Towards a Generic GIS for Dike Management in Flood Plain Areas: from Conceptual Design to Real Applications

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SUMMARY

France counts several thousands kilometres of diked up rivers for flood protection. The last decade floods in France but also in other European countries showed that dikes did not present a high safety level and could break according to various mechanisms. The issues of the dikes safety, the way of evaluating and improving it, as well as the safety of the protected areas, are essential. It raises the problem of the long term management of the dikes related data. As dikes are long linear structures, the geographical positioning of these data becomes essential. Thus, the development of a new GIS application in this field was considered by Cemagref as a major stake.

Using a user-centre structured approach for analysing and designing GIS, Cemagref built up progressively such a generic GIS application. The industrial software is currently under development and it will be implemented beginning of 2004 for two local dike managers. Furthermore, one plans to interest additional dike managers in order to validate the genericity of this GIS application. New functionalities are also under investigation like the automatic assessment of dike safety.

KEYWORDS: *Flood risk, Dike, GIS, Flood Plains Integrated Management, Method for GIS Development*

INTRODUCTION

France counts several thousands of kilometres of rivers that are diked up for flood protection. The majority of these dikes are very old (some dating back to the Middle Ages) and of heterogeneous constitution, because continually raised elevated, widened and/or repaired since their construction. They have, moreover, various legal statutes: state owned (e.g. the Loire river) or managed by associations (e.g. the Isère river), or local communities unions (e.g. the Ouvèze, Agly, and Vidourle rivers and the Camargue area), or private individuals.

The floods which occurred during these last years notoriously highlighted the lack of safety from these ageing hydraulic works: dikes failures on Ouvèze river (1992) and the Rhône in Camargue (1993-94), concerns for the Rhine and the Meuse rivers dikes in 1995, more recently, breaches of the Aude and Agly rivers dikes following the catastrophic floods of November 1999 in Languedoc-Roussillon, and finally many dikes failures in the Gard department in 2002. Strong fears also weigh on the Loire levees, protecting now more than 300.000 people: the last three major floods (1846, 1856 and 1866), indeed, had caused a total of some 337 breaches in the protection system.

These events demonstrate that in addition to the "natural" flood hazard, there is also a "technologic" risk of dikes failure even if these works were precisely made to contain the floods. Risks study and prevention turn more complicated. In parallel, because of the (relative…) shelter offered by these supposedly safe dike systems, stakes heavily increased these last decades because of a more or less controlled land development. The flood-protection dikes safety issue, its assessment and reinforcement, thus is today crucial. The French Ministry of Environment (MEDD[6]) - in charge, on one hand, of the prevention policy against natural risks (development of the Risks Prevention Plans - PPR) and on the other hand, of controlling the authorized hydraulic works - is more and more active since 1994 on the technical and legal aspects of the dike safety issue, with technical assistance from CEMAGREF.

PROJECT HISTORY AND METHODOLOGY

Needs for a "dike GIS"

Considering the huge amount of data required for assessing and managing dike systems, as well as the importance of geo-positioning these data, CEMAGREF decided in 1998 to investigate the opportunity and feasibility of a GIS.

Strategic diagnosis

Using a structured approach for analysing and designing Information Systems (Rouzet & Labbé, 1997), CEMAGREF financed and carried out in 1998 a first study called "strategic diagnosis" (Belouze, 1999). Loire and Vidourle rivers managers as well as people from the Ministry of Environment were interviewed on their practices and their expectations of a GIS. Analysing these two diked up areas was interesting since they are very different, both from the hydraulic and organisational points of view.

This study resulted in a typology of diked up systems management and planning activities. This typology is represented by a double entry grid (Table 1): the columns correspond to the three main management activities and the rows correspond to three geographical levels of management and planning. Each cell corresponds to specific management and/or planning activities based on a distinct information system, computerized or not.

The interviews results confirmed the opportunity of our GIS approach. Moreover, this study allowed identifying which activities, among the range described in Table 1, the GIS should focus on. The priority should be given to a GIS for dikes and river bed management at the intermediary level handled by the local managers. The GIS should also be able to manage mor e accurate information (1:500 scale) but just in the form of documents and not of detailed geographic database.

