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SUMMARY

The report provides a summary of the work that has been carried out in Task 17 under Theme 2 of the EC research project FLOODsite that focused on evacuation modelling and traffic management related to flood events. When flooding of populated areas occurs or is likely a management system for the road network in and around the flood prone areas is useful to carry out the following:

- Identify the routes for the safe evacuation of people;
- To facilitate the access of the emergency and rescue personnel to the flood prone areas;
- To prevent traffic using roads that have a high probability of becoming inundated.

There were three pilot sites that were utilised in Task 17 as follows:

- The Thames Estuary in the UK;
- The Schelde Estuary in the Netherlands;
- The Gard Region in France.

A review of flood management practice in Europe has been carried out. The conclusions of the review were as follows:

- Most countries within the European Union (EU) make a distinction between the organisations that are responsible for water management and those that are responsible for emergency management;
- Responsible for emergency plans often takes place at a local authority or local government level;
- There is limited experience within the EU of employing systematic approaches and modelling tools to develop evacuation plans for flood event management.

With respect to the user requirements for flood event management the following conclusions have been reached:

- The timing, speed and method of communication of reports are critical to effective emergency management during a flood;
- Robust and integrated communication links between the organisations involved in the response during a flood helps to ensure an effective response;
- Organised evacuation is only used as a form of emergency response in very rare circumstances. In most of Europe the authorities have no powers to forcibly evacuate people from their houses during floods and most evacuation is initiated by individuals or households;
- There is need for tools and methods to assist in the planning of evacuations and to estimate the optimal use of the transport network and the time required for execution of an evacuation.

A review of evacuation models used worldwide for a range of hazards, (including technological hazards such as nuclear accidents), was carried out. There are three main scales at which evacuation models are employed for flood event management as follows:

- **Micro** – This corresponds to a scale where each individual receptor at risk (e.g. person, vehicle or property) is modelled and there is a detailed representation of the evacuation routes;
- **Meso** – This corresponds to a scale that is between a micro and macro-scale. In meso models the receptors are lumped together. The evacuation time is estimated by assessing the demand for and the capacity of the evacuation routes, which are evaluated on a geographical basis;
- **Macro** – In a macro model the receptors are lumped together. The estimates of the evacuation times are based purely on the distance to the exit of the at risk area, the capacity of the route and the average evacuation speed. A macro scale model is often used to provide an initial estimate of the evacuation time for a large area. (e.g. at a regional scale).

The type of evacuation model that is appropriate for a particular flood risk area will depend on the level of risk and the processes which the evacuation modelling is seeking to inform. Densely populated urban area where the scale of potential evacuation is large may require a detailed simulation model where the traffic and flood hazard is modelled in a truly dynamic way.

An understanding of the level of congestion delay that is inevitable under even the most effective traffic management schemes, and also the level of spontaneous evacuation that may occur in advance

of an official evacuation warning are other issues that need addressing. Flood evacuation in most of Europe has been infrequent, and there is little readily available data to accurately calibrate detailed models at present.

In the Thames pilot study two areas were chosen to test evacuation models. The two areas were the Thamesmead embayment and Canvey Island that have populations of 43,000 and 37,000 respectively. Three evacuation models were piloted as follows:

- BC Hydro Loss of life model (LSM) that can model each individual person (i.e. at a micro scale);
- A network based non-linear optimisation model;
- A simple spreadsheet model.

Although time consuming to set up the BC Hydro LSM micro-scale model provides the most useful results. Not only can evacuation times be assessed for a number of emergency management interventions (e.g. road closures, safe havens) but the model also computes the injuries and loss of life for each method. The LSM model is also the only one that has a dynamic interaction between the receptors (e.g. people, vehicles) at risk and the flood hazard. Other meso and macro scale models only generally provided first order of magnitude in terms of the evacuation times. These could be useful at high level planning stage but are unlikely to be useful for detailed emergency planning

A number of evacuation models were applied in the Walcheren and Zuid-Beveland East and West islands in the Schelde Estuary in the Netherlands. The evacuation models that were employed in the area were not very detailed and can only be applied at a macro scale with the exception of the LSM model. ESCAPE and EC both model the flows of total number of inhabitants per postal code zone. The main problem with macro-scale models, like EC and ESCAPE, is that they do not help the decision maker to make plans for one specific part of the area.

In the Gard Region of France work was carried out to develop a prototype flash flood forecasting model to forecast when roads become inundated, because during floods in 2002 a number of motorists were killed when their vehicles were swept away. The work was carried out in three stages:

1. The identification of the road inundation potential based mainly on local geographical information.
2. Developing rainfall-runoff models on the watersheds located upstream the identified points prone to flooding.
3. Combining the flooding potential of roads with the estimated flood discharges, to provide an integrated tool able to forecast in real time the flooding of roads.

The results obtained from the model were promising. The prototype was able to rate the inundation probability in advance with an acceptable level of accuracy: i.e. relatively high hit ratios (proportion of actually flooded points affected by a high risk level between 70% and 100%) with a minimum false alarms, about 50% of the points with a forecast high probability of flooding were not inundated.

In conclusions there has been little work undertaken in Europe, or the rest of the world, related to evacuation modelling and traffic management for flood event management. Previous work carried out in Europe has been generally limited in scope and carried out a macro- and meso- scale. This is the first time a micro-level evacuation model that dynamically links the movement of receptors (e.g. people and vehicles) with the flood wave has been applied to tens of thousands of receptors in a European situation. From the work carried out it would appear that micro-scale models, although more time consuming to set up, provide emergency planners and other end users with more insight into the areas at greatest risk and also provide decision makers with other risk metrics (e.g. number of buildings that have collapsed, loss of life, inundation of escape routes). However, to be effective such models should be applied to the whole area at risk. More work needs to be carried out to make evacuation models more “user friendly” so that they are used more widely.

CONTENTS

Document Information	ii
Document History	ii
Acknowledgement	ii
Disclaimer	ii
Summary	iii
Contents	v

1.	Introduction	1
1.1	Structure of the report	1
1.2	Background to the disaster cycle	2
1.3	Definition of evacuation	4
1.4	Stages in evacuation planning	4
1.5	Pilot sites.....	6
1.5.1	Thames Estuary	6
1.5.2	Schelde Estuary	6
1.5.3	Gard Region	6
1.6	Links with other FLOODsite tasks and projects.....	7
2.	Review of flood event management practice	8
2.1	Introduction	8
2.2	The United Kingdom	8
2.2.1	The legal framework for flood management and emergencies	8
2.2.2	Role of organisations in response to a flood event.....	9
2.2.3	Classification of flood incidents and response standards.....	11
2.2.4	Emergency response.....	14
2.2.5	Management and co-ordination of local operations	14
2.2.6	Evacuation planning.....	18
2.2.7	Evacuation and rescue models currently used in the UK.....	19
2.2.8	Conclusions	19
2.3	The Netherlands.....	19
2.3.1	The legal framework for flood management and emergencies	19
2.3.2	Institutional framework.....	21
2.3.3	Emergency flood management.....	23
2.3.4	Methods and models to support emergency evacuation.....	25
2.3.5	Conclusions	26
2.4	Germany	27
2.4.1	The legal and institutional background	27
2.4.2	Emergency flood management.....	32
2.4.3	Methods and models to support emergency flood management	34
2.5	France	36
2.5.1	The legal framework for flood management and emergencies	36
2.5.2	Emergency response.....	37
2.5.3	Flood preparedness and evacuation.....	37
2.6	Hungary	39
2.6.1	Background to flood management in Hungary	39
2.6.2	The institutional framework for flood management.....	40
2.6.3	Organisation of flood emergencies in Hungary	40
2.6.4	Evacuation and rescue planning.....	41
2.7	Summary for the European Union.....	42
2.7.1	Framework on flood risk management.....	42

2.7.2	Framework on civil protection	43
2.7.3	Institutional framework	44
2.7.4	Emergency flood management	44
2.7.5	The Inspire directive and its implications for flood event management	45
2.8	The cost of evacuation	45
2.9	Conclusions	46
3.	User requirements for evacuation planning	47
3.1	Introduction	47
3.2	Organisation of evacuation planning	47
3.2.1	Introduction	47
3.2.2	Stakeholders	47
3.2.3	Lessons learnt	47
3.2.4	Information requirements	47
3.2.5	User requirements	47
3.3	Designing of an evacuation plan	48
3.3.1	Introduction	48
3.3.2	Stakeholders	48
3.3.3	Lesson learnt	48
3.3.4	Information requirements	48
3.3.5	User requirements	48
3.4	Pre-flood awareness	48
3.4.1	Introduction	48
3.4.2	Lesson learnt	48
3.4.3	User requirements	49
3.5	Flood emergency stage	49
3.5.1	Introduction	49
3.5.2	Lessons learnt	49
3.5.3	Information requirements	49
3.5.4	User requirements	49
3.6	Assessment of evacuation options	50
3.6.1	Introduction	50
3.6.2	Lessons learnt	50
3.6.3	Information requirements	50
3.7	Evacuation	50
3.7.1	Introduction	50
3.7.2	Lessons learnt	50
3.7.3	Information requirements	50
3.7.4	User requirements	50
3.8	Shelter	51
3.8.1	Introduction	51
3.8.2	User requirements -	51
3.9	Return	51
3.9.1	Introduction	51
3.9.2	User requirements	51
3.10	Conclusions relating to user requirements for evacuation	51
4.	Background to evacuation modelling for flood event management	53
4.1	Introduction	53
4.2	Micro, macro and meso scale evacuation modelling	53
4.3	Data requirements for evacuation modelling for flood event management	54
4.4	Review of evacuation models	55
4.5	Conclusions	55
5.	Pilot application for the Thames Estuary, UK	57

5.1	Background to the Thames Estuary pilot site	57
5.1.1	Links with the Thames Estuary 2100 project.....	58
5.2	Thamesmead embayment	58
5.2.1	Canvey Island.....	60
5.3	Data availability for the pilot areas.....	64
5.4	Evacuation and emergency planning modelling for the two pilot areas.....	64
5.5	Micro-scale evacuation and loss of life modelling	64
5.5.1	Introduction to the BC Hydro LSM model	64
5.5.2	Aims of the testing	67
5.5.3	Implementation of the LSM to the Thamesmead embayment	67
5.5.4	Implementation of the LSM to Canvey	74
5.5.5	Modelling of the 1953 flood event.....	74
5.5.6	A method to make a quantitative assessment of the modelled scenarios.....	77
5.5.7	Conclusion.....	79
5.6	A non-linear optimisation-based model for evacuation.....	79
5.6.1	Introduction	79
5.6.2	Setting up the model.....	79
5.6.3	Conclusions and recommendations	82
5.7	Application of simple spreadsheet based approach	83
5.7.1	Background to method	83
5.7.2	Results.....	83
5.7.3	Conclusions	85
5.8	Response of end users.....	85
5.9	Conclusions and recommendations	85
6.	Pilot application for the Schelde, the Netherlands	86
6.1	Introduction	86
6.2	Description of the area, flooding in the area and evacuation possibilities.....	86
6.2.1	Pilot area.....	86
6.2.2	Potential flood patterns	87
6.2.3	Evacuation possibilities and potential shelters.....	89
6.3	Application of the Evacuation calculator	92
6.3.1	Description of the Evacuation Calculator model	92
6.3.2	Approach.....	95
6.3.3	Results of the application of the EC on the Schelde Pilot.....	97
6.3.4	Discussion and conclusions.....	102
6.4	Application of the evacuation module in the ESCAPE DSS.....	103
6.4.1	Description of ESCAPE DSS.....	103
6.4.2	Approach.....	106
6.4.3	Results of the application of ESCAPE on the Schelde pilot.....	108
6.4.4	Conclusions and discussion.....	109
6.5	Application of INDY	109
6.5.1	Introduction	109
6.5.2	Background to INDY	110
6.5.3	Approach.....	111
6.5.4	Results of the application of INDY on the Schelde pilot.....	115
6.5.5	Extensions to basic scenarios using INDY.....	117
6.6	Model comparison	124
6.6.1	Technical comparison	124
6.6.2	Comparison of results	127
6.7	First response of end user group.....	128
6.8	Conclusion and recommendations for the Schelde pilot	128
7.	Pilot application for the Gard Region of France	132
7.1	Introduction	132

7.2	The choice of the Gard pilot area	132
7.3	Description of the PICH inventory	132
7.4	Hydrological data	134
7.5	Geographical data	136
7.6	Evaluation of the road vulnerability	137
7.6.1	Introduction	137
7.6.2	Step 1: identification of the potentially flooded road sections	137
7.6.3	Identification of road flooding vulnerability indicators	138
7.6.4	Conclusions	144
7.6.5	Combination of flood vulnerability indicators	145
7.6.6	Validation and conclusions	146
7.7	Distributed rainfall-runoff simulation	147
7.7.1	Specification of the rainfall - runoff model	147
7.7.2	Model parameterisation	148
7.7.3	Choice of Curve Numbers (CN)	149
7.7.4	Choice of river reach widths	149
7.7.5	Calibration procedure	150
7.7.6	Calibration results	151
7.7.7	Validation of the results	154
7.8	Conclusions	155
7.9	Development of a road inundation forecasting prototype	155
7.9.1	Objectives and evaluation criterions	155
7.9.2	Definition of a submersion risk index	156
7.10	Evaluation of the proposed approach	157
7.10.1	Detection of the hot spots	157
7.10.2	Time sequence of submersion warnings	160
7.11	Use of emergency routing techniques developed by the Orchestra project piloted in the Gard Region	162
7.11.1	Introduction	162
7.12	Background to the internet based routing services developed under Orchestra	165
7.13	Application of the web based routing services to the Gard Region	166
7.14	End user consultation	166
7.14.1	Background	166
7.14.2	User feedback	167
7.15	Conclusions	168
8.	Conclusions and recommendations	169
8.1	Conclusions	169
8.1.1	Introduction	169
8.1.2	User requirements for evacuation planning	169
8.1.3	Evacuation modelling for flood event management	169
8.1.4	Application of evacuation models in the Thames Estuary	170
8.1.5	Application of evacuation models in the Schelde Estuary	170
8.1.6	Development of a prototype flash-flood warning system for roads in the Gard Region	172
8.2	Recommendations	172
9.	References	173
Tables		
Table 2.1	Management activities in the UK	12
Table 2.2	Response activities in the UK	13
Table 5.1	Selected LSM objects	66
Table 5.2	Range of scenarios modelled for Thamesmead showing the code used to denote each model run	70

Table 5.3	Percentage of fatalities within Thamesmead for the modelled scenarios	73
Table 5.4	Percentage of people injured within Thamesmead for the modelled scenarios	74
Table 5.5	Costing weightings to assess different emergency planning options	77
Table 5.6	Costing weightings to assess different emergency planning options	77
Table 5.7	Summary of results of the evacuation time based on a simple spreadsheet model	83
Table 6.1	Overview of the exits and their capacity	95
Table 6.2	Description of evacuation categories and their car occupation	96
Table 6.3	Distribution of inhabitants over the different evacuation categories	96
Table 6.4	Summary of all assumptions used in the application of the Evacuation Calculator on the Schelde pilot	97
Table 6.5	Resulting evacuation times for evacuation of the whole area for different sets of assumptions	99
Table 6.6	Evacuation time of Walcheren compared with the evacuation time of the whole pilot area	101
Table 6.7	Evacuation times for use with ESCAPE	106
Table 6.8	Simulations carried out with ESCAPE	107
Table 6.9	The calculated evacuation times for each combination of the parameters in ESCAPE	108
Table 6.10	Overview of the exits links and their capacity	112
Table 6.11	INDY evacuation times for the 12 basic scenarios	116
Table 6.12	Scenarios compared by the assignment used.	116
Table 6.13	Scenarios compared on the exits used.	117
Table 6.14	Comparison of evacuation times using linear and S-curve departure profiles	118
Table 6.15	Outcomes of INDY with the addition of the tunnel	120
Table 6.16	Outcomes of INDY with the shortest path	120
Table 6.17	Overview of shelter capacity	122
Table 6.18	Resulting evacuation times - simulations with and without the shelters	123
Table 6.19	Comparison of evacuation times – Evacuation of whole area and critical area	124
Table 6.20	Comparison of Evacuation Calculator with ESCAPE	125
Table 6.21	Comparison of the outcomes of the three models	127
Table 7.1	Results of the initial analysis	138
Table 7.2	Sorting efficiency based on the altitude indicator value	141
Table 7.3	The sorting efficiency based on the slope indicator value.	142
Table 7.4	Sorting efficiency based on the area indicator value	143
Table 7.5	Sorting efficiency based on the discharge indicator value	144
Table 7.6	Sorting efficiency based on the proposed indicator combination	145
Table 7.7	Validation results of the flooding potential index computation method – method 1, combination of geographical indicators and method 2, index based on a discharge ratio	146
Table 7.8	Sets of widths based on the Stralher orders and the flood magnitude.	150
Table 7.9	Results of the rainfall - runoff model adjustment	152
Table 7.10	Results of the rainfall – runoff model validation	154
Table 7.11	Verification of the Crupedix and 1 in 2 year return period discharge estimation formula on gauged catchments of the Gard region.	157
Table 7.12	Probability of flooding with or without the hazard information	157
Table 7.13	Synthesis of results obtained for the 21 November 2003 storm on for the test areas	159
Table 7.14	Results for the 6 September 2005 storm	159

Figures

Figure 1.1	The disaster risk management cycle	3
Figure 1.2	The stages of evacuation related to the preparation and response phases of the disaster risk management cycle	4
Figure 2.1	Setting up an inner cordon for incident control	17
Figure 2.2	Setting up an outer cordon for incident control	17
Figure 2.3	System of primary water defences and dike rings in the Netherlands	20
Figure 2.4	Administrative and operational responsibilities in a flood emergency in the Netherlands	23

Figure 2.5	Example of a map of the Dike ring 43 in the Netherlands inundated area after 24 hours	26
Figure 2.6	Acts and orders for disaster protection in Germany relevant to emergency flood management.	29
Figure 2.7	Organisational chart for emergency flood management in Saxony	31
Figure 2.8	Organisational chart of emergency flood management in North Rhine-Westphalia	31
Figure 2.9	Conceptual framework of the DISMA system	35
Figure 2.10	Extracts of the Aude departmental document in France on major risks	39
Figure 4.1	Micro, meso and macro scale evacuation model with the suggested scale of their application	54
Figure 5.1	The locations of Thamesmead and Canvey Island within the Thames Estuary	58
Figure 5.2	Satellite image of Thamesmead	59
Figure 5.3	Age distribution for Thamesmead	59
Figure 5.4	New development in Thamesmead	60
Figure 5.5	Satellite image of Canvey Island	61
Figure 5.6	Canvey island during the 1953 flood	61
Figure 5.7	Age distribution for Canvey Island	62
Figure 5.8	Flood defences in the north of Canvey Island	63
Figure 5.9	New single storey housing on Canvey Island	63
Figure 5.10	High-level architecture of the Life Safety Model	65
Figure 5.11	The object damage and loss concept in the Life Safety Model	66
Figure 5.12	Inundation modelling for Thamesmead based on TUFLOW modelling	68
Figure 5.13	Process by which the UK census and property data was converted to be compatible with the LSM	69
Figure 5.14	Typical results people at risk units for a Thamesmead inundation simulation	71
Figure 5.15	Status of vehicles for a typical Thamesmead inundation simulation	71
Figure 5.16	The effects of road closures on people in the Thamesmead embayment	72
Figure 5.17	The effects of the number of safe havens on the percentage of people reaching safety after a breach has occurred	72
Figure 5.18	The effects of the number of safe havens on the status of people	73
Figure 5.19	Typical results for Canvey Island with two safe havens in place	75
Figure 5.20	Comparison of the number of properties on Canvey Island in 1953 and 2001	76
Figure 5.21	Results of the loss of life model for the 1953 flood for Canvey Island	77
Figure 5.22	Assessment of six emergency planning options using a scenario utility	78
Figure 5.23	Assessment of 60 emergency planning options using a scenario utility	78
Figure 5.24	Greenshields' linear speed – concentration relationship	80
Figure 5.25	Representation of the Thamesmead road network in the model	81
Figure 5.26	The six different locations of safe havens that were tested	82
Figure 5.27	Thamesmead road network used for the spreadsheet macro-model	84
Figure 5.28	Canvey Island road network used for the spreadsheet macro-model	84
Figure 6.1	The Schelde pilot area	87
Figure 6.2	Water depths resulting from breaches at the locations indicated with the red dots for in 1 in 4,000 year sea level conditions	88
Figure 6.3	Areas where water rises quickly if breaches occur at the locations shown in Figure 6.2	89
Figure 6.4	Pilot area divided into 'hazard zones'	90
Figure 6.5	A map of tall buildings and higher areas in the pilot area	92
Figure 6.6	Example of an area with a population density that is evacuated according to the three management options in EC	94
Figure 6.7	The evacuation process as schematised in the Evacuation Calculator	94
Figure 6.8	The exit locations as used in the Evacuation Calculator	96
Figure 6.9	Departure profile 1: the fraction of persons that has left home as a function of the time in hours	97
Figure 6.10	Cumulative curves of arrival (red line) and outflow (green line) as a function of time	100
Figure 6.11	The extent of the polders threatened by floods from the Westerschelde and the extent of the postal code areas in which this threatened area is situated	101
Figure 6.12	Modular setup of ESCAPE	104

Figure 6.13	Diagram of the evacuation area	105
Figure 6.14	Map of study area used in ESCAPE	107
Figure 6.15	Bottleneck effects at an initial time step	110
Figure 6.16	Bottleneck effects at a later time step	110
Figure 6.17	The exit points as used in the application INDY	112
Figure 6.18	The reference assignment using all the exit points.	113
Figure 6.19	The nearest assignment using all the exit points	114
Figure 6.20	Optimised assignment using all the exits points	114
Figure 6.21	S-curved departure profile over eight hours	115
Figure 6.22	Congestion appears everywhere when only using the eastern exits	117
Figure 6.23	Linear (red) and S-curved (blue) departure profile over 16 hours	118
Figure 6.24	Entrance Westerschelde tunnel at Terneuzen	119
Figure 6.25	OmniTrans network with the Westerschelde tunnel (optimised assignment)	120
Figure 6.26	Traffic flows after 15 hours of evacuation	121
Figure 6.27	Traffic flows after 15 hours of evacuation with only the shortest route used	122
Figure 6.28	Possible flood scenario	123
Figure 7.1	The Gard Region, the four calibration and the three validation areas and the location of the road flooding based on the PICH database	133
Figure 7.2	Number of flood events in the PICH database during the last 40 years for the calibration and verification areas	134
Figure 7.3	Gauged river basins in the Gard Region showing the location of the calibration areas	135
Figure 7.4	The three types of inundation mechanisms and their identification based on geographical data: intersections, low road sections and bordering road section	138
Figure 7.5	Result of the extraction of the sections of the road network sensitive to flooding on the four calibration areas	139
Figure 7.6	Theoretical densities of an indicator value for the PICH and non PICH set and separation efficiency based on a threshold (0.2 in this case)	139
Figure 7.7	Density and distribution functions of the normalised altitudes for the PICH and Non PICH sets in the four calibration areas.	140
Figure 7.8	Density and distribution functions of the normalised slope for the PICH and Non PICH sets in the four calibration areas	141
Figure 7.9	Density and distribution functions of the normalised catchment area for the PICH and non PICH sets in the four calibration areas	142
Figure 7.10	Density and distribution functions of the normalised discharge ratio for the PICH and non PICH sets in the four calibration areas	144
Figure 7.11	Distribution functions of the combined index value for the two tested connectors (left) and of the normalised discharge ratio (right) for the PICH and Non PICH sets in the four calibration areas	145
Figure 7.12	Distribution function of the inundation return period of the PICH road sections in the Red, Orange and Yellow classes	147
Figure 7.13	Representation of a catchment in the CINECAR model	148
Figure 7.14	A theoretical example of Strahler ordering of a river network	150
Figure 7.15	Conquerac, 08/09/02, Nash [0.65,0.77]	153
Figure 7.16	La Rouvière, 21/11/03, Nash [0.49,0.51]	153
Figure 7.17	St-Jean, 21/11/03, Nash [-0.52,-2.32]	153
Figure 7.18	Generargues, 21/11/03, Nash [0.31,0.32]	153
Figure 7.19	St-Jean, 21/11/03, Nash [-0.62,-0.30]	153
Figure 7.20	Corbes, 17/10/01, Nash [0.29,-0.30]	153
Figure 7.21	Comparison between the simulated (global CN) and measured hydrographs. Anduze, 30/09/03, Nash [0.70,0.56]	154
Figure 7.22	Comparison between the simulated (global CN) and measured hydrographs. Mialet, 08/09/02, Nash [0.83,0.51]	154
Figure 7.23	Comparison between the simulated (global CN) and measured hydrographs. Mialet, 21/11/03, Nash [-3.61,-6.27]	155

Figure 7.24	Distribution of the return period of flooding with and without the definition of vulnerability classes	156
Figure 7.25	Cumulative rainfall over the Gard Region on 21 November 2003 in millimetres and location of the test areas	158
Figure 7.26	Warnings for Area 4 for the 21 November storm (low and high hydrological modelling hypotheses)	158
Figure 7.27	Total cumulative rainfall accumulation over the Gard region on 6 September 2005 and location of the testing areas	160
Figure 7.28	Warnings for Area 1 for the storm on 6 September 2005 (low and high hypothesis)	160
Figure 7.29	The first phase of the September 2005 flood	161
Figure 7.30	Second phase of the September 2005 flood	163
Figure 7.31	Third phase of the September 2005 flood	164
Figure 7.32	Example of the Orchestra project web based system for risk assessment for road networks on the French – Italian border	165
Figure 7.33	Application of the Orchestra web based application to the Gard Region of France	166

1. Introduction

1.1 Structure of the report

This report was produced as part of the Innovative and sustainable management theme, (Theme 2) of the EC research project FLOODsite. This report focuses on sub-theme 2.2 that deals with flood event management. The objective of sub-theme 2.2 is *“to improve flood risk mitigation that are applied during the flood event, through improved technology for flood warning in small flash flood catchment and through national schemes for emergency evacuation”* (FLOODsite, 2004).

The report provides a summary of the work that has been carried out as part of Task 17 under Theme 2 that focused on evacuation modelling and traffic management related to flood events. When flooding of populated areas occurs or severe flooding is likely a management system for the road network in and around the flood prone areas is useful to carry out the following:

- Identify the routes for the safe evacuation of inhabitants that may be required or may spontaneously occur;
- To facilitate the access of the emergency and rescue personnel to the flood prone areas;
- To prevent traffic using roads that have a high probability of becoming inundated.

To develop emergency management plans, information is needed on the characteristics of floods, the infrastructure, the capacity of the infrastructure and the vulnerability of the people at risk. In recent years the awareness of the need for tools that facilitate evacuation, crisis and rescue planning has increased.

Task 17 aims at the development of generic methods and tools for identifying appropriate evacuation and rescue plans in different river systems (i.e. low land rivers and upstream flash flood rivers). In the case of low land river floods the work has mainly focused on the problems evacuating people from areas at risk, whilst in the flash flood areas evacuation is not a solution and the main problem is the control of the traffic on the road network and the identification of safe routes for the rescue squads to reach the flooded areas.

The report has been structured as follows:

Chapter 1	This provides the background to the disaster risk management cycle and an introduction to the evacuation process. It also details the links that have been made to other Tasks within FLOODsite and other relevant projects;
Chapter 2	This reviews operational flood management including the legal and institutional frameworks, evacuation and rescue methods and models and the emergency flood management procedures in a number of European countries;
Chapter 3	This outlines the user requirements for evacuation planning for the various stages of the evacuation process;
Chapter 4	This provides background to evacuation modelling for flood event management;
Chapter 5	This details the application of evacuation and loss of life models for two densely populated areas in the Thames Estuary, UK;
Chapter 6	This chapter details the application of three evacuation models to part of Zeeland in the Netherlands;
Chapter 7	This describes the development of a flash flood modelling tool to assess and forecast the vulnerability of roads in the Gard Region of France to flash flooding;
Chapter 8	This provides overall conclusions and recommendations;
Chapter 9	This chapter details the references used to compile this report.

1.2 Background to the disaster cycle

The management of natural risks is a public task for which governments at all levels hold a certain amount of responsibility. The management of risk involves a wide range of actions and activities that fall within one of the following four activities:

- Prevention and mitigation;
- Preparation;
- Response;
- Recovery.

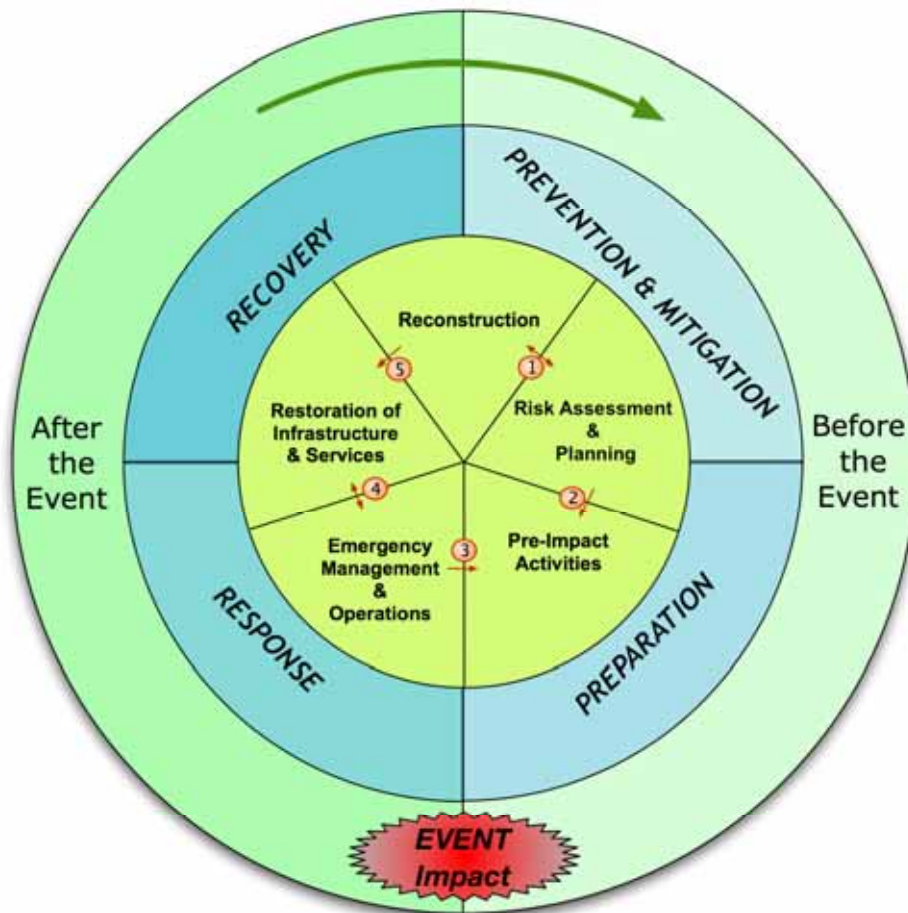
Evacuation management is an activity that forms part of the response to a flood emergency. As such it is one of the many options decision makers have available for dealing with floods. Other possible options could be the construction of structural measures such as emergency barriers or flood storage areas and non-structural measures such as the implementation of flood forecasting schemes. Figure 1.1 shows how emergency management fits into the disaster cycle (Atkinson et al, 2006).

The cycle depicted in Figure 1.1 shows the breakdown of the general disaster management phases i.e. Prevention and mitigation, Preparation, Response and Recovery, into more concrete activities, including Reconstruction, Risk Assessment and Planning. Figure 1.1 shows the interaction between these activities. Access to valid knowledge from different information sources is necessary to accomplish the activities in a timely fashion with a high level of quality in the results. Another complication not depicted in the diagram is the interaction between different stakeholders and decision makers on different administrative levels and territorial boundaries (Atkinson et al, 2006).

For each of the main phases the following general types of information relation to disaster risk management:

- **Prevention and mitigation:** Different organisations will follow different methodologies to analyse and produce results on different scales for hazards, vulnerabilities and risks. In many cases hazard and risk maps are produced that can be used to aid planning. In this phase emergency plans will be produced.
- **Preparation:** From the analysis carried out in the previous phase, emergency plans will be validated. When an alarm is activated, emergency scenarios could be simulated to determine how best to minimise the impact of the event, this could include the need to use forecasting models. Additionally, pre-emergency plans might be used to communicate to the affected stakeholders, and alert the appropriate decision makers.
- **Response:** Spatial information accessible through information services allows more timely interventions of teams and more efficient management of the operation on site. Additionally, non-spatial information like procedures, emergency plans and authorisation modules can be quickly accessed and communicated. Further, information on critical infrastructures and services damaged by the event will be needed to prioritise actions needed to protect the affected area. Finally, efficient and reliable communication channels will be necessary to assure the transportation of this information between the appropriate decision makers and other emergency management actors.
- **Recovery:** Information on damaged infrastructure and services will be needed as well as the location of the population at risk, in order to prioritise actions. This stage often focuses on reconstruction.

(Source: Atkinson et al, 2006)



- Note:
- ① Reconstruction (i.e. Land Use Planning) can be influenced by Risk Assessment & vice versa.
 - ② Pre-Impact scenario analysis is often conducted based on previously constructed emergency planning scenarios.
 - ③ Lessons Learned from Emergency Experience feeds back into pre-impact planning as well as perhaps exploiting existing communication strategies.
 - ④ Emergency Management can prioritize the restoration of services during the response. Service restoration can support the management of the current emergency situation.
 - ⑤ After temporary restoration of the most relevant services, reconstruction might be necessary to guarantee a better quality of the service or to recover all non functional services.

(Source: Atkinson et al, 2006)

Figure 1.1 The disaster risk management cycle

The response of authorities towards emergencies is often cyclical. This means that this year's disasters are next year's preparation. Organisations like governments and civil protection authorities expand their experience and knowledge about their activities each time a disaster occurs. In this way the organisations learn from previous experiences in disasters and strive towards improving their knowledge and skills in order to be better prepared for the next disaster. It is therefore important that the documentation of these lesson learnt plays a large role in defining user requirements.

1.3 Definition of evacuation

Evacuation is a response to the immediate or forecast threat of flooding that is expected to pose a risk to life, health or well-being. It involves people moving from their houses or places of business to 'safe' locations, out of the flood risk area where they are able to shelter until it is possible and appropriate for them to return. Figure 1.2 shows how the eight main stages in evacuation planning and how they are related to the preparation and response phases of the disaster risk management cycle.

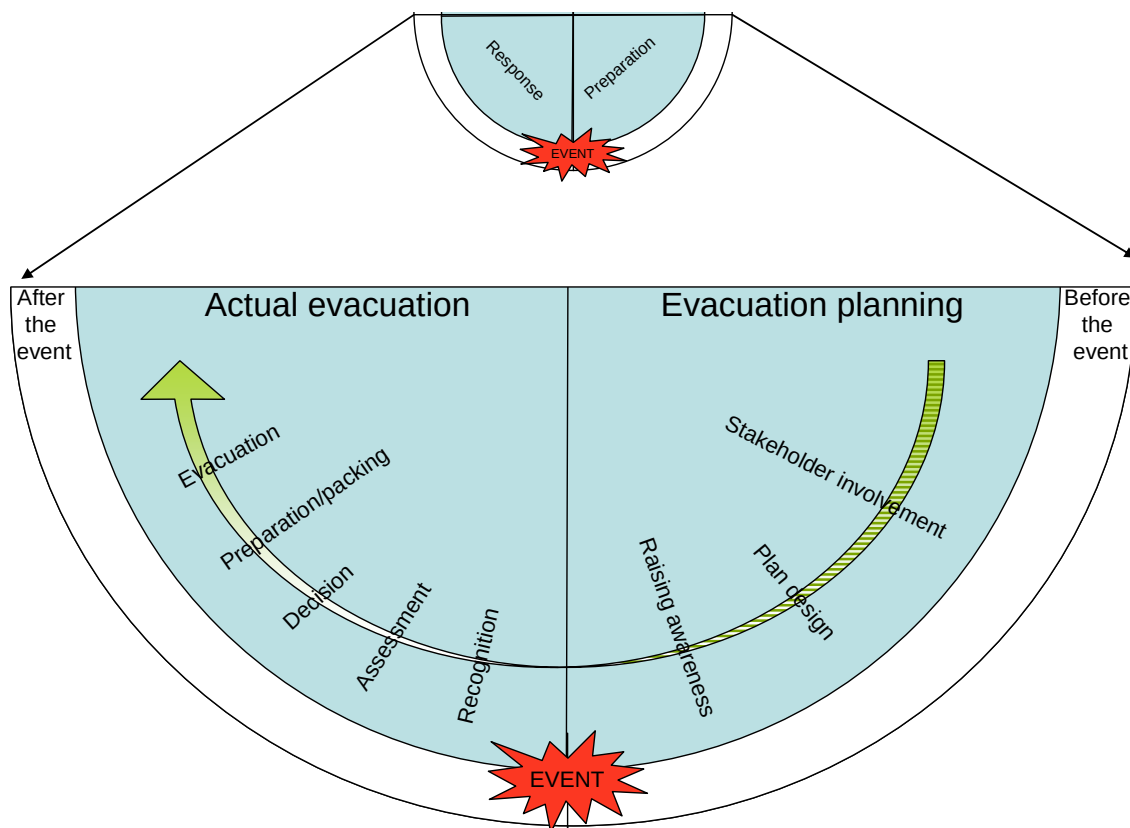


Figure 1.2 The stages of evacuation related to the preparation and response phases of the disaster risk management cycle

1.4 Stages in evacuation planning

In evacuation planning eight main stages can be identified. These are detailed below.

1. Stakeholder involvement

Before the actual start of the planning takes place it is important to recognise who should be involved in the planning process. Research has demonstrated a huge added value of involving appropriate stakeholders since they bring with them an amount of experience and knowledge that might be useful for planning an organisation (Atkinson et al, 2006).

2. Design of the plan

In this stage the actual emergency plan is designed and exercises carried out. The previous stage should have provided a clear idea of the responsibilities of different actors in the process.

3. Pre-flood preparedness

This will determine the level of flood awareness and is likely to influence whether people receive official (or unofficial) warnings and how they act on them. People who have had previous experience of flooding may extend or reduce the time between warning and evacuation, depending on the level of the previous flood and their understanding of the warning codes (Atkinson et al, 2006).

4. Flood emergency stage

a) Recognition of critical situation

The physical parameters of the flood define the emergency, and the official recognition of an emergency defines the response. The depth of water and velocity of the flow are just two of the factors upon which a decision about the seriousness of a flood and evacuation may be made, whether by an official or by the individual householder.

b) Assessment of evacuation options

Given a certain flood forecast and the estimation of the likely flood extent the availability of the various escape routes can be assessed. On this basis an assessment of evacuation options will be carried out. The results of this assessment form the basis for the decision to evacuate and for any of the actions to be taken in the rest of the process.

c) Decision to act upon critical situation

The development of the source of risk (e.g. floodwater depths and velocities) needs to be monitored. After recognising a critical situation and its potential development over time, the decision is taken to evacuate.

5. Evacuation (leaving home)

Whether or not people evacuate in a structured manner (i.e. on recommended routes, using recommended transport modes, to recommended shelter zone) will depend on whether an official evacuation recommendation is given, and how much guidance is provided to assist evacuees in their decision-making.

6. Emergency shelter

The official response at the scene will direct those affected towards the official rest centres or reception centres that have been set up by teams coordinating response. Clearly this necessitates good liaison and communication between all those involved, but in particular between the official responders and those coordinating that response across different local authority departments. For some, emergency response terminates when householders reach the rest centre, whereas for many the disaster may only just have become apparent at this stage. Communication and coordination between those involved in the response and the public is paramount at the rest centre (Atkinson et al, 2006).

7. The return

There may need to be temporary accommodation between emergency and return. A coordinated re-entry process is paramount, with appropriate social and technical support.

8. Debriefing

At the end of an evacuation it is necessary for the stakeholders to evaluate the result of the evacuation and their respective contributions to it. This is regarded as extremely important since it allows organisations to improve themselves and their actions.

These in relation to the end user requirements are further discussed in Chapter 3.

1.5 Pilot sites

There were three pilot sites that were utilised in Task 17 as follows:

- The Thames Estuary in the UK;
- The Schelde Estuary in the Netherlands;
- The Gard Region of France.

These are briefly described below. Chapters 5, 6 and 7 detail the inundation and evacuation modelling that has been carried out for each of these pilot sites.

1.5.1 Thames Estuary

The Thames Estuary is the large estuary where the River Thames flows into the North Sea. The estuary is one of the largest inlets on the coast of the UK. Saltmarshes and mudflats dominate the area, although much of the length has man-made embankments where the land behind is now cultivated or used for grazing. The inner Thames Estuary, now named Thames Gateway, on both banks of the river, has been designated as one of the principal development areas in Southern England by the Office of the Deputy Prime Minister, and much development is planned for this area (ABI, 2006). Two specific areas of interest have been researched with regards to evacuation and loss of life modelling. These are the Thamesmead embayment located just downstream of the Thames Barrier and Canvey Island that is located in the mouth of the estuary. One of the objectives of such an approach was to identify the usefulness of the output of such models to emergency planners for use in the planning stage of evacuation planning. This work is discussed in detail in Chapter 5.

1.5.2 Schelde Estuary

The Schelde pilot site is located near the south-western border of the Netherlands and Belgium and covers the tidally influenced part of the Schelde River. The Dutch part of the river is called 'Westerschelde' and is a typical estuary with multiple river branches and inter-tidal mud flats. The areas of interest in which evacuation models have been applied within the Schelde pilot are all within the province of Zeeland and comprise the following areas:

- Walcheren;
- Zuid-Beveland West;
- Zuid-Beveland East.

Walcheren is piece of land that used to be an island. However, polders and a dam across the Sloe strait now connected it to the (former) island of Zuid-Beveland, which in turn has been connected to the North Brabant mainland. Walcheren lies between the Oosterschelde in the north and the Westerschelde in the south and is roughly the shape of a rhombus. Zuid-Beveland is also a piece of land that used to be an island. It is now a peninsula, crossed by the Canal through Zuid-Beveland on the west and the Schelde-Rhine Canal to the east. Evacuation models have been applied to these areas to assist emergency planners in Zeeland to improving their planning of evacuations. This work is detailed in Chapter 6.

1.5.3 Gard Region

The Gard River is in southern France. The Gard is 133 km long including its longest tributary "Gardon de Saint-Jean". It rises in the Cévennes and discharges into the Rhône River. In September 2002 and again in December 2003, the Gard had record level floods that damaged many of its bridges including the Pont Saint-Nicolas. In the 2002 floods 24 people were killed and the economic damage was estimated at €1.2 billion. Many of the people that were killed were in cars that were swept away (Gaume and Bouvier, 2004). As part of the work that is being carried out in the Gard Region a prototype forecasting system to assess when roads will be inundated has been produced. This model

can be used in the preparedness, assessment and decision making stages of the evacuation process. The development of the prototype model is detailed in Chapter 7.

1.6 Links with other FLOODsite tasks and projects

There has been a strong link with a number of FLOODsite Tasks including:

- Task 1 Identification of flash flood hazards;
- Task 14 Designing and ex-ante evaluation of innovative strategies;
- Task 16 Real-time guidance for flash-flood risk management;
- Task 19 Framework for flood event management planning;
- Task 23 Flash flood basins – monitoring and validation;
- Task 24 Pilot study of the River Thames Estuary;
- Task 25 Pilot study of the Scheldt Estuary.

Links were also made with Task 10 of the FLOODsite project that focuses on socio-economic evaluation and modelling methodologies. Unfortunately the methodologies developed under Task 10 were not available in time to use in Task 17. Other key links have been made with the following projects:

- Thames Estuary 2100 project, UK;
- ORCHESTRA. This is an EC FP6 project. The overall aim of the project is to design and implement an open service oriented software architecture that will improve the interoperability among actors involved in multi-risk management.

2. Review of flood event management practice

2.1 Introduction

This chapter provides a review of flood event management in a number of countries in Europe including:

- The UK;
- The Netherlands;
- Germany;
- France;
- Hungary;
- General overview of Europe.

This review covers the legal framework and institutional set ups in these countries and their experience with operational flood management. This chapter focuses particularly on the management of flood emergencies, and evacuation and rescue methods and models.

2.2 The United Kingdom

2.2.1 The legal framework for flood management and emergencies

Background

The main piece of legislation covering emergency management in the UK is the Civil Contingencies Act. This legislation and accompanying non-statutory measures give a single framework for civil protection in the UK. This objective of the Civil Contingencies Act is to improve the UK's ability to deal with the consequences of major disruptive incidents by improving the planning process at a local level, building better contacts between agencies and improving the link between local areas and central government.

