Frameworks for flood event management

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SUMMARY

Introduction
The work described in this report has been carried out as part of the European research project FLOODsite (task 19). The objective was to link knowledge and models from FLOODsite theme 1 (risk analysis) and theme 2 (risk management) in a Decision Support System (DSS) in support of flood event management planning and practice. The specific objectives were:

1. To obtain insight into the different types of decision support systems that have been made in the past or that are currently being used, and determine which of these DSSs would be most suitable for event management planning;
2. To implement and test two outline DSSs;

The work was structured as follows:

- A review was carried out on decision support systems in Europe, to get insight in previous experiences and learn about user requirements for flood event management;
- A methodological framework was extracted from this first activity, to be applied in the three pilots of the Thames, the Schelde and the Gard;
- For two pilots a prototype DSS was prepared based on this methodological framework, and tested among the end users. In the third pilot a two-dimensional approach to the preparation of flood event management plans was validated;
- General conclusions were drawn as well as pilot-specific conclusions and recommendations.

Review of existing DSSs
As a first activity a review was carried out on available DSSs for flood event management in the UK, the Netherlands and France. All the described systems are more or less "generic". They may have been set up and applied for a specific area only, but their modular set-up would with some effort allow application for other areas as well. Also some form of Geographical Information System (GIS) is present in most systems. In most systems there are different layers to show spatial information on various subjects. Some systems also contain a public part (web-based) for providing up-to-date information to the public during an emergency, via internet. Surrey Alert and FLIWAS are examples of such systems.

User requirement
Based on the review of existing DSSs as well as from interviews with end users, the most important user requirements were listed. A decision support system for flood event management in the NL and the UK typically contains the following:

- (Pre-calculated) results of various flood scenario’s (differing breach locations and characteristics and differing hydraulic conditions);
- Flood hazard at vulnerable locations;
- People and objects at risk;
- Safe havens and exit routes;
- Coordination of all event response personnel;
- Storage of other relevant site-specific data;
- User-friendly method to present results.

The exact requirements will depend on the responsibilities of the user. For instance, in the Netherlands the authorities responsible for an evacuation are not the same as those responsible for flood alleviation. In the Netherlands it would not be helpful to combine both tasks in a single DSS. In other countries, however, this combination might be a prerequisite.
Methodological framework

Based on these user requirements a methodological framework for flood event management DSSs was developed. It shows the eight modules that are generally relevant in flood event management:

1. The external driver module describes the existing situation prior to the flood and the boundary conditions for the flood event;
2. The tools module consists of the tools used in the other modules;
3. The management response module describes the management options available to the decision maker;
4. The boundary conditions of the flood event such as fluvial / tidal water levels from a flood forecasting system form the input of the hazard module;
5. The exposure module compares the information on the flood characteristics with information on the distribution of inhabitants, livestock, property and utilities;
6. The vulnerability module defines the potential for the receptors (e.g. people, livestock and buildings) to be harmed;
7. In the consequence module a damage and casualties model combines the exposure and the vulnerability and calculates the damage to people, livestock, property and utilities;
8. The risk module combines the results of the consequence module for the different breach locations. The combined risk is expressed as the expected damage of a forecasted flood event under the selected management option.

The methodological framework was developed in close cooperation with task 18 on long-term flood risk management DSSs (McGahey et al, unpublished). There are small differences between both frameworks, for example the time horizon, importance of a risk measure, type of management response.

The framework was applied in two prototype DSSs, which were developed for the estuaries of the Thames and the Schelde. In addition, (part of) the framework was applied to two urban flooding cases in France.

Thames pilot

FLINTOF (Flood INcident Tactical and Operational Framework) was developed and applied on the Thamesmead embayment (UK). It was not designed to identify ‘optimal’ solutions with respect to flood event management, but rather to provide information on selected options for use in the emergency management planning and decision-making process. Furthermore, FLINTOF does not contain hydrological or hydraulic simulation engines nor does it require the use of specific hydraulic modelling software. However, FLINTOF does require the input of two-dimensional hydrodynamic modelling results at a suitable temporal interval. The spatial and temporal interval of the hydrodynamic modelling results that can be input into FLINTOF is flexible.

The key features of the FLINTOF are as follows:
- Organisation and viewing of spatial-temporal data relevant to emergency planning;
- Use of information from external models (e.g. hydraulic models) to assess:
  o Flood extents and depths, and
  o Flood hazard as a function of velocity and depth;
- Calculation of the flood risk to people in terms of number of injuries and fatalities;
- Assessment of the road network with respect to emergency access;
- Use of information from external evacuation models to display typical evacuation times at a census enumeration level;
- Estimation of the probability of building collapse;
- Providing information for the appraisal of different emergency management interventions;
- Archiving of data sets.
A FLINTOF project comprises two parts:

(i) A relational database that is controlled by the FLINTOF interface.
(ii) An ArcGIS project that is managed by the FLINTOF and performs automated data processing and visualisation.

The database contains scenarios that can be developed and evaluated by the user. After the relevant data has been imported, various aspects can be assessed.

**Schelde pilot**

The user requirements showed that the decision maker is most interested in combining the flood inundation knowledge with an evacuation model. From the DSS-review it became clear that currently two DSSs for flood event management are in use. One of them combines flood characteristics with an evacuation model, but that model does not allow for a detailed analysis of evacuation routes and potential road congestion (Lumbroso et al, 2008). Thus it was tried to combine the flood risk analysis from task 14 (De Bruijn et al, 2008) with the evacuation model INDY, that came out best from the evacuation model comparison study (Lumbrosos et al, 2008).

A prototype support system for evacuation planning (Evacuation Support System, ESS) was developed and applied in the Schelde flood-prone area of Walcheren and Zuid-Beveland. It supports decision makers in making evacuation plans, by providing relevant information on the area at risk. The ESS is a tool that links different breach locations to a database with flood-simulation results of flood events. Spatial information is present, for example topographical data, location of hospitals and postal code zones containing the number of inhabitants.

Based on the end user consultation in Zeeland, the ESS for the Schelde was found to be very useful in giving insight into the flood hazard and consequences. New flood event scenarios can be added, which makes it a compact and dynamic library of all simulations done in one area. For evacuation planning via the ESS a more detailed traffic model is needed. For example, the end users need to learn about locations where congestion will most likely occur.

**French pilot**

In France there was a need for a pragmatic approach, which can contribute to the preparation of flood event management plans in urban areas using 2D hydrodynamic models for attribution of flood risk. This two dimensional approach was validated on two example sites in France.

The objectives of the community safeguard plan are: planning the organization within a commune for warning, informing, protecting the population in the event of known risks. The plan contains various components such as the organization of the local command centre, the actions to be carried out by the responsible personnel for each emergency service, an inventory of facilities (transport, accommodation, and supplies) and specific measures.

The two-dimensional model outputs give information about inundation and important characteristics of the flood such as water depth and velocity which are valuable for devising flood protection measures. Using the flood hazard information, maps were produced and hazards were categorized based on the impact of flooding on population.

The main conclusion from the French pilot is that the Telemac 2D model provides useful information for preparation of flood event management planning. For example, the model results allow management to make decisions such as moving a school entrance or preparing evacuation routes on a very detailed scale (buildings and streets). However, the following limitations must be considered:

- The buildings are modelled as ‘solid’, while in reality the water may flow through windows and doors;
- There is no groundwater component;
- Regular updating of the input data is required.
General conclusions

The main conclusions that were reached are as follows:

1. The two DSSs: FLINTOF (Thamesmead embayment) and ESS (Schelde) provide relevant information to the end user, who needs to make a decision on either operational management or evacuation strategies. The DSSs are country-specific, i.e. adjusted to the countries’ models and commonly used methods;

2. Spatio-temporal risk estimation has strong potential to improve emergency response. By having this ‘risk-information’ (e.g. loss of life, injuries, damage to buildings) available emergency response officials can prioritize efforts to those areas impacted. Initial priorities can be established to coincide with areas of greatest hazard or projected loss of life. In addition, risk projections can be used to estimate the level of resources required to support certain disaster assistance programmes e.g. temporary sheltering;

3. The DSS methodology is flexible and could be applied throughout Europe providing the relevant data are available;

4. The hazard-consequence-risk procedure is an effective way to structure the data, but very much expert-based. The end user is interested in knowing directly the water depths and velocities, how many people are at risk, which roads are available and how much time is required to evacuate or to find shelters. This is a mix of hazard, exposure, consequence and management.

5. The products of this research are most relevant for the implementation of the Floods Directive (Directive, 2007). Tools have been provided to plan flood event management (flood risk management in the very short term). By making use of hydrodynamic model results and available data on area vulnerability, the preparation of flood event management plans is supported. Also evacuation routes and best locations for shelters can be derived from this information. Together with evacuation and rescue planning, this will most likely reduce the adverse consequences of floods.
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document Information</td>
<td>ii</td>
</tr>
<tr>
<td>Document History</td>
<td>ii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>ii</td>
</tr>
<tr>
<td>Disclaimer</td>
<td>ii</td>
</tr>
<tr>
<td>Summary</td>
<td>iii</td>
</tr>
<tr>
<td>Contents</td>
<td>vii</td>
</tr>
</tbody>
</table>

1. Introduction
   1.1 Structure of the report                                           | 1    |
   1.2 Background to flood event management                             | 2    |
      1.2.1 Frameworks                                                  | 2    |
      1.2.2 Tasks and application types                                 | 2    |
   1.3 Pilot applications                                              | 3    |
   1.4 Links to other projects and FLOODsite activities                | 3    |

2. Review of existing decision support systems                         | 1    |
   2.1 Introduction                                                     | 1    |
   2.2 United Kingdom                                                   | 2    |
      2.2.1 Introduction                                                | 2    |
      2.2.2 Environment Agency Management System (AMS) Online          | 2    |
      2.2.3 SurreyAlert                                                 | 3    |
   2.3 The Netherlands                                                  | 4    |
      2.3.1 Introduction                                                | 4    |
      2.3.2 ESCAPE Decision Support System                              | 5    |
      2.3.3 FLIWAS                                                      | 5    |
      2.3.4 Calamity Information System Regge & Dinkel (CIS-Regge)       | 6    |
   2.4 France                                                          | 8    |
      2.4.1 Introduction                                                | 8    |
      2.4.2 Automated regional hydrologic alarm system (ALHTAIR)        | 8    |
      2.4.3 Model for economical assessment of flood damages (ALPHEE)   | 9    |
      2.4.4 High water prevention and forecast by means of spatial techniques (PACTES) | 9 |
      2.4.5 OSIRIS                                                      | 10   |
   2.5 Differences in and resemblances of the UK, Dutch and French DSS | 11   |

3. User requirements in flood event management                         | 13   |
   3.1 General considerations                                           | 13   |
   3.2 Requirements for the Netherlands                                 | 13   |
   3.3 Requirements for the UK                                          | 14   |
   3.4 Requirements for France                                         | 15   |

4. DSS Methodology                                                     | 17   |
   4.1 Methodological framework                                         | 17   |
      4.1.1 General approach                                            | 17   |
      4.1.2 Scheme                                                      | 18   |
   4.2 Risk-based decision support                                     | 21   |

5. Pilot application for the Thames Estuary, UK                        | 24   |
   5.1 Aim of FLINTOF and user requirements                             | 24   |
      5.1.1 Vision for FLINTOF                                          | 24   |
      5.1.2 Core principles of FLINTOF                                  | 24   |
      5.1.3 User requirements                                           | 25   |
5.2 Introduction to the Thames Estuary ................................................................. 26
5.2.1 Overview of Thamesmead embayment ...................................................... 27
5.2.2 Data availability for the pilot area ............................................................ 29
5.3 System description ....................................................................................... 29
5.3.1 General ..................................................................................................... 29
5.3.2 Scenarios in FLINTOF ............................................................................. 30
5.3.3 Database in FLINTOF ............................................................................. 33
5.4 Functionality ................................................................................................. 34
5.4.1 Introduction ............................................................................................... 34
5.4.2 Development of a Scenario and importing base data ......................... 34
5.4.3 Importing hydraulic modelling results ................................................. 35
5.4.4 Assessment of the level of the flood hazard ..................................... 35
5.4.5 Flood risk to people .............................................................................. 38
5.4.6 Emergency access for vehicles ............................................................. 44
5.4.7 Evacuation time ..................................................................................... 48
5.4.8 Assessment of the probability of buildings collapsing ................... 49
5.4.9 Scenario evaluation ............................................................................... 50
5.5 First response of the end user group .......................................................... 52
5.6 Conclusions and pilot specific recommendations ...................................... 53
5.6.1 Conclusions ............................................................................................ 53
5.6.2 Recommendations .................................................................................. 54

6. Pilot application for the Schelde ................................................................. 57
6.1 Introduction .................................................................................................. 57
6.2 Aim of DSS and user requirements ............................................................ 57
6.3 Overview of the pilot area ............................................................................ 58
6.3.1 Overview .................................................................................................. 58
6.3.2 Model schematization and choice of breach locations ....................... 60
6.4 System description ....................................................................................... 61
6.5 Functionality ................................................................................................. 62
6.5.1 General information ................................................................................ 62
6.5.2 External driver module .......................................................................... 64
6.5.3 Hazard module ....................................................................................... 64
6.5.4 Exposure module .................................................................................... 66
6.5.5 Consequence module ............................................................................ 66
6.5.6 Management response module .............................................................. 66
6.5.7 Example of a breach scenario ................................................................. 67
6.6 First response of the end user group .......................................................... 69
6.7 Conclusions and pilot specific recommendations ...................................... 69

7. French pilot applications ......................................................... 71
7.1 Introduction .................................................................................................. 71
7.2 Objective ..................................................................................................... 71
7.3 Methodology ................................................................................................. 72
7.3.1 Methodological aspects of flood hazard and flood risk mapping ....... 72
7.3.2 The French regulatory tool Plan Communal de Sauvegarde (PCS) ... 75
7.4 TELEMAC 2-D brief description ............................................................... 79
7.5 Application sites ............................................................................................ 80
7.5.1 Flooding issue of Nice ........................................................................... 80
7.5.2 Flooding issue of unidentified site in southern France ..................... 81
7.6 Results .......................................................................................................... 83
7.6.1 Risk assessment stage .......................................................................... 84
7.6.2 Organisation of local disaster management: ..................................... 86
7.6.3 Urban infrastructure management planning ....................................... 89
7.6.4 Flood Protection ...................................................................................... 89
7.7 Conclusions and pilot specific recommendations.............................................. 90

8. Conclusions and recommendations ........................................................................ 93
8.1 Conclusions on review of existing decision support systems................................. 93
8.2 Conclusions on flood event management framework and pilot implementations93
8.3 Recommendations ............................................................................................. 94

9. References ............................................................................................................... 96

Tables:
Table 2.1 Summarized overview of recently developed ‘decision support systems’ in the United Kingdom, the Netherlands and France 1
Table 5.1 Level of the flood hazard 36
Table 5.2 Guidance on debris factors for different flood depths, velocities and dominant land uses39
Table 5.3 Area vulnerability 40
Table 5.4 Calculation of flood warning score 40
Table 7.1 Summary of information for evacuation planning 88

Figures
Figure 1.1 Scheme showing the interaction and links with other task of the FLOODsite project 4
Figure 2.1 Example of the latest news available to the general public via SurreyAlert over the internet (SurreyAlert.Info, 2003) 4
Figure 2.2 Example screen of the Regge & Dinkel application. 7
Figure 4.1 A disaster cycle with focus on flood event preparation and response 17
Figure 4.2 Methodological framework for flood event management 19
Figure 5.1 The location of Thamesmead 27
Figure 5.2 Satellite image of Thamesmead 28
Figure 5.3 New development in Thamesmead 28
Figure 5.4 Opening screen of FLINTOF 30
Figure 5.5 The four components of a FLINTOF Scenario 31
Figure 5.6 The management of Scenarios within a FLINTOF project 31
Figure 5.7 Scenario referencing system 32
Figure 5.8 FLINTOF Scenario comparison screen 32
Figure 5.9 Example screen of the FLINTOF database 33
Figure 5.10 Scenario management window within FLINTOF 35
Figure 5.11 The seven steps in the development of a FLINTOF Scenario 37
Figure 5.12 Overview of the flood risks to people method 38
Figure 5.13 Social vulnerability of people in the pilot area 41
Figure 5.14 Number of people injured per km² 43
Figure 5.15 Number of deaths per km² 44
Figure 5.16 Vehicle stability curves as a function of water depth and velocity 46
Figure 5.17 Hazard and emergency access vehicles after a breach has occurred 47
Figure 5.18 Display of evacuation times 48
Figure 5.19 Function relating velocity and depth to the probability of building collapse 50
Figure 5.20 Map providing an indication of the probability of building collapse 51
Figure 5.21 Screen allowing different scenarios to be compared 51
Figure 5.22 Schematic diagram showing FLINTOF at the centre of a FEM system 55
Figure 6.1 Overview of the study area (bright green) as part of the province of Zeeland 59
Figure 6.2 Left: Sea dike at Westkapelle (West of Walcheren), Right: Harbour of Terneuzen, 59
Figure 6.3 Extreme water levels, statistically derived in IMDC (2005), for different return periods60
Figure 6.4 Example simulation of breach area growth in time in SOBEK, for a breach depth of 8 m and a maximum breach width of 200 m (for sand) 61
Figure 6.5 Schematic overview of Schelde ESS 62
Figure 6.6  Typical ESS start-up screen showing the pilot area and clickable breach locations 63
Figure 6.7 Modules in the ESS (enlargement of the above figure) 63
Figure 6.8 Typical ESS screen showing the pilot area and clickable breach locations 64
Figure 6.9 Part of a map in the ESS, showing tabulated information on hazard and vulnerability data for one selected postal code zone 65
Figure 6.10 ESS map showing a topographical layer with the maximum flood depth per hectare for an event in the East of Zeeland (Rilland) 67
Figure 6.11 Example of an ESS map showing the maximum water depth for each postal code zone (breach scenario ‘Rilland’) 68
Figure 6.12 ESS screen showing the time of inundation for a breach scenario ‘Rilland’ 68
Figure 7.1 Flood Hazard mapping based on water depth and velocity 73
Figure 7.2 Flood Risk Mapping 74
Figure 7.3 Flood hazard classification based on a cross product of water depth and velocity 74
Figure 7.4 Example of a PCS organisation scheme 76
Figure 7.5 Steps to be followed in diagnosing the risk 77
Figure 7.6 Scheme for the respond of the commune to an event 79
Figure 7.7: Flooding of the Var River in November 1994 80
Figure 7.8 Elevation Map produced from aerial photographs of 1/5000 scale 82
Figure 7.9: Model application site - an unidentified urban site in southern France 83
Figure 7.10: Schematization of input and output of a 2D Hydrodynamic model 84
Figure 7.11: Flood Hazard mapping for the project site in Nice for Q_{100} flood 85
Figure 7.12: TELEMAC-2D database for flood risk assessment 86
Figure 7.13: Map showing velocity of flood and graph showing evolution of flood depth at a residence building in unidentified site. 87
Figure 7.14: Routes of evacuation during flooding event 87
Figure 7.15: Example of flood protection recommendation based on 2D output 90
1. Introduction

1.1 Structure of the report

This report describes the work that has been carried out as part of Task 19 in the European research project FLOODsite.

The objective was to link knowledge and models from FLOODsite themes 1 (risk analysis) and 2 (risk management) in a Decision Support System (DSS) in support of flood event management planning and response. This research focused on short term action during or just before a flood crisis situation as well as preparation of flood event management plans to support this.

The specific objectives were:

1. To obtain insight into the different types of decision support systems that have been made in the past or that are currently being used, and determine which of these DSSs is most suitable for flood event management planning;
2. To implement and test two prototype DSSs;
3. To show how a combination of hazard maps, risk maps and vulnerability information can be used in flood event management planning and response.

These objectives are most relevant for the implementation of the Floods Directive (Directive, 2007), as flood event management plans will most likely reduce the adverse consequences of floods. Flood event management concerns people's deaths and not so much the economic damage.

Based on a review of existing flood event management DSSs and corresponding user requirements, a methodology is presented to support flood event management planning. The methodology also applies for long term flood risk management, which is presented in the Task 18 report (McGahey et al, unpublished). There are small differences with the FEM framework, which are stressed in chapter 4.

The methodology is implemented to three pilot locations. The Thames pilot and the Schelde pilot focused mainly on developing tools for visualizing and combining available information on flood extent, consequences and the effect of management response. The French pilot tested the suitability of the available 2D hydrodynamic model to provide necessary information for use in urban flood event management.

In each pilot close communication with the envisaged end user existed. The relevant authorities were consulted during and after the development of the prototype, to ensure user-friendliness and relevance. The received feedback on the functionality and usefulness is included in the report.

This report is structured as follows:

Chapter 1 Introduction to flood event management frameworks and definitions;
Chapter 2 A summary of the review of flood event management decision support systems (Maaten et al, 2007);
Chapter 3 The lessons learned and user requirements for decision support systems for flood event management (Logtmeijer, 2006);
Chapter 4 A methodological framework which has been used as guidance for developing the two prototype DSSs for the pilots Thames and Schelde (Van der Vat et al, 2007);
Chapter 5 Description and functionality of the prototype DSS as developed for the Thames;
Chapter 6 Description and functionality of the prototype DSS as developed for the Schelde;
Chapter 7 Description of the research that was carried out on the suitability of 2D models in the preparation of flood event management plans in France. Two pilot sites were considered;
Chapter 8 The overall conclusions and recommendations.
1.2 Background to flood event management

1.2.1 Frameworks

During a flood event, the responsible authorities need to make decisions on operation of barriers and on evacuation/rescue strategies. Temporary flood protection is sometimes an option and if so it must be decided on quickly. Also people are served by knowing evacuation routes and a forecast of blocked roads.

The name ‘DSS’ stands for Decision Support System, and is a general term used for a variety of computer-based systems that support managers in making decisions. Some support systems focus on short term management, others on the long term. Some only provide information, others interact with the end user. Some are applicable at a local scale, others at a national level.

