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# DAM-BREAK FLOOD RISK MANAGEMENT IN PORTUGAL

## A RESEARCH PROJECT

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## 1 - INTRODUCTION

The overall objectives of the NATO FLOODRISK Project is to develop and support technical and policy guidelines as well as instruments for safety management activities and to solve problems related to potencial abnormal floods induced by dam failures.

ln Portugal there are now almost 100 large dams and 800 medium and small dams. A large percentage of them were built some decades ago. These dams have been well designed and constructed but now they may not meet the present design of standards and new environmental and hydrologic conditions.

According to the Portuguese dam safety legislation (1990) al major dams must have a dam break analysis: owners and governmental agencies have to define flooding maps, risk zoning and emergency plans.

Also there is an increasing number of small and medium dams that are or have been built with limited funds and that can not afford detailed studies.

## PROJECT STRUCTURE

The Project is divided into five subprojects:

**1** - Hydraulic analysis and computational simulation.
**2 -** Dam and reservoir safety analysis.
**3 -** Land-use, safety management and civil protection.
**4 -** Computer aided decision support system.
**5 -** Experimental integrated emergency system and training.

The Project methodology will include one case study based on a selected site for general field studies. The final testing of the developed methodologies will include exercises with dam failure scenarios at Arade valley in South of Portugal.

## PROBLEMS TO BE SOLVED

The project intends to contribute to solve problems in the context of both a future Portuguese integrated safety system against dambreak floods and the Portuguese dam safety legislation. The main problems to be solved are:

**1** - Hydraulic and hydrologic-related problems
**2 -** Land-use management
**3 -** Social perception and public information
**4 -** Risk analysis, safety and crisis management and practice
**5 -** Use of advanced information systems

## EXPECTED IMPACT OF THE PROJECT

The project results will contribute to the improvement of the Portuguese safety legislation and to an integrated dam-break flood risk and safety management in Portugal, as well as to create innovative prototypes and an advanced aid system to emergency actions.

**The direct outputs of the project are:**

**1)** advanced information and computational technologies for support decision making on flood simulation and prediction (numerical code, dam-database)

**2)** guidelines for operational safety management (level of local communities and local and regional authorities)

**3)** national recommendations and guidelines for dam designers and safety officials

**4)** studies on public perception on risk areas

**5)** studies on land-use management on risk areas

**6)** center of crises for operational safety management under emergency actions

The following **INSTITUTIONS AND FUTURE USERS** will participate in the Project:

- 'Laboratório Nacional de Engenharia Civil" (**LNEC**), the National Laboratory of Civil Engineering and "Instituto Superior Técnico" (**IST**), a part of the Lisbon Technical University (**UTL**) " directly involved in the research activities on the Project.

- 'lnstituto da Água **(INAG),** the Portuguese governamental agency for water resources management and dam licensing; it is also the owner of a great number of dams, specially for water supply and irrigation.

- "Electricidade de Portugal" (**EDP**), the main Portuguese utility for power production. EDP operates the larger **hydropower** infrastructures in lhe country.

- "Serviço Nacional de Protecção Civil" (**SNPC**), the Portuguese authority for coordination of civil protecion services; it is responsible for the establishement and activation of warning, evacuafion, medical care and vital protection procederes in case of large accidents.

The Project is also being carded out in close cooperation with regional and local authorithies. This paper contains a short presentation of the topics under development in sub projects 1, 2 and 3. Futher material can be found in the book " Dams and Safety Management at Downstream

Valleys” edited by A. Betâmio de Almeida and Teresa Viseu, Balkema (1997).

## 2 - DAMS, VALLEYS AND SAFETY CONCEPTS

### *2.1. Systems and safety*

Each dam, with its reservoir and own foundation area, can be considered as a system, the **dam-reservoir system** (DRS). An abnormal and dangerous response of this system, in what concerns the downstream safety, can be provoked by different causes or disturbances:

- extreme inflows due to rare hydrologic events;
- geotechnical disturbances;
- structural failure;
- operation error;
- war or sabotage;

and can induce potentially severe or catastrophic accidents. In fact, any abnormal outflow from DRS will perturbate the downstream system or **downstream-valley system** (DVS), including the river, the land and the people with its social organisation and infrastructures. In Figure 1 these two systems are schematically represented.

Generalised damages or losses will be a DVS response to abnormal DRS outflows (floods). Life, economic, cultural and environmental losses are, among others, the result of the global system behaviour to an hazardous DRS response to inflows or other perturbations.

In what concerns the global dam safety two main objectives can be referred:

– to minimise the possibility of a dam hazard and failure due to an operational error or malfunction;

– to minimise human (life) losses.

How to reach this goal within the framework of safety regulations and management is a question to be analysed.

An integrated **dam and downstream valley system** (DDVS) should be considered for safety and risk management (Figure 2). Each sub-system (dam and downstream valley systems) will have its own safety procedures and methodologies or criteria. However, each one will depend on the other:

- DRS design criteria will depend on potential downstream damages and on its own structural and operational reliability;
- DVS protection will depend on upstream response to inflows and to other perturbations as well as on its own strategies and non-structural defences;
- Warning and other operational information systems will guarantee a safety link between the two systems.

Figure 1. DRS and DVS systems. The former system is a potential threat to the people living in the second system.

Dam owners, safety and community authorities will have a shared responsibility during dam lifetime, related to the global safety level accorded with authorities and with public acceptance (Figure 3).

### 2.2. *Safety standards and procedures*

Structural and hydraulic design requirements included in dam safety standards try to reflect the state-of-the-art in these specific domains in order to guarantee a reasonable level of safety. Together with instrumentation for surveillance monitoring and construction quality control, they are an irreplaceable tool for dam design and safety guarantee.

In what concerns the downstream valley, present codes for large dams include a risk assessment and requirements related to:

- risk classification according to potential downstream damages due to a dam failure;
- flood (including dam-break floods) studies including inundation maps and damage evaluation;
- valley zoning according to flooding danger characteristics;
- emergency plans;
- warning and alert systems;
- training and simulation exercises.

Figure 2. Dam safety: An integrated safety management of both systems can be considered during design phase and dam exploitation lifetime as a continuous and dynamic process.

These kind of procedures are based on a pseudo-static reference situation of the DVS. Dam owners and dam safety authorities are the main actors in this “safety contract”. In some countries the inundation maps and the valley zoning are even not free to public knowledge. Land managers are also not motivated for taking in consideration flood risks, due to natural events or due to dam accidents or incidents, in their planning and day-to-day decisions.

Figure 3. The integrated dam and valley safety can induce an accepted risk shared by dam owners, authorities and public.

During dam lifetime urban areas within the valley can grow without control and, on the other hand, the river hydrologic characteristics (DRS inflow floods) can severely change with time due to different causes. The effective safety and protection level can then become very different from the apparent safety given by the strict enforcement of existing standards and regulations.

### *2.3. Environmental risk and liabilities*

New dams to be built have to overpass the public enquiry process and an environmental impact evaluation where safety problems will be discussed. What will be the public and local authorities reactions to the inundation maps and zoning and their risk acceptance for the future can be difficult to foresee. Nowadays, and in the future, the power of the media in open democratic societies are changing the decision methodologies and the public perception of technological progress.