Civil Contingencies Act (CCA)

The Civil Contingencies Act (CCA) and accompanying non-legislative measures and Regulations deliver a single integrated framework for civil protection. The Act applies to the whole of the UK, including devolved administrations and came into force in 2004. "Emergency" is defined under the Act as "*an event or situation which threatens serious damage to human welfare in a place in the UK, the environment of a place in the UK, or war or terrorism which threatens serious damage to the security of the UK*" (HM Government, 2005a). Part 1 of the Act establishes a new statutory framework for civil protection at the local level. Part 2 repeals existing emergency powers legislation and allows the development of special temporary legislation aimed at providing the powers required to deal with a serious emergency" (HM Government, 2005a).

The Act provides a basic framework defining what tasks should be performed during an emergency, and how co-operation should be conducted. Working to a common framework, local responders are required to make their own decisions in the light of local circumstances and priorities about what planning arrangements are appropriate in their area. The CCA recommends an Integrated Emergency Management (IEM) procedure that comprises six related activities:

- Anticipation;
- Assessment;
- Prevention;
- Preparation;
- Response;
- Recovery.

(HM Government, 2005b).

Responders are categorised into two categories. Category 1 (core) responders are those organisations at the core of emergency response:

- Emergency Services (police, fire, ambulance, maritime and coastguard agency);
- Local authorities (all principal, port health authorities);
- Health bodies;
- Government agencies (Environment Agency, Scottish Environment Protection Agency (SEPA)).

Category 1 responders are subject to the full set of civil protection duties, as follows:

1. Risk assessment;
2. Business continuity management (BCM);
3. Emergency planning; and
4. Maintaining public awareness and arrangements to warn, inform and advise the public.

A fifth duty applies to local authorities alone:

5. Provision of advice and assistance to the commercial sector and voluntary organisations.

Category 2 responders are “co-operating” bodies who, while less likely to be involved in the heart of planning work, will be heavily involved in incidents that affect their sector. They include:

- Utilities (electricity, gas, water, sewerage, telephone);
- Transport (rail, underground, airport, harbour, highways);
- Strategic health authorities;
- Government agencies (e.g. Health and Safety Executive).

Two duties that are prescribed for all responders include:

- 1 Co-operation; and
- 2 Information sharing.

(HM Government, 2005b).

2.2.2 Role of organisations in response to a flood event

This section details the role of the various organisations in flood event management. These fall under the following headings:

- Category 1 responders;
- Category 2 responders;
- Others.

Details of the Category 1 responders responsibilities are given below.

Environment Agency

The Environment Agency is the lead agency in England and Wales for warning those at risk and maintaining and improving flood defences. The Environment Agency’s powers are mainly permissive. They maintain a flood warning system, but have not previously had a statutory duty to warn the public. The Act places a general duty on the Environment Agency to maintain arrangements to warn the public and provide advice and information about flooding. However, that duty to warn does not solely apply to the Environment Agency. When a potential flood impinges on the functions

of another Category 1 responder, then it too has a duty to warn. The Environment Agency provides warnings as much to other responders, who must take decisions on, for example, evacuation, as it does to the public. Category 1 responders will generally identify and agree that the Environment Agency should be the lead responder for warning, informing and advising the public.

During a flood incident, the Environment Agency is committed to undertaking the following actions:

- Issue timely flood warnings to those at risk and to operational organisations in accordance with the Environment Agency's customer charter, by constant monitoring of weather, catchment and coastal conditions, prediction of future river and sea levels, preparation of warnings for locations at which forecast or actual levels might result in flooding and dissemination of warnings;
- Work in co-operation with professional partners to ensure a seamless and integrated response to flood incidents, including advising the police on the need to declare a major civil emergency and providing representatives to the various emergency control points;
- Manage its reputation by proactive and reactive actions to protect and enhance the Agency's reputation during a flood incident;
- Collect and record data during a flood incident in accordance with the National Flood Data Collection Manual e.g. flood levels, flows and extent; number and depth of property flooding;
- Monitor and inspect the flood defence system against design standards of defence and, at undefended flood-prone communities to report on incidents of actual or likely failure and so enable emergency action to be assessed and undertake;
- Undertake a reactive response to minimise the risk of failure of flood defence assets, remedial action upon failure of flood defence assets and mitigation measures to limit the extent and damage of flooding during an incident;
- Erect/install temporary defences to limit the extent and damage of flooding to an undefended community or individual property;
- By local agreement, once it has ensured that its own systems and defences are secure, support the police, local authorities and reservoir undertakers via the multi-agency command and control structure to the extent that their resources (materials, equipment, manpower) and other duties permit;
- Participate in flood incident contingency planning at Local Resilience Forum and lead/support the flood-related subgroups.

(Environment Agency 2005b, HM Government 2005a, 2005b)

Local Authorities

Local Authorities play a critical role in civil protection. Local authorities maintain a small hub of planners who co-ordinate and facilitate emergency planning and response work across the authority. They have key statutory responsibilities for environmental health, housing, social services and highways and exercise a community leadership role. Local Authorities work with the police, fire and rescue services and the Environment Agency to co-ordinate the response during severe flooding.

(Environment Agency 2005b, HM Government 2005a, 2005b)

Police forces

Police forces co-ordinate response to most land emergencies, including flooding. In particular, they will co-ordinate the activities of responders at and around scene of a land-based sudden-impact emergency.

Fire and rescue authorities

Fire and rescue authorities co-ordinate search and rescue activities. Their responsibilities include:

- Working with the police and others to plan for flood emergencies;

- The rescue of people trapped by floods;
- Pumping out of flood affected properties;
- Allocation of duties and training of staff;
- Identification and allocation of resources including boats and other rescue equipment.

Category 2 responders

The private sector is a crucial player in the response and recovery processes and must work closely with emergency services and local authorities to deliver timely restoration of essential services and to minimise the wider impact of the flood on the community. There are sector-specific emergency planning arrangements in each of the following sectors to build resilience and put in place effective response frameworks.

Other co-operating bodies

Other significant cooperating bodies in flood response include:

- Regional Resilience Teams and the National Assembly for Wales;
- Armed forces;
- The Meteorological Office and/or regional weather centres;
- Media;
- Voluntary sector;
- Local community

2.2.3 *Classification of flood incidents and response standards*

Classification of flood incidents

In England and Wales the Environment Agency classifies flood events into four categories as follows:

1. Category 1 flood incident

This is a flood event that results in:

- Death or serious injury caused by flooding and/or
- “High Impact flooding” i.e. more than 100 properties and/or nationally significant infrastructure, such as a motorway or mainline railway.

2 Category 2 flood incident

This is a flood event that results in:

- “Low Impact flooding” i.e. property flooding affecting less than 100 properties and/or
- Flooding of locally significant infrastructure, such as main roads and the local rail network.

3 Category 3 flood incident

This is where there is flooding of minor roads or land used for agricultural, recreational or domestic purposes (including gardens).

4 Category 4 flood incident

A Category 4 “flood incident” is one where no flooding occurred.

Flood incident response standards adopted in 2006

The incident response standards adopted by the Environment Agency for the year 2005/2006 are detailed in Tables 2.1 and 2.2. These tables help to inform the requirements of flood incident managers in England and Wales.

Table 2.1 Management activities in the UK

Adopted incident response standard	Consequences of adopting standard
Incident management activities Incident Rooms established and resourced effectively for short duration (three days or less) events. Standby rotas, shift working and welfare arrangements established for short duration events. Production of situation reports (SITREPS)	Compliant with incident management policy and service maintained at current levels. Moderate increase in flood risk due to lack of resources for prolonged events leading to danger to the public and the built environment. Low risk of lower priority incidents escalating in priority with much greater environmental impact. Failure to ensure sufficient resources to deal with prolonged flood incidents leading to moderate stress levels amongst Agency staff. Fair relations with Local Authorities and Emergency Services. Limited negative publicity in media. Sufficient information or evidence to take action.
Issue timely flood warnings Issue timely flood warnings for potential Category 1, 2 and 3 flood incidents. No flood warnings for Category 4 flood incidents.	Low risk of danger to the public and the built environment due to lack of warnings at lower priority incidents. Low risk of lower impact incidents escalating to high impact incidents. Good relations with Local Authorities and Emergency Services. High credibility with the public, media, Department for Environment Food and Rural Affairs (Defra), government Agencies etc. Little negative publicity in media due to failure to warn communities during floods.
Working in Co-operation with Professional Partners Provide information and advice from Incident Rooms to professional partners as requested during category 1 flood incidents. Attend all multi-agency Strategic groups. Attend multi-agency Tactical and Operational groups only where necessary for the avoidance of loss of life and/or for the safe and effective deployment of Environment Agency resources in undertaking their role and responsibilities.	Low risk of communication failure leading to a less effective response. Low risk of negative publicity in media. Some gaps in feedback from partners on the impact and needs of the communities affected by flooding to aid prioritisation of the Environment Agency's own activities. Fair relations with professional partners and the public.
Manage the Environment Agency's reputation Respond to media requests and interviews at the appropriate level Media trained operational staff available. Assist others in management of Very Important People (VIP) visits to affected areas. Proactive use of the Local media but no proactive promotion of national strategic issues.	Minor Increase in flood risk during the incident due to adverse and inaccurate media reporting causing the public to panic or fail to take effective action to mitigate against damage or protect themselves. Minor increase in flood risk over time after the flood incident due to lack of promotion of strategic flood risk issues during times of heightened awareness (e.g. climate change and development on the flood plain) Moderate credibility with the media, public, Defra and other Government Agencies.

(Environment Agency, 2005a, 2005b)

Table 2.2 Response activities in the UK

Adopted incident response standard	Consequences of adopting standard
Operation of assets Operate Environment Agency Flood Defence assets in accordance with operating rules, during actual or likely category 1 or 2 flood incidents. Flood defence assets will only be operated on a best endeavours basis during actual or likely category 3 flood incidents. No manual intervention to operate flood defence assets during Category 4 incidents.	Low risk of danger to very small communities, individual properties, the public and the built environment due to non-attendance and non-operation of assets in response to low priority incidents. Risk of danger to public and the built environment due to non attendance at wrongly assessed incidents. Good credibility for the Agency. Fair relations with emergency services and Local Authorities Time taken dealing with incident follow-up. Lack of information or evidence to take action at non attended sites.
Monitoring and inspection Monitor and inspect flood defence assets with a condition rating 4 or 5 during actual or likely category 1 and 2 flood incidents. During actual or likely category 1 and 2 flood incidents, flood defence assets with a condition rating 3, with minimal risk to life, will be monitored on a best endeavours basis only related to degree of risk. No monitoring and inspection of flood defence assets with a condition rating 1 or 2 or during actual or likely Category 3 and 4 incidents.	Severe risk of danger to the public and the built environment due to non-identification of failure or likely failure of assets at low priority incidents. Severe risk of danger to the public and the built environment due to non-attendance at wrongly prioritised incidents. Risk of lower priority incidents escalating to a higher priority with much greater environmental impact. Loss of credibility of Environment Agency. Fair relations with Emergency Services and Local Authorities. Excessive time taken dealing with incident follow-up diverting resources. Significant negative publicity in media. Lack of information or evidence to take emergency action at non attended sites
Reactive response Attend flood defence assets that have failed, or where there is a significant risk of failure, that may result in Category 1 and 2 flood incidents. Take emergency action where feasible and safe to do so. On a best endeavours basis, attend and take emergency action at flood defence assets that have failed, or where there is a significant risk of failure, that may result in Category 3 flood incidents. No attendance or emergency action at: flood defence assets that have failed, or where there is a significant risk of failure, that may result in Category 4 flood incidents..	Risk of danger to the public and the built environment due to non-attendance of actual or potential failure of assets at low priority incidents. Low risk of danger to public and the built environment due to wrongly prioritising incidents. Loss credibility of Environment Agency with farmers and rural communities. Fair relations with emergency services and Local Authorities Considerable amount of time taken dealing with incident follow-up diverting resources. Lack of information or evidence to take action at non attended sites.
Erection of temporary defences Attend and provide advice to others in the erection/installation of temporary defences which may prevent Category 1 and 2 flood incidents. Provide assistance, including materials, equipment and erection/installation of temporary defences which may prevent Category 1 incidents and Category 2 flood incidents, in excess of 10 properties, on a best endeavours basis. Attendance unlikely where less than 10 properties involved No attendance at Category 3 or 4 flood incidents.	Moderate to low risk of danger to the public and the built environment due to absence of temporary defences. Low risk of lower impact incidents escalating to high impact incidents. Strained relations with some Local Authorities and Emergency Services. Credibility of the Agency in question due to inconsistent service delivery. Some negative publicity in media due to inconsistent service delivery.

(Environment Agency, 2005a, 2005b)

2.2.4 Emergency response

‘Response’ encompasses the actions taken to deal with the immediate effects of an emergency. In many flood scenarios, it is likely to be relatively short and to last for a matter of hours or days, so rapid implementation of arrangements for collaboration, co-ordination and communication are, therefore, vital. Response encompasses the effort to deal not only with the direct effects of the flood itself (e.g. rescuing individuals, protecting property etc) but also the indirect effects (e.g. disruption, media interest etc).

Effective response procedures should be flexible and tailored but follow a common set of underpinning principles:

- Continuity (of working, but at a faster pace and in more testing circumstances);
- Preparedness (clarity of roles and responsibilities);
- Subsidiarity (decisions taken at lowest appropriate level, with co-ordination at highest necessary level);
- Direction (clarity of strategic aim and objectives, enabling prioritisation and focus of the response and recovery effort);
- Integration (effective co-ordination to produce integrated effort);
- Co-operation (positive engagement and information sharing);
- Communication;
- Anticipation (ongoing risk identification and analysis).

Flood response refers to the operations that may be initiated to reduce the hazard of an actual flood after a flood warning has been issued. These include road control, building up of defences, evacuation, rescue and providing information and advice to communities affected by flooding.

Road control may be undertaken by the police or local road authority, depending on local agreements. It involves closing roads which are liable to flood, planning and implementing detours, signposting, and be used to warn road users of flooding.

The Environment Agency and local authorities may build up defences using sand bags or other means, although sand bags have a number of disadvantages and are not used by some local authorities. Local authorities also provide labour, equipment and facilities for conducting a range of response tasks, including for example lifting or moving furniture for the elderly and disabled. Local authorities also provide temporary accommodation and food for evacuees.

Flood wardens are members of the community, who will always be available during the time of a flood. It should be noted that many floodplain residents will be preoccupied and therefore unable to undertake flood warden duties. Each flood warden is allocated a group of properties, and they are responsible for making sure everyone is aware of the flood. In addition, wardens may facilitate the evacuation of individuals, particularly families with children, the elderly and other vulnerable groups. Flood wardens must be identifiable and known to the local community.

(Environment Agency, 2005a, 2005b)

2.2.5 Management and co-ordination of local operations

The objectives for a combined response to a flooding emergency are as follows:

- Saving and protecting life;
- Relieving suffering;
- Containing the emergency;
- Providing the public with warnings, advice and information;
- Safeguarding the environment;

- Protecting property;
- Maintaining or restoring critical services;
- Maintaining normal services at an appropriate level;
- Promoting and facilitating self-help in the community;
- Facilitating investigations;
- Facilitating the physical, social, economic and psychological recovery of the community; and
- Evaluating the response and recovery effort and identifying lessons to be learned.

There is a general national framework in use for managing emergency response and recovery that is applicable irrespective of size, nature or cause of an emergency, but remains flexible enough to be adapted to the needs of particular circumstances. Adoption of this nationally agreed management framework helps integrate plans and procedures between and within agencies and across geographical boundaries. It also ensures that all agencies understand their roles and responsibilities in the combined response. The framework identifies the various tiers of management in emergency response and recovery, and defines relationships between them. It provides a framework within which individual agencies can develop their own response and recovery plans and procedures.

Within the framework, the management of the response and recovery effort is undertaken at one or more of three ascending levels, which are defined by their differing functions rather than by specific rank, grade or status:

- **Bronze** – operational level;
- **Silver** – tactical level;
- **Gold** – strategic level.

In rapid onset emergencies within a limited geographical area, the emergency management framework will usually be constructed from the bottom up and the bronze level will be activated first. Escalation of the event or greater awareness of the situation may require the implementation of a silver or even a gold level.

Bronze

This is the level at which the management of immediate “hands-on” work is undertaken at the site of the emergency or other affected areas. Personnel first on the scene will take immediate steps to assess the nature and extent of the problem. Bronze commanders will concentrate efforts and resources on specific tasks within their areas of responsibility. The police will generally co-ordinate an operational response. Where the silver level of management is established, bronze commanders become responsible for implementing the silver commander’s tactical plan (HM Government 2005a, 2005b).

Silver

The purpose of the silver command is to ensure that actions taken by the bronze are co-ordinated, coherent and integrated in order to achieve maximum effectiveness and efficiency. Silver commanders will:

- Determine priorities for allocating resources;
- Plan and co-ordinate how and when tasks will be undertaken;
- Obtain additional resources if required;
- Assess significant risks and use this to inform tasking of bronze commanders;
- Ensure the health and safety of the public and personnel.

In a rapid onset emergency when there is an identifiable scene and the emergency services are in the lead, then silver will usually work from an incident control point located nearby or adjacent to the flooded area.

Where there is more than one scene or incident, it may be necessary to invoke the gold level of management to take overall command and set the strategic direction. Once this occurs, silver commanders continue to effect multi-agency co-ordination within their area of responsibility, while simultaneously directing tactical operations within the strategic direction and parameters set by gold (HM Government 2005a, 2005b).

Gold

Gold command is triggered where an event or situation is likely to have:

- Especially significant impact;
- Substantial resource implications;
- Large number of organisations;
- An extended duration.

The multi-agency group, which brings together gold commanders from relevant organisations, is called the Strategic Co-ordinating Group (SCG). The SCG will:

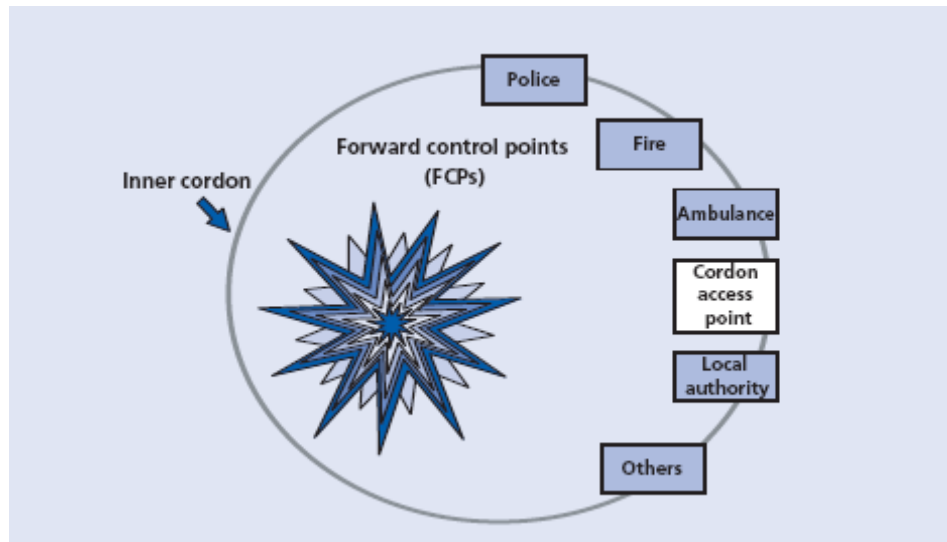
- Determine and promulgate a clear strategic aim and objectives and review them regularly;
- Establish a policy framework for the overall management of the event or situation;
- Prioritise the demands of silver and allocate personnel and resources to meet requirements;
- Formulate and implement media-handling and public communication plans; and
- Direct planning and operations beyond the immediate response in order to facilitate the recovery process.

In most emergencies with significant recovery implications, a Recovery Working Group (RWG) will also be established. For a flood emergency, it will normally be the role of the police to co-ordinate the gold management level and therefore to chair the SCG. Depending on the nature, extent and severity of the emergency, either the regional tier or central government may become involved. The SCG will then become the primary interface with these other levels of response.

Arrangements necessary in the immediate vicinity of the flood include:

- Assessing control measures with regard to reducing risk;
- Deciding the functions to be controlled by each agency after taking account of:
 - the circumstances;
 - the professional expertise of the emergency services and other agencies;
 - statutory obligations; and
 - overall priorities;
- Reception and engagement of utility companies' staff (e.g. gas, electricity and water) on essential safety work, or to effect the restoration of essential services, where appropriate; and
- Setting up an inner cordon to secure the immediate scene and provide a measure of protection for personnel working within the area, as illustrated in the Figure 2.1 below. All those entering the inner cordon should report to a designated cordon access point. This ensures that they can be safely accounted for should there be any escalation of the incident, and affords an opportunity for briefing about the evacuation signal, hazards, control measures and other issues about which they need to be aware. People entering the inner cordon must have an appropriate level of personal protective equipment, while those leaving must register their departure.

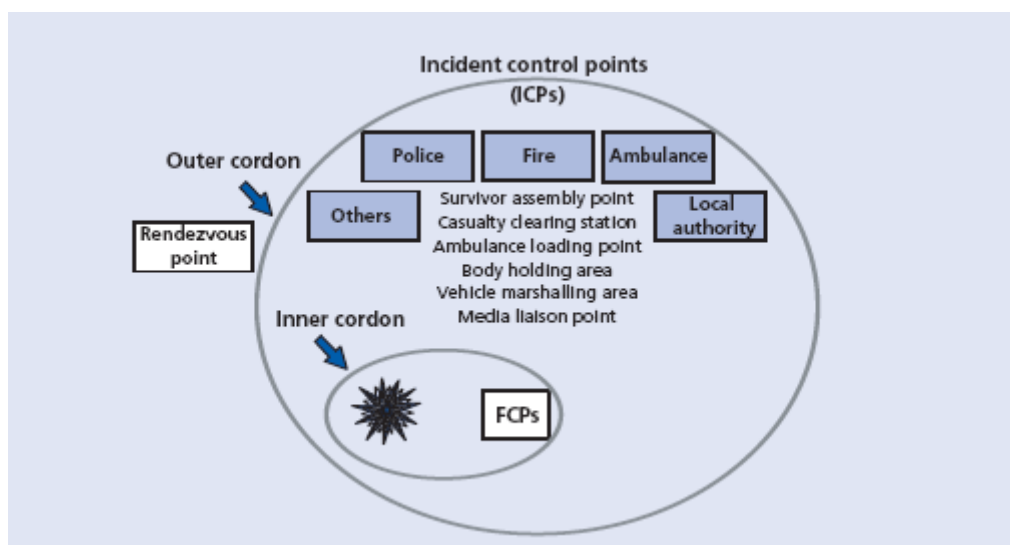
(HM Government 2005a, 2005b).



(Source: HM Government 2005b)

Figure 2.1 Setting up an inner cordon for incident control

If practical, an outer cordon may have to be established around the vicinity of the incident to control access to a much wider area around the site as shown in Figure 2.2. This will allow the emergency services and other agencies to work unhindered and in privacy. Access through the outer cordon for essential non-emergency service personnel should be by way of a scene access control point.



(Source: HM Government 2005b)

Figure 2.2 Setting up an outer cordon for incident control

Other issues that should be addressed at this level include:

- Establishing internal traffic routes for emergency and other vehicles (including a one-way system where appropriate); and
- Deciding on the location of key functions or facilities, for example:
 - Casualty clearing station(s) to which the injured can be taken;
 - An ambulance loading point for those who need to be taken to hospital;
 - A collection/assembly point for survivors before they are taken to a Survivor Reception Centre;
 - Possible helicopter landing site(s);
 - A rendezvous point or points for all responding personnel, which may be some distance from the scene in the event of a bomb incident or incidents involving hazardous materials;

- A marshalling area for assembling vehicles and equipment;
- A body holding area that is under cover and protected from public view;
- A media liaison point.

(Source: HM Government 2005b)

2.2.6 Evacuation planning

It is important to note that in the UK evacuation can only be advised not ordered. The possible need for evacuation of the public from the immediate vicinity may have to be considered at a very early stage. In some circumstances it may be necessary to advise the public on whether they should evacuate a given area or remain and shelter indoors.

It is normally the police who recommend whether or not to evacuate and define the area to be evacuated. Their recommendation will take account of advice from other agencies. The Fire and Rescue Service will inform them about risks associated with fire, contamination and other hazards. Ambulance services and local authorities can advise on problems associated with moving people who are frail, disabled or at risk for any other reason. Local authorities will also be able to identify individuals or groups of individuals that may need particular support. Local authorities can also advise on the location of pre-designated rest centres and on other possible places of shelter within the area (HM Government 2005a, 2005b).

The police can only recommend evacuation and have no power (except within the inner cordon in response to a terrorist incident) to require responsible adults to leave their homes. Past experience has shown that people with domestic pets may be unwilling to leave their homes unless arrangements include them.

In deciding whether to evacuate or not, it is necessary to assess whether bringing people outdoors may put them at greater risk than leaving them where they are to shelter indoors. This is particularly important where flood water levels are likely to rise quickly.

When planning for contingencies, building occupiers should seek professional advice on whether there are areas in the building where people can shelter safely. Such areas must be structurally robust and should be equipped with telephones, first-aid facilities, adjacent toilet facilities and a water supply.

There are particular problems in evacuating hospitals, prisons and nursing homes, and in evacuating those individuals who are at home, but are frail or vulnerable. Large scale evacuation is a last resort owing to the length of time it takes to complete and the risks the public may be exposed to as a consequence of being evacuated. Local planning should include arrangements to support people sheltering in their own homes where this is the safest option.

However, when there is a decision to evacuate, evacuation assembly points should be set up near the affected area. If time permits, these should be signposted. People in the affected area should be advised to go to their nearest evacuation assembly point. People taking prescribed and other medications should be reminded to carry these with them, and particular attention needs to be paid to those with sensory impairment.

Bearing in mind that evacuation may be at different times of day or night and from locations as different as homes, industrial complexes, shopping malls, venues, ports or airports, various methods can be used for warning and informing the public: loudhailers, tannoy, mobile public address systems, radio or TV announcements, works sirens, display screens, scoreboards and monitors, or various combinations of these methods (HM Government 2005a, 2005b).

The police will, as far as is practicable, take steps to ensure the security of property left empty after evacuation. In the event of an extended evacuation, the local authority may have to consider other security arrangements.

Arrangements for warning, evacuation and securing property must take account of any safety risks to emergency service and local authority personnel that arise from exposure to hazards. At the evacuation assembly point, the dispersal of evacuees to survivor reception centres or rest centres must be co-ordinated.

2.2.7 Evacuation and rescue models currently used in the UK

There are currently no models used or under development to support evacuation and rescue for flood management in the UK. The response to flood risk management in the UK has mainly focused on flood defence asset management, and forecasting and warning to reduce flood risk rather than on organised evacuation.

2.2.8 Conclusions

The following conclusions can be reached for the UK regarding flood management

- The emergency response to incidents in the UK is governed by the Civil Contingencies Act 2004;
- It is not the Environment Agency's responsibility to organise evacuation as a part of an emergency response to flooding;
- Timing, speed and method of communication of reports are critical to effective emergency management during a flood;
- More robust and integrated communication links between the organisations involved in the response during a flood helps to ensure an effective response;
- Organised evacuation is only used as a form of emergency response in very rare circumstances. The authorities have no powers to forcibly evacuate people from their houses during floods. In terms of evacuation normally people "self-evacuate";
- The response to flood risk management in the UK has mainly focused on flood defence asset management, and forecasting and warning to reduce flood risk rather than on organised evacuation.

2.3 The Netherlands

2.3.1 The legal framework for flood management and emergencies

Background

There are three administrative levels in the Netherlands:

- National level. At this level there is the Council of Ministers and the related ministries and the Dutch parliament.
- Provincial level: There are 12 provinces, each with a Provincial Council. This is similar to a provincial parliament that nominates a provincial executive board (the 'deputies'), chaired by the Provincial Governor (the Queen's Commissioner).
- Municipal level: A Municipal Council, municipal executives (the aldermen) appointed by the council, and a Mayor as chairman of council and aldermen.

All the above levels play different roles in the management of flood emergencies. These are described below.

Relevant flood mitigation legislation

The primary law relating to flooding in the Netherlands is the Flood Protection Act, 1996 (Wet op de waterkering). The Flood Protection Act specifies the level of safety against flooding for all areas in

the Netherlands that are protected by dikes. The level of service of the defences is not the same for the whole country. The level of service of the defences depends on the number of people that live behind them and on the economic value of the elements at risk. The Flood Protection Act describes a system of primary water defences that protect 53 lowland dike ring areas with different protection levels, varying from a 1 in 500 year failure probability for some 'void' areas, to a 1 in 10,000 year level of service for the densely populated western part of the Netherlands. In 2005 42 small dike rings along the Meuse were added to the system. They have a failure probability of 1 in 250 per year. The system of primary dike rings is shown in Figure 2.3.

The Flood Protection Act also refers to the high-water reference levels related to the failure probability for certain locations. Every five years the Ministry of Transport, Public Works and Water Management determines, for a number of locations along each dike ring, the high-water reference levels that the managing institutions of the primary dikes and hydraulic structures have to take into account to comply with the prescribed failure probability. Most dikes and structures are managed by a water board. The high-water reference levels and related probabilities are published in a document known as the Boundary conditions book (Randvoorwaardenboek), which reflects the latest research on for instance the effect of the climate change on flood levels.

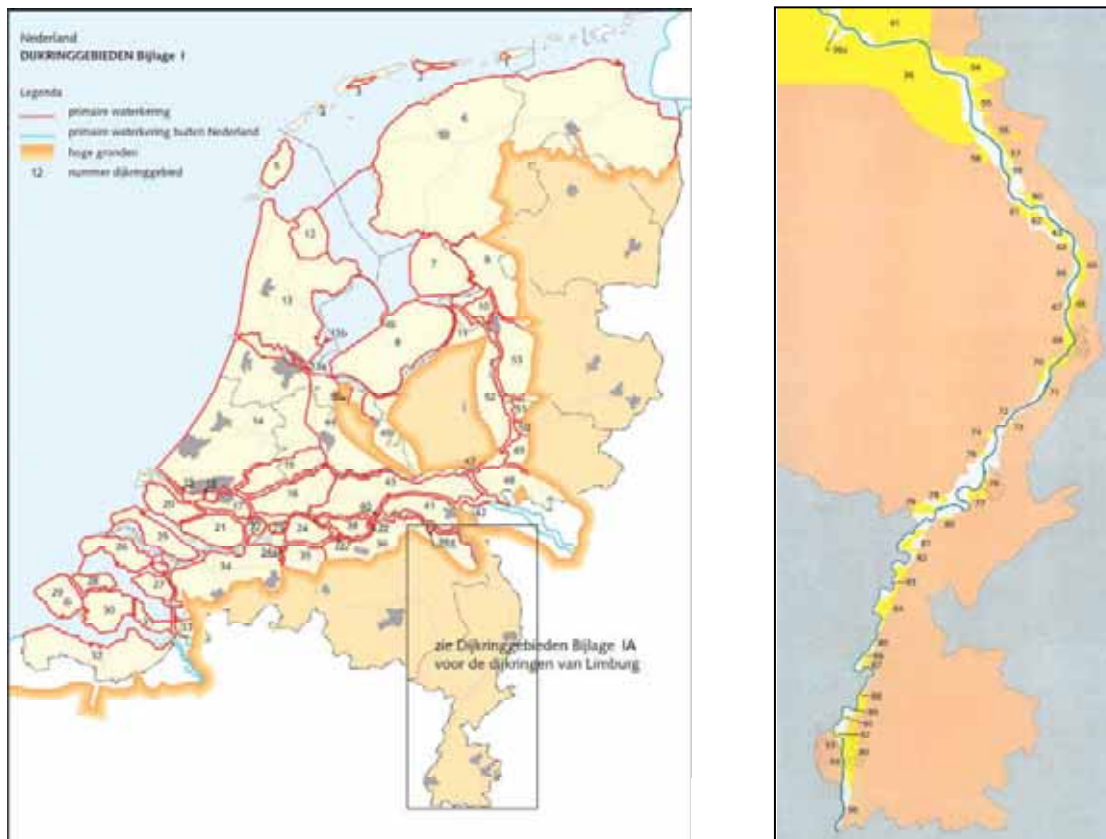


Figure 2.3 System of primary water defences and dike rings in the Netherlands

The provincial level of government has responsibility for the supervision of all primary water defences in its region. Every five years the managers of the dikes and structures, often the water boards, have to report to the province about the condition of the water defences. Based on the reference levels the water defence managers determine if their dikes and structures are still compliant with the latest boundary conditions for the required level of service. The reports are summarised and commented on by the provinces and by the ministry, and finally discussed in parliament. The results of this discussion guide investments related to the improvement of the flood defence system.

The water boards control the majority of the primary flood defences. There is a special Water Boards Act, 1991 (Waterschapswet). The act outlines the responsibility of the water boards to keep the water

defences in good condition. The provinces control the water boards. However, the act mainly deals with regulations concerning the creation of water boards by the provinces, regulations concerning the composition of the Water Board's Council and the ability to issue regulations, as well as matter related to financing and taxes.

The Water Administration Act, 1900 (Waterstaatswet) deals with the management of 'waterstaatswerken', described as the surface water and water defences, including the related structures, on a national, regional or municipal scale. With respect to flood conditions the act gives specific directives in §17: Provisions for preparation and acting in case of danger ('Voorzieningen inzake voorbereiding op en optreden bij gevaar').

This act provides guidance to 'water managers' concerning what are known as “calamity plans”. Such a plan includes an inventory of the kind of emergencies that may happen and their potential risks, the measures to be taken, the required equipment and the services to be provided by different institutions. The following are also included in the plan:

- The organisation of the emergency response team;
- The warning and reporting procedures;
- The quality assurance of the plan.

Finally the act requires regular exercises to be carried out. The plans require updating at least every four years.

In 1999 the Rivers Act of 1908 was withdrawn and integrated with the Act on State Waters and Infrastructure, 1996 (Wet Beheer Rijkswaterstaatswerken). The main objective of this act is to control the construction of properties in the state waterways.

There are several general laws that have an indirect relation with flood management. The Provincial Act, 1992 (Provinciewet) defines the internal organisation of a province and its relations with the government, municipalities and water boards. Apart from the water boards, the act does not contain specific information on the issues such as water, floods or emergencies. The Local Government Act, 1992 (Gemeentewet) describes similar items for the municipality as the Provincial Act does for the province. However, Article 175 of the act¹ allows in the case of emergencies and disasters, full power to be delegated to the mayor to act as necessary. The mayor is allowed to override other regulations, except those in the Dutch constitution.

The Act on disasters and severe accidents, 1985 (Wet rampen en zware ongevallen) is also applicable for flood emergencies. The act deals mainly with the preparation of emergency management plans by municipalities and the provinces. In accordance with the Local Government Act the mayor has the primary responsibility to act in case of an emergency. The commander of the fire brigade has the operational command, under the supervision of the mayor. For emergencies that exceed the territory of the municipality the mayor can ask assistance from the provincial governor. In the case of a national disaster the Minister of Home Affairs may get involved.

2.3.2 Institutional framework

Emergencies are dealt with at three different administrative levels in the Netherlands as follows:

- Municipality level;
- Provincial level;

¹ Artikel 175: In geval van oproerige beweging, van andere ernstige wanordelijkheden of van rampen of zware ongevallen, dan wel van ernstige vrees voor het ontstaan daarvan, is de burgemeester bevoegd alle bevelen te geven die hij ter handhaving van de openbare orde of ter beperking van gevaar nodig acht. Daarbij kan van andere dan bij de Grondwet gestelde voorschriften worden afgeweken.

- National level.

In the case of an imminent flood posing a threat, the municipality is the primary managerial level for this type of emergency, with the mayor in command. However, it will be clear that a flood will seldom be limited to one municipality's boundaries. For example, a dike failure will result in an inundation that will gradually spread out over the protected dike ring area, as shown in Figure 2.3. During this process more and more municipalities may get affected. To cope with this 'supra-municipal' aspect the individual mayors concerned can choose one of them as the coordinating mayor. If the flooding remains regional the provincial level of government is involved at an administrative level. The national government level will of course be informed and provide assistance and directions where needed, but it will not lead the operation.

At the provincial level, the provincial governor (the queen's commissioner) is the highest administrative official. The duties and competences of the provincial governor during a regional emergency will probably change somewhat in the near future, when the recommendations of recent advice to the government are implemented. Currently under Dutch law the provincial governor can 'direct' and assist, but is not in command.

The province draws up the provincial emergency coordination plan. The governor screens the municipal emergency management plans and can enforce changes in such plans. In the case of an emergency the governor can make available the input of provincial services and can act as intermediary between the (coordinating) mayor and regional or governmental institutions for the supply of assistance. The governor also has the power to give directions to a mayor with regard to the actions to be taken during an emergency and to provide the operational management in a 'supra-municipal' disaster area. In case of a *national* disaster the Minister of Home Affairs coordinates on the governmental level with support from the National Coordination Centre.

The chain of functional responsibility with respect to flooding consists of the following organisations:

- The Water Board, which is a regional water management organisation and responsible for the primary dikes of one or more dike rings. If the water retaining function of a dike is in jeopardy the water board has the power to appropriate properties and instruct inhabitants in the dike ring to assist with and to make available vehicles and tools to combat a threatening inundation.
- The Provincial Water and Environment Service supervises the functioning of the water boards. The service can give instructions to the water boards on supply from or discharge to surface water that is not managed by government or province.
- The Ministry of Transport, Public Works and Water Management and its executing agency Rijkswaterstaat assess water levels that trigger various levels of warning in the main rivers and in the IJsselmeer every year. Rijkswaterstaat's Institute for Inland Water Management and Waste Water Treatment provides actual water levels and predictions on a regular basis. In the case of a threatening flood the frequency of the updates on water level and prediction is increased. The Ministry gives instructions to a province on the supply and discharge of water under extreme conditions.

The main professional emergency rescue and aid providers during flood conditions and evacuation, acting under the supervision of the (coordinating) mayor, are:

- The fire brigade, for rescue, technical assistance and providing emergency pump capacity.
- The medical and public health institutions who provide urgent medical and mental health care, and preventive health care.
- The police who maintain public order, criminal inquiries, traffic regulation, closing and guarding certain areas, and identification of casualties.
- The municipality who is responsible for the registration of victims, burial, damage registration.

- The municipality usually takes responsibility for warning the public, an actual evacuation (people, livestock), provision of primary needs (shelter, food, clean water), and environmental care (during an inundation dangerous substances may start floating around).

Figure 2.4 shows the operational and administrative responsibilities in a flood emergency in the Netherlands.

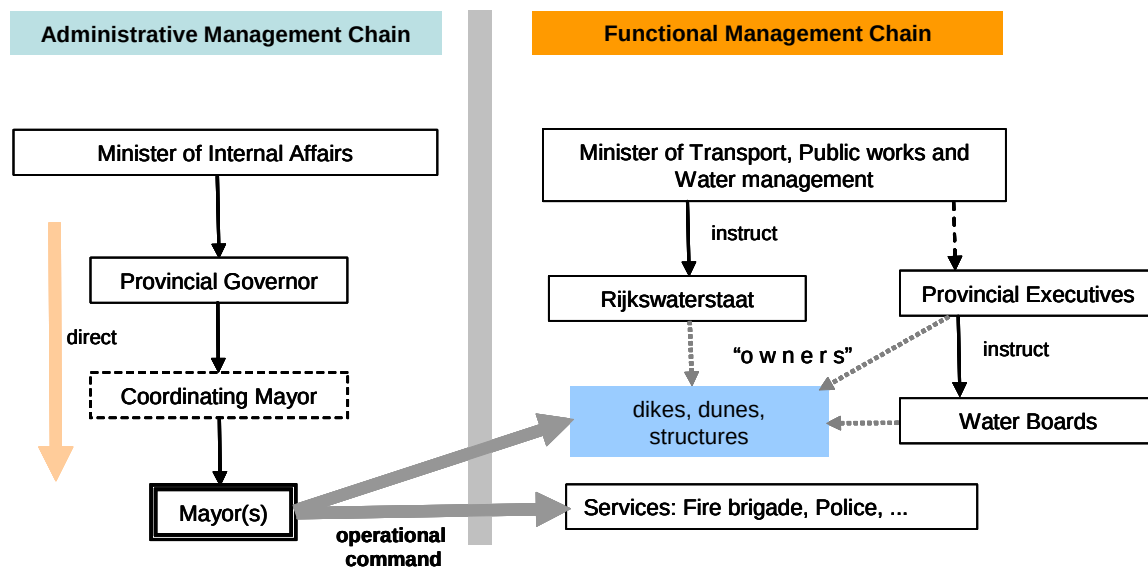


Figure 2.4 Administrative and operational responsibilities in a flood emergency in the Netherlands

2.3.3 Emergency flood management

When a flood is expected or after flooding has actually started, there is a wide variety of measures that can be implemented. With respect to infrastructure the following measures may apply.

Closure of infrastructure

There are many structures in the primary dikes that protect a dike ring area. These include ship locks, sluices, non-return sluices, pumping stations, tunnels and 'coupures'. The latter are gaps in the dike that allow traffic to move between the protected dike ring and areas outside the dike, like quays and harbour areas.

The structures in the primary dike ring have instructions as to what the managing institution of a structure should do if certain flood warning levels are predicted or have been reached. The measures to be taken usually consist of closing doors, gates or valves. The owners of these structures are obliged to perform test closures at regular intervals, usually once a year. In such a test the whole chain from the forecasting of a high water level, alert, warning and mobilisation of personnel, and the actual closing is tested. In such a test potential weak points in the procedures are detailed, for example, keys of gates that are missing, emergency power generators that did not start. For coupures the closing devices are often steel or wooden bars that have to be placed in grooves. For example, often they are not stored at the structure's location but elsewhere, in a municipal workshop or similar.

Temporary reinforcements of dikes

For certain sections of the dike a high-water alert may call for temporary measures. Some dikes may have a crest height that is not yet been constructed to the latest design flood level, or the height may be sufficient but the slope protection is still insufficient to resist design waves (the outer slope) or the

effect of overtopping waves (the inner slope). In these cases a temporary additional protection with sandbags may be necessary.

There are also dikes that are sensitive to piping. This is where seepage through the dike may cause an internal erosion of the dike core material and the formation of pipes through which a water flow may develop that can affect the dike stability. The dike sections that are vulnerable to piping are usually known to the authorities. At such locations sand bags are placed on the inner dike toe to provide a counter pressure to reduce piping.

Activation of retention areas

The use of retention areas to reduce flood levels has been seriously studied by a Governmental Commission. The commission's report was submitted in 2002. It considers the use and necessity of retention areas. Areas where a controlled inundation is accepted in a critical flood situation, to prevent an uncontrolled inundation at some other place. This is known in Dutch as a 'noodoverloopgebieden' i.e. emergency inundation areas. The report considered a number of potentially suitable areas along the Rhine and Meuse. However, currently no retention area has the final status of 'noodoverloopgebied' that will be used in a future flood emergency. The reasons for this are various including the financial compensation required to pay the affected inhabitants, the critical timing to obtain an optimum effect of a retention area and because nobody wants to inhabit these areas.

Closure of storm surge barriers and gates

There are three structures in the Netherlands that have a key role when there is a severe threat of flooding. They are all located in the western part of the Netherlands, where the threat from the North Sea is dominant:

- The Hollandse IJssel barrier (1958) located just east of Rotterdam. It was constructed after the 1953 flood disaster for extra protection of the low areas along the Hollandse IJssel which is under normal conditions in open connection with North Sea. With a level of down to 6 m below sea-level this area is in fact the lowest of the country. During the 1953 disaster the stability of some dike sections there was critical, they nearly failed. One dike section was just prevented from collapsing by sinking a river-vessel on its slope.
- The Eastern Schelde storm surge barrier (1986) protects the dikes along the Eastern Schelde estuary. It is closed as soon as the North Sea reaches a certain level. It was constructed as an alternative for the originally planned enclosure dike, to preserve the tidal regime and its related very special ecological system, but also to maintain the high value fishery and aquaculture area (e.g. mussels, oysters).
- The Maeslant storm surge barrier (1997) provides extra protection of the urban and industrial areas along the Rotterdam Waterway.

The expression 'extra protection' as used here needs some clarification. The primary dikes along the dike ring form the primary water defence. However, the safety given by either of these barriers could compensate the need for further heightening of dike sections to comply with the safety levels in the Flood Protection Act. Dikes in this part of the country are often in densely built urban areas, and consequently dike improvement is a complicated and expensive matter.

