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Towards a spatial information infrastructure for flood management in The Netherlands

Scholten, Henk J.[1*], LoCashio, Andrea[1,2] & Overduin, Theo[3]

[1]*Geodan IT BV, Jan Luijkenstraat 10, 1071 CM Amsterdam, The Netherlands; E-mail henk@geodan.nl;* [2]*Vrije Universiteit, De Boelelaan 1105, room 2E-02, 1081 HV Amsterdam, The Netherlands; E-mail andrea@geodan.nl;* [3]*Province of Gelderland, P.O. Box 9090, 6800 GX Amsterdam, The Netherlands; E-mail t.overduin@prv.gelderland.nl*

Abstract. The immense value of a geographic information system for flood control has been experienced by the decision-makers of the Dutch province of Gelderland during the flood of the Rivers Meuse (Maas) and Waal in January 1995. Superimposing different 'data layers', GIS-experts could detect the weak parts in the dikes and generate an evacuation plan. Shortcomings within the organization were experienced as well: important data could not be retrieved, and the coordination of efforts by the different governmental departments and institutions was not optimal. To overcome these shortcomings and to optimize the modelling process, a spatial decision support system (SDSS) is being proposed, aggregating several models, heuristic and procedural, into integrated software tools. As becomes clear from two cases of flood control described, 'emergency managers' should be able to communicate about spatial data available and have access to selected spatial data. In order to improve communication between data sources, data processing and the use of relevant spatial data in GISs, a new 'Spatial Information Infrastructure' (SII) needs to be developed. This requires both technical and organizational solutions and standards. Proper documentation of the data will allow the GIS-experts to more quickly find, store, update and reuse the data. A range of 'metadata' services exist documenting data sets, typically limited by thematic or national boundaries. There are no standards in common practice for structuring and classifying spatial information. The user of spatial information cannot easily browse across Web-sites and compare products from different suppliers. Even if the search has been successful, the user all too often has to face a complex process of negotiation, and highly technical data integration issues. A consortium of European GIS-experts has addressed these problems and launched the 'European Spatial Metadata Infrastructure' (ESMI) project with the objective to link existing and future metadata systems using Internet.

Keywords: Emergency management; GIS; Metadata system; Meuss; Oder; Risk assessment; River flooding; Spatial Decision Support System; Spatial Information Infrastructure; Waal.

Abbreviations: GIS =Geographic Information System; ESMI =European Spatial Metadata Infrastructure; SDSS =Spatial Decision Support System; SII =Spatial Information Infrastructure.

Introduction: Example of a river flooding

On 30 January 1995, the water levels of the Dutch rivers Waal and Maas were rising at an alarming rate and there was a threat of dike breaches (Fig. 1), particularly in the southwestern part of the province of Gelderland (Fig. 2). The development of this catastrophe and its consequences will be described in this paper, as an example of calamities and their management in lowland countries with both major rivers and a relatively long coastline. As in earlier similar cases, important decisions had to be made by provincial and national authorities at extreme speed as enormous interests were at stake. Strategic information needed to be available to support these decisions directed at minimizing loss of human lives, livestock and economic damages.

Obviously, an operational 'geographical information infrastructure' would be of great value in such a situation, where data need to be integrated and analysed and information needs to be presented in a fast and flexible manner. In retrospect, much went wrong in the attempts to cope with this near-catastrophe regarding the integration of data, links with the available models, and the information to support decisions and communication, while not all authorities involved had access to the available information. Yet, it was generally felt that on the whole the province of Gelderland coped well with this kind of extreme situation, thanks to the GIS which had been developed by experts of the Province (Akker et al. 1995).

Using a GIS and having access to data of other, national water-management departments, the provincial water managers were able to estimate the risk of dike breaches and to calculate the speed and route by which population and livestock would have to be evacuated.

