A SIRS for flood protection dikes management: from user's needs to application

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English summary

France counts several thousands kilometres of flood-protection dikes. Methods for evaluating and improving their safety, as well as the safety of the protected areas, are essential. This also raises the problem of long term management of dikes-related data. As dikes are long linear structures, georefencing these data is essential. Cemagref is currently working on the design, development of a new SIRS (Spatial Information-Reference System) to be able to inventory the dikes, to describe their state, to plan their follow-up and maintenance, and also to describe their surroundings.
The history of this process, from the opportunity study to the actual implementation of the SIRS for the management of two real dike systems, is described in this paper.

Résumé français : *Un SIRS pour la gestion des digues de protection contre les inondations : de l'analyse des besoins à l'application*

La France compte plusieurs milliers de kilomètres de digues de protection contre les inondations. Les méthodes pour évaluer et renforcer la sécurité des digues, ainsi que la sécurité des zones protégées, sont essentielles. Cela pose entre autres le problème de la gestion à long terme des données relatives aux digues. Comme les digues sont des structures à fort linéaire, le référencement géographique de ces données est essentiel. Le Cemagref a travaillé sur la conception, le développement et le déploiement d'un SIRS (Système d'Information à Référence Spatiale), pour : inventorier les digues, décrire leur état, planifier leur suivi et leur maintenance, ainsi que de connaître leur environnement.
L'historique de la démarche, depuis l'étude d'opportunité jusqu'à l'implémentation pour la gestion de deux systèmes endigués réels, est décrite dans le présent article.

Streszczenie polskie : ***Projekt SIRS do zarządzania wałami przeciwpowodziowymi : od określenia potrzeb użytkowników do zastosowań praktycznych***

We Francji istnieje wiele tysięcy kilometrów wałów przeciw powodziowych. Niezwykle istotnymi są metody oceny i poprawy ich bezpieczeństwa, jak też metody ochrony terenów przyległych. Związane to jest z zarządzaniem bazą danych dotyczących wałów. Ze względu na linearność wałów, ważnym jest usytuowanie przestrzenne danych. Cemagref pracował nad taką koncepcją, jej rozwojem i zastosowaniem SIRS (Przestrzenny System Informacjno-Referencyjny) w celu umożliwienia inwentaryzacji wałów, opisu ich stanu i planowania nadzoru i utrzymania, jak też do rozpoznania ich otoczenia.
W artykule przedstawiona jest historia powstania programu, oraz studium możliwości zastosowania SIRS-u do zarządzania dwoma rzeczywistymi systemami wałów.

1.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, 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 Authorities (e.g. the Ouvèze, Agly, and Vidourle rivers and the Camargue area) or even private individuals.

The floods which occurred during these last years notoriously highlighted the lack of safety from these ageing hydraulic works: ruptures of dikes 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 arise for 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 flood. Risks study and prevention turn out to be 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. Thus the issue of the flood-protection dikes safety, its assessment and reinforcement, is presently crucial. The French Ministry of Environment (MEDD) - 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 the assistance of CEMAGREF.

2. History of the project and methodology

2.1. Needs for a "dike SIRS"

Considering the huge amount of data required for monitoring 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 SIRS[1].

2.2. Strategic diagnosis

Using a structured approach for analysing and designing Information Systems (Rouzet C., and Labbé S., 1997), CEMAGREF financed and carried out in 1998 a first study called "strategic diagnosis" (Belouze P., 1999). Loire and Vidourle rivers managers as well as people from the Ministry of Environment were interviewed on their current practices and their expectations concerning a SIRS. Analysing these

[1] *Spatial Information-Reference System*

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 lines 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.

	Prevention / planning		**Crisis**
	Dikes and river bed management	**Flood plains management**	**Crisis management**
1/25.000	Programming of works and maintenance	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

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

2.3. Generic " Dikes SIRS " model

The next phase, started in 1999 and completed in 2000, aimed to assess, from a technical point of view, the local managers needs in term of information and functionalities. With the support of the Ministry in charge of Environment, CEMAGREF then developed a SIRS prototype based on a generic conceptual model to help the managers to understand better the potential of the tool and thus, refine their expectations (Pardo C, 1999, Cemagref, 2000, Chryat Mr., 2000, Paquier A., and al., 2000, Maurel P., et al., 2000, Maurel P., 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 dike up area took into account the results of the research undertaken by CEMAGREF in the field of dike diagnosing.
The prototype combined an alphanumeric database linked to geographical data managed through 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 presentation of the prototype to several regional and national stakeholders once more confirmed their interest in developing such a SIRS.

