DAM BREAK EMERGENCY RESPONSE INFORMATION SYSTEM

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Abstract: Although considered of low risk, incidents with dams may cause significant damage both directly and indirectly. Direct losses are usually easier to assess (assuming human lives are quantifiable), but indirect losses are difficult to measure and may take some time before the original situation is restored. Disaster prevention and vulnerability reduction have been topics of major concern in many local, national or international organisations for some years. These can be accomplished through emergency management which begins with hazard identification and planning for disaster mitigation but encompasses other activities as risk analysis, risk response and recovery. Therefore, an emergency management system with capacity to: i) forecast critical situations; ii) warn the population as well as the authorities; and iii) support the civil protection system to deal with an emergency, is a most helpful tool to minimize the impact of an accident. The Information System described herein fulfils mainly the third objective, i.e. it is intended to help the Civil Protection System in Portugal, to respond to an emergency caused by the failure of a dam. It is an Internet-based application, which integrates all relevant data for the implementation of a dam emergency plan. These data include the main characteristics of the dam and its reservoir, the characterisation of the dam downstream valley as well as the response procedures to be followed in an emergency.

1. INTRODUCTION

The increasing focus on dam safety is a problem of major concern to scientists and entities responsible for designing, licensing, constructing and managing such structures. In spite of the growing experience in designing and building dams, as well as in using more appropriate materials, dam safety is increasingly a debated issue among the international community. At the same time, there is a growing public awareness of the potential risk for people, structures and property in the downstream valley. This calls for adequate disaster mitigation measures. Risk mitigation, a significant component of flood risk management (Plate, 1997, Almeida *et al*. 2003), can be achieved through structural and non-structural measures for prevention and preparedness. It is the non-structural instruments that interest us the most. Among these instruments, emergency plans play a significant role in disaster mitigation.

This paper will focus on advanced planning to minimise life and property damages. It elaborates on dam break flood emergency planning in Portugal and presents the conceptualisation of an information system to support both the dam owner and downstream emergency management response agencies. The Alqueva case study is presented.

Section 2 makes a brief characterisation of the Alqueva dam and its downstream valley. Section 3 outlines dam break emergency planning in Portugal. Section 4 discusses an emergency response system for dam accidents. Section 5 describes the SAGEAlqueva information system. Finally, Section 6 emphasises the importance of this information system and outlines future developments.

2. ALQUEVA DAM AND DOWNSTREAM VALLEY

The Alqueva dam is part of a complex scheme that includes the Alqueva power plant with a power house at the dam toe, and the Pedrógão dam and power plant, under construction.
The Alqueva dam is located on the Guadiana River, a transboundary river that flows from Spain. It is a double curvature concrete arch dam, 96 m high and founded on rock. Its crest is 458 m long and 7 m wide. The crest elevation is 154 m. The two spillways (with 3 gates) are located in the dam body and have a maximum discharge capacity of 6,300 m^3/s. The bottom outlet located inside the diversion tunnel may discharge up to 160 m^3/s. The normal water level is 152 m. The maximum flood level is 154.7 m and the minimum operating level is 135 m. The reservoir area, corresponding to the normal water level, is 250 km^2 with a gross capacity of 4,150 hm^3 and an effective capacity of 3,150 hm^3, by far the largest in Portugal.
The reservoir surrounding area is vast and one of the least developed in Portugal, the inland Alentejo. Therefore, the dam comes out as the next great hope of progress and development for the Alentejo inhabitants. The downstream valley is long. It borders or crosses 9 Municipalities from the dam to the river mouth, in the Atlantic Ocean. The whole area may suffer the impact of a dam rupture.
A door-to-door survey carried out in 2002 showed that with the exception of a few small towns the valley is sparsely populated.
A total of about to 2,000 people live or work in the flood-liable area. The most critical situations, which call for extra care, are some markets, schools and senior citizen homes located on the flood flow path. The markets and schools are highly populated places; therefore, warnings must avoid panic. The elderly require special attention due to their frail condition or disabilities.
Seventeen bridges across the water course, some electricity transmission lines or water and sewage mains may suffer the flood impact and be damaged.
In addition, some farmhouses and stables or fish farmers can be found in the inundated areas. In general, the above description gives an idea about the elements in risk.