During the summer of 1997, the river Oder at the Polish-German border exceeded its bed. A flood disaster could not be prevented. The immediate demand for detailed information could not be supplied in time. The central civil defence organisation in Warsaw, Poland

Fig. 1. Dike reinforced with sandbags - January 1995 (photo by Rijkswaterstaat DWW, Delft).

concluded that the Polish government could have reacted more adequately if data on waterways, reservoirs and digital terrain models had been available. After this organisation started its central office in January 1997, only water level monitoring was possible. Data from other Polish institutions and adjoining German districts were needed to develop a model for risk assessment. An evacuation plan was not available. Not knowing where to find the data needed, the managers had not enough time to react adequately. A most important future step will be the development of emergency management plans.

Nearly all Dutch provinces and ministries now have developed a GIS-infrastructure based on ESRI software and Oracle and INGRES data bases. The GIS-infrastructure of the province of Gelderland is shown in Fig. 2, including recommendations for improvements.

How did this infrastructure contribute to solutions of the problems arising during the high-water crisis? First, it showed the consequences of the impeding flood. Second, these consequences were partitioned for specific groups, such as civilians, industry and commerce, and farming, including their livestock at risk. Third, measures were proposed fast. The first results arrived within two hours. Fourth, estimations of the expected damages as a result of the possible flooding and the economic consequences of an eventual evacuation were made.

The next step was to make an inventory of the *status quo* regarding dike reinforcements, differentiated into sections: (1) dikes already reinforced; (2) dikes being reinforced; and (3) in need of reinforcement. Maps showing soil conditions in combination with the strength of the dikes were an important part of the information for detecting possible weak spots.

Given the continued rise of the water, the safety of citizens and companies could no longer be guaranteed and the first decisions to evacuate people and livestock were taken during day 2. Boundaries of the areas to be evacuated were directly implemented into the GIS in order to ensure an up-to-date overview and further spatial analysis.

Many basic data were available in digital form and various models were available. However, digital elevation data of roads and railways were lacking, and a well-functioning, robust flood model, that would be able to simulate the consequences of a possible dike breach, were not available. Contacts were established with various regional and national institutions in order to obtain the missing data. There was no time to discuss exchange standards or possible data transformation. Fortunately, all important institutions were using the same software at the time. Still, much improvisation and creative thinking was necessary to derive an emergency solution and to visualize the possible consequences of dike breaches (Akker et al. 1995). The rivers reached their highest level in the afternoon of day 3. At that moment 210000 inhabitants of western Gelderland were evacuated, as well as 210000 cows, 184 000 pigs, 1.6 million chicken and 75000 other animals. At the end of the same week people (and animals) were allowed to return home.

Meanwhile an entirely new demand for GIS maps had been developed. Accelerated dike reinforcement in combination with other measures, such as deepening and widening of the river bed had suddenly become a hot political issue in The Netherlands again.

What can we learn from this experience?

In the case of Gelderland the GIS helped to prevent a disaster by enabling the authorities to react adequately and in time. The provincial officials were able to assess the number of inhabitants and companies concerned and the size of livestock threatened. Maps showing the soil conditions in combination with the strength of the dikes were generated quickly. In order to visualize the consequences of a dike breach, a model was designed based on the successive flooding of hydrological sub-areas, called ‘panden’ (Fig. 3).

After the first pand would have been filled up to the edge of the first obstacle, here highway A15, the second pand will fill up until the water again reaches the lowest point of the following obstacle, the Amsterdam-Rhine canal, to flood the following ‘panden’. Pand V turned out to have a higher threshold than the previous obstacle, the highway A2, and therefore was assumed to fill up to the last obstacle – the main dike to the left in Fig. 3. Assumptions were made on the volume of water per unit of time streaming into the panden in case of a dike breach and together with the volume of each pand, the time it would take per pand to fill up was calculated.