The knowledge and acceptance (or not acceptance) of a dam risk assessment by local authorities and inhabitants of the downstream valley and what will be the risk and land management during dam lifetime, are very important topics for liability assessment and future shared responsibilities.

Land zoning will cause eventual damages in what concerns land devaluation and potential economic losses due to use restrictions. Public need to feel the necessity of such procedures and trust on the risk assessment.

## 3 - DAM-BREAK FLOODS AND INUNDATION MAPS

### *3.1. - General Considerations*

Dam-break inundation studies need to be made for the purpose of determining the impact of a Dam-Break Flood (DBF) on downstream area and for Emergency Action Plans (EAP). Inundation maps are obtained, for different dam failure scenarios, by numerical simulations based on computational models: physical models are now too expensive. Severe DBF are different from the ordinary natural floods by the following main reasons:

- very high peak discharge and water depth values;
- eventual occurrence of movable bores (or shocks);
- fast and violent flooding of the banks with strong two-dimensional effects in flood plains, including oblique shock waves and a very irregular water surface;
- flooding of previously dry land with abnormal dissipative effects;
- transport of sediments and debris;
- very difficult validation and calibration of the models for each case.

Large flood or “sunny-day” initial conditions as well as the dam mode of failure (breach characteristics) including the “domino” failure effect on downstream dams need to be specified.

In the last ten to fifteen years, the hydraulic specialists developed sophisticated DBF models, based on one and two-dimensional hydrodynamic models, and on advanced numerical techniques (ALMEIDA and FRANCO, 1994).

The flood studies include a map depicting the predicted extent of flooding downstream of a dam, with among other information, maximum depths and flow velocities, time of first wave arrival and time of highest depth, maximum rate of rise of the water level and duration of flooding over a specified level.

Simplified or hydrodynamic models will give different results in what concerns the inundated area and extreme hydraulic characteristics.

Different map scales, computational discretization levels associated with calibration errors will certainly cause uncertainties, despite the sensitivity analysis that can be made. This uncertainty is one of the aspects to be considered should a valley risk management be implemented.

Natural valleys are, as a rule, very irregular and present a series of contractions, abrupt widenings confluences and flood plains. Strictly speaking, the flow induced by a dam-break is three-dimensional, with an extreme rapid variation of the flow variables in the three directions. However, a three-dimensional (3-D) simulation is still difficult and CPU requirements become huge for real engineering cases. Until a few years ago, for engineering purposes, it was used, as a rule, the one dimensional (1-D) approach. Recently, the two-dimensional (2-D) modelling has been the subject of several research works and the reference of real cases 2-D simulations can be found in technical literature.

In a long and narrow, with a approximately constant section, valley a 1-D simulation can be a correct option, but, on contrary, if the valley is wide or with bends, confluences or abrupt variations of the cross section, a 2-D simulation is needed, and the 1-D simulation gives results far from reality.

### *3.2 - Brief description of the developed computational models*

In this section, the one-dimensional dam-break model - ROTBARR - and the two-dimensional model - BIPLAN - are briefly described. Both models were developed at the "Instituto Superior Técnico" by Franco and Almeida (FRANCO, 1988; FRANCO and ALMEIDA, 1990 and FRANCO, 1996).

#### - ROTBARR MODEL -

The dam-break flood wave propagation model - ROTBARR - was developed for a general cascade dam rupture analysis in which dams are treated as internal boundary conditions or as special computational elements. The river geometry (cross sections defined by points), the roughness and the configuration of the dams and their mode of rupture (duration and geometry of the breach evolution) are data requirements for the model. The initial discharge in the river is also needed.

ROTBARR model is based on the Saint-Venant equations written in the conservation form. The equations are solved by the MacCormack TVD scheme (high resolution total variation diminishing scheme). The traditional MacCormack scheme were adapted with a additional step, according to the theory of total variation diminishing (TVD) following the methodology proposed by GARCIA-NAVARRO, ALCRUDO and SAVIRON (1992).

The initial conditions are obtained by routing the steady state flow for the imposed initial discharge in the river and in the reservoirs.

In the boundary conditions (e.g. dams) this method was used together with the method of the characteristics.

The rupture of each dam is characterised by the linear evolution of the breach whose area can increase more or less rapidly according to the type of dam.

The following set of equations is solved in each time step:

–one upstream characteristics equation $C^+$;

–one downstream characteristics equation $C^-$;

–the continuity equation;

–the equivalent discharge equation (corresponding to the breach, the spillway, the turbines, and outlets).

The discharge through each breach is corrected by a factor attributed to Brater (FREAD 1979) when submerged tailwater effects occur.

The system to be solved is a non-linear one with four equations and four unknowns which is solved by the Newton-Raphson technique. The upstream boundary condition is an hydrograph and the downstream condition is a steady or a dynamic rating curve.

The outputs of the model can be in form of hydrographs at any section of the river including the variation of the discharge, water depth and velocities along the time, and the respectives maximum values along the river. It is also possible to obtain the inundation areas at the downstream valley.

## - BIPLAN MODEL -

The 2-D model - BIPLAN - was developed for the simulation of dam-break flood waves in irregular topography valleys where the 1-D approach loose validity, such as: flood plains and strong variation of the cross section or alignment.

The model is based on the full 2-D shallow water equations - the two-dimensional Saint-Venant equations - solve by the MacCormack TVD method. The adaptation of the MacCormack scheme to convert this scheme in a high resolution scheme following the TVD theory, was based on the methodology proposed by ALCRUDO (1992) and is well documented in FRANCO (1996). The model used a Cartesian computational grid (fully dense grid) and the time interval is variable and is calculated in each time step with a maximum Courant number equal 0,9. The accuracy of this new model was tested by using a special experimental facility at the Portuguese Civil Engineering National Laboratory (LNEC).

The topography (ground level at each node) is obtained with an ARCINFO GIS system. The outputs can also be presented at ARCINFO or on a CAD support. The initial conditions are obtained for a steady state flow, with a pre-specified discharge, calculated in a previous running of the model, with a constant hydrograph at the upstream section of the simulated region.

The model have two external boundary conditions at the upstream and downstream sections of river on the simulated area. At the upstream boundary an hydrograph (obtained with the 1-D model) is imposed and at the downstream section a radiation condition are used.

To recognise the topography and the possible ways for the flow, temporary (in each time step) internal boundary conditions are generated in function of the water levels and ground levels in the neighbour computational nodes.

### *Case-study results and discussions*

The 1-D model-ROTBARR and the 2-D model BIPLAN were applied to a case study - the Arade Dam in Arade River (Algarve - South of Portugal). The Arade Dam is a earthfill dam with a central clay core, 50 m in height, with a crest length of 246 m and with a reservoir gross capacity about 28 hm$^3$. The maximum discharge capacity is 500 m$^3$/s. In two kilometres, downstream from the Arade dam, the river present a canyon type section. Downstream of this reach, the river flows through a flood plain in which make two important bends and a receive a tributary. Downstream of the flood plains the valley narrow again. This section is the downstream end of the 2-D simulation. Figure 4 illustrate the study domain.