Raising demountable flood walls and pumping

Demountable flood walls are mainly applied in the Meuse basin in the province of Limburg. As soon as a local warning level is reached the demountable flood wall units are mobilised and put in place. They usually protect only small areas such as quays or streets along the river. The height of these structures does not usually exceed more than one metre. In fact coupures without a permanent closing device also belong to this category. Pumping is usually only applied to get rid of water that leaks through (temporary) closing devices, e.g. sand bags. It is not used as a measure on its own.

Evacuation and rescue

In the Netherlands the view is taken that preferably an evacuation should be preventive. Timing of a preventative evacuation is crucial. For example, if the evacuation takes place and eventually no flooding occurs there are numerous political and financial ramifications. However, if the evacuation starts too late and is not completed before the failure of dikes or structures, the risk of casualties as a result of flooding is high. In the 1953 flood disaster in the south-western part of the Netherlands there was little preventive evacuation.

The high-water in the Rhine in January 1995 provoked a large-scale preventive evacuation in the polder areas along the Rhine branches in the province of Gelderland. About 175,000 people were evacuated from these areas². This was the first time since 1953 that a major inundation threatened and that an evacuation had to be considered seriously, and finally realised. Although no flooding occurred in 1995 this event acted as a catalyst to streamline the organisational processes and the information flows before and during an evacuation.

2.3.4 *Methods and models to support emergency evacuation*

The large-scale preventive evacuation during the 1995 flood emergency led the Dutch authorities, to improve the collection and dissemination of information during a flood emergency and to streamline the cooperation between the many partners involved. Several activities were initiated. To provide the parties concerned with timely and reliable information the Rijkswaterstaat agency, part of the Ministry of Transport, Public Works and Water Management, started the development of the automated High-water Information System (HIS). This system consists of an operational part, for fast and adequate action during a flood emergency, and of a policy part that helps all parties that may get involved in a flood emergency to be well-prepared.

The policy part contains three modules:

- The inundation module, which shows what happens if a dike fails at a specific location. For example, how fast will the polder inundate, what parts are inundated first and what will be the inundation depth as a function of time. This allows the measures that will be most effective to minimise the effects of the inundation to be estimated.
- The damage and casualties module determines the consequences of a dike failure. On the basis of data on the inundation depths and current velocities in the inundated area, calculated by the inundation module or originating from another source, the damage is calculated in terms of casualties³, victims and economic losses. This information will allow an assessment of the effect of different measures to mitigate flood damage. One interesting option of the module is that it can also be used to determine the positive effects of a preventive evacuation in terms of the number of casualties and victims that can be avoided.
- The evacuation calculator provides useful information for the preparation of regional evacuation plans. The input data for the evacuation calculator consists of:
 - The network of potential evacuation routes and their capacity;
 - Data on the capacity of the exits of the area to be evacuated;
 - The 'evacuation load' to the nodes of the network: people, cattle and goods to be evacuated.

On the basis of this input and a traffic model the evacuation calculator calculates the time needed to evacuate the area along the available routes to the exits of the area. The traffic model applies different

² 75,000 people in Bommelerwaard, Ooijpolder, Land van Maas en Waal, Land van Heusden en Altena; 100,000 people from Culemborgerwaard and Tielervwaard

³ The word '*casualty*' is rather ambiguous; it is used here in the sense of loss of live (so only cases of drowning, no broken legs or similar repairable injuries). *Victims* are people affected in some way by the inundation. Economic losses are damage to properties (private or public) and production losses.

options to manage the outflow of evacuees, by providing different degrees of control over departure time and exit routes to follow.

The operational part of the HIS consists of two modules:

- The monitoring module provides a detailed map of the measures and predicted water levels for the situation where there is no inundation yet. The module compares these water levels with the crest levels of the water defences and gives a red alert on the map for any alarming situation. An example of such a map is shown in Figure 2.5.
- The logbook module enables the users of the HIS to save the messages that reach the coordination centre. The messages may, for example, refer to water leaking through structures, reports on dike seepage, navigation, blocked roads.

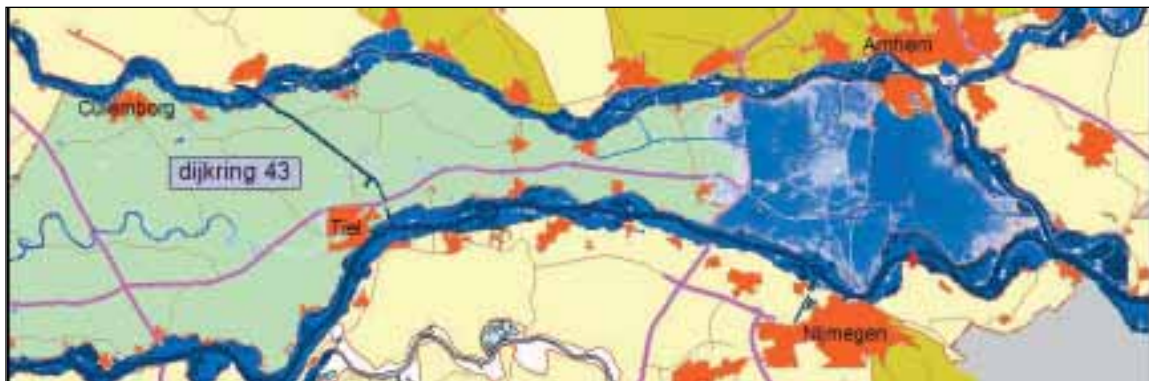


Figure 2.5 Example of a map of the Dike ring 43 in the Netherlands inundated area after 24 hours

In parallel to the development of the HIS a number of water boards have developed an Automated Script for High-water (GDH, Geautomatiseerd Draaiboek Hoogwater) to handle the complex data flows during the occurrence of a flood in the main rivers. The GDH contains all the information of the existing scripts on paper for high-water situations, with the actions to be executed if certain water levels are reached or exceeded. The GDH keeps track of all the required actions and their status.

The development of both systems stopped around 2004, when it was decided to integrate with the newly commissioned German-Dutch EU Interreg-IIIb project entitled NOAH. The NOAH partners are STOWA (a Dutch foundation for applied research in water management), four Dutch water boards, Rijkswaterstaat and the German Regierungspräsidium Karlsruhe (with six local public authorities) and the Hochwasser-schutzzentrale in Stadt Köln. Part of this project is the development and implementation of a new web-based IT flood emergency information system called FLIWAS (Flood Information and Warning System). The system will include an evacuation module for which the Evacuation Calculator of HIS will be the basis. The Fliwas project is planned to be ready in 2007.

The FLIWAS project concentrates on fluvial flooding. Another EU funded project, ESCAPE, focussed on the risks of coastal flooding, where the prediction time is often much shorter than for fluvial flooding. In the Escape project authorities from Dutch, Belgian and English regions cooperated. In 2002 to 2004 a DSS was developed and tested, again based on inundation calculations and GIS. The Escape DSS also contained a module for the calculation of potential damage and casualties as a result of inundation, and a module that permits the calculation of the time required for the evacuation of a certain area as a function of the location and number of people to evacuate, the capacity of evacuation roads and the available exits of the area.

2.3.5 Conclusions

Most of the preventative measures for floods taken in the Netherlands are related to infrastructure. There are a number of structures that need to be closed to prevent flooding. If such devices were only

used during actual emergency situations, there is a fair chance that the closure may fail. Therefore most management plans of hydraulic structures contain prescribed test closures, for instance once per year.

Preventive evacuation is a quite drastic measure that often affects many people. The decision to evacuate must be based on reliable data that are available at the right time to the right people. After the 1995 flood emergency the managing authorities made great efforts in the development of decision support systems and tools (e.g. ESCAPE, Evacuation Calculator, Fliwas). However, they have not yet been applied to an actual flood emergency. To date these tools have only been used in exercises. The main lesson identified from the exercise was that effective communication between the many parties involved is difficult in flood incident management. It appeared that sometimes information was not shared or not transmitted via the prescribed channels.

2.4 Germany

2.4.1 The legal and institutional background

Legal framework

Germany is a federal republic comprising 16 federal states. Within the federal states there are different administrative districts at a regional level. At the next level there are rural counties and urban districts. All other municipalities belong to a county or are urban districts. As a result of the administrative system in Germany there are two different kinds of legislative competencies (Article 70 et seq. basic law): The competence of the federation, called “exclusive competence”, and the “competing competence” that means that the federation has only guiding competences and the federal states have the legislative competence. Examples of the exclusive competence of the federation are currency issues, air traffic and telecommunication. For example, the competing competence is used in matters of water management, disaster protection and nature protection. Emergency flood management in terms of preparation and averting danger is part of disaster protection. The following sections give an overview of the acts and responsibilities in civil defence and disaster protection in Germany.

With regards to water issues there is the Water Balance Act of 27 July 1957 on the level of the federation which has been changed and endorsed lastly in 3rd May 2005. It includes regulations for surface waters, coastal waters, groundwater, water management and the regulations for surface waters also contain rules for flood protection (§§ 31a to 32), such as principles of flood protection, floodplains and flood-prone areas, flood protection plans and co-operation in catchments. These regulations deal primarily with flood prevention. Owing to the competing competence, the federal states have their own Water Acts, e. g. Saxon Water Act. The Saxon Water Act has a similar structure to the German Water Balance Act. One part deals with flood protection, too (§§ 99 to 100b). Flood protection, flood protection action plans, flood protection concepts, floodplains and source areas are explicitly mentioned.

The regulations of the Water Balance Act are related to flood prevention, but not to emergency flood management. They have been recently enhanced by the Act for the Improvement of Preventive Flood Protection (Flood Protection Act) dated 3 May 2005. For disaster protection there are the Civil Defence Act at a federal level and the Disaster Protection Acts in the federal states. The Civil Defence Act of 25 March 1997 only regulates defence in case of attack and therefore the protection against enemy actions. The act covers self-protection, warning of the population, accomplishing measures for health protection and for the protection of cultural heritage.

The federal states are responsible for disaster protection. Hence, every federal state has its own Disaster Protection Act, e. g.:

- Bavaria: Bavarian Disaster Protection Act (BayKSG);
- Baden-Württemberg: Act for Disaster Protection (LKatSG);
- Saxony: Act for Rearrangement of the Fire Protection, Rescue and Disaster Protection (BRKG);

- North Rhine-Westphalia: Act for Fire Protection and Salvage (FSHG).

The Disaster Protection Acts of the federal states deal mostly with three issues:

- Fire control;
- Rescue issues;
- Disaster protection.

In most acts the term “disaster protection” is defined and the responsibilities are regulated and authorities including their tasks are named. For instance the Disaster Protection Act of Saxony names three disaster protection authorities and their main tasks of preparing for a disaster and mitigating its impacts (e. g. emergency flood event) (§§ 7 and 8). The Disaster Protection Act of North Rhine-Westphalia also rules preparative and operational defence measures for the case of an emergency such as a flood (§§ 21 to 24 and 25 to 31). It also names three controlling institutions and disaster protection authorities (§ 33) (for details see chapter 1.2). Furthermore, there can be additional orders and regulations at a ministry level. In every federal state the Ministry of the Interior is responsible for disaster protection. For example, in Saxony there is the Disaster Protection Order (KatSVO) which provides more detailed regulations concerning emergency planning and disaster management. There is also an administrative regulation of the Saxon Ministry of the Interior on the ambulance units and on the water officials for disaster protection. Moreover, there is an administrative regulation of the Saxon Ministry of the Interior concerning disaster protection planning in the Free State of Saxony (KatSPlanungsVwV) of 30 April 2002. This regulation rules the compilation and updating of general disaster protection plans and of special alarm and operation plans by the lower disaster protection authorities (i.e. at a county level).

In the North Rhine-Westphalia the Ministry of the Interior an Order on Crisis Management has been enacted. In this order the principles of crisis management are listed and tasks and structures are defined and explained. However, even at a ministry level the orders often do not contain much guidance on evacuation planning. This is because the responsibility for disaster protection lies with the rural counties and urban districts. Figure 2.6 shows the important acts and orders for disaster protection which include emergency flood management and the main tasks they are responsible for.

Institutional framework

As previously described flood emergency management in Germany is part of disaster protection which is the responsibility of the federal states. There are three institutional levels for disaster protection:

- The federal state level;
- The regional level;
- The municipal/rural county level.

The national level does not have “commanding functions” in this regard but has to complement the disaster protection by the formation of the federal agency Technical public social aid (THW). At a federal state level, the Ministries for the Interior are responsible for intra-regional tasks of disaster protection such as central measures and for forming of guiding devices. The Ministries of the Interior can be supported by further ministries or offices. The regional councils can be responsible for the coordination of the rural counties. However, the rural counties and urban districts are the executive authorities. At this level the fire brigades, public social-aid organisations, rescue, police and appropriate authorities work together. Sometimes there is an additional department for disaster protection and a department for the environment, in addition a flood protection centre may be formed. This is done mainly in large cities. Owing to the specific regulations in the federal states, the following description of emergency flood management is based upon examples. The federal states of Saxony and North Rhine-Westphalia have been chosen because of their particular exposure to floods and their representation of a western and an eastern federal state.

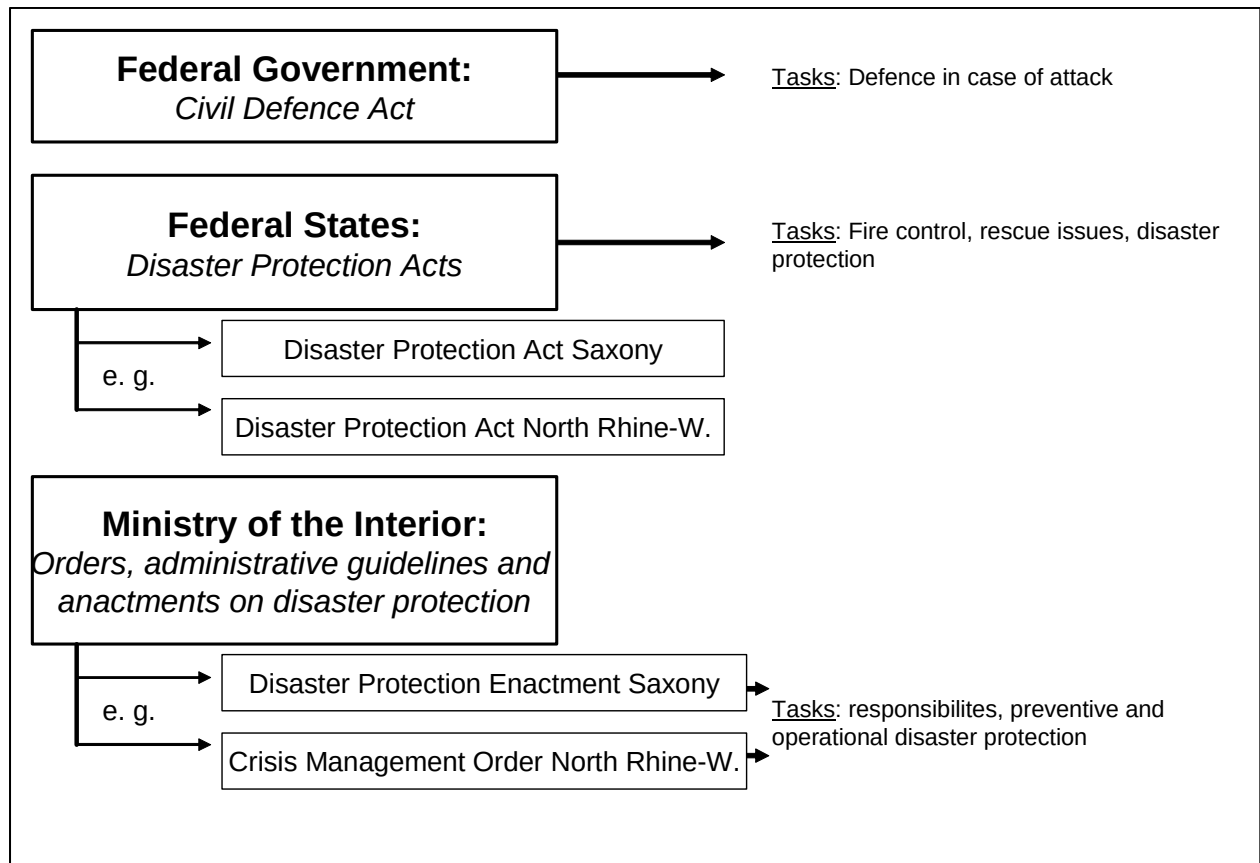


Figure 2.6 Acts and orders for disaster protection in Germany relevant to emergency flood management.

Flood emergency management in Saxony

The organisation of flood emergency management is shown in Figure 2.7. There are three disaster protection authorities on different levels: the highest, the higher and the lower Disaster Protection Authority. In Saxony the Ministry of the Interior is the highest disaster protection authority (department police head quarters, unit fire control, rescue and disaster protection). Under §8 (1) Saxon Disaster Protection Act it has to provide the legal and organisational framework for disaster protection and to support the lower authorities in their tasks. Hence, potential disasters have to be analysed and an “information programme” for the disaster management has to be provided. The highest disaster protection authority arranges the contacts with the other federal states. If necessary, the highest disaster protection authority takes over responsibility for the emergency.

The Ministry of the Interior is supported by the Saxon Ministry of Agriculture and Environment (SMUL) and the Saxon State Office of Environment and Geology (LfUG) which belongs to the SMUL. The LfUG forms the Flood Protection Centre (HWZ). The HWZ monitors water levels. This data is sent to the German Weather Service (DWD) and flood events are forecast. During a flood event the HWZ releases flood warnings and gives details of the development of the event. Flood warning information can also be sent by telephone or videotext.

The regional districts of Dresden, Chemnitz and Leipzig form the higher disaster protection authorities and have the supervision of the plant fire departments that work at a municipal level (§ 8 (2) Saxon Disaster Protection Act). In addition, the regional districts have to support the lower disaster protection authorities. If necessary, the higher disaster protection authority takes over responsibility for the emergency.

The rural districts and urban districts are the lower disaster protection authorities and therefore executive authorities. They have to develop warning and disaster protection plans and are responsible for the preventive and operational flood emergency management, and the information of the public. Furthermore, in the rural counties a co-ordinating office has to be established (§§ 7, 11, 38 Saxon Disaster Protection Act). If an emergency is foreseeable, the lower disaster protection authority has to give a disaster “pre-warning”. When the calamity is occurring, the authority has to give disaster alarm and is allowed to give instructions to the private organisations of public social aid and if necessary to the police. In the City of Dresden, for example, the Department for the Environment is responsible for the designation of floodplains and the Department for Disaster Protection deals with the emergency flood management in co-operation with the Saxon Flood Protection Centre.

Example North Rhine-Westphalia

Similar to Saxony, in North Rhine-Westphalia there are three Disaster Protection Authorities: the highest, the higher and the lower authority. The organisational set up is shown in Figure 2.8. The highest authority is the Ministry of the Interior which is responsible for central measures and has to support the salvage. Furthermore, it maintains the Institute of the Fire Brigade. At the same time it is the highest controlling institution.

With respect to flood emergency management, the Ministry of the Interior is supported by the Ministry of Environment, Nature Protection, Agriculture and Consumerism and the appropriate State Office for Environment that includes the flood message service. The message service provides information on current water levels. The regional government (higher Disaster Protection Authority) has to nominate an officer in charge for the district and to implement measures for rural counties and for urban districts. It also forms the higher controlling institution. As in Saxony, in North Rhine-Westphalia the rural counties and urban districts are executive units and the appropriate disaster protection authorities. The chief administrative of the rural county is the lower controlling institution. The rural counties have to prepare hazard defence plans and are responsible for the implementation of disaster defence and their preparation. Furthermore, a guiding device at a county has to be established. The main administrator has to nominate operation controllers with an officer in charge who has to supervise the single measures and is allowed to issue instructions (§ 30 Disaster Protection Act NRW). In addition, an information office may be set up.

In Cologne there is a flood protection centre which provides actual water levels and prognoses (including monitoring). It is also responsible for the consultancy of the citizen in case of flood event. When a certain water level is reached in the Rhine the control room is permanently staffed. The organisational chart of emergency flood management in North Rhine-Westphalia is shown in Figure 2.7.

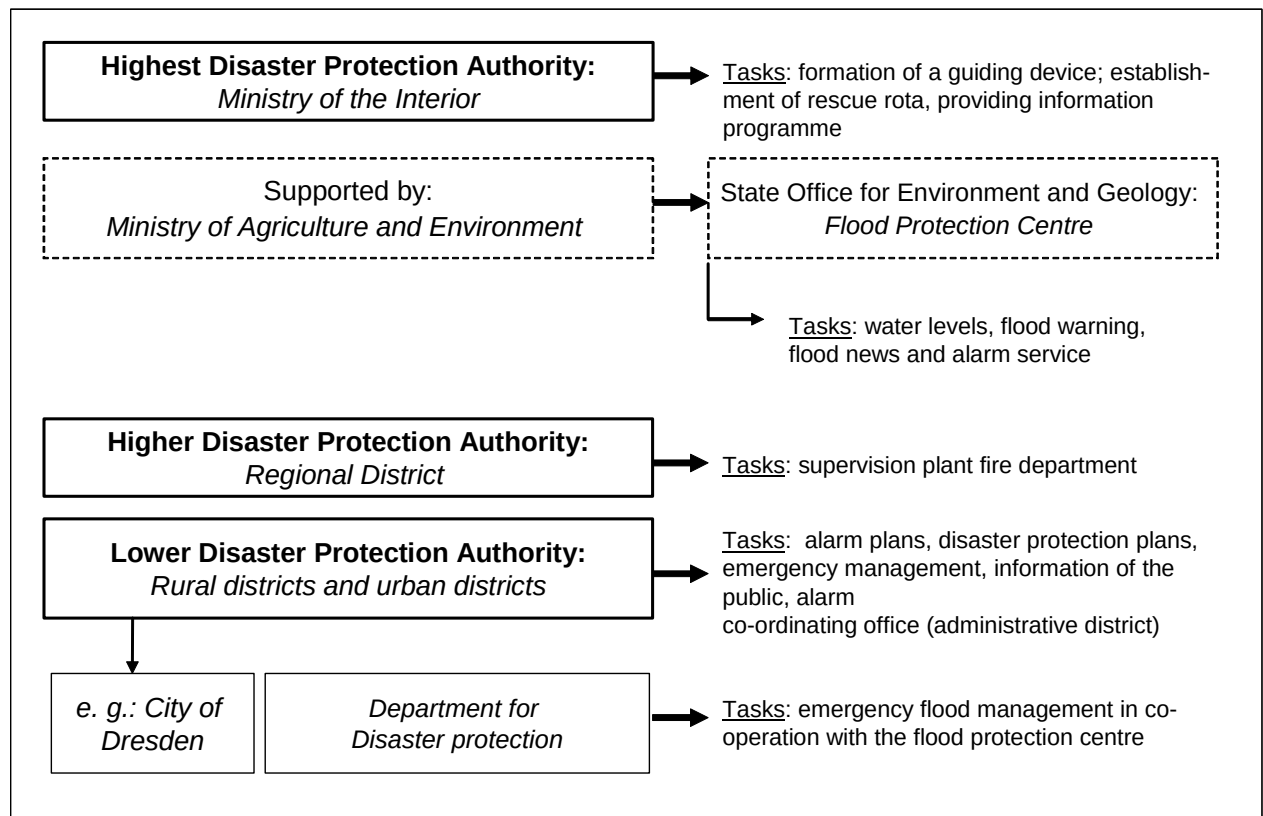


Figure 2.7 Organisational chart for emergency flood management in Saxony

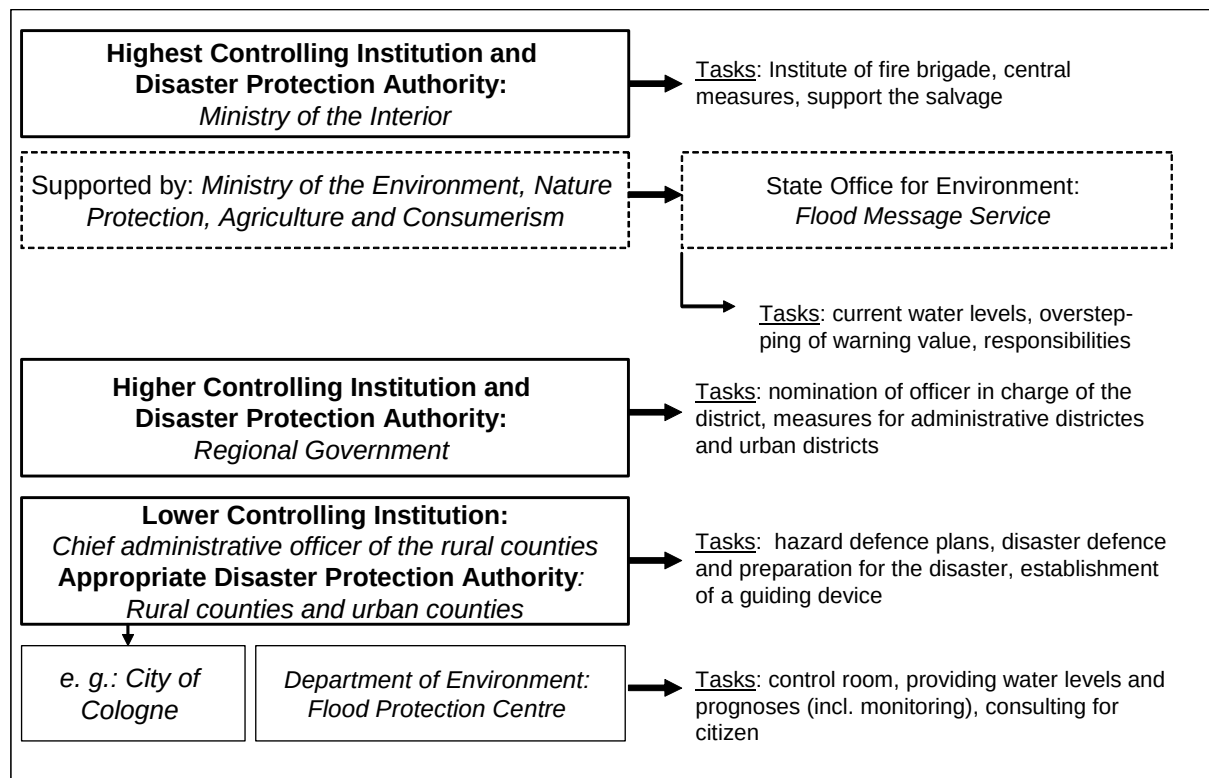


Figure 2.8 Organisational chart of emergency flood management in North Rhine-Westphalia

2.4.2 Emergency flood management

In this chapter the procedures and sequence in the case of a major flood event are illustrated. Emergency flood management is organised and accomplished by the lower disaster protection authorities that are the rural and urban districts, the measures to be implemented are described with two examples related to the City of Dresden as the capital of Saxony and the City of Cologne as the biggest city of North Rhine-Westphalia.

City of Dresden and Saxony

Flood warnings for Dresden are the responsibility of the lower water authority. There are four warning phases per water level gauge and every phase characterises a certain situation of an emergency which necessitates certain measures:

- Alert phase 1: Announcement service
- Alert phase 2: Controlling service
- Alert phase 3: Guarding service
- Alert phase 4: Flood defence.

As soon as the alert phase 3 has been activated (at a water level of 6.00 m for the Elbe River in Dresden) and alert phase 4 is expected (water level 7.00 m) the lower disaster protection authority declares “disaster pre-alarm”. If these conditions are fulfilled the disaster alarm can be activated which means that the fire brigade now has authority over the private aid organisations. Whilst the activation of disaster pre-alarm is compulsory, the activation of disaster alarm is not. However, it is possible to activate disaster alarm after the time alert phase 4 has been achieved (cf. SächsKatSVO § 9).

The basic plans for emergency flood management in Dresden are disaster protection maps, alarm, and operational maps. The disaster protection maps are used from the time disaster pre-alarm has been activated. The alarm maps are configured as registers and contain an array of information for different working groups. Well before the beginning of a flood event the operational plans are used. These plans contain general guidelines for planning and are for instance available from the fire brigades. The disaster protection plan and alarm plan maps are also available from the Management System DISMA (cf. chapter 3). In Dresden the maps neither describe processes nor do they include any ‘if-then-guidelines’, but they can be seen as databanks, including information on emergency flood management (Survey of the Department Order and Safety Dresden).

In case of an emergency flood event two special units operate. The first one is an operational and tactical guiding unit. The second one is the administrative organisational unit, the so-called administration guiding device (§ 5 KatSG Sachsen). The members of these units take up employment from the time disaster pre-alarm is activated.

Before any measures can be implemented the necessary decisions have to be made. The technical authorities (e.g. the water authorities, environmental departments) assess the situation based upon online data and onsite inspections. The appraisal is put forward to the administration unit which that assesses the available information and is responsible for decision making. Most of the measures that have to be implemented are dependent on the situation. Examples for important measures are as follows:

- Filling and distribution of sand bags for common needs (Responsibility: Department for Fire Control and Disaster Protection);
- Establishment of mobile protection walls by using maps that include water levels in half meter steps (Responsibility: Department for Fire Control and Disaster Protection)
- Closure of infrastructure and beginning of traffic diversions (Responsibility: Department for Road Engineering);
- Establishment of temporary flood defences;

- Restriction of navigation (Responsibility: Department for Shipping);
- Commencement of evacuations (Responsibility: City of Dresden).

The decision whether an area has to be evacuated is also made by the administrative units. If the operational units on location recognise that a certain area is threatened by a flood they have to inform the administrative unit which organises the evacuation. Therefore, certain steps have to be accomplished. The public needs to be informed and emergency accommodation must be prepared. Furthermore, care in emergency accommodation has to be assured and means of transport must be available. When the area is evacuated it also has to be secured. All steps of evacuation depend on the situation.

City of Cologne/North Rhine-Westphalia

In Cologne the professional fire brigade is the responsible authority for warning and leading the emergency management organisations and units. Furthermore, units are established by the operation controllers of the fire brigade. The fire brigade has to coordinate together with the Flood Protection Centre of Cologne. When high water levels are expected a crisis management group is formed in order to coordinate. In case of unexpected disastrous events the responsibilities of the crisis management group is devolved to the disaster control management.

The flood protection centre Cologne, which is established by the Department for Urban Drainage, is directly responsible to the crisis management group. The main tasks of the centre are:

- Coordination of the different offices and departments;
- Informing the urban offices about water levels and process of the flood event;
- Information and warning of the citizens and establishment of a service telephone.

Thus, there are three main working fields for the flood protection centre of Cologne:

- Providing information for the citizens and media;
- Monitoring of weather and water levels;
- Formation of the emergency management unit.

The professional fire brigade can also be supported by the Bundeswehr (German Federal Armed Forces) in erecting temporary flood protection, filling of sand bags and in controlling constructions for flood protection. With respect to warning and counselling of the citizens there are different instruments such as leaflets, posters for warning, information via radio and television, and announcements by loudspeakers. Cologne is divided into approximately 1,000 warning boroughs. There are a number of flood protection measures for Cologne that need to be implemented. Examples include the commissioning of the pumping stations, closure of infrastructure, assembling of temporary flood defences, closure and opening of dykes and flood protection walls.

The fire brigade, the Office for Fire Protection, the rescue and citizen protection are responsible for averting the danger of an emergency flood event. Operations are carried out at three levels of priority:

- The first priority is where there is a threat to people;
- The second priority is where substantial damage to properties could occur;
- The third priority covers everything else.

In Cologne the Office for Housing, the fire brigade, the Federal Armed Forces and further organisations are responsible for the evacuation in case of a major flood event. The evacuation plan is available from the professional fire brigade and it contains information about decision making for evacuations, the assessment of the time needed and the formation of working groups. There have to be several working groups for preparation of the evacuation and transport planning, warning and information, transport, assurance and control, accommodation, supervision, evacuation of animals, and

recirculation.

At water levels of 11.00 to 12.00 m in the Rhine 100,000 people have to be evacuated from Cologne. For evacuation the professional fire brigade takes over control and coordination. To undertake an early evacuation a forecast of the water levels in the Rhine is required. In parallel, numerous planning measures are undertaken and evacuation scenarios are prepared for the case of a sudden failure of flood defences.

2.4.3 Methods and models to support emergency flood management

To support emergency flood management some German cities use Disaster Management or Information Systems such as:

- Disaster Management System DISMA;
- The Flood Information and Protection System HowISS;
- Flood Information and Warning System FLIWAS.

The information system FLIWAS is still under development and will be completed in 2007. FLIWAS is based upon available information, models, data, warning and operational plans, flood hazard maps, and disaster scenarios. All the relevant data are shown via a web-based information system. The objective is to form a link between forecasting systems and operational maps of disaster protection.

The Flood Information and Protection System HowISS is used in the city of Heidelberg. HowISS is employed for the management of flood protection plans and for the preparation of an individual warning plan. The warning plan is the core element of the system. HowISS also contains a central databank. Flood forecasts and up-to-date measured data are delivered to the system. HowISS manages data concerning administrative offices, personnel, events, measures, water levels and locations. As a result HowISS generates an individual warning plan for the flood forecasts. The warning plan shows the measures that need to be implemented and the details of the implemented measures.

The Disaster Management System DISMA is applied to emergency planning and management and to the simulation of “extraordinary incidents”. It consists of the four modules data, hazard assessment, mapping, and planning and is a decision support system. The module data forms the core element of DISMA. For inquiries different filters can be used to select and show the required information (e. g. on material, equipment, means of transport). The DISMA-map provides the possibility of users managing different views and showing different maps. It is possible to connect the geographical information data with other information. It is also possible to store different maps in DISMA-catalogues, for instance flood hazard maps, flood warning maps, and evacuation maps

DISMA system used in Dresden is an important basis for the administrative emergency unit and can be understood as a databank. Decisions cannot be made by DISMA but it is important for decision-making and implementation of measures. It includes a variety of different information, e. g. on public utilities, addresses, telephone number. For certain buildings information on how many persons are living and/or working there and their age can be accessed. This may be useful information for evacuation planning. However, the DISMA system has to be maintained and used constantly. At the moment the communication in case of emergency flood events in Dresden is done via email and telephone. There is one person who records all the measures and contacts. Therefore, a log record is kept. The next version of DISMA will also include a communication-module. Figure 2.9 shows the DISMA conceptual framework. The DISMA system in Dresden is complemented by the use of systems for traffic control and information.

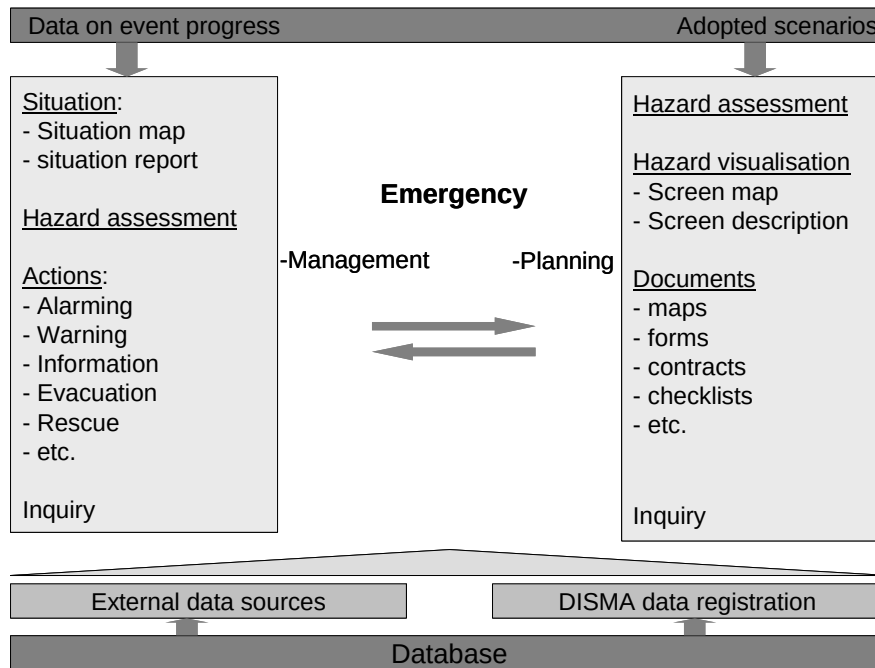


Figure 2.9 Conceptual framework of the DISMA system

The Saxon Flood Protection Centre also has a project called 'Integrated hazard map for municipal flood protection' (INGE). This incorporates software for the visualisation of flood warning documents and for giving an overview on property at risk depending on the current and expected water levels. It can be used by authorities and operational units as instrument for decision-making in planning and implementing disaster management. Within INGE database there is information concerning water levels, institutions, personnel, responsibilities, warning information, and water depth/damage curves. It is also possible to integrate digital photos, text documents, and further data. The following flood protection tasks can be supported:

- Hazard analyses and risk assessment for existing or planned objects that need to be protected
- Determination and prioritisation of measures that have to be implemented before and during a flood event
- Coordination and optimisation of operative measures of flood protection, evacuations, etc.
- Alarming of responsible persons and institutions in case of a flood event
- Information of operational units and other helpers about certain objects, possibilities of access, flooding borders, etc.
- Supporting the detailing of the implementation of measures during flood events through available information and maps
- Supporting the planning, accomplishing, and analysis of exercises and trainings for disaster protection.

INGE can be used in networks with common central databases as well as on a laptop. The core element is an interactive hazard map (INGE GIS). If the current water level is given as input to the system every object threatened by flooding could be marked and printed as map or as a list or saved and sent as an email.

All the information and data are presented in a database which is divided into clear forms. INGE can facilitate and advance the work of flood event management as well as during the phases of planning, training, and post-processing. INGE is already used in two Saxon towns (Glauchau and Meißen) and will be implemented in two more towns (Torgau and Radebeul) in the near future. Additionally, the Saxon flood protection centre also provides different maps of flood protection, such as (potential)

flood areas (the 1 in 100 year flood extent), hazard maps for certain municipalities, and areas that were flooded during the flood event 2002. In addition, there is an atlas on flood hazards in Saxony that also includes maps on damage potentials.

2.5 France

2.5.1 The legal framework for flood management and emergencies

French legislation concerning natural hazards mitigation and management has developed over the last 20 years. The key legislation is detailed in the sections below.

Law on the compensation of natural hazards victims, 1982 ⁴

The 82-600 law on the compensation of the victims of natural hazards introduced a hybrid system of compensation based on private insurance. It aimed to formalise the principle of national solidarity concerning natural hazards written down in the French Constitution. Each citizen has an obligation to be insured against natural hazards. This insurance is incorporated within their household insurance. The same proportion of the total household insurance amount is allocated to the natural hazard insurance system (15% at the moment), independently of the level of exposure of the house to natural hazards. The system is only activated if the state administrations declare an event as “an exceptional natural hazard”, typically the return period of the considered event must exceed 1 in 10 years. The damage caused by lower return period events are not insured.

A new land use regulation tool was introduced by the 1982 law to complement this insurance system, to limit new urban extensions in exposed areas: the plan d'exposition aux risques PER (risks exposition plan). According to the estimated hazards and their magnitude, these plans delimit red areas where no new constructions are permitted and blue areas where constraints concerning the constructions can be imposed. This limit on development in exposed areas is the major tool of the French natural hazard mitigation policy.

Law on the organisation of rescue services⁵, 1987

This law set up the strategic organisation of the rescue operations described below, and introduced a new management reference document: the ORSEC plan (organisation des secours, Rescue organisation). This document defines the rescue procedures and lists the available public and private means and the conditions for their use. This law also affirmed the need of the raising public awareness and the creation of a risk analysis and preventive information cell in each department prefecture (Cellule d'analyse du risque et d'information preventive; CARIP).

Law on the prevention of technological and natural catastrophes, 2003⁶

This law led to changes in the French flood forecasting system. It also reaffirmed the necessity to raise the population risk awareness. It placed an obligation on mayors to regularly inform the population about the existing risks, the prevention measures and the risk management procedures, and the obligation to make an inventory of existing flood level indications of previous major floods and mark these levels on a permanent support.

⁴ Law 82-600, 13/07/1982, « relative à l'indemnisation des victimes de catastrophes naturelles »

⁵ Law n° 87-565, 22 July 1987, « relative à l'organisation de la sécurité civile, à la protection de la forêt contre les incendies et à la prévention des risques majeurs ».

⁶ Law 2003-699, 30 July 2003, « relative à la prévention des risques technologiques et naturels et à la réparation des dommages ».

2.5.2 Emergency response

Role of local authorities and administrations

The responsibilities of the mayor

The mayor is in charge, under the supervision of the Préfet of the department, of the municipal police⁷. This responsibility includes the prevention and the management of all possible emergencies such as flooding⁸. Depending on the magnitude of the event, the mayor should also inform and ask for the intervention of the upper administrative level: the Préfet de department and the state services.

A new management tool, the municipal safeguard plan (plan communal de sauvegarde PCS) has been introduced by the article 15 of the 2004 law on the modernisation of the rescue services⁹ to help the mayor and the municipal services in this task. The PCS synthesises existing procedures to save human lives, decrease material damages and protect the environment. One part of the PCS is devoted to the possible evacuation procedures.

The implementation of a PCS is the mayor's responsibility. It is not compulsory, however, it is recommended by the law. One PCS should be written for each identified risk. To our knowledge, very few PCSs have been established in France at the moment.

The responsibilities of the Préfet of the department

The Préfet is the coordinator of the state administrations in a department. In the case of the management of a crisis which exceeds the territorial limits of a municipality, the Préfet is responsible for the supervision of the rescue operations and has the authority over the state but also local authorities rescue services. In the case of a major crisis exceeding the limits of a department, the designated Préfet de zone de défense (Prefet of the defense zone) takes in charge the supervision of the rescue operations. A national disaster is directly managed by the French Interior Minister. This subsidiarity principal is described in the articles 17 to 22 of the already cited 2004 law on the modernisation of the rescue services.

At each decision level, a document called ORSEC plan (organisation des secours, Rescue organisation) introduced in 1987¹⁰ is available. This document defines the rescue procedures and lists the available public and private resources and the conditions for their use. When the Préfet "activates" the ORSEC plan, he has the possibility to requisition these means according to the conditions defined in the plan. The owners of the requisitioned private resources receive a monetary compensation after the event. The costs of the rescue operations are paid by the municipality. In the case of a major catastrophe, the majority of the costs are borne by the French State.

2.5.3 Flood preparedness and evacuation

Raising flood awareness

A great deal of effort has been made at raising and maintaining the flood awareness of the population in France since 1987. A so called risk analysis and preventive information cell has been created in the

⁷ Art. L 2212-1, code des collectivités territoriales.

⁸ Art L 2212-2, code des collectivités territoriales « La police municipale a pour objet d'assurer le bon ordre, la sûreté, la sécurité et la salubrité publiques. Elle comprend notamment : 5° Le soin de prévenir, par des précautions convenables, et de faire cesser, par la distribution des secours nécessaires, les accidents et les fléaux calamiteux ainsi que les pollutions de toute nature, tels que les incendies, les inondations, les ruptures de digues, les éboulements de terre ou de rochers, les avalanches ou autres accidents naturels, les maladies épidémiques ou contagieuses, les épizooties, de pourvoir d'urgence à toutes les mesures d'assistance et de secours et, s'il y a lieu, de provoquer l'intervention de l'administration supérieure »

⁹ Law n° 2004-811, 13 August 2004, « de modernisation de la sécurité civile ».

¹⁰ Law n° 87-565, 22 July 1987, « relative à l'organisation de la sécurité civile, à la protection de la forêt contre les incendies et à la prévention des risques majeurs ».

Prefecture of each department (CARIP, cellule d'analyse des risques d'information preventive). It groups together elected representatives, the directors of the departmental state administrations, representatives of associations involved in risk management like the Red Cross, the local media¹¹. The CARIP is responsible for:

- The coordination of information and documents on technological and natural risks at the level of the department (Dossier Départemental sur le Risques Majeur), and the level of the communes (Dossiers communaux synthétiques). These documents provide an inventory of the risks to which the areas are exposed and of the major stakeholders at risk².
- An inventory of the camping places and tourist facilities particularly exposed to flood risks and the definition of specific risk management procedures, and possibly the decision of closing risky facilities¹² that are deemed to be at high risk.
- The preparation of the natural disaster damage compensation procedures¹³.
- The publication of information documents and recommendations on risk and crisis management. Examples are presented below.

Since the new law on technological and natural risk management was introduced in 2003¹⁴ the mayor has the following responsibilities related to the following:

- Make an inventory of existing flood level indications of previous major floods and mark these levels on a permanent support: a totem pole for instance.
- Inform the population of his municipality of the existing risks, of the prevention measures and provide details of the French damage compensation (insurance) system at least once every two years.