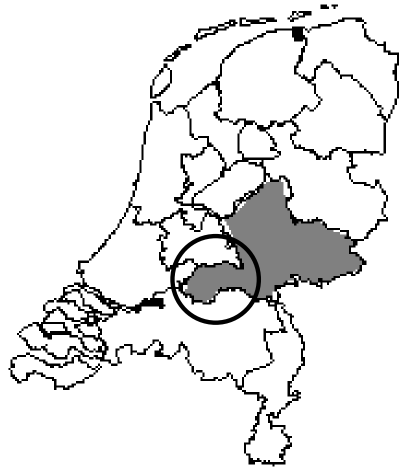

Fig. 2. GIS-infrastructure for the province of Gelderland, including three types of recommendations for improvement: *Data integration*: Define standards for format and quality of data within and between departments; formulate rules regarding frequency of data collection and storage (for, e.g., water level and dike quality); *Analysis*: Provide well-tested models; define link between models and information for decision-makers; *Communication*: Define communication rules and channels between analysts and decision-makers.

Boundaries of the province and position of the area between the Rivers Waal and Maas most critically threatened (circle) are indicated.

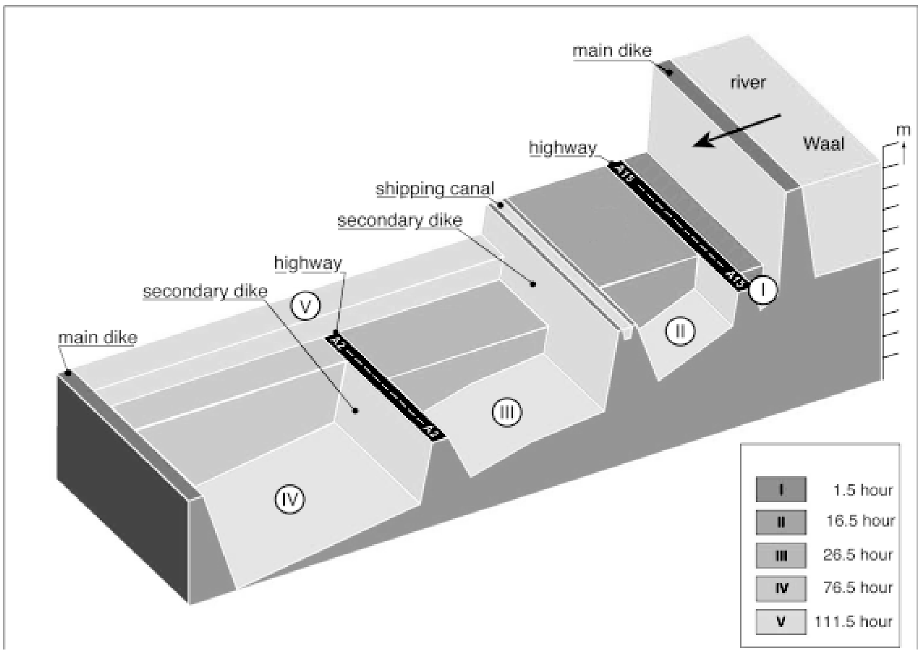

Fig. 3. Schematic presentation of the inundation model of hydrological sub-areas (‘panden’) and derived evacuation time per ‘pand’ (I-V) (Akker et al. 1995).