A 1-D model simulation (ROTBARR model) of the propagation of the flood wave provoked by the dam-break was performed. The flood hydrograph obtained at a section downstream of the dam (Figure 2) was used as input for BIPLAN model at upstream section of the 2-D domain. The time of dam breach evolution was 15 minutes and the breach was considered as rectangular (40 m wide). For both models the Manning-Strickler coefficient is $K_s = 30\ m^{1/3}/s$. The total time of simulation was 5 000 s.

In Figure 4 are represented the hydrographs obtained by 1-D and 2-D models at section 13 (5.9 km from the ruptured Arade dam). A comparison between these two hydrographs clearly shows a maximum difference in water depth of about 4 m. The maximum water depth obtain by the 1-D model is 78% greater then the maximum water depth obtained by the 2-D model at the some section (at the talwegue). This difference is very important and shows that the maximum depth can be very sensitive to model type, a factor to be considered in preparing zoning maps and in the selection of the computational accuracy needed for satisfaction of dam safety regulation.

In Figure 4 is represented a 3-D graphical output of a simulation instant (t = 3 000 s) of the water and topography.

In Figure 5 is represented the flow velocity field for the time 1 500 sec. and the strong re-circulation and 2-D character of the flow at some places of the domain can be clearly seen.

## 4 - THE INTEGRATED APPROACH

The new integrated approach for dam risk assessment and management means not only an enlarged physical domain of analysis and operation, including both DRS and DVS, but also a combination of advanced engineering techniques and consideration of public feelings or social values related to dam safety and flood risk. Both aspects seem to be essential for efficacy improvement of valley safety procedures and of risk decision-making processes.

With the social dimension associated to the safety procedures it will be possible to create communication links between the quantitative (or objective thematic) approaches, developed by engineers, and the intangible values, perceptions and feelings (or subjective thematic) approaches of laymen and public in general that will judge potential dam benefits and threats.

In fact, this integrated methodology is being proposed for different environmental risks analysis and decision-making models (Cothern, 1996).

Figure 4. Dam-break study location and vicinity. Cross section used in ROTBARR model and 2-D domain used in BIPLAN

Figure 5. Flood hydrograph (Q = Q(t)) obtained by the 1-D model at the downstream section of the dam. This hydrograph was used as input by the 2-D model

Figure 6. Hydrograph (d = d(t); d = water depth) at section 13 (5.9 km downstream the dam) obtained with the 1-D and 2-D models

Figure 7. 3-D graphical output of the water level and topography (t = 3 000 s)

Figure 8. Flow velocity field (t = 1 500 s)

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, the free media and society are now part of the decision process on what concerns a large dam impact. 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 risky decisions be from its own responsibility and for its own benefit. So, the benefits of the project and the threat real dimensions of it 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.

Engineers are very pragmatic and it is not easy to develop an integrated operational methodology, including the quantitative physical or **objective** approach and the **subjective** domain of human feelings and values, with guaranteed pre-fixed results, the new approach must conciliate the individuals and the group of people under potential threat as a whole. Social psychology and sociology are two social sciences that will be introduced in the interdisciplinary set of specialists involved in dam safety and valley risk assessment and management. They will try, among other methods, the quantification of the social characteristics or profile of the people under potential threat along the valley.

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 control of the nature need now to be considered a challenge that must have the support of the public, which means that the knowledge and acceptance of the not ultimate benefits of a dam is not only a specialised technical problem but also an open issue for very different actors, including laymen.

Among other characteristics, the following difference between the two approaches can be easily identified:

> –engineering and physical sciences have methods that can be universally applied (with the same initial conditions the some results can be expected);
>
> –social sciences are strongly dependent on local, or regional, cultural characteristics, including abnormal human behaviours (each valley will be a new case within a new social or cultural context).

This can lead to a severe methodological shift between the two types of approaches: the subjective one introducing potential uncertainties into the process and unpredictable results in the decision-making planning. This is a true practical problem but in the present (and much more in the future) society, based on free information and participation, this uncertainty will be much more dramatic and harmful should the subjective human behaviour and feelings and other social values be out of the decision and management processes of environmental and safety issues.

Safety and risk management will be possible if people believes or trust the engineers and scientists that generate the dam risk assessment.

The systematic practice of new integrated methodologies can give the confidence and the basis for a comprehensive and successful framework with new guidelines. Meanwhile the following general principles should be taken in consideration:

> –Quantitative or objective risk assessments are not easily understood or felt by laymen. Perceptions are the result of complex subjective and objective factors including emotional feeling and values. So,

public perception of rare events can be very different from what scientists or specialists feel.

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

–Public participation within a framework of respect of both objective information and subjective beliefs can be a critical more towards an accepted shared risk and an efficient non-structural valley risk management against floods and dam incidents or accidents.

–Ethical principles can not be neglected in this process. These principles will apply to both short and long time decisions and consequences as, respectively, the following two examples: the new approach for dam risk decision should not be transformed in just a trick for more easily to impose a decision to the public; the uncertainty about values and choices of future generations should not be completely neglected nor be a source of block to our decisions (Catron *et al.*, 1996).

–A moral dimension should also be considered in the accepted shared risk: a freely accepted risk by the people living along the valley may be not enough to make that process morally acceptable.

For large floods (DRS outflow response) and potential rare events, including dam accidents, a set of emergency procedures need to be prepared as it is now required by the safety regulations and is the role of the civil protection systems. 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 management should include abnormal floods and dam outflows.**

## 5 - DAM SAFETY AND RISK ASSESSMENT

### *5.1 Practical risk concept*

Accepting a practical definition, dam **risk** can be considered as an assessment of the likelihood that a shortfall in some aspect of the dam will cause its failure (CANTWELL and MURLEY, 1988). **Hazard** is a measure of the potential loss of life, and of property and services downstream of the dam. Risk and hazard are then concepts related to the potential threat for the valley community.

A safe dam, according to a USBR definition, is one which does not impose unacceptable risks on the public by its presence. What is acceptable or not by the different actors of the dam safety process is not easy.

Without any dam (or similar structure) built in a valley, people living along it will be under the natural flood threat or risk and their respective hazards. A natural or initial reference situation can then established.

The construction of a dam will perturbate nature and potentially modifies the flood threat. It will be one of the aspects of dam environmental impact.

Quantification of the incremental threat caused by the dam on the downstream valley is a very important goal. Three aspects are typically considered on codes and guidelines:

- sudden water releases from the dam, treaching the habits of the valley inhabitants;
- modification of natural floods due to DRS operational behaviour;
- dam-break flood induced by a failure scenario.

All these three aspects need to be considered together in what concerns the downstream risk management. In such an integrated safety procedure dam-break flood is the extreme catastrophic scenario.

Among the panoply of procedures to be taken by dam owners and engineers, including a sound structural analysis and design, an optimised hydraulic exploitation, a minimum freeboard, an efficient maintenance and surveillance instrumentation and a flood warning system, the choice of spillway design flood, or the maximum safe inflow to DRS without dam failure, is considered to be a critical factor for downstream safety. Historical overtopping and other dam rupture causes related to severe floods are the main reason for such emphasis in this factor, specially with the embankment type of dams.