In the current research a DSS is a computer-based information system that supports the ability of authorities to make flood management decisions at the regional level. Whereas task 18 dealt with long-term planning issues in flood risk management, task 19 (current report) focused on the ‘operational’ management of an actual flood event. The term operational refers to the fact that the end-user must take immediate action without sufficient time to perform model runs. Examples of actions that require immediate initiation include the closure of dams and gates, deciding which areas are to be evacuated and which people will require rescue efforts.

A DSS can assist the user by quickly showing the available information on water levels, objects at risk, evacuation routes, resident vulnerability, etc. This support can be given during the preparation of flood event management or during the actual flood event.

1.2.2 Tasks and application types

**Tasks**

Flood event management concerns different tasks to be accomplished:

- Short-term actions to prevent flooding (operation of barriers and retention areas);
- Actions to reduce the impact of flooding (opening or closing gates in the hinterland);
- Preparation of evacuation plans;
- Preparation of rescue plans;
- Evacuation before or during a flood event; and
- Rescue after a flood.

The content of the tasks can differ slightly between different natural systems, such as:

- Low land areas with a flat topography and deep, large polders that can be flooded as a whole. The distance to safe places will typically be in the order of tens of kilometres. The source of flooding can be fluvial and/or tidal;
- Sloping areas with an undulating topography where only the river valley can be flooded. The distance to safe places will typically be in the order of hundreds of meters. The source of flooding will be mostly fluvial; and
- Hilly and mountainous areas with a steep sloping topography where flash floods can occur. The distance to safe places will typically be in the order of hundreds of meters. The source of flooding is fluvial.

**Application types**

Flood early warning is a requirement for all flood event management; without proper forecasting a flood, event management cannot take place. Different types of systems have very different lead times for flood early warning. In low land river systems, the lead time will be typically on the order of
several days. The lead time for flooding from sea in low land areas and for fluvial flooding in sloping areas will be much shorter (on the order of 12 hours). Flash floods are the most erratic and their lead time will be on the order of hours.

For systems with fluvial and tidal flooding, operational flood management is very relevant. Short-term actions such as operation of barriers and gates, might prevent flooding or reduce the impact. In flash-flood systems few opportunities exist to influence the probability of flooding and the flood pattern by management actions.

Evacuation is important for all areas except those where flash-floods occur. The general problem in all areas is that the lead time might not be enough to complete an evacuation. Since in low land and sloping areas people are much better protected during a flood event when in their houses than when on the road, the decision whether or not to evacuate will be very important for decision support. An important issue for both evacuation and rescue is the availability of the transport network under flooding conditions. Traffic management therefore also forms an important part of the decision support in all natural systems.

1.3 Pilot applications

Three pilots were chosen to further develop the existing knowledge on DSSs. In each pilots different aspects of the DSS development process are identified, all of which try to meet the user requirements that came out of the DSS-review and end-user consultations.

The DSSs for the Thames and Schelde pilot allow users to compare hazards and risks related to flood event management, using the common hydrodynamic model output as a basis. Various management options and their effect can then be tested.

The French pilot dealt with urban flash floods. The use of a two-dimensional (2D) hydrodynamic model was investigated and the contribution of the results to community safeguard plans was assessed. The principal benefit of the research lies in the integration of the appropriate sources of information for preparing emergency plans.

1.4 Links to other projects and FLOODsite activities

The current study is related to other activities carried out in FLOODsite (see Figure 1.1):
1. FLOODsite task 8
   There was interaction with task 8 on flood inundation modelling in the urban flooding pilot in France;
2. FLOODsite task 10
   Interaction with the Thames pilot related to the socio-economic evaluation and modelling technologies;
3. FLOODsite task 14
   Results of the flood risk analysis carried out for this task on ‘Long term strategies for flood risk management’ (De Bruijn et al, in prep) were used to develop evacuation strategies;
4. FLOODsite task 17
   Results obtained in this task on Evacuation and traffic modelling (Lumbroso et al, 2007) have been used in the development of the DSSs;
5. FLOODsite task 18
   The methodological framework was developed in close cooperation with task 18, which aims at decision support for long term flood risk management. The review of DSSs was also carried out jointly with this task;
6. FLOODsite tasks 24 and 25
   The results of the current study have been used in the workshops organized in task 24 and 25. Findings are reported in the book ‘Methodologies for Integrated Flood Risk Management – Research Advances at European Pilot Sites’ (Schanze, in prep).
Links to projects outside of FLOODsite are listed below, per pilot.

**Thames pilot**
In the Thames pilot use is made of the knowledge and models available from several projects. The main link formed was with the Thames Estuary 2100 project. The Environment Agency’s Thames Estuary 2100 project (TE2100), is developing a tidal flood risk management plan for London and the Thames estuary. The main objective of the project is to determine the appropriate level of flood protection needed for London and the Thames Estuary for the next 100 years. The effects of climate change, such as sea level rise, increased rainfall and storm frequency, mean that London and the Thames Estuary will be at greater risk from flooding in future years. Furthermore, many flood risk areas are undergoing development and regeneration, meaning that more people, buildings and infrastructure are likely to be exposed to the risk of flooding in the future. Inundation models developed by the TE2100 project were used in the pilot and the TE2100 team were consulted with regards to the exact areas within the Thames Estuary where the tools were to be piloted.

Links were also made with a number of other projects including the FLIWAS project and Modelling and Decision Support Framework (MDSF) 2 project. This was to ensure that there was no overlap in the research activities and that the work carried out in the Thames could be integrated into future work carried out by the Environment Agency.

**Schelde pilot**
In the Schelde pilot application was tuned in with several projects, to avoid overlap:

- The FLIWAS project (www.hisinfo.nl) was contacted to avoid overlap in research activities. This means that the current study has been tuned in with the international cooperation projects of NOAH and VIKING. FLIWAS is dealing with the communication and response part of the evacuation process, where the current project focused on the technical aspect and information provision to the decision-makers;
- Discussions took place with the new Dutch ‘Taskforce Management Overstromingen’. This taskforce of decision-makers in the Netherlands and aims to improve the preparation to flood crisis situations (http://www.platformoverstromingen.nl/tmo);
- The project Flood Control Room 2015 (www.ijkdijk.nl) aims to develop a real-time monitoring system for all embankments in the Netherlands to be prepared for potential dike breaches. This project can benefit from the work carried out in the current research.

![Figure 1.1 Scheme showing the interaction and links with other task of the FLOODsite project](image-url)
2. Review of existing decision support systems

2.1 Introduction

This review describes the existing DSSs for flood event management and is summarized from the FLOODsite technical note (Maaten et al, 2007) that was written for Task 19. Several DSSs for long-term flood risk management were described as well. The reason for this was that they offer insight into decisions on the functionalities and architecture of the DSS for flood event management.

Table 2.1 provides an overview of all reviewed DSSs in the UK, the Netherlands and France. The description of each DSS contained the following aspects: short description, architecture, functionality, data requirements, application of the decision support system, current end users, and flood events in which the decision support system has been used. The summary in the next sections is limited to a description of the DSSs for flood event management. DSSs for long term flood risk management are discussed in detail in (McGahey et al, unpublished).

Table 2.1 Summarized overview of recently developed ‘decision support systems’ in the United Kingdom, the Netherlands and France

<table>
<thead>
<tr>
<th>Country</th>
<th>Name</th>
<th>System type</th>
<th>Functionality</th>
<th>Current End users</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>AMS</td>
<td>Management system</td>
<td>Listing processes, roles &amp; responsibilities for flood incident management</td>
<td>Environment Agency, England and Wales</td>
</tr>
<tr>
<td></td>
<td>MDSF</td>
<td>GIS</td>
<td>Supporting long term planning in flood risk management</td>
<td>Environment Agency and their consultants</td>
</tr>
<tr>
<td></td>
<td>SurreyAlert</td>
<td>Website</td>
<td>Information sharing</td>
<td>General public, partly restricted to police, fire brigade, councils, etc.</td>
</tr>
<tr>
<td>NL</td>
<td>Planning Kit</td>
<td>DSS</td>
<td>Supporting discussion among stakeholders about the evaluation of river design alternatives</td>
<td>All stakeholders (eg river managers, inhabitants, planners, policy makers, engineers)</td>
</tr>
<tr>
<td></td>
<td>DSS Large Rivers</td>
<td>DSS</td>
<td>Supporting discussion on planning and assessment of river landscapes</td>
<td>Not used anymore</td>
</tr>
<tr>
<td></td>
<td>IVB-DOS</td>
<td>DSS</td>
<td>Exploration of structural river design measures to reduce water levels</td>
<td>Not used anymore</td>
</tr>
<tr>
<td></td>
<td>ESCAPE</td>
<td>DSS</td>
<td>Supporting decision making in times of emergency; Calculating required evacuation time</td>
<td>Province of Zeeland</td>
</tr>
<tr>
<td></td>
<td>FLIWAS</td>
<td>Informati on and warning system</td>
<td>Information sharing based on high water level forecasts</td>
<td>Governmental organisations in NL and Germany</td>
</tr>
<tr>
<td></td>
<td>CIS Regge</td>
<td>Local calamity informati on system</td>
<td>Information on and instruction for emergencies and actions to be taken.</td>
<td>Waterboard</td>
</tr>
<tr>
<td>France</td>
<td>ALTHAIR</td>
<td>Flood forecastin</td>
<td>Information on hydrographs for different locations, based on data</td>
<td>Flood forecasting service in Gard</td>
</tr>
</tbody>
</table>
### 2.2 United Kingdom

#### 2.2.1 Introduction

Within the UK the main DSS used in flood risk management is the Modelling and Decision Support Framework (MDSF). The MDSF is widely used in England and Wales for developing long-term flood risk management plans and strategies. Although not developed for flood event management many metrics encompassed by the MDSF are relevant to flood event management (e.g. the assessment of floodwater depth and risk in terms of economic damage and number of people affected).

Environment Agency Management System (AMS) Online forms the basis of a decision support framework for flood event management within the Environment Agency. It contains a structured set of process diagrams and documents on flood event management. However, it’s main purpose is to act as a repository for processes and procedures that are related to flood event management.

One of the major issues that has been highlighted by various reports into the Environment Agency’s flood event management system is that communication between the various actors is crucial to good event management. A system such as SurreyAlert, if used nationally by the Environment Agency in conjunction with other emergency responders, would help to address these concerns.

#### 2.2.2 Environment Agency Management System (AMS) Online

**Description and functionality**

The Environment Agency has recently introduced a system for flood event management on its internal intranet known as the Environment Agency Management System (AMS) Online. The AMS is not a decision support system as such. The AMS is a management system and is used to define the roles and processes involved in flood event management. The AMS forms the basis of a decision support framework for flood event management within the Environment Agency. It has a series of nested process diagrams that define the Environment Agency’s flood event management process from end-to-end: from detection, forecasting, warning through to response and delivery (Environment Agency, 2005).

There are three main functions of the Environment Agency’s AMS. These are as follows:

(i) To bring together documents and procedures related to flood event management
(ii) To link together the processes and activities related to flood event management

(iii) To provide details of the roles and responsibilities of the Environment Agency with respect to flood event management

Data requirements
The AMS requires the following (Environment Agency, 2005):

- Representation of the flood event management process in the form of a series of nested diagrams.
- Environment Agency document and procedures related to flood event management.
- The roles of the various departments within the Environment Agency.

2.2.3 SurreyAlert

Description and functionality
The SurreyAlert system comprises two main parts as follows:

- SurreyAlert extranet;
- SurreyAlert public web site.

The extranet is a secure website that can only be accessed by Surrey's Police, Fire and Rescue, and Ambulance Services, Surrey County Council and the 11 District and Borough Councils in Surrey in England. It is used to exchange information securely and in “real-time” during major incidents in the county of Surrey. These incidents are not just specifically related to flooding but to all incidents for example an outbreak of foot and mouth disease, or a serious road accident.

It is also used to hold the organisations' useful information, so that all emergency responders have access to, using the principle of “gather information once, and use it many times” (SurreyAlert.Info, 2003). The use of this type of intranet system for both major and minor incidents is important in providing a medium for fast and effective communications between multiple agencies.

The SurreyAlert public website is available to the general public and provides them with a snapshot of the latest incidents. An example of a typical screen that the public would be able to access is shown in Figure 2.1.

Data requirements
All types of information that is important to share between emergency managers.
2.3 The Netherlands

2.3.1 Introduction

The Dutch DSSs were commissioned by the Dutch Ministry of Transport and Public Works to help support decision making on a specific aspect of flood risk management that was considered urgent at the time. Development of each tool has taken two or more years of input by teams consisting of water management experts, software developers, and clients/users.

Each of the described tools has cost hundreds of thousands of Euros. However, only one of the tools is actually used in practice: the Planning Toolkit (and the derived web-based Water Manager). The Planning Kit is the most recent DSS and was developed taking into account lessons from the other projects. This tool was simple in its design, transparent in its functioning and limited in scope and ambition. However, this does not mean that it required less effort to develop. Its user-friendliness increased the amount of work needed.

A comparison of the Planning kit DSS and the Irma-Sponge DSS Large Rivers (both developed for long-term flood risk management) shows that even in DSSs when the run-time of the model is short, end users often prefer a DSS based on "pre-cooked" model results, instead of having to run the models as part of the DSS. The main reason for not wanting the models to be part of the DSS is that those type of DSSs can only be applied by a group of experts with different backgrounds (i.e. a combination of modellers and decision makers). Similar reasons were found during the review of other DSSs for long-term flood risk management that were developed in the Netherlands. For instance, one of the reasons the end users stopped using the DSS IVB-DOS was that because the DSS tried to combine several models with one interface, it was too complex and contained too many functions. The users indicated that at present, they prefer to work with the individual models and not with the DSS combining the models.
2.3.2 **ESCAPE Decision Support System**

**Description and functionality**

ESCAPE stands for European Solutions by Co-operation And Planning in Emergencies. ESCAPE is a joint venture between the Province of Zeeland (the Netherlands), the provinces of Oost-Vlaanderen and West-Vlaanderen (Belgium) and the county of Essex (England) (Windhouwer et al, 2005). The framework of the ESCAPE project comprised the development of a Decision Support System (DSS). The ESCAPE DSS ensures a structured decision making process during an impending or an actual disaster. The system calculates the time required to evacuate a struck area, as well as the best route to use in doing so. Apart from this a time schedule is made, which shows the number of evacuated people and the activities to be carried out during the evacuation with an indication which activities are on the critical path.

**Data requirements**

In making these decisions, the system makes use of information supplied by staff of the provincial government. Information pertaining to the area of the disaster, number of inhabitants, anticipated water level (through the High water Information System, DWW (2006)) and traffic routes must be entered. Computation of evacuation times also requires information on number of inhabitants at different locations in the potentially flooded area. The model applies a fixed total time of 13 hours for decision making, response and preparation for any area in Zeeland. This is the period that precedes the actual evacuation.

2.3.3 **FLIWAS**

**Description and functionality**

A joint Dutch/German cooperation developed a sophisticated system for high water and emergency management: the FLood Information and Warning System (FLIWAS). FLIWAS enables decision-makers, water managers and other concerned to take the right decisions at imminent high water levels. FLIWAS is developed in cooperation with two other relevant projects in the field of flood risks and calamity suppression, i.e. HIS (DWW, 2006) and VIKING (www.programmaVIKING.nl).

HIS (acronym for High water Information System) is an automated computer system of the Directorate-General for Public Works and Water Management. At imminent or existing high water levels HIS offers up-to-date information of threatened localities in retaining walls and dams. HIS also can generate a graphical overview of a potential breach and related safety issues for inhabitants of a threatened area. FLIWAS will incorporate the operational part of HIS.

VIKING is a joint project of the Dutch province of Gelderland and the German state of North Rhine-Westphalia aiming to improve trans-boundary calamity management.

FLIWAS supports decision-makers, water managers and other people concerned to take the right decisions at imminent high water levels. This is done using the following modules:

- Water levels and other externally acquired data and forecasts are entered into FLIWAS automatically or by hand. Data is visualised by means of time-related diagrams, longitudinal sections and cross-sections. The system will issue a warning as soon as the water level exceeds a predefined threshold value;

- The user defines emergency response plans and links all interventions to the organisation responsible and/or related to a flood defence asset, e.g. an embankment section, a sluice or a pumping station. In addition the user is able to assign each intervention to a phase. In a phased approach the emergency level is upgraded in discrete steps, or phases. The decision to upgrade will automatically initiate all interventions assigned to that phase. The emergency level of each relevant asset is shown in a map using different colours;

- In operational mode FLIWAS uses the selected emergency response plan and available information to recommend required measures or phase shifts. Based on the decision of the
operational manager FLIWAS will inform the responsible staff instantaneously by means of fax, e-mail or SMS messages. Progress is monitored from the coordination centre.

- FLIWAS supports the evacuation decision making process. Evacuation plans for various flooding scenarios and evacuation strategies can be developed with the Evacuation Calculator (EC). The EC is part of the FLIWAS-DSS;
- The Resource Management module in FLIWAS is instrumental to support the operational use of emergency response plans. This module, together with up-to-date duty rosters and stock lists, allows appropriate planning of human resources, tools and materials;
- The system automatically logs everything that the system and its users do: interventions and actions by the user, recommendations made by the system, manual and automatic import of data into the system. This makes it possible to ‘replay’ the emergency situation after the flood event. Hence, it is possible to evaluate and cross-reference the decision making process to the information that was available at the time the decision was made. The evaluation module in FLIWAS is an important tool in identifying required improvements to emergency response plans, as well as improving the organisation and the knowledge level of the users;
- To assess emergency response plans in FLIWAS and to train future users of the system, FLIWAS includes particular testing and training modules. When these modules are activated external communication is blocked and historical data (time series) are used instead.

Data requirements

Data requirements depend on the modules the user wants to apply, but can include:

- Water level and discharge information (hydraulic loadings)
- Emergency response plans
- Information on potentially flooded areas (probable water depths and flow velocities)
- Information on the road network and the number of people to be evacuated
- Overview of available human resources, tools and materials to be used for evacuation and rescue

Water levels and other externally acquired data and forecasts are entered into FLIWAS automatically or by hand. Data is visualised by means of time-related diagrams, longitudinal sections and cross-sections. The system will issue a warning as soon as the water level exceeds a predefined threshold value.

2.3.4 Calamity Information System Regge & Dinkel (CIS-Regge)

Description and functionality

The "Calamity Information System" (CIS) contains information on different types of emergencies and on instructions for actions that need to be taken and was developed for the Regge & Dinkel water board. The CIS is a fully web-based application.

The centre of the system is the command screen from which links to different information sources and models can be activated. Figure 2.2 shows an example screen of the Regge & Dinkel application. All actual and relevant information is shown on a map via GIS shape-files and the related database-files. Several map layers can be shown with information on scenarios (inundation, power failure, drought, etc.). Possible emergencies are related to drought, flooding, effluents, etc.

Data requirements

Information on scenarios for inundation, power failure, drought, etc. Databases with information on vulnerable objects.
Figure 2.2  Example screen of the Regge & Dinkel application.
2.4 France

2.4.1 Introduction

There are currently three existing management tools in France: ALHTAIR, PACTES and OSIRIS-inondation. All three focus on flood management and have been developed for real-time use. ALHTAIR is mainly a flood forecasting system and it does not include a vulnerability and risk assessment part. PACTES is still in the pre-operational stage. OSIRIS-inondation appears to be the only risk assessment and crisis management tool at a local level which is operational and widely disseminated to local administration for planning.

It is worth noting that the evaluation and the communication on the risk is based on predefined scenarios and maps: no new flooded area computations and queries to identify the threatened stakes or to compute management response are undertaken in real time.

Use of GIS as an interface is now widely spread in natural hazard assessment and management. This kind of tool allows a good synthesis of various information and an easy communication between the different stakeholders.

Road networks have seldom been taken into account, despite their great importance during a crisis. Although some road crisis management plans are under development in floodplains (mainly in the Loire river valley in France), nothing seems to exist or to be planned for flash floods even though a management of the traffic appears to be a major concern in this type of flood. This clearly justifies the attempt within the task 17 of the Floodsite project (Lumbroso et al, 2008) to develop traffic management tools for use during crises.

2.4.2 Automated regional hydrologic alarm system (ALHTAIR)

Description and functionality

ALHTAIR stands for ‘Alarme Hydrologique Territoriale Automatisée par Indicateur de Risque’ and is a flood forecasting tool. The tool contains a distributed hydrological model that is able to simulate flood hydrographs at various locations of the river network using ground observations of rainfall intensities and water levels in the rivers with estimates of efficient rainfall through meteorological radar. The system uses a GIS to display the spatial data and the forecasts.

The ALHTAIR system is composed of three tools, which are integrated in the ArcGIS environment: CALAMAR, HYDROKIT and ALHTAIR rainfall-runoff model. CALAMAR® provides calibrated (using automatic ground rain gauges network) radar precipitations for all hydrological units of the basin. HYDROKIT® exploits the digital terrain model to:
- Extract the physical characteristics of a catchment.
- Determine the concentration time.
- Establish longitudinal profiles of a river network.
- Analyse the time of overland flow transfer of a basin and define isochrones.

ALHTAIR rainfall-runoff model has the following functionality:
- Determination of the efficient rainfall contributing to the overland flow taking into account spatial variability of the catchment and its characteristics including infiltration rate (production function).
- Transfer of the overland flow through the drainage system.