3. DAM BREAK EMERGENCY PLANNING IN PORTUGAL

Dam Break Emergency Plans aim to minimise the effects of a potential incident or accident with this dam and to protect people and property in the downstream valley. They should function as an up-to-dated storage container of relevant data and procedures enabling the dam owner, the water authorities and the civil protection services to prepare themselves to face the catastrophe. Therefore, they must clearly:

- Define the decision and command chain;
- characterise the elements at risk: the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructures, etc, at risk in a given area (UNDRO 1991);
- inventory the available resources and means;
- list notification, warning, evacuation and report procedures.

Consequently, providing they are regularly updated and tested, emergency plans will be a fundamental emergency management tool to support planning, evaluation and training in pre-emergency stages and to help emergency managers to respond promptly and efficiently to dam hazards.

In Portugal, large dams, that is, dams higher than 15 m or with a storage capacity larger than 100 000 m^3, are subject to the Safety Regulation (Decree Law no. 11/90 of January 6). This makes it compulsory for dam owners to perform dam break risk analysis studies, to draw inundation maps and to prepare emergency plans.
A later agreement signed by the Water Authority and the Civil Protection Services made the Emergency Plan foreseen in the Safety Regulation to be split in two: an Internal Emergency Plan and an External Emergency Plan.
The Internal Emergency Plan (IEP) refers to the dam and its appurtenant structures. It aims to guarantee dam safety control and must contain all procedures and actions to be taken by the technical staff if an accident occurs. It must also identify the risk zoning. The IEP Director is the responsible person to co-ordinate actions if an accident occurs with the dam
The External Emergency Plan (EEP) is mainly concerned with the actions to be taken by the Civil Protection agents and must include an inventory of the available resources to respond to a disaster. The EEP Director is the responsible person to co-ordinate the response actions along the valley.
Both Plans must also provide notification and warning systems and specify the hierarchical decision chain, the mission and responsibilities for each of the chain members.
Depending on the severity of the observed event, response actions are classified according to a four-step response level system: 1-blue or pre-

emergency; 2-yellow; 3-orange: 4-red. A fifth level, corresponding to the recovery situation is sometimes considered.
Still according to the Safety Regulation, the Dam Owner (DO) is the entity responsible for preparing and applying the Dam Internal Emergency Plan. The response actions in the downstream valley are a responsibility of the civil protection agents co-ordinated by the Civil Protection Services (CPS). These services are organised in three levels: National, Regional and Local. For a localised small hazard, only the local services may be called on. For more serious hazards and for those affecting some districts, the local means may not be sufficient and the authority to co-ordinate the response may be of a higher level, either regional or national.

4. AN EMERGENCY MANAGEMENT SYSTEM

4.1 Motivation and Objectives

Internal and External Emergency Plans of dams are primarily paper documents, static by nature. This poses several questions: How can IEP and EEP be updated in a straightforward and practical way? Which information can be accessed and by whom? How can agents, at different levels of decision, share their acquired knowledge?
The obvious answer to the above questions and issues is an information system, which can provide different functionalities to meet the needs and requirements of the involved agents, whose actions depend on the response level in which the emergency is classified (Section 3). Table 1 summarises the main agents to be involved in a dam break induced emergency and the main actions they must perform.

4.2 General Requisites

Due to the decentralised structure of the civil protection services (Section 3), emergency management is carried out in a distributed way, with different teams positioned in different geographical locations. To meet this requirement, the system must allow for different agents with diverse objectives and needs to share and change information remotely. For instance, specific user interfaces and functionalities must be available for managing emergency by national, regional and field agents.