In what concerns the valley dam related hazards, the design flood and the dam-break flood are both associated to the incremental risk provoked by the dam. To quantify this incremental risk due to the presence of a dam in the valley, a risk assessment is made usually based on objective or pseudo-objective elements. To understand what is its effective meaning for laymen people and how to improve this procedure is a challenge within the present framework of dam safety regulations.

### *5.2 Design flood and risk quantification*

In current engineering practice two fundamental approaches are used for the design flood (or inflow) selection (ICOLD$^{a), b)}$, 1992): methods based mainly on flow data and methods based mainly on rainfall data. Among the several methods that are available, those based on a hydrometeorological analysis and on the estimation of the Probable Maximum Flood (PMF) are favoured by several countries (*e.g.* USA and UK); direct statistical analysis of flood discharges are largely accepted by other countries. However there are also mixed criteria and, even with the PMF approach, risk economic analysis also introduce probabilistic aspects in what concerns downstream hazards. In some regulations a distinction is made between dam safety and spillway discharge capacity leading to two design floods: the dam safety check flood (with the spillway and the dam on the verge of failure) and the spillway design flood. The first one is often made equal to the PMF and the second one is usually taken as a percentage of PMF or a flood with a given probability of exceedence.

In several countries it is considered that a high-hazard dam should be designed so that the maximum possible flood could be discharged without the dam failure: the spillway is thus designed for a design flood with a return period of 10 000 years.

Due to inadequate data available on rainfall events and the imprecise calculation of low frequency floods or of PMF, the freeboard play the role of safety factor or “ignorance factor” (BOUVARD 1988, ICOLD Congress, General Report, Q.63) and it is thus essential to size it adequately, specially in the case of an embankment dam (LAFITTE, 1992).

A risk economic analysis based on the costs related to an enhanced dam safety and on the expected downstream damages, due to dam overtopping and failure, is a theoretical approach to find the economic optimum design flood or spillway capacity. The human life associated costs is a severe drawback of this analysis, specially for highly dense populated valleys. On the other hand, the reliability of flood and dam failure probabilities can be very low for very long recurrence intervals. Even if an optimum solution with the minimum total cost is found, the downstream valley system is introduced in the economic analysis as a passive reference situation.

Whatever the method for design flood selection, the real value and meaning of the final risk quantification can be very controversial. Dam engineers can feel satisfied with a calculated design flood probability of exceedence or a dam failure probability (*e.g.* by a tree fault analysis) in what concerns the safety of the dam-reservoir system, or DRS. However, for the downstream valley system, safety and risk management, as well as for the valley inhabitants, what will be the practical meaning of that probability?

### *5.3. Societal risk*

An approach for downstream risk assessment is based on the societal risk criteria. This is an alternative approach to traditional safety standards and regulations as regards protection of human life from dam failure (McDONALD, 1995).

Experience and research have shown that the community can accept risks to life if the risk is low enough or is below the Socially Acceptable Risk (SAR). According to McDonald there are two measures of socially acceptable risk:

–Individual risk;

–Societal risk.

Individual risk is the total probability that a particular person will die through dam lifetime. Societal risk reflects society's aversion to disasters or catastrophes. It has no regard to particular persons and simply limits the frequency of events that would be expected to kill more than a certain number of people.

For both risks different acceptance levels can be specified. The larger risk level or Limit Risk will be an upper boundary: risks larger than this one are unacceptable. Another level is called the Objective Risk. Risks below this last one are acceptable. Risks between the Limit and the Objective Risks are tolerable only if risk reduction is impracticable or if risks are to be as low as reasonably practicable or ALARP principle (MELCHERS, 1993).

The Australian National Committee on Large Dams (ANCOLD) has adopted an interim societal risk criteria (Figure 8). The ANCOLD guidelines make several recommendations concerning the socially acceptable risk to life (MacDONALD, 1995) as, by example, the following ones:

- For new dams, and upgrading of existing dams, ensure that the average risk of individual death from dam failure does not exceed $10^{-6}$ per exposed person per annum.

- For existing dams, individual risks up to 10 times those for new dams could be tolerable, subject to application of the ALARP principle.
- New dams, and dams being upgraded, should satisfy the Societal Risk criterion (Figure 9).

Figure 9. Interim ANCOLD societal risk (McDonald, 1995).

Generally, according to ANCOLD criteria, a risk of 0.001 lives per dam per year is considered the maximum tolerable. Where 1 000 lives losses would result from failure the criteria require the annual risk per dam to be 0.0001 lives or less or a probability of failure of $10^{-7}$ per year or less from all causes.

To assess individual risk it is necessary to evaluate the risk to particular persons from all dam failure modes.

Advances in structural safety control, including probabilistic methods and reability theories, have been presented at several conferences, including the International Conference on Safety of Dams held in Coimbra, 1984 (SERAFIM, 1984). However, the dam failure probability as a quantitative safety appraisal is still very questionable from the scientific point of view. Fanelli (1991) argues that "if probabilities are to be somehow related to physical frequencies of occurrence, the existence of a large homogeneous population is a prerequisite; but this is not the case for dams, which are always unique". According to Fanelli "the concept of probability has actually been introduced mainly to cover the important aspects of inevitable uncertainty and incompleteness of knowledge on which design is based".

The scientific basis of societal risk limits is questionable and the acceptable risk curve seems to be accepted by subjective feelings and by comparison with other event probabilities (*e.g.* merchant shipping, natural catastrophes, nuclear plane and auto accidents).

The upper limit in a societal risk criteria when applied to densely populated valleys gives very questionable results indeed. Typically we can say that a loss of more than 500-1 000 lives due to a large dam failure could be an expected value in a large number of european valleys. ANCOLD criteria requires the probability of dam failure per year be less than or equal to $10^{-6}$ to $10^{-7}$ which seems to be beyond the limit of accuracy that can be given by practical engineering. So, for high hazard dams, with expected human losses more than 200 persons (Bureau of Reclamation), best available technology and engineering judgement is required. These accidents are viewed as "national tragedies that are forever remembered by the public" (USBR, 1996). No specific actions are then possible for these cases and "multiple defences" should be implemented (USBR, 1996). This means that the societal risk approach is not powerful enough to deal with the downstream risk management, or DVS safety, specially for densely populated valleys. However, for valleys not so populated (*e.g.* with a number of live losses less then 200) it can be the basis of an operational risk assessment methodology.

## 6 - DOWNSTREAM RISK AND PUBLIC PERCEPTION

### *6.1. Emergent problems*

The concept or risk perception was introduced by social scientists as a shortcut to understand the difference between the risk concepts of experts and lay people. Lay risk perception was described by SLOVIC (1980) as a three dimension structure:

- Dread risk dimension, related to the seriousness of the threat, opposing risks with a low threat potential to those with a high threat potential.
- Known risk dimension, opposing familiar risks to distant ones.
- Number of people under risk, opposing risks which affect only a few people to those whom are exposed a lot of persons.

Within this theoretical framework, the concept of "risk perception involves people's beliefs, attitudes, judgements and feeling, as well as the wider social or cultural valves and dispositions people adopt toward hazards and their benefits. The perception of risk is multidimensional, with a particular hazard meaning different thing to different people. Risk perception cannot be reduced to a single subjective correlate of a particular mathematical model of risk, such as the product of probabilities and consequences, because this imposes unduly restrictive assumptions about what is an essentially human and social phenomenon" (PIDGEON , 1992).