Evacuation

Some examples of recommendations published in the Aude departmental document on major risks (2003) are given in Figure 2.10. Aude is a region in France exposed to severe flash floods. These examples illustrate the fact that, except for camping places, evacuation is generally not recommended in France and considered as a very last resort. A suggestion was made after the 2002 floods in the Gard region¹⁵ to build refuges on the roof of some houses if they are below the maximum water level so that the occupants have a place to take shelter before being the rescued.

If evacuation is considered necessary, the procedure should be described in the municipal safeguard plan (Plan communal de sauvegarde). The typical procedures are described in the regulation 2005-1156 of the 13 September 2005. These can be summarised as follow:

- Ideally, the evacuation must be prepared for by providing a pre-alert message to the affected population to give information about a possible evacuation and explain the procedure. A second message is given at the start of the evacuation. Both messages have to be clear.
- Teams are created to organise the evacuation, with one team per area to be evacuated. If necessary, specific means are prepared for the evacuation of the population and schools, for example, transport can be requisitioned. If some of the residents refuse to evacuate their houses their location should be noted. If the situation becomes dangerous they should be forcibly

¹¹ décret d'application n° 90-918 du 11 octobre 1990 précisant le contenu et la forme des informations ainsi que les modalités de leur diffusion.

¹² Décret du 13 juillet 1994 relatif à la mise en sécurité des campings, arrêté du 6 février 1995 fixant le modèle du cahier des prescriptions de sécurité dans les terrains de camping.

¹³ Law 82-600, 13/07/1982, « relative à l'indemnisation des victimes de catastrophes naturelles »

¹⁴ Law 2003-699, 30 July 2003, « relative à la prévention des risques technologiques et naturels et à la réparation des dommages ».

¹⁵ Inspection Générale de l'environnement, 2003. *Retour d'expérience des crues de septembre 2002*, rapport technique, Ministère de l'Ecologie.

http://www.environnement.gouv.fr/infoprat/Publications/syntheses-ige/2003/media/crues_gard.pdf

evacuated. People with reduced mobility have to be identified and helped. After the evacuation, every building must be checked to be sure that there is nobody remaining in the area.

- A safe place must be designated and prepared for the evacuated people to take shelter. This is typically a public building like a school or a gymnasium. This place must be located as close as possible to the evacuated areas.
- The evacuated areas must be protected. This is to avoid looting and vandalism in the evacuated area.

<i>L'évacuation</i>  La mise à l'abri dans un refuge sur place est souvent préférable à une évacuation, notamment pour toutes les habitations qui ne sont pas fortement exposées lors de la montée des eaux.  Si l'évacuation apparaît comme l'ultime solution, - évacuer rapidement, - gagner un point en hauteur ou le refuge indiqué, - suivre strictement les consignes données par les autorités.	About Evacuation Taking shelter on the spot is often preferable to an evacuation, particularly when the buildings are not exposed to potentially destructive flood flows. If evacuation is the only option then: • Evacuate without delay • Move to high ground or an designated refuge • Follow the orders of the authorities
<i>Prévoir</i>  - l'installation, au-dessus du niveau des plus hautes eaux (dans les étages supérieurs, les combles ou sur le toit de l'habitation), d'une zone refuge accessible de l'intérieur et de l'extérieur (pour les secours),  - sur les ouvertures, des dispositifs mécaniques destinés à ralentir l'entrée de l'eau, - les moyens de surélever le mobilier ou de le monter dans les étages, - la mise en sûreté des véhicules avant l'inondation.	Before the flood • Install a refuge, above the highest known flood water level which is accessible from both inside and outside the house • Slow down entrance of water through the openings • Raise the furniture above the flood water or move it upstairs • Put vehicles in a place safe before the onset of flooding
<i>Ne pas...</i>  Ne pas s'engager à pied ou en voiture dans une zone inondée : une voiture n'est plus manœuvrante dans 30 à 50 cm d'eau ; ne pas forcer les interdictions. Reporter ses déplacements à plus tard,  Ne pas prendre l'ascenseur... pour éviter de rester bloqué, Ne pas aller chercher ses enfants à l'école... l'école s'occupe d'eux,  Ne pas téléphoner... afin de libérer les lignes pour les secours,	Do not... • Do not walk or drive in a flooded area. It is not possible to control a car if the depth of water is between 30 and 50 cm. • Do not force pass through roadblocks. Postpone your travels. • Do not take the lift as it may get stuck • Do not go and fetch your children at school. The school will take care of them • Do not use phone as the lines need to be left free for the emergency services
<i>Agir</i>  Fermer les portes, fenêtres, soupiraux, aérations... pour ralentir l'entrée de l'eau et limiter les dégâts,  Couper l'électricité et le gaz... pour éviter l'électrocution et l'explosion,  Monter dans les étages avec : eau potable, vivres, papiers d'identité, radio à piles, lampe de poche, piles de rechange, vêtements chauds, médicaments... pour attendre les secours dans les meilleures conditions,  Écouter la radio... pour connaître les consignes à suivre,  Se tenir prêt à évacuer les lieux à la demande des autorités... prendre ses papiers d'identité et si possible, fermer le bâtiment.	Act • Close doors, windows and other openings to slow down the entrance of water and limit the damages. • Switch off the electricity and gas to avoid electrocution and explosions. • Go upstairs with: drinking water, supplies, identity papers, radio, torch, batteries, warm clothes, medicines and wait for the assistance under the most favourable conditions. • Listen to the radio to get the latest instructions • Be ready to evacuate when requested to by the authorities' request. Take your identity papers and if possible lock your home.

Figure 2.10 Extracts of the Aude departmental document in France on major risks

2.6 Hungary

2.6.1 Background to flood management in Hungary

In Europe, Hungary ranks only behind the Netherlands with respect to flood exposure with over two-thirds of its arable land at risk to fluvial, ground water and flash flood. In Hungary, like many of the

former socialist countries of Central and Eastern Europe, the central government has traditionally taken the primary responsibility for protecting the public from all aspects of floods. The water authorities have invested large sums in a network of flood defences. Together with taking full responsibility for protecting the Hungarian public from flood risks, the government is held accountable for any water that comes through or over the flood defences. Although there is no statutory requirement for the Hungarian Government to compensate flood victims, the national authorities almost always take full liability for private damages in the event of a breach of flood defences, and compensate victims for other types of flood damage such as groundwater inundation.

2.6.2 The institutional framework for flood management

Under the current Water Act, the responsibility for undertaking technical activities related to flood defence for structures owned by the state is assigned to the state water agencies, the State Water Service (SWS). The SWS is also responsible for the regional planning, organisation and professional guidance and supervision of flood control and emergency operations of other interested parties, including supply of all the data and information concerning hydro-meteorological and fluvial hydraulic conditions, as well the structural conditions of existing flood defence structures in order to assist the preparation of structural and non-structural preventive and emergency plans of other organisations. The SWS comes under the remit of the Ministry of Environment and Water (MEW), the National Water Centre (NWC) and the Environmental and Water Directorates (EWD).

In terms of flood management Hungary is divided up on the basis of the catchments into 12 districts, each with its own district water authority. The legislation, policy and strategy of the SWS are set by the MEW, while the operative control of the EWDs is provided by the NWC. The local functions are performed by the EWDs. The Minister of MEW controls the technical functions of flood fighting with support from the National Technical Controlling Headquarters providing the workforce and resources of the SWS can control the emergency situation.

The operation and maintenance of the flood defence in a particular area is the responsibility of the local director of the EWD involved. When a flood emergency occurs the entire personnel, machines, equipment, and materials of the EWD can be mobilised should this be required. This is in accordance with the plans prepared in advance for an emergency service. The flood defences that an EWD is responsible for usually consist of 10 to 15 sections, each of which are usually between 30 to 50 km in length.

2.6.3 Organisation of flood emergencies in Hungary

Direct technical assistance in flood emergencies is provided by the Flood and Drainage Emergency Organisation (FDEO) which is located in Budapest. It has a trained workforce, machines and equipment that enables it to carry out a variety of engineering operations, such as pile and sheet pile driving, dewatering, blasting, separate country-wide communication, ice control with special ice-breakers and aerial reconnaissance with the own flying service.

During a flood emergency the FDEO is under the direct control of the National Technical Controlling Headquarters. Defence squads equipped are available at each EWD. The National Forecasting Service within the Environmental Protection and Water Management Research Institute (VITUKI) supports floods emergency activities by collecting, and analysing the hydrometeorological data and compiling these into flood forecasts.

In addition to these technical flood defence activities, a number of administrative measures are necessary, such as planning and carrying out rescue operations, evacuation and resettling, mobilisation, transport, health and other care of the public workforce involved in flood fighting, policing the inundated areas, assessment of damage etc. The implementation of the administration activities related to defence is organised and guided in the case an of emergency by the Municipal (County) Local Defence Committees established under the CX Act on Defence, 1993 legislation. These committees are presided over as follows:

- In the case of the Municipal Defence Committee by the Lord Mayor;
- In County Defence Committees by the chairman of the county assembly;
- In Local Defence Committees by the mayor. The members are the heads of the regional and local organisations who are competent in various activities: the director of (county/municipal) public administration office, the town clerk, the mayor of a town vested with county rights, the commander responsible for the deployment of armed forces and other organisations determined by the Government (e.g. police, border police, civil defence, communications inspectorate, the transportation authority, the water authority).

The liaison officers attached to the various relevant ministries support the Minister of MEW in coordinating the technical and administrative issues of emergency activities. The flood defence organisation is responsible for flood defence with respect to technical, issues, warnings, rescue and evacuation plans. Staff members, workforce and equipment in EWDs where there is no flood emergency may be assigned to flooded areas that require additional resources.

In emergency situations, which cover large areas, and where several EWDs are no longer capable of handling the situation, the government commissioner assumes control. The commissioner is the Minister of MEW. To perform all the required activities in such emergency situations, he is vested with powers to draw on the labour of the population, as well as on the equipment, tools, materials, machines and vehicles of private sector organisations, based on the rules laid down in the National Flood Emergency Mobilisation and Cooperation Plans. In cases where the public workforce is inadequate, he can mobilise the military, civil defence and the police. In the case of national emergencies, control of the situation is assumed by a Governmental Co-ordinating Committee (GCC), the members of which are the administrative state secretaries of the sectors involved in flood fighting.

The organisation of “local damage control” is the responsibility of the municipalities. Local damage control includes the mitigation of effects of intensive local rainfall that might cause inundation in low lying areas and mitigating the effects of flooding from small streams. The organisation of local damage control is based on the local government structure of the various communities. The head of the defence organisation is the mayor, who is free to request in cases of emergency technical assistance from the EWD competent in the area.

2.6.4 Evacuation and rescue planning

Although evacuation and rescue modelling is not carried out in Hungary evacuation and rescue plans are prepared regularly. These plans cover all types of emergency situations including flooding, chemical spills, terrorist attacks etc. This section presents the methodology and the content of the evacuation and rescue planning for flooding.

The flood management and the emergency management belong to two different ministries, namely the Ministry of Environment and Water Management and Ministry of Interior. The two organisations co-operate in the planning phase as well as during the emergency situation.

The evacuation and rescue plans for flooding are prepared in two phases. The water management prepares a so called “localisation plan” which provides all the information of the possible inundation including water depth, velocity, duration and lead time. It also includes possibilities of “localisation” (confinement) of the inundation by defining those locations where the spreading of water can be prevented or delayed. Based on this information the second phase of the evacuation/rescue plan is prepared. The emergency/rescue plans cover saving people, livestock and materials. It also deals with environmental problems (e.g. prevention of spreading of pollutants). A typical table of content of an emergency plan includes:

- I. General description and major data of the town
- II. Glossary (explanation of terms used in the document)
- III. Legal background

- IV. Task during/prior to flooding
 - IV.1. The flood prone area
 - Number of inhabitants to be evacuated/rescued
 - Evacuation/rescue routes (roads, rail, traffic control points etc.)
 - IV.2. Shelter service
- V. Check-list of task to be performed
- VI. Shelter register
- VII. Catering facilities
- VIII. Register of Hospitals
- IX. Registry of vehicles (available for evacuation)
- X. Registry of materials needed for the evacuation

The plan considers the number of people to be evacuated at the level of houses and/or block of houses, depending on the density of population. It also takes into account the number of vehicles (e.g. buses) available for transportation, the escape routes and the shelters with their capacity. The catering facilities, hospitals with the number of beds are also included into the plan.

The annexes of the evacuation/rescue plans include:

- The organisation charts of the emergency organisation at different alert levels;
- The names, addresses and telephone numbers of emergency crew;
- A “to-do-list”;
- The transportation needs, with the meeting points;
- The available transportation means;
- The material needs (e.g. beds, blankets, tents).

The emergency/rescue plans are updated yearly.

2.7 Summary for the European Union

On a European level two legal frameworks (Bouchon, 2005) are relevant with respect to flood risk management. The first one is the framework on water and water management, the second is on the framework on civil protection. These are detailed below.

2.7.1 Framework on flood risk management

The framework on flood risk management describes the legal instruments and policy objectives. The European Commission Communication COM (2004) 472 of 12 July 2004 "Flood risk management - flood prevention, protection and mitigation" analyses the measures already taken and proposes an action programme on flood prevention, protection and mitigation. The European Commission proposes that the Member States should cooperate with it, to draw up and implement a coordinated action programme for flood prevention, protection and mitigation. This action plan would include in particular:

- Improving cooperation and coordination between Member States, through the development and implementation of flood risk management plans for each adversely affected river basin and coastal zone;
- The development and implementation of flood risk maps by the Member States;
- Improving information exchange, sharing of experiences, and the coordinated development and promotion of best practices. These measures would in fall within the responsibility of the European Commission;
- Developing stronger linkages between the research community and the authorities responsible for flood management;
- Improving coordination between the relevant community policies;
- Increasing awareness of flood risks through wider stakeholder participation and more effective communication.

- The communication also sets out guidelines concerning the essential features of the flood risk management plans and flood risk maps to be drawn up by the Member States.

Before the proposition of this action programme, the Communication COM(2002) 481 from the Commission to the European Parliament and the Council entitled “a solidarity based initiative: the European Community response to the flooding in Austria, Germany and several applicant countries”(2002) had drawn up a list of measures that can be taken directly and in the future, in particular the creation of an EU Disaster Relief Fund, to come to the aid of the Member States and applicant countries, whose citizens suffer, as a result of natural disasters in general and flooding in particular. This communication sets the need for financial resources to help the affected countries to recover. For this, the European Commission was planning mainly to:

- Reallocate existing resources using the possibilities offered by the rules governing the Structural Funds, the common agricultural policy (CAP) and aid to the applicant countries;
- Establish a Disaster Relief Fund at Community level to respond to the consequences of major disasters by rapidly mobilising the necessary resources;
- Modify their development programmes so they can:
 - Concentrate funds on flood-related measures in affected regions under ongoing operational programmes and single programming documents;
 - Introduce new measures to rebuild infrastructure and for productive investment in companies and training and employment schemes;
 - Shift funds from other measures and priorities to the appropriate existing or newly-created measures.

2.7.2 Framework on civil protection

A second relevant legal and institutional framework is the framework on civil protection. Before the first Community Action Programme in the field of civil protection, the implementation of the Resolution 91/C198/01 of 8 July 1991 on improving mutual aid between Member States in the event of natural or technological disaster established several operational instruments. Instruments have been established by the European Commission in collaboration with the Civil Protection Authorities of Member States to ensure better preparedness in the case of requests for mutual assistance. Following this, the Council Decision 98/22/EC of 19 December 1997 established the first Community action program in the field of civil protection. This first Community action programme sets up an action program to foster cooperation among the Member States in the field of civil protection. It lays down a Community program to protect the environment, people and property in the event of natural or technological disaster. Its purpose is to step up cooperation on civil protection between Member States. In accordance with the principle of subsidiarity, Community cooperation supplements national action, in order to make the national programs more effective. Funding for specific actions is subject to certain criteria. The objectives of the specific actions are:

- To lessen risk and damage to persons, property and the environment;
- To increase the degree of preparedness of those involved in civil protection (training courses, exchanges of experts, simulation exercises);
- To improve response techniques (developing and adapting new technologies to the requirements of civil protection);
- To promote information and raise public awareness of the rules of self-protection (e.g. travelling exhibitions, distribution of information material)

The perspectives for future developments in this field refer to the conclusions of the recent Communication from the European Commission (COM (2004) 200) entitled "Reinforcing the Civil Protection Capacity of the European Union" (2004). The Communication examines the EU's capacity for civil protection intervention, both inside and outside the EU and proposes improvements where necessary. The European Commission reports that, two years after its entry into force, the Community

intervention mechanism has shown that it can work to the benefit of participating countries. However, it notes that a number of issues require special attention:

- Information gaps, in respect of which the European Commission proposes defining the types of emergency most likely to trigger the Community mechanism and the available response capabilities in terms of personnel and equipment;
- A need for more training and a focus on interoperability, notably by means of further development of a programme of training and joint exercises;
- A need for better communication and improved coordination, notably between the various instruments available to the EU and by requiring Member States to inform the Monitoring and Information Centre when a major disaster occurs and/or whether they call for assistance or respond to such calls;
- Financial issues, both inside and outside the EU, in respect of which the Commission proposes to review and possibly extend the possibility of Community funding for transport costs, for operations both inside and outside the EU, and to examine the feasibility of providing immediate funding to Member States, where the costs associated with additional emergency measures overwhelm their immediate financial capacities.

In conclusion, the EC as such does not employ methods and models towards evacuation management. Given the principle of subsidiarity, this is deemed to be a national task. The White paper on European governance (COM(2001) 428) states that from the conception of a policy to its implementation the choice of the appropriate level of action is supposed to be proportional to the level of at which action is taken.

2.7.3 Institutional framework

In a European institutional framework the numbers of entities or actors that play a role depend on the scale of the event. Owing to the principle of subsidiarity events are dealt with at the lowest possible level and are only subject to European intervention if cross-border effects occur. European actions are geared towards supplementing national actions in order to make them more effective.

2.7.4 Emergency flood management

The Natural Environment and Disaster Management and Information Exchange (NEDIES) project has produced information on lessons learnt and that have been gathered with respect to floods and flood management. NEDIES is a European Commission project developed in the framework of the DG Joint Research Centre Institutional Programme "Safety and Emergency Management for Man-Made and Natural Hazards" aimed to support EU policies, mainly those of the Civil Protection and Environmental Emergencies Unit of DG Environment, in the area of prevention, mitigation and management of natural risks and technological accidents.

The lessons learnt emphasised the following:

- Strategic coordination;
- Role designation;
- Task prioritisation through risk assessment and forward planning;
- Training and formation of all stakeholders;
- Inter-disciplinary collaboration;
- Inter-organisational collaboration;
- Forecasting, alert and warning systems;
- Availability of material and human resources;
- Allocation of material and human resources;
- Communication strategies;
- Dissemination of information to the public;
- International co-operation.

It is important to note that the lessons learnt mostly fall within the domain of “soft” approaches. Typically they cover the field of organisational aspects and the implementation of data and information.

2.7.5 The Inspire directive and its implications for flood event management

INSPIRE (Infrastructure for Spatial Information in Europe) is an initiative launched by the European Commission during 2002 and developed in collaboration with Member States and accession countries. It aims at making available relevant, harmonised and quality geographic information to support formulation, implementation, monitoring and evaluation of community policies. The INSPIRE Directive, a major initiative of the European Commission, will provide rules and regulations on the availability and harmonisation of geospatial data. It has a strong link with other regulations concerning the management of natural hazards such as the new Flood Directive. This last directive will require preliminary flood risk assessments of river basins and coastal zones completed across the EU by 2011, flood hazard maps drawn up by 2013 and flood risk management plans to be in place by 2015. These tasks require an intensive use of geospatial data. Owing to its approach, in which it puts emphasis on river basins and not on political territories as the unit of analysis, a strong need arises for the trans-boundary exchange of geospatial data concerning flood risks and therefore on data harmonisation.

The introduction of the INSPIRE directive will pose certain guidance on how such data on flood risks should be published and harmonised, an effort that will not just affect the national activities but that will also permeate through the lower more local levels of government. It is with this in mind that a requirement arises for the type of data and the publication of data used and produced in flood risk management. Data should be published accompanied with meta-data according to guidelines laid out in the INSPIRE Directive and its implementation rules. These guidelines can be found at the inspire website: <http://www.ec-gis.org/inspire/index.cfm>. It is recommended that flood risk managers become familiar with this legislation and investigate what it implies for their operations

2.8 The cost of evacuation

There appears to be little readily available reliable data in Europe relating to the cost of evacuation. During the August 2002 Elbe river flood in Germany a significant effort was to evacuate people as well as commercial and agricultural assets. The official evacuation of people was implemented by the official disaster management bodies such as fire brigades or the police, and the Federal Armed Forces. However, the majority of people organised their evacuation and accommodation themselves (Von Kirchbach, 2002). This makes it difficult to estimate the costs of the evacuation (Olfert, 2007).

With regards to the resources required for the costs could be calculated for personal, transport and consumables (e.g. fuel) of the various organisations involved. For example, in the Freestate of Saxony, evacuation of people was supported by the German Federal Armed Forces. It has been estimated that their effort with respect to the evacuation and flood fighting amounted to 1.5 million km travelled in vehicles, 15,500 operating hours of heavy machinery, 2,265 helicopter flying hours and 50 reconnaissance missions by tornado jet aircraft (SMUL, 2003). However, many more organisations were involved in the evacuation and additional aircraft were used for the evacuation of 2,900 patients from inundated hospitals in the city of Dresden.

The above figures apply to more than just the evacuation. The evacuation is only one component of disaster management and the corresponding efforts are usually counted jointly with the other tasks related to flood risk management. As a result, it is difficult to isolate the evacuation costs. In Germany the disaster management costs are sectoral and contain evacuation costs as part of the overall effort. The Federal Ministry of Justice refers to a total of €224 million disaster management costs for the German Länder only. For the Freestate of Saxony the state wide disaster management costs were reported to be €136 million (SMUL 2003). There is one cost directly related to evacuation that can be identified, relocation costs for hospitals amounting to €11 million. However, additional items such as

disaster management costs of €88 million or costs of local fire brigades €10 million are also likely to contain evacuation costs, which however, cannot be detailed.

An additional aspect of evacuation costs are accommodation costs which are part of evacuation costs. It is known, that during the August 2002 Elbe river flood 7,400 beds were made available in 43 local schools (Von Kirchbach 2002) for evacuated population and helpers. However, this effort is not described in financial terms.

What has been described for the evacuation of people is similar for the evacuation of commercial and agricultural assets. Available figures mainly provide the general overview. For example, the IKSE (2004) describes that evacuation and clearance costs of the August 2002 Elbe river flood amounted to €15 million for 1,375 agricultural companies. The MLU (2003) shows the evacuation costs for agriculture for the State Sachsen-Anhalt to be €1 million. More detailed figures on evacuation costs are, for the time being, not part of the official disaster management information.

There has been some work carried out in the USA by Whitehead, 2000 relating to the evacuation costs for hurricanes. The best estimate of hurricane evacuation costs in North America were the often-stated to be approximately “one million US dollars per mile” of evacuated coastline. In a sample of North Carolina residents who experienced 1998’s Hurricane Bonnie, evacuation behaviour was used to estimate household evacuation costs to estimate the aggregate opportunity costs of hurricane evacuations (Whitehead, 2000). The hurricane evacuation costs for ocean counties in North Carolina ranged from about US\$1 to US\$50 million depending on storm intensity and emergency management policy. These costs were found to be much less than “one million dollars a mile” of evacuated coastline (Whitehead, 2000).

2.9 Conclusions

There main conclusions relating to flood event management practice are as follows:

- Most countries within the European Union make a distinction between the organisations that are responsible for water management and the organisations that are responsible for emergency management;
- Responsibility for developing and implementing emergency plans often takes place at a local authority or local government level;
- There is limited experience within the European Union of employing systematic approaches and modelling tools to develop evacuation plans for flood event management. If the tools do exist then and are employed in practice they are often very generic and only applicable at a macro-level as detailed in Chapter 4;
- There is a need for more training and a focus on “interoperability” between different agencies;
- Good co-ordination and communication between the organisations that are responsible for responding to floods is important for good flood event management and effective evacuation;
- The costs of evacuation are not well reported or easy to quantify.

3. User requirements for evacuation planning

3.1 Introduction

The objective of this chapter is to detail the user requirements for planning evacuations in response to a flood and to understand the requirements of an evacuation planning tool from an end users' and decision makers' point of view. The information contained in this chapter is based on a number of surveys of end users carried out in France, the Netherlands and the UK.

3.2 Organisation of evacuation planning

3.2.1 Introduction

At this stage it is important to involve all the relevant stakeholders and make them aware of their responsibility during a flood emergency. The raising of this awareness serves to prepare the stakeholders so they can plan their business continuity. The planning of an evacuation can be seen as the main activity that contains the other six activities. It is a separate stage in the process. However, evacuation planning is not an activity that stands alone; it is an option in a wide range of available options in the field of disaster management. Besides this the planning for evacuations is part of an ongoing process of local (and regional) stakeholders.

3.2.2 Stakeholders

At this stage it is important to develop an understanding of the various roles stakeholders can have. Different stakeholders have indeed different responsibilities and communicate in different languages. It is therefore important to meet at an early stage and reach consensus about the process, the goals and the communication.

Depending on the legal framework, various stakeholders can be involved in the process of emergency planning. Stakeholders can be divided into two groups according to their involvement, either direct or indirect. There is a group of stakeholders with a direct stake due to their duties and responsibilities. This group typically has a certain amount of power in deciding on the strategy. A second group will have an indirect stake owing to the fact that they are affected but they are lacking this certain amount of power or a say in the decision making process.

3.2.3 Lessons learnt

Lessons learnt from evacuation planning in other countries show that at this stage it is important to:

- Define organisation structures;
- Design communication strategies;
- Define task and duties according to (i) capabilities, (ii) legal duties and responsibilities;
- Organise the available data in a systematic way e.g. through the use of a common language;
- Develop a strategy on how to use resources in which main priorities on use are defined.

It is also important to understand who takes responsibility for the road network and its management.

3.2.4 Information requirements

The information requirements can be summarised as follows:

- (i) Roles and responsibilities of stakeholders need to be defined;
- (ii) Data - An overview should be gained of what kind, how much and what quality of data is available to support the decision making process.

3.2.5 User requirements

User requirements at this stage can be summarised as follows:

- The identification of functional involvement in the planning and evacuation process;

- Assessment of possible evacuation planning zones and identification of elements at risk and their owners/operators;
- Assessment whether the available data is sufficient and of good enough quality to be used in decision making.

3.3 Designing of an evacuation plan

3.3.1 Introduction

Once stakeholders have been organised into working committees the planning for emergencies can start. Whereas in the previous stage the emphasis was on organising the planning this stage concerns the planning for the events, which includes the evaluation of diverse scenarios and the distribution of tasks and activities.

3.3.2 Stakeholders

Various stakeholders are involved at this stage, as identified in the “organising the planning” stage, most notably: local government stakeholders in the field of law-enforcement, transport, civil protection.

3.3.3 Lesson learnt

Lessons learnt from evacuation planning in other countries show that at this stage it is important to:

- Prioritise interventions;
- Take into account the duration of a flood;
- Plan for rescue services;
- Design a strategy for the deployment of resources;
- Assess the amount of available resources.

3.3.4 Information requirements

The following information is required at this stage:

- (i) **Assessment of available resources** - An assessment of the available resources needs to be carried out (e.g. availability of vehicles for evacuation).
- (ii) **Flooding scenarios** – This could include the extent, depth and velocity of the water for a variety of scenarios.

3.3.5 User requirements

At this stage the stakeholders have the following requirements:

- Data on people to evacuate and the resources available;
- Knowledge on the potential flooding pattern, as characterised by the timing of flood, flooding depth and flow velocity for different scenarios. T
- An estimate of the time required for evacuation. This information can be compiled for the different flooding scenarios using an evacuation model.
- Information for the different flooding scenarios of the possible number of casualties.

3.4 Pre-flood awareness

3.4.1 Introduction

The objective at this stage is to develop an understanding of the level of risk in certain situations. The key stakeholders involved are usually local government and depending on the scale of the event that is being prepared for, also higher levels of government. At this stage emergency planning zones are often defined.

3.4.2 Lesson learnt

Lessons learnt from pre-flood awareness in other countries show that at this stage it is important to:

- Communicate plans to public at large;

- Make plans publicly available;
- Raise an understanding of warning codes;
- Regular exercises are the only way to maintain pre-flood awareness and preparedness.

3.4.3 User requirements

To deliver an evacuation message containing the main evacuation routes, description of safe havens and a description on how to behave during an evacuation to the affected inhabitants. This message should be differentiated according to the situation of the inhabitants regarding risk, evacuation routes and safe areas and shelter place.

Awareness and preparedness of staff of the involved authorities and services can be increased and maintained by regular exercises. An important role of these services is to emphasise the coordination among different organisations with different roles. Exercises should be held at different levels, ranging from the practical implementation of traffic control to strategic consultations between the highest representatives of the organisation. To implement higher level exercises flooding and evacuation scenarios are required as an input.

3.5 Flood emergency stage

3.5.1 Introduction

The objective of this activity is to decide on whether to start an evacuation. An evacuation can be started if the forecast situation is deemed to be so severe that staying in place is no longer an option. If staying put is not an option as the degree of risk a population is unacceptable then an evacuation can be commenced. The key stakeholders at this stage are generally Local Governments employees.

The main activity at this stage is to make an assessment of the elements at risk and to see whether or not the current level of risk meets a pre-defined threshold of risk that is deemed to be the threshold between acceptable and non-acceptable risk.

3.5.2 Lessons learnt

Lessons learnt from flood emergencies in other countries show that at this stage it is important to:

- Planning of event in advance;
- An emergency plan is necessary but in some cases not sufficient;
- Informal networks of linked communities;
- Long term inundation may require additional evacuations due to decrease in quality of life in directly affected and indirectly affected areas;
- Flood plans should be made available at large;
- Any planning should be integrated with hydrological forecasting;
- Planning should include availability of roads during an event.

3.5.3 Information requirements

The following information is required at this stage:

- An assessment of the elements at risk** - This includes properties and vulnerable people.
- An assessment of the advantages and disadvantages of evacuation** – This should include an assessment of the injuries prevented and the lives saved weighed against the risks.

3.5.4 User requirements

The users require the following information:

- The likelihood of the occurrence of a flooding event;
- Possible size and extent of the flood event;
- The elements at risk;
- Possible number of casualties;
- The time required for evacuation;

- The current and future state of the road network and the time left for evacuation.

3.6 Assessment of evacuation options

3.6.1 Introduction

The main objective at this stage is to decide on the main evacuation routes. Once it has been decided that an evacuation has to be commenced it becomes important to monitor the situation and keep track of possible implications of changes. The key stakeholders involved at this stage are those with a responsibility for the road network (e.g. local governments, police forces, highway authorities, owners of road networks).

3.6.2 Lessons learnt

Lessons learnt from flood emergency in other countries show that at this stage it is important to have:

- Risk information contributes to identifying evacuation routes and shelters;
- Information on road network availability is crucial for rescue services.

3.6.3 Information requirements

The following information is required at this stage:

- (i) Development of risk during the evacuation of the population**
- (ii) Development of risk during possible evacuation in terms of civil protection**

For both of these it is important to have an idea of the availability of the road network as the flood event progresses.

3.7 Evacuation

3.7.1 Introduction

At this stage the main objective is to alert the population that they are to be evacuated. There is also a requirement to provide for a timely and safe clearance of people from an area. This needs to be done by providing effective warning messages to people. The key stakeholders at this stage are the local government and population to be evacuated.

3.7.2 Lessons learnt

Lessons learnt from evacuations in other countries show that at this stage it is important to:

- Identify the most vulnerable people;
- Coordinate records of evacuees;
- Arrange for auxiliary transport;

3.7.3 Information requirements

The following information is required at this stage:

- (i) Who to warn** - A list of household addresses containing the exact households which are supposed to be evacuated is required.
- (ii) Contents of the message** – The warning message should clearly communicate to the public the actions that they have to undertake.

3.7.4 User requirements

The user requirements at this stage are as follows:

- A list of addresses that need to be reached;
- A message containing information on collection points, routes and shelters;
- Instructions for how to behave during an evacuation for the public;
- Registration system for determining the end of evacuation.

The final evacuation plan needs to be disseminated to the proper authorities and proper traffic management needs to be implanted on the basis of this plan.

3.8 Shelter

3.8.1 Introduction

The objective at this stage is to temporarily shelter the inhabitants until they can return home. People are normally housed in shelters that are typically large public buildings that provide enough space and facilities to keep people e.g. schools and sports halls.

3.8.2 User requirements

At this stage an inventory of large buildings, that provides enough basic facilities, to shelter the people who have been evacuated for a certain period of time is required. An inventory also needs to be made of nearby suppliers of necessary material for sheltering people (beds, linen, sanitary equipment, food, and drinks)

3.9 Return

3.9.1 Introduction

Once the flood has receded people usually want to return to their homes. The objective at this stage is to assess if this is possible

3.9.2 User requirements

The same service that delivers the assessment of risk in the first stages of a disaster could in theory also deliver the same service in this stage. This means that a continuous assessment of risk in the emergency planning zone is needed in order to know at what point in time the area is safe enough to return to.

3.10 Conclusions relating to user requirements for evacuation

The following general conclusions can be reached:

- The timing, speed and method of communication of reports are critical to effective emergency management during a flood;
- A knowledge of the road network, location of the vulnerable elements at risk and evacuation times are key to evacuation planning;
- Robust and integrated communication links between the organisations involved in the response during a flood helps to ensure an effective response;
- A flood event management system that provides estimates of flood extents and depths for breach scenarios would assist with emergency response;
- Organised evacuation is only used as a form of emergency response in very rare circumstances. In most of Europe the authorities have no powers to forcibly evacuate people from their houses during floods and most evacuation is initiated by individuals or households;
- There is need for tools and methods to assist in the planning of evacuation/rescue operations and to estimate the optimal use of the transport network and the time required for execution of an evacuation;
- There is little experience within the European Union of using methods and models to support the planning and execution of evacuation and rescue operations for flood events.

The following conclusions have been reached regarding concerning the various stages of the evacuation process.

(i) Planning

There is a requirement for forward planning and risk assessment when it comes to evacuation. This would focus on the actions that need to be done during an evacuation and would compare them with the amount of resources available. The goals would be:

- To understand at what point a disaster turns into a crisis and external help is deemed to be necessary.
- To understand what tasks and activities need to be carried out and how these should be priorities under different circumstances.

(ii) Pre-flood awareness

There is a need to deliver an evacuation message during a flood emergency containing the main evacuation routes, description of shelters, and a description on how to behave during an evacuation.

(iii) Flood emergency stage

During the flood there is a requirement for the following:

- Information on size and extent of the flood event;
- Information on elements at risk;
- Information and characterisation of a critical level, i.e. a pre-determined threshold that, if exceeded, still allows for safe clearing of an emergency planning zone.
- Damage assessment and calculation of cost of evacuation.

The ultimate goal is to have an informed decision on the value of an evacuation. This would provide decision maker with an insight of in to the advantages and disadvantages of evacuation.

(iv) Assessment of evacuation options

An assessment of the evacuation options needs to be made including:

- The risks associated with various evacuation options;
- Identification of safe areas and shelters;
- An inventory of auxiliary transportation that can be used and called upon;
- Identification of collection points.

(v) Shelter

An inventory of large buildings that provide enough basic facilities to shelter the evacuees is required. A list of suppliers of materials such as beds, linen, showers, food, and drinks is also useful.

(vi) Return

There is a need to assess risk continuously in the emergency planning zone so that it can be established at what point in time the area is safe enough to return to.

(vii) Debriefing

There is a requirement for stakeholders to compare their actions in the context of the flood event with their pre-determined objectives. If large discrepancies exist, then these need to be explained and the explanation need to be used to up-date existing evacuation and response plans.

4. Background to evacuation modelling for flood event management

4.1 Introduction

The modelling of the evacuation process generated by an approaching flood is important for those responsible for the efficient and safe movement of people during evacuation. It can identify “bottlenecks” in the system before they are experienced in an evacuation, it can also be used to determine the impact of road closures due to flooding, the impact of phased evacuation on traffic loading, and many other possible consequences of an evacuation event. Being able to model alternative evacuation scenarios can lead to the establishment of appropriate evacuation policies, strategies, and contingency plans and can help facilitate communication and information transfer.

Preparation for emergency action must be taken before the event. Some of the reasons for early preparation are that the conditions within a disaster affected region tend to be chaotic. Communication is difficult and command structures can break down because of logistical or communications failure. Human behaviour during the emergency is hard to control and predict. There is a need for improving the following:

- Understanding of the social side of emergency management processes;
- Understanding of human behaviour during the emergency;
- The communication between the population affected by the disaster and emergency management authorities;
- Preparedness through simulation, or investigation of “what-if ” scenarios.

This Chapter provides some general background to the different types of evacuation model that are used at different scales for flood event management.

4.2 Micro, macro and meso scale evacuation modelling

There are three main scales at which evacuation models are employed for flood event management as follows:

- **Micro** – This corresponds to a scale where each individual receptor at risk (e.g. person, vehicle or property) is modelled and there is a detailed representation of the evacuation routes. A complex modelling system (e.g. an agent-based model) is often used to estimate the evacuation times for each individual receptor;
- **Meso** – This corresponds to a scale that is between a micro and macro-scale. In meso models the receptors are lumped together. The evacuation time is estimated by assessing the demand for and the capacity of the evacuation routes, which are evaluated on a geographical basis;
- **Macro** – In a macro model the receptors are lumped together. The estimates of the evacuation times are based purely on the distance to the exit of the at risk area, the capacity of the route and the average evacuation speed. A macro scale model is often used to provide an initial estimate of the evacuation time for a large area. (e.g. at a regional scale).

The distinction between micro, meso and macro scale evacuation models and the typical scales at which they are applied is shown in Figure 4.1. The type of evacuation model that is appropriate for a particular flood risk area will depend on the level of risk and the processes which the evacuation modelling is seeking to inform. A densely populated urban area where the scale of potential evacuation is large may require a detailed simulation model where the traffic and flood hazard is modelled in a truly dynamic way. An understanding of the level of congestion delay that is inevitable under even the most effective traffic management schemes, and also the level of spontaneous evacuation that may occur in advance of an official evacuation warning are other issues that need addressing.

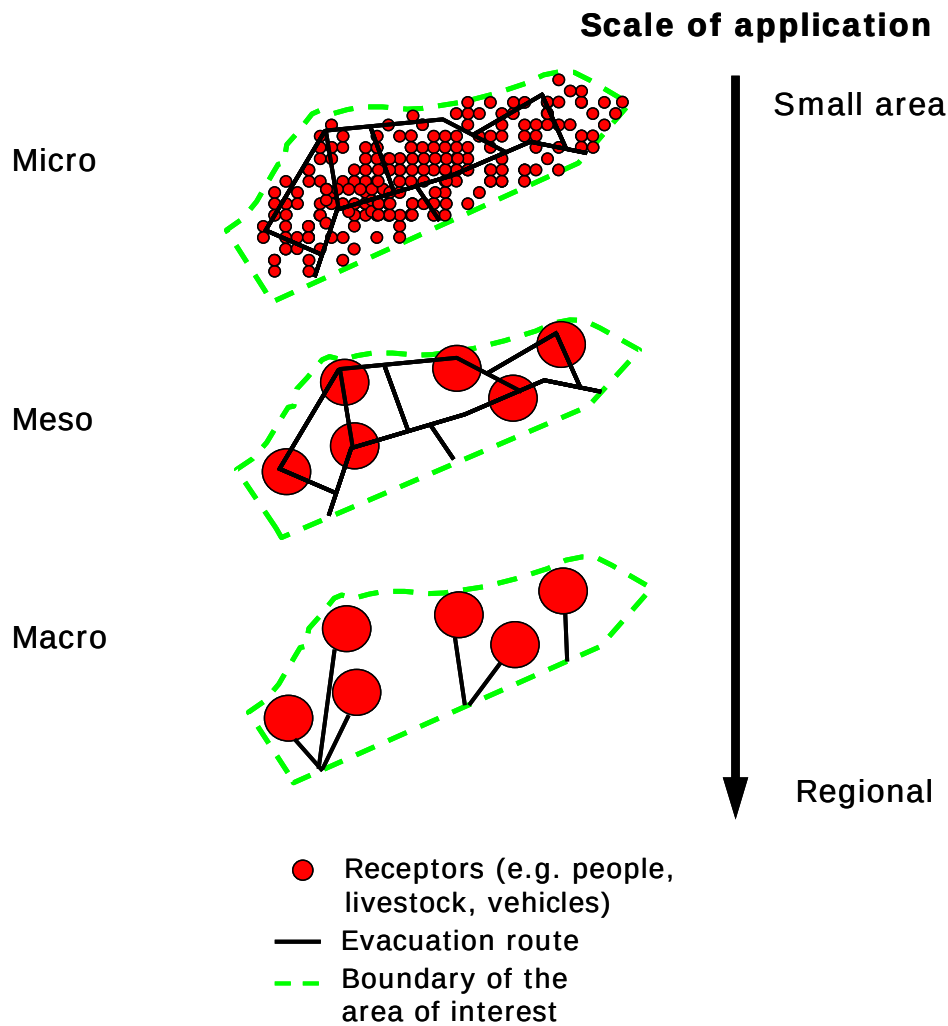


Figure 4.1 Micro, meso and macro scale evacuation model with the suggested scale of their application

4.3 Data requirements for evacuation modelling for flood event management

To realistically simulate a major population evacuation, the following information is required:

- A description of the transportation infrastructure, most usually the road network and also pedestrian routes where applicable;
- A description of the spatial distribution of population, by time of day and type of activity;
- A description of vehicle utilisation during an emergency of the type under consideration;
- A representation of the timing of people's response to the emergency, and how this timing varies by a person's location and current activity at the time that they find out about the threat;
- A representation of evacuee route and destination selection behaviour;
- A representation of any traffic management controls that may be incorporated within the evacuation plan;
- A representation of any non-evacuation based protective actions taken by significant population sub-groups within the area at risk;
- A representation of the flood hazard in terms of extent and sometimes in terms of the spatio-temporal variability of the depth and velocity.

4.4 Review of evacuation models

A review of evacuation models used worldwide for a range of hazards, (including technological hazards such as nuclear accidents), has been carried out as part of Task 17. This review is available as the Technical Note entitled “Review of evacuation rescue methods and models - T17-07-04” (FLOODsite, 2006). The review found that in general the evacuation models available could be grouped as follows:

1. Traffic simulation models;
2. Evacuation behaviour models;
3. Time-line/critical path management diagrams.

Traffic simulation models comprise either micro, meso or macro types of traffic stream simulation, with simple, static or dynamic types of traffic route assignment. Micro-simulation is based upon detailed simulation of individual vehicle movements. Meso-simulation is based on movements of traffic streams coupled to relatively simple evacuee route selection logic. Dynamic traffic assignment (macro-simulation) pays more attention to the route selection process and relies upon a more aggregate representation of traffic as a series of flows, while attempting to match this demand for road space to the capacity of the highway system’s links and intersections.

Detailed network evacuation models allow the planner to experiment with a selection of alternative evacuation routes, destinations and evacuee response rates as a means of determining effective evacuation strategies. This process of generating plans and expected network clearance (evacuation) times currently requires a five-step process, involving the creation and calibration of:

- A traffic generation sub-model;
- A traffic departure time (traffic loading rate) sub-model;
- A destination selection sub-model;
- A traffic route selection sub-model;
- A user specified plan set-up, analysis and revision procedure.

A time-line diagram shows the critical path of emergency response for flood evacuation. This method has the advantage of showing how critical the relationship is between flood prediction, evacuation decisions, emergency service response and community actions and the passage of time in a flood. The resulting time-line can then be used to show participants in a flood planning or response activity what has to be done, when it has to be started, and approximately how long it might take during the flood scenario analysed (FLOODsite, 2006).

4.5 Conclusions

The type of evacuation model that is appropriate for a particular flood risk area will depend on the level of risk and the processes which the evacuation modelling is seeking to inform. A densely populated urban area where the scale of potential evacuation is large may require a detailed simulation model where the traffic and flood hazard is modelled in a truly dynamic way. An understanding of the level of congestion delay that is inevitable under even the most effective traffic management schemes, and also the level of spontaneous evacuation that may occur in advance of an official evacuation warning are other issues that need addressing.

A real-world process of managing a mass evacuation is far more complex than the multi-step evacuation modelling process. Speed of access to information will often be just as important as accuracy. The decision-maker needs a way to filter the incoming signals, a way to separate the important problems from the rest of the noise. Relational database and graphical animation tools, potentially supplemented by expert system logic attached to real time traffic surveillance and control is perhaps the ultimate expression of this sort of user assistance for the evacuation planning purposes (FLOODsite, 2006).