3. Ongoing developments: analysis and design

3.1. SIRS detailed study of 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 SIRS adapted to its own situation.

3.1.1. 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 fork off just upstream from 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-Rhône, 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 the right bank dike (10 km long) ;
- the right bank dike of the Grand Rhône, from Arles to the sea (58 km long) and the 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 development of arborescent vegetation. When they are not maintained, they are invaded by a large reed, called “canne de Provence” (Arundo Donax).

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 is now 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-Côte 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. The association employs nine people, including five dikes watchers.

3.1.2. SIRS specifications for Camargue

2001 was then devoted to study the technical, economic and organisational feasibility of the SIRS for this particular diked up area (Turpeaud B. 2001, Maurel P., et al. 2001a). This was done in collaboration with SYMADREM, and DDE[2] of Bouches-du-Rhône, SYMADREM's main engineering contractor for studies and works. Several scenarios for developing and implementing the SIRS were proposed. After choosing one of these scenarios, the terms of reference of the information system was prepared by CEMAGREF on behalf of SYMADREM.

3.2. SIRS 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 SIRS adapted to its own needs. After a phase of negotiation 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 SIRS suited to both managers.

3.2.1. 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[3] or ASF[4] after the 1859 historical flood. Presently, 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 profile of the dikes 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 a core of earth (old dike from the 19th century) covered, on all its faces, by uncompacted crusher-run aggregate up to 2 meters thick (raising of the dikes done in the 20th century);
- both slopes values are 2(V)/3(H), with a protection of the river-side slope;
- crest of the dikes 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, the 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 erosion of materials, but without breach;
- about ten places with observable seepage on the downstream slope;

[2] Departmental Direction for Public Works
[3] Authorized Union Association (a type of association of property owners, organized by law)
[4] Forced Union Association (a type of association of property owners, organized by law)

- 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 associations of original land owners (25 %). Its investment budget is about 2.5 millions Euros and it aims to develop, maintain and repair the existing works. Ten people including four technicians and two field agents are employed to fulfill these tasks.

3.2.2. Similarities and differences between SYMADREM and AD-IDR

The history, length and height of the dikes, on one hand, and the size of the management organizations, on the other hand, are similar in both Camargue and Isère diked up systems. Nonetheless, a significant geomorphological difference concerns the setting out of the dikes compared 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.

3.2.3. Specifications for a common SIRS 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.

3.3. Continuation of work on a generic SIRS

The accumulated experience on the Cisse, Camargue and Isere diked up areas 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.

3.4. SIRS specifications for Camargue and Isere

3.4.1. A generic data model for the software application

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

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

A thorough conceptual modeling work of the data base and data-processing of the SIRS 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 core of the SIRS application is able to efficiently store and manage the data patrimony, while remaining sufficiently flexible to accomodate various diked up situations. In this sense, the "dike SIRS" 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 against flooding is a major concern. A special attention was paid to the model managing temporal elements so that the software user can retrieve for example past dike conditions, historical floods or other disorders. 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 the world.

Adaptability of the generic SIRS data model
The data model is organized into four groups (called packages in UML[5] language) of classes. The current version of the data model includes about one hundred and fifty object classes.
The part of the data model covered by the first version of the SIRS 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 modeling " 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 computerized in certain diked up areas, we will just focus in this case on the interoperability between the SIRS and these other information systems.