	Prevention / planning		**Crisis**
	Dikes and river bed management	**Flood plains management**	**Crisis management**
1/25.000	Works and maintenance programming	Hazard / negotiations of protection objectives	Intervention plan and flood warning system
1/10.000 1/5.000	Dikes diagnosis Vegetation maintenance	Zoning Plan regulations (land-use policy)	Vigilance plan by sector
1/500	Topography and visual inspection of dikes Works realisation	Public river domain management	Intervention on weak points (breaches, coffer dams)

Table 1 : Systemic view of diked up systems management and planning activities

[6] Ministère de l' Ecologie et du Dévelopment Durable [Ministry of Ecology and Sustainable Development

Generic "Dikes GIS" model

The next phase, started in 1999 and completed in 2000, aimed to assess, on a technical point of view, the local managers needs in term of information and functionalities. With the financial support from the Ministry of Environment, CEMAGREF then developed a GIS prototype based on a generic conceptual model to help the managers better understand the tool potential and thus, refine their expectations (Pardo, 1999, Cemagref, 2000, Chryat, 2000, Paquier et al, 2000, Maurel et al, 2000, Maurel et al, 2001b).

This model was developed on the Cisse river levee and valley, located in the Loire middle course.

The conceptual data model of a generic diked up area took into account the results of the research undertaken by CEMAGREF in the field of dike diagnosis.

The prototype combined an alphanumeric database linked to geographical data managed with a GIS. No particular Graphic User Interface (GUI) was developed at this stage of the project. The database was including general cartographic documents used as a background, dikes technical data, data relating to the vigilance plans, and finally hydraulic computation outputs for several dike breaking scenarios. The prototype presentation to several regional and national stakeholders once more confirmed their interest for developing such a GIS.

ONGOING DEVELOPMENTS: ANALYSIS AND DESIGN

GIS detailed study for Camargue

The model was then presented on various occasions to several local dike managers. Among them, SYMADREM (association of local authorities, in charge of the dikes along the Rhône river and the Mediterranean coast in Camargue) was very interested by a fast development of a GIS adapted to its own situation.

The Camargue dikes and SYMADREM

The dikes of the Camargue area mainly protect the large delta formed by the two arms of the Rhône, which branch off just above Arles city. The wedge of low land between these two branches is called Camargue. Arles south-western districts constitute, with the three localities of Saintes-Maries-de-la-Mer, Salin-de-Giraud and Port-Saint-Louis-du-Rhone, the main urban areas exposed in this easily flooded area. The dike system includes:

- the left bank dike of the Petit Rhône, from Arles to the sea (44 km long), and the final part of its right bank dike (10 km long) ;
- the right bank dike of the Grand Rhône, from Arles to the sea (58 km long) and its left bank dike from Arles to Port-Saint-Louis (40 km long) ;
- the "maritime dike" in the South which protects the Camargue from sea level rises, between Saintes-Maries and Salin-de-Giraud (about 40 km long).

The dikes of the Provence part of Camargue are thus approximately 200 km long. Built in the middle of the 19th century from grounds mainly extracted near their foot, they have an average height of 5 m and a narrow original profile: the average width on the crest is 2 m only and slope ranges from 1/1 to 1/2. Most of the time, the dikes are separated from the river by a wooded or cultivated fringe, named "ségonnal" in local toponymy. The dikes themselves form arid embankments, not very favourable to the growing of arborescent vegetation. When they are not well kept, they are invaded by a large reed, called “Canne de Provence”.

These dikes came into the limelight during the Rhône river floods in October 1993 and January 1994. They broke in 16 places, causing two successive floodings of most of the Camargue plain. These events leaded to the creation of SYMADREM to replace the old defaulting land owners associations. SYMADREM now is responsible for the management of all the dikes described before. The average annual budget of SYMADREM is roughly 4.6 million Euros, coming from the Provence-Alpes-Cote

d'Azur Region authority (30 %), the Bouches-du-Rhône Department authority (25 %), the three communal authorities of the delta (5%). The remaining 40% are financed by the State. Nine people are employed by the association, including five dikes watchers.

GIS specifications for Camargue

2001 was then devoted to study the GIS technical, economic and organisational feasibility for this particular diked up area (Turpeaud, 2001, Maurel et al, 2001a). That was done in collaboration with SYMADREM, and DDE[7] of Bouches-du-Rhône, SYMADREM's main engineering contractor for studies and works. Several scenarios for developing and implementing the GIS were proposed. After choosing one of these scenarios, the terms of reference of the information system was prepared by CEMAGREF on behalf of SYMADREM.