Realistic response curves and their translation into evacuee mobilisation rates are critical inputs to the subsequent evacuation time estimation process. Flood evacuation in most of Europe has been infrequent, and there is little readily available data to accurately calibrate detailed models at present.

5. Pilot application for the Thames Estuary, UK

5.1 BACKGROUND TO THE THAMES ESTUARY PILOT SITE

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 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 (ABI, 2005).

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 down 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 (ABI, 2005).

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:

- **Climate change** – as the oceans warm and the ice caps melts, 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.

(FLOODsite, 2005)

A number of methods were used to provide estimates of wither evacuation times or the percentage of people that were evacuated from the following to areas in the Thames Estuary:

- Thamesmead embayment;
- Canvey Island.

The majority of both these areas are at or below sea level, and they are protected against inundation by a series of flood embankments and walls. The location of the two sites within the Thames Estuary is shown in Figure 5.1. The background to these sites is discussed below.

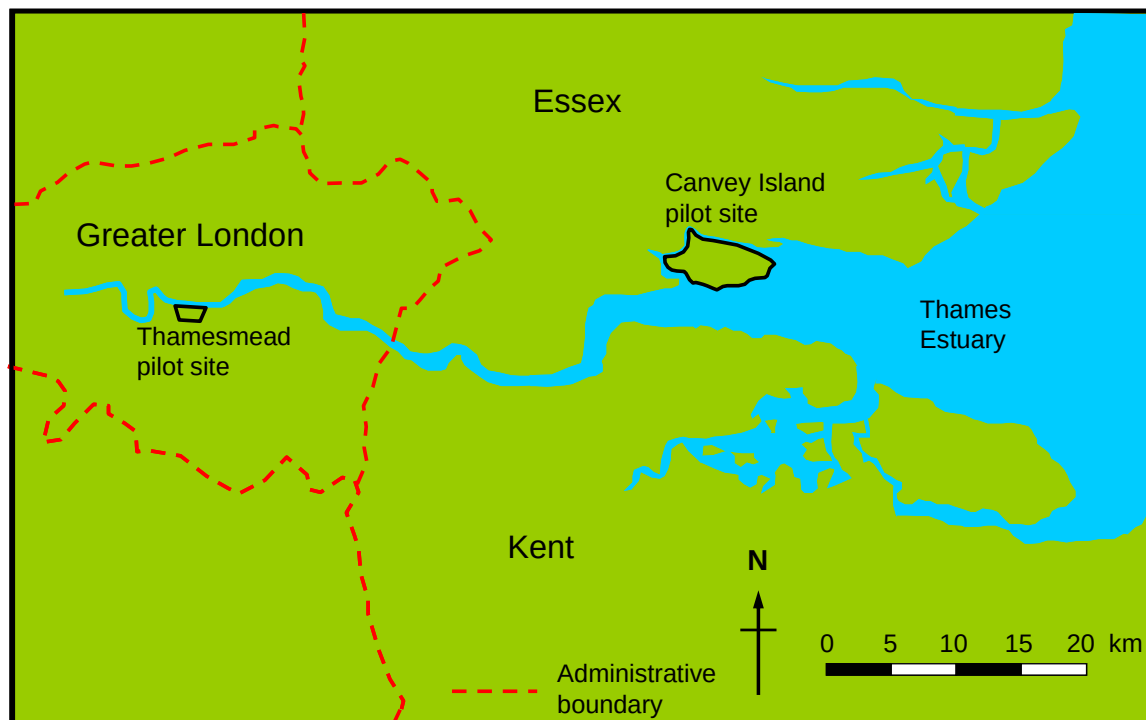


Figure 5.1 The locations of Thamesmead and Canvey Island within the Thames Estuary

5.1.1 Links with the Thames Estuary 2100 project

Use was 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. Inundation models developed by the TE2100 project were used in the Thamesmead embayment and the TE2100 team were consulted with regards to the locations where breaches in the flood defences of the Canvey Island and Thamesmead have the highest probability of occurrence.

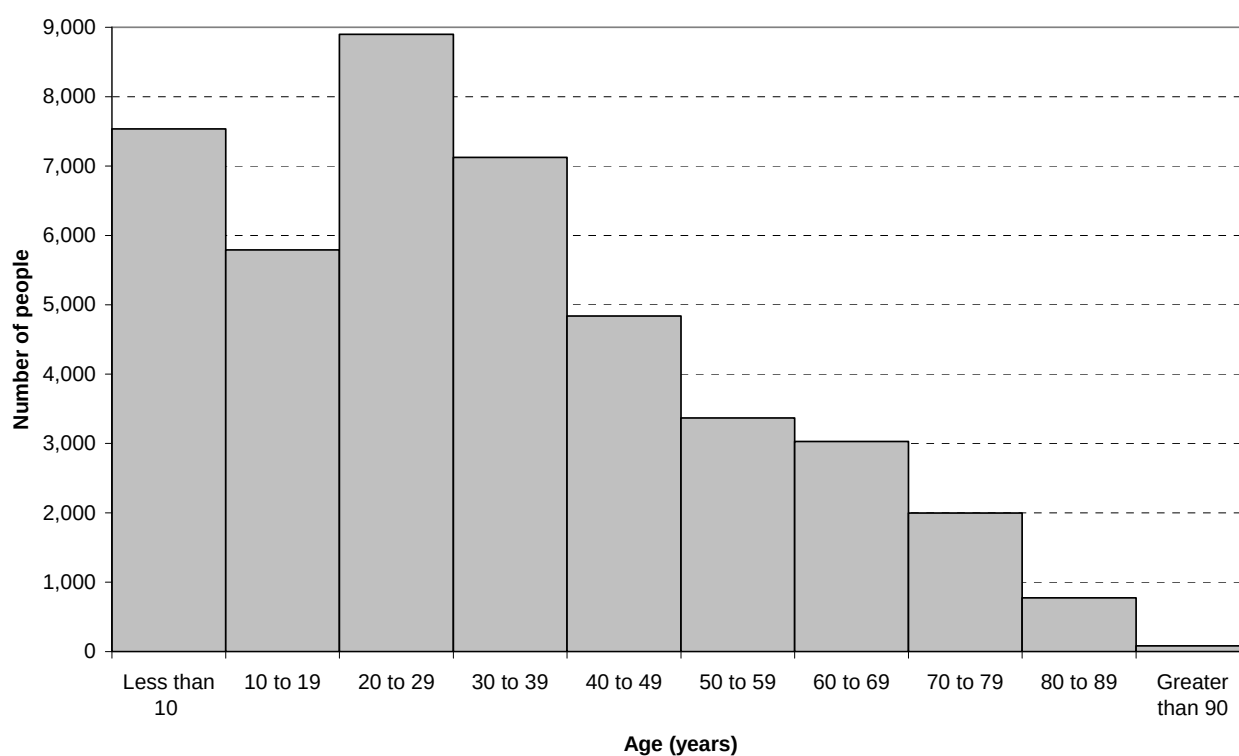
5.2 Thamesmead embayment

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. However, since the initial development there have been a number of developments built with living quarters at the ground level. The area is defended by a flood embankments and walls. These provide protection against the 1 in 1,000 year flood (Wigfall, 1997).

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. The age range of the Thamesmead area is shown in Figure 5.3. 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 5.4.



Figure 5.2 Satellite image of Thamesmead



(Source: Office for National Statistics, 2002)

Figure 5.3 Age distribution for Thamesmead



Figure 5.4 New development in Thamesmead

5.2.1 Canvey Island

Canvey Island, shown in Figure 5.5, is an island in the Thames Estuary, covering an area of 18.5 km². The mean high water mark of the Thames Estuary at Canvey Island is higher than most of Canvey Island's land. The first sea defences were constructed in 1623 and Dutch settlers formed the first Canvey Island communities of the modern era. The population did not expand rapidly until the 1920s, with 1,795 inhabitants in 1921 but over 6,000 in 1927 during which time the number of buildings rose from 300 to about 1,950 (Kelman, 20020). In 2001 its population was estimated to be approximately 37,000 (Office for National Statistics, 2002).

In 1953 the island was inundated by the "Great North Sea Flood", shown in Figure 5.6 that breached flood defences and resulted in the deaths of 58 people and the destruction of several thousand houses. The age distribution for Canvey Island is shown in Figure 5.7. Approximately 8.6% of the population are aged over 70. There are a total of approximately 15,400 cars on the island. In 2001 there were a total of 15,490 residential properties on Canvey Island (Office for National Statistics, 2002).

The likelihood of flooding of the access routes to and from Canvey Island will increase following sea level rise. Access to Canvey Island is currently only possible by two roads (A130 and B1006), both of which are connected to the same roundabout. Any disruption to these routes would hamper evacuation and severely limit access to the industrial areas on Canvey Island, including potential disruption to gas terminals and oil storage depots. This could have significant implications for the national economy since Canvey Island is one of the main gas distribution centres for the UK.

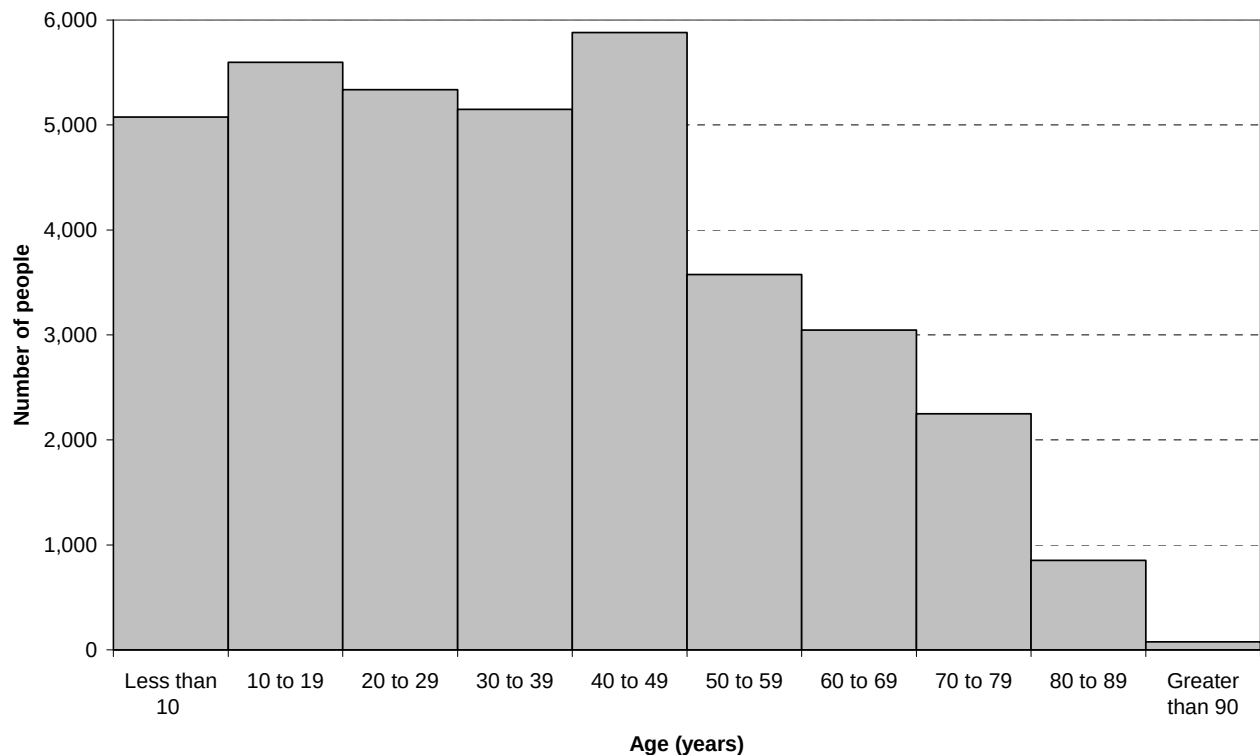


Figure 5.5 Satellite image of Canvey Island



(Source: Canvey Island Web site, 2007)

Figure 5.6 Canvey island during the 1953 flood



(Source: Office for National Statistics, 2002)

Figure 5.7 Age distribution for Canvey Island

At present, Canvey Island is protected by a concrete sea wall that rises approximately 3 m to 4 m above the high tide level. A typical view of the Canvey Island flood defences is shown in Figure 5.8. It has been found that whilst substantial, these defences show signs of deterioration such as cracks in the concrete, and the degradation of seals between slabs. Metal access doors also represent a weak point with imperfect seals around them, bolts have to be manually placed to shut the gates and bolt holes are prone to get blocked with debris (Kelman, 2002). It is estimated that the current standard of protection at Canvey Island of 0.1% (1 in 1,000 years) will be reduced to 0.5% (1 in 200 years) by 2030 owing to the reasons detailed in Section 5.1.

On Canvey Island, it has been estimated that approximately 91% of dwellings are houses and 9% flats. Most properties have two storeys, and have a mean floor level 0.3 m above the surrounding ground levels. Thirty percent of properties are bungalows and 45% of flats are situated at ground floor level, there is thus a large risk to life and property with limited opportunities to temporarily move to a higher level (Kelman, 2002). Figure 5.9 shows some of the more vulnerable single storey housing that has recently been constructed on Canvey Island close to the flood defences. It is possible that a majority of the island would be inundated if a major storm surge occurred and led to major overtopping of defences. However, this is still considered to be a very rare event. The failure or breaching of a seawall is a more likely option and would involve more localised severe flooding depending on the exact breach scenario that occurred.



Figure 5.8 Flood defences in the north of Canvey Island



Figure 5.9 New single storey housing on Canvey Island

5.3 Data availability for the pilot areas

The following data was available for the two pilot areas 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);
- **Number of vehicles** – The total number of cars at an Output Area level is available from the 2001 census (Office for National Statistics, 2002);
- **Topographic data** – LIDAR survey data was available for both Thamesmead and Canvey Island with a vertical accuracy of approximately ± 25 mm;
- **Flood depths and velocities** - Two dimensional hydrodynamic modelling results, undertaken using the TUFLOW software, were available for both pilot areas 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 was available. This data is in the form of a geo-referenced point (Environment Agency/Defra, 2005).
- **Road network** – Details of the major roads were digitised from existing maps;
- **Historical data** – Historical data for the 1953 flood was available from a number of sources for Canvey Island.

The majority of the data

5.4 Evacuation and emergency planning modelling for the two pilot areas

This section describes the implementation of the evacuation models in the two embayments Thames. Various methods have been employed at two different scales. These are as follows:

- **Micro-scale modelling** – This has been carried out using the BC Hydro LSM model and is detailed in Section 5.5;
- **Meso-scale modelling** – This has been undertaken using a non-linear optimisation-based model and is detailed in Section 5.6;
- **Macro-scale modelling** – This has been based on a simple spreadsheet based method that is a function of the road capacity and assumed average velocity. This method is outlined in Section 5.7.

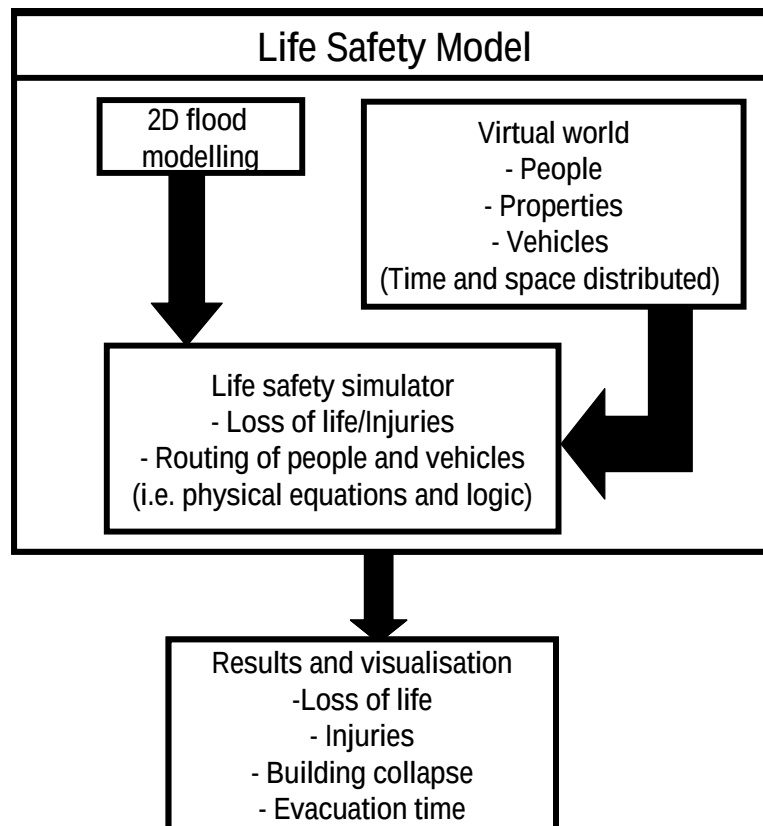
5.5 Micro-scale evacuation and loss of life modelling

5.5.1 Introduction to the BC Hydro LSM model

Operators of dams or other major flow control structures need to assess the risk that these systems can pose to downstream communities, particularly from a major breach failure, although this can apply to any high flow event. Traditional simplistic and empirical methods that have been used to determine loss of life from such catastrophes have tended to over-predict the fatalities. It was considered that the variability and site-specific nature of each flood event was not well represented in these simple techniques, and that a “phenomenological” approach should be developed, that better simulates the physical interactions of people, vehicles and buildings in a major flood event. Although the Life Safety Model (LSM) requires a significant input of time and resources to set up the model for any flood catchment, it does provide a far more transparent and defensible set of predictions, which incorporate a wider range of variables influencing loss of life than traditional “black box” approaches.

Figure 5.10 shows the main conceptual components of the LSM. A key part of the system is the description of the natural environment of the study area, which comprises the topography, water bodies, and the socio-economic environment (e.g. people, buildings, roads and vehicles). This information is normally available from existing GIS mapping and population statistics. For each scenario tested, these attributes need to be given an initial state, specifying the time of day, and where each individual, group of individuals and vehicle is located. As well as the natural environment, the

output from a two dimensional hydrodynamic model is used to specify the velocity and depth at locations within the study area, to simulate the progress of the flood wave. The central Life Safety Simulator takes these inputs and uses a set of physical equations and behavioural logic to determine the interactions and the fate of each individual.



(BC Hydro, 2004, 2006)

Figure 5.10 High-level architecture of the Life Safety Model

The system models the “fate” of a set of objects, which are described by their position at each time step through the simulation. Examples of these objects are given in Table 5.1. Each object can have a set of properties that describes its normal location/condition during a week, such as travel times, school/work hours, and weekend activities. Other time-varying properties include the ability of the object to withstand the effect of the flood wave, and how it would react to the approaching wave, with and without a formal evacuation warning.

The model uses a generalised event logic to determine the location of each object, whether it is aware of the flood wave, whether it is trying to find a safe haven, what happens if it encounters the flood, and whether the object survives or not. A loss function related to each object (e.g. people, buildings, vehicle) specifies the ability of an object to resist the impact from the flood wave, in terms of depth and velocity, and how these can change during an event. There can be instantaneous loss when an individual encounters fast-flowing water, or a group who have sought safety in a building can suffer cumulative loss if the building collapses or a slow deterioration in health if they are exposed to the flood water for a significant length of time, as a result of hunger or cold. This is illustrated in Figure 5.11.

Table 5.1 Selected LSM objects

LSM object	Description
Digital Terrain Model (DTM)	A topographic representation of the flood hazard zone
Population At Risk Unit (PARU)	This is an individual who is within or near the impact zone. This unit represents the individuals who are at risk.
Population At Risk Group (PARG)	A PARG is one or more PARU escaping from the flood wave. The people share the same attributes such as location, direction and mode of transport.
Building	Man made structures (e.g. houses, schools, shopping centres) that contain PARU
Outdoor place	An outdoor area (e.g. park, playground) where PARU might congregate
Vehicle	A land based vehicle that can carry an escaping PARU or PARG
Road and trail network	The road and path network that connects all the various objects that make up the road system
Warning centre	A location from which a warning can be issued and spread to the local population
Safe haven	A location where people would be safe from the flood

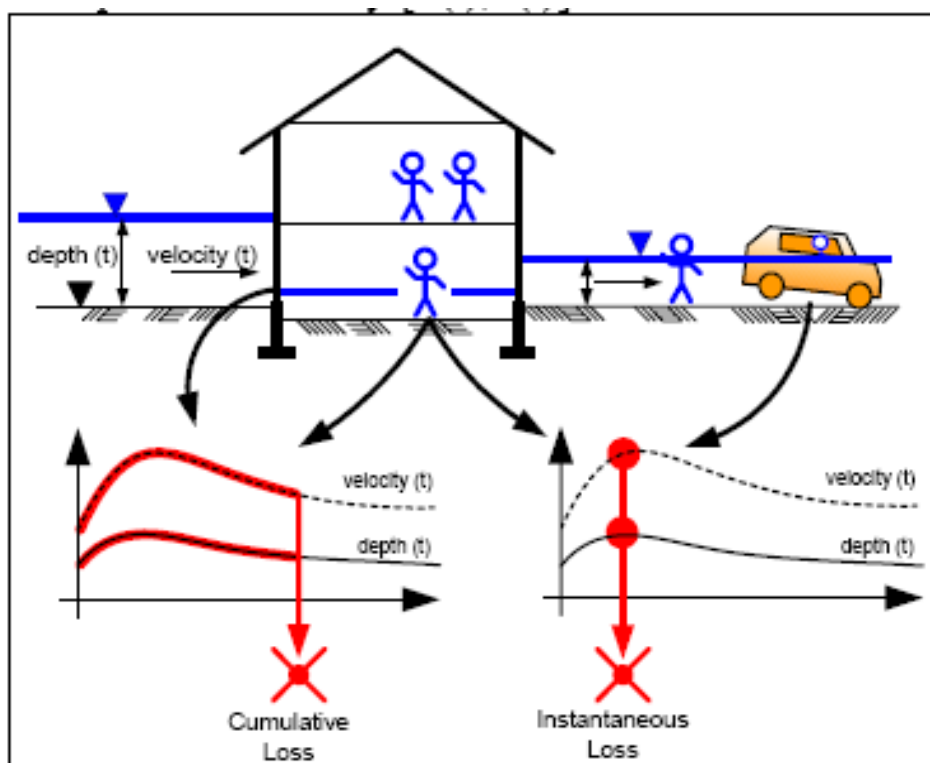


Figure 5.11 The object damage and loss concept in the Life Safety Model

The BC Hydro Life Safety Model (LSM) allows the following to be assessed for dam breach and flood scenarios:

- Loss of life modelling including:
 - Estimates of number of fatalities and injuries for different scenarios
 - Number of vehicles swept away
 - Number of buildings destroyed
- Evacuation modelling including:

- Time to evacuate area at risk for different flooding scenarios
- Effect of road closures, warning dissemination, use of safe havens
- Awareness of people during a flood incident

The BC Hydro LSM provides dynamic interaction between receptors (i.e. people, vehicles and buildings) and the flood wave. The LSM model provides estimates loss of life from:

- Drowning;
- Exhaustion;
- Building collapse;
- Cars being swept away.

The LSM allows provides the number of people who have been “toppled” by the floodwater. This can be used as a proxy for the number of injuries that are likely to occur as a result of the flood wave. The LSM software, this provides comprehensive outputs for analysing the whole flood event, making use of static GIS maps, or visualisation of the wave progress and when and where the fatalities took place. The sections below describe the results of the application of the LSM to two locations in the Thames Estuary.

The BC Hydro Life Safety Model (LSM) comprises the following tools:

- The Life Safety Model Environment (LSME) tool that is used to create the “virtual world” (i.e. the “People World”). In essence, it puts the data files in the correct format for use with the two dimensional life safety model.
- The Life Safety Model 2D (LSM2D) component is the tool that computes the loss of life, movement of people and vehicle and the number of building and vehicles that are destroyed.
- The Red Kenue tool that provides a visualisation of LSM2D results, providing graphics and animations.

5.5.2 Aims of the testing

The aims of testing the LSM in the UK were as follows:

- To assess the possibility of employing the LSM for flood event management planning, rather than its original purpose of emergency planning for dam breaks;
- To assess whether it was possible to use the beta version of the LSM in the UK to estimate evacuation times for people using data readily available in the UK;
- To test if the LSM could be applied to 40,000 to 50,000 individual receptors in the UK. This number of receptors is an order of magnitude more than it had been applied in the past;
- To see it was possible to compare the results of the LSM in terms of evacuation times with other evacuation models developed for the project;
- To assess the accuracy of the estimates of loss of life and building collapse provided by the LSM.

Considerable work was carried out to make the results of the available two dimensional modelling that had been carried out compatible with the requirements of the LSM.

5.5.3 Implementation of the LSM to the Thamesmead embayment

Introduction

The BC Hydro LSM model was applied to Thamesmead using the readily available data that is detailed in Section 5.3. The breach scenarios for the flood defences were based on previous work that had been carried out for the Thames Estuary 2100 project that HR Wallingford is currently undertaking for the Environment Agency. Figure 5.12 shows the results of the inundation modelling

that has been carried out using the two dimensional hydrodynamic model TUFLOW. In order to make the TUFLOW output compatible with the LSM a bespoke piece of C++ code was written.

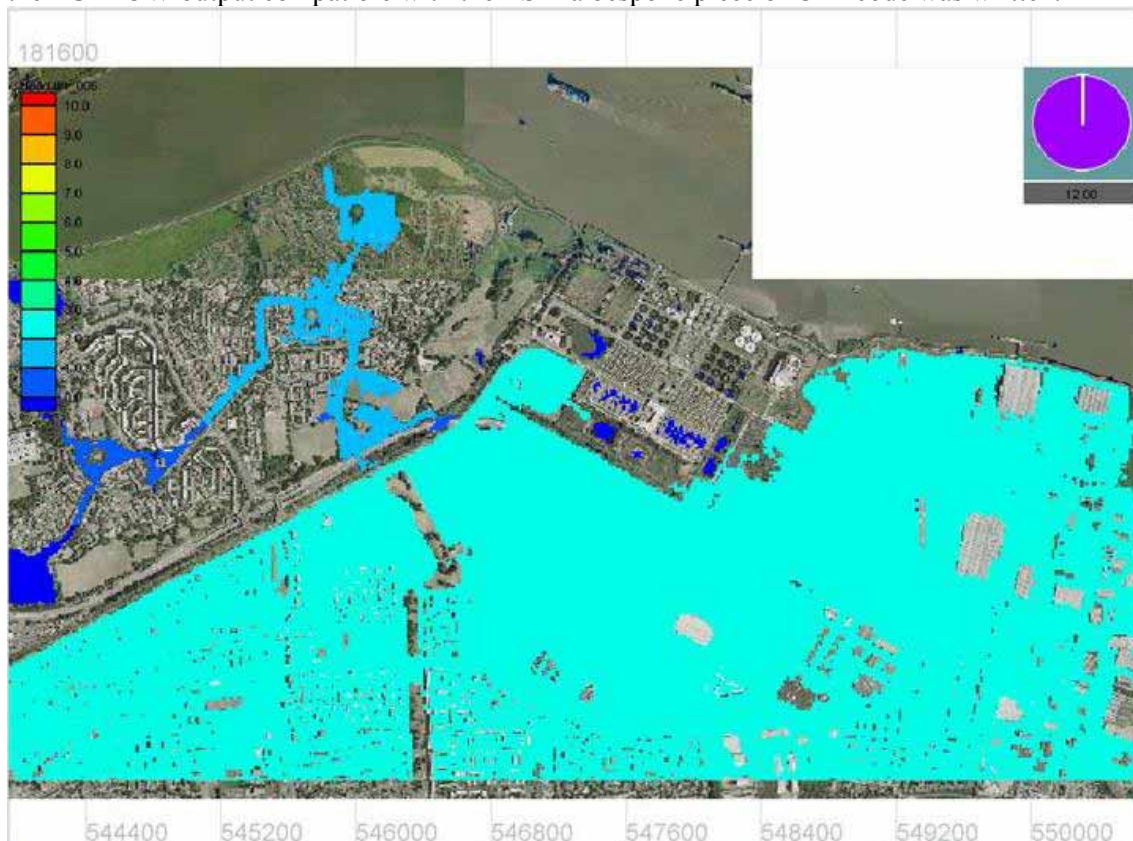


Figure 5.12 Inundation modelling for Thamesmead based on TUFLOW modelling

Modelled scenarios

A number of scenarios have been modelled using LSM2D. Table 5.2 provides an overview of the matrix of LSM model runs that were undertaken for the Thamesmead area. A number of parameters were varied including:

- The number of safe havens;
- Road closures;
- Number of warning centres;
- Rates of warning dissemination.

The scenarios that have been investigated include:

- Two safe havens;
- Four safe havens;
- Six safe havens;
- Eight safe havens;
- Ten safe havens;
- Ten safe havens with road closures when the water level reaches 0.6 m;
- Ten safe havens with a delayed rate of warning.

The process by which the UK data was converted to be compatible with the BC Hydro Life Safety Model (LSM) as shown in Figure 5.13.

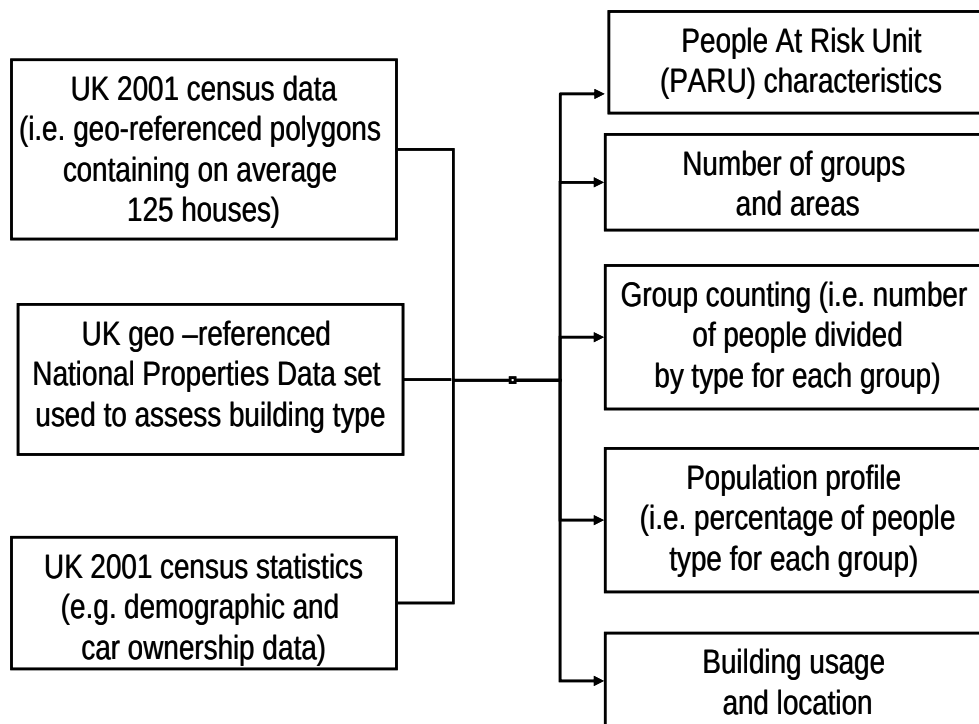


Figure 5.13 Process by which the UK census and property data was converted to be compatible with the LSM

In total 60 different evacuation scenarios have been modelled. Figures 5.14, 5.15, 5.16, 5.17 and 5.18 provide graphs of some of the typical results that have been produced by the LSM for Thamesmead. Figure 5.17 illustrates that the number of safe havens in the pilot area has a significant effect on the time that it takes people to reach safety. Increasing the number of safe havens from 4 to 10 means that the percentage of people who reach safety four hours after the flood defence has breached almost doubles from 40% to 72%. Further details of the results are given in Tables 5.3 to 5.4.

For the 60 different scenarios that are outlined in Table 5.2 the number of fatalities varied from a minimum of 406 to a maximum of 2,378 people. The average number of fatalities was found to be 1,296. There are approximately 43,000 people that are exposed to the flooding in the Thamesmead embayment, so the LSM model indicates that on average about 3% of the exposed population will suffer fatalities. Research by Jonkman, 2007 indicates that the expected number of fatalities is usually between 0.7% and 1.3% of the exposed population (Jonkman, 2007). However, in these cases many of the population have evacuated before the hazard occurred. In the pilot study of Thamesmead it the “worst case” of everybody being at home has been assumed. In the historical data collected by Jonkman many of the people had already been evacuated from the exposed area so it is expected that in the case of Thamesmead where it was assumed that no evacuation would occur prior to the flood event that the percentage of fatalities would be much higher. It is interesting to note that Tables 5.4 and 5.5 indicate that the number of fatalities and injuries appears to be most sensitive to the number of safe havens that are in the pilot area rather than the warning dissemination time or road closures. This would indicate that in terms of emergency management for the Thamesmead area it may be best to raise awareness of high rise buildings that are resilient enough to withstand a flood wave that could be used as safe havens.

Table 5.2 Range of scenarios modelled for Thamesmead showing the code used to denote each model run

	2	4	6	8	10
Number of safe havens					
Road closures (Rd)	2Rd	4Rd	6Rd	8Rd	10Rd
Decreased rate of warning (RoW)	2RoW1	4RoW1	6 RoW1	8 RoW1	10 RoW1
Road closure and decreased RoW	2RdRoW1	4RdRoW1	6RdRoW1	8RdRoW1	10RdRoW1
Additional warning centre (wc2)	2wc2	4wc2	6wc2	8wc2	10wc2
wc2 and Rd closure	2Rdwc2	4Rdwc2	6Rdwc2	8Rdwc2	10Rdwc2
wc2 and decreased in RoW in wc1	2RoW1wc2	4RoW1wc2	6RoW1wc2	8RoW1wc2	10RoW1wc2
wc2 decreased RoW in wc2	2RoW2wc2	4RoW2wc2	6RoW2wc2	8RoW2wc2	10RoW2wc2
Wc2 and decreased RoW in wc1 and in wc2	2RoW1RoW2wc2	4RoW1RoW2wc2	6RoW1RoW2wc2	8RoW1RoW2wc2	10RoW1RoW2wc2
Wc2 and decreased RoW in wc1 and Rd closure	2RdRoW1wc2	4RdRoW1wc2	6RdRoW1wc2	8RdRoW1wc2	10RdRoW1wc2
wc2 and decreased RoW in wc2 and Rd closure	2RdRoW2wc2	4RdRoW2wc2	6RdRoW2wc2	8RdRoW2wc2	10RdRoW2wc2
wc2 and decreased RoW in wc1 and wc2 and Rd closure	2RdRoW1RoW2wc2	4RdRoW1RoW2wc2	6RdRoW1RoW2wc2	8RdRoW1RoW2wc2	10RdRoW1RoW2wc2

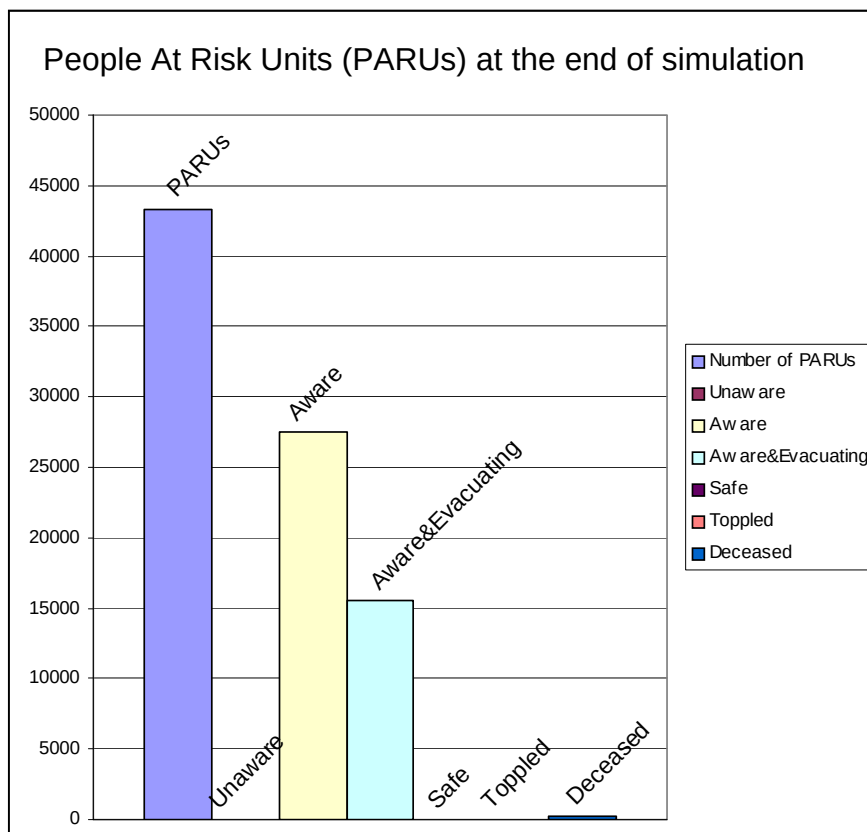


Figure 5.14 Typical results people at risk units for a Thamesmead inundation simulation

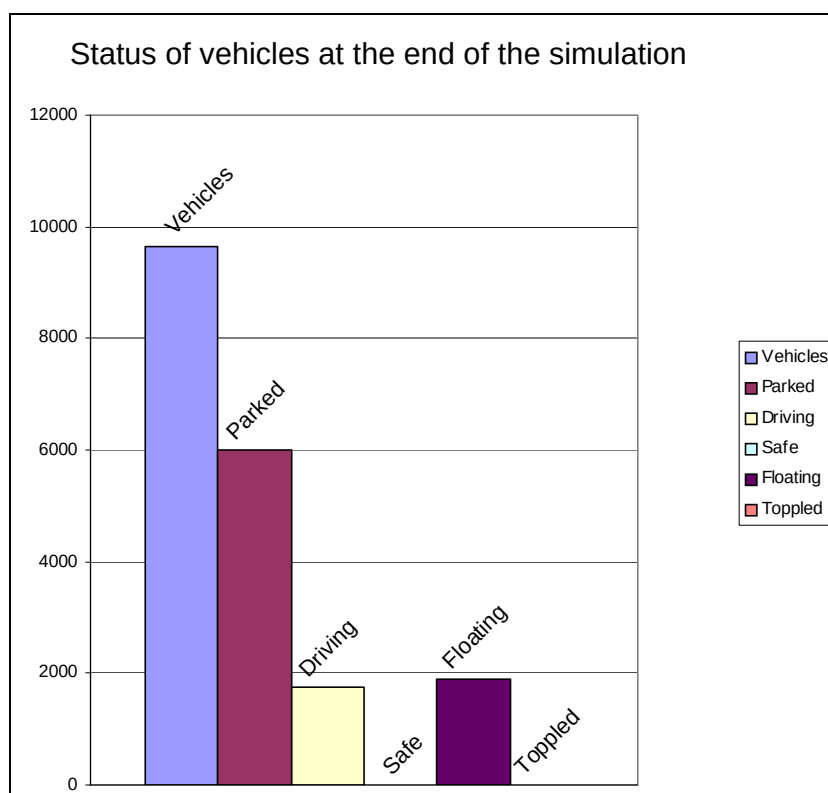


Figure 5.15 Status of vehicles for a typical Thamesmead inundation simulation

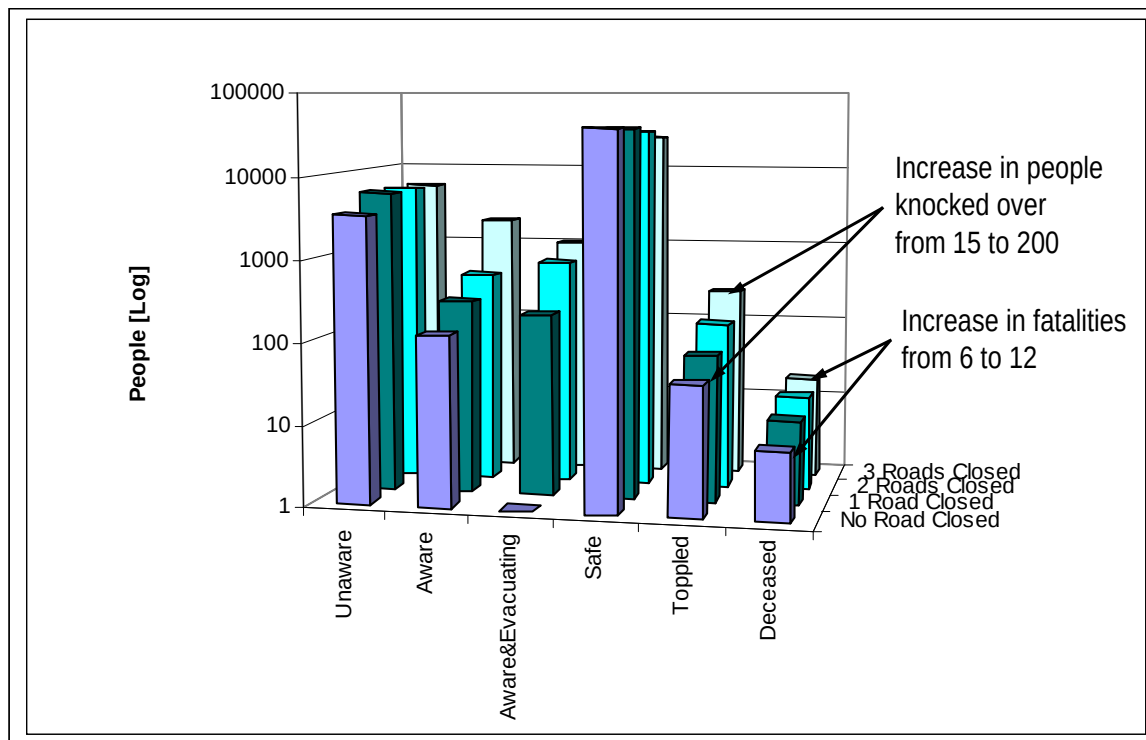


Figure 5.16 The effects of road closures on people in the Thamesmead embayment

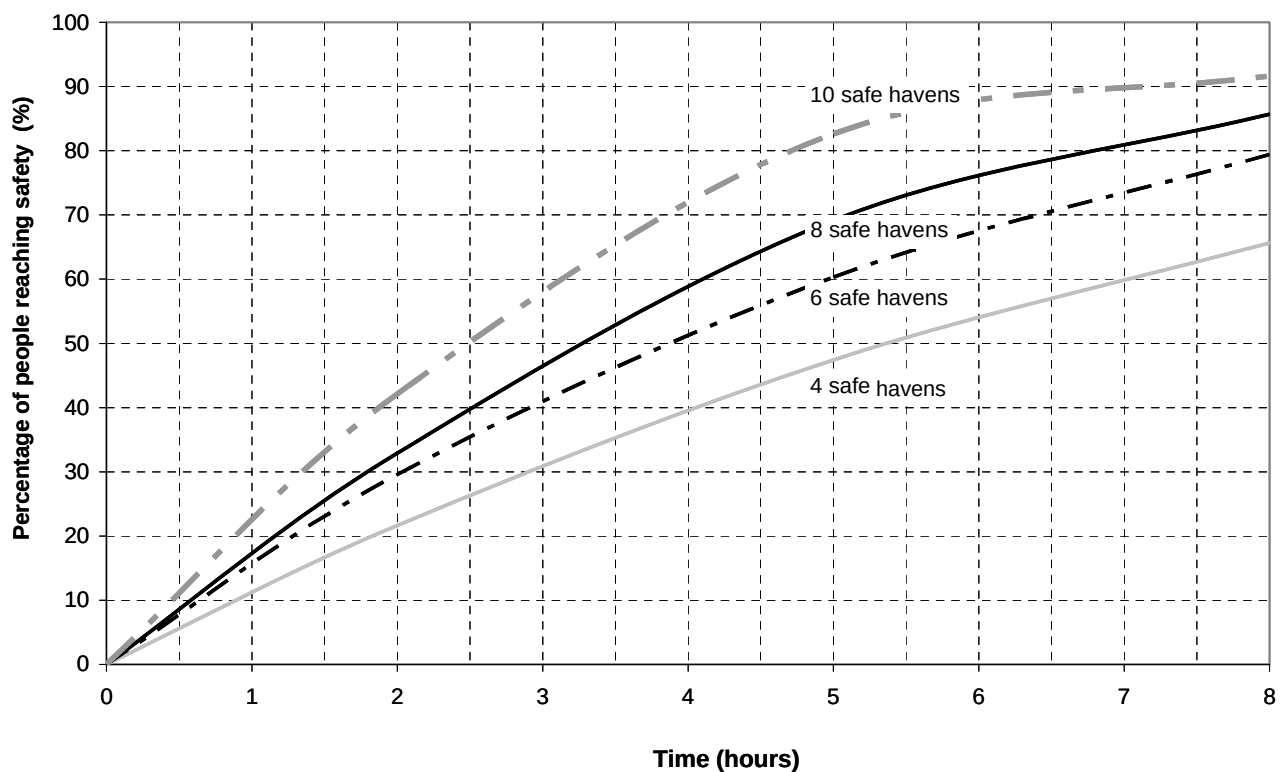


Figure 5.17 The effects of the number of safe havens on the percentage of people reaching safety after a breach has occurred

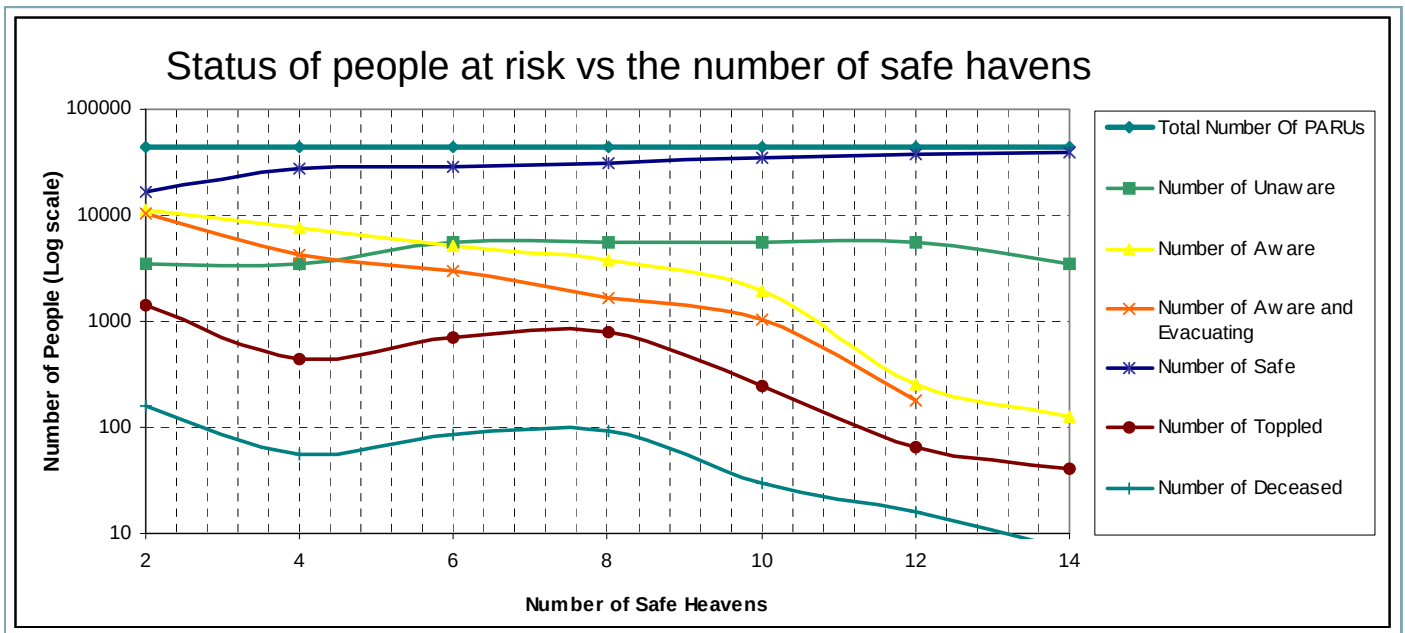


Figure 5.18 The effects of the number of safe havens on the status of people

Table 5.3 Percentage of fatalities within Thamesmead for the modelled scenarios

Modelled scenario	Number of safe havens				
	2	4	6	8	10
Road closure	4.9	2.7	3.5	1.0	1.6
Road closure and decreased rate of warning in first warning centre (RoW)	4.9	2.6	2.5	2.6	1.1
Decreased rate of warning in first warning centre	5.5	3.0	2.7	2.0	1.1
Additional warning centre (wc2)	5.5	3.1	3.5	2.0	2.4
Additional warning centre (wc2) and road closure	5.3	3.1	3.2	2.6	0.9
Additional warning centre (wc2) with reduced rate of warning	5.3	3.2	3.0	*	*
Additional warning centre (wc2) with reduced rate of warning in first warning centre (wc1)	5.5	3.1	3.0	2.0	2.3
Decreased rate of warning in both warning centres	5.5	3.1	3.2	2.6	1.6
Two warning centres (wc1 and wc2) with reduced rate of warning and a road closure	5.0	3.1	2.7	1.5	2.3
Additional warning centre (wc2) with reduced rate of warning in first warning centre (wc1) and a road closure	5.3	2.0	3.2	1.3	*
Additional warning centre (wc2) with reduced rate of warning and a road closure	5.3	3.2	3.5	1.4	1.3

*Results were not available for these runs owing to bugs in the software

Table 5.4 Percentage of people injured within Thamesmead for the modelled scenarios

Modelled scenario	Number of safe havens				
	2	4	6	8	10
Road closure	10.8	7.4	5.1	1.4	3.0
Road closure and decreased rate of warning in first warning centre (RoW)	11.1	6.0	5.4	0.6	5.5
Decreased rate of warning in first warning centre	11.1	8.1	5.4	2.9	1.1
Additional warning centre (wc2)	11.1	5.9	5.5	*	*
Additional warning centre (wc2) and road closure	11.1	5.9	5.4	2.7	2.8
Additional warning centre (wc2) with reduced rate of warning	10.8	5.4	5.5	4.8	3.2
Additional warning centre (wc2) with reduced rate of warning in first warning centre (wc1)	10.8	5.4	5.4	2.9	3.0
Decreased rate of warning in both warning centres	10.8	7.9	5.1	5.0	1.1
Two warning centres (wc1 and wc2) with reduced rate of warning and a road closure	11.1	5.5	5.6	2.9	3.0
Additional warning centre (wc2) with reduced rate of warning in first warning centre (wc1) and a road closure	10.9	8.1	5.1	5.1	3.3
Additional warning centre (wc2) with reduced rate of warning and a road closure	11.1	7.4	7.4	1.4	*

*Results were not available for these runs owing to bugs in the software

5.5.4 Implementation of the LSM to Canvey

Introduction

The BC Hydro LSM model was applied to Canvey Island using the readily available data that is. Inundation modelling of Canvey Island was carried out using the two dimensional hydrodynamic model TUFLOW. Two breach scenarios in the north of the island have been modelled.