Data requirements

ALHTAIR uses the following data:
- Digital topographic maps (extracted from IGN’s BD ALTI® - vector, scale 1:50000, resolution 50m in horizontal and 2m in vertical direction).
• Land cover maps extracted from European Environmental Agency (EEA) CORINE Land Cover (vector, scale 1:100000) and National Forest Inventory (l’Inventaire Forestier National – scale 1:25000) and three images of SPOT satellite dated May and August 2001 and January 2002).
• Digital geological maps (raster, 1:50000 and 1:80000 from French Geological Survey - BRGM).
• Land use map extracted from BDSol-LR® (vector, 1/250000) provided by Institut National de Recherche Agronomique – INRA).
• Flood prone area maps extracted from IGN’s Scan100® and Scan25® maps.
• Real-time observations of rainfall and water level in rivers from measurement network of a given catchment.
• Real-time spatial estimates of the rainfall intensity as seen from the meteorological radar.
• In the case of flood event additional inundation maps can be provided by Earth Observation satellite operators to the crisis management centre 24 hours after initialisation of the International Charter of Space and Major Disasters(23).

2.4.3 Model for economical assessment of flood damages (ALPHEE)

Description and functionality
The ALPHEE model estimates the flood damage costs in the Ile-de-France region and is used to test the efficiency (cost-benefit analysis) of the existing and considered flood mitigation devices (reservoirs, polders in floodplains, etc.). The system is in operational use for two purposes:
• To estimate real flood damages (direct and indirect);
• To simulate a potential impact of a hydraulic structure (both in the river minor bed or flood plain) on damage reduction.

The ALPHEE model is composed of a hydrological model, a hydraulic model and an economic model. These three tools are integrated in the Map Info GIS environment.

ALPHEE is used for the following purposes:
• To define hydrological response of the catchment, possibly influenced by the reservoir lakes;
• To select and simulate the impact of a certain number of hydraulic constructions in the minor bed and flood plains in the Seine, Marne and Oise rivers;
• To estimate the direct and indirect damage related to a given flooding (real or hypothetical);
• To analyse the results and impacts at the scales appropriate to the problems.

Data requirements
ALPHEE manipulates a wide range of geo-referenced objects such as:
• Points : electricity substations, water production plants, sewage farms, …
• Areas : classes of land use, French Statistical Office INSEE blocks, catchment surface units corresponding to flood plains,
• Lines : transportation networks (roads, railways, etc.)
• Spatial information in RASTER format : Images, aerial photographs, IGN SCAN25 maps.

2.4.4 High water prevention and forecast by means of spatial techniques (PACTES)

Description and functionality
PACTES stands for ‘Prévention et Anticipation des Crues au moyen des TÉchniques Spatiales’ and is a French transverse initiative, which involves end users (civil protections, services of the Ministry of Environment) at national, regional and local scale, research laboratories, remote sensing data and service providers and industrial companies. The project covers all phases of flood management: prevention, forecasting and alert, crisis management and post-crisis assessment phases (Goutorbe et al., 2000; Reuche, 2001). The main idea was to create an overall processing chain, starting from the data provided by ground or space instruments, up to the final decision support tools and information management. Every part of the process integrates simulation models provided by research
laboratories: meteorology, hydrology, hydraulics, ground and satellite telecommunication, satellite navigation.

PACTES simulates flood scenarios through meteorological, hydrological and hydraulic simulation models. This simulation can be run in two different modes using different simulation models. The first one (off line mode) generates risk maps assessing the flood scenarios and their impacts. The second one (on-line mode) generates real time forecasting based on rainfall observations. During the forecasting phase the system, through the above mentioned simulation models, generates flood extents (compared with historical flood extent maps). It will continue to run also during the flood emergency together with the activities required by the emergency management organisations e.g. reporting, bulletins preparation, event monitoring, on-site intervention management, etc.

**Data requirements**

In PACTES approach, space technology is used in three main ways: (1) radar and optical earth observation data are used to produce Digital Elevation Maps, (2) land use - earth observation data are also an input to weather forecasting, together with ground sensors; (3) satellite-based telecommunication and mobile positioning.

### 2.4.5 OSIRIS

**Description**

OSIRIS stands for ‘Operational Solutions for the management of Inundation Risks in the Information Society’ and was originally a 5th EU FP project under the IST (Information Society Technology) programme (Erlich, 2007). Its goal consisted in improvement of the dissemination, using Information and Communication Technologies (ITC), of information on flood risk to citizens for better prevention or crisis management. In the framework of OSIRIS activity a prototype of a tool called “OSIRIS-Inondation” (Morel et al., 2002; Morel, 2004a; Morel, 2004b) has been developed to provide operational solutions to local managers on the Loire River basin. The main objective is to provide an interface which can help the local stakeholders to make use of the official forecasts and to link them to other documents: flood prevention plans, rescue organisation plans. The prototype was specified, tested and validated by the different groups of stakeholders represented by an active OSIRIS partner and committed end-user Etablissement Public Loire (EPLoire).

OSIRIS-Inondation is a tool that can be used in local or remote access modes with two main functions: crisis planning preparation and crisis management. Developed as a web oriented service it uses Internet Explorer as a basic access environment. The user-friendly interface allows the following tasks to be performed:

- **Simulations**: It does not perform complex calculations (it is not aimed at engineers): it integrates technical data and makes them understandable to no-technical end-users in terms of:
  - Forecasts: interface with/access to official forecasts, editing, validation, exploitation.
  - Hydrology – mapping of flooded areas integrated into the scenarios.

- **Scenarios**: local situation or a series of predefined situations triggered by the forecast flood state (for example: a forecast local water level of 3.50 m will trigger a "1 in 100 year return flood" scenario, with resulting flood states, actions and resources)

- **Interfaces**: ability to interface OSIRIS-Inundation with other tools:
  - Automatic warnings
  - Local databases (directories)
  - Operational crisis management

**Data requirements**

The database contains information common to all stakeholders located on the same territory:
• general information about the territory
• cartographical references: maps and potential flooded sectors corresponding to flood plains,
• reference scales
• inundation scenarios.

The "stakeholder" information database contains information related to:
• stakeholder categories
• vulnerability associated to each stakeholder
• list of appropriate actions
• human and material means

2.5 **Differences in and resemblances of the UK, Dutch and French DSS**

The decision support systems described in this chapter are rather different, as not all of them were developed for the same purpose of flood event management. Nevertheless there are a number of **resemblances**. All the described systems are more or less "generic". They may have been set up and applied for a specific area, but their modular set-up would allow application for other areas as well. Also some form of **GIS** is present in most systems. For some DSSs this may only be in the form of a simple map for orientation purposes, but usually multiple layers are available to present spatial information for various scenarios.

In DSSs where results of model calculations have to be taken into account in the decision making, those results are usually not calculated in real time. In most models a selection is made from **pre-calculated** sets of model output. Exceptions are FLIWAS, where in the evacuation module an adaptation of the traffic model results to the actual situation during an evacuation will be possible, and PACTES, where efforts are made to produce real-time run-off predictions on the basis of (forecasted) rainfall.

Some DSSs contain a **decision** part for the emergency managers, but they contain also a **public** part (web-based) for providing up-to-date information to the public during an emergency, via internet. Surrey Alert and Fliwas are examples of such systems.
3. **User requirements in flood event management**

From the previous chapter it is known which decision support methods and tools are currently available for flood event management in the three countries of the UK, the Netherlands and France. In this chapter the requirements of the decision makers are investigated to see where the current tools are lacking.

Most of this chapter is taken from the FLOODsite Technical Note on user requirements in flood evacuation management (Logtmeijer, 2008). This document provides an overview of the description of user requirements as they have been gathered by studies in literature, contacts with end-users and interviews with stakeholders and experts.

### 3.1 General considerations

A framework that aims at evacuation planning needs to incorporate the results of hydrological models as well as one- or two-dimensional flooding inundation models. The latter types of models often have long computational times (e.g. 10 hours or more), which make them less applicable for real-time flood event management. In addition the model set-up would have to be adapted during the flood event as a results of changes in the boundary conditions (e.g. water levels) and the location of breaches in flood defences, so that the model schematisation represents the actual conditions. In a crisis situation, the user must be sure to have an answer within a limited amount of time. Hence, a practical alternative is to develop a DSS that incorporates the results of ‘pre-run’ or ‘pre-cooked’ model scenarios or best practice procedures.

In broad terms a DSS for flood event management may include:

- Results of various inundation scenarios caused by failure of the flood defence system at a number of locations, under different hydraulic loading conditions and with different breach widths;
- Knowledge of flood alleviation options such as emergency flood storage, temporary flood protection, etc.;
- Flood hazard at vulnerable locations in real time;
- Safe access/exit routes;
- Coordination of all event response personnel.

The exact requirements will depend on the responsibilities of the user. For instance, in the Netherlands the authorities responsible for an evacuation are not the same as those responsible for flood alleviation. It would therefore not be helpful to combine both tasks in a single DSS. In other countries, however, this combination might be a prerequisite.

### 3.2 Requirements for the Netherlands

For Dutch flood event managers a DSS should have the following functions:

- **Enable the storage of pre-run model results.** The results of different types of models, such as flood inundation models and evacuation models must be stored in the DSS.
- **Enable storage of other relevant data.** These data may comprise items such as location, number and vulnerability of people at risk, coordination of event response personnel, optimisation of safe routes for rescue services in cases where warning time is minimal.
- **Have the possibility to run simple models.** Although complex two-dimensional flood inundation models will not be used as part of the DSS, it might be useful to incorporate the simpler and faster models on evacuation or application of flood event measures. The models that could be incorporated in the DSS must be fast, robust, easy to use, and provide additional, but not critical, information. Critical information will come from the pre-run model results stored in the DSS.
- **Run fast.** The required information is produced in a short time, on the order of minutes.
- **Be robust.** The system should not fail in a crisis situation. To be sure that the information included in the DSS always is available, a paper copy of all maps, tables and other documents can be made.
Information requirements for evacuation decisions are as follows:
• Information on most likely location and time of failure of the dikes;
• Description of the pattern of inundation, ideally with for every polder one location of dike failure;
• Distribution of population, vulnerable objects and factories;
• The evacuation model should be able to run real time and the user should be able to intervene, e.g. when a road is unexpectedly blocked. This is not possible with the existing Escape DSS;
• The evacuation model should distinguish the following phases in the evacuation: preparation, warning, voluntary evacuation, forced evacuation from six hours before expected flooding and end of the evacuation two hours before the expected flooding;
• The evacuation module should be able to work with safe areas (i.e. higher grounds, flood secure buildings, etc.) within the existing dike rings and should plan exit routes to those safe areas;
• Information should also be prepared for communication to the public.

Other criteria that may play an important role in the selection process for a suitable DSS are:
• User-friendliness. This applies both to the interface and to the presentation of results in maps and graphs;
• Spatial aspects. If the DSS is linked to a GIS, results may be presented spatially on maps, which are easy for decision makers to understand;
• Data requirements. What types of data are needed, how are they input to the DSS, and how easy can they be obtained in practice?
• Quantification of uncertainty. Each module has an uncertainty. The cumulative uncertainty of all steps determines the confidence a decision maker will (or should) have in the outcome.

3.3 Requirements for the UK

From the various reviews that have been carried out of Local Authorities’ and the Environment Agency’s flood event management procedures and systems, the following can be concluded regarding their requirements (Lumbroso, 2006):

• There is a need for the Environment Agency to be able to estimate the timing, extent, and depth of flooding not only for “routine” flood events, but also for “unexpected” events such as breaches of flood defences or dam breaks;
• There is a requirement for the Environment Agency to be able to forecast the possible breaches of flood defences in order to issue timely warnings;
• There is a need to assess the risk that various receptors (e.g. people and properties) may be exposed to under various forecast floods;
• There is a need to improve communication between all the actors involved in flood event management, because it is often difficult for them to know what each organisation’s response is and also to know what is happening in real-time during a flood event;
• There is a requirement to facilitate decision making under uncertainty;
• There is a need to assess evacuation times.

In terms of the source - pathway - receptor risk model (HR Wallingford, 2002) the following information is required by Environment Agency project managers:

(i) Source

Information in terms of the source includes fluvial and tidal water levels. The decision support framework needs to be run for a number of “pre-defined” flood events and the effect of these events on various elements at risk assessed.
(ii) **Pathway**
In terms of pathways incident managers require the following information:

- Flood extent;
- Water depth;
- Velocity of water in the floodplain;
- Rate of inundation and rate of rise of water;
- Progression of inundation with animations to show emergency planners how a particular flood will develop;
- Probability of breaches in flood defences and their effects in terms of inundation times and water depths.

(iii) **Receptors**
In terms of receptors the actors in emergency planning require the following information:

- Number of commercial and residential properties at risk of flooding and the water depth at these properties. The risk in terms of the possible economic damage could be a useful indicator with regards to any “flood fighting” that may need to be implemented (e.g. sand bags, implementation of demountables). However, this is already available via another framework, the Modelling and Decision Support Framework (MDSF) developed for the Environment Agency. However, this functionality could easily be added to FLINTOF;
- Number of people at risk of flooding together with an estimate of their vulnerability, and the likelihood of injuries or fatalities under particular scenarios.
- The effect of possible flooding on key locations such as police and fire stations, hospitals, emergency control centres and areas designated as shelters;
- The transport network and the depth of water affecting important transport links (e.g. escape routes) for various scenarios;
- Estimates regarding evacuation times and safe havens.

### 3.4 Requirements for France

The results of the OSIRIS project formed a major input for the assessment of the users’ requirements and the review of flood event management decision support. Tests of the usefulness and suitability of the prototypes being built in the project were conducted with many appraisal groups associated with flood damage mitigation, as well as with inhabitants at risk for flooding. This latter group, as well as local- and county-level crisis managers, were the most frequently used appraisal groups.

Moreover, the French Community Safety Plan (PCS) was studied to specify the user requirements. The French ‘Plan Communal de Sauvegarde’ is used to prepare a community to possible (flood) crisis management by creating the management plans for the economic stakes in the urban areas. This plan shall include the useful information for an evacuation: identification of the vulnerable zones, actions to communicate as well as to evacuate, safe areas… In this case, the forecast of flooded part of the road network must be established around the flooded zones in order to identify the safe accesses for the rescue vehicles (SDIS, police). Furthermore, the forecast must be done sufficiently early to prevent these vehicles from being trapped. This is further explained in chapter 7.3.2.
4. **DSS Methodology**

4.1 **Methodological framework**

4.1.1 **General approach**

The methodological approach for flood event management (Van der Vat et al, 2007) is based on the disaster cycle as discussed in FLOODsite Task 17 (Lumbroso et al, 2007) and on the terminology presented in the FLOODsite report *Language of Risk* (Gouldby et al, 2005). The flood event itself is defined as an extremely high (forecasted) water level that most likely will cause flooding. The aim of the framework is to structure the development of a decision support system for relevant authorities in flood event management. This decision support can be given during the preparation phase of flood event management or during the actual flood event (response). The support should lead to risk-based decision making, where the risks resulting from different management options are compared and assessed. The methodological framework was jointly developed with task 18 on long term flood risk management.

Flood event management merely takes place in the lower half of the disaster cycle (Figure 4.1), i.e. in the preparation and response phases. Within the preparation phase the management of the actual event is planned. For example evacuation plans are designed. The preparation phase also consists of measures that can be taken in the time between the forecast of a flood event and the actual event. Examples of these measures are operation of barriers and retention areas and temporary raising of dikes with sand bags. Long term flood prevention measures, such as lowering of the floodplain are not incorporated.

*Figure 4.1 A disaster cycle with focus on flood event preparation and response*
In the response phase the aim is to reduce the flood consequences. This can be done by influencing the way the flooding proceeds by opening or closing gates in the hinterland, or by evacuation and rescue. Evacuation deals with the relocation of humans, livestock and capital goods from an area threatened by flooding to a safe place. Evacuation takes place before roads are blocked or houses are being flooded. The evacuation activity is started during the preparation phase, when the forecast is given. Rescue takes place during the flood event. The amount of resources used for rescue and the way they are deployed needs to be determined beforehand. An important issue to be addressed in flash flood areas is the state of the transport network to be used by rescue services.

4.1.2 Scheme

The scheme below (Figure 4.2) presents the methodological framework for flood event management DSSs (Van der Vat et al, 2007). The framework consists of several modules. The external driver module describes the existing situation prior to the flood and the boundary conditions for the flood event. The tools module consists of the tools used in the other modules. The management response module describes the management options available to the decision maker. The analysis is described in the modules in the central column.

The boundary conditions of the flood event such as fluvial / tidal water levels from a flood forecasting system form the input of the hazard module. Based on an analysis of the reliability of the flood defence system, the most likely locations of failure of the defence system are selected. For each location a failure probability is established. For dikes, a breach growth model can be applied to describe the growth of the breach over time and its final dimensions. The information on water level and breach location and growth can be combined in a hydrodynamic inundation model to calculate the flood characteristics for each possible failure location. At the level of the hazard module, the decision maker can influence the flood characteristics by flood prevention measures and operational flood management measures, as described in section 1.2.2.

The exposure module compares the information on the flood characteristics with information on the distribution of inhabitants, livestock, property and utilities. This defines the exposure to the flood event. The exposure can be influenced by execution of an evacuation or by a rescue operation.

The vulnerability module defines the potential for the receptors (e.g. people, livestock and buildings) to be harmed. The input to the vulnerability module is based on a series of empirical or theoretical damage functions for each receptor, providing a relation between flood characteristics and level of harm.

In the consequence module a damage and casualties model combines the exposure and the vulnerability and calculates the damage to people, livestock, property and utilities. Damage to inhabitants can be expressed as number of people affected, exposed or injured and the number of casualties to be expected. Damage to livestock property and utilities is expressed as value lost. The damage calculation is executed for each possible breach location. If management options such as evacuation have been selected, their influence will be incorporated through the resulting effect in the exposure.

The risk module combines the results of the consequence module for the different breach locations. Combination takes place based on the probability of failure at a certain location and the calculated damage for this location. The combined risk is expressed as the expected damage of a forecasted flood event under the selected management option. Again damage can expressed as value lost, number of people affected, exposed or injured and the number of casualties.
Figure 4.2 Methodological framework for flood event management

**Exposure module**
- Fluvial / tidal water levels at different locations
- Breach locations and growth
- Flood characteristics (depth, velocity, extent)

**Vulnerability module**
- People (spatial distribution, age, shelter)
- Livestock (spatial distribution, shelter)
- Property and utilities (spatial distribution, shelter)
- Actual capacity of transport network (under flood conditions)

**Consequence module**
- Damage to inhabitants (affected people, exposed people, casualties)
- Damage to livestock, property and utilities (expressed in the value lost)

**Risk module**
- Expected damage for a forecasted water level summed over the different breach locations expressed in euros or number of people harmed

**Tools module**
- Flood Early Warning Systems
- Reliability of flood defence system
- Hydrodynamic model

**External module**
- Discharge
- Water level
- Precipitation
- Wind
- Tide
- Topography
- Drainage system

**Management response module**
- Operational flood prevention (sand bags, retention areas, storm surge barriers)
- Operational flood management (closure of gates)

**Provision of Information to Decision Makers**
- Fluvial / tidal water levels at different locations
- Breach locations and growth
- Flood characteristics (depth, velocity, extent)
- People (spatial distribution, age, shelter)
- Livestock (spatial distribution, shelter)
- Property and utilities (spatial distribution, shelter)
- Actual capacity of transport network (under flood conditions)

**Evacuation, rescue and warning**
4.2 Risk-based decision support

The aim of a methodology for flood event management (FEM) is to allow the decision maker to take better informed decisions. This can be done by supplying in a structured way all relevant information. A useful step is to integrate the information into one measure for flood risk management (FRM) decision making: the risk. The methodology also applies for long term flood risk management. The Task 18 report (McGahey et al, unpublished) shows the methodological framework applied for long term flood risk management. There are small differences with the FEM framework, which are stressed below.

Meaning of probability and risk

The risk is defined as the product of the probability of a flood event and the associated consequence (damage) summed over all possible flood events for a certain location.

In flood event management, the time horizon is much shorter than in long term FRM. This means we are interested in the probability of flooding given an extreme water level prediction. The result is that the probability of the flood event is much higher than the average flood probability (per year). Therefore, the consequence and the risk values in FEM are much closer. The main uncertainty in the period between the forecast and the actual flood is the flood pattern. This is determined by the breach locations for low land areas and for flash flood areas by the exact location of the rainfall.

Thus, the concept of using risk as a measure in the decision making process is the same in both FEM and long term FRM. However, the risk value might differ because in FEM other types of probability are sometimes used. The exact value of the calculated risk is not that important, it is the difference with the risk under other management options that counts.

Management options

In both FEM and long term FRM, flood risk maps can be produced and desirable management options can be selected and compared on the flood risk for different (combinations of) options. In long term FRM decision are taken on a higher level and management options comprise policy directions or strategic alternatives, not ready-to-implement measures (see also De Bruijn et al, 2008). In flood event management the options are much more detailed, location-specific and ready to be implemented.

Types of impact

The planning of flood event management concerns people's deaths and not so much the economic damage, in contrast to long-term FRM, where both aspects are as relevant.

The next two chapters describe the development of two prototype DSSs and their application on the estuaries Thames and Schelde. Chapter 7 describes the application of (part of) the framework to two urban flooding cases in France.
5. Pilot application for the Thames Estuary, UK

5.1 Aim of FLINTOF and user requirements

5.1.1 Vision for FLINTOF

The DSS is known as the Flood INcident Tactical and Operational Framework (FLINTOF). The long term vision for FLINTOF was that it should provide a transparent, flexible, and efficient framework, within a Geographical Information System (GIS) environment. As such it would produce risk maps for a variety of receptors in support of the planning of the flood event management process in a systematic manner that ensures consistency between users.

The objectives of the Flood Incident Tactical and Operational Framework (FLINTOF) were as follows:

- To facilitate the effective interrogation of existing data relating to the assessment of the level and spatio-temporal distribution of flood risk relevant to emergency management throughout an area (e.g. in terms of loss of life, evacuation and transport links);
- To allow existing data to be supplemented by further analysis, where required and practicable;
- To enable the implications of emergency planning scenarios on flood risks, and policies for flood event management to be assessed;
- To include measures that support the social impact in the assessment flood emergency management;
- To allow flexibility in terms of the spatial and temporal scale at which the DSF can be employed.

It is important to note that at present FLINTOF has been set up only as a prototype piece of software.