GIS detailed study for Isere

In 2002, a new dike manager, the Departmental Association for Isere, Drac and Romanche (AD-IDR) rivers expressed its high interest in a GIS adapted to its own needs. After a negotiation phase between the project partners (SYMADREM, AD-IDR and CEMAGREF), it was decided to take into account the specific AD-IDR needs, and to develop a GIS suited to both managers.

Isere dikes

The first dikes to protect Grenoble urban area were built by Associations created by royal decrees. These Associations have been transformed into ASA[8] or ASF[9] after the 1859 historical flood. Actually, 13 residents Associations cover all the Isere river from the boundary with the department of Savoie upstream, up to St Gervais-le-Port downstream, as well as the mountain streams of Drac and Romanche.

The current dikes profile results from work carried out at the end of 19th century and the beginning of 20th century, then from reinforcements mainly financed by the state government in the 1930th:

- internal structure with an earth core (old dike from the 19th century) covered, on all its faces, by uncompacted crusher-run aggregate up to 2 meters thick (dikes raising done in the 20th century);
- both slopes values are 2(V)/3(H), with a river-side slope protection;
- dikes crest about 4 m wide, supporting a traffic path, sometimes bituminized (cycle track).

The two ten year return period floods which occurred during winter 2000-2001 somewhat deteriorated the confidence placed until there in the works. Indeed, visual monitoring allowed to locate alarming disorders:

- a zone where the free board was reduced to less than 40 cm (for a flood with a ten years return period!)
- piping in two places with starting materials erosion, but without breach;
- about ten places with observable seepage on the downstream slope;
- a subsidence observed 3 to 4 weeks after the last flood.

AD-IDR, which now manages all these dikes (total length about 200 km), was created in 1936 through the impetus given by the State. It is an administrative public agency (EPA : Etablissement Public à Caractère Administratif) which gathers the Department local authority (50%), 62 bordering commune authorities (25%) and 13 originel land owners associations(25 %). Its investment budget is about 2.5 million Euros and it aims to develop, maintain and repair the existing works. Ten people including four technicians and two field agents are employed to fulfil these tasks.

Similarities and differences between SYMADREM and AD-IDR

The history, the length and the height of the dikes, on one hand, and management organizations size, on the other hand, are similar in both Camargue and Isère dike systems. Nonetheless, a significant

[7] Department Direction for Public Works
[8] Authorized Union Association (a type of assocaition of property owners, organized by law)
[9] Forced Union Association (a type of assocaition of property owners, organized by law)

geomorphological difference concerns the dikes setting outcompared to the river bank. Unlike the dikes of Camargue, those of Isere, most of the time, are located in the immediate vicinity or even directly extend the (generally stiff) river bank. This situation exposes them directly to the risks of scouring and/or mechanical instability. Moreover it keeps a high water content inside the dikes, which favours the growing of large trees on the slopes.

In addition, administrative statuses, as well as outside partners are different in both cases.

Specifications for a common GIS between SYMADREM and AD-IDR

The computer application specifications were formalized in a new version of the terms of reference and were validated by SYMADREM and AD-IDR during several common working meetings. Related supportive actions were also defined: specifications of field observation methods, staff training and coupling with other information systems already used by the managers.

The accumulated experience on the Cisse, Camargue and Isere diked up areas studies and during other occasions (strategic diagnosis phase, exchanges with other dike managers during professional training courses) provided enough elements to elaborate the specifications of a generic software application.

A generic data model for the software application

The expectations from SYMADREM and AD-IDR managers concerning the GIS are as follows:

- easier information handling and retrieval, particularly through geographical and alphanumeric queries;
- improved mapping production;
- speeding up tasks execution;
- fast and reliable service to satisfy external requests for information.

A thorough conceptual modeling of the data base and data-processing of the GIS application were carried out by CEMAGREF, based on the analysis of the current situations and the expressed needs in the three diked up areas (Cisse, Camargue and Isere).

This modeling was carried out in such a way that the GIS application core is able to efficiently store and manage the data patrimony, while remaining sufficiently flexible to accommodate various diked up situations. In this sense, the “dike GIS” is considered as generic.