Modelled scenarios

The following scenarios have been modelled:

- Different numbers of safe havens;
- 1953 historical flood event.

A typical result with two safe havens in place is shown in Figure 5.19.

5.5.5 Modelling of the 1953 flood event

In order to validate the BC Hydro LSM model the 1953 flood event on Canvey Island was modelled. The details of this work are outlined below.

Data collection

In order to validate the BC Hydro LSM model the 1953 flood event that occurred in Canvey Island was reconstructed. During the 1953 flood, which occurred at night, the flood defences in Canvey Island were breached in a number of locations. It is estimated that on Canvey Island alone 58 people died and that 10,000 had to be evacuated. A historical analysis of Canvey Island was undertaken in order to construct the situation that existed in 1953. The following was carried out:

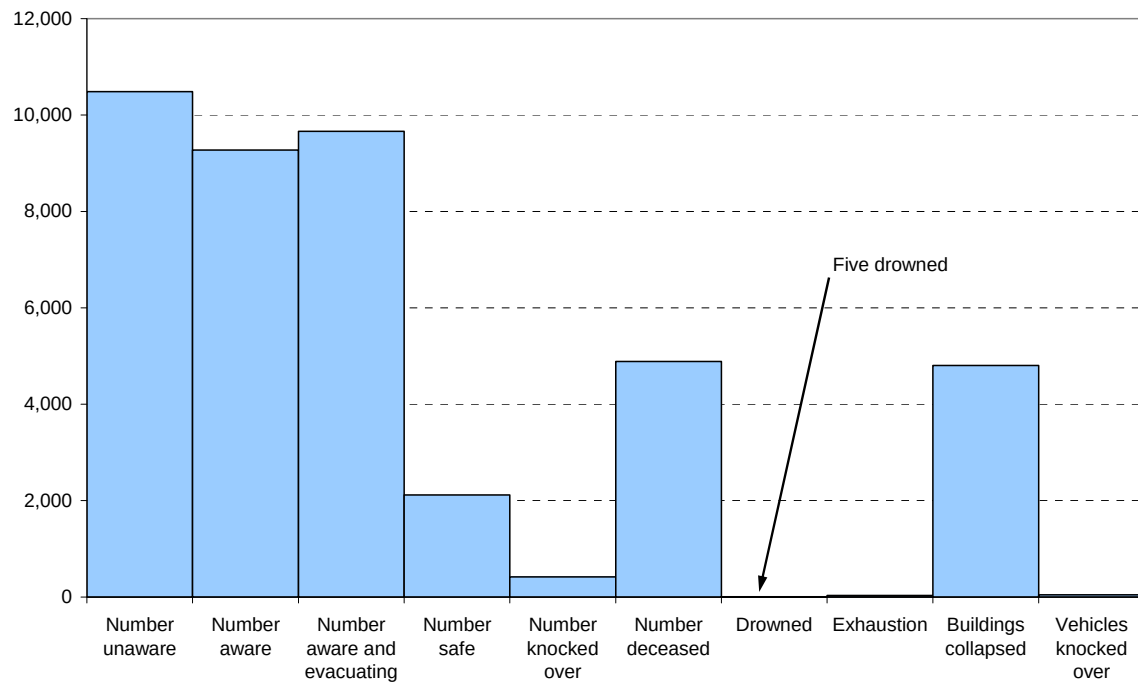


Figure 5.19 Typical results for Canvey Island with two safe havens in place

(i) Historical analysis of the 1953 flood event

This was based on the following:

- Newspaper reports from 1953;
- Footage from video archives;
- Reports from police archives;
- Census data from 1951;
- Other sources (e.g. books written about the event).

(ii) Reconstruction of 1953 flood levels

This was based on the following:

- Data from the HR Wallingford and Meteorological Office archives;
- Other literature sources.

(iii) Representation of the 1953 flood defences and location of breaches

The 1953 flood defences were represented using:

- Pictures of the 1953 event;
- Historical maps;
- Data gathered on site visits.

A comparison of the building density between 1953 and 2001 for Canvey Island is shown in Figure 5.20.

Results

The results of the re-creation of the 1953 flood event agreed well with historical data. The BC Hydro LSM model indicated that 100 fatalities had occurred during the 1953 event. This number is dependent on the “resilience factors” applied to both people and buildings. The actual number of

people that died in 1953 was 58. The number of buildings estimated to be destroyed during event by the model was similar to that available from anecdotal evidence. The results of the modelling are shown in Figure 5.21.

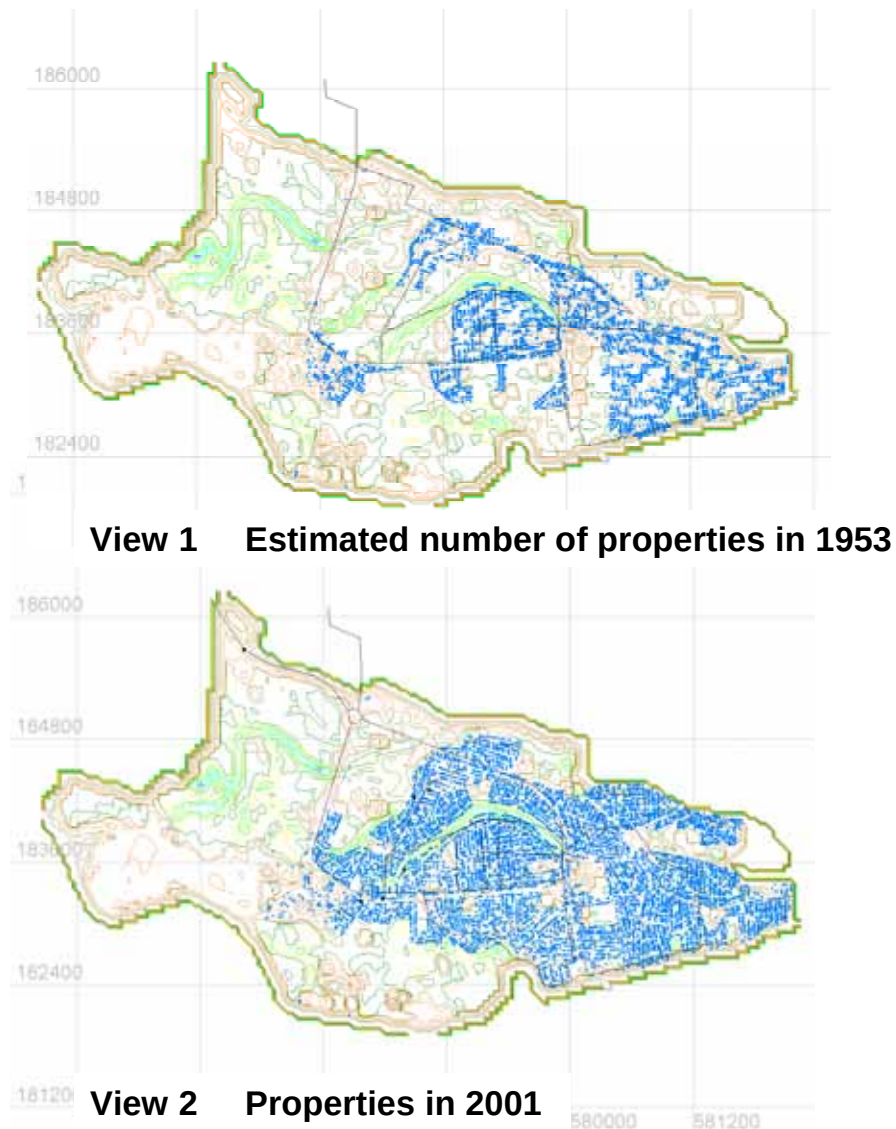
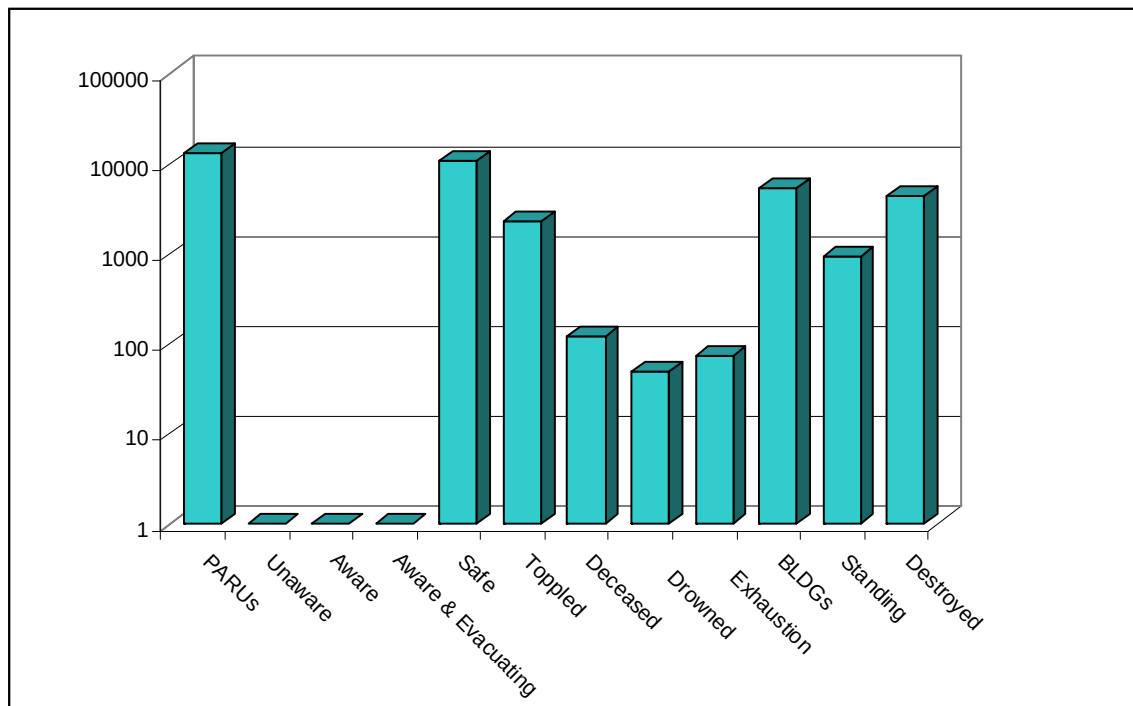


Figure 5.20 Comparison of the number of properties on Canvey Island in 1953 and 2001



Note: PARUs is People At Risk Units; BLDGS is buildings

Figure 5.21 Results of the loss of life model for the 1953 flood for Canvey Island

5.5.6 A method to make a quantitative assessment of the modelled scenarios

There are a number of criteria by which the “success” of different emergency management plans can be assessed. These include criteria such as:

- The weighted normalised percentage of people that have reached a safe haven after 5 hours;
- The weighted normalised percentage of people who lose their life;
- The weighted normalise percentage of vehicle losses.

The importance of each of the above criteria have been given a weight as shown in Table 5.5.

Table 5.5 Costing weightings to assess different emergency planning options

Emergency management objective	Weighting
Minimising the loss of life	0.7
Minimising the number of vehicles that are damaged	0.1
Minimising the time required for people to reach a safe haven after five hours	0.2

A “cost” has been allocated to each alternative as shown in Table 5.6.

Table 5.6 Costing weightings to assess different emergency planning options

Scenario	Cost option
Two safe havens (2sh)	0.2
Four safe havens (4sh)	0.4
Eight safe havens (8sh)	0.8
Ten safe havens (10sh)	1.0
Ten safe havens with road closures when the water level reaches 0.6 m (10shrc0.6)	1.0
Ten safe havens with a delayed rate of warning (10shRoW0.5)	0.8

$$u_k = \sum_i (1 - g_i(\alpha_k))$$

g_i is the normalised weighted value of i th the criterion

Configuration	Utility score
2 sh	0.82
4 sh	0.95
8 sh	0.87
10 sh	0.92
10 sh rc 0.6m	0.93
10 sh Row 0.5	0.91

Figure 5.23 shows that the assessment of the 60 emergency planning options considered the closure of eight roads proved to have the highest utility score. This method has been researched to show that

quantitative methods can be used to assist decision makers choose between a wide variety of different methods.

5.5.7 Conclusion

The following conclusions were made concerning the LSM:

- The LSM allows dynamic interaction between the receptors and the flood hazard;
- Provides a more scientifically robust method for estimating loss of life than other methods previously used in the UK (e.g. Risk To People method). However, it takes longer to implement than other methods owing partly to the bugs in the LSME software that is used to set up the virtual world;
- It has potential to be used to inform emergency plans for heavily defended areas (e.g. London, some coastal areas) and dam risk assessments in the UK. The effect of the following can be assessed for different flood events:
 - Location and the number of safe havens;
 - The effect of road closures;
 - Rate of dissemination of warning;
 - The time of day and the location of the population;
- It is difficult to assess exact evacuation times from the model results. However, it is possible to ascertain the percentage of people that reach safety by a certain time. This is a useful parameter in evacuation planning;
- The LSM uses a relatively simple traffic model in the form of the Greenshields equation. There is scope to improve this with further input from traffic modellers;
- In its present state the LSM is not “user friendly” enough to be used by organisations such as the Environment Agency or the Emergency services without a significant amount of training;
- The LSM has the potential to be adapted in the future to provide estimates of the fatalities and evacuation times for other hazards (e.g. chemical or nuclear accidents).

There is considerable potential for the use of LSM in the UK and the rest of Europe, and that its use within the FLOODsite project has been beneficial. The LSM model has been presented to the Environment Agency Thames Estuary 2100 (TE2100) team, who were impressed by its capability. However, as part of convincing the Environment Agency and emergency planners of the LSM’s value, a key issue will be the ease with which LSM can be readily set up for new areas in the UK. Owing to the current issues with the LSME software this is not that straightforward.

5.6 A non-linear optimisation-based model for evacuation

5.6.1 Introduction

The BC Life Safety Model is a good example of a micro-model in that it models each receptor (e.g. person, vehicle or building individually). However, it is a very data intensive model and can be time consuming to set up. As part of the research carried out as part of Task 17 a quick and simple method that could be used to compute the evacuation scenario at a meso-scale without a large amount of data having to be prepared was investigated. An evacuation model based on the non-linear optimisation programming solution was tested implemented.

5.6.2 Setting up the model

This model takes in account the road network, considering the different kinds of road in terms of their capacity with respect to the number of vehicles/km/lane. The road capacity was related with the actual vehicle’s velocity by means of the Greenshield linear speed-concentration formula developed in 1935. The Greenshield traffic model, although derived from empirical data in 1935 is still widely used. The Greenshield model was developed a model of uninterrupted traffic flow that predicts and explains the trends that are observed in real traffic flows. While Greenshield’s model is not perfect, it is fairly accurate and relatively simple.

Greenshield made the assumption that, under uninterrupted flow conditions, speed and density are linearly related. This relationship is expressed mathematically below.

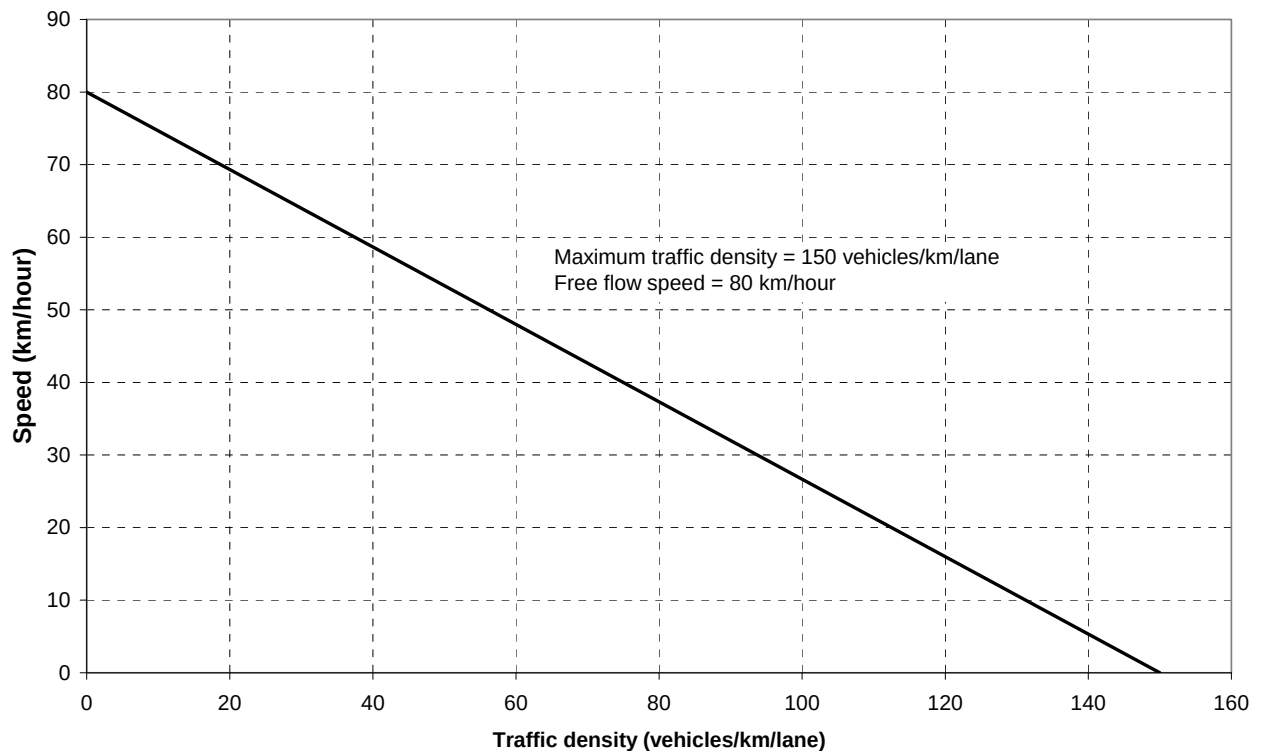
$$V = A - Bk$$

Where:

V is the speed of the vehicle in km/hour;
A and B are constants determined from field observations;
k is the traffic density in terms of vehicles/km.

(Greenshield, 1935)

Greenshields equation is used in the BC Hydro LSM model it was also applied in the non-linear optimisation based model for evacuation. In a road network using the Grennshield equation as the traffic density increases the traffic flow increases to some maximum value, but a continual increase in density will cause the flow to decrease until “jam density” and zero flow conditions are reached. The Greenshield equation used is shown in Figure 5.24.



(Source; Greenshields, 1935)

Figure 5.24 Greenshields' linear speed – concentration relationship

A non-linear optimisation model was applied to the Thamesmead area. The Thamesmead road network was represented as shown in Figure 5.25 by a series of branches and nodes. Two safe havens were located for each modelled scenario at a number of points in the network. It is assumed in the model that all the people evacuate by road vehicle.

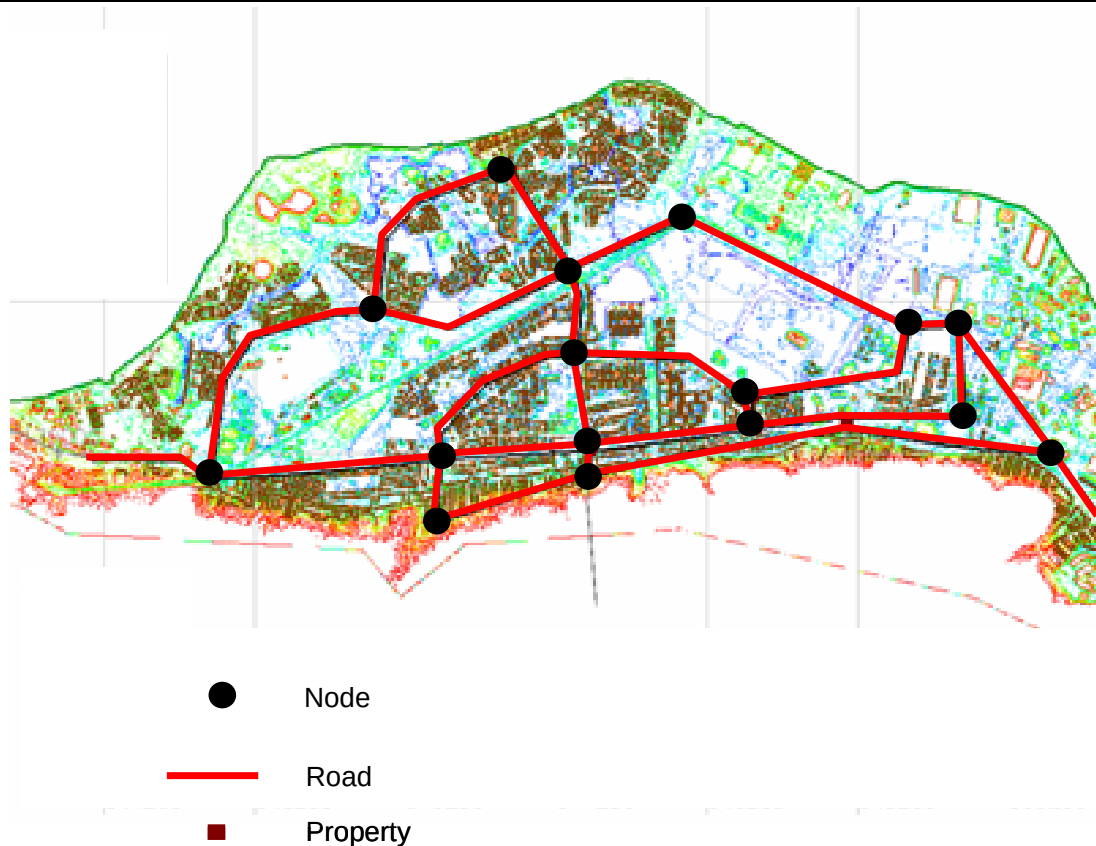


Figure 5.25 Representation of the Thamesmead road network in the model

The model optimises the number of vehicles passing through each road segment, minimising the time that is needed for them to reach a safe haven. The model also assesses which is the optimal safe haven for each vehicle. The model utilises a “branch and bound” method has been used. This is a systematic method for solving optimisation problems. This model assesses the optimal ways for the vehicles to reach the safe havens. The objective function is the function that is to be numerically optimised, in this case it is the total time for all the vehicles to reach the safe havens.

The model was constructed as follows: the objective function minimises the time required for the vehicles to reach the safe havens. This was calculated from the velocity of the vehicles in each branch of the network. This depends on the road congestion, which is given by the Greenshield equation. There were three constraints that form the boundary for the variables:

- There must be continuity at each node in terms of the number of vehicles;
- All the vehicles have to reach one of the safe havens before the end of the simulation;
- There is a limit on the road capacity defined by the Greenshield equation.

The model optimises the number of vehicles passing through each road segment, minimising the time that is needed for them to reach a safe haven. The model also assesses which is the optimal safe haven for each vehicle. The model utilises a “branch and bound” method. This is a systematic method for solving optimisation problems. This model assesses the optimal ways for the vehicles to reach the safe havens.

The potential to use such a model has been tested by choosing two nodes in the network as safe havens and changing the position of these nodes, in order to have the different evacuation paths. This could be used to help decision makers organise evacuations and to optimise number of vehicles going through each road. The total cumulative time that the vehicles spend in the network is minimised. Six different locations of safe havens were investigated. The locations of the safe havens are shown in Figure 5.26. The estimated evacuation time by vehicle varied from 4.7 hours to 11 hours depending on the location of the vehicles. These results indicate to decision makers that if people are in resilient

two storey buildings then the best options is for them to stay at home and move to the second floor if an unexpected breach has occurred.

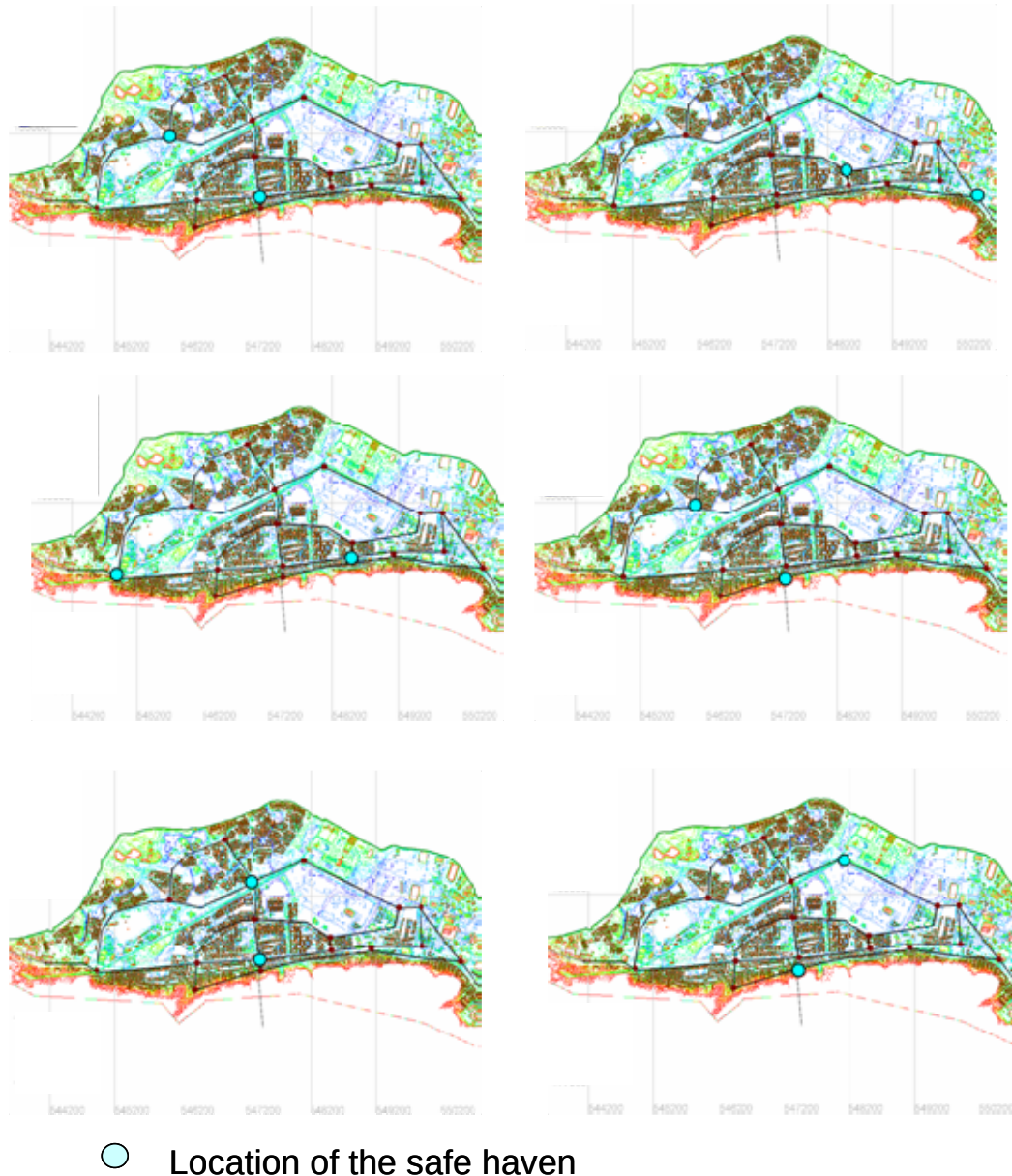


Figure 5.26 The six different locations of safe havens that were tested

5.6.3 Conclusions and recommendations

To apply this model details of the road network of the area are needed. The more detailed the information on the network the more accurate the results will be. However, the more complex the computation will be. It is important to note that using a more detailed road network means more time is required to set up the model. The model set up needs to make assumptions concerning how many vehicles depart from each node, so if a detailed network is used it could be time consuming to set up

the model in terms of assigning vehicles to each node. A non-linear optimisation-based model for evacuation has several advantages for use at a meso-scale:

- It is relatively quick to set up such a model for small areas;
- It can be simply modified;
- Large areas can be modelled using relatively simple networks;
- A number of different evacuation routes and locations of safe havens can be tested quickly.

However, it should be noted that this method optimises the cumulative time in the network and as such it is not necessarily simple to obtain the evacuation time for a particular node. The model also makes simple assumptions regarding flow in the traffic based on the Greenshield formula. It could be used as meso scale tool to assess evacuation times for large areas providing details of the various pathways were available.

5.7 Application of simple spreadsheet based approach

5.7.1 Background to method

A simple spreadsheet based approach was investigated that could be employed by local authorities at a macro-scale to make a quick overall estimate of the maximum time it could take to evacuate an area. The spreadsheet based method requires the following data:

- Number of vehicles;
- Distance of the vehicles from the exits.

The spreadsheet based method is simple in nature. It makes the following assumptions:

- Everybody evacuates the area by car;
- There are no traffic jams;
- All the vehicles are assumed to travel at a constant speed.

The spreadsheet based approach is similar in principle to the Evacuation Calculator that is detailed in Chapter 6 of this report. The method was tested in both Thamesmead and Canvey Island. The simplified road networks used for these locations are shown in Figures 5.27 and 5.28 respectively.

5.7.2 Results

Table 5.7 provides a summary of the results for the ten scenarios that have been modelled. It is interesting note that although the model makes a large number of very simple assumptions the evacuation times that range in value for Thamesmead from 5.5 hours to 17.9 hours are of the same order of magnitude as those provided by the more detailed models.

Table 5.7 Summary of results of the evacuation time based on a simple spreadsheet model

Scenario	Maximum time to evacuate area assuming vehicles travel at 30 km/hour (hours)	Maximum time to evacuate area assuming vehicles travel at 60 km/hour (hours)
Thamesmead – Assuming 750 vehicles/hour exit capacity	17.9	11.9
Thamesmead – Assuming 1,500 vehicles/hour exit capacity	8.3	5.5
Thamesmead – Assuming 3,000 vehicles/hour exit capacity	3.3	2.2
Canvey Island – Assuming 1,500 vehicles/hour exit capacity	19.7	13.1
Canvey Island – Assuming 3,000 vehicles/hour exit capacity	9.5	6.3

Note: The model results assume everybody is resident at home

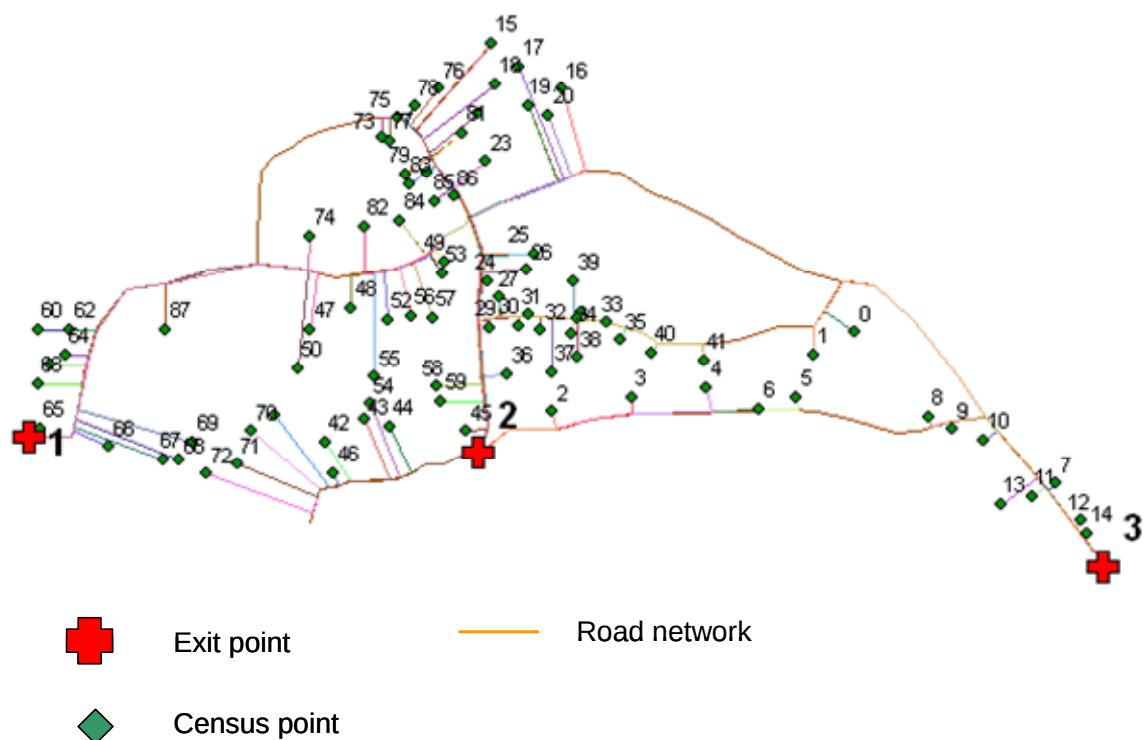


Figure 5.27 Thamesmead road network used for the spreadsheet macro-model

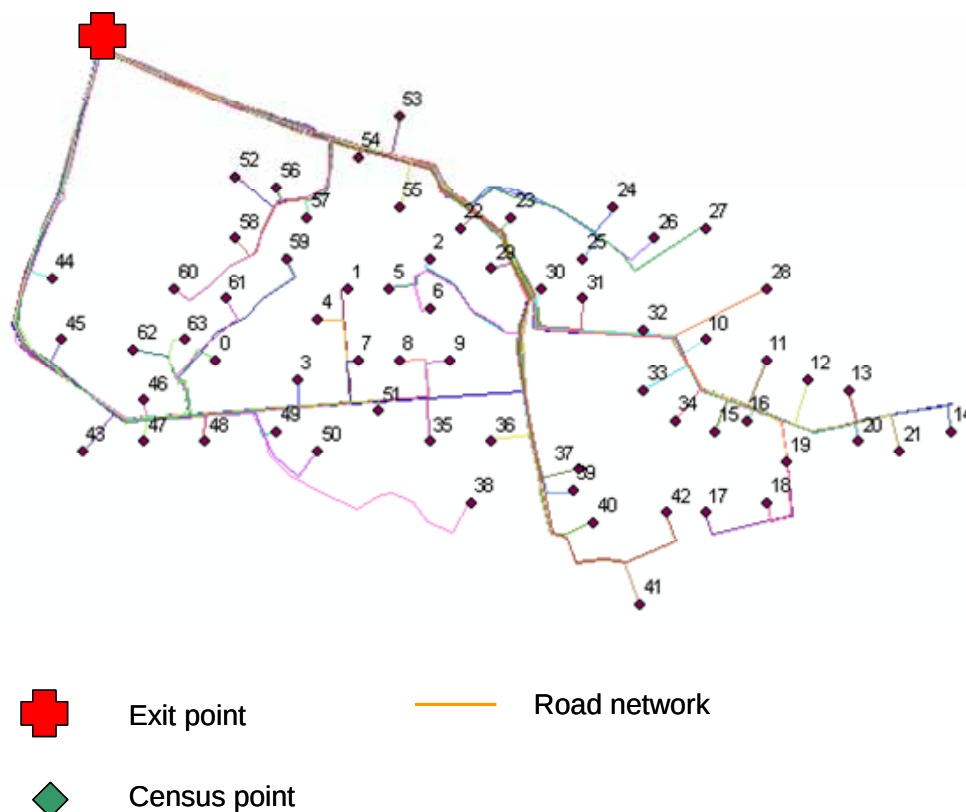


Figure 5.28 Canvey Island road network used for the spreadsheet macro-model

5.7.3 Conclusions

The spreadsheet model is simple to set up. However, it can only usefully be employed at a macro-scale as it makes several simplifying assumptions such as assuming that all the traffic flows freely. However, if geo-referenced census road network data are readily available then a first order estimate of the evacuation time can be made very quickly.

5.8 Response of end users

A one day end user workshop was held at HR Wallingford in January 2008 to discuss the research that had been undertaken and its relevance to end users. Twenty end users from the following organisations attended the workshop:

- The Environment Agency;
- Coast Guard;
- Local authority emergency planners based in the Thames Estuary;
- Government Resilience Forum members;
- Department of Communities and Local Government

The end user response was encouraging. All the end users felt that the tools presented were useful in improving the formulation of emergency plans for flood event management. The key points made by the end users were summarised as follows:

- The tools allow the risks involved in evacuation to be assessed;
- The software presented could be used to analyse not only flood defence breaches but also dam breaks;
- Emergency planners could use the results to identify safe havens and alert people in the at-risk area where to move before a flood event occurred;
- The tools could be developed further so that they were used as tools in emergency planning exercises.

The end users agreed that the responsibility for evacuation modelling should be held by the Environment Agency and their expertise should be used to inform local authority emergency plans.

5.9 Conclusions and recommendations

Three methods have been tested that are applicable at three different spatial scales:

- Micro-scale;
- Meso-scale; and
- Macro scale.

Although time consuming to set up the BC Hydro LSM micro scale model provides the most useful results. Not only can evacuation times be assessed for a number of emergency management interventions (e.g. road closures, safe havens) but the model also computes the injuries and loss of life for each method. Once the initial “virtual” world has been set up in the LSM is relatively quick to make changes to the model to assess the impact of different interventions and management strategies. However, at this stage the LSM is not user friendly. Other meso and macro scale models only provided first order of magnitude in terms of the evacuation times. These could be useful at high level planning stage but are unlikely to be useful for detailed emergency planning

6. Pilot application for the Schelde, the Netherlands

6.1 Introduction

This chapter discusses the Schelde pilot study. For this pilot study the following models were applied:

- **Macro scale** Evacuation Calculator (EC)
- **Macro scale** ESCAPE Decision Support System (DSS)
- **Meso scale** INDY

The Evacuation Calculator (EC) is incorporated in the Dutch Flood Information System (HIS), ESCAPE and INDY have been developed by Netherlands Organisation for Applied Scientific Research Building and Construction Research (TNO) and others. INDY has been used previously to estimate evacuation times for other areas than Zeeland. ESCAPE was jointly developed by authorities of the North Sea regions of the Netherlands, Belgium and the United Kingdom. It has been applied to parts of Zeeland, but not to the whole of Zeeland.

As discussed in Section 4.2, there are three main scales at which evacuation models are employed for flood event management: micro, meso and macro scale. The EC and ESCAPE are both macro scale models, as they provide evacuation time estimates for groups of people. The road network in the EC is simplified by driving distances stored in an “origin-destination matrix” combined with an average driving velocity. The road network in ESCAPE is slightly more detailed, representing various road capacities in the network. INDY is able to model different routes between the origin and destination, and allows for the occurrence of congestion. INDY is therefore suitable for use at a meso scale. None of the software tested were able to model the individual behaviour of people and therefore no simulations could be undertaken at a micro scale.