5.1.2 Core principles of FLINTOF

FLINTOF was not designed to identify ‘optimal’ solutions with respect to flood event management, but rather to provide information on selected options for use in the emergency management planning and decision-making process. Furthermore, FLINTOF does not contain hydrological or hydraulic simulation engines nor does it require the use of specific hydraulic modelling software. However, FLINTOF does require two dimensional hydrodynamic modelling results at a suitable temporal interval. The spatial and temporal interval that can be used by FLINTOF is flexible.

A major benefit of bringing such systems to the emergency management process is that they provide common approaches to improve preparedness, as well as providing a greater degree of transparency and replicability. A number of core principles have been considered in developing FLINTOF, which include:

- **User driven** - The concepts set out in this Chapter were based on consultation with key stakeholders. Flexibility to respond to a range of user requirements is essential to ensure that any operational DSF based on FLINTOF is a success.
- **Deliverable** - Major consideration was given in developing FLINTOF that it could be used as a prototype for an operational system for use by the Environment Agency and Local Authorities.
- **Functionality** – The scope of works included under this project represent a necessary minimum level for flood event management, rather than a fully comprehensive level of functionality. However, the current DSF is flexible enough to allow data from a range of models to be imported and used.
- **Modular approach** – An over-arching framework was developed in order to accommodate the initial functionality, but the FLINTOF framework could be easily developed to incorporate future needs and additions.
• **Integrated** – The proposed system cannot be seen in isolation but is set within a broader context and must be compatible and mutually supportive of both specific projects and systems (e.g. Environment Agency data protocols and systems).

• **Sustainable** – Consideration was given to the longer-term future of the proposed system as well as the immediate needs of users to achieve a balanced and pragmatic framework.

### 5.1.3 User Requirements

A number of meetings have been held with the Environment Agency and emergency planners from Local Authorities. The potential end users indicated that FLINTOF should have the following characteristics and functionality:

- Facilitation of the assembly and management of data related to flood event management;
- Estimation of flood extent and depths on a spatio-temporal level i.e. as the flood progresses;
- Provision of guidance on the level of flood hazard prediction throughout the area of interest;
- Estimation of the risks to various receptors in terms:
  - Loss of life and injuries to people;
  - Emergency access;
  - Probability of building collapse;
- Provision of a framework for evaluating different flood incidents and emergency management options.

Although the DSS will not be able to address all of the above issues it will go some way toward addressing many of them. For the Thames pilot the DSS should be able to provide the following risk-based information:

- Residential properties at risk and depths of flooding;
- Commercial property at risk and depths of flooding;
- Services/utilities at risk and depths of flooding;
- Process operational centres at risk and depths of flooding;
- Transport infrastructure at risk and depths of flooding.

In order to support the decision as to whether to evacuate an area the DSS also needs to provide answers to the following questions:

- Can all residential properties that are at risk of flooding evacuate voluntarily if required? For example, is the road network safe? Is there a shelter readily available?
- If there are areas that could not safely evacuate, is there an alternative emergency plan in place to manage risks appropriately?
- At what point should evacuation be recommended over and above moving to upper floors in property or near-by property?
- Are there utility stations at risk that would make remaining in the property dangerous or difficult? (e.g. electrical substations, sewage treatment plants).
- Are emergency plans in place to manage risks to such utility infrastructure?
- Are hospitals or other key services (e.g. police, fire, ambulance stations) at risk?
- Are emergency plans in place to manage risks to key service infrastructure?
- Are flood event management process centres at risk, if yes are alternative plans in place?
- For areas where an evacuation may be required:
  - Where are people most likely to require evacuation assistance (ie the most vulnerable and/or those in locations where risks to people are highest)?
  - Are safe haven locations appropriate and available?
  - Times to evacuate (if available) sufficient for likely flood characteristics?
- What traffic management measures should be put in place to ensure minimum disruption to traffic flow and or minimum risks to life from evacuation process?
5.2 Introduction to the Thames Estuary

The Thames Estuary is one of the United Kingdom’s major east coast estuaries. It extends from the tidal limit of the River Thames at Teddington Lock, Richmond in the west, through the heart of London, to Southend in Essex a distance of some 106 km. The characteristics of the flooding regime change moving downstream from Teddington, where it is dominated by fluvial events, to the hazards posed by storm surges and waves in the downstream reaches near Southend. The Thames Estuary has a history of flooding with records dating back to the eleventh century.

Surge tides are the biggest flood hazard to development along the tidal Thames. The tides are caused by areas of low pressure that can cause large increases in sea levels. The surge pushes up the Thames Estuary after travelling down the North Sea. Encroaching development into the river has reduced the capacity of the river to cope with the additional volume of water thus increasing floodwater levels.

The Thames Estuary was chosen as a pilot site by the FLOODsite team for a number of reasons. There are approximately 500,000 properties, housing 1.25 million people, and a significant proportion of London’s essential infrastructure is at risk from flooding. The area also has tidal salt marsh and extensive mudflats exposed at low water, which provide important habitat to a wide variety of species (FLOODsite, 2005).

In January 1953, the east coast of England was devastated by a tidal surge causing some of the worst floods in recent memory. A number of extreme weather events combined to cause major flooding in the Thames Estuary. Over 300 people died, 24,000 houses were damaged or destroyed and over 30,000 people were evacuated (Brown et al, 2007).

London’s existing flood defences, including the Thames Barrier, provide a very high level of protection against flooding, but this will gradually decline over time. The flood defences currently protect London against water levels that, on average, might occur once in a thousand years. Flood risk is increasing in the Thames Estuary because of (FLOODsite, 2005):

- **Climate change** – as the oceans warm and the ice caps melt, the level of the seas around the British coast is rising and intense rainfall and extreme stormy conditions are likely to increase in the future;
- **Land level lowering** – the south-east of England is slowly sinking in relation to the sea; a legacy from the last ice age;
- **Ageing flood defences** – the current flood defences that protect London and the other communities along the estuary are getting older and more costly to maintain;
- **Increasing development** – the pressure for more houses and jobs within the tidal floodplain is increasing.

This Chapter focuses specifically on the application of a prototype Decision Support Framework to the area know as Thamesmead. The location of Thamesmead is shown in Figure 5.1.
5.2.1 Overview of Thamesmead embayment

Thamesmead is a "new town" constructed in the late 1960s in London on an area of marshland on the southern bank of the River Thames downstream of the Thames Barrier. The area had been inundated in the North Sea Flood of 1953, so the original design of the buildings placed living accommodation at first floor level or above, used overhead walkways and left the ground level of buildings as garage space (Wigfall, 1997). However, since the initial development there have been a number of developments built with living quarters at ground level. The area is defended by flood embankments and walls. These provide protection against the 1 in 1,000 year flood (Marchal, 1978).

A satellite photograph of Thamesmead is shown in Figure 5.2. Thamesmead covers an area of approximately 12 km² and data from the 2001 census indicates that it has a population of about 43,000 making it one of the most densely populated areas in London (Office for National Statistics, 2002). Thamesmead has a relatively transient population. It is thus likely that the general knowledge of the population relating to the possible flood risk to the area is low. It has been estimated from recent census data that approximately 6.6% of the population in the Thamesmead embayment are aged over 70 years of age. There are a total of around 24,000 residential properties and approximately 12,800 cars in the Thamesmead pilot area (Office for National Statistics, 2002). A view of one of the new housing developments in Thamesmead is shown in Figure 5.3.
Figure 5.2  Satellite image of Thamesmead

Figure 5.3  New development in Thamesmead
5.2.2 Data availability for the pilot area

The following data were available for the pilot area for use in the evacuation modelling research:

- **Population data** – This is from the 2001 census data and is available at an Output Area level. Output Areas contain an average of around 125 houses. The 2001 survey data provides details of the age distribution of the population and other socio-economic details (Office for National Statistics, 2002);
- **Vulnerability** – The vulnerability of the population in the form of a Social Flood Vulnerability Index (SFVI) (Environment Agency/Defra, 2005);
- **Topographic data** – LIDAR survey data with a vertical accuracy of approximately ±25 mm;
- **Flood depths and velocities** - Two dimensional hydrodynamic modelling results, produced using the TUFLOW software for the pilot area for a number of flood defence breach scenarios;
- **National property data set** – A national property data set that provides geo-referenced details of each of the properties in England and Wales. This data is in the form of a geo-referenced point. It details some 50 different types of property (Environment Agency/Defra, 2005);
- **Road network** – Details of the major roads were digitised from existing maps.

5.3 System description

5.3.1 General

The key features of the FLINTOF can be described as follows:

- Organisation and viewing of spatial-temporal data relevant to emergency planning;
- Use of information from external models (e.g. hydraulic models) to assess flood extents and depths, and flood hazard as a function of velocity and depth;
- Calculation of the flood risk to people in terms of number of injuries and fatalities;
- Assessment of the road network with respect to emergency access;
- Use of information from external evacuation models to display typical evacuation times at a census enumeration level;
- Estimates of the probability of building collapse;
- Providing information for the appraisal of different emergency management interventions;
- Archiving of data sets.

A FLINTOF project comprises two parts as follows:

(iii) A relational database that is controlled by the FLINTOF interface.
(iv) An ArcGIS project that is managed by the FLINTOF and performs automated data processing and visualisation.

The opening FLINTOF screen is shown in Figure 5.4.
5.3.2 Scenarios in FLINTOF

Within FLINTOF a series of scenarios is developed. A scenario is a unique combination of the following:

- Flood event (e.g. 1 in 1,000 year flood);
- Day of the week when the flood event occurs. The user is currently limited to choosing between weekday or weekend;
- Time of the day: morning, midday, afternoon, evening or night;
- Emergency management intervention (e.g. traffic management, setting up of safe havens). This is done using tools and models that are external to FLINTOF.

Each scenario must be unique and is assigned a Scenario Reference by FLINTOF automatically. The user assigns the relevant input data (e.g. hydraulic modelling results, emergency management intervention) to each Scenario respectively. The four components of a Scenario are shown in Figure 5.5. FLINTOF allows a database of different Scenarios to be built up and to be evaluated. The Scenarios are managed by FLINTOF as shown in Figure 5.6. The user can set up as many Scenarios as they believe are useful for their needs.
Figure 5.5  The four components of a FLINTOF Scenario

Figure 5.6  The management of Scenarios within a FLINTOF project
It is important to note that each Scenario reference is unique. It is defined by four pairs of digits. The first two represent the flood event, the second two represent the day of the week, the third pair represent the time of day, and the final two represent the emergency management intervention. The Scenario reference system is shown in Figure 5.7. The user cannot change a Scenario’s reference once the base data has been loaded. This process is then repeated for several Scenarios and an evaluation is carried out of the results.

Figure 5.7  Scenario referencing system

A Scenario can either be: “Not started”, “In progress”, “Completed” or “Rejected”. The latter option is available to allow unwanted Scenarios to be stored in the database. Figure 5.8 shows a typical Scenario comparison screen that would be available to the user when they had completed a number of Scenarios.

Figure 5.8  FLINTOF Scenario comparison screen
5.3.3 Database in FLINTOF

FLINTOF comprises a customised database. Based on the ArcGIS system, the FLINTOF database is centred on the capabilities to accept core data and to display it in order to assist in understanding issues related to flood event management. The functionality incorporates protocols and standards for transferring and importing core datasets and to support emergency management planning for a range of flood events. The functionality includes:

- Importing and handling of existing Environment Agency digital datasets related to flood hazard and extent such as indicative flood maps and/or other return period flood outlines;
- Importing and handling of datasets and information for use as input to and/or output from associated modelling tools such as two dimensional hydraulic models;
- GIS functionality for combining spatial datasets across different theme layers to assess risks to people, emergency access routes and to estimate the risk of buildings collapsing;
- Presentation and viewing of mapped theme layers;
- Exporting of key derived datasets (e.g. risk to people or evacuation maps) with agreed meta-data descriptions that can be imported into other Environment Agency or Local Authorities data base systems.

Metadata is important in the context of FLINTOF and should be attached to all input data and output data. The metadata provides the following:

- Structured descriptions of all input data and output data;
- A means of carrying the memory of what sort of processes were used to develop a given output data set;
- A means of carrying the memory of what sort of scenarios and other assumptions were used to develop a given output data set;
- A means of finding results with particular characteristics thus avoiding the need to repeat an analysis;
- Allows the development of decision support capabilities in the future.

An example screen shot of the FLINTOF database is shown in Figure 5.9.

![Example screen of the FLINTOF database](image-url)

Figure 5.9 Example screen of the FLINTOF database
5.4 **Functionality**

5.4.1 **Introduction**

This Section describes the functionality of FLINTOF. It covers the following:

- Development of a Scenario;
- Importing the hydraulic modelling results;
- Assessment of the flood hazard;
- Emergency access;
- Risks to people;
- Evacuation times;
- Probability of buildings collapsing.

5.4.2 **Development of a Scenario and importing base data**

The first action in the development of a Scenario is to import the data into the FLINTOF base data. The core data is detailed in Section 5.4 and comprises the following:

- Census data;
- Social Flood Vulnerability Index (SFVI);
- Topographic data;
- Flood depths and velocities for the required time steps;
- National property data set;
- Road network;
- Evacuation times;
- Background raster Ordnance Survey 1:50,000 scale maps.

The user goes into the Scenario construction window of FLINTOF and sets up a Scenario, comprising:

- Flood scenario;
- Day of the week;
- Time of day;
- Emergency management intervention.

Figure 5.10 shows the Scenario management window. It should be noted that any compatible GIS data can be imported into FLINTOF. For ease of manipulation when using FLINTOF, data should cover the complete geographical area for which the emergency management planning is being carried out. For example, flood depths and velocities would be required to cover the whole area for which risk-to-people estimates are required. There are seven steps when developing a FLINTOF Scenario:

1. Importing the base data
2. Importing the hydraulic modelling results
3. Displaying the combined flood hazard in terms of velocity and depth
4. Assessing the emergency access
5. Computing the flood risk to people
6. Displaying the evacuation times
7. Estimating the number of buildings destroyed

*Once these seven steps have been undertaken the Scenario is complete. The seven steps are shown in Figure 5.11.*
5.4.3 Importing hydraulic modelling results

FLINTOF is a spatio-temporal system and requires two-dimensional modelling results on derived on a grid basis. The results should comprise a flood depth and velocity grid for each time step. The number of grids that need to be loaded into FLINTOF is dependent on the length of the flood event and the temporal resolution at which the user wishes to display the results. For the purpose of the pilot study the flood modelling data has been imported using a 20 m x 20 m grid at a 15 minute temporal resolution. The modelled flood event lasted for a total of about eight hours.

5.4.4 Assessment of the level of the flood hazard

FLINTOF allows an assessment of the level of the flood hazard to be made. The flood hazard level can be categorised and mapped by combining the floodwater velocity and depth as shown in Table 5.1. This allows various levels of flood hazard to be categorised and mapped. This categorisation of flood hazard is based on that used in the “Flood risk to people” research carried out by HR Wallingford (Environment Agency/Defra, 2005c). This part of FLINTOF falls under the hazard module of the methodological framework in that flood depth, velocity and extent data are used to assess the level of the hazard with respect to people.
## Table 5.1  Level of the flood hazard

<table>
<thead>
<tr>
<th>D(V + 0.5)</th>
<th>Degree of flood hazard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.75</td>
<td>Low</td>
<td>Caution &quot;Flood zone with shallow flowing water or deep standing water&quot;</td>
</tr>
<tr>
<td>0.75 to 1.25</td>
<td>Moderate</td>
<td>Dangerous for some (e.g. children) &quot;Danger: Flood zone with deep or fast flowing water&quot;</td>
</tr>
<tr>
<td>1.25 to 2.5</td>
<td>Significant</td>
<td>Dangerous for most people &quot;Danger: flood zone with deep fast flowing water&quot;</td>
</tr>
<tr>
<td>&gt;2.5</td>
<td>Extreme</td>
<td>Dangerous for all &quot;Extreme danger: flood zone with deep fast flowing water&quot;</td>
</tr>
</tbody>
</table>

Note: D is the flood depth in m  
V is the velocity in m/s  
Note the level of flood hazard is with respect to people  
(Source: Environment Agency/Defra, 2005c)
Figure 5.11 The seven steps in the development of a FLINTOF Scenario

1. Base data
   - National census data at an Output Area level (e.g. number of people, age)
   - National property data set
   - Digital Terrain Model (DTM)
   - Road network
   - Ordnance Survey maps (1:50,000 base map)
   - Other relevant data (e.g. police, fire stations, hospitals, community centres)

2. Hydraulic modelling results
   - Two dimensional hydraulic modelling results

3. Flood hazard data
   - Flood depth grids at required time step (D)
   - Velocity grid at the required time step (V)
   - Estimation of the hazard at each time step as a function of D x V

4. Flood risk to people
   - Assessment of the flood hazard rating
   - Assessment of the area vulnerability
   - Assessment of people vulnerability
   - Estimation of number of people injured and killed for different scenarios
     (e.g. times of day, day of the week)

5. Road network analysis for emergency access
   - Assess flood hazard in terms of V x D at all the points on the road network
   - Assess the time at which roads become closed to cars, fire engines, ambulances and other vehicles
   - Highlighting of safe evacuation routes

6. Evacuation scenarios
   - Display of evacuation times at an Output Area or Ward level
   - Display of different evacuation times for different scenarios
     (e.g. road closures, rates of warning, times of day, day of the week)

7. Probability of building collapse
   - Assess V x D for all buildings
   - Provide spatio-temporal evaluation of likelihood of buildings being destroyed
5.4.5 Flood risk to people

Introduction
FLINTOF has been designed to incorporate the “Risks to People method” developed under a previous research project for the Environment Agency (Environment Agency/Defra 2005b, 2005c). The Risks to People method considers the physical characteristics of flooding and flood vulnerability, to determine the overall flood risks to people. Figure 5.12 provides an overview of the approach.

\[
\text{Flood risk to people} = \text{Flood hazard} \times \text{Area vulnerability} \times \text{People vulnerability} \times \text{Number of people at risk}
\]

(Source: Environment Agency/Defra, 2005c)

Figure 5.12 Overview of the flood risks to people method

The method (Environment Agency, 2005c) is based on the three concepts of Flood Hazard, Area Vulnerability and People Vulnerability. These are combined for each zone of the floodplain to estimate the annual average individual or societal risk of serious harm or fatalities due to flooding. These three concepts are explained below.

- **Flood Hazard** describes the flood conditions in which people are likely to be swept over or drowned in a flood, and is a combination of flood depth, velocity and the presence of debris;
- **Area Vulnerability** describes the characteristics of an area of the floodplain that affect the chance of being exposed to the flood hazard. People are more vulnerable in areas of low rise, single-storey buildings, campsites and open floodplain areas than in areas of two-storey or high-rise buildings that can provide “safe refuge” above the maximum flood level;
- **People Vulnerability** describes the characteristics of the people affected by flooding and their ability to respond to ensure their own safety and that of their dependants during a flood.

The exposure in terms of the number and spatial distribution of people within the floodplain is also required. In terms of the methodological framework shown in Figure 5.12, FLINTOF combines the hazard, exposure and vulnerability to allow the risk to people in terms of fatalities and injuries to be calculated at each time step of the flood event being considered in the FLINTOF Scenario. The method by which FLINTOF estimates the flood risks to people is described briefly below.

During the development of the method the research project reviewed a large number of flood hazard and vulnerability variables and criteria (Environment Agency/Defra, 2005c). The final set of criteria required for each element of the flood risk to people method are as follows:
Flood hazard
- Depth of flood water (m);
- Velocity of flood water (m/s);
- Debris factor (score);

Area vulnerability
- Flood warning: including the percentage of at-risk properties covered by the flood warning system; percentage of warnings meeting the two-hour target; and the percentage of people taking effective action (score);
- Speed of onset of a flood (score);
- Nature of the area. For example multi-storey apartments; typical residential/commercial/industrial properties; bungalows, mobile homes, campsites, schools (score).

People vulnerability
- Percentage of residents aged 75 years or over;
- Percentage of residents suffering from long term illness.

(Environment Agency/Defra, 2005b, 2005c)

Estimation of the flood hazard
The Flood Hazard is calculated using the following equation:

\[ HR = D(V + 0.5) + DF \]  \hspace{1cm} \text{(Equation 5.1)}

Where:
- HR is the flood hazard rating;
- D is the depth of flooding in m;
- V is the velocity of floodwaters in m/s
- DF is the debris factor calculated using Table 5.2. DF is a function of floodwater depth, velocity and land use.

Table 5.2 Guidance on debris factors for different flood depths, velocities and dominant land uses

<table>
<thead>
<tr>
<th>Depths</th>
<th>Pasture/Arable</th>
<th>Woodland</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 0.25 m</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.25 to 0.75 m</td>
<td>0.0</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>d&gt;0.75 m and/or v&gt;2 m/s</td>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

(Source: Environment Agency/Defra, 2005c)

Debris has a significant impact on the level of the flood hazard. It should be noted that there is little reliable data on the importance of such a factor. The factors shown in Table 5.2 have been taken from the Flood Risk to People Methodology (Environment Agency/Defra 2005b, 2005c).

Estimation of the area vulnerability
Area vulnerability is a function of the effectiveness of flood warning, speed of onset of flooding and nature of area (including types of buildings). The area vulnerability is calculated using Tables 5.3 and 5.4.
Table 5.3  Area vulnerability

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1 - Low risk area</th>
<th>2 - Medium risk area</th>
<th>3 - High risk area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of onset</td>
<td>Onset of flooding is very gradual (many hours)</td>
<td>Onset of flooding is gradual (an hour or so)</td>
<td>Rapid flooding</td>
</tr>
<tr>
<td>Nature of area</td>
<td>Multi-storey apartments</td>
<td>Typical residential area (Two storey homes); commercial and industrial properties</td>
<td>Bungalows, mobile homes, busy roads, parks, single storey schools, campsites, etc.</td>
</tr>
</tbody>
</table>
| Flood warning   | Score for flood warning = 3 - (P1 x (P2 + P3)) where 
                  | P1 = % of warning-coverage target met 
                  | P2 = % of warning-time target met 
                  | P3 = % of effective-action target met |
| Area vulnerability (AV) = sum of scores for ‘speed of onset’, ‘nature of area’ and ‘flood warning’ |

(Source: Environment Agency/Defra, 2005c)

Recent values for P1, P2 and P3 are given in Table 5.4. These can be updated using more recent data when available.