Table 1 – Objectives of the dam break emergency response information system

	Objectives	Agents
Pre-Emergency	Prepare list of potentially serious incidents	DO
	Identify steps to provide for quick response actions	
	Enter and update data on the dam and appurtenant structures and on relevant documents	
	Provide inundation maps	
	Identify rescue procedures	CPS
	Enter and update available resources.	DO and CPS (all levels)
	Retrieve data on available resources	
	Define the decision and command chain	
	Identify roles and responsibilities	
	Promote training and exercises	
	Enter and update information about the elements at risk	CPS (local and regional)
	Retrieve data on elements at risk	CPS
Emergency	Retrieve data (inundation maps, available resources, elements at risk, …)	DO and CPS
	Issue notifications	IEP Director and EEP Director
	Issue warnings	
	Issue press releases	
	Allocate resources	
	Organise and deploy rescue teams	
	Check communications	
	Call for briefings	EEP Director
	Prepare and transmit situation reports	IEP Director, CPS

Safety requirements must also be guaranteed through appropriate authentication control by username and access password.
Consequently, the system must formally define its users and their access privileges. Figure 1 identifies the profiles of the principal agents who need to access the correct information to respond timely and adequately to unexpected situations. According to Costanzo and Gadomski (1998), fault decision and human errors are caused by wrong information and inability to process information in the context of emergency response.

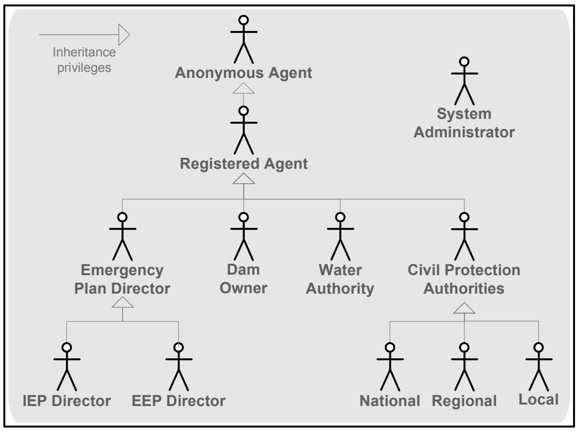

Figure 1 – Agent profiles in a dam break emergency management system

4.3 Functional Requisites

Depending on the agent profile, the functionalities listed below, corresponding to the actions agents may take (use case scenarios), must be available. In general, data inputs are made only under normal conditions, response level 1.

Authentication: for registered agents (see Figure 1), a pair username/password is required to log into the system, thus guaranteeing privacy.

Accessing dam info: the user (anonymous agent) may select a dam and get information on its main characteristics, view its location or print a report; registered agents with the required privileges (dam owner) may modify these data or insert new data.

Classifying the hazard: the IEP Director or the Dam Owner may classify the accident level, based on the behaviour of a number of variables. Whenever there is a change in this level, all registered agents must be automatically notified (functionality not implemented yet).

Set/Get elements at risk: all agents can retrieve lists of buildings and people in the risk area, that is, the flooded area for the extreme scenario of rupture. Only local authorities can insert more elements at risk.

Set/Get agencies: all agents can view and list all agencies related to the dam or the Emergency Plans: Dam Owner, Water Authority, Designer(s), Constructor Consortium, Civil Protection Agents, etc..

Set/Get procedures: the registered users can view or list the set of procedures to respond to the crisis. The actions to be taken by each responsible agency as well as the notification, warning and evacuation plans are among these procedures.

Set/Get documents: all relevant documents related to the dam, including the design-related reports, the inspection reports and the emergency plans are stored and available for download.

Simulate scenarios: this functionality should allow defining scenarios, *i.e,.* crisis situations, when the elements at risk, available resources, and simulated agents in the field have different behaviours. Simulation of these scenarios will be used in a normal situation in order to test and refine procedures/behaviour/actions rules defined by the Emergency Plans (IEP and EEP).

