problems in this domain. The attitudes towards risk influences safety decisions and measures and can avoid or induce an accident. There are many examples in engineering domains where serious accidents and catastrophes occurred due to a lack of good risk perception and communication. The organisational and operational aspects of risk management and emergency planning need to take in consideration these psychological and cultural factors.

This work was also a contribution for the integrated risk management, especially in what concerns the strategy for the public acceptance of a certain level of risk related to dams.

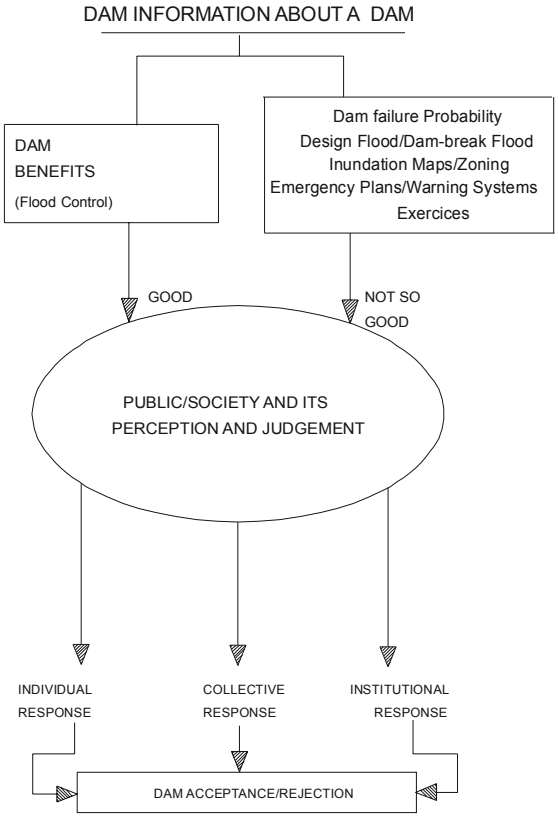

Fig.8. Information flux about a dam is a strong factor for public and society response and dam acceptance.

The knowledge of human occupation patterns and of public risk perception along the valleys is a fundamental tool to support risk communication strategies for dam acceptance (Fig. 8) in general and warning and evacuation procedures as well pos-disaster actions.

6 Valley emergency planning

Emergency management aims at protecting life, minimizing 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 is adequate tools to guide the civil protection authorities to take an effective response.

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 and valley risk management program, in which valley vulnerability mitigation and emergency management practices are stressed and developed.

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.

7 Risk mitigation and control

The expected risk level can be obtained by dam and valley risk assessment including risk analysis techniques. Each risk level will be associated to the expected valley damages due to a potential dam accident or failure. Among these damages, the expected life losses are the most important in what concerns the risk acceptance by the public or by the society.

Most of the societal risk acceptance criteria (Almeida and Viseu, 1997) are based on the number of fatalities (N) due to a dam failure. For each N, a limit risk is proposed and the maximum accepted probability of failure per dam per year with expected loss of life greater or equal to can be found, as well as the acceptance range based on the ALARP principle (as low as reasonably practicable). What is the scientific support of these societal risk criteria is an important question.

Should the expected risk calculated for a specific valley be greater than the acceptable societal risk criteria, and special control measures need to be considered. The type of measures will depend on the dam and valley characteristics and on a cost-benefit analysis.

As an example, in the Arade valley case study (NATO project), the expected loss of life's (202) without any warning system could reach 4300 fatalities. Based on empirical criteria for the prediction of the expected 202 with warning (Graham, 1999) the number of fatalities can decrease from 4305 to 650. This reduction will make the acceptable societal risk compatible with the estimated overtopping probability of Arade dam (10^{-7}). Another measure can include valley land-use management and special emergency and evacuation plans. Are these measures acceptable in what concerns the risk control or it will be more acceptable to introduce structural measures in the dam (e.g. to increase the dam freeboard)?

In the future, as integrated risk management should guarantee a certain level of accepted risk value: should the expected losses increase in the future and new mitigation measures would be enforced in order to reduce them and maintain the risk level.

8 Ethics and risk communication

Public participation and information implies a reasoning on ethics related to risk communication and effects. Some dam exports and safety officials have the opinion that risk information may frighten

so much the population that can induce a problem greater than the one we want to solve or mitigate. However, there are other opinions about this subject: the valley risk mitigation can not be possible without the public participation and information and the participation of local authorities.

Risk communication is a complex process and risk acceptance arise ethical and liability problems. Scepticism among experts and authorities can favour a democratic principle of decision with the participation of members of the public as voter is a process of risk acceptance. On the other hard, others experts ask why should we do what the majority prefer in the domain of safety or risk? The democratic choice can be against long-term decisions involving the sustainability principle.

We need to separate the public participation in the risk decision process and the public information and acceptance of the valley risk level.

Viewing engineering as an experiment on a societal scale the principle of informed consent focuses on the human beings potentially affected by technology. According to Manheim[1], "all individual or group that can potentially be affected by future modification (due to technology) should have access to the pertinent information". This principle is against the traditional concept that engineering activity is by principle good for the society and the public and the participation of laymen is negative.

The concept of a downstream risk level accepted and shared by the three actors in dam safety and acceptance decision process includes the principle of informed consent as a general basis. However, when the participation and the discussion leaves the field of experts and dam safety authorities, strong emotions can disturb the process as fear and panic.

Public risk perception can be largely a matter of risk comparison and decision-makers are encouraged to see risk acceptance as a problem of risk communication. However, these comparisons and negotiation techniques can easily violate ethical principles.

Another difficult issue is the selection by the public of measures among those proposed in the framework of a valley risk management, in order to reduce the valley risk related to a potential dam accident. Experience says that the choice of structural measures (e.g. the choice of a design flood with a greater period of return and the reinforcement of the dam spillway) are generally preferred to those that are non-structural (e.g. an improved warning system and risk zoning or a new evacuation plan). This behaviour is the basis for a serious position against public information based on quantitative risk assessment and land zoning: public will reject any acceptable and reasonable risk level and will impose solutions inspired by fear that are not feasible. That would jeopardize all the risk decision process. This point can be avoided by making use of a sense of practicality.

The risk communication involving public representatives is useful and possible if the risk levels are low enough in order that a trustworthiness sense as well as a relaxed climate of discussion can be easily attained.

[1] In RACINE et al., 1991 – Éthique et Ingénierie McGraw Hill (p. 219).

The results of the quantitative risk analysis should be discussed between dam experts and dam safety officials, as well as the dam owner, and the decisions related to cases with an estimated high level risk should be solved with less or none public participation.

The public risk communication should be based on actions to reduce the potential losses or damages without any dam safety suspicion (e.g. as it is the safety belt paradigm).

9 Conclusions

The results and recommendations 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 research about dam risk perception was made in Portugal.

Dam safety legislation in several countries is 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.

A dam safety program was implemented at the end of the last decade involving 40 large dams and500 small dams. Several emergency plans are being prepared. These special cases are considered as prototype cases: Arade and Funcho dams, Sabugal dam (as urban zone near the dam) and Alqueva dam (a large reservoir with a large number of dams upstream and a long valley downstream).

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