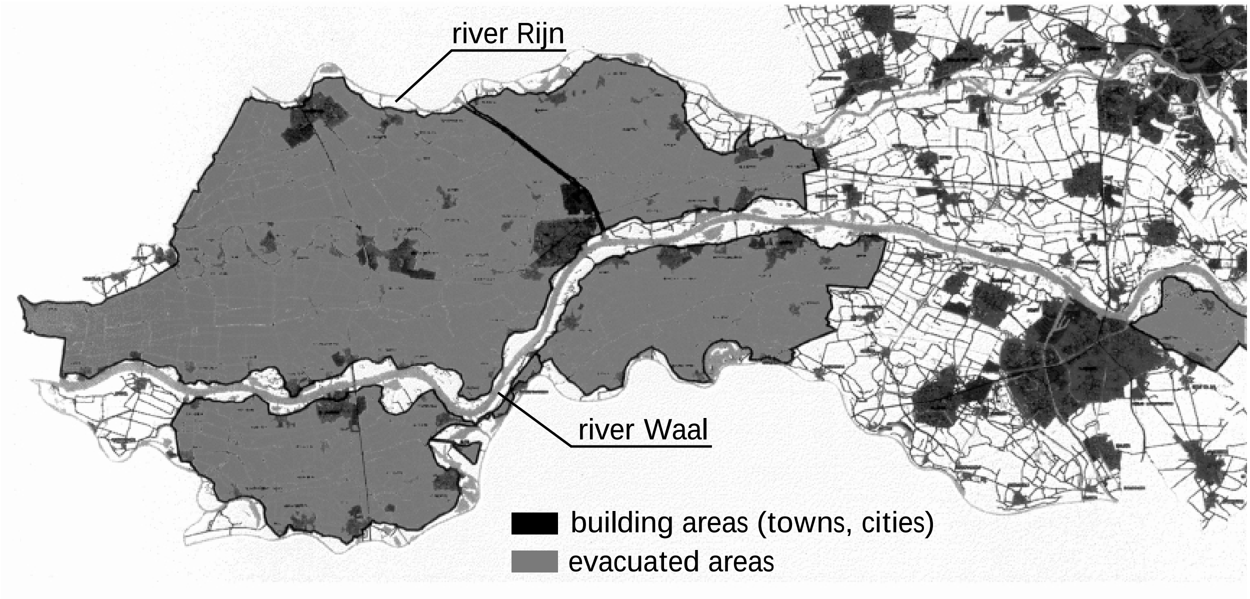

Fig. 4. Evacuated areas in the Province of Gelderland, The Netherlands (Akker et al. 1995).

Based on these results estimations were made on how fast the population and livestock would have to be evacuated. Shortcomings of these calculations were lack of time to thoroughly test the model, and absence of digital elevation data for roads and railways. On Day 3 this model –as improvized as it was – was completed and was immediately used. On the basis of this model and additional information, additional areas were evacuated, so that in total 640 km^2, or one third of the province, was involved (Fig. 4).

In retrospect, the application of the GIS was not optimal, especially regarding the coordination between the different authorities. Police, fire departments and other services should have had access to the same spatial information. The scenarios of the different evacuation plans asked for a lot of creativity at crucial moments. Further automation and structuring of these decision-support tools should have been achieved. Negative effects of the ad-hoc character of the decision-making could have been reduced by embedding the emergency management in a framework where exchange and access to data is regulated, knowledge and experience with modelling can be shared, and communication between involved departments is coordinated.

In both catastrophes, that in The Netherlands and that in Polen, the respective authorities and experts had to experience that the access to the necessary data, on the regional, national and multinational level, was the main obstacle in achieving a rapid, optimal management of the consequences. Thus the prevailing question remaining is: How to get access to the information needed?

The position of a GIS in flood-control projects

As GIS-technology is particularly designed to support applications with a strong spatial implication, it is obvious that GISs will take a central place in flood-control projects. Nowadays, GIS-technology entails a wide range of tools for storing, manipulating and presenting spatially related information. Many organizations and research laboratories in various fields collect data for planning and policy purposes and benefit increasingly from GIS-methodology to store and handle such data. Nevertheless, in the field of spatial analytical applications there is still a major discrepancy between GIS as an instrument for handling spatial data and GIS as a tool for exploratory, confirmatory or decision-supporting spatial analysis. In particular in this area an interesting research challenge rests in linking the tradi-

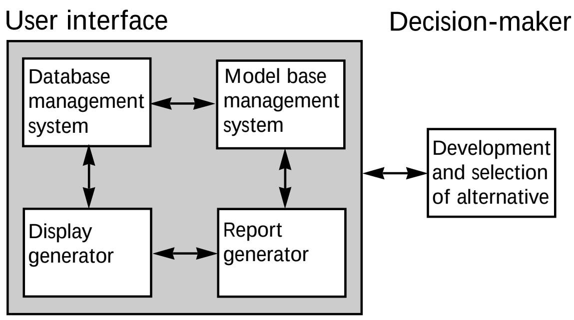

Fig. 5. Modules for a Spatial Decision Support System (Armstrong et al. 1986).

tional GIS functions to spatial analysis and evaluation to improve the quality of decision making. The flood application with its combination of spatial information, models and decision making offers an interesting opportunity to further explore this challenge.