[5] UML : Unified Modeling Language

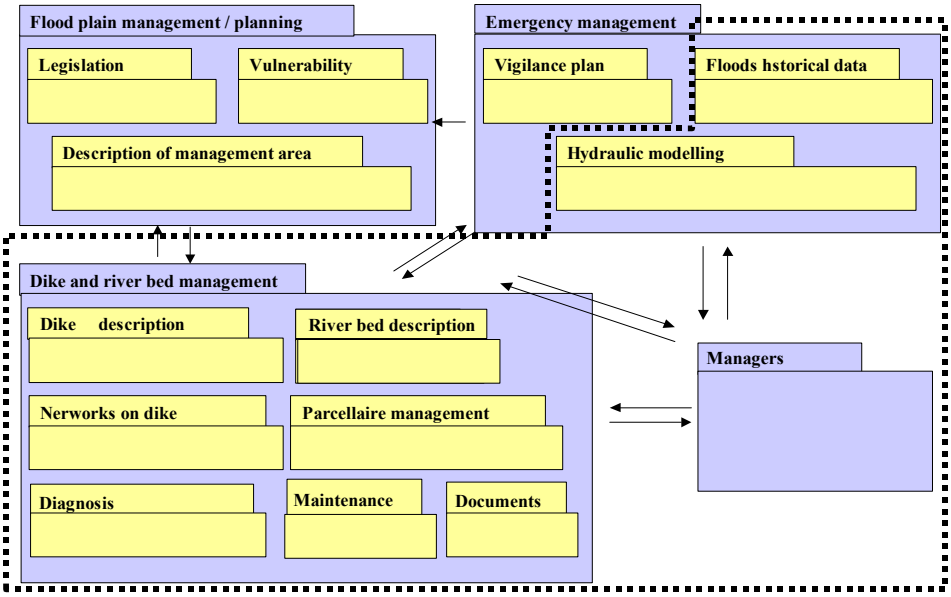
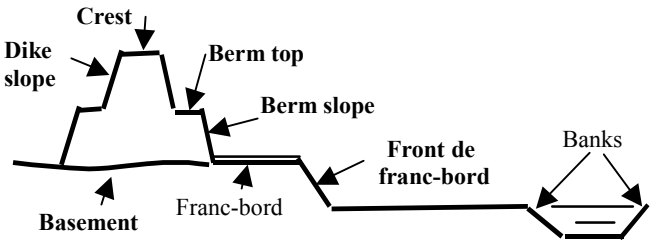


Figure 1: Data conceptual model main packages (Packages included in the 1st version of the SIRS, currently under development, are surrounded by dotted lines)

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

Figure 2: Cross section modeling of a dike.



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 elements (e.g. for the crest, its geometry, its composition) are described longitudinally in the shape of homogeneous sections. 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 SIRS 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.

3.4.2. Field data collecting

Feeding the SIRS 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 frequent updating. They concern the external structure of the dike 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). Periodically they will also have 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).

4. On-going developments: coding et implementation

Year 2003 is devoted to the development of the SIRS application 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 P., et al. 2002a, Maurel P., et al. 2002b). CEMAGREF intervenes as a third party, as technical advisor for the Project Owners.