By applying all models on the Schelde pilot and comparing the results, conclusions can be drawn on the reliability of the model results. The question is what result is caused by the model architecture (e.g. assumptions on velocity and road capacity, applied algorithms) and what result is caused by the characteristics of the area of study (e.g. population density, road network, exit points). The aim was to ascertain which what model is most suitable for the planning of an evacuation. Our focus in this study was on the technical planning aspect, i.e. which inhabitants go where, when do they leave, how long does it take them to reach safety and which route do they take.

This chapter describes:

- The application of the different models and the resulting evacuation times;
- The applicability of the models to meet various objectives with respect to the evacuation process;
- Technical differences between the models.

6.2 Description of the area, flooding in the area and evacuation possibilities

6.2.1 Pilot area

This pilot focuses on the area of the Netherlands to the north of the Westerschelde. This is shown in Figure 6.1. This area consists of three islands:

- Walcheren;
- Zuid-Beveland West;
- Zuid-Beveland East.

The islands are surrounded to the west by the North Sea, to the south by the Westerschelde Estuary, to the north by the Oosterschelde and to the east the Kreekrak and Rijn-Schelde Canals. The threat of flooding mainly occurs from the North Sea and Westerschelde Estuary. The Oosterschelde is less likely to experience extreme water levels as its connection to the North Sea is protected by a barrier. The embankments along the Westerschelde are between about 8 m to 11 m above mean sea level, whilst those along the Oosterschelde have heights of about 5.5 m to 8 m above mean sea level.

The pilot area was reclaimed by the sea. There are several old embankments in the area that show the incremental land reclamation. These are shown in black in Figure 6.1. These secondary embankments limit flooding when failure of the main dikes occurs. The area has approximately 200,000 inhabitants. Most of them live in the cities of Goes, Middelburg and Vlissingen. Land use consists of agriculture and various industries. The area attracts many tourists in summer. The Westerschelde is an important navigation route towards the important harbour of Antwerp along the Schelde River in Belgium.

The area was hit by a serious flood in 1953. During this flooding large areas of the Netherlands were inundated, many people died and thousands lost their homes, possessions and farms. After 1953 new safety standards for flood risk management were developed. In the pilot area flood protection standards have been set to a 1 in 4,000 year level (i.e. a 0.025% annual probability).

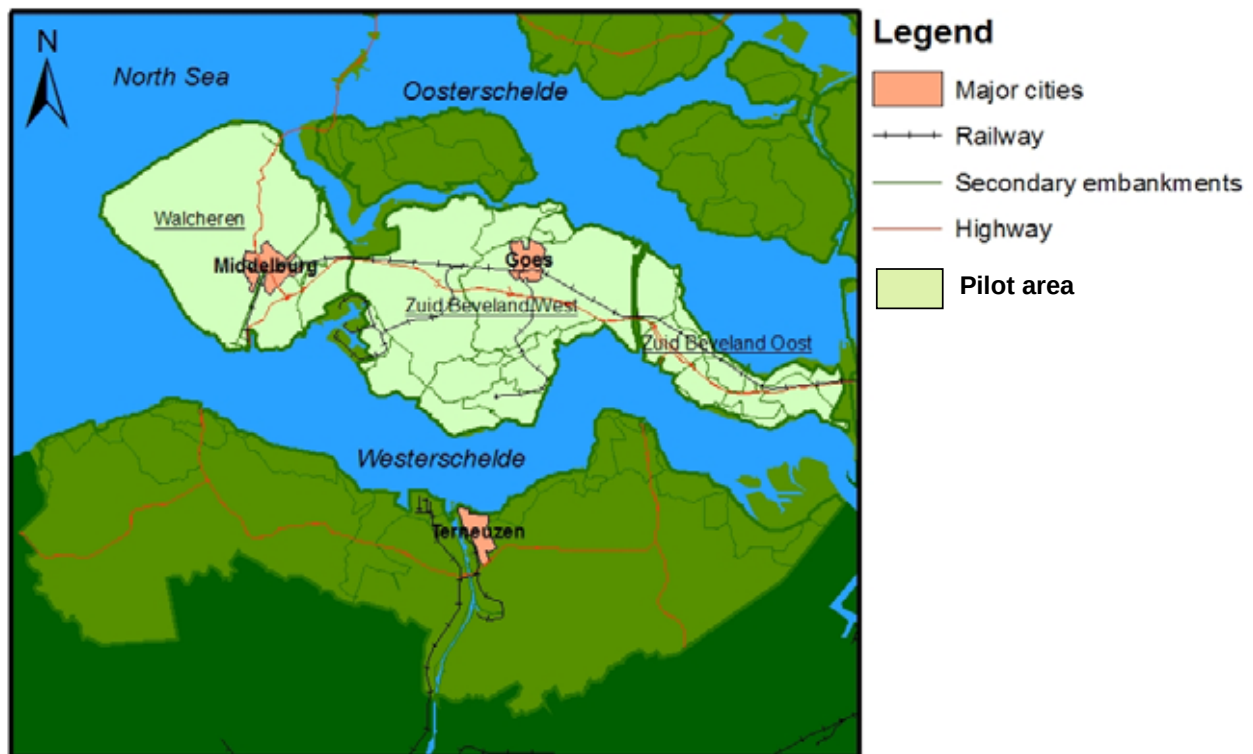


Figure 6.1 .The Schelde pilot area

6.2.2 Potential flood patterns

The area that will become flooded depends on the embankment failure location. Figure 6.2 shows the estimated water depths for a large number of embankment failure locations along the Westerschelde Estuary. It is expected that only one or a few of these locations will breach at the same time. The breach locations in the model simulation have been chosen based on the vulnerability of the flood-prone area. This resulted in an estimation of the flood risk as explained in De Bruijn et al (2008). Figure 6.2 also shows that the secondary embankments limit the flood extents. Owing to these secondary embankments, large parts of the area are expected to remain dry.

Not all the inhabitants in the pilot area face the same level of risk during flooding. Within the study area different zones can be distinguished:

- Zone 1 ‘High rise’** Areas that may be flooded and may face high flow velocities or high water level rise velocities;
- Zone 2 ‘Low rise’** Other areas that may become flooded, but where the rise in the water is slow and water depths are less than 2 m;
- Zone 3 ‘Dry’** Areas that will probably stay dry. It should be noted that the probability of flooding from the north (i.e. ‘Oosterschelde’) is not taken into account.

This distinction is comparable to that proposed by Jonkman (2007) where three ‘hazard zones’ are defined depending on the flow velocities, rise rate and water depth. Jonkman in addition differs between zones with high velocities and zones with rapidly rising water. In the current study they were combined into one zone known as ‘High rise’ (Klijn et al).

The location of these zones depends on the expected dike breach location and the presence of local compartments formed by ‘line elements’ such as secondary dikes. Once potential dike breach locations are known, these zones can be identified. Zone 1 occurs close to the dike breach location and in small deep polders. When flow velocities are high in these areas houses may collapse and inhabitants may suffer casualties. Evacuation should begin in Zone 1, while Zone 3 may not need to be evacuated at all. The areas with high rise rates are indicated in Figure 6.3. More information on the production of this map can be found in (Mens et al, 2007).

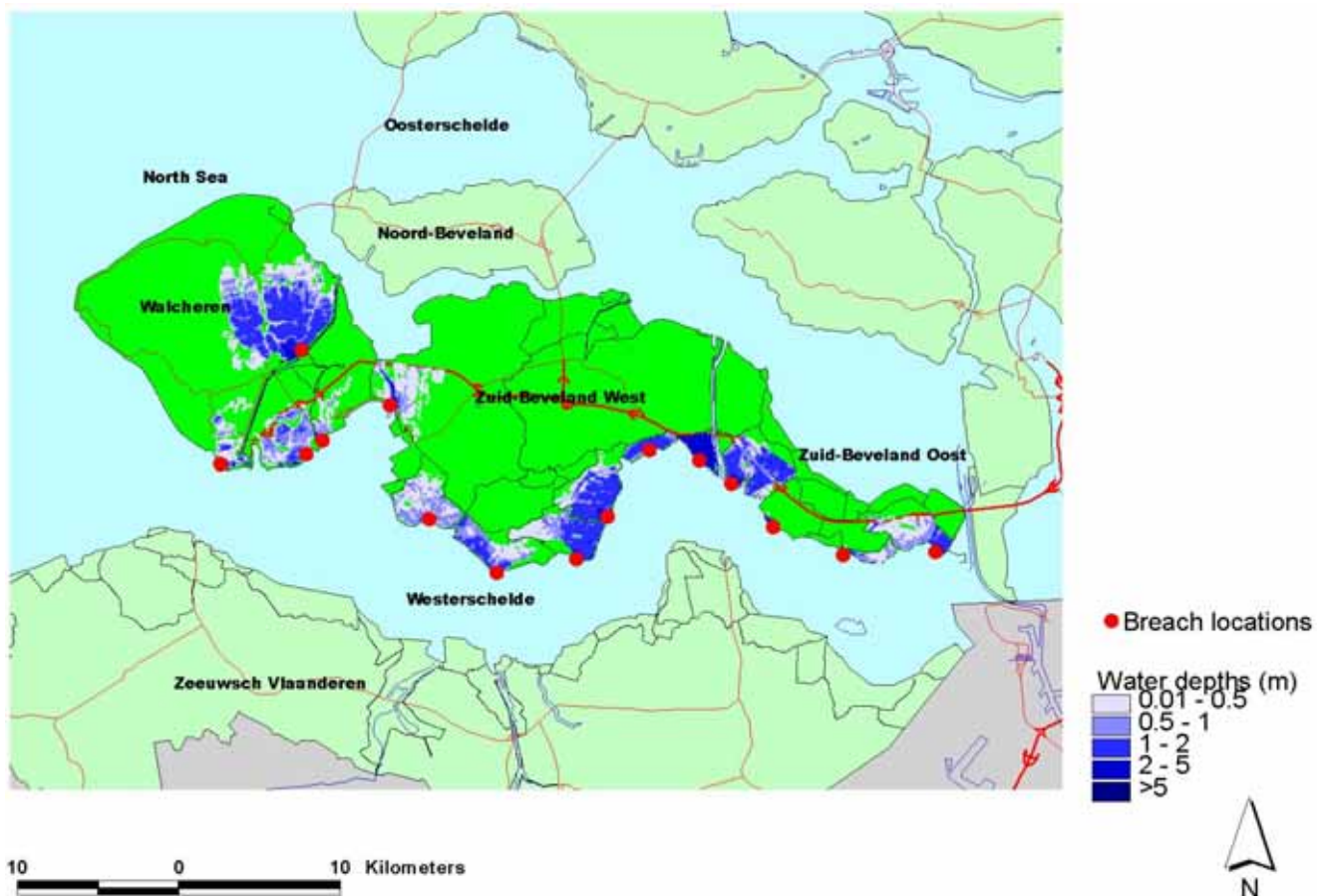


Figure 6.2 Water depths resulting from breaches at the locations indicated with the red dots for in 1 in 4,000 year sea level conditions

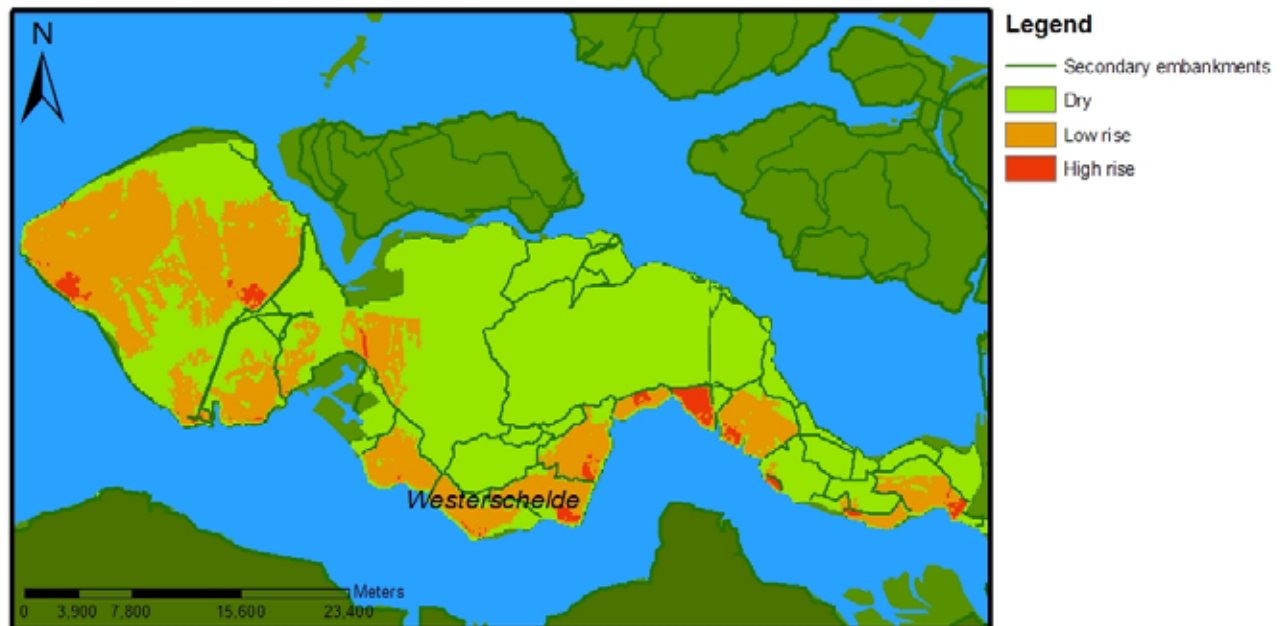


Figure 6.3 Areas where water rises quickly if breaches occur at the locations shown in Figure 6.2

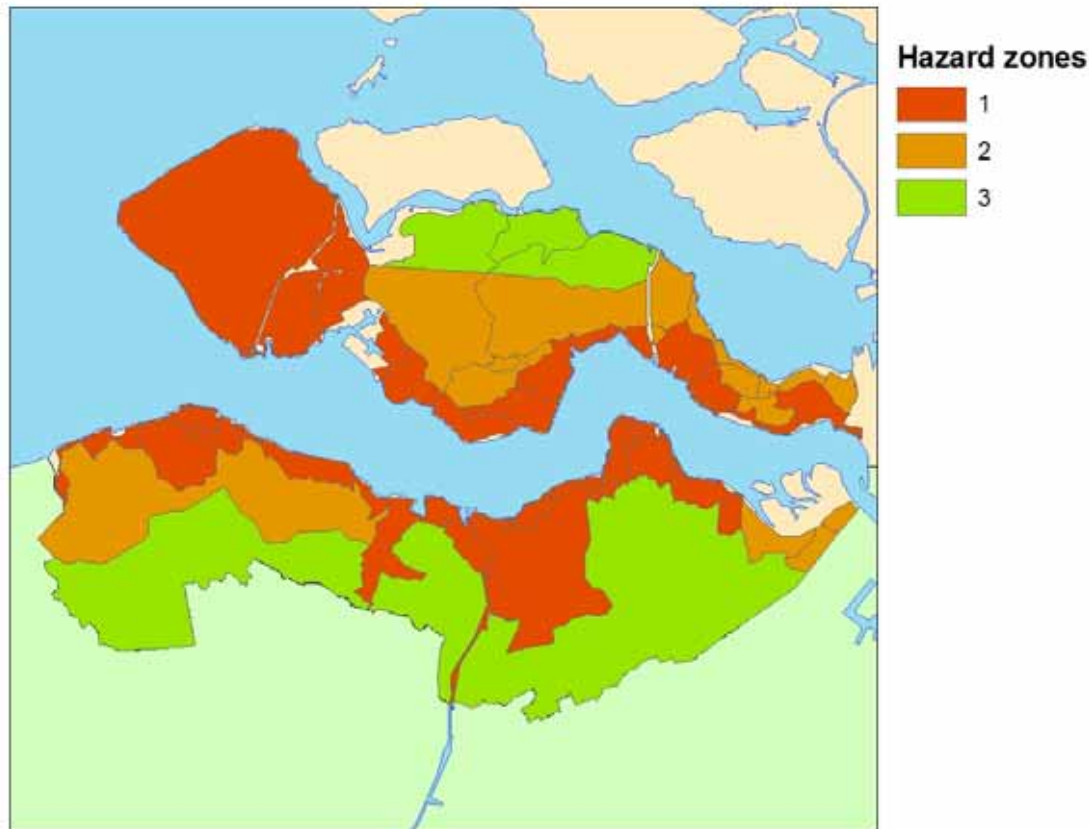
Figures 6.2 and 6.3 indicate that, according to the model results, large areas of the pilot site will stay dry and that only near breaches can high flow velocities be expected. In small and deep compartments (polders) high rates of water level rise can be expected. Those polders are thus more vulnerable than large polders with slow rising water tables. Figure 6.4 shows the resulting three 'hazard zones' for the pilot area. Zone 1 is located directly behind the primary dike, where the risk of a dike breach is highest and would result in relatively high velocities, rise rates and water depths. Zone 2 areas are located behind secondary embankments or other line elements such as roads or higher areas. Zone 3 shows the areas where no water is expected from a flood from the Westerschelde. It should be noted that a breach on the north coast has not been taken into account.

6.2.3 Evacuation possibilities and potential shelters

If flooding occurs, people in the area may do one of the following:

- They may evacuate. In this report 'evacuation' is defined as 'leaving the pilot area';
- They may also move to local safe havens. These may be high buildings, dunes or strong embankments above the flood water level;
- They may also stay at home and go to their first or second floor.

These options are discussed below.



Note: Zone 1, shown in red has a high probability of flooding with high rise rates and velocities
Zone 2, shown in orange, denotes areas with a lower hazard ('low rise')
Zone 3 shown in green stays 'dry'.

Figure 6.4 Pilot area divided into 'hazard zones'

Evacuation

If large scale flooding is expected evacuation may be the best option. Although the pilot area consists of islands, people may leave the area via numerous routes. Possible exit routes include:

- The A58 highway that leaves the area over a bridge on the east side;
- Two small bridges at the east side;
- Two dams located on the north-west side of the area. These dams connect the pilot area with the island Noord-Beveland. From that island, cars may go to the north across the Oosterschelde Barrier. This barrier is closed for traffic during storms;
- To the south there is a main road going to Terneuzen. This road connects the pilot area with the mainland at the south of the research area by a large tunnel underneath the Westerschelde Estuary.
- There are also ferries for pedestrians and a railway that goes across a bridge to the east.

Whether all these routes will be available for evacuation depends on the timing of the evacuation. If a storm or flood event has already commenced the dams may be closed. The tunnel may also be closed well before flooding actually occurs. The bridges in the east can be used also during storms. If evacuation occurs when the storm has commenced or after flooding has started, some roads may be blocked by debris (e.g. fallen trees) or by floodwater.

The Province of Zeeland, in which the pilot area is located, will only advise or order evacuation if it is likely that evacuation can be completed before flooding occurs. This is because cars are dangerous places to be during a flooding. If there are traffic jams there is a risk that vehicles will be trapped or swept away by the floodwater.

The decision to evacuate depends on the forecast time of the flooding, the forecast flood hazard, the weather conditions and the expected duration of evacuation from a certain area. Evacuation should not be undertaken when combinations of heavy storms and precipitation or combinations of freezing temperatures and precipitations are expected. In those cases, accidents may block roads and evacuation may not be effective.

Evacuation procedure

In the pilot area the procedure in which decisions are taken on evacuation is currently triggered by the water level forecasts at Vlissingen. Forecasts are provided by the SWD (Stormvloed Waarschuwingsdienst), the Hydro-meteorological service in Zeeland, and Rijkswaterstaat. Forecasts in this region usually have a lead-time of six hours. Efforts are currently being made to extend the lead-time to 48 hours.

If the forecast water level at Vlissingen exceeds 3.10 m above mean sea level then “Alarm state 3” is reached. “Alarm state 3” is part of an alarm system with 5 states which describe the risk of a disaster. For each state certain actions are required. A warning is distributed when the expected level exceeds 3.70 m mean sea level. “Alarm state 4” is reached when the expected water level exceeds 4.10 m above mean seal level. In Alarm state 3 the mayors of the municipalities are responsible for the emergency response. In alarm state 4 the governor of the province takes overall responsibility. The Province of Zeeland, in which the pilot area is situated, has prepared an emergency plan for all the municipalities with respect to flooding. In these plans transportation plans are available for schools, hospitals and nursing homes. Other people are expected to evacuate themselves. When the Governor of the Province decides that evacuation is necessary, this is communicated to the relevant authorities. The public is informed by radio and television broadcasts. The police are responsible for traffic management during evacuation.

There is little information in literature on evacuation concerning the time it takes to make a decision, to warn and to finally respond. The following times have been estimated by Frieser (2004), based on empirical data on the flood hazard in the Netherlands in 1995 and on hurricane and train derailment accidents in the USA. and Canada:

Decision making:	Four hours
Warning:	Three hours
Response by inhabitants and organisations:	Six hours

This leads to a total of 13 hours before the actual evacuation process can start. In both ESCAPE and Evacuation Calculator this preparation time is excluded from the simulations.

Organisation of the evacuation:

Evacuation may be organised in different ways: People may just be advised to leave, without further information. They may also be advised to take a certain route. In some cases if it is possible to manage traffic people may even be *ordered* to take a certain route. If the level of organisation is high, people may even be ordered to leave at a certain time and take a certain route. However, people will not always obey those orders and leave at the time told and go in the direction told.

To inform and advise the public and to organise an evacuation, the government needs at least the following information:

- Information on most likely location and time of failure of the embankments;
- Likely flood patterns;
- Weather conditions;
- Duration of evacuation of the different areas within the region;
- Population characteristics, and location of vulnerable people, objects and dangerous industries (e.g. chemical factories, large fuel deposits);

- Location of shelters and safe havens inside the area.

Evacuation to safe havens

In addition or in parallel with evacuating the whole of the affected area it is also possible to advise people to go to nearby safe havens (i.e. safe locations). Such locations may be areas of high ground, high buildings in the area, dunes or embankments. During storms it may be difficult for people to stay outside for long periods of time. If there is a choice it is better for people to go to safe havens such as schools, hospitals and apartment buildings instead of dunes, embankments. Decision makers need maps of potential shelters. Figure 6.5 shows a map with tall buildings and the higher areas within the pilot area. The high areas of ground and these buildings may serve as safe havens.

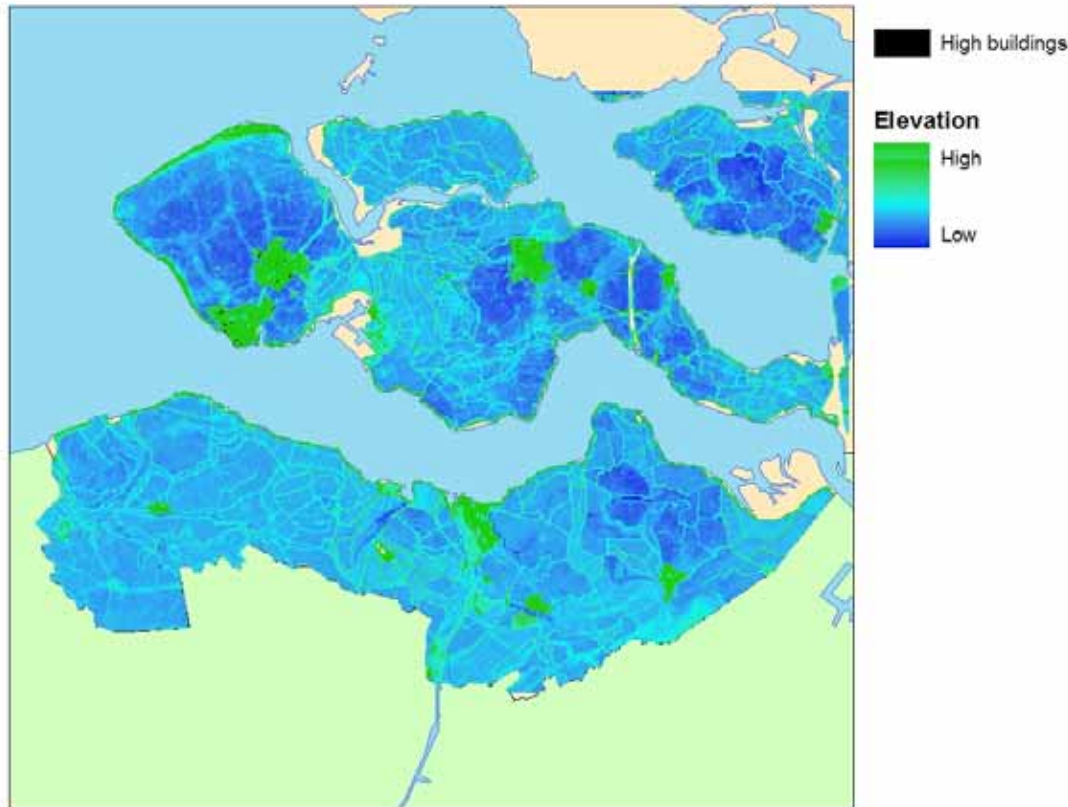


Figure 6.5 A map of tall buildings and higher areas in the pilot area

Stay at home

Under the following conditions, staying at home during a flood is considered a viable option:

- The building has more than one level;
- Flow velocities are low;
- The building is not expected to collapse (e.g. it is constructed from concrete)

This option is advantageous in that the risk of injury during evacuation is averted, as well as the risk of looting. The disadvantage is that, because flood durations can be extensive, evacuation after a flood may be time-consuming. In 1953 some areas were flooded for months.

6.3 Application of the Evacuation calculator

6.3.1 Description of the Evacuation Calculator model

The Evacuation Calculator (EC) was developed to calculate how much time is required for evacuation and to determine the effect of traffic management during the evacuation process on the required

evacuation time. It is a macro-model that focuses on traffic flows and not on individual people or vehicles. The EC includes the evacuation of both persons and livestock. It was developed by M. van Zuilekom of the Faculty of Engineering, Center for Transport Studies at University of Twente and funded by RWS-DWW. It has been included in the Dutch Flood Management System (Hoogwater Informatie Systeem (HIS)). The EC has already been applied to three dike rings in the Netherlands: the Noordoostpolder, Zuid-Holland and Land van Heusden/De Maaskant.

The EC uses postal code areas as spatial scale. It first calculates the number of trips needed to evacuate each postal code area which is marked as a 'source zone'. The number of trips depends on the number of people and cattle present and the distribution of the people over different evacuation categories.

Secondly, it distributes the number of trips from all source zones over the different exits available. For this distribution there are three options:

- **Reference:** The evacuees from each source area are equally distributed over each exit. Each exit thus receives the same number of people;
- **Nearest exit:** People go to the exit nearest to them;
- **Traffic management:** The number of kilometres and the outflow at the exits is optimised.

Figure 6.6 shows a schematic example of applying the three management options for an artificial area with 300 inhabitants. One hundred people are closest to the upper exit and 200 persons are closest to the lower exit. We have assumed that the upper exit has a higher capacity than the lower one. In the nearest exit option people choose the closest exit regardless of the exit capacity. The result is that more people leave the area through the lower exit. As this exit has a smaller capacity than the upper exit, this option will not be the most efficient one in terms of minimising the evacuation time.

In the reference option, the evacuees from each source area are equally divided over the exits, as a result of which the distances travelled by many of the evacuees are not optimal. Owing to the fact that cross flows are not taken into account with EC, the evacuation times tend to be underestimated. To compensate for this, the reference option was created to increase the travel distances, which serves to increase the evacuation time. Hence whilst the reference option itself does not represent a realistic evacuation strategy, it is intended to give an estimate of the evacuation time in a realistic situation in which cross flows have been taken into account. In the traffic management option more people are directed towards the exit with the highest capacity. This will result in the most efficient evacuation, but is not necessarily what will happen in reality.

Thirdly, the EC calculates the time needed for all people to organise themselves for departure and to drive from the source zone to the exit zone. The EC also determines the time needed for outflow at the exit. The EC process is shown in Figure 6.7.

The EC focuses on the general evacuation process at a macro-scale. In the EC the evacuation of vulnerable people from hospitals, elderly homes, child day care centres is not incorporated explicitly. The organisation of evacuation assistance, traffic management and other rescue services is not incorporated either.

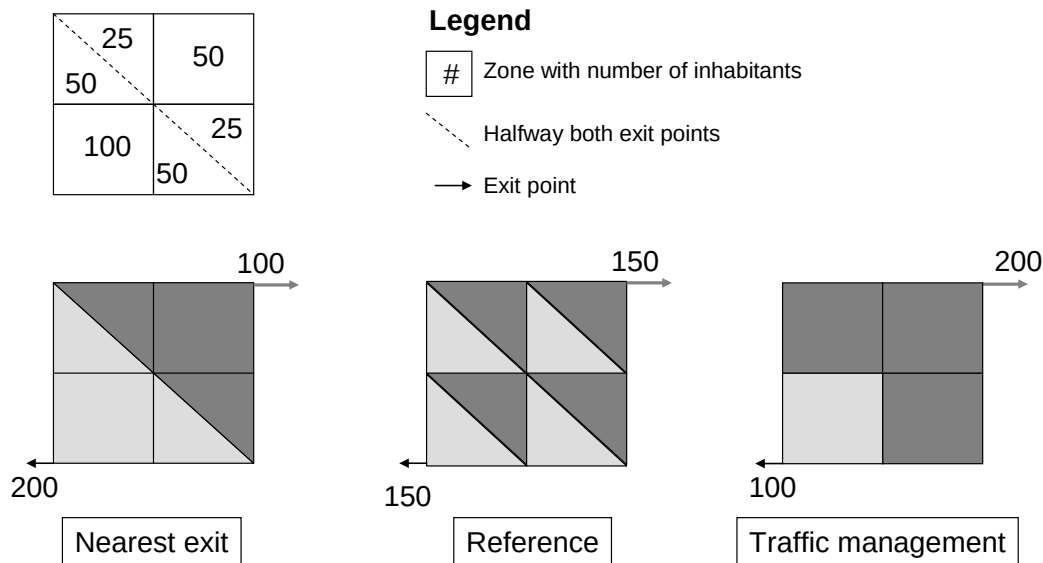


Figure 6.6 Example of an area with a population density that is evacuated according to the three management options in EC

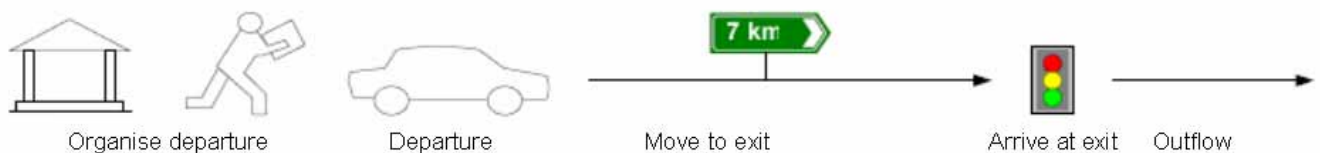


Figure 6.7 The evacuation process as schematised in the Evacuation Calculator

The time needed for evacuation of an area in the EC depends on:

- Number of persons and cattle present;
- Number of persons and cattle who stay behind;
- Departure profile (how quickly do people leave);
- Distance to the exit;
- Average speed of driving to the exit;
- The outflow capacity of the exit;
- The organisation of the evacuation.

The EC requires the following input data:

- The source zones (i.e. four digit post code areas where people are evacuated from);
- The exits (i.e. four digit post code areas just outside the evacuated area);
- The distance between the source zones and exits;
- The number of people and cattle present in each source zone;
- The capacities of the exits and their relative attractiveness.

To estimate the evacuation time with the EC several assumptions must be made. The most important ones are summarised here:

- **Number of people present:** All inhabitants are assumed to be present. However, in reality during working hours, holidays and on other special days many people may not be at home.

- **All people respond to the evacuation warning:** In previous applications it was assumed that everyone responded on the evacuation order.
- **Departure:** The model requires a departure profile, which indicates how quickly people leave after they have received an evacuation order. For this departure profile an “S-shaped” curve is usually used.
- **Average number of people per vehicle:** The distribution of people over different categories, and the occupation rate of vehicles means must be assumed.
- **Average velocity:** The model requires an assumption on the average travel velocities. This velocity depends on the type of roads, the conditions of the roads, the occurrence of traffic jams and the weather. Usually an average velocity of 20 km/hour is used. However, because cars usually drive faster, the use of this low figure means that some delay is incorporated in the estimate.
- **Outflow at the exits:** The capacity of the exits depends on the road type and on expected traffic jams at or near the exit. If traffic jams outside the evacuated area the capacity of the exit in the model must be reduced by a reduction factor. In previous applications of the EC a reduction factor of 0.2 was used on the exit capacities.

The use of all these assumptions introduces a high degree of uncertainty on the results. The results must thus be considered with care.

6.3.2 Approach

In this research the EC has been applied to provide an estimate of evacuation times. The results of the EC have not been used directly; they have not been attributed to a traffic model. To apply the EC in the pilot area the source areas and exits were identified first. The exits are presented in Table 6.1 and Figure 6.8. The road network and the socio-economic data were derived from the traffic model New Regional Model (NRM). The distribution of the evacuees across different categories and their occupation of cars have been copied from previous applications. They are shown in Tables 6.2 and 6.3.

Table 6.1 Overview of the exits and their capacity

Exit	Source code (PO zone)	Description	Exit type	Capacity (trips/hour)
1	4634 (3240)	Highway A58 (2 lanes) and main road (1 lane)	Bridge	6,144
2	4641 (3242)	Secondary road	Bridge	1,200
3	4542 (3175)	N62 Westerschelde tunnel (2 lanes)	Dam	3,200
4	4493 (3147)	N57 Middelburg to Noord-Beveland (1 lane)	Dam	1,500
5	4484 (3143)	N256 Goes to Noord-Beveland (1 lane)	Tunnel	1,500

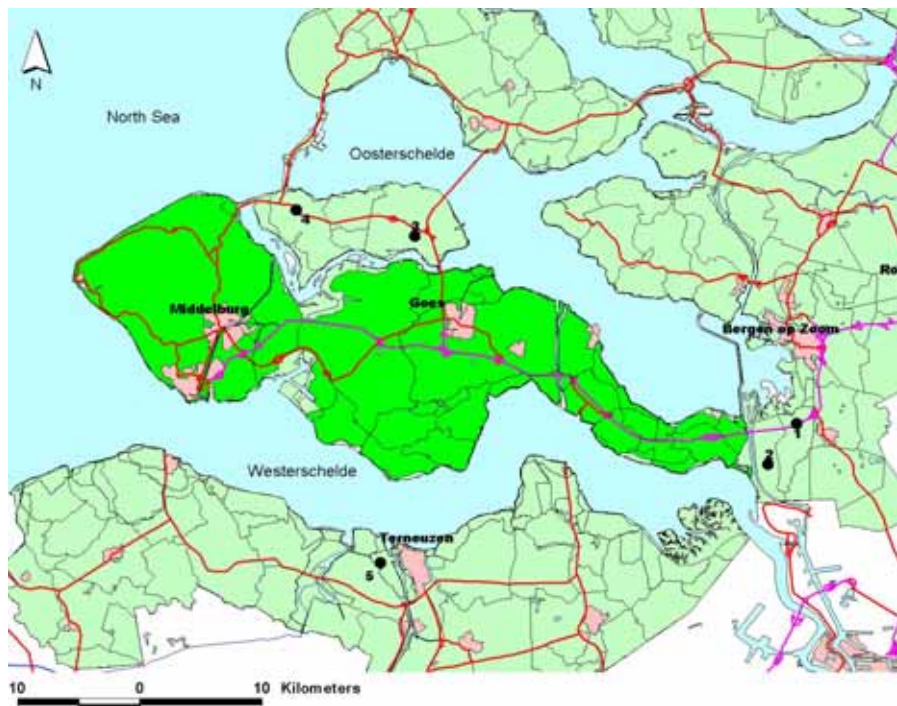


Figure 6.8 The exit locations as used in the Evacuation Calculator

Table 6.2 Description of evacuation categories and their car occupation

Evacuee Category	Transport Means	Number of occupants	Car equivalent *
Person (private transport)	Car	2.26	1
Person (public transport)	Bus	20	2
Person (assisted evacuation)	Car	1	1
Cattle	Truck	40	2
Pigs	Truck	90	2
Poultry	Truck	4,000	2

Note: The occupation represents the number of people or cattle in one transport means. The “car equivalents” show the number of cars equivalent to the transport mean used. For example: It is expected that 4,000 chickens can be evacuated in one truck. One truck counts as 2 cars.

Table 6.3 Distribution of inhabitants over the different evacuation categories

Description	Percentage of inhabitants less than 65 years old	Percentage of inhabitants 65 years or older
Self evacuation - Car	92	80
Self - Public transport	7	10
Assisted evacuation	1	10

To apply the model to the Westerschelde area a number of assumptions were made. These are presented in Table 6.4. The results are discussed in the next sections.

Table 6.4 Summary of all assumptions used in the application of the Evacuation Calculator on the Schelde pilot

Parameter	Options
Evacuated Area	Entire study area, South side, Walcheren
Organisation	Reference, Traffic Management, Nearest Exit
Exits	All*, Exclusion of dams and tunnels
Average Velocity	20 km/hour 30 km/hour
Departure	Profile 1, Profile 2
Reduction Factor (R)	R = 1, R = 0.2

* Excluding the tunnel

Figure 6.9 shows the departure profile 1. The departure profile 2 is similar, but the duration to evacuate 50% of the inhabitants is only 3.5 hours instead of 7 hours and the duration to evacuate 90% of the inhabitants is 5.1 hours instead of the 10.2 hours shown in profile 1.

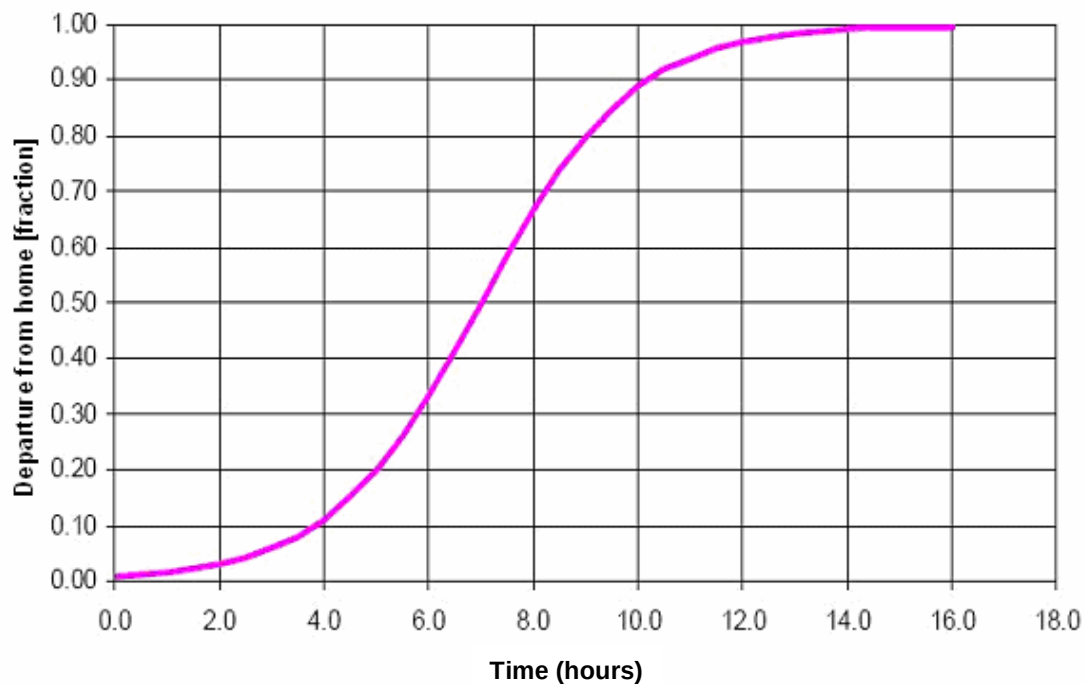


Figure 6.9 Departure profile 1: the fraction of persons that has left home as a function of the time in hours

6.3.3 Results of the application of the EC on the Schelde Pilot

Evacuation of the whole area

The resulting times for the evacuation of the whole area as calculated by the EC for different sets of assumptions are presented in Table 6.5. Table 6.5 shows the following:

Estimated evacuation time

Evacuation times ranged between 12 and more than 72 hours. The evacuation time depends on arrival time to the exit and on the outflow capacity of the exit. The arrival time in turn depends on the departure profile, the average vehicle velocity and the management strategy. The outflow capacity depends on the type of road. The final outflow was reduced by a factor 1 (no reduction) or a factor 0.2 (80% reduction)

Effect of the reduction factor

When the outflow capacity is very low, it becomes the determining factor, and the vehicle arrival time becomes irrelevant. Therefore, all cases in which the capacity of the outflow is reduced by a factor of 0.2, the evacuation time is more than 45 hours. For all cases in which the outflow capacity is not reduced (i.e. factor = 1), the number and speed of arrivals at the exit and outflow through the exit determine the total evacuation time. In the cases with the 'reference' and 'nearest exit' organisation option, the outflow capacity is the limiting factor for the total evacuation time, while in the better organised cases, the outflow is less limiting and the arrival time more important.

Effect of the departure profile

For all cases with a faster departure profile (i.e. profile 2) the resulting total evacuation time is shorter than comparable cases with the slow departure profile (i.e. profile 1). When the organisation option 'reference' or 'nearest exit' is used, the difference between using profile 1 and profile 2 is only one or two hours in the evacuation time. When the organisation option 'traffic management' is used the difference between the two departure profiles is eight to nine hours in the evacuation time.

Effect of the flow velocity

The total evacuation time was relatively insensitive to the average flow velocity. When the velocity was increased from 20 to 30 km/hour the evacuation times were reduced by a maximum of one hour.

Effect of the number of exit points

The closing of the dams for the duration of the evacuation is only important when the evacuation is not well organised. With the 'reference' strategy, the closing of these exits increases the evacuation time from 24 hours to 40 hours. In case of 'nearest exit' the evacuation time is decreased from 33 to 25 hours (profile 1) and from 17 to 32 hours (profile 2). For the option 'traffic management' the closure of the dams has no effect on the evacuation duration. This is due to traffic being routed to those exits which remain open.

Effect of the organisation

The strategy 'traffic management' results in the shortest evacuation times in all cases, regardless of the number of exit points used. The difference between the other two strategies is more complicated. When all the exits are used, the strategy 'nearest exit' results in a longer evacuation time than the strategy 'reference' (33 hours compared to 23 hours). However, when only the bridges are used the strategy 'nearest exit' results a shorter evacuation time (16 to 25 hours compared to 40 hours). This is because when all exits are used, the 'nearest exit' strategy routes more than half of the population to roads with a low capacity, whereas in the 'reference' strategy only half of the population makes use of these lower capacity roads. When only the bridges are used, the strategy 'nearest exit' is faster than the strategy 'reference' because in this situation the entire population divide themselves over two exit points: a highway and a local road (low capacity). In the 'reference' strategy the population is spread over the exit points equally, whereas in 'nearest exit', because more of the population is located near the highway, more than half the population is routed to the highway

Table 6.5 Resulting evacuation times for evacuation of the whole area for different sets of assumptions

Departure profile	Organisation	Velocity	Exits used	Reduction factor capacities	Evacuation time (hours)	Run
1	Reference	20 km/h	Only bridges	1	41	1
				0.2	>72	2
			All, except tunnel	1	24	3
				0.2	> 72	4
		30 km/h	Only bridges	1	40	5
				0.2	>72	6
			All, except tunnel	1	23	7
				0.2	>72	8
	Traffic management	20 km/h	All, except tunnel	1	22	9
				0.2	46	10
			Only bridges	1	22	11
				0.2	47	12
		30 km/h	All, except tunnel	1	21	13
				0.2	46	14
			Only bridges	1	21	15
				0.2	46	16
	Nearest exit	20 km/h	All, except tunnel	1	33	A1
				0.2	>72	A2
			Only bridges	1	25	A3
				0.2	>72	A4
		30 km/h	All, except tunnel	1	33	A5
				0.2	>72	A6
			Only bridges	1	25	A7
				0.2	>72	A8
2	Reference	20 km/h	Only bridges	1	40	17
				0.2	>72	18
			All, except tunnel	1	22	19
				0.2	>72	20
		30 km/h	Only bridges	1	39	21
				0.2	>72	22
			All, except tunnel	1	22	19
				0.2	>72	20
	Traffic management	20 km/h	All, except tunnel	1	13	21
				0.2	46	22
			Only bridges	1	13	23
				0.2	46	24
		30 km/h	All, except tunnel	1	13	25
				0.2	46	26
			Only bridges	1	12	27
				0.2	45	28
	Nearest exit	20 km/h	All, except tunnel	1	32	B1
				0.2	>72	B2
			Only bridges	1	17	B3
				0.2	>72	B4
		30 km/h	All, except tunnel	1	32	B5
				0.2	>72	B6
			Only bridges	1	16	B7
				0.2	>72	B8

Figure 6.10 shows the results for the situations in which the whole area is evacuated. Departure profile 1 has been used, the average velocity is 20 km/hour and all exits, except the tunnel are used. The reduction factor on the exit capacity is 1 or 0.2 and the organisation of the evacuation is 'reference', 'traffic management' or 'nearest exit'. The red line indicates the cumulative number of cars that have arrived at the exit as a function of time and the green line indicates the cumulative outflow of cars through the exit. When the outflow capacity is limited, the difference between the two lines is largest. The difference indicates the amount of congestion at the exit points.