An architecture and structure for such a GIS-'decision support environment' also called spatial decision support system (SDSS) is described by Armstrong et al. (1986) and shown in Fig. 5. The core of the system consists of a spatial database, a set of exploratory and confirmatory spatial models/techniques to analyse this data set and modules for displaying and graphically querying the outcomes (e.g. cartographic, exploratory and simple statistical techniques). Special attention should be given to data characteristics like resolution, reliability, standardisation and consistency (Thewessen et al. 1992). Another important issue is the analysis of the data. One of the key benefits of a GIS is that data collected from different sources can be related to generate new, previously unknown information. This can be achieved through overlay techniques with locational information or through combining attribute information using statistical or modelling techniques.

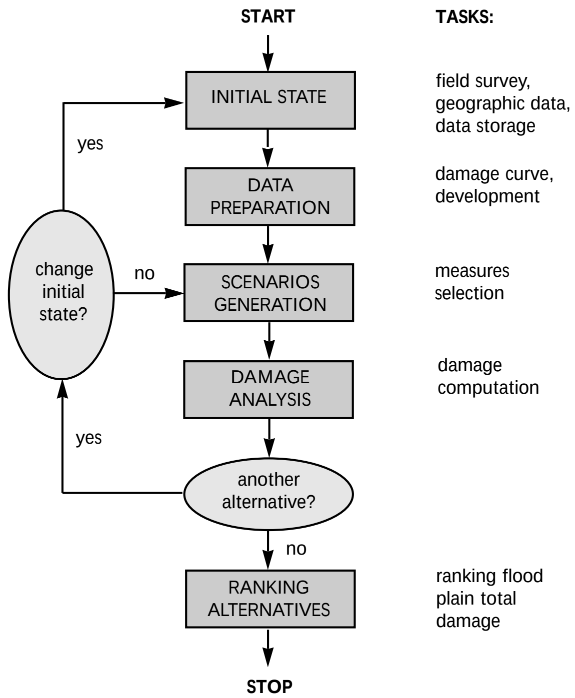

Fig. 6. Diagram showing the Flood Management Procedure (Simonovic 1993).

A SDSS for flood control management

A more structural approach for flood control management has been investigated by Simonovic (1993) by taking into account the need of managers for some form of subjective evaluation or informed judgement, in addition to the use of numerical models. Since floods affect different groups of people, decision makers have to consider that there may be different opinions on what should be the best solution to a prevailing problem. Through the aggregation of several models, procedural and heuristic, into integrated software tools, a decision support system is designed, focusing on the interface between the user and data, and models and computer (the human-model-machine interface). The system developed by Simonovic (1993) combines the use of optimization techniques and other numerical models with GIS, an expert system (ES) assisting in the input of data into the models to be used in flood damage analysis, engineering expertise and database management software. The architectural design of the DSS for flood control management basically follows the architecture for an SDSS as proposed by Armstrong et al (1986).

The design is based on a combination of a functional, decision process oriented approach, and a tool based approach. The result is a combined architecture built with four components: The system manager, database module, model base module and the display module. The system manager integrates the other parts of the system and also controls all the processes within the DSS, making use of expert system technology.

The SDSS provides support to the flood management. Simonovic (1993) distinguished four stages of a flood management procedure (Fig. 6). During the first stage, 'Initial State', a survey of all data related to the flood plain is conducted. These data are used in the second stage, 'Data Preparation', and processed for the mathematical models to be used for the flood damage analysis. The selection of structural and non-structural measurements takes place in stage 3, 'Scenarios Generation', generating different flood-management alternatives. Flood damage analysis for alternative flood control plans is performed in the last stage, 'Damage Analysis'. An expert system module assists in all stages through a sequential consultation designed to maintain the focus of the user on the necessary activities within each step of the process.