Table 5.4 Calculation of flood warning score

<table>
<thead>
<tr>
<th>Environment Agency Region</th>
<th>Percentage of warning coverage target met (80%) = P1</th>
<th>Percentage of warning time target met (100%) = P2</th>
<th>Percentage of effective action target met (75%) = P3</th>
<th>Flood warning Score = 3 - (P1 x (P2 + P3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anglian</td>
<td>0.69</td>
<td>0.75</td>
<td>0.48</td>
<td>2.15</td>
</tr>
<tr>
<td>Midlands</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- East</td>
<td>0.16</td>
<td>0.54</td>
<td>0.48</td>
<td>2.83</td>
</tr>
<tr>
<td>- West</td>
<td>0.34</td>
<td>0.54</td>
<td>0.48</td>
<td>2.66</td>
</tr>
<tr>
<td>North East</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Yorkshire &amp; Humber</td>
<td>0.94</td>
<td>0.88</td>
<td>0.48</td>
<td>1.73</td>
</tr>
<tr>
<td>- North East</td>
<td>0.66</td>
<td>0.88</td>
<td>0.48</td>
<td>2.10</td>
</tr>
<tr>
<td>North West</td>
<td>0.81</td>
<td>0.00</td>
<td>0.48</td>
<td>2.61</td>
</tr>
<tr>
<td>Southern</td>
<td>0.76</td>
<td>0.65</td>
<td>0.48</td>
<td>2.14</td>
</tr>
<tr>
<td>South West</td>
<td>0.76</td>
<td>0.61</td>
<td>0.48</td>
<td>2.17</td>
</tr>
<tr>
<td>Thames</td>
<td>0.76</td>
<td>0.65</td>
<td>0.48</td>
<td>2.14</td>
</tr>
<tr>
<td><strong>England</strong></td>
<td><strong>0.76</strong></td>
<td><strong>0.63</strong></td>
<td><strong>0.48</strong></td>
<td><strong>2.15</strong></td>
</tr>
<tr>
<td>Wales</td>
<td>0.56</td>
<td>0.63</td>
<td>0.73</td>
<td>2.23</td>
</tr>
</tbody>
</table>

(Source: Environment Agency/Defra, 2005c)

The ‘speed of onset’ is clearly an important factor affecting flood vulnerability. If floodwaters rise very slowly, people will be aware and be able to react, ensuring their own safety and the safety of others. If there is rapid flooding people have little opportunity to seek safe refuge (Environment Agency/Defra, 2005c).

There are three classes for the speed of onset criteria:

- Onset of flooding is very gradual (many hours) – score of 1
- Onset of flooding is gradual (an hour or so) – score of 2
- Rapid flooding – score of 3

(Environment Agency/Defra, 2005c)
Assessment of the people vulnerability

The “broad-scale” approach to the assessment of people vulnerability uses the Flood Hazard Research Centre Social Flood Vulnerability Index (SFVI). The SFVI for each Output Area is a core national dataset. The three social groups used for the SFVI are:

- The long-term sick – residents suffering from limiting or long-term illness as a percentage of all residents;
- Single parents as a proportion of all residents;
- The elderly – residents aged 75 and over as a percentage of all residents.

The SVFI also incorporates four financial deprivation indicators that are based on the Townsend Index. This focuses on deprivation outcomes (such as unemployment), rather than targeting predefined social groups. The rationale for this decision is based on the premise that it is the intention of the SFVI to target social groups that from previous research are known to be particularly badly affected by flooding. The Townsend Indicators are (Environment Agency/Defra, 2005a):

- Unemployment – unemployed residents aged 16 and over as a percentage of all economically active residents aged over 16;
- Overcrowding – households with more than one person per room as a percentage of all households;
- Non-car ownership – households with no car as a percentage of all households;
- Non-home ownership – households not owning their own home as a percentage of all households.

Figure 5.13 shows the SFVI mapped for the pilot area within FLINTOF.
The people vulnerability can also be estimated from the UK national census data from the following:

- The percentage of residents aged 75 years or over;
- The percentage of residents suffering from long term illness.

**Assessment of the number of injuries and fatalities**

FLINTOF maps the flood risk to people in terms of injuries and fatalities per km² for each time step of the flood event for each Scenario. This involves combining layers of data on flood hazard, area vulnerability, people vulnerability and population using the formulae given above. Of the variables in the method, only the hazard rating varies as the flood progresses. It is also possible to map the average annual numbers of injuries and deaths against flood frequency using FLINTOF. However, to do this it is necessary to apply the method to several flood events, where the probability of the flood event is well defined.

The number of injuries at each time step is calculated using the following equation:

\[ N(I) = N \times X \times Y \]  
*(Equation 5.2)*

Where:

- \( N(I) \) is the number of injuries;
- \( N \) is the population within the floodplain;
- \( X \) is the proportion of the population exposed to a risk of suffering an injury for a given flood at a given time step. The value of \( X \) is based on the flood hazard and the area vulnerability;
- \( Y \) is the proportion of those at risk who will suffer an injury. The value of \( Y \) is based on people vulnerability.

The number of deaths at each time of the flood event is estimated as a function of the number of injuries \( N(I) \). The greatest impact on life is likely to be for more extreme events and therefore the choice of events must include or, in a special cases, exceed the 0.1% annual probability or 1 in 1000 year flood. However, in terms of emergency management planners need to look at a wide range of different possibilities including breaching of flood defences.

The steps used in FLINTOF for estimating the flood risks to people are detailed below.

1. **Hazard rating**
   The flood hazard at each time step (HR) is calculated using equation 5.1. Specifically, the hazard rating is calculated from the two dimensional hydraulic modelling velocity and depth grids produced for each time step of the flood event.

2. **Area vulnerability**
   The area vulnerability is calculated as a score using the information detailed in Table 5.3 above. The area vulnerability score is calculated for each grid as follows:

   [Area vulnerability = Flood warning score + Speed of onset score + Nature of area]

   If the score exceeds 100 then the score is taken as simply 100.

3. **Number of people at risk**
   The percentage of people at risk as a percentage of the population in each grid is calculated as follows:

   [Percentage of people at risk = HR x Area vulnerability]
4. Determining numbers of deaths and injuries

An estimate is made of the people vulnerability (Y) score using either the percentage of people over 75 years of age and the percentage of people that are disabled or infirm added together or the SFVI. The number of injuries is then estimated as follows:

Number of injuries = Number of people at risk x 2 x People vulnerability

The number of fatalities is estimated as follows:

Number of fatalities = Number of people at risk x 2 x HR

The annual average number of injuries and deaths can be estimated, however, it is necessary to repeat the above calculations for a number of different flood frequencies (usually at least five) and combine the results.

Figure 5.14 and Figure 5.15 show maps produced by FLINTOF of the number of people injured and fatalities per km² for one time step of a 1 in 1,000 year flood used in one of the FLINTOF Scenarios.

Figure 5.14 Number of people injured per km²
5.4.6 Emergency access for vehicles

Background

Experience from past floods, particularly in the United States, shows that a common hazard that causes a risk of death or serious injury to people is the instability of vehicles in the floodwater. This hazard presents a number of potential consequences. The primary consequence is the injury or death of a person resulting from them being trapped in the vehicle when it loses stability. The likelihood of this occurring relates to the behaviour of that person, since it is often the case that people underestimate the velocity or depth of the floodwater and attempt to drive through it when it is in fact unsafe. If the person is trapped in a vehicle in floodwater they are vulnerable to a range of risks e.g. drowning and injury or death caused by debris impact on the vehicle or the vehicle crashing into a structure (Environment Agency/Defra, 2005d).

Keller and Mitsch (1993) carried out research on the stability of both cars and people in flood conditions in order to inform the design of urban streets as floodways for floods greater than around the five year return period when the underground drainage system reaches capacity. Their findings resulted in recommendations for the design of road cross sections to minimise the risk to people on the road during a flood. The research took an entirely theoretical approach and considered the physics of vehicle and person stability in flood conditions. The analysis of vehicle stability involved calculations for three types of common cars (Environment Agency/Defra, 2005d).

The vehicle stability calculations were based on the distribution of the buoyancy force between the two axles. The axle load for the front and rear axle was estimated from car manufacturer specifications. Vehicle instability occurs when the drag force imposed by the flowing water at an axle
is equal to the restoring force due to the axle load. The drag force acting on the side of the vehicle is a function of the density of water, the drag coefficient, the submerged area of the vehicle projected normal to the flow and the velocity of flow. The value of the drag coefficient is itself a function of depth.

It is useful to attempt to characterise the stability thresholds of a vehicle in water in order to provide general guidance for evacuation plans. The stability of vehicles represented within FLINTOF allows emergency planners to visualise what roads remain open to which vehicles as the flood event unfolds.

**Calculation of flood hazard to vehicles**

The analysis of Keller and Mitsch (1993) provides a simple method for estimating the forces exerted on a stationary vehicle in floodwater. The method considers vehicle mass and dimensions, buoyancy and drag forces and can be used to determine the velocity of water required to make a vehicle unstable at low depths and also the depth at which a “water-tight” vehicle would float. The results produced from these calculations are subject to several assumptions (Environment Agency/Defra, 2005d):

- The method does not consider hydrostatic pressures of water on the upstream face of the vehicle which may make it unstable at lower velocities;
- Forward momentum is not considered and when vehicles are driving at speed they could “lose grip” and “aquaplane” at much lower depths and velocities;
- The volume displaced by a vehicle and consequently the buoyancy force may be lower as we have assumed that the wheels and the chassis form a solid volume.

To carry out the calculation of vehicle stability the following information is required:

- Vehicle length (m);
- Vehicle width (m);
- Gross vehicle weight (N);
- Height of chassis (m);
- Total area of tyres in contact with the road (m²).

The calculation process follows the steps below:

**Step 1 Calculation of the buoyancy force, (Bf)**

The buoyancy force (Bf) in Newtons is given by the following equation:

If the water level is below the level of the vehicle chassis:

\[
Bf = \rho DA_{\text{Tyres}}g \tag{Equation 5.3}
\]

If the water level is above the level of the vehicle chassis:

\[
Bf = \rho H_{\text{Chassis}} A_{\text{Tyres}} g + \rho (D - H_{\text{Chassis}}) LW \tag{Equation 5.4}
\]

Where:

- \( \rho \) is the density of water;
- \( g \) is the acceleration due to gravity;
- \( D \) is depth of the floodwater;
- \( A_{\text{Tyres}} \) is the area of the tyres in contact with the ground;
- \( H_{\text{Chassis}} \) is the height of the vehicle chassis;
- \( L \) is the length of the vehicle;
- \( W \) is the width of the vehicle.
Step 2  Calculation of the axle load in wet conditions

This is found from summing the buoyancy force and the axle load in dry conditions as follows.

\[ F_{Axle} = F_{Veh} - Bf \]  
(Equation 5.5)

Where:

- \( F_{Axle} \) where is the axle load in wet conditions;
- \( F_{Veh} \) is the weight of the vehicle in N.

Step 3  Calculation of the restoring force at the axle (\( F_r \))

\[ F_r = \mu F_{Axle} \]  
(Equation 5.6)

Where:

- \( \mu \) is the friction coefficient, set at 0.3 after Bonham and Hattersley (1967) in Keller and Mitsch (1993).

Step 4  Calculation of the velocity at which the vehicle will become unstable (\( V \))

\[ V = 2 \left( \frac{F_r}{\rho C_d A_{Tyre} D} \right)^{0.5} \]  
(Equation 5.7)

Where \( C_d \) is the drag coefficient, set at 1.1 if the water level is below the chassis and 1.15 if the water level is above the chassis (Keller and Mitsch, 1993).

Figure 5.16 shows the instability of a standard car, van, ambulance and fire engine in floodwater. As depth increases the velocity required to make a vehicle unstable decreases. This is because the downward force of the vehicle is countered by increased buoyancy. When flood depth is greater than the chassis height a larger amount of water is displaced and stationary vehicles will float at fairly shallow depths between 30 cm and 100 cm. At this stage the assumptions regarding vehicle weights and chassis heights have been researched from manufacturers literature but other assumptions regarding the amount of water displaced by tyres are estimates.
FLINTOF utilises the relationships shown in Figure 5.16 to estimate the length of road that remains open to each vehicle at each time step of the flood event. This allows the emergency services to assess evacuation routes and to advise the police on which roads to shut. Figure 5.17 shows the development of the flood hazard as a breach in a flood defence occurs and how this affects the accessibility of the roads to different types of vehicles.

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*Figure 5.17 Hazard and emergency access vehicles after a breach has occurred*
5.4.7 Evacuation time

In terms of the evacuation modelling the Environment Agency and emergency planners need to be able to answer the following questions:

- Can all at-risk residential properties evacuate voluntarily if required? (i.e. is the road network safe, not cut-off and is there somewhere safe to evacuate to?)
- If there are areas that cannot safely evacuate, is there an alternate emergency plan in place to manage risks appropriately?
- Where are people most likely to require evacuation assistance (i.e. the most vulnerable and/or those in locations where risks to people are highest)?
- Are safe-haven locations appropriate and available?
- Are times to evacuate (if available) sufficient for likely flood characteristics?

(Lumbroso, 2006)

Evacuation is normally organised by the emergency services. Evacuation can be affected by:

- Inability to drive along evacuation routes because of rising floodwaters;
- Bottlenecks on evacuation routes due to inability of the roads to cope with the increased volume of traffic;
- Unavailability of suitable evacuation equipment such as boats, lorries and helicopters.

FLINTOF allows the evacuation times to be imported and displayed. Figure 5.18 shows a typical example of an evacuation time screen.

![Evacuation time screen](image)

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*Figure 5.18 Display of evacuation times*
At present FLINTOF is only able to provide a display of the evacuation times. These can be imported from external models such as the Evacuation Calculator and the BC Hydro LSM tools. However, there are plans in the future to have a simple integrated model embedded within FLINTOF to enable the user to obtain first order estimates of evacuation times at an enumeration area (i.e. census output area level).

### 5.4.8 Assessment of the probability of buildings collapsing

Buildings are a potential place of refuge in a flood and are frequently used as such by the people in a flood risk area. The partial or complete failure of the buildings in which people are sheltering to provide a safe refuge is consequently a significant factor in the number of deaths resulting from flooding. Buildings can collapse because of water pressure, scour of foundations, or a combination of these. In addition, the debris carried by a flood in the form of trees and rocks can cause damage. Buildings close to a watercourse frequently experience undermining as the flood erodes the channel and undercuts the buildings’ foundations. Some damage can occur to buildings if the depth differential between the outside and inside water levels exceeds 0.5 m.

FLINTOF allows the user to gain a qualitative estimate of the probability of buildings collapsing at each time step of a flood event for a particular Scenario. FLINTOF assumes that the two key factors that determine building collapse are depth and velocity. There were various options available for the building collapse analysis. A Dutch science and engineering consultancy (Roos, 2003), investigated the thresholds of velocity-depth combinations that result in a certain probability of building collapse for four different types of building structure. Secondly, and more simplistically, the RESCDAM project proposed that total collapse of masonry, concrete and brick buildings will occur when (Helsinki University Technology, 2000):

\[
VD \geq 7 \text{m}^2/\text{s} \quad \text{and} \quad V \geq 2 \text{m/s}
\]

Where:

- \(V\) is the velocity of the floodwater
- \(D\) is the depth of the floodwater

There has also been research carried out in the USA (Kelman, 2002) into the velocity and depth thresholds that can cause buildings to collapse during a flood event. In FLINTOF a hybrid approach was used based on various pieces of research using the following thresholds:

- \(VD \leq 3 \text{m}^2/\text{s}\) Probability of collapse is low
- \(3 \text{ m}^2/\text{s} < VD \leq 7 \text{m}^2/\text{s}\) Probability of collapse is medium
- \(VD > 7 \text{m}^2/\text{s}\) Probability of collapse is high

This relationship is shown diagrammatically in Figure 5.19. FLINTOF uses the geo-referenced National Property Database and the flood hazard maps to assess the probability of building collapse for each building at each time step of the flood wave. It should be noted that the algorithm used to assess the probability of building collapse can be easily changed or a number of other algorithms included. Figure 5.20 shows a map produced by FLINTOF maps indicating the probability of building collapsing for a certain time step of a flood event. Specific types of buildings that are particularly prone to collapse during floods include chalets, caravans and other lightweight structures. The method adopted in FLINTOF assumes that buildings are constructed from brick or concrete.
Figure 5.19 Function relating velocity and depth to the probability of building collapse

5.4.9 Scenario evaluation

In order to assist the user to assess different emergency management options and flood scenarios, FLINTOF provides a form that summarises the results of Scenarios tested. Scenarios that have been tested and rejected from consideration are not included in the Scenario evaluation procedure. The Scenario evaluation form allows the following to be compared over the area of interest:

- Number of people injured;
- Number of fatalities;
- Number of buildings destroyed;
- The average evacuation time;
- The length of road shut to evacuation vehicles at the peak of the flood.

A typical Scenario evaluation screen is shown in Figure 5.21. This allows different emergency management plans to be easily compared and assessed using a variety of risk metrics.
**Legend**

**Probability of building collapse**
- none
- low
- medium
- high

**VxD**
- $V \times D < 3$
- $V \times D < 7$
- $V \times D > 7$

**Defences**
- Breach point

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**Figure 5.20** Map providing an indication of the probability of building collapse

**Figure 5.21** Screen allowing different scenarios to be compared
5.5 First response of the end user group

An assessment of user requirements has shown that there are several weaknesses with emergency management plans for floods in the UK. These weaknesses are as follows (Berghouse, 2006):

- Thirty percent of plans have not been published or communicated to people in the area;
- Thirty percent of plans have not been seen or validated by the Environment Agency;
- Police plans do not have flood evacuation routes identified and 20% do not include traffic management measures in their evacuation plans at all;
- Evacuation routes are set out in less than 20% of the plans;
- Vulnerable groups (including caravan sites) are identified in less than 40% of plans;
- Utility installations and telecommunication are located in less 20% of plans;
- Only a minority of plans identify shelters (i.e. safe havens). These are intrinsically linked to evacuation procedures.

On 24 January 2008 a one day workshop was held at HR Wallingford with 20 key stakeholders to disseminate the results of Task 19 and to get feedback on the FLINTOF decision support system that had been developed. The workshop was attended by 20 stakeholders including members of the following organisations:

- Environment Agency flood incident managers;
- Local Authority emergency planners based in the areas of the Thames Estuary where FLINTOF had been piloted;
- Staff from the fire and rescue services;
- Department of the Communities and Local Government responsible for emergency planning;
- Members of various Government Resilient forums.

The workshop comprised a number of presentation and demonstrations of the research that had been carried out. A number of breakout sessions were held in which a number of questions were posed to the end users including:

1. What methods are needed to improve flood incident management planning?
2. Are the methods/tools presented helpful? What functionality needs to be added?
3. Who would use these tools currently and who may use them in future?

The feedback provided by the stakeholders I summarised below.

1. Methods and tools required to improve flood incident management planning

There was a general consensus that there is a requirement for methods and tool that can be used for validating flood incident management emergency plans and also for use in emergency planning exercises related to flooding. There was also a need for a tool that can be used in a post event debrief role so that could be used to review flood events.

2. Are the methods/tools presented helpful? What functionality needs to be added?

There was unanimous agreement amongst the stakeholders that the FLINTOF decision support system would be useful in improving the planning for flood incidents. There was also a general feeling that the FLINTOF tool could assist with formulating safety plans for reservoirs and in identifying safe havens. In future it was felt that it may be possible to FLINTOF with forecasts of flood inundation results and the life safety model to get more accurate estimates of risk to people. FLINTOF could also be used to share information between various responders via an internet based system. In terms of additional information many of the emergency planners agreed that there was a need for database of buildings that included their heights and number of floors, as well as an indication of where the critical infrastructure (e.g. hospitals, police stations, electrical substations) is located.

3. Who would use these tools currently and who may use them in future?
Many of the participants at the workshop stated that the end users for the tools was depend on a number of issues including:

- Technical capacity with the organisations;
- Compatibility required with existing systems;

There was a general agreement that within the current institutional set up in the UK the FLINTOF tool should sit with the Environment Agency as they have the key technical expertise with regards to flooding. It was felt that the Environment Agency could use FLINTOF to work together local authority emergency planners to improve the quality of emergency plans in areas where the residual flood risk is relatively high.

5.6 Conclusions and pilot specific recommendations

5.6.1 Conclusions

There is a clear need for a framework such as FLINTOF to be used in a systems based approach to flood event management. The current version of FLINTOF provides the following spatio-temporal analysis:

- Flood hazard;
- Flood risk to people;
- Emergency access;
- Evacuation times;
- Probability of building collapse.

There is a clear need for the Environment Agency and the emergency services (e.g. the police and the ambulance service) to be able to coordinate their response to a flood event. During a flood event the following key questions need to be addressed:

- Can all at-risk residential properties evacuate voluntarily if required? For example, is the road network safe, not cut-off, somewhere safe to evacuate to?
- If there are areas that could not safely evacuate, is there an alternative emergency plan in place to manage risks appropriately?
- At what point should evacuation be recommended over and above moving to upper floors in property or near-by property?
- Is there critical infrastructure (e.g. water and power facilities) at risk that would make remaining in the property dangerous or difficult?
- Are emergency plans in place to manage risks to such utility infrastructure?
- Are hospitals or other key services (e.g. police, fire, ambulance stations) at risk?
- Are emergency plans in place to manage risks to key service infrastructure?
- Are flood event management process centres at risk?
- For areas where an evacuation may be required:
  - Where are people most likely to require evacuation assistance (i.e. the most vulnerable and/or those in locations where risks to people are highest)?
  - Are safe haven locations appropriate and available?
  - Are times to evacuate (if available) sufficient for likely flood characteristics?
- What traffic management measures should be put in place to ensure minimum disruption to traffic flow and or minimum risks to life from evacuation process?