Risks can be considered as unacceptable by a population, simply because the decision was made without a proper consultation with the local authorities, or because the population claims have been ignored during the decision process, or even because the decision process was not clear (LIND and TYLER, 1988). These conclusions are very important in what concerns dam projects and their decision process when submitted to a public enquiry or discussion.

One way of preventing this specific kind of perceived injustice and the consequent inacceptability of a project is to increase public participation and information since the beginning of the project. How to conciliate this public participation and laymen concepts with expert concepts and the need of a fast decision. How to conciliate the benefits and advantages for the society of a dam project with the particular fears and attitudes of those living downstream the reservoir?

Dam owners are supposed to know the potential downstream hazards and the inundation risk maps will be taken in consideration for zoning, evacuation plans and exercises. How to conciliate all this information with public participation and final acceptance? In some countries the answer is to restrict the information about downstream risks, avoiding the public knowledge of flood studies and inundation maps. This procedure is based on the idea that it will be in the benefit of all society that those directly under dam risks (inhabitants and local authorities) do not realise the magnitude of the threat. The reason for that is the knowledge of the gap between the expert or engineering risk concepts and the laymen concepts of risk, threat and catastrophe.

In fact, a $10^{-6}$ or $10^{-8}$ probability can have the meaning of an acceptable safe dam for the engineers but the inundation map of the dam-break flood associated to this probability can be a terrifying vision for people living in a town downstream of the dam.

### *6.2. Human behavioural response*

Living near a dam exposes the population to the risk of a technological accident, and this risk is known by those living in the mainstream. In case of dam failure threat, problem oriented coping strategies are in many ways similar to those used to cope with natural floods. However, there are some important differences between the two cases: the consequences of a large dam failure flood tend to be much more severe due to the small warning time for those living near the dam and this type of flood disaster violates the basic human expectations for control over technology, and induces a sense of loss of control which is difficult to overcome (BAUM, 1987). ICOLD (1992) informs that "it is difficult to assess the impact of a dam failure on public opinion, but it is doubtful whether society would tolerate a second accident in the area before a further forty years or so had passed". Within the General Hazards Coping theory framework, LIMA and FAISCA (1992) summarise the behavioural response to natural flood threat, separating individual from collective actions in each of the stages (Table 2). This response behaviour is now being adapted to dam-break floods.

A dam can be conceived as an environmental stress (*i.e.* an external event that constitutes a potential threat) to downstream valley system (DVS). Cognitive adjustments to a stress are the different cognitive strategies to regulate the fear and anxiety provoked by long - lasting situations of stress. The different forms of coping leads to a minimisation of the threat: unrealistic optimism, personal and vicarious control, denial and focus on benefits are some of the more common strategies.

Cognitive adaptation model proposes that personal well being and mental health depend on optimistic view of the future and an enhanced view of the self, which are, in many cases, illusory. This model would predict that residents living close to the dam, in flood prone areas, would show higher levels of positive illusions than those living in more distant places, as a cognitive strategy to cope with a continuous threat (LIMA, 1996).

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Dam related risks can be difficult to accept by those who have no experience of living near these structures. Under normal circumstances, communities who live near a dam tend to minimise the risk and they have learned to cope with the threat. This human risk minimisation can result in a lack of interest for the preventive actions including defensive land-use management.

Table 1. Types of reactions to natural floods (adapted from LIMA and FAÍSCA, 1992)

| Type of Adjustment | Individual Response | Collective Response |
|---|---|---|
| Bear Loss | • Do nothing<br>• Pray<br>• Wait for help<br>• Go to higher places | • No flood prevision system<br>• No warning system |
| Share Loss | • Insurance | • Civil protection<br>• Social service for catastrophe situation |
| Modify Event | • Political lobbying to development of structural measures<br>• Community participation to inform and use structural measures | • Intensive structural measures (dams, reservoirs, etc.)<br>• Extensive structural measures (forest planting) |
| Prevent Effects | • Attend weather forecast<br>• Family evacuation plan<br>• Emergency kit and food<br>• Search for preventive information<br>• Specific actions inside the house to obstruct the water<br>• Change the building (flood proofing) | • Public information and education<br>• Warning systems<br>• Emergency plans<br>• Definition of construction and maintenance codes and regulations |

| | | |
|---|---|---|
| Change Location or Use | • Intention of mobility | • Zoning<br>• Relocation of residents in flood areas |

### *6.3. Positive illusions related to dam risk*

Some dramatic dam failures that occurred in the past all over the world have emphasised the need to increase dam safety (Lebreton, 1985, Ramos, 1995). Lave (l990) points out that the implementation of an effective and credible waming system can prevent the possibility of death as a consequence of a dam failure. ln Portugal we do not have a past experience of this kind of accidents and, for the first time, a project is under development which aims to improve the protection of the population at risk (Ahneida et al., 1990).

The present study aims to explore dam-related cognitive illusions in order to increase the efficacy of future warning system implementation in Portuguese dams.

The cognitive adaptation theory (Taylor, 1983, 1989) proposes that well adjusted people develop positive illusions in three domains: self~ enhancement perceptions, exaggerated behefs of control and an optimistic view of the future. Many studies showed that people exposed to different kinds of threat specially develop those illusions.

This observations suggested that people used this positive cognitions as a successful strategy to cope with the awareness of the threat. ln Portugal this model was applied to seismic risk perception (Lima, 1993). The results of this study showed that people with greater awareness of this risk minimise its impact and probability using positive illusions.

We hypothesised that subjects under dam-related risk show a greater awareness of the danger but also a greater minimisation of the threat than people not subject to this risk.

We expect that they minimise the risk using an unrealistic positive self-perception, an exaggerated perception of control over the threat and an unrealistic optimism about the future.

### CASE STUDY

This study took place in a city located in the south of Portugal - Silves, which is the first case study in the NATO PO-FLOOD RISK Project (Almeida et al., 1996). The data was collected in three different areas in order to operationalize three different levels of risk exposure. The first area was a high risk area near the river (Area 1), the second was a lower risk area near the castle (Area 2) and the third was a none risk area, near the train station located on the other side of the river (Area 3).

In the questionnaire we included demographic data, flood experience data, awareness of dam failure risk, perceived risk of dam failure and positive illusions related to this risk.

Dam risk awareness included: worry (1- not at all to 5- very much), frequency of thoughts (1- never to 5- frequently); city and house affected (1- not at all to 5- very much).

Dam failure perceived risk included: dam failure probability in 2 and 10 years (1 - not at all probable to 5- very much probable).

Positive self illusions included: self-efficacy (1- I am certain that I could not do it to 5- I am certain that I could do it). Positive control illusions: control over life and over risk (1- strongly disagree to 5- strongly agree). Unrealistic optimism: evaluations of house safety (1- more unsafe than other houses to 5- much more safe than other houses); and of house damage (1 - less damage than other houses, 5- much more damage than other houses).

This questionnaire was applied by an experienced interviewer. Our sample included 91 persons of both genders (56% female), all with flood experience. On the first area people were younger than on the other areas. Due to this result the age was controlled in further analysis.