The stages described above can to some extent be identified in the case of Gelderland. The number of inhabitants and companies concerned and the size of livestock in the relevant area were assessed and maps showing the soil conditions in combination with the strength of the dikes were generated (Initial State). In order to visualise the consequences of a dike breach a model was designed, based on the successive flooding of hydrological sub-areas (Data Preparation). From this, rather improvised, model evacuation plans had been

Types of User	Information Demand	User Demand	Type of GIS	Development
Information specialist	Data	Analysis; flexibility	Large;flexible	Links to other packages
Policy-Maker	Data and pre-treated data (= Information)	Analysis; Good accessibility; Weighing and Optimizing models	Compact Manageable	Macro-languages; interfaces to other packages
Decision- Maker	Strategic information	Good accessibility; Assessing impacts of Alternative options	'Small and beautiful'; Transparent presentation	User-friendly interface; Key information
Interested Citizen	Information	Good accessibility	'Small and beautiful'; Transparent presentation	User-friendly interface

Fig. 7. Types of user demands for a Geographical Information System (GIS).

derived (Scenarios Generation). Due to lack of time and structural guidance the stage of Disaster Analysis of alternative flood control plans could not be performed. Much depended on the creativity of the provincial officials, which led to the ad-hoc character of several decisions made. The consultation of different data bases through the Expert System module can support the manager in the choice of data, models and parameters to be used as well as to select the optimal flood control measures.

Towards a spatial information infrastructure for water management

From the two examples mentioned in the Introduction it becomes clear that different kinds of users want to communicate with the 'flood-control GIS'. In order to improve communication between the data sources, data processing and the use by experts, a 'structure' needs to be defined and implemented to support this communication. Such a spatial infrastructure should, among others, be 'open' to many users, make data accessible and support the integration of data from various sources. To make this possible not only technical issues should be considered (such as computers, networks, data bases, GIS), but also organizational issues (procedures for e.g. data acquisition) and standards (e.g. for data exchange). GIS thus changes from a stand-alone environment towards an instrument embedded in this Spatial Information Infrastructure (SII).

At the organizational level there is a growing interest in improving communication between the data user and data-processing layer. Several large-scale initiatives have been launched to support and encourage the development of such an infrastructure. In the United States the clearing-house concept and the National Spatial Data Infrastructure (Tosta 1995) are examples of such initiatives. Similar activities have been started in Europe (INFO2000) and in the different member states (Kok 1995).

A Spatial Information Infrastructure is difficult to define. While a precise description may not be desirable, it can be perceived as a process which is in part directed and in part spontaneously developed. This process is taking place gradually and in close relationship with people working in the field. The SII is not a goal in itself, but will serve the objectives of interested parties. Elements playing a part in the SII are related to the various users, who have different demands for spatial information, but who share the same data. A SII can be defined as: 'A collection of policies, data sets, agreements, standards, technology (hardware, software and electronic communication) and knowledge providing the different users with the geographic information needed to carry out a specific task'.

Obviously, initiatives have to be undertaken to develop the SII for water management or flood control. In the next paragraphs we will present the progress that has been made in developing the 'soft' and the 'hard' parts of this infrastructure.

A spatial information infrastructure: framework

The case of the large-scale evacuation operation in the province of Gelderland illustrated that the use of the GIS was not perfect. Nevertheless decisions were taken, safeguarding lives and livestock. The quality of the decisions could have been strongly improved by enlarging the availability of digital data and analytical models not only in terms of quantity of data but also in respect to the existence of a clear framework of responsibilities for its collection, maintenance, and dissemination (Burrough et al. 1996). Considering the four general functions of a GIS as they have been distinguished by Scholten & Padding (1990): preparation, analysis, display and management of geographical data, it can be concluded that not all users wish, or need, to make similar use of these main functions (Fig. 7).

Therefore a framework should enable the different users of geographical data to retrieve the data needed and to assess the quality of that data according to their demands. The following key elements should be part of this framework, eventually leading to an SII:

1. Agreements and standards
2. Rules on access
3. Metadata
4. Core data
5. Education and research
6. Information technology
7. Modelling.

1. Agreements and standards

Many national, regional and ‘special-use’ groups have developed standards and methods for transferring and handling spatial data. By establishing a common set of metadata terminology, definitions and extension procedures, the standard will promote the proper use and effective retrieval of spatial data and provide information about an organization’s database to others.