The FLINTOF framework allows flood risk managers to go some way to addressing these questions. The Environment Agency has indicated that they need a systems based approach to emergency management (Berghouse, 2006). The FLINTOF system is the first step towards this objective. FLINTOF allow emergency managers to carry out the following:
• Assess flood hazard in terms of a combination of flood velocity and depth rather than just purely flood extent or depth;
• Allow the best evacuation routes to be assessed for a range of scenarios or possibly in future using real-time forecasts;
• Allow the emergency services to identify:
  - Safe havens;
  - The location of vulnerable groups and the population groups where the risk to life and injuries is greatest;
  - Assess which roads get cut off first to emergency vehicles;
  - Where critical infrastructure (e.g. hospitals, police stations) are at risk.

FLINTOF also has the potential to assist with emergency planning exercises. The Environment Agency holds emergency exercises with the police and other emergency services.

The main conclusions that have been reached are as follows:

(i) Spatio-temporal risk estimation has strong potential to improve emergency response. By having this risk information available a emergency response officials can prioritize response and recovery efforts to focus on those areas impacted. Initial priorities can be established to coincide with areas of greatest hazard or projected loss of life. In addition, risk projections (e.g. loss of life, injuries, damage to buildings) can be used to estimate the level of resources required to support certain disaster assistance programmes e.g. temporary sheltering.

(ii) The system is flexible and can be applied throughout England and Wales.

(iii) The rapid risk estimates provided by FLINTOF could be integrated with other real-time information technologies to produce an integrated real-time emergency management support system as discussed below.

5.6.2 Recommendations
In the future FLINTOF could be at the centre of GIS web tool, for England and Wales. This would provide details of the following to all the key stakeholders involved with flood event management:

• Government office boundaries;
• Flood emergency plan boundaries;
• Details for Environment Agency, local authority, emergency services, flood wardens and other voluntary back-up organisations;
• Names, full contact details (mobile and pager) for each respondent, plus back-ups;
• Roles and responsibilities;
• Size of available resources;
• Mobile phone/communications availability;
• Locations of stakeholder bases and control centres.

This would have to be a high security site to ensure privacy of information and would only be available on Category 1 responders’ sites. A schematic diagram of this set up is shown in Figure 5.22. There may be the possibility in the future to operate FLINTOF on a real time basis that would allow the Environment Agency to update the emergency services of the flood risk as flood forecasting information becomes available, i.e. rather than just forecasting floodwater levels it would be possible to forecast the flood risk and prioritise the response to the flood based on the forecast results.
Figure 5.22 Schematic diagram showing FLINTOF at the centre of a FEM system
6. Pilot application for the Schelde

6.1 Introduction
The methodological framework as shown in chapter 2 was used as foundation for the development of a decision support system. This framework is a general set up for all kind of physical systems, which means some parts can be left out in the Schelde application. The DSS can be used in case of a critical situation, when extremely high water levels are forecasted and dikes show signs of weaknesses. Moreover, the DSS is a useful tool in developing evacuation plans. The end user can very quickly try out different scenarios and directly see the effect on the evacuation time and routes.

The following sections describe the purpose of the DSS, the physical system characteristics of the Westerschelde estuary, the data that were included in the DSS and the functionality of the prototype. Finally the findings from the end user consultation, that was carried out in the final stage of the development of the prototype DSS, are described.

6.2 Aim of DSS and user requirements

Requirements and existing DSSs
Based on the summary of requirements in chapter 3.2, a DSS for evacuation planning in the Netherlands should include the following information:

- Information on most likely location and time of failure of the dikes;
- Description of the pattern of inundation, ideally with for every polder one location of dike failure;
- Distribution of population, vulnerable objects and factories;
- The evacuation model should be able to run real time and the user should be able to intervene, e.g. when a road is unexpectedly blocked. This is not possible with the existing Escape DSS;
- The evacuation model should distinguish the following phases in the evacuation: preparation, warning, voluntary evacuation, forced evacuation from six hours before expected flooding and end of the evacuation two hours before the expected flooding;
- The evacuation module should be able to work with safe areas (i.e. higher grounds, flood secure buildings, etc.) within the existing dike rings and should plan exit routes to those safe areas;
- Information should also be prepared for communication to the public.

This shows that the decision maker is most interested in combining the flood inundation knowledge with an evacuation model. The question was whether existing DSSs already have this functionality.

From the DSS-review it became clear that currently two DSSs for flood event management are in use: ESCAPE DSS and FLIWAS. ESCAPE DSS contains an evacuation model, but does not combine with flood characteristics. FLIWAS contains an evacuation model (Evacuation Calculator, EC) and has the functionality to show flood characteristics and expected damages. However, from the work in task 17 (Lumbroso et al, 2008) it was learned that the EC is a macro-scale model that does not allow for a detailed analysis, for example of road congestion.

Because the aim of this research was to combine existing knowledge and models and not to develop a new evacuation model, it was tried to combine the flood risk analysis from task 14 (De Bruijn et al, 2008) with the evacuation model INDY, that came out best from the model comparison study (Lumbrosos et al, 2008).

Focus
Besides the combination of flood risk maps and evacuation models, the user required information on safe areas or shelters, dike failure locations and communication to the public. There are several
reasons to not focus on these aspects. From task 17 it became clear that currently no models are available that are able to simulate evacuation to safe areas within the at-risk-area. It was chosen not to put effort in developing such a model. As for dike failure, it is generally very uncertain where and when dikes will break. This subject is addressed in the project Flood Control Room 2015 (www.ijkdijk.nl), which aims to develop a real-time monitoring system for all embankments in the Netherlands. The last subject that was not covered in the current study, is preparing the information for communication to the public. Risk communication is a complex issue for which perceptions of the public need to be investigated first. This is covered in the Dutch research project ‘PROmO’ (www.omgaanmetoverstromingsrisicos.nl).

The development of the evacuation support system
The purpose of the Decision Support System (called from now on: ‘Evacuation Support System, ESS) is two fold:

1. Support policymakers in making evacuation plans;
2. Support decision makers at the time of a flood event.

The first one is typically risk-based. There is no danger yet and consequences can be evaluated without time pressure. Different evacuation plans can be developed and compared. In this case risk is expressed as the number of exposed people and the expected casualties as a result of the breach location with a probability of occurrence.

The second purpose deals with decisions which must be made quickly. Extremely high water levels are forecasted about 6-12 hours in advance. A quick decision has to be made whether people need to be evacuated or not. Possible considerations that need to be addressed immediately are whether there is enough time to direct the most vulnerable residents to a shelter, and whether hospitals or other susceptible objects in the area are expected to be flooded. The ESS should serve as a central information source that can easily be accessed by all persons in charge.

6.3 Overview of the pilot area
6.3.1 Overview
The Westerschelde estuary is a lowland polder system in the Netherlands, protected from the sea by embankments. Critical water levels occur during a severe storm in combination with spring tide. Early warning for critical water levels is provided by the national climate institute. For the Westerschelde area flood management options are restricted to evacuation. In addition sand bags can be placed, which is expected to save some time but is not seen as a preventive measure.

The Schelde catchment consists of the Schelde river, the Westerschelde Estuary and its polders. The Schelde river flows from France through Belgium into the Westerschelde in the Netherlands; a wide estuary connected to the North Sea, as shown in Figure 6.1. The average discharge of the Schelde river near the Dutch-Belgium border is 127 m3/s. The water levels in the Schelde River and Westerschelde are influenced by the tides. The tidal difference in the Westerschelde increases from west (3.86 m) to east (4.83 m) and it increases further on the Schelde River (ARCADIS et al., 2004). Critical water levels for the Schelde Estuary occur when severe storm surges coincide with high tides.

This case study includes only the area at the north of the Westerschelde which is bounded at the north by the Oosterschelde water body. This flood-prone area mainly consists of low-lying polders. It is divided into different dike rings by connected embankments or higher areas. The three dike ring areas are called Walcheren, Zuid-Beveland-West and Zuid-Beveland-Oost (see Figure 6.1). Ancient secondary embankments are present in the flood-prone area which may significantly affect the flood extent and flood depths in the dike rings. Land use in the flood-prone area consists of residences, industries, transport, agriculture and nature, tourism and fisheries.
In 1953 a storm at the North Sea combined with high tides caused severe damage and casualties in the Netherlands, as well as some damage in Belgium. This flood triggered the development of the Delta Plan which includes amongst others the raising of embankments along the Westerschelde so that they are able to withstand a design water level with a probability of 1/4000 per year.

In the province of Zeeland, the actual strength of embankments is not known. Most embankments have a long history and information on characteristics is not present. Because of this, the probability of breaching as a result of high water levels is not known in detail. If a dike breaches, water levels could rise relatively fast. Forecasts for extreme weather conditions will be available about 6-12 hours beforehand. This may provide enough advanced warning to evacuate some areas and save lives, but for a full evacuation at least 24 hours are needed.

For more information on the Westerschelde characteristics, reference is made to Task 14 (De Bruijn et al, in prep).

Figure 6.1  Overview of the study area (bright green) as part of the province of Zeeland

Figure 6.2 Left: Sea dike at Westkapelle (West of Walcheren), Right: Harbour of Terneuzen,
6.3.2 Model schematization and choice of breach locations

The effect of extreme sea conditions is modelled with SOBEK, a combined hydrodynamic one dimensional and two dimensional model, in cooperation with Task 14 (De Bruijn et al, 2008). This model contains both the Westerschelde and the flood-prone areas. The Westerschelde is schematized as quasi-2D by simulating flow through the main channels and interlink those by 1D branches. The flood-prone area is schematized by a 2D grid containing cells of 1 hectare, showing the average elevation. Boundary conditions for this model are the tide at Vlissingen and the upstream inflow from the Schelde River. The model simulates the flood pattern and the resulting maximum water depths. The model is discussed in more detail in the appendix of Task 14.

High water levels in the Schelde estuary are caused by combinations of storm surges and high tides. Relevant variables to consider when describing sea conditions for flooding are thus astronomic tiding, storm surges at the Noordzee (North Sea), wind directions and wind speeds and the interaction between these variables. Of these variables the maximum, duration and time profile needs to be understood. A Belgian consultant (IMDC, 2005) did a statistical analysis on these variables in order to To study the flood consequences of an extreme event the conditions with probability of 1/10000 per year were used, which differs from the safety standard of 1/4000 year water-level probability. However, the difference has a minimal effect on the resulting water level (on the order of a few centimetres) and flood extent.

![Extreme tide at Vlissingen](image)

**Figure 6.3** Extreme water levels, statistically derived in IMDC (2005), for different return periods

It is uncertain where embankments will break, at what moment they will break and how many breaches will occur during extreme conditions. Since breaching is unsure until the last moment, a number of breach locations have been simulated. For our study area 12 locations were chosen more or less randomly from available simulations in task 14 (De Bruijn et al, 2008). Embankments are assumed to fail when the water level reaches the 1/4000 per year safety standard. If an embankment fails the breach is assumed to grow to a width of 200 m with a growth rate according to the VanderKnaap formula (SOBEK manual).

An example of the resulting breach growth function in time is given in Figure 6.4. In this example the breach grows to a depth of 8 m (relative to the dike crest) in the first seconds, after which it develops until a width of 200 m. This was assumed to be a representative width for the Westerschelde embankments, based on the results of task 14 (De Bruijn et al, 2008).
Next to all failure locations in the outside embankments, the sluices in the Canal of Walcheren may fail, possibly followed by a breach in the embankments of the Canal. Secondary embankments are assumed to hold.

6.4 System description

The Schelde ESS is basically a tool that links different flooding scenarios to a database with simulation results. In the background spatial information is present in the form of layers built up from shapefiles. HTML functionality is supported so that the user can click on objects and receive pop-ups with additional information. These objects such as breach locations or hospitals are also linked to the scenario’s. Figure 6.5 shows the schematic overview of the system.

The user is asked to choose one breach scenario, allowing simulation results stored in the database to be shown on the screen. Via a menu the type of map can be selected, for example a map showing the inundation time for each location.

The simulation results are shown on top of the spatial layers, mostly in the form of raster layers. When clicking on one of the grid cells (one for each hectare in this case), the grid value (e.g. maximum water depth and time of inundation) is shown in the upper right corner of the screen. Some of the maps are in the form of polygons representing the postal code areas and showing for example the number of inhabitants in each zone or the number of inhabitants still present after 20 hours of evacuation.

For the evacuation results two maps are prepared based on results from task 17 (Lumbroso et al, 2007). One map shows the results of the simulations with the Evacuation Calculator, the second map show the simulations carried out with the evacuation module in DSS ESCAPE.

The ESS allows for tabular presentation of some of the data, for example a table with evacuation times for each postal code zone.
6.5 **Functionality**

6.5.1 **General information**

The prototype DSS for the Schelde pilot, called Evacuation Support System (ESS), was built following the general framework as introduced in chapter 2. As the purpose of the ESS is evacuation management, some modules of the framework can be left out or reduced.

Figure 6.8 shows a screen dump of the ESS as it appears on the screen after installation of the software. On the left the modules from the framework can be found (enlarged in figure Figure 6.7). The modules are explained in more detail below.

The following information is shown in the current screen:

- **Introduction** How to get started and an overview of the pilot area, supported by satellite images (internet connection required);
- **Reports** Background information to FLOODsite and reports to be downloaded.

In the upper left corner, a dropdown menu is present from which a ‘breach scenario’ can be chosen. Each scenario represents a breach location or a set of breach locations. The next sections describe for each module the maps or data that are available for each of the breach scenarios.
Figure 6.6 Typical ESS start-up screen showing the pilot area and clickable breach locations

Figure 6.7 Modules in the ESS (enlargement of the above figure)
6.5.2 External driver module

The external driver module of the Schelde ESS consists of actual weather conditions and resulting water levels at Vlissingen. For that a connection is made with renown websites.

All data that feeds into the ‘tools module’, which represents the hydrodynamic models, damage functions, flood defence reliability models, etc., is not included in the external driver module. This is because the output of these models is stored in the ESS and the ESS end-user is not expected to fill the database himself. Some of it, such as population data and the road network, can be found in the exposure module.

6.5.3 Hazard module

For each breach scenario three maps are available, and a simulation of the chosen flood scenario as a function of time can be viewed by selecting ‘animation’.

The maps present the following information per grid cell of 1 ha:

1. Maximum water depth;
2. Maximum velocity;
3. Time of inundation;
4. Potential building collapse;
5. Rise-zones.

The first three maps result directly from the hydrodynamic model. There are two ways to present the data after a three-day simulation:

- Maximum value within a postal code zone (Figure 6.9).
- Maximum value per hectare (Figure 6.10);

The first option can be very useful for the decision maker, as other relevant data such as number of inhabitants, population density and the total area is typically known per postal code zone. In this way the hydraulic information is connected to the vulnerability data. The end user can click on one or more zones and visualize all relevant information in a table. This also allows for comparison with other zones and breach scenarios.

Figure 6.9 Part of a map in the ESS, showing tabulated information on hazard and vulnerability data for one selected postal code zone

Maps 4 and 5 are derivations from the first three maps. The map ‘potential building collapse’ shows which buildings are expected to collapse. The building collapse is estimated based on the maximum velocities calculated from the hydrodynamic model and information from literature on the stability of different types of buildings (Asselman, 2005).

The map ‘rise-zones’ shows zones with high- and slow-rising water as a result of a breach scenario. According to HIS-SSM, fatalities can occur because of high water levels, high rise velocities (> 0.5 m/hour), high flow velocities (>2 m/s) or a combination of these factors. For each breach scenario these factors are available from the SOBEK model results. High flow velocities are not found in the Schelde pilot and where high water levels occur is known from the first map in this module. Therefore the map shows two zones:

1. Slow rise \( w_i + w_{i+1} + w_{i+2} < 1.5 \text{ m/hour} \)
2. High rise \( w_i + w_{i+1} + w_{i+2} > 1.5 \text{ m/hour} \)

Where:

- \( w \) = Rise velocity (m/h)
- \( i \) = Time step (h)
The first assumption for the rise-zone is that a high rise velocity only becomes dangerous if it occurs longer than 3 hours. This could be any combination of rise velocities during three time steps, if the total is 1.5 m/hour. The second assumption for the rise zone is that after 24 hours the people have had enough time to get away. Therefore the zones were only identified during the first 24 hours of the simulation.

6.5.4 Exposure module

For each breach scenario four maps are available with the location and number of inhabitants, livestock and infrastructure as well as a map with shelters. Tall and stable buildings and high areas are shown. Shelters, defined as non-coastal high buildings with more than four stories, could be used in an evacuation.

These maps concern the exposure of the area and are provided by the province of Zeeland and the local water board. The maps show the number of inhabitants and their spreading based on where their houses are, livestock (not included in the prototype), potential shelters and infrastructure.

Shelters are defined as stable buildings of over four stories that are not coastal.

As infrastructure map a dynamic traffic model could be connected, however the prototype contains a static road network.

Ideally the inhabitants map would include information on the time of day. During a regular working day most people are in school or at work, while during the night people are usually at home. This functionality is not included in the prototype ESS.

6.5.5 Consequence module

For each breach scenario, maps are available with an estimation of casualties and affected people. Both are derived from a combination of hazard maps and exposure maps. Specifically, the water-depth maps (hazard) are combined with the population-density map (exposure) provided by the province. Where the hazard and exposure overlap represents the area where residents are potentially affected (consequence). The number of exposed people is dependent on the evacuation plan. If no evacuation is carried out the number of exposed people equals the number of affected people. The options ‘graphs’ and ‘tables’ are available to compare consequences of different breach scenarios.

6.5.6 Management response module

The purpose of this module is to get insight in how the decision maker can reduce the casualty-risk by responding with an evacuation call. This supports the end-user in making evacuation plans long before a flood event happens. The idea was to let the user choose the areas to evacuate and directly show the effect on evacuation time and decreasing number of expected casualties.

Thus, information would need to be provided by the ESS that answers the following questions:

- Which areas are evacuated (to be selected by the user)?
- What is the total evacuation time?
- Which routes towards safety are the most efficient?
- How does this affect the number of casualties?

To support this functionality, an evacuation model is needed. From task 17 we learned the INDY traffic model is the most appropriate model in support of evacuation planning. However, as the work on the Schelde pilot progressed, it was also learned that “large parts of the area will most likely stay dry. For the province of Zeeland it is therefore more useful to prepare evacuation plans for parts of the area instead of for the whole area” (Lumbroso et al, 2008). To support evacuation planning on a more local scale, a finer resolution of postal codes and road network needs to be modeled with INDY than actually happened in task 17. Therefore, the management response module in the prototype version of the ESS could not further be developed. Nevertheless, to show the functionality of a management
response module, the results of ESCAPE, one of the other evacuation models, were included in the ESS.

In later versions the user will be allowed to create an evacuation plan in the ESS by clicking on exit points and available shelters for each breach scenario. The effect of this ‘plan’ will be shown by the calculated evacuation time needed and the amount of people potentially exposed. Seeing the results of different evacuation plans right away on the screen, the user becomes familiar with the effects of certain actions. This knowledge can be used in the process of making the full detailed evacuation plan.

6.5.7 Example of a breach scenario

In the current example the breach location ‘Rilland’ has been selected. The location is shown by a red dot with a name tag (Figure 6.10). The background map shows a topographical map of a part of Zeeland. The maximum water-depth map is shown on top of the topographical map. The maximum water depth is highest close to the breach location. Figure 6.12 shows the time of inundation. The red area gets flooded within 2 hours after breach initiation.

Figure 6.12 shows the time of inundation. The red area gets flooded within 2 hours after breach initiation.

Figure 6.10  ESS map showing a topographical layer with the maximum flood depth per hectare for an event in the East of Zeeland (Rilland)
Figure 6.11 Example of an ESS map showing the maximum water depth for each postal code zone (breach scenario ‘Rilland’)

Figure 6.12 ESS screen showing the time of inundation for a breach scenario ‘Rilland’
6.6 **First response of the end user group**

On the 5th of September, 2007 potential end-users of the ESS were asked to give their feedback on the prototype system. Representatives of the province of Zeeland as well as the local waterboard were present.

Two activities were undertaken:

1. Presentation and discussion of the first results from the application of two evacuation models on the Schelde pilot: Evacuation Calculator and ESCAPE. This research was carried out under Task 17; and
2. Presentation and discussion of the prototype evacuation support system (ESS). This system was developed under Task 19.

The findings from the second activity are summarized below, whereas the findings of the first activity can be found in the Task 17 report (Lumbroso et al, 2007).

**General remarks**

It was noted that besides the technical aspect, evacuation management deals with important political issues:

- An evacuation experience that turns out to be unnecessary afterwards, will influence the response for the next evacuation call;
- An official evacuation decision is only taken when the critical water level forecast is given and by then it will be too late to start an evacuation. Before that, some people will individually decide to evacuate, leading to chaos on the roads.

It can be concluded from this that one should focus on local evacuation instead of evacuating the whole (study) area. It is important to know where congestion occurs and where alternative routes exist.

**Feedback to the evacuation planning support system**

- It quickly gives insight in the local situation, this will certainly help to create evacuation plans;
- It answers the needs of the decision maker;
- It can show the need and possible locations of developing real shelters in the area.
- Some of the legends are confusing;
- More information at the same time/ on the same screen is preferred in the form of a table. For one breach scenario information on the most vulnerable area, postal code of that area, number of inhabitants, evacuation times, etc. could be shown right away.

The last two points were addressed in the last version of the prototype.