4.4 Architecture requisites

On one hand, the major goal of the emergency response system (see Table 1) is data sharing. On the other hand, these data are spatial sensitive. Therefore, it seems appropriate to consider a Geographic Information System as the data repository structure and to take advantage of three of its main functionalities (Constanzo and Gadomski (1998): i) **access to geodatabase** (a safe repository of spatial data where every piece of data is geo-referenced); ii) **use of GIS operators** (spatial querying, distance and topological operators, etc.); iii) **visualization** (GIS standard user interface includes functionalities for manipulate thematic maps).

Finally, these data should be accessed through friendly and popular user interfaces like web browsers. Since the web mapping development has reached a high degree of performance (Al-Sabahan *et al.*, 2003; www.esri.com or http://freegis.com), a web-based architecture is assumed as a good solution. The main components of this architecture are:

– GIS database server;
– Spatial data map server;
– Web server;
– Dam break emergency response logic;
– Internet-based user interface, *i.e.* browsers.

These components can be based on open-source or proprietary solutions. Some advantages and disadvantages of both solutions can be found in Harvey and Han, 2002.

5. SAGEALQUEVA: A REAL SYSTEM

5.1 Data model

SAGEAlqueva is a system to support emergency managers to implement both the Internal and External Emergency Plans for the Alqueva dam. It can store all relevant data and makes them easily accessible when needed.

These data consist of the characteristics of the dam and its appurtenant structures, the relevant documents of the project and construction, the wave flood characteristics (for an extreme scenario), the social and economical characteristics of the downstream valley. For those at risk, a thorough portrayal of the households (composition, age, education level and disabilities of their members) is also included as well as building construction features.

Since all data is GIS-based (Section 4.4), SAGEAlqueva provides a set of spatial data layers – geographic layers that support the general identified uses cases for an emergency response information system, as can be seen in the Table 2.

Table 2 – Geographic Information Layers for a dam break emergency response information system

	Layer	Data format
Basic data	Administrative divisions	Vector
	Roads and railways	Vector
	Elevation	Vector
	River network	Vector
	Land use	Vector
	Military Chart	Raster
Resource	Firemen	Vector
	Security Forces	Vector
	Medical personnel	Vector
	NGOs	Vector
	Health care locations	Vector
	Medical equipment	Vector
	Shelters	Vector
	Transport and repair vehicles	Vector
	Search and rescue, repair equipment	Vector
	Fuel and lubricants	Vector
	Stockpiling supplies and materials	Vector
	Communication systems	Vector
Scenario	People and Buildings at risk	Vector
	Concentration areas	Vector
	Inundated areas for two scenarios	Vector
	Risk zoning	Vector

The system was conceived and developed in such a way that it can easily be expanded for future functionalities. Although this prototype can only share information (Sections 1.2 and 1.3), it is expected that, in the future, such functions as diagnosis, alert and prediction will be implemented, allowing the system to make suggestions for decision-making. Figure 2 shows the functional modules (domain model) used in SAGEAlqueva

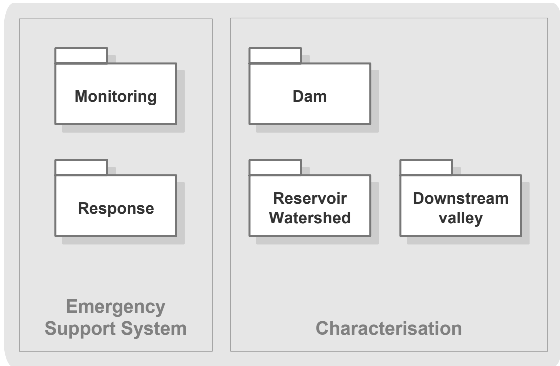

Figure 2 – Organization of functional modules in SAGEAlqueva

Reservoir and watershed: includes the water level in the reservoir, water use, rainfall in the watershed, etc.;
Monitoring: includes the relevant dam-related structural and hydraulic observations that may help to detect an inside abnormality; it is intended to works in real-time providing readings of dam instruments and watershed instruments;
Dam: includes the main characteristic of the dam and its appurtenant components, the report on inspections, the dam project, etc.;
Downstream valley: in addition to a brief physical characterisation of the valley, it contains the thorough characterisation of the elements at risk, including the inundation maps (Section 1.3);
Response: includes all available resources, possible failure scenarios and procedures to respond to a crisis, together with the decision chain and functionalities for situation reporting.