Analyses of variance were performed on each of the dependent variables with age being a covariant. A post hoc test was also conducted (Tukey Honestly Significant Difference) whenever necessary.

### *Threat awareness*

Results show that inhabitants in area 1 have a greater threat awareness than subjects in the other two areas. They thought more often about the dam failure possibility and they were more worried about this possibility. They thought that the city would be more affected and also their house.

### *Dam failure risk perception*

Results for the variable dam failure risk perception showed that people on area 1 and 2 minimise the possibility of dam failure occurrence as compared to area 3. They consider this probability as very low or even inexistent for the next two years and also for the next ten years.

*positive illusions*

Results show different cognitive beliefs in the samples studied, which are congruent with our predictions.

*Unrealistic optimism about the future*

We analysed the existence of unrealistic optimism in two steps. First we compared the estimation of subjects from area 1 and 2 on the perception of safety and eventual damages in their houses in case of dam break. Afterwards we compared those self reported events with the evaluation of safety and damages made by area 3 residents.

The results for the self evaluation for house safety shown that people on the first area considered their house less safe than people of area 2. But when we compared their self evaluation with the evaluation of people on area 3 we saw that the y overestimate their house security. Area 2 and 3 subjects do not differ in their safety evaluations concerning Area 2 houses.

The results show that people on area 1 estimate greater damage for their house than area 2 (F(1,70)= 17.799, p<.0001). Once again when we compared their results with evaluation done by the persons of area 3 we found that they underestimate their probability of darnage (F(1,59)= 89.296, p<.0001). For this variable we didn't, also, observed differences between area 2 and area 3 evaluations concerning the damages in Area 2 houses.

To summarise the results, we can say that the sample people in area1 showed greater awareness of the threat and at the same time greater minimisation of the risk. This group also revelled greater positive evaluation of their capacities to cope with threat and higher levels of control over the risk. We didn't find the expected differences between area 1 and area 2 for the variables house safety and damage probability. However, when we compared the evaluations results of the first group with the evaluations of the third group we observed the expected optiniistic effect. These results suggest that people with higher levels of threat awareness minimise the risk of dam failure using positive illusions.

### *6.4 Human response to warning systems*

A warning system and an evacuation from flood-prone areas seems to be one of the best protection procedures to avoid lives losses. The efficacy of these systems depend, among others factors, on the warning time. According to U.S. experience it was concluded that a warning time of 1-2 hours or more is sufficient to reduce the number of deaths almost to zero (LAVE *et al.*, 1990 and Brown and Graham, 1988).

This is an important topic for analysis because the conclusions valid in the U.S.A can not be universal. Public response to flood warnings can vary from one community to another.

The warning system can be considered as composed by several subsystems (MILETI, 1994):

- Detection subsystem, collects and analysis information and makes predictions about a potential accident;
- Management subsystem, integrates the risk information and warns the public when warranted; this subsystem can be composed by local emergency officials or by an automatic export system;
- Response subsystem, or public response to warnings received based on the basis of their own interpretations or perceptions.

According to Mileti, the human decision about warnings go through a sequential process: hearing the warning, understanding it, believe or not to believe it, personalisation of the warning and decision about it (*e.g.* to evacuate or to confirm). All these phases depend on human factors or receiver factors and on physical aspects of the warning signal or sender factors. The former ones will depend on environmental, social, psychological and physiological. In what concerns the sender factors, the social science research concluded that "the warning message it self is one of the most important factors in determining the effectiveness of a warning system (MILETI, 1994).

This particular topic is one of the most important for downstream protection and it should be considered as an high-priority research objective for social sciences applied to downstream valley system.

## 7 - DOWNSTREAM VULNERABILITY

Downstream risk assessment includes the vulnerability quantification related to a potential dam-break event. Uncertainty is modelled by probabilities. Damages will depend on the future risk management and on human collective response and survival capability to a flooding crisis.

The risk of human losses at downstream valley, from a single dam failure cause or event *i*, can be expressed by the following basic equation:

$$R_i = PE_i \cdot f_{Fi} \cdot f_{Li} \tag{1}$$

where $R_i$ = the average probability of human losses per year and per person due to dam failure mode *i*; $PE_i$ = the annual exceedance probability of the cause of dam failure mode *i*; $f_{Fi}$ = the average conditional probability of dam failure mode *i* given that the initiating event has occurred; $f_{Li}$ = the average conditional probability of individual human loss given that the dam has failed according to mode *i*.

The total average risk of human losses at DVS, $R_t$, due to dam failure, is the sum of the probabilities for each failure mode:

$$R_t = \sum_{i}^{n} R_i \tag{2}$$

where n = number of failure modes due to flooding, seismic, slope failure, foundation or piping failure, among others loading or disturbance in DRS system.

According to a societal risk criteria, the total probability $R_t$ of failure should to be less than the Limit Risk in order to be acceptable. The selection of the emergency design flood can then be made through equation (1), should the expected number of fatalities due to a dam failure and probabilities $f_{Fi}$ and $f_{Li}$ be estimated.

For a flood disturbance, $f_{Fi}$ will depend on hydraulic and operational factors (*e.g.* reservoir level and spillway operation) and on dam characteristics (*e.g.* type of dam and strength to overflow). Typically, for earth dams, failure is usually considered as soon as the dam is overtopped by the flow. The evaluation of $f_{Fi}$ is a challenge for dam engineers specially in what concerns the foundation and structural fiability and the hydraulic design of a dam. Progress in dam safety is expected to decrease dam failure probability for each mode *i*, $f_{Fi}$, including the failure due to inflow floods.

In a very general way, downstream vulnerability, *Dv*, will be a function of physical characteristics of the flood and of the valley system, as well as of the social characteristics of those living in each flood prone sub-area *j* along the valley:

$$\mathrm{Dv}_j = \left[\mathrm{FC\ .\ WS\ .\ LO\ .\ IS\ .\ SC\ .\ N\,*}\right]_j \tag{3}$$

where $Dv_j$ = downstream vulnerability in each sub-area; *FC* = flood risk characterisation; *WS* = warning and evacuation system; *LO* = land occupancy risk management; *IS* = infrastructure (buildings) susceptibility to flood damage; *SC* = social characterisation index and *N** = total number of persons under risk.

The summation of all $Dv_j$ will give the overall Dv. After calibration, $Dv$ can be the expected number of fatalities in the overall downstream area or the probability $f_{LF}$. Each factor will be a function of several variables:

- Flood risk characterisation (from flood studies and inundation maps), *FC* depends on inundation area, maximum depth of flooding and flow velocity, time of wave arrival and of maximum depth, rate of depth increase and duration of flooding, as well as on hydraulic and hydrologic conditions before and after dam failure (*e.g.* day or night, flood or "sunny day" and cascade dam response).

- Warning and evacuation system, *WS* depends on the lead time warning and on people response and evacuation procedures including preparedness status and the hour and season of the year effects on expected survival rate.

- Land occupancy, *LO*, depends on the land-use and risk management strategies and on the level of permanent human occupancy in flood-prone areas according to the zoning criteria.

- Infrastructure (building) susceptibility to flood damage, *IS*, depends on the average structural characteristics of buildings in the area.