6.7 **Conclusions and pilot specific recommendations**

The first aim was to list the specific requirements for decision support in flood event management. From the review of existing DSSs in the Netherlands it was concluded that the end-users are generally decision-makers, who prefer a database with pre-cooked model results rather than several linked models that need to be run real-time. It was found that the existing DSSs for flood event management lack in combining the flood risk analysis and results of evacuation models. From the end-user consultation, which was held half-way the project, it was also found that there is a need for combined information on for example the most vulnerable area, postal code of that area, number of inhabitants and evacuation times.

The prototype DSS succeeded in combining different types of flood risk maps (maximum water depth, risky places because of quickly rising water, potential building collapse, time of inundation, etc.) with evacuation-model results and characteristics of the area such as location of hospitals and number of inhabitants for each postal-code zone. Evacuation models were not included. However the added value
of including results of evacuation models in the form of maps and animations has been proven. Exact results from evacuation modelling done in task 17 could not be included in a proper way, because of the model resolution that was found too coarse for local evacuation planning support.

The end-user consultation with the province of Zeeland and the waterboard Zeeuwse Eilanden has shown the need for a DSS like the prototype ESS. They would use it mainly for preparation of evacuation plans, and not so much during the event itself. It was found very useful as a dynamic library, in which new breach scenario’s can easily be added to the database.

An important conclusion was drawn on the scale of the evacuation plan. One tends to focus on the evacuation of the whole of Zeeland, while a great deal of the area will most likely stay dry. It is worth focussing on local evacuation instead of evacuating the whole of the province. However, evacuation models should still be applied to the area. It can be expected that the road capacity is not optimal, even if only one part of the area at risk is forced into an evacuation.

**Recommendations**

It is recommended for future versions of the ESS to develop a pre-processing tool that allows the importation of model results by the end user. Currently the ‘expert’, or the developers of the ESS are needed to include new results.

As a result of the work carried out in Task 17, it is recommended to develop evacuation models that contain a detailed road network. This allows for evacuation planning by local communities and for inclusion of the results in the ESS.
7. French pilot applications

7.1 Introduction

Urban flooding occurs where there has been development within stream floodplains. Urbanization increases the magnitude and frequency of floods by increasing impermeable surfaces, increasing the speed of drainage collection, reducing the carrying capacity of the land and, occasionally, overwhelming sewer systems. In most of the urban area, roads are usually paved. With heavy rain, the large amount of rain water cannot be absorbed into the ground and leads to urban floods.

The primary cause of urban flooding is a severe thunderstorm or a rainstorm proceeded by a long-lasting moderate rainfall that saturates the soil. Floods in urban conditions are flashy in nature and occur both on urbanised surfaces (streets, parking lots, yards, parks) and in small urban creeks that deliver water to large water bodies. Other causes of urban floods are:

- inadequate land use and natural waterways training
- failure of the city protection dikes
- inflow from the river during high stages into urban drainage system
- surcharge due to blockage of drains and street inlets
- soil erosion generating material that clogs drainage system and inlets
- inadequate street cleaning practice that clogs street inlets

Floods disrupt the social systems of the countries and the cities, and cause substantial economic losses. The appropriate preparation of the cities to flood events is necessary and requests:

- elaboration of the flood hazard maps
- definition of the vulnerable zones
- implementation of risk maps and appropriate tools for flood risk management

Traditional one-dimensional hydraulic models are inadequate to simulate the spatial behaviour of free surface flows in urban environments and if used, require too many assumptions regarding flow diversions and potential confinement. Advances in the computational speed of computers has facilitated the reality of using two-dimensional flood routing programs to efficiently simulate these complex urban flood environments with accuracy and detail.

7.2 Objective

The aim of the research is the validation of a pragmatic approach, which can contribute to the preparation of flood risk management plans in urban areas using 2D hydrodynamic models for attribution of flood risk. Data has been taken from the available examples of application of TELEMAC-2D System (www.telemacs-system.com) (Hervouet and van Haren, 1994; Hervouet and van Haren, 1996; Hervouet et al., 2001).

The French ‘Plan Communal de Sauvegarde’ (or Community Safeguard Plan – PCS, Ministère d’Intérieur (2006)), as a part of a regulatory law on modernization of the rescue services, is used to prepare a community, among other risks, to possible flood crisis management by creating the flood crisis management plans to the economic stakes in the urban areas. It is tried to discover to what extent the 2D modelling can contribute to the PCS preparation at the local level for flood risk management.

Two application sites have been selected in the Mediterranean region of France. One of the sites is a borough of the city of Nice, an area with high level of flood risk exposure due to Var river high level flows concomitant with storm surge and the second one is an urban area of an unidentified city in the same Mediterranean region of southern France.
The first task in the research led by SOGREAH was identifying the assets (stakes) in the study area through inventory and detailed analysis of the available information of the cities under consideration. The identified assets (stakes) such as residential areas, public centres, open areas and infrastructures are categorised in such useful way for the study and management of flooding. In the two consecutive tasks the core application of the 2D modelling for flood risk assessment through in-depth study of the vulnerability of the assets (stakes) and the respective flood hazards was performed. For this, the use of two already existing TELEMAC 2D models was made with the set up for the two project sites taking into account the topography, geometry of various structures and different hydraulic properties in the area (SOGREAH, 2007).

For the flood events tested in different scenarios the results obtained from the 2D hydrodynamic model such as the flood water depth, velocity field, the discharge and duration of submersion have been used in the analysis. This analysis is incorporated into the different steps in flood management planning such as flood hazard assessment, risk analysis and disaster management planning.

Finally, the research brings an insight into the efficiency of any two-dimensional modelling approach (and specifically TELEMAC 2D System) as a source of information for a decision support tool for flood management by assessing the extent to which the model contributes to the requirements of the PCS. The report provides also some suggestions related to the model for better improvements of 2D approach to urban flood modelling (characterised by a complex geometry of the domain) coherent with the PCS regulations.

7.3 Methodology

7.3.1 Methodological aspects of flood hazard and flood risk mapping

Flood hazard maps show the extent of the floodplains, and flood risk maps show the extent of the floodplains and the assets at risk of flooding within the floodplains. Not only are these maps needed for flood risk assessment, but they can also provide valuable information for planning a range of activities including the emergency response to a flood disaster.

In coherence with the European Flood Directive (Directive, 2007) and “Language of Risk” (Gouldby B. et al., 2005) for the purpose of mapping of inundation extend, hazard and risk are defined as follows:

**Hazard**

A hazard may be defined as a situation with the potential to result in harm. A hazard does not necessarily lead to harm, but identification of a hazard does mean that there is a possibility of harm occurring. In the context of flooding, a flood hazard exists in areas where flooding can occur.

**Risk**

Risk is a combination of the chance of a particular event, with the impact that the event would cause if it occurred. Risk therefore has two components: the chance (or probability) of an event occurring and the impact (or consequence) associated with that event.

\[
Risk = Probability \times Consequences
\]

or

\[
Risk = Hazard \times Vulnerability
\]

In the context of flooding, the probability is the chance of the flood occurring and the consequences are the impacts of the flood (for example, damage to buildings).
**Vulnerability**

Vulnerability is a sub-function of risk. The term encompasses the characteristics of a system that describes its potential to be harmed. It can be expressed in terms of all functional relationships between expected damage and system, characteristics (susceptibility, value of elements at risk), regarding the whole range of relevant flood hazards. Vulnerability maps show the location, type and number of buildings, people, areas of crops and important infrastructure that are at risk from flooding.

**Flood hazard maps**

The purpose of a flood hazard map, in its simplest form, is to inform flood management. A “layer” on the map may then be used to identify the appropriate management responses: those points such as bridges and crest lines which need to be watched; points where emergency flood fighting works may protect the areas behind them; those areas where warning is necessary; which areas should be evacuated in the event of a flood; where buildings should be discouraged if possible because they lie in a floodway; and where flood proofing of buildings may be satisfactory because they are only in a passive flood storage area.

The main method for identifying flood hazards is via flood hazard maps. To evaluate flood hazard fully, the following is needed:

- Identify which areas will be flooded;
- How often the floodplain will be covered by water;
- The depth of the floodwater;
- The velocity of the floodwater;
- Duration of the submersion of flooded area;

The flood risk maps are produced by crossing the flood hazard and vulnerability maps as provided on the following examples (Fig. 7.1 – 7.3).

In flood risk assessment stage it is important to assess the degree of hazard in the floodplain and to prioritise the effort in producing flood maps where the flood hazard is high. Figure 7.2 shows the categorisation of hazards for flood hazard mapping based on the water depth and velocity of the flooding. One method by which flood hazard can be categorised is based on the impact of flooding on population exposure.

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![Figure 7.1 Flood Hazard mapping based on water depth and velocity](image-url)
These categories are:

**Low:** - There are no significant evacuation problems. If necessary, children and elderly people could wade to safety with little difficulty; maximum flood depths and velocities along evacuation routes are low; and evacuation distances are short.

**Moderate (Average):** - Areas where fit adults can wade to safety, but children and the elderly may have difficulty; evacuation routes are longer; and maximum flood depths and velocities are greater.

**High:** - Fit adults have difficulty wading to safety; evacuation routes are longer again; and maximum flood depths and velocities are greater (up to 1.0 m and 1.0 m/s respectively).

**Very high:** - Boats or helicopters are required for evacuation; wading is not an option because of the rate of rise and depth and velocity of floodwaters. Maximum flood depths and velocities exceed 1.0 m and 1.0 m/s respectively.
In general most flood hazard maps only show the flood extent for a particular annual probability of flooding or return period. The 1 in 100 year return period (or 1% annual probability) flood extent is often used for national flood mapping projects.

In the context of urban flood studies Telemac-2D was used in order to elaborate the appropriate hazard maps. For a given computational domain, given boundary conditions and a given initial condition, the two-dimensional solver computes the water depth and the depth-averaged velocity vector in the domain. The quality and accuracy of the input data and the numerical scheme determine the quality of the results. TELEMAC-2D uses unstructured finite element meshes that allow local refinements of the geometry and enable an accurate description of rivers, shorelines, roads, motorways, levees and in particular urban infrastructure (such as buildings and sewers) to be taken into account for an appropriate urban flooding representation so that they can be targeted for improvement.

Resulting flood hazard maps crossed with the vulnerability of assets allows to produce risk maps, although the 2D models produce much more valuable information for urban flood risk prevention and planning.

This is a main objective of the study to identify 2D modelling approach benefits in this respect.

7.3.2 The French regulatory tool Plan Communal de Sauvegarde (PCS)

The 2004 French law of civil safety organization created tools necessary to the mayor in his major role of civil safety management with the establishment of the PCS with a strong association of organization of the civil safety. Amongst tools the PCS has vocation to organize the mobilization of the local response, explaining the engagement of a participatory safety approach.

The organization of the PCS allows to face very diverse situations: major catastrophes strongly reaching the population (people deceased or wounded, destroyed houses), disturbances of the community life (interruption of the drinking water supply or energy, bad weather, heat wave, epidemic), and more current accidents (fire, of circulation). The objective of the Community Safeguard Plan is to prepare beforehand while being formed, obtaining modes of organization, technical tools to be able to face all these cases and to thus avoid rocking in a crisis. So far, multiple initiatives were carried out to for years develop the communal organizations of management of an event for civil safety. The PCS tries to make the synthesis of this work, it can be used to prepare with any type of situation at the risk. Each community being a particular case: environment, risks, density of population, etc. are elements thus the PCS guide should adapt to the local needs.

To be effective at the time of an event, the mayor and his services must fully adapt the procedures and the actions envisaged by the plan. This objective cannot be achieved by proposing one standard ground work. The PCS guide is thus directed for a realization in control by the community. It presents a method of development, tools and the examples which the community must adapt. It is this deliberation of dialogue which makes it possible to acquire them knowledge, good behaviours and useful reflexes at the time of unexpected situations. The intervention of an external partner helping the community to carry out its PCS is evoked. According to the tasks that the community wishes to entrust to the subcontractor, it can be drawn from the PCS document. Intended for all the community, of most modest at the maximum important, the PCS guide contains much information; however, it should not impress. It was conceived way so that each community can extract information that is essential for it to carry out its PCS. A guide was created for the project leader and the team. Throughout the step, a teaching work and of sensitizing bound for all the actors concerned (elected persons, territorial agents, external partners, population) is necessary. In addition to the elements of this guide, the project leader can rest on the information contained in “the memorandum of the Community Safeguard Plan (PCS)”.

The duties and responsibilities in the PCS are articulated around the stages to follow. It is possible, in comparison with the size of the community, not to follow strictly this chronology even to jump or add
stages but in a general way, it is adapted to all the communities. Work load rising from the implementation necessarily depends on:

- size of the community,
- number of actors whom the community wishes to associate with the step,
- level of detail which the community wishes to reach.

Last point, the implementation of a step in the preventive information for the populations during major risks and in particular elaboration of the Information memorandum Communal on the Major Risks can take place before, in parallel or following the development of the PCS. The diagnosis of risks can, in particular, be shared for two subjects that are complementary approaches; they allow giving all its direction to delivered information with the citizen and more particularly with the instructions which condition reaction of the population in the event of risk.

**Management of the process of elaboration and implementation of a PCS**
The elaboration and implementation of a PCS requires an appropriate organisation between local stakeholders (DDE – county infrastructure directorate, DIREN – regional environmental protection directorate, SDIS – county service of fire brigades and safety, CG – County council) : steering committee plays a dominating part in the project. The committee should be composed of the mayor, some elected officials, the PCS project leader, the director general of services (if such function exist in the community), and legal bodies other representatives.

**Figure 7.4 Example of a PCS organisation scheme**

**Diagnosing the risk:**
Diagnosing the risk involves identifying the hazardous phenomena and assets (stakes) and defining strategies of action. This includes studying occurrence and intensity of the hazard with the stakes that correspond to the whole population and the goods that will be affected by the phenomenon or activities of human.
Diagnoses of the hazard:
- Identification of the hazard
- Scenario of occurrence

Survey of the assets (stakes):
- Human
- Economic

Crossing hazards / stakes:
- Cartography of the risk

Figure 7.5 Steps to be followed in diagnosing the risk

**Informing and warning the population:**
In order to have good flood warning and information disseminated within the population, the preparation should involve; Identifying sources, measures and means of warning, methods of diffusion of alarm to the population. With the scale of the commune, alarm must be conceived to two levels:

- reception of an alarm,
- diffusion of an alarm in the population.

The diffusion of alarm to the population undoubtedly constitutes the most delicate mission for a commune for two reasons:

- it must be planned, reliable and exhaustive,
- it is not a usual (daily) mission to the commune. It is not thus a question “of reorganizing” a current competence.

To alert the population, it is necessary to use, according to the case, all the means available so that the fellow-citizens apply the security instructions which will have been communicated to them as a preliminary. The alarm of the populations is thus a particular mission which must be the subject of a basic work leading to the realization of a procedure for the use of the means of alarm for the scenarios under consideration like for any other case not envisaged.

The mayor must take the required measures to make sure of the good course of alarm in order to be sure that all the inhabitants apply the instructions which will have been diffused to them within the framework of the preventive information campaigns.

**Creation of communal organisation:**
The PCS also describes the determination of the command functions and application sites with specific missions to accomplish. The mission of safeguard which the commune will have to carry out according to the phases of the event must be identified and organized in participatory approach. The three phases of an event of civil safety are:

- **Urgency** which is the period immediately after the event and that can last from few hours to few days long. The actions to be taken here are reflexes, to alert and inform the first aid, protection and assistance of the population.
Post-Urgency begins as soon as the emergency phase starts to decline (withdrawal of the first-aid organizations). This phase can be from a few days to a few weeks. The main tasks in this phase are support of the population investigation and measurements of repairing.

Return to Normal: This period begins after the phase post-urgency, can continue until a year or even beyond. Support to the affected population and rebuilding damages are main activities to be done.

The diagnosis of the risks makes it possible to identify foreseeable scenarios. However, the commune can be subjected to other scenarios not envisaged for which its organization must also be able to function. The adaptability is a pledge of effectiveness and safety.

Analyzing the operational tools:
The tools synthesized in this phase must imperatively be; clear, insightful, concise and simple to update.

Technical and organisational information are the two basic types of information for analysing the operational tools in the PCS.

“Technical” information:
- existence of the risks diagnosis and survey of the means: the list of the risks identified on the commune and the various threatened stakes (schools, commercial centres, etc…),
- the list of the average materials available on the commune,
- the list of the buildings being able to be used for re-lodging,
- the list of the means of alarm and methods of their use to ensure a fast diffusion of the information within the population,
- the list of the people having to take share with the device and their personal co-ordinates.

“Organisational” information rising from work on the organization:
- people having to take share with the device and theirs responsibilities in possible form of a flow chart,
- actions that each one of these people (or groups of people) must realize,
- methods to contact them quickly (diagram of call, use of an automatic tool, etc.),
- the place where the actors will meet and methods of its implementation (list of the material necessary).

Operational maintenance of the device in time:
The documents composing the PCS must be designed to facilitate and follow the updates. This includes tools for up-to-date maintenance of the data, training, education and the experience feedback. Indeed, the up to date maintenance data is the indispensable condition for the effectiveness of the tool. For example, during the event, if the telephone numbers are not allotted any more or the incomplete lists of materials, the organization will waste an invaluable time and thus its effectiveness.

Generally, the PCS, in its paper form, is present in several specimens within the town hall and hence, the update of the files, directories or other documents must imperatively be done for all versions in circulation. With this intention, it is essential to have set up a documentary procedure of follow-up.

Training and the information of the personnel and others actors of the organization also form part of this missions. These actions aim at maintaining the level of knowledge of the people working in the project. For example, articles can be published in the internal newspaper, to gather the groups of the project to point out the importance to them for up to date maintenance of the data, etc.
The training activities/information must allow:
- with the whole communal personnel and elected officials to know the device,
- to transmit information to the partners commune,
- to develop the work in participatory way,
- to motivate the persons working on the project and to maintain an appropriation strength during and after the development of the PCS.

This information or training is particularly important following the exercises and therefore, the lesson learnt from the exercises must lead to modifications in the PCS. The exercise can be organization of internal exercises or the participation of an external structure (prefecture, industrialists, etc.) and the correct exploitation of the lesson require time.

![Figure 7.6 Scheme for the respond of the commune to an event](image)

### 7.4 TELEMAC 2-D brief description

Two dimensional (2D) hydrodynamic are now becoming a common practice for simulations of a large range of free surface flows such as marines tides, floods and dam-breaks. Among other existing computational tools of this type, TELEMAC, the hydroinformatic system built and used at Electricité de France and distributed by Sogreah contains a module called Telemac-2D computational software that calculates free surface flows in natural water bodies Hervouet and van Haren, 1994; Hervouet and van Haren, 1996). For a given computational domain, given boundary conditions and a given initial condition, using finite element method TELEMAC-2D solves the two-dimensional shallow water flow equations operating on non structured grids of triangular elements.

The unstructured finite element grids represents some advantages over finite differences approach as it allows local refinements of the geometry and enables an accurate description of the model boundaries (rivers, shores, roads and levees, and in the case of urban domain buildings, streets and typical infrastructure, which may have an impact on the hydraulic path). Nevertheless, it is worth noting the actual real representation of features and structures on the ground such as geometrical details of a
building in a city (for example its capacity of absorption of a part of a flow) or every tree in a forest is far beyond reach of existing models.

7.5 Application sites

7.5.1 Flooding issue of Nice

Nice is the fifth largest city of France. It has a Mediterranean climate; the city enjoys mild and sunny weather most of the year. Summers are hot and dry but are often moderated by a breeze. There are two rivers flowing through Nice, namely the Var to the west, and the Paillon to the East.

The Var catchment has an area of about 2822 Sq. km and elevation from 3000 m.a.s.l in the mountains to 0 m.a.s.l at the mouth to the Mediterranean Sea. The river rises at an altitude of about 1800m in the vicinity of the “Col de la Cayolle” and traverses about 125 km to the end.

The Var River has been subjected to frequent spates and floods out of which the worst event happened in November 1994 when the river Var had a large flood with an estimated peak discharge of 3350 m3/s. This flood destroyed two weirs, leads to large flooding areas and several damages on the infrastructure (e.g. bridges, roads). This flood was estimated to have a return period of 80 years from the study the river Var conducted by SOGREAH in 1999.

![Figure 7.7: Flooding of the Var River in November 1994](image)

The area of the city of Nice considered in the model is the flood plain of the Var river. Two sectors of the city have been zoned for this flood modelling study as shown in the Figure 7.8, boroughs <<CAP 3000>> and the <<Aréna-Californie>>. These areas are adjacent to the Var River and have been observed from the topographic study and past events, to be susceptible to flooding by the over-bank flow of the river during high flows.

The area is not densely populated; however, there are large commercial centres with large parking lots and many public service and official buildings including the administrative. There are also open fields such as parks and sport fields. Some but not dense forest with bush also exist in part of the section of the riverbank. The area also consists of major infrastructures such as motorways and railways.

The flood discharges considered in different scenarios of the modelling are:

- Flood of the Var of 3800 m3/s with breach of dyke;
- Flood of the Var of 5000 m3/s without breach of dyke;
- Flood of the Var of 5000 m3/s with breach of dyke.
The first event is believed to have been occurred during the year 1994 flood (corresponding to Q80) and the 5000 m3/s is the estimated Q100 probable maximum flood.

The hydraulic model that has been set up to calculate the floods of the sectors concerned allows to determine the heights of water and the rates of the flow (velocity and discharge) in each of the streets and ground discovered. It is possible to take into account a deviation of water by the network of the sewers in the form of sink and source terms. This means that it is possible to have in some precise points of the taking away automatic (term of disappearance) water.

7.5.2 Flooding issue of unidentified site in southern France

The recent past of unidentified site in southern France marked the memory of the inhabitants through stormy events violent one having caused local floods. However, it is established that these events are only fairly important compared to those observed in the Mediterranean. Indeed, this site has not known in these 40 last years of stationary stormy phenomena comparable with those having marked the memories on the frontage of the areas nearby for example.