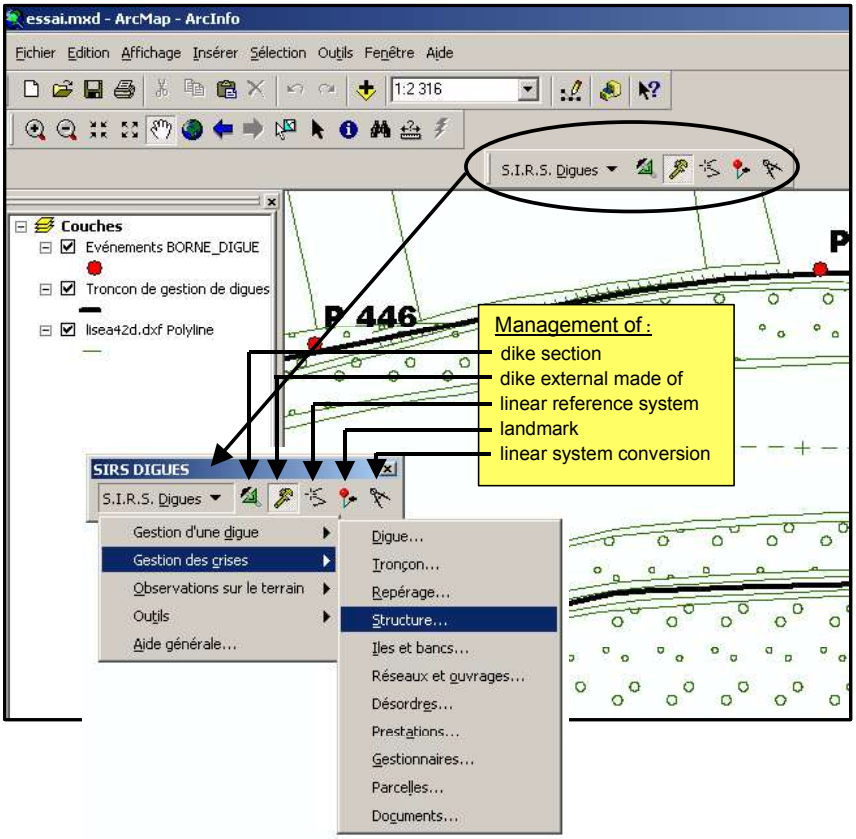
4.1 Programming of the SIRS application

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 SIRS 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 development of the application is based on ArcGIS (© ESRI) and Access (© Microsoft) software, and includes four successives 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 which were defined in the first place. The specifications and the development of each new prototype start as soon as the previous one has been validated.

Figure 3: Illustration of the interface of the SIRS application under development



4.2 Implementation of the application at the dikes

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.

5. Prospects for improvement

In parallel, studies on two new sites have been launched in 2003, aiming to extend the use of the SIRS to new diked up situations. An additional research work is focusing on dike safety indicators. All these studies will contribute to improve or even to extend the generic model.

5.1. Loire river

A study, financed by the Regional Directorate for the Environment (DIREN) of Loire-Brittany, more widely relates to the diagnosis and the prospects in term of data-processing for the management of the fluvial public domain on the Loire. The private engineering firm ISL and CEMAGREF collaborated to this study. After developing interview grids, interviews with various state services implied in the management of the dikes were carried out. The results allowed to define the potential use of a tool similar to the SIRS. However, the technical and institutional situation is much more complex than in the cases of Camargue and Isère, mainly because of the presence of several administrative services, acting at various levels.

Some state technical services in charge of dikes management are fully able to exploit a tool such as the SIRS, of course adapted to their own needs. Some of these services have to manage other types of information that could be integrated into the SIRS. Some other ones, for example at the regional, basin or national levels, which are exchanging data with the dike managing units, expressed some needs that are not covered by the current SIRS project yet.

In this context, usefulness of co-operative and multi-scales information systems is obvious.

5.2 Vistula river (Poland)

The second study is part of a partnership with Polish Polytechnic Institute of Cracow. A first meeting, held in February 2003, validated the interest of Polish partners to test the SIRS tool on the Vistula river dike system. A work program has started in September 2003, with the coming at CEMAGREF of a Polish researcher. Before the end of 2003, two main tasks will be simultaneously performed : testing the SIRS with a Polish dikes data set and carrying out a strategic diagnosis of the Polish dikes context by making an inventory of the various actors and data flows.

5.3. Production of safety indicators for dikes

A PhD thesis has started at CEMAGREF in November 2002 to produce indicators for the risk of dike failure. These indicators should later be integrated in the SIRS model (Serre D, 2003).

A first phase under progress includes a review of literature on GIS dedicated to linear infrastructures (channels, roads, tunnels, etc.) and/or on networks (irrigation systems, pipes, etc.), as well as state indicators for these types of structures.

Then, using a functional analysis method developed for dams (Peyras L, 2003), the next step will be to determine the role of each component of the dike (body of dike,

crest, upstream slope, downstream slope) and the mechanisms liable to prevent each element from functioning correctly.

Four risks are taken into account: overflow, internal erosion, scouring and slopes sliding (Degoutte, 1999). To each of these risks, the concerned dikes elements will be associated : for example, in the case of the overflow risk, the associated elements are the type of coating on the crest and the value of the slope opposite to the river side. Once these associations defined, it will thus become possible to construct safety indicators. A notation scale adapted to dike manager decision-making will have to be defined.

In all cases, the SIRS should contain, if not the model of calculation of these indicators, at the very least the input data necessary to this model.

6. Conclusion

The main benefit of implementing a SIRS dedicated to the management of flood protection dikes is, of course, the preservation of information for the future. It was indeed noted, since Cemagref started to work on dikes, that unfortunately very few information about dikes was available at a given moment (loss of information in the course of time due to the loss of files or of "living memory"). The SIRS 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 only some specificities will have to be added to adapt the application to new diked up situations.

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

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