Information safeguarding

Being able to follow the evolution of a work in order to establish a reliable diagnosis of its role and safety against flooding is a major concern. A special attention was paid in the model to managing spatio-temporal elements so that the software user can retrieve for example past dike conditions, historical floods or other disorders, repairs or reinforcements. Such a tool will help safeguard all the dikes informational patrimony in an efficient way. It brings a solution to the traditional problem of progressive or brutal forgetting of past situations, in particular when dikes watchers are retiring or leaving their position. This is the case for SYMADREM and AD-IDR, but probably also for every dyke system in France.

Adaptability of the generic GIS data model

The data model is organized into four groups (called packages in UML[10] language) of classes. The current data model version includes around one hundred and fifty object classes.

The part of the data model covered by the first version of the GIS application, which is currently under development, is delimited by the dotted lines. It includes two main packages, "Dikes and river bed management" and "Managers" as well as two sub-packages, "hydraulic modelling " and "floods history". We consider that it corresponds to the generic part, which is common to all the diked up situations in France. Packages "management and land planning of the flooding area" and "vigilance plan" might be developed in later versions according to managers expectations. If these functionalities are already

[10] Unified Modelitg Language

computerized in certain diked up areas, we will just focus in this case on the interoperability between the GIS and these other information systems.

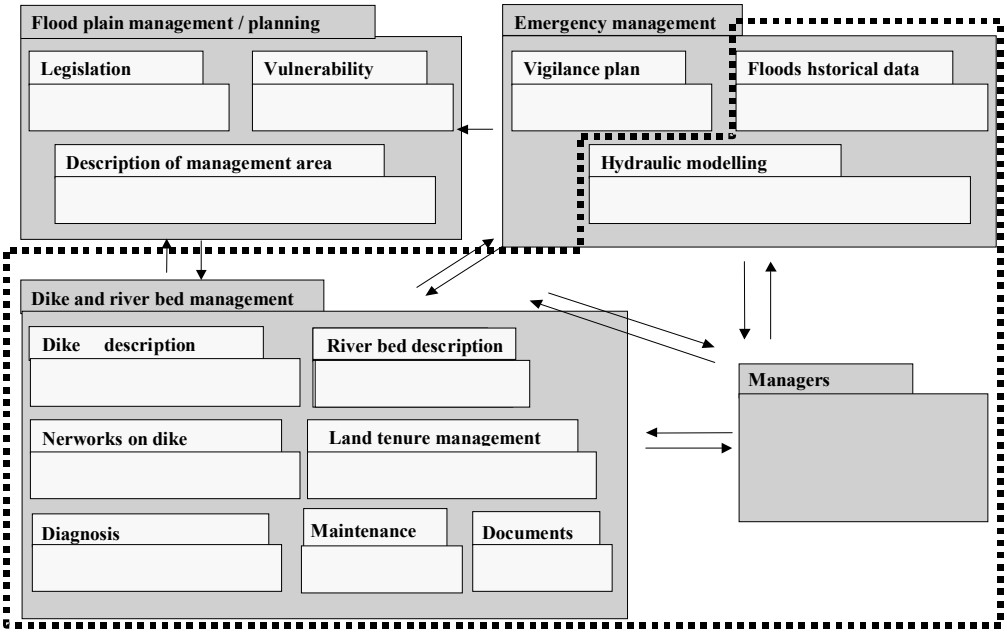

Figure 1: Data conceptual model main packages (Packages included in the 1st version of the GIS, currently under development, are surrounded by dotted lines)

In the "dike description" package, a dike cross section is modelled by 6 elements written in bold in figure 2.

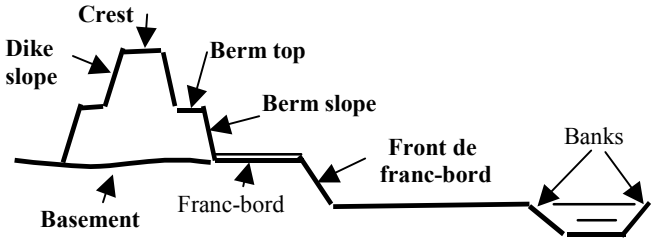

Figure 2: Dike cross section modeling.