The first two modules are not built-in components of the SAGEAlqueva. Rather they will establish a link to the Structural Monitoring System to be implemented in the dam and to the Water Resources National Information System that provides hydro-meteorological data.

5.2 Architecture and technologies

The actual architecture of the SAGEAlqueva is shown in Figure 4. Its components are presented in a classical arrangement of software engineering, *i.e.* 3 tiers: database; logic; and presentation.

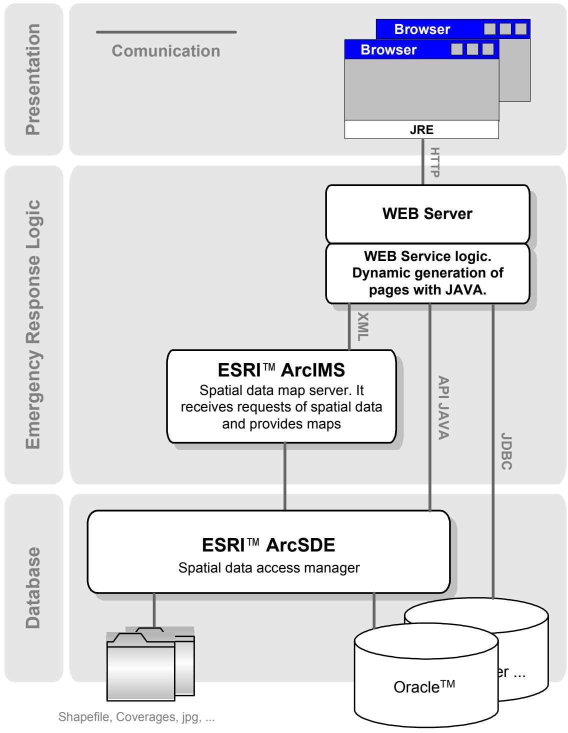

Figure 4 - SAGEAlqueva architecture and technologic components

Basically, the SAGEAlqueva dam break emergency response system is a web service. Because the GIS database server (Oracle™ and ArcSDE™) and the spatial data map server (ESRI™ ArcIMS) are basic and critical components in the architecture of this web service, they are implemented with proprietary technologies offering robust and secure solutions. Components to implement the system logic and deliver the web contents are built using cheaper solutions (JAVA technology), but widely used and highly efficient.

The Web service architecture, using open communication and data transfer protocols (e.g. XML), presents some advantages, namely allowing the system to easily import data avoiding duplication. For example, as said before, the SAGEAlqueva uses, in a transparent way monitoring data stored elsewhere (Figure 2, session 5.1).

6. FINAL CONSIDERATIONS

Emergency response systems play an important role in risk mitigation induced by dam ruptures in two different ways: i) providing a unique storage container of all relevant data; ii) helping to prepare and implement emergency plans.

SAGEAlqueva, the dam break emergency management prototype presented herein, has an architecture prepared to grow in agreement with the future needs of the emergency agents. It is a distributed architecture based on open- source components and on proprietary software (spatial database and map server, the critical components). However, the architecture requisites allow guaranteeing: platform independence; easy integration with other server-side technologies; scalability; robustness and security.

In the future, the system is expected to incorporate diagnostic and predictive modules aiming to build a decision-making system. Then it will be possible to create dam break scenarios and assess the associated damages. The whole system will then be used in training by simulating hazards and orienting civil protection agents better to perform their tasks.

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