2. Rules on access

Rules on access should cover various aspects of organizational, political and legal nature. Government agencies play a major role in gathering and updating spatial data. Rules have to be considered under which the government agencies may operate on the competitive information market. Both government agencies and service providers often hold personal data. In order to protect the rights of individual privacy, legislation on the disclosure of personal information is needed, as well as codes of practice and an independent review panel (Burrough 1996).

3. Metadata

Most spatial data are used many times, perhaps by more than one person; typically, data are produced by one individual or organisation and used by another. As spatial-data producers and -users handle more data, proper documentation will allow them to better manage data production, storage, updating and reuse. To ensure that data are not misused the assumptions and limitations affecting the collection of the data must be fully documented. Metadata allows the producer to fully describe a data set, so that users can understand the assumptions and limitations and evaluate the data set’s applicability for their intended use (Danko 1997).

4. Core data

Within the Spatial Information Infrastructure a nucleus of common harmonized data should be available functioning as a reference for the wide range of data sets at European, national and local level. As suggested by Burrough et al. (1996) these core data sets should contain:

- A common geodetic reference
- Elevation maps including coastlines
- Main land use and soil types; ecological data sets
- Data on major roads and railways
- Hydrography
- Data on administrative boundaries
- Population data.
- Economic data sets

Once a small-scale core data set has been established, the core data can be used as an anchor for different data sets, and may also be extended.

5. Education and research

The development of an infrastructure can only take place with the backup of an educational program for (geographic) skills and knowledge. A variety of actions aimed at training technicians, educating users and informing decision-makers is needed.

A particular aspect highlighted by Burrough et al. (1996), is the relatively limited diffusion of the use of spatial data for research outside the core disciplines of geography, surveying and planning. More efforts are necessary to compare and exchange methodologies across disciplines and industries.

6. Information technology

Products of information technology form important tools for collecting, analysing and presenting spatial data. The range of commercially available products that candidate for the implementation of a GIS has widened (such as geo-processing, remote sensing, GPS (Global Positioning System), multimedia, network communication and EDI (Electronic Data Interchange).

The development of new products has to be followed and examined for their possible integration within a GIS and/or a Spatial Information Infrastructure.

7. Modelling

To support the water manager during various stages of flood control, several models, procedural and heuristic, have to be combined and integrated into software tools eventually forming an SDSS, as presented by Simonovic (1993). The system should assist interactively in entering data into a model, providing an interfacing with geographic data, generating possible scenarios and visualising interpretation of data.

As Burrough et al. (1996) concluded, Europe is not taking advantage of the wealth of data it has, as compared to other parts of the world, because the framework for using all data is not yet available. Through developing such a European framework it is possible to build upon the many initiatives already existing at national, European and international level.

Several metadata services are available on Internet. The wealth of data documented by these services is enormous. Indexing these existing metadata services can be done with little effort and will benefit the data users, the metadata services and the data providers. Indexing metadata services should have priority and can be considered the logic first step towards a European Spatial Information Infrastructure.

Metadata services: clearing-houses

The range of metadata stored by existing clearing-houses is typically limited by thematic or national boundaries. Examples of current thematic metadata services in Europe are:

- European Wide Service Exchange (EWSE) from the Centre for Earth Observation (CEO), a directory for remotely sensed data and services;
- The Geographical Data Description Directory (GDDD) from MEGRIN, containing information about products of European mapping agencies;
- Geological Electronic Information eXchange System (GEIXS) for geological data;
- The European Environment Agency (EEA) for environmental data;
- EUROSTAT for statistical information.

Examples of current metadata services at the national level are:

- Spatial INformation Enquiry Service (SINES) run by Ordnance Survey lists all UK government geographic data sets;
- The National System of Geographic Information (SNIG), coordinated by the Centro Nacional Informação Geográfica (CNIG), provide similar information about public and private data in Portugal;
- The National Clearing-house for Geo-Information (NCGI) in The Netherlands, coordinated by the Advisory Council for Real Estate Information (RAVI) provide search facilities for metadata from cooperating organisations.