This diagram corresponds to the most complex case of a dike cross section. In this sense, it can be seen as generic. However, in most diked up situations, the cross section is simpler: absence of berm and/or "franc-bord" (Isère case), "franc-bord" slope identical to the bank (Camargue case).

The characteristics of these various cross section elements (e.g. for the crest, its geometry, its made up) are described longitudinally in the shape of homogeneous sections using the multicriteria dynamic segmentation technic . This requires to locate all information on the dikes using explicit linear reference

systems, landmarked and used by the agents in charge of field observations. In Isere, landmarks are positioned every 200 m because the dense tree coverage prevents GPS use and thus obliges to position field observations in comparison with the landmarks. In Camargue, since the dikes are relatively free of trees, positioning with GPS will be possible and the landmark system will consequently be less dense than in Isere. The GIS application under development is able to handle several linear reference systems as well as classical cartographic projection systems. Specific tools have been developed to convert GPS coordinates into dike linear coordinates. These functionalities are consolidating the generic character of the application.

Field data collecting

Feeding the GIS with good quality data will be one of the key conditions of appropriation of this tool by the final users. Since the dike guards are the main data providers, a very detailed attention was paid to elaborate field observation cards.

Part of the data will have to be collected, during a heavy initial census, but these data will not afterwards require regular updating. They concern the dike external structure as well as hydraulic, energy and roadway networks. After this period, the dike guards will be mobilized episodically for hydraulic surveys and visual inspections in case of floods (during the crisis and after). They will also have periodically to observe disorders and to monitor the repairing works.

Our approach consisted in elaborating field survey cards as ergonomic as possible for an operational use in the field, independently from the software application, then to develop on this basis graphic user interfaces for data capture.

Since the beginning, staff from SYMADREM and AD-IDR has been closely associated to the project. Several tests have been carried out to optimize the field survey methods, particularly for the initial census phase (number of agents, allocation of roles, equipment and survey cards).

ON-GOING DEVELOPMENTS: CODING AND IMPLEMENTATION

Year 2003 is devoted to the GIS application development by a software firm, then to its deployment within SYMADREM and AD-IDR. Both organizations are co-owners of the contract carried out in the frame of a national call for tenders (Maurel et al, 2002a, Maurel et al, 2002b). CEMAGREF intervenes as a third party, as technical advisor for the Project Owners.

GIS application Programming

Several contractual documents were written at the very start of the study. In the Quality Plan, responsibility, role, and the intervention framework of each person were specified. A working organization including the information exchange procedures was also elaborated. Technical and pilot committees gave opportunity to narrowly associate the managers to the definition and the validation of the software. The administrative provisions were discussed and included in a document specifying the administrative clauses of the contract (CCAP). Among other things, this document specifies the deadlines, the delay penalties and the distribution among the partners of controls and tests of the software.

The GIS application code is the joint ownership of SYMADREM and AD-IDR. CEMAGREF, on its side, has the right to use the application for research, teaching and demonstration purposes. It can also improve the initial data model.

The application development is based on ArcGIS (© ESRI) and Access (© Microsoft) softwares, and includes four successive prototypes to better control the evolution of the development. Each prototype is defined by detailed terms of reference based on the general specifications of the application initially defined. The detailed specifications and the development of each new prototype start as soon as the previous one has been validated.

Implementation of the application at SYMADREM and AD-IDR

During the deployment of the application, at the beginning of 2004, staff training as well as technical assistance are planned for several months to help the managers take in hand this tool and adapt their working procedures, in particular the way to conduct field surveys.

CONCLUSION

The main benefit of implementing a GIS dedicated to the management of flood protection dikes is obviously the preservation of information for the future. It was indeed noted, since Cemagref started to work on dikes, that very few information about dikes was unfortunately available at a given moment (loss of information in the course of time due to the loss of files or of "living memory"). The GIS under development will allow to get a description of the dike not only at the current date, but also for previous periods, which is useful when a diagnosis has to be carried out.

Since the method of development chosen by Cemagref is based on a generic dike model already defined, its advantage is that some specificities only will have to be added to adapt the application to new dike up situations.

The initial phase called “strategic diagnosis”, has made possible to conceive this GIS dedicated to dike managers, while keeping in mind the wider context of the integrated management of diked up flood plains. In the future, that will facilitate the interoperability of such an information system with those belonging to other stakeholders.

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