The two boroughs of unidentified city in southern France considered in the flood modelling are shown on Figure 7.11. The two boroughs (surface of 19.2 km² and 4.7 km² respectively) are located at the immediate downstream of the three catchment slopes and upstream of the offshore bar. In addition, the rivers draining these catchments cross these urban areas underground, until their rejection at the sea and hence, during a period of high rainfall, overflows can occur on the streams upstream of the covered zones.

TELEMAC 2D model has been set up for the two disconnected catchments in the project area. A review and make use of the TELEMAC-2D has been done on the previous study conducted by SOGREAH that includes:

1 This site remains anonymous in this report until authorisation of the client to use the data for research purposes.
- Hydrological study of three upstream catchments that drain rain water to the two boroughs.
- Establishment of Hydrodynamic model TELEMAC 2D
- Analysis of the flood risk and proposition of flood management plans

![Elevation Map produced from aerial photographs of 1/5000 scale](image)

Within the framework of a preliminary study the community of unidentified site in southern France was classified as zone with the very high risk of flooding, in particular because of the current and future urbanization on the basins slopes immediately upstream of two boroughs indicated on the Figure 7.12.

The hydro-geomorphologic and hydraulic studies thus relates to the basins slopes of the rivers of River 1, River 2 and River 3, in order to determine the risks of flood on the districts of the Borough 1 and Borough 2. Indeed, these two districts are located at the immediate downstream of the three basins slopes and upstream of the offshore bar. In addition, the river draining these basins cross these districts urbanized in underground, until their rejection at sea. So in period of rising, overflows can occur on the rivers upstream of the covered zones.

However, today still, there is no certainty, in particularly due to the lack of concrete data. Therefore this study is to carries out a concerted synthesis and proposes elements of reference making it possible to progress in the step of quantitative evaluation of the risks. This quantification requires several levels of intervention:

1. Evaluation of the hydrographs of flows for an event of natural and exceptional (beyond the natural event). This evaluation passes by the preliminary determination of the rains to retain.
2. Establishment of fine hydraulic models in order to quantify the heights and speeds, therefore the risk in sectors strongly urbanized with the downstream of the basins,
3. Analysis of the risks and stakes, to propose and envisage installations intended to decrease the width of the floods to the right of the urbanized places.
In addition to the urbanisation, the area has high slopes that contribute to the occurrence of flooding. At some sections, the river was trained (an underground tunnel), which modified the natural section of the river and during intense precipitations aggravate the risk.

![Figure 7.9: Model application site - an unidentified urban site in southern France](image)

The flash flood character of the inundations considered in this site require a precise knowledge of the rainfall pattern distribution in the catchment and as there are no historical hourly rainfall records for past flood events the 10-year and 100-year return period accumulated precipitation estimates of respectively 78 mm and 140 mm in 24 hours was adopted. For the purpose of simulation scenario the exceptional event observed in the region corresponding to 228 mm in 24 hours was also adopted.

The floods considered in the modelling are of 10 year and 100 year return periods. Different model runs such as 2D flood modelling with and without the urban drainage and with varying mesh sizes have been tested.

### 7.6 Results

As it has been indicated in the introduction section, the core of this project is to assess the benefits of 2D modelling for flood event management planning at local or community level based on the French regulatory tool the community safeguard plan. This is done by first outlining the requirements of the community safeguard plan and studying the inputs from the 2D modelling to these requirements.

The objectives of the community safeguard plan are planning the organization within a commune for warning, informing, protecting supporting the population in the event of known risks. The plan contains various components such as: The organization of the local command centre, the actions to be carried out with the responsible personnel for each emergency service, an inventory of facilities (transport, accommodation, and supplies) and specific measures.
Various stages of the community safeguard planning that require inputs from the model result have been described in the following sections.

### 7.6.1 Risk assessment stage

Risk assessment is a crucial preliminary to operational planning that is pertinent in relation to risks (scenarios) and suited to the local context (stakes, resources, etc.). Risk assessment involves:

- Hazard assessment
- Definition of assets (stakes) and vulnerability
- Risk analysis
- Vulnerability reduction measures

**Hazard assessment:**

Hazard assessment involves collection and analyzing data and information from local information to get an idea of the hazard and to determine decisive elements in the hazard assessment steps such as selection of the flood event, then comes the calibration and validation phase and extraction from the simulated results of different parameters for analyzing the hazard, such as selection of flood parameters (time varying water levels and velocities, maximum inundation depth attained, duration of submersion) for categorization. More information on the process of calibration and validation can be found in Hervouet et al (2001) and SOGREAH (2007).

Flood hazard maps can be produced from the outputs of 2D hydraulic modelling by overlaying the maximum velocity map on to the maximum water depth maps. Figure 7.11 shows the flood hazard mapping for the project site in Nice for 5,000 m$^3$/s flood due to a dike breach. The flood hazard maps produced for different scenarios of the other site in this project have been annexed to this report.

![Figure 7.10: Schematization of input and output of a 2D Hydrodynamic model](image-url)
Definition of stakes (stake) and vulnerability assessment:
Definition of stakes involves inventory and location of stakes through study of documents, enquiries and field observations followed by determination of vulnerability function. The latter may be obtained as a function of potential damages (what requires an economic evaluation). In the present approach the vulnerability is expressed as an attribute to each object identified as an asset (stake). These attributes allow mapping of identified stakes showing vulnerability levels. The step in this approach has been determined by using the vulnerability coding, obtained from the county infrastructure administration, which is based on the land cover and previous study of stakes analysis and the vulnerability of the project sites.

Risk analysis:
As described in the previous sections the flood risk map is obtained by overlaying the hazard map on vulnerability maps and hence the flood risk maps illustrate the spatial distribution of risks. The 2D model main input here is with to the hazard map which is produced from the direct outputs of the model.

Summarising information concerning stakes in a table helps in setting up and updating an operational plan. Vulnerable stakes identified in the project areas include: schools, residential areas, hospitals, commercial centres, administrative buildings, public areas such as sport fields and parking lots, etc.

Vulnerability reduction measures
In the context of urban flood risk this is usually done through both structural and no structural measures allowing planning for sustainable environmental land use and strategies of urban development, basic service upgrading, focusing on integrated, people-centred participatory approaches, stressing mitigation-preparedness techniques.
Development of contingency plans for disaster management and revision/adaptation of policy and legal frameworks is a part of such measures.

![Diagram of TELEMAC-2D database for flood risk assessment](image)

Figure 7.12: TELEMAC-2D database for flood risk assessment

### 7.6.2 Organisation of local disaster management:

The main task in this stage is assisting and supporting the population in the event of evacuation. Key information that should be planned beforehand is:

- Decisions of the areas to be evacuated, the time of evacuation and the means of evacuation based on the evacuation criteria
- Preparation of the temporary refuge for the evacuee in advance
- Involving associations, emergency services (possibly from several communes).
- Developing cooperation and solidarity between flooded and "resource" communes
- Defining needs and possibilities for inter-commune action and logistics for rescue teams

The key information obtained from TELEMAC 2D model for evacuation planning at different various precision levels are:

- Areas to be evacuated and evacuation criteria
- Evacuation refuges sites

**Areas to be evacuated and evacuation criteria:**

The areas to be evacuated during a certain flood event can be delineated using the flood risk map which is by crossing hazard map and the vulnerability. In addition to the flood hazard mapping TELEMAC-2D database provides vital information on flood duration and propagation direction at point which for the deciding and planning evacuation. Information about the various vulnerable stakes, such as type of Structures (buildings), population, routs converging to the flood area, etc. are obtained through vulnerability studies. Therefore, superimposing information, about the flood and the assets (stakes) enables to identify the areas to be evacuated, the timing and the ways of evacuation.
Figure 7.13: Map showing velocity of flood and graph showing evolution of flood depth at a residence building in unidentified site.

On the example presented in Figure 7.14, in an event of 100-years flood, the information required for evacuation planning such as the water depth and velocity of flood with the duration for each level of flooding are produced from TELEMAC-2D. Information regarding the stakes is the type of building, its height, number of users, etc. This should be collected from the stake holders and analysed with the TELEMAC-2D for developing evacuation criteria and the plan such as evacuation routes selection.

**Evacuation refuges planning:**
The flood hazard map produced from the TELEMAC-2D database can be overlaid on base map of the area so that safe and convenient refuges will be identified.
The general information required for evacuation planning is summarised in
Table 7.1.

Figure 7.14: Routes of evacuation during flooding event
Table 7.1: Summary of information for evacuation planning

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
</table>
| Base maps | - Base maps (topographic maps in scales of 1:2,500, 1:10,000 and 1:25,000)  
- General-purpose maps |
| Areas to be evacuated | - Boundaries of jurisdictional districts and blocks, school districts and neighbouring associations' territories |
| Evacuation refuges | - Refuges  
- Public facilities (kindergartens, elementary schools, junior and senior high schools, colleges and universities, civic centres, assembly halls, gymnasiums, etc.) |
| Evacuation criteria | - Evacuation criteria  
- Past evacuation activities (issuance and communication channels of advisory and imperative evacuation warnings, refuges set up, number of refugees accommodated) |
| Number of residents to be evacuated | - Population by district  
- Households by district |
| Dangerous spots on evacuation routes | - Spots with potential steep-slope collapse, mud flows and debris torrents  
- Roads blocked by past inundation  
- Past landslide spots  
- Underpasses  
- Bridges |
| Communication channels | - Communication channels and appliances for use in emergency |
| Underground spaces | - Locations of underground spaces, and emergency communication system to users |
| Facilities for those vulnerable in the event of emergency | - Number of residents to be assisted  
- Facilities for the vulnerable (hospitals, homes for the elderly and handicapped, and other facilities concerned) |
| Bodies and agencies concerned | - Local municipal facilities  
- Prefectural facilities  
- National facilities  
- Fire fighting facilities  
- Police stations and call boxes |
| Disaster prevention facilities and equipment | - Administrative wireless radio stations for disaster prevention, loudspeakers, sirens  
- Disaster prevention centres  
- First-aid stations, information-display facilities on flood damage  
- Water level stations and rain gauge stations |
| Medical facilities | - Emergency hospitals  
- Public health centres  
- Hospitals, doctors' offices and clinics |
| Lifelines | - Water supply and sewerage plants, gas works, power plants and substations  
- Telecommunication facilities (telephone exchange offices) |
| Social welfare facilities | - Homes for the elderly and handicapped |
7.6.3 Urban infrastructure management planning

The urban infrastructure management planning encompasses the planning of managing various urban utilities such as, roads, parking areas, waste collection systems, water supply and electricity, etc.

Traffic management planning:
The vulnerability of the road and street network at the risk of congestion and blocking can be determined by taking account of the geometry of each street and road. Two important data needed for the management planning are:

- traffic direction, convergence of the roads towards the flood zone, existence of an escape root to the flooded sector. This is done using the road network information in the area and by incorporating the flood hazard information from the TELEMAC-2D to assess the locations, durations and extent of blocking of roads due to flooding
- and the traffic flows through the arteries and the junctions in rush hour which is an information to be obtained from the stakeholders or from road network modelling.

The two assets identified and included in the vulnerability map are crossed with appropriate hazard maps in order to detect the locations of high human concentration that are liable to high risks of congestion.

Parking areas:
Parking areas delineated in high flood hazard areas based on the model result should be evacuated in time. This is due to mainly two reasons. The first is for the safety of the vehicles and the second reason it to leave space for the flood so that the vehicles will not be obstacle for the against recession of the flood.

Public health planning:
The probability of an increase in the frequency and intensity of extreme events is the key to advocating preparedness as the chief reaction to the risk of flooding. Early warning of a risk of flooding, and an appropriate response by the population, have been shown to be effective in reducing casualties.

Appropriate planning for floods enables communities to respond effectively to possible threats to health. Local and central authorities can organize and effectively coordinate relief activities, including making the best use of local resources and properly managing national and international relief assistance.

In the aspects of public health, flood hazard maps give information regarding the depth, the velocity and direction of propagation with the duration. This information can be linked to the infrastructures representing strategic importance for public health such as water supply systems and sanitary systems to assess the risk of contaminations. With an available information of the type of a contaminant (amount and loading function) it is possible, through the combination with the velocity field to identify the possible points of pollution of the flood water or drinking water with the contaminant. This obtained information may be utilized for warning purpose.

7.6.4 Flood Protection

The 2D Model outputs give information about inundation and important characteristics of the flood such as water depth and velocity which are valuable for devising flood protection measures. Figure 7.16 gives one application example of utilisation of 2D model output result for urban flood protection work from the model for borough 2 of the anonymous site. It shows a high school that has been identified as with high risk of flooding by the water draining from a road upstream. The model reveals that the flood on the highway has a very high velocity of above 2m/s which can be very distractive and can wash away humans and objects including vehicles on the way. The model also revealed that in
short period of time the water can enter the school compound which is facing the road and it will make a pool in the compound of the school due to the fence wall.

This increases the flooding exposure of the people in the school and creates difficulties for evacuation. Therefore, from the results of 2D model simulation it appears the entry should be changed to a safe, opposite side of the compound or another adequate way out should be installed on a safe side.

![Diagram showing flood protection recommendation based on 2D output](image)

**Figure 7.15: Example of flood protection recommendation based on 2D output**

### 7.7 Conclusions and pilot specific recommendations

Two dimensional hydrodynamic models represent advanced tool for urban flood modelling due to the various benefits assessed and described in the previous sections of this report. Use of an unstructured irregular grid in defining different features and geometry of buildings in urban areas makes it more flexible and precise than the other type of modelling schemes. The 2D model outputs reply the requirements of various aspects of flood management and flood control.

It has also been noted that all the requirements of flood management the 2D models contribute into are also of the main interests of the community safeguard plans. Incorporating the 2D model outputs in such planning of risk management reinforces the effectiveness of the plan. Furthermore it gives a better understanding of the problem so that solutions can be divided in a better way than the traditional methods such as those based on past historical events or using other crude methods. The feedback from the county urban emergency planners expected before the end of the Floodsite project will bring additional insight in this respect.

Based on what has been presented in the results section of the report, it can be concluded that the benefits of 2D hydrodynamic models for urban flood modelling is of a great significance over the other traditional 1D hydraulic models that need many assumptions. Experience shows that one-dimensional (1-D) models that are appropriate for channel flows are difficult to apply for flows in urbanised area in which the numerous obstacles relevant to urban infrastructure modify the flow path.
In flood hazard assessment also, 2D hydrodynamic models are a reliable tools to apply than to simply rely on the past historical benchmarks, as they are no more applicable once there is a change in the environment. However, along with the benefits and its precision, there are some observed gaps still to be filled in through continuous improvements of the modelling techniques.

One of the observed limitations of the modelling is that, the TELEMAC-2D model still has no ground water component and it doesn’t simulate any interaction between the aquifer and flooding for unpaved areas. In the same category of limitations is the fact it has also no module of urban drainage network for coupling the urban drainage and the flood simulations, which could give a better accuracy in estimation of the flood variables. In the framework of current RIVES R&D project (RIVES, 2006) partially funded by French national program related to urban areas, it is envisaged to set up a coupling of models of surface and network, which will allow to obtain a better assessment of flood risk in the urban areas for events with lower return period of occurrence.

The methodology of dealing with building structure in hydrodynamic 2D modelling for urban and suburban area has also some limitations related to the used tools. As it has been observed in the TELEMAC-2D modelling for the two application sites, the buildings have been taken as solid objects; however in reality, above certain level the buildings accommodate certain volume of water or pass out through doors and windows, which never make them to be solid objects. The decision should be based on close sight visits and scrutiny of the type of buildings and their resistance to the flooding.

As the quality of the model result depends on the quality of the input data and the model scheme, the model should always be updated for the future changes in the area, such as construction of a new developments of the city in construction of building, roads and any other development before it will be applied to planning or decision making purpose.

Overall, two dimensional hydrodynamic modelling provide key information that are very useful at the various stages of flood event management planning at a local level and hence it is recommended to be used in preparation of the flood risk management plans by respective planners.

The study carried by SOGREAH under Task 19 allows to formulate the following benefits of any 2D modelling approach, which uses unstructured grid:

- Realistic, geo-referenced - therefore GIS-compatible - description of the topography-bathymetry,
- Accurate representation of the topography-bathymetry: the topography in a 2D model is generally represented by 100 times more nodes than in a 1D model,
- Detailed and accurate description of flow velocities and submersion durations,
- Improved quality of flow representation useful to flow analysis,
- Optimal and realistic outputs, transferable under a GIS (and consequently to any GIS based DSS)
- High quality static and dynamic (animated) outputs facilitating the presentation/understanding of study results.
8. Conclusions and recommendations

8.1 Conclusions on review of existing decision support systems

A review of existing decision support systems (DSSs) in the UK, the Netherlands and France has been carried out. There seems to be limited experience with DSSs for flood event management. Therefore, discussion systems for river design alternatives, warning systems, management systems and flood forecasting tools were considered as well.

It was concluded that all available systems can be treated as more or less ‘generic’, i.e. allowing application for other geographical areas. In most systems some sort of GIS is present to show spatial information on various subjects. Also, most systems contain a database with pre-calculated sets of model output. Only a few systems allow for real time traffic simulation or real time runoff forecasts. Finally, a few systems contain a public part providing information to the public during an emergency.

In general it can be concluded that currently there is little experience with flood event management DSSs. No such system is being used operationally in either the Netherlands, UK nor in France. However, FLIWAS (a joined Dutch – German development) is a flood event communication system under construction.

It turned out from interviews with end users that for flood event management there is a need for a system showing:

- Flood event inundation scenarios;
- Flood alleviation options;
- Flood hazard at vulnerable locations;
- People and objects at risk;
- Safe havens, exit routes;
- Coordination of all event response personnel.

End-users have different responsibilities and their requirements regarding the functionality of a flood event management DSS varies according to their responsibilities and technical capacity. This enhanced by the differences in constitutional arrangements in the different countries.

8.2 Conclusions on flood event management framework and pilot implementations

A methodological framework for flood event management DSSs was developed. It can be concluded that this framework helps structuring and integrating the information in support of flood event decisions. However the end user responses show that this framework has no added value to them.

This research started with the aim of risk-based decision making for flood event management. In the context of flood risk management in general and particularly as defined in the FLOODsite language of risk, risk metrics are defined as a combined measure of probability and consequence. This leads to an average number of euros per year or expected number of affected persons. The three pilot applications showed that these kind of risk numbers are not suitable for evacuation and traffic management. The ‘risk estimates’ as proposed in both FLINTOF and the ESS are more general defined and comprise flood extents, number of casualties, potential building collapse and evacuation times.

The methodological framework was applied in three pilots. The three pilot applications did not cover the whole scope of the this framework, but focused on specific aspects defined by the different end users. Two prototype DSSs, FLINTOF and ESS, were built for the Thames and the Schelde pilot respectively. The DSSs are country-specific, i.e. adjusted to the countries’ models and commonly used methods. The DSSs address different end-users that have different responsibilities and information requirements. Because of this, the DSSs were implemented as different software tools. The ESS
provides assistance on making evacuation plans before the actual flood event, while FLINTOF also provides information on emergency access during a flood. In addition, FLINTOF requires a higher level of technical expertise of the end user, compared to the ESS.

Despite these differences, we found that the resulting prototype DSSs have more in common than expected beforehand. Both systems show risk maps for different flood scenarios and support evacuation planning by showing the effect of management response options to reduce the impact of flooding. This means a combined technical framework for both DSSs might have been successful. Whether different implementations of a DSS for FEM are needed thus depends on the type of natural system more than on the type of end-user.

In the French pilot the input from 2D modelling to the requirements of emergency planning in urban areas was studied. The central part of the framework was applied to show how hazard maps, vulnerability maps and risk maps can be used to plan activities that reduce the impact of flooding. Not only can these be maps be used to plan evacuation routes, but also for related city planning such as safe locations of parking areas and water supply systems, and designation of safe exit points of hospitals and schools.

The products of this research are most relevant for the implementation of the Floods Directive (Directive, 2007). Tools have been provided to plan flood event management (flood risk management in the very short term). By making use of hydrodynamic model results and available data on area vulnerability, the preparation of flood event management plans is supported. Also evacuation routes and best locations for shelters can be derived from this information. Together with evacuation and rescue planning, this will most likely reduce the adverse consequences of floods.

The authors of this research have tried to involve the end users, by paying attention to their requirements and by asking them feed back on the preliminary prototype DSSs and the preliminary results obtained during the research. Their comments and suggestions were included in the final prototype DSSs, of which a guided tour can be found on the enclosed CD ROM.

8.3 Recommendations

The following is recommended regarding the flood event management DSSs:

- The prototypes should be developed further and implemented, using real and complete data, in close cooperation with the end users in order to learn more about their practical applicability;
- A dynamic link with evacuation models should be incorporated, allowing for interactive event planning by the end user;
- DSSs should be used to create real life evacuation plans in the form of a test case. This will show the usefulness of the DSSs and will allow identification of issues for further development.
- A simple exchange should be made possible between the information in the Schelde DSS and FLIWAS, a DSSs under construction that focus on communications and responsibilities in flood event management;
- DSSs for evacuation and rescue planning would have to be secured to ensure privacy of information and would only be available to selected emergency responders’ sites;
- In the future the DSSs might be operated on a real time basis that would allow the water management organisations to update the emergency services of the flood risk as flood forecasting information becomes available, i.e. rather than just forecasting floodwater levels it would be possible to forecast the flood risk and prioritise the response to the flood based on the forecast results. This also allows coupling with dike breach forecasts from a realtime embankment monitoring systems, such as currently being developed by Deltares (www.Deltares.nl);
- Flood event scenario based DSSs offer a unique training environment for both decision-makers and intervention forces.
The following recommendations can be deduced from the work on inundation modelling for flood event management in urban areas:

- Buildings are currently modelled as solid objects, while in reality the water may flow through windows and doors and each of the objects represents a storage capacity, which is disregarded now;
- The effects of interaction with the sewer system and groundwater should be included in the modelling approach.
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