- Social characterisation, *SC*, depends on the social studies about the inhabitants of the sub-area including the local human density, age and education profile, as well as the risk public perception level and response to crisis situations.

According to (1) and (3), $PE_i$ will be:

$$PE_i = \frac{R_F}{f_{Fi} \sum_j^M Dv_j} \tag{4}$$

An iterative procedure should to be applied because *FC* will also depend on flood magnitude. Simplified versions of (3) and (4) can be applied in this kind of risk assessment.

A vulnerability index $I_v$ can be defined as following:

$$I_v = \frac{\sum_j^M Dv_j}{N^*} \tag{5}$$

The objective risk index $I_{Ro}$ for the flood failure mode will be:

$$I_{Ro} = PE_i \; . f_{Fi} \; I_v \tag{6}$$

A subjective risk index $I_{Rs}$ can also be defined by the following way:

$$I_{Rs} = I_{Ro} \, . I_{RP} \tag{7}$$

where $I_{RP}$ = public risk perception index.

## 8 - LAND USE MANAGEMENT SUPPORT SYSTEM

### *8.1. Introduction*

Within NATO project *Dam Break Flood Risk Management In Portugal* is under development a study concerned with:

a. The interface between risk management and land use planning techniques in the specific case of dam break flood risks;

b. Developing methods and tools to be used by local, regional and national authorities, that integrate flood risk in planning and management of valleys downstream of dams;

c. Developing of risk management techniques among land use planners and authorities that are responsible for location of infrastructure and public services and improve the application of these techniques.

One of the tools being considered is a decision support system, based on GIS technology, and containing relevant data for land use management in face of dam break flood risk, subsequentely called land use management decision support system (LUMDSS). This system, subsequently called *the land use management module*, is part of a larger information system, being developed within the NATO research project.

### *8.2 The Lumdss*

Land use is a dynamic reality. Changes occur daily and are carried about by a large number of different agents, both public and private. The actions taken by these agents are not necessarily co-ordinated and don’t necessarily obey to common objectives or rational decision making. Even the public agents represent different levels of administration, different jurisdictions and different sectorial interests and technical points of view and don't comply with an overall rationality.

Many aspects of land use are hard to grasp and characterise. Human occupation of a certain territory is permanently changing and census and enquires only give us pin-point readings of the reality. The forces driving land use changes are multi-criterial and are usually not predictable by general laws.

In face of this, land use planning is a technically and politically accepted form of futurology. It deals with the probability of things to happen and tries to establish basic rules and procedures to achieve common goals and better or unconflicting results.

Some of the actions previewed by planners never occur and others occur differently. By happening so, the very assumptions for the planning guidelines are put in question, requiring regular updating of the plans.

Land use plans are thus never completely carried out. But they are useful to guide rational decision-making and minimise conflict between contradictory actions.

In this sense, land use planning mediates a struggle between a dynamic reality and a mainly static organisational framework. Land use planning methods must be perfected to make the organisational framework more dynamic.

This way of reasoning finds its full application in the subject of this research project. As a starting point, there is a valley, downstream of an existing or projected dam. This valley has a current occupation. Facing the risk that is brought about by the dam, land use management decisions in the valley should immediately be oriented by three major considerations:

a. To avoid increased exposure to risk of existing occupations;

b. To create alternatives for the more exposed existing occupations, particularly strategic infrastructure and service facilities;

c. To assist civil protection authorities in drawing emergency plans.

The rationale behind the study is that adequate safety in the valley can only be achieved through the permanent consideration of risk in the current land use decisions. This requires appropriate information and an adequate decision support system, allowing for good co-ordination and timely communication of the different agents concerned.

In case of an accident there will be little or no time to produce new information. Thus, the LUMDSS must be prepared both to assist current land use management decisions and also to assist crisis manegement and emergency procedures.

Thus, the development of LUMDSS was oriented by two main objectives:

a. To support current land use management decisions and current dam operational decisions that may affect land use or people and property in the downstream valley;

b. To prepare and support emergency dam operational decisions and civil protection operations in case of dam failure or severe accident.

Related to the above mentioned objectives, two different potential groups of users for the system are being considered:

a. Current users;

b. Intermittent users.

Typical current users being considered are:

1. Regional and local authorities;
2. Public authorities and companies responsible for planning, building and managing major public infra-structures and services at regional and local level;
3. Dam owners and managers;
4. Water and environment authorities;
5. Private land use planners and technicians involved in urban land development projects, agricultural and forestry projects, etc..

### *8.3. The Arade river case study*

In the Arade River case study, it is recreated what should be a normal procedure regarding land use management in face of dam-break flood risk:

a. Studying exposure to risk of human settlements, specially urban areas, urban expansion areas and strategic infrastructures and services facilities.

b. Studying the chains of decision that lead to major land use changes.

c. Showing how to integrate land use plans and inundation maps.

d. Showing how to integrate risk management in decisions that lead to major land use changes

e. Showing how to feed back relevant land use decisions to those responsible for drawing inundation maps and making emergency plans.

Typical intermittent users being considered are:

1. Civil protection authorities at all levels
2. Dam managers;
3. Regional and local authorities;
4. Water and environment authorities.

Typical current uses of the information stored in the system will be:

a. The evaluation of exposure to risk, to assist land use planning and management decisions;

b. The evaluation of alternative solutions, to assist decisions on the localisation of major infrastructures an services,;

c. The assessment of the impact of controlled floods, to assist current dam operational decisions.

Typical intermittent uses of the information stored in the system will be:

a. The preparation and revision of emergency plans;

b. The drawing and revision of flood risk zoning maps by dam ;

c. The assessment of the impact of uncontrolled floods, to assist emergency dam operational decisions and civil protection operations.

The strong local and regional character of most of the potential users, the need for accurate and detailed information, permanently updated, and for good knowledge of the actual conditions on the field, and the need for fast and graduate response in case of an emergency, advise that the information system be primarily tailored to local needs.

Thus, development of the LUMDSS is being carried out from the local perspective, with data collection starting at local level. Aggregation to regional and national levels will provide central planning and management with the necessary overall picture, allowing for strategic assessment and decision making.

Analysis of the plans and projects and their confrontation with the inundation maps produced by the use of hydraulic was also carried out. This showed that:

a. Some strategic infrastructure is located well within the risk zone and would be flooded. Such is the case of an electrical transformer station and several power lines that supply the whole western part of Algarve and a telephone sub-regional station. Such is also the case of several bridges linking major towns in the area, where hospital facilities are located;

b. Schools and service facilities are also located in floodable areas;

c. Several planned urban expansion areas are located well within the risk zones. Such is the case of the major urban expansion of an importante local town and of a marina development with associated real estate building.

### *8.4 - Organising data*

#### *Data collection and organisation*

Data collection is proving to be a long and sometimes hard process, due to several (expected) shortcomings:

a. Data is dispersed. Due to lack of co-ordination and the still predominant use of traditional methods and analogical tools, each authority has only one part of the overall picture;

b. Data is not updated. This is true both regarding basic data and thematic data;

c. Data is incomplete. Some thematic data is available for some areas and not for others within the risk zone.