In a review of metadata services, carried out by the GI-META on behalf of the European Community, it became clear that there are no standards in common practice for structuring and classifying geographic information (Wood & Casetti 1996). The user of geographical information cannot easily browse across sites and compare products from different suppliers. Even if the search has been successful the user all too often has to face a complex process of negotiation, and highly technical data integration issues.

A European approach: ESMI

An European approach, enabling intergovernmental, international cooperation, seems necessary for a more effective flood management of trans-boundary rivers, as has been demonstrated in the Dutch and the Polish case. The above-described metadata services are specific, thematically or nationally oriented and rely on central servers, which may be separate from the actual geographic data. They do not communicate so there is some duplication which gives rise to inconsistencies. This problem has been picked up by the consortium for European Spatial Metadata Infrastructure (ESMI, http://www.geodan.nl/esmi). The consortium's objective is to link existing and future metadata systems using the Internet and aims at providing a single, easy to use access gate through the Web.

An interface prototype (http://gasa.dcea.fct.unl.pt/esmi/ has been developed allowing to search at three different levels of sophistication. The next interface version will be particularly directed to the professional user and will operate with search variables from the metadata common core. This common core has been identified through the analysis of the metadata standards, namely the European standard, CEN/TC 287, the International ISO/TC 211 and the American Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (Abreu et al. 1998).

Supporting access to data: the WWW

WWW-sites can offer considerable flexibility in searching, not only at specific sites, but also for searching across different sites. According to Wood & Cassetti (1996) only a few sites have the right balance between detail and content. Having browsed through one site a transfer to a different site is likely to present the user with a totally different environment (see Wood & Cassetti, 1996 for review of WWW-sites offering metadata services). At present, technical limitations for on-line services slow down the process of transmitting and displaying images. However, the steep demand curve for the Internet should result in improvement in service quality. CD-ROM does hold promise for the infrequent distribution of high-volume data samples, to be used in conjunction with on-line browsers. Additionally, CD-ROM would be an appropriate delivery medium for viewer or navigation applications.

As pointed out by Burrough et al. (1996) a major effort is needed to further develop the interface between technology, science and society to better respond to the needs and aspirations of our living environment.

Recent studies by Fonseca et al. (Scholten& LoCashio 1997) aimed at using the potential of multimedia to integrate data of different kind, time and spatial scales. In these studies the use of multimedia technology for spatial analysis is basically considered a tool for visualization, simulation, communication and exploration of complex spatial data. The underlying notion is that making use of digital video and sound will contribute to better understanding of spatial phenomena and facilitate communication between and amongst groups of experts and users and therefore enhance the quality of decision making. Fonseca et al. have analysed the background of the design of an Environmental Multimedia Exploratory System. Furthermore, future developments on the use of multimedia technology are sketched, including issues of WWW-implementation and the use of Quicktime®VR technology. The development of new exploratory tools may be beneficial for the Spatial Information Infrastructure by allowing the user to investigate and visualise complex spatial data.

Conclusions

The case of flood control management in the Dutch province of Gelderland showed that in using a GIS the water managers were able to analyse the situation quickly and take precautions by developing an evacuation plan. Yet, the lack of certain important data, well-tested models and communication between governmental services and parties involved, demanded much creativity of the decision-makers. A more structural approach can be achieved by designing an SDSS embedded in a Spatial Information Infrastructure (SII). In doing so, efforts of governmental services and departments can be coordinated, making an evacuation a well-organised operation. The development of an SII should be carried out by all parties involved ensuring its correct use and functionality.

That disasters do not stop at national boundaries was demonstrated once again by the flood disaster in Poland. The lack of basic procedures and methods between the neighbouring countries Poland, the Czech Republic and Germany hindered the exchange of vital information. Structuring and coordinating activities for flood control management at the European level should parallel efforts at regional and national level. The European Spatial Metadata Infrastructure as being developed by the ESMI consortium could function as a starting point. Being part of a (European) SII may help emergency managers to support their decision-making and weigh alternatives. Eventually, whether decisions made and actions taken will be adequate depends on the human capacity of the people in charge.

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