Besides imposing longer collecting times and many institutional contacts, these shortcomings require additional work by the project team, to complete and make the different data compatible.

This experience is though a valuable result of the study, as it gives a good hint of the difficulties associated with the generalisation of this method to the entire country.

Using GIS technology, the collected data is being organised and presented in two forms: maps and alphanumeric data base.

#### *Maps*

Basic geographical information (topography, roads, urban areas, river network and some major infrastructures and services) was obtained from

Portugal Military Map (Carta Militar de Portugal), scale 1:25.000, in digital form (1979 edition).

This base map was up-dated using:

a. Ortophotomaps, scale 1:10.000, in analogical form (1991 edition);

b. Cadastral maps, in analogical form, scale 1:2.000, supplied by local authorities;

c. Project documents, in analogical form, supplied by road and harbour authorities;

d. Field observations.

Three thematic maps were subsequently prepared over the base map:

a. Current land uses;

b. Planned land uses;

c. Major infra-structures and public services.

Information on the current land uses was obtained through field work and ortophotomaps. Information on the planned land uses was obtained from the zoning maps of the Municipal Master Plans (analogical, scale 1:25.000).

Information on major infrastructures and public facilities and projects of large infrastructures, was obtained from different sources:

a. Information on the electric network was obtained from maps supplied by the regional electric company The high and medium tension networks (150 to 15 kV) were drawn in analogical form at scale: 25.000, using de Portugal Military Map as base map. The lower tension network is represented in analogical form, at scale 1:2000, using cadastral maps as base maps.

b. Information on the telecommunications network was supplied by the national telephone company. The area covered by each main station, is represented in a map in analogical form, at scale 1:25.000. using the Portugal Military Map as base map. The network is drawn over cadastral maps, in analogical form, at scale 1:2000.

c. Information on the location of relevant public services (hospitals, schools, administrative buildings, water reservoirs, etc.) was obtained from the zoning maps of the Municipal Master Plans and through field work.

Up-dating the base map and preparation of the thematic maps involved extensive digitalisation from the different sources mentioned above and was very time consuming. The main difficulties found during this process were:

a. The last updating of the Portugal Military Map is from 1979. Since the study area suffered major changes along the last 20 years (significant increase in urbanisation and several major roads, bridges and other infrastructures were built, such as the Portimão harbour, the new East-West highway across Algarve, the new bridge for the Arade river, the new regional hospital at Portimão etc.),. updating work carried out in the framework of the study was extensive;

b. Available ortophotomaps (scale 1:10.000) and cadastral maps (scale 1:2.000) do not fully cover the study area and are as well not updated;

c. The topography of the valley has also suffered extensive changes during the last decades. After the construction of the dam, an irrigated area has spread, first in the valley, and more recently, with the new irrigation methods (micro and drip irrigation), up the hillsides. This enlargement of the irrigated area involved the construction of terraces, changing not only the topography of the valley but also the soil and subsoil characteristics (due to stone removal). In Silves, the construction of new roads and major social equipment involved earthworks and changes in land relief. The subsequent correction of topographic data in the maps was not done. This fact is very important for the definition of the limits of flooded area.

d. Discrepancies were found between ortophoto- and cadastral maps, mainly regarding topographic information.

e. Cartographic and geographic co-ordinates differ between the three Municipal Master Plans. The. Portimão Plan used military co-ordinates and grid (Hayford-Gauss). Silves Plan used the UTM grid but all the co-ordinate values have been erased. In the Lagoa Plan the UTM grid is not visible due to the graphic symbols used and the co-ordinate values have also been erased.

f. The conventions and symbols used in the zoning maps of the Master Plans hide the basic information and are not clear, *i.e.*, similar symbols are used for different soil uses. Finally the symbols used to represent the limits of municipal borders are too thick (4 mm tick at scale 1:25.000 represent 100 metres).

### *Alphanumeric data base*

The alphanumeric data base consists of a list of objects that were found to be relevant for the scope of the study. A list of these objects, as they have been preliminary retained in the data base, is presented in Table 2.

Table 2- List of objects in the land use management module

| |
|---|
| Land use |
| Accessibility |
| Energy supply infrastructures |
| Water supply infrastructures |
| Telecommunication infrastructures |
| Liquid gas infrastructures |
| Public services buildings and installations |
| Local administration buildings and installations |
| Central and regional administration buildings and<br>installations |
| Other relevant buildings and installations |

The objects listed in Table 2 refer to:

a. Land use - classification is done in three classes: urban, urban expansion and non urban areas;

b. Accessibility - comprises roads of all classes, bridges, railways and railway stations, harbours, airports and heliports;

c. Energy supply infrastructures - comprises high and medium tension networks, transformer stations, control stations;

d. Water supply infrastructures - reservoirs, water treatment stations, pumping stations, main pipe network;

e. Telecommunication infrastructures - telecom-munication centres, relay stations, antennae;

f. Liquid gas - Depots, reservoirs, main pipe network;

g. Public services buildings and installations - health centres, hospitals, schools, elderly care centres, civil protection, police, fire station, museums, libraries, etc.;

h. Local administration buildings and installations - town hall, administrative buildings, machinery depots, storehouses;

i. Central and regional administration buildings and installations - administrative buildings, machinery depots, storehouses;

j. Other relevant buildings and equipment - irrigation systems, pharmacies, fair and exhibition halls, sports fields and halls, cinema and theatre halls; petrol stations.

For each object, two types of attributes were defined: cartographic attributes and alphanumeric attributes. Cartographic attributes are used mainly to locate and identify the object. Alphanumeric attributes are used to characterise the object.

In this characterisation particular attention has been given to:

a. Identification of the authority in charge for management;

b. Conditions for continued access and operation in case of flooding;

c. Capacity for supporting emergency operations.

Table 3 shows a list of frequent alphanumeric attributes that are found in the data base when the object is a building or an installation.

Table 3 - Example of alphanumeric attributes

| |
|---|
| Name/Code |
| Location |
| Plot area |
| Building area |
| Capacity |
| Manager in charge |
| Service area |
| Security level |
| Autonomy |
| Access |

The alphanumeric attributes listed in Table 3 refer to:

a. Name - Identification of the building or installation (name or code, as relevant);

b. Location of the object - Post address;

c. Plot area - Area of land affected to the building or installation;

d. Building area - The total floor area under roof;

e. Capacity - Parameter that defines the capacity of the object according to its actual human occupation or it's interest in support of emergency operations (number of students at a school, water capacity in water reservoirs; number of beds in an hospital; number of ambulances in the fire station, etc.);

f. Manager in charge - Authority/organisation that is in charge of the building or installation;

g. Service area - The area that is served by an installation or service facility (for instance, the area served by a telecommunications centre);

h. Security level - The maximum level water can reach before operation of the installation or facility must be stopped;

i. Autonomy - The number of hours the building or installation can operate on current supply storage (for instance, the number of hours generators in hospitals, schools, head-quarters, etc. will run on current fuel supply);

j. Access - Normal and alternative accesses in case of flooding.

## 9 - CONCLUDING REMARKS

The NATO Project will be finished in 1999-2000 and their final results and recommendations will be published.

The developments in sub-project related to the computer aided decision support system will be present in another paper written for this Seminário.