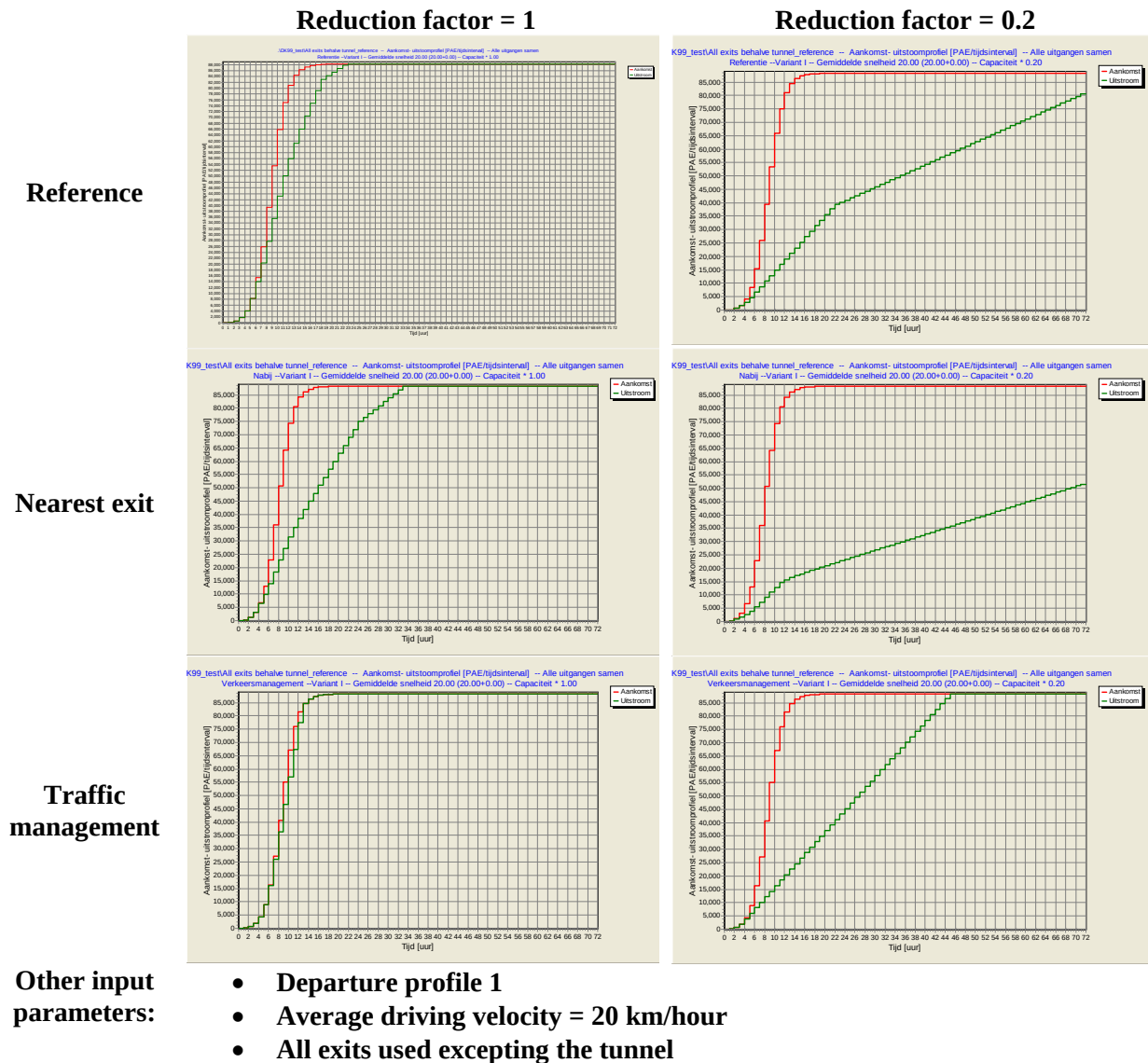


Figure 6.10 Cumulative curves of arrival (red line) and outflow (green line) as a function of time

Partial evacuation of the area

To evaluate possibilities to evacuate only a part of the area the following situations were studied:

1. Evacuation of only Walcheren – In this case people may go to Zuid-Beveland or Noord Beveland;
2. Evacuation of people from the south side to the north side or to the mainland in the east.

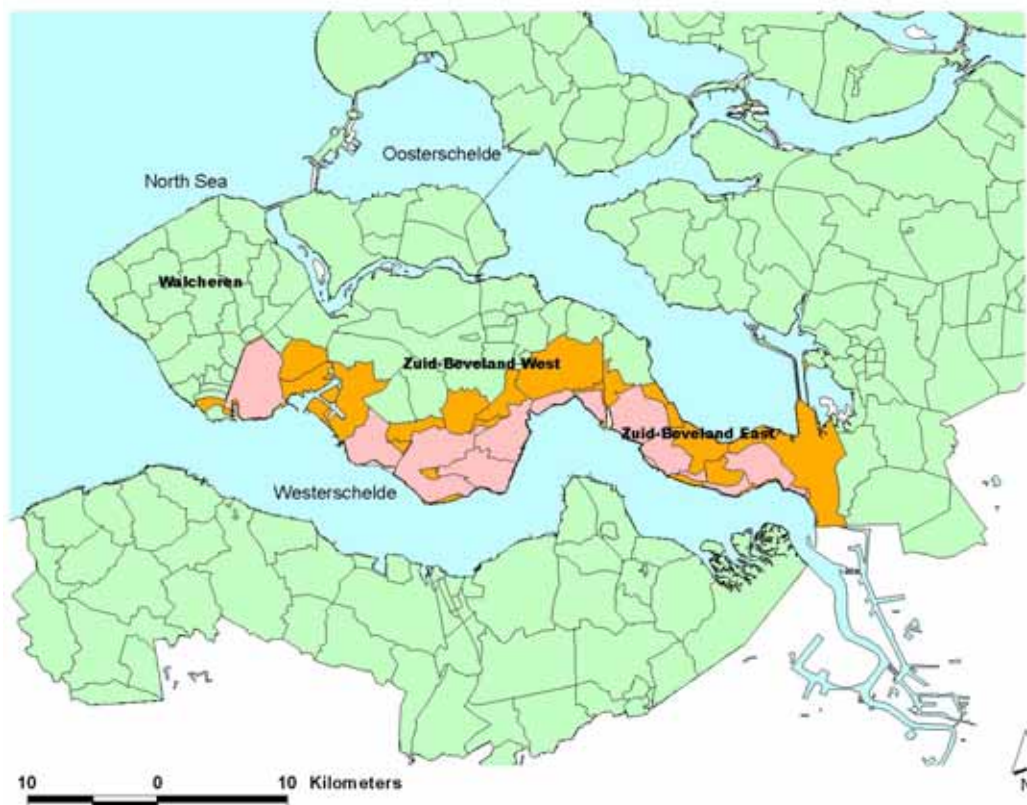
Table 6.6 shows the evacuation times for Walcheren assuming that this is the only area that is required to be evacuated. The times are shorter than those of the whole area, especially when traffic is not managed well and the outflow capacity is reduced owing to traffic jams. If traffic is well managed, the differences are small. The evacuation of Walcheren has been estimated to last between 11 and 44 hours. The time needed for all people to leave their home (about 11 hours for departure profile 1 and

about 6 hours in departure profile 2) means that evacuation durations cannot be shorter than those durations, even if the actual travel time is relatively small.

Table 6.6 Evacuation time of Walcheren compared with the evacuation time of the whole pilot area

Reduction factor	Organisation	Departure profile 1 – Evacuation times (hours)		Departure profile 2 – Evacuation times (hours)	
		Total area	Walcheren	Total area	Walcheren
1	Reference	24	21	22	12
	Traffic management	22	21	13	11
0.2	Reference	>72	44	>72	43
	Traffic management	46	27	46	25

If flooding is likely to be caused by extreme water levels and waves on the Westerschelde, rather than the Oosterschelde and North Sea, it may be possible to evacuate only the areas along the Westerschelde. Owing to the fact that the Evacuation Calculator calculates evacuation times on the scale of Postal Code areas, first those Postal Code areas which are (partly) situated in polders along the Westerschelde area were selected. Not all areas along the Westerschelde were considered dangerous in this example: Walcheren and areas which only have a very small dike stretch along the Westerschelde were excluded from the analysis. Figure 6.11 shows the extent of the polders threatened by floods from the Westerschelde in pink and the extent of the postal code areas in which this threatened area is situated denoted by pink and orange.



Orange shows the area threatened by floods, Pink and orange shows the extent of the post codes

Figure 6.11 The extent of the polders threatened by floods from the Westerschelde and the extent of the postal code areas in which this threatened area is situated

The application of the EC to this situation is not necessarily useful in emergency planning because the level of detail of the calculations in the EC is too coarse and because the time needed for people to travel from their homes to a safe location is probably small compared to the time that decision makers

and the inhabitants need to decide on evacuations. In the EC the evacuation time is determined by the following region characteristics:

- The distance between the source and exit postal code area;
- The exit capacity.

The distance between source and destination postal code area is very small in this case. People only need to travel to the neighbouring area. In reality, distances are 5 km to 10 km at a maximum. There are many roads going from south to north. The exit capacities of all the roads together are high. However, since the distances are small, people may also walk or cycle to neighbouring polders. The total number of people in the threatened area is 43,000.

The evacuation travel time for these people is considered very small compared to time which policy makers need to decide on evacuation, and the preparation time of the people. Therefore, no EC calculations have been made.

Safe areas and shelters

The EC is considered not to be useful to study the possibilities of people to reach safe havens because:

- The road network is not incorporated in the EC model itself. The model uses distances between centres of different postal code areas across the road-network and average travel times. For shelters and safe havens this approach is not detailed enough.
- The areas are incorporated on the scale of postal code areas only. These postal code areas are large. People from one postal code area may go to shelters within the same postal code area. In the EC a postal code area can only be a 'source' or an 'exit' zone and not both. If an area within the pilot area is identified as an 'exit' zone, the people within that zone are not counted as evacuees anymore. This means that the number of people that must find a safe haven is not determined in the correct way, if the EC is used and exits are identified within the research area.

The EC has therefore, not been used to study the possibility of advising people to go to shelters or safe locations within the pilot area. The possibility of evacuating only the south side, when the area bordering the Westerschelde is threatened by flooding, may be valuable. The distances are much shorter and the number of people to evacuate is much smaller. In case of sudden threats and little preparation time, such an evacuation strategy may be advisable.

6.3.4 Discussion and conclusions

From the application of the EC on the Schelde Pilot the following conclusions can be made:

Assessment of evacuation times

- If traffic jams at the exits can be avoided and most people leave the area by the A58, evacuation can be completed within about 12 hours. This means that if forecasts with a lead-time of 48 hours were available, evacuation is still feasible. However, if traffic jams occur, evacuation will last much longer. Further research with traffic models which help to assess if and where traffic jams occur, is thus necessary if decisions on evacuation should be made.
- Evacuation times may be reduced most efficiently by reducing the organisation time that inhabitants need. If they leave soon after the evacuation order is given, evacuation times may be short.
- Evacuation of the western part of the area (Walcheren) is faster than evacuating the whole area. Differences are largest for situations in which traffic management is not feasible. Calculated evacuation durations for Walcheren are 11 hours to 44 hours.
- Evacuation of the polders that are situated along the Westerschelde seems a sensible option in the situation where the available time is limited and flood threats are caused by the Westerschelde water body. The evacuation time for this option could not be calculated with the EC. For such an

evacuation the period of time needed to reach a decision on evacuation and for inhabitants to get ready and leave is more important than the actual travel time.

Assessment of safe havens

The EC is not suitable to study the possibility of people going to shelters in case of an imminent flood.

General conclusions on the EC

- The EC shows that traffic management and a the rapid departure of people are the two factors which are most important for minimising the total evacuation time;
- The EC does not contain information or results related to the occurrence of traffic jams. Assumptions on traffic jams must be made by the user. For an assessment of the occurrence of traffic jams, it is necessary to apply traffic models.
- The EC is applicable on the scale of dike rings i.e. at a macro-scale. When small areas need to be evacuated and people need to travel only short distances, the EC is not a useful tool. The decision time and the time between a warning and the departure of people are the deciding factors.

6.4 Application of the evacuation module in the ESCAPE DSS

6.4.1 Description of ESCAPE DSS

The European Solutions by Co-operation And Planning in Emergencies (ESCAPE) was a joint venture between the Province of Zeeland in the Netherlands, the Provinces of Oost-Vlaanderen and West-Vlaanderen in Belgium and the county of Essex in England. As part of the ESCAPE project a Decision Support System (DSS) has been developed. The DSS system consisted of a module that calculates the time required to evacuate a stricken area, as well as the best route to use. This module has been applied to the study area of the Schelde by Gilewska (2007). The following sections are derived from her work.

The ESCAPE DSS has a modular setup. This is shown in Figure 6.12. It consists of a decision module, data input and a schedule module. These modules are explained in more detail in the sections below. For this research only the evacuation part of the DSS was used.

Data module

In order to make a decision on evacuation, information is needed on the weather conditions, high water levels, number of inhabitants, their capacities to take independent action and characteristics of the road network. Information on critical water levels comes from the High water Information System (HIS, Rijkswaterstaat). This information helps to predict when and where the high water level is exceeded. The available time left for evacuating is derived from this. Information on weather conditions is ideally provided by the Royal Netherlands Meteorological Institute (KNMI).

Schedule module

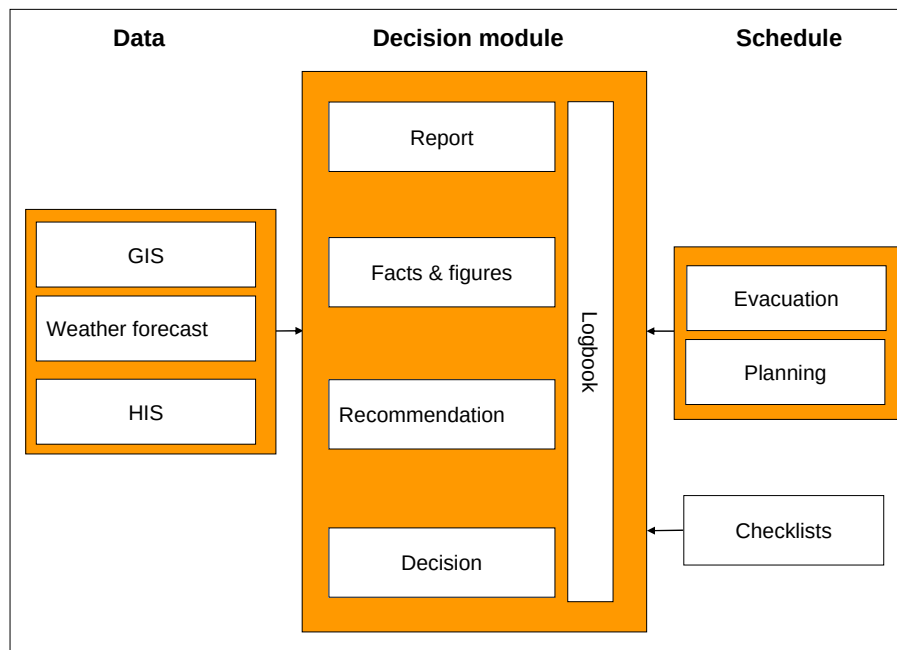
The schedule module identifies which activities must be started at what time and gives the relationship between the planned activities. This gives an overview of the evacuation process. The Schedule module is subdivided into a planning and evacuation module, which are linked. The more time planning requires the less time is left for evacuation. The final evacuation plan consists of three phases:

- (i) Decision-making.
- (2) Preparation.
- (3) Implementation.

During the first phase the actual situation is evaluated. During the second phase the preparation for evacuation takes place: Public transport is prepared for transport of evacuees, the police get ready for setting the traffic control and cordoning off evacuation routes, and people pack their personal

belongings. The last phase is a period in which the actual evacuation occurs, from the moment the first evacuees leave their homes until the moment everyone has reached safety.

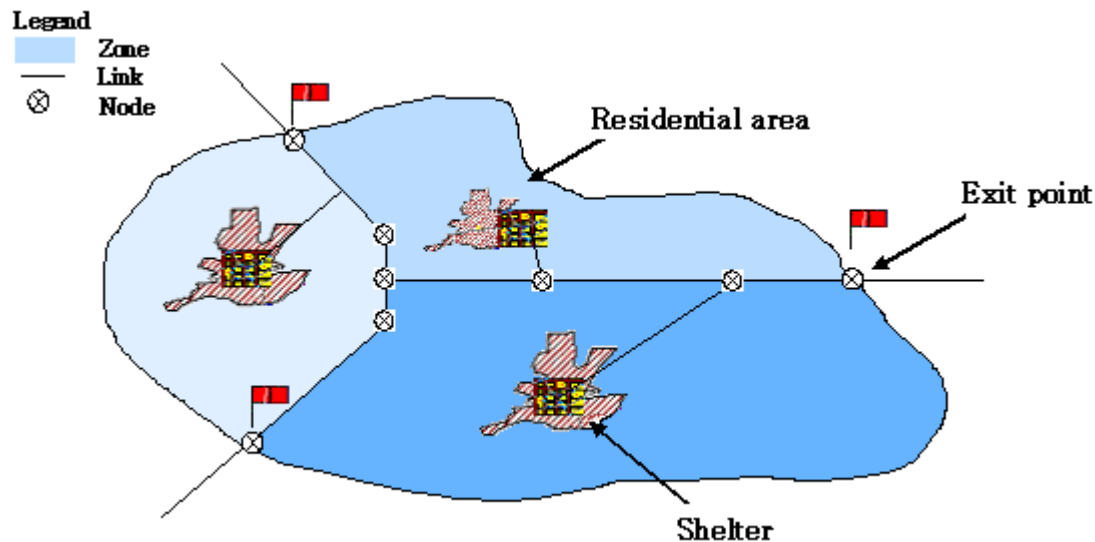
The evacuation module provides a simulation of people getting into their cars and leaving the area at risk. This calculation is based on the assumption that the evacuation will proceed in an organised manner. This involves the residents getting individual advice about their departure time and the route to follow to one of the area exits. This calculation also depends on the number of exit points from which the residents can leave the area.



Note: GIS means Geographical Information System
HIS means High water Information System

Figure 6.12 Modular setup of ESCAPE

Figure 6.13 shows an evacuation area with a number of exit points, shelters and links. The whole area is divided into zones based on postal codes, including the number of inhabitants. People from one zone are advised to take a particular route to a particular exit point. People requiring aid are evacuated by buses. The links represent the road network in the study area. The network is simplified and shows straight connections between nodes with a fixed capacity (i.e. number of cars per hour). Instead of evacuating people out of the area, they could be moved to shelters or safe havens. Exit points are the last points within the area of risk, through which the evacuees leave the area.



Source: Gilewska, 2007

Figure 6.13 Diagram of the evacuation area

Decision module

This module stores information required to take a responsible decision. The evacuation advice is based on the input from the data module, evacuation plan and certain decision rules.

Assumptions

A fully managed evacuation is assumed, to avoid traffic jams that cannot be dynamically modelled. In reality this means people need to stay at home until it is their turn to evacuate. In the model this allows for using the maximum road capacity. The shortest path towards the assigned exit points is calculated. The road capacity is constant.

In general people leave the area at risk with their own cars, while disabled people will be evacuated with buses or ambulances. Each of the buses drives back and forth between assigned zone and exit point. The number of people requiring help as well as the maximum number of buses is fixed by the user.

Input parameters

The following parameters can be changed by the user:

- Area to be evacuated;
- Number and location of exit point;
- Number of people requiring help;
- Usage and capacity of shelters.

The total planning time, before actual evacuation, is fixed to 13 hour. This is shown in Table 6.7. It includes 1 hour for observations of the critical situation, 4 hours for decisions on whether to evacuate, and in parallel 1 hour for the warning of inhabitants, 8 hour for road preparations, 5 hours for preparation of people requiring help and 8 hours for preparation of people evacuating with their own car. After this, the actual evacuation process starts, for which the required time is calculated.

Table 6.7 Evacuation times for use with ESCAPE

Phase	Phase duration (hours)	Tasks	Task Duration (hours)
Decision-making	5	Observation of critical situation	1
		Decision to evacuate	4
Evacuation preparation*	8	Preparation of evacuation routes	8
		Warning of inhabitants	1
		Self-preparation of inhabitants	8
Evacuation implementation	<i>calculated</i>	Evacuation of inhabitants	<i>Calculated</i>

* Tasks within this phase are carried out concurrently

Output parameters

The output of the ESCAPE contains:

- (1) The number of evacuees as a function of time (separate towards to exit points and shelters);
- (2) Bus distribution within zones;
- (3) Number of trips for each of the buses;
- (4) The required time for partial and complete evacuation;
- (5) Routes toward exit points. The evacuation routes are also coloured based on the exit point they are connected with.

Shelters

For cases in which the required evacuation time exceeds the available evacuation time, ESCAPE allows people to move into shelters. In this case, a second simulation is carried out to model the movement of the remaining inhabitants into shelters, the duration of which depends on the capacity and location of the shelter, and the location of the remaining inhabitants.

6.4.2 Approach

The evacuation module in ESCAPE was used to calculate the required evacuation time to partially and completely evacuate all inhabitants present in the area. The shelter function was also tested. Table 6.8 shows all combinations of parameters that have been simulated. The whole area contains a total number of inhabitants of 200,146. The western area consists of the dike ring of Walcheren, while the inundated area is based on simulations carried out in Task 14 of FLOODsite (Klijn et al). For exit points one can choose between the highway to the mainland, bridge and the dam, or a combination of all of these. This is comparable to the settings used in the application of the Evacuation Calculator. This allows results to be compared. Table 6.9 shows the simulations carried out with ESCAPE. Figure 6.14 shows the map of the study area with the exits shown by red flags and shelters shown by yellow squares.

Table 6.8 Simulations carried out with ESCAPE

Area	Exit point	People requiring help	Shelters	Simulation number
Whole Area	Bridge and dam	No	-	1
			x	2
		Yes	-	3
			x	4
	All*	No	-	5
			x	6
		Yes	-	7
			x	8
	Highway	No	-	9
			x	10
		Yes	x	11
			x	12
Western Part	Dam	Yes	x	13
	Highway and main Road	Yes	x	14
	All*	Yes	x	15
Flooded Area	All*	Yes	x	16

* 'All' represents Highway, Bridge and Dam for the evacuation of the whole area, includes the main road for the evacuation of the western area, and represents many smaller exit roads for the evacuation of the flooded area.

x Shelters were included in the simulation

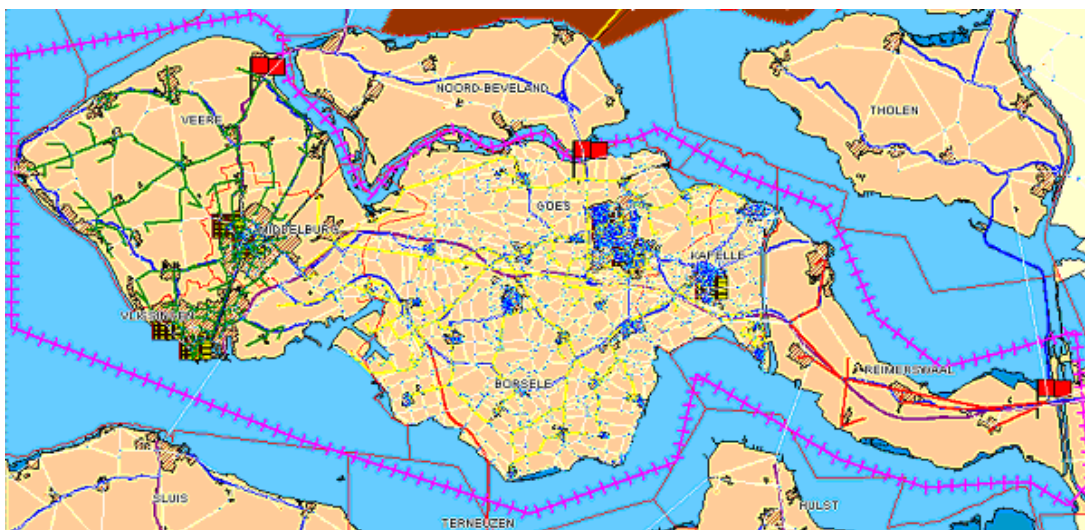


Figure 6.14 Map of study area used in ESCAPE

6.4.3 Results of the application of ESCAPE on the Schelde pilot

Table 6.9 shows that for each case the total evacuation times including the preparation time of 13 hours. The output is mostly dependent on the number of exit points used.

Table 6.9 The calculated evacuation times for each combination of the parameters in ESCAPE

Exit points	Evacuees requiring help	Shelters	Whole area	Western part	Flooded area
Dam	No	x	-	-	-
			-	-	-
	Yes	x	-	-	-
			-	58	--
Bridge and dam	No	x	53	-	-
			53	-	-
	Yes	x	53	-	-
			53	-	-
Highway	No	x	54	-	-
			54	-	-
	Yes	x	54	-	-
			54	-	-
Highway and main road	No	x	-	-	-
			-	-	-
	Yes	x	-	-	-
			-	58	--
All*	No	x	44	-	-
			44	-	-
	Yes	x	44	-	-
			44	40	47

Evacuation of the whole area

For the case in which all exit points are used, the evacuation time was estimated to be 44 hours. For cases in which only the bridge and dam or the highway are used, the evacuation time was estimated to be about 10 hours longer.

Evacuation of the flooded area

For the case in which only the flooded area is evacuated, the estimated evacuation time of approximately 47 is considered unreliable; this is because despite a significant reduction in evacuees, increased exit points, and short travel distances, the resulting evacuation time was greater than in certain cases of evacuation of the entire study area.

Evacuation of the western part

The time required to evacuate the western part of the area (Walcheren) was found to range from 40 to 58 hours, depending on the exit points used. An interesting result was that, in the case in which all the exits were used, the time to evacuate Walcheren was estimated to be only 4 hours less than the time required to evacuate the whole study area. This is because the road-use by the residents of Walcheren, and the traffic load, are comparable in both cases. During evacuation of the whole study area, the dam to Noord-Beveland is used exclusively by the residents of Walcheren, thus the load at this exit is unchanged between the two cases. The other exit used by the residents of Walcheren is the highway to the east; in the case of a western evacuation Walcheren residents represent the only traffic load at this exit. However, in the evacuation of the entire study area, because of the distance the Walcheren residents must travel to reach the highway, the traffic load is already significantly reduced by the time they arrive at the exit. Thus in both cases Walcheren residents use the dam and the highway as exits, and in both cases the Walcheren residents represent the bulk of the traffic load at these exits.

People requiring help

The number of people requiring help does not influence the total evacuation time. This can be explained by the fact that the two activities of evacuating people with cars and people requiring help are carried out in parallel and the number of people requiring help is relatively small. The fact that buses have to drive back and forward is not taken into account. This might influence the capacity of the roads, as not all roads are used in the same direction.

Shelters

No conclusions can be drawn from the test with assigning shelters. This functionality is not developed enough in ESCAPE to be used for the current study.

6.4.4 Conclusions and discussion

Evacuation times

The results of the evacuation module in ESCAPE show that the evacuation of Walcheren and Zuid-Beveland will take between 44 and 54 hours. The two main assumptions are that there is no traffic jam, traffic is fully controlled, and evacuees follow the evacuation plan. This is not very realistic, as people's behaviour in stressful situations is very uncertain.

The use of shelters and safe havens

ESCAPE is not suitable to calculate evacuation time to emergency shelters. This is due to the simplistic algorithms used, that do not represent reality in any way.

Use of the ESCAPE software

ESCAPE was developed within a limited time frame, therefore it is not very user friendly and some of the calculation methods are not transparent. In general, for situations in which the traffic can be fully controlled, it gives evacuation times that are lower than those estimated with the Evacuation Calculator. This can be explained by the use of a more detailed road network. A more detailed comparison is made in the next section.

6.5 Application of INDY

6.5.1 Introduction

The simulation and planning of an evacuation can be done by using dynamic and static traffic assignment models. Dynamic traffic assignment (DTA) models differ from static models in that traffic flows can differ over time in contrast to constant flows in static models. Traffic jams can be simulated with dynamic models, as well as structural changes in the network during the simulation. Hence in case of large-scale evacuations, the use of the dynamic model is the best option. For the evacuation model the dynamic traffic assignment model called INDY was used. This model was jointly developed by TNO and the Delft University of Technology. The model allows the analysis of

traffic scenarios on transportation networks. Its flexible modelling of the interactions between travel demand and infrastructure supply allow it to predict the traffic conditions of a road network over time, identify the locations where congestion occurs and estimate the corresponding delays.

In the following sections the application of INDY to evacuation modelling is investigated. This is a summary of the work carried out by Joost Mak (Mak, 2008), which is reported in a FLOODsite technical note.

6.5.2 Background to INDY

The dynamic traffic assignment algorithm INDY was jointly developed by TNO, TU Delft and the KU Leuven. The algorithm allows the analysis of traffic scenarios on transportation networks. INDY is able to predict the traffic conditions of a road network over time via its flexible modelling of the interactions between travel demand and the infrastructure. It can also identify the locations where congestion occurs, determine the effects of bottlenecks and estimate the corresponding delays. INDY can take into account different user classes (e.g. driver and vehicle types), making the framework completely “multi-class”. However, in the evacuation modelling only one user class (i.e. one driver and one vehicle type) is taken into account. The dynamic version of congestion modelling cannot handle more than one user class yet. However, within evacuation modelling other large vehicles such as trucks are not used because of the high probability of them being blown over during a storm surge. INDY is also able to model dynamic traffic management measures and incorporate road pricing.

INDY is able to model congestion. Figures 6.15 and 6.16 show the effects of a traffic jam at two time steps. Figure 6.15 shows initial building up of the traffic jam. Figure 6.16 shows the effect of the blockage on other road parts at a later time step.

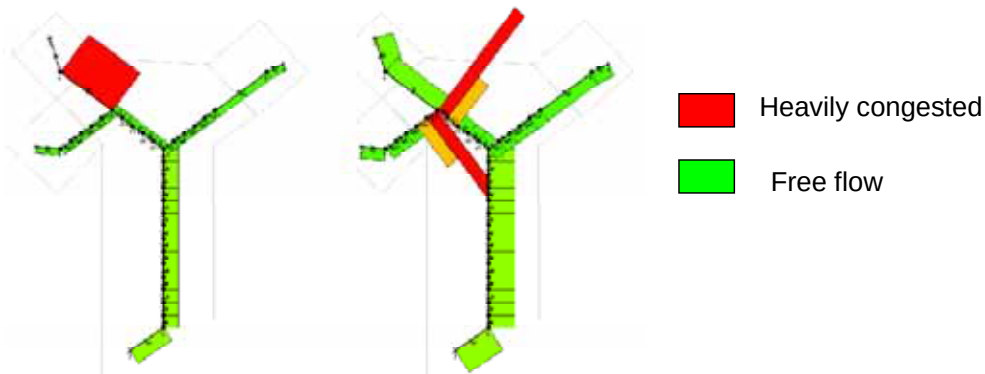


Figure 6.15 Bottleneck effects at an initial time step

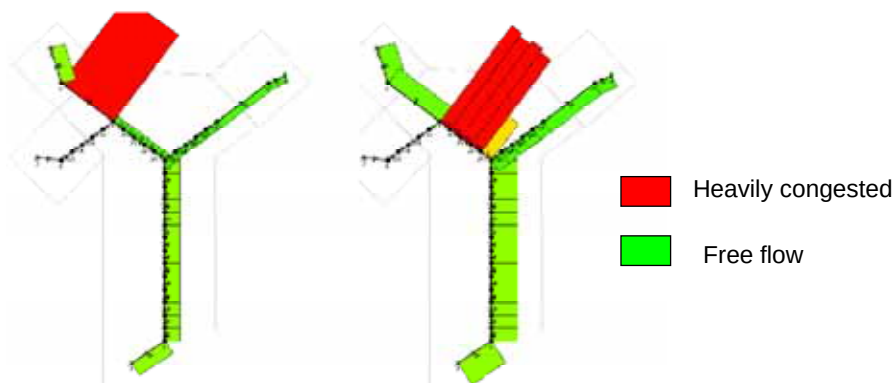


Figure 6.16 Bottleneck effects at a later time step

The way of modelling the congestion is shown on this simple network in Figures 6.15 and 6.16 where the people drive from south to north. The height and the colour of the rectangles projected on the road provides information on the current density of vehicles on that part of the network. The green rectangles indicate that there is no congestion and that there is free flow. The large red rectangular indicates areas where the congestion is very heavy.

The situation pictured on the left shows the way in which congestion is modelled in a static way. The vehicles build up in a 'vertical' waiting line. With this vertical waiting line only the delaying time of the traffic waiting just before the bottleneck is accounted for and not the other traffic flows on the network. This waiting line is created at the bottleneck location but not in front of it as would occur in real traffic jams. This static name needs not be confused with the static assignment model. Static in this sense means a static way of modelling blocking black. The latter on the other hand concerns the time element in traffic modelling.

On the right side the dynamic version is shown. Here we see the appearance of so-called horizontal rows. Now the waiting line is located in front of the bottle neck. It is modelled in a more realistic way than the static version. Traffic flows on one road part can now feel the effect of congestion further down the road.

Optimising the traffic flow

INDY can search for an optimal spread of the road users over all possible routes. During this process the actual situation on the road is taken into account. Not all macroscopic dynamic models are capable of this. Moreover is INDY route-based instead of link-based. This means that the travel times of all the different routes are kept track of, instead of just adding the different link travel times. This is important when it comes to evacuation modelling where the evacuation routes often are known beforehand and are given as input. Balancing the flows will give better results than when people are just sent over the shortest paths. The results of INDY can therefore be used to influence the route choice behaviour of the road users in order to minimise the congestion during the evacuation process.

Modelling junctions

The current version of INDY is not able to model the effect of junctions yet. Delays because of traffic lights as well as crossing and merging traffic flows are not modelled explicitly. In evacuation modelling the number of crossings may be lower than in normal situations.

OmniTrans

OmniTrans is an transportation planning package that allows for pre- and post-processing of INDY. OmniTrans makes it possible to view the used road network, and projects the simulation results from INDY onto the network.

6.5.3 Approach

INDY has been tested on the pilot area of the Westerschelde in two ways:

1. A number of basic scenarios were defined, in order to compare the results with the other two models.
2. Extensions to these scenarios were made to test if the evacuation procedure can be optimised.

In this section the implementation of INDY is described as well as the setup of the basic scenarios.

Road network

The scale of the road network is based on the National Regional Model (NRM) PoCo4 (four digit postal codes). For the current research area, this order of detail is sufficient. For smaller areas such as

small cities it may not be detailed enough to produce reliable conclusions because of the limited number of roads available.

Use of INDY in evacuation modelling

Because INDY is a DTA model, it is able to simulate traffic over the network in a realistic way such that the results serve as a good indication of the expected traffic outcome resulting from an evacuation. The Origin Destination (OD) matrix is used to store the routing needed to bring people from their homes to a safe location. Thus it specifies the location and length of the routes from all the zones lying in the area at risk to the different exit points. Based on a departure profile, INDY simulates all these trips over time. After the simulation is completed, the results can be visualised using the OmniTrans software.

Exit points

Exit points are the roads leading to safe areas outside the at-risk area. In the current study five exit points have been selected as shown in Table 6.10 and Figure 6.17.

Table 6.10 Overview of the exits links and their capacity

Exit	Exit point	Destination	Number of lanes	Exit type	Capacity (cars/hour)
1	Highway A58	North of Brabant	2	Bridge	4,000
2	N289	North of Brabant	1	Bridge	1,600
3	N57	Noord-Beveland	1	Dam	1,600
4	N62	Zeeuws-Vlaanderen	2	Tunnel	3,200
5	N256	Noord-Beveland	1	Dam	1,600

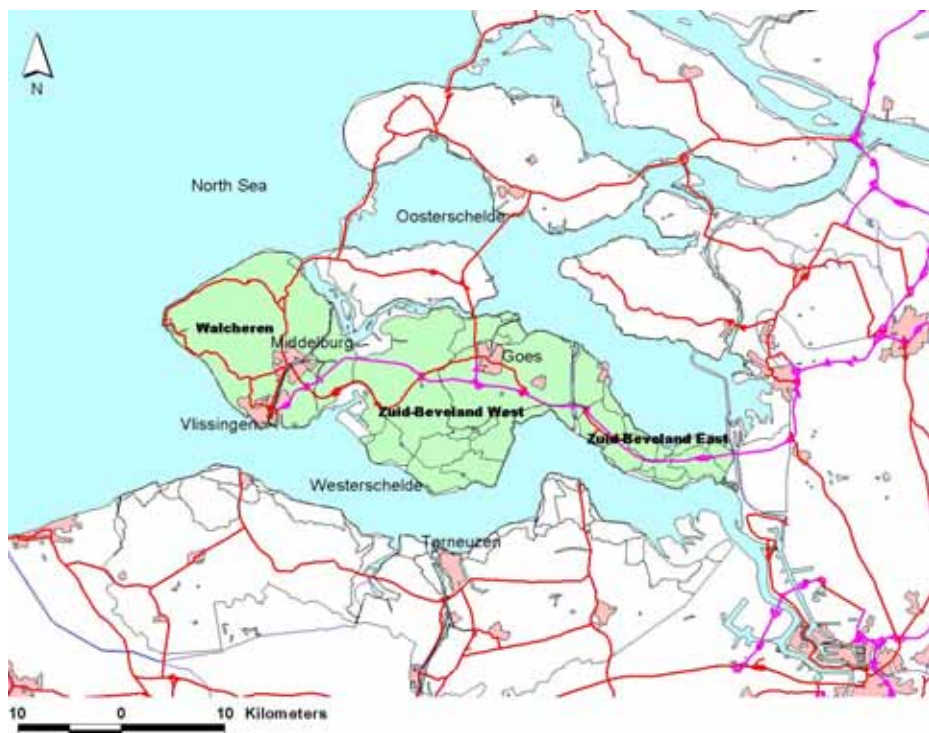


Figure 6.17 The exit points as used in the application INDY

In the basic scenarios there were two options related to the available exit points:

- All exit points were available for evacuating the area at risk, with the exception of the tunnel to Terneuzen.
- Only the eastern roads leading to Brabant were used. This option was considered because the exit points in the north are surrounded by water, and may therefore become inundated in the event of a flood.

Assignment of zones to exit points

The assignment of exit points to the at-risk zones was an important factor in the evacuation modelling, as it determines how the traffic is spread over the network. Defining the exit-point incorrectly can result in increased traffic congestion, thereby lengthening the total evacuation time.

To create the basic scenario three assignment methods were applied:

- Reference assignment;
- Nearest assignment;
- Optimised assignment.

The *reference assignment* represents a situation in which the inhabitants are free to choose their own route following an evacuation call. For this assignment the inhabitants from each zone are divided over all exit points according to a so-called impedance ratio. This ratio is based on the distance from zone to exit point. This ratio defines the percentage of the people in that zone that go to the corresponding exit. The closer a zone is to an exit point, the lower the ratio and the more people go there. Figure 6.18 presents the *reference assignment*. This slightly differs from the reference option in the Evacuation Calculator, as each exit point in the EC receives the same number of people.

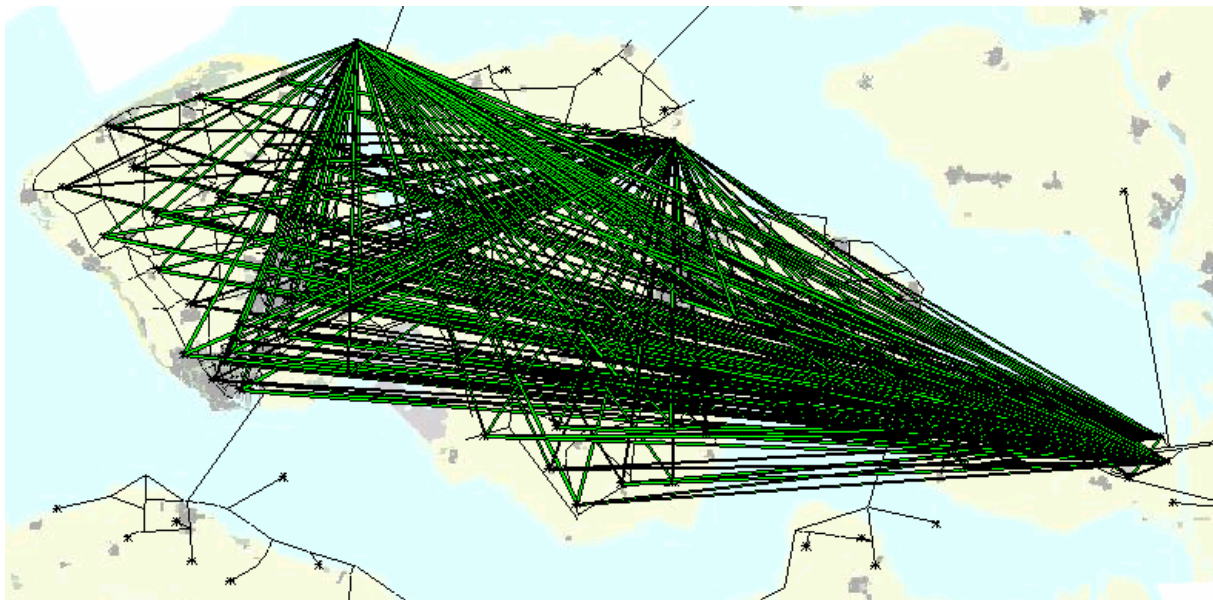


Figure 6.18 The reference assignment using all the exit points.

For the nearest assignment all inhabitants from a zone are assigned to the nearest exit point. The nearest assignment is presented below in Figure 6.19. This assignment is comparable to the nearest exit option in EC.

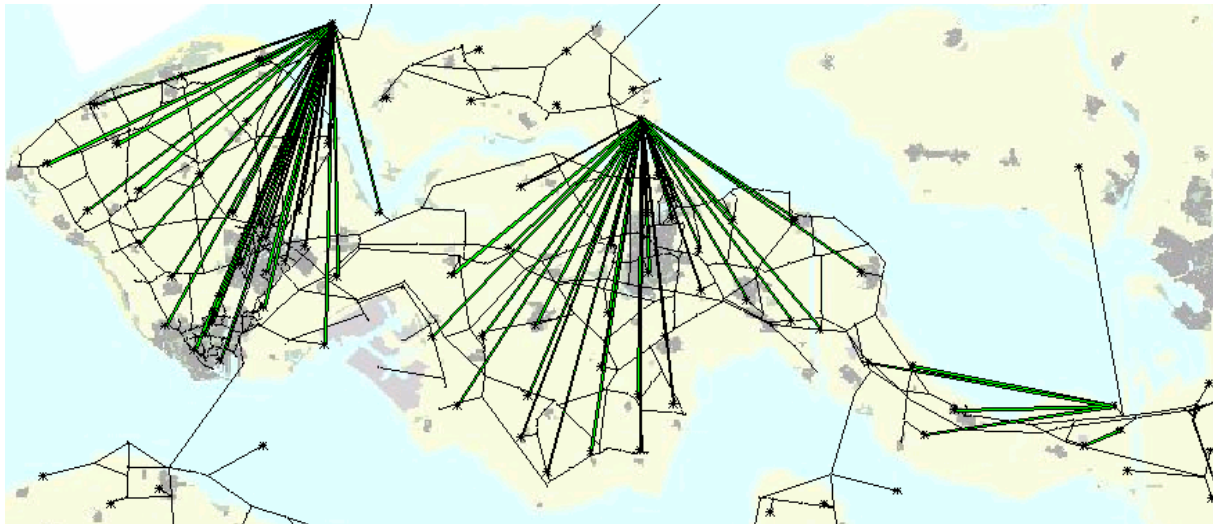


Figure 6.19 The nearest assignment using all the exit points

In the optimised assignment the distribution is done such that exit capacity and travel distance are both optimised. The exit capacity is based on the road capacity of the last link before the exit point. The assignment method begins by selecting the exit point with the lowest ratio of assigned evacuees to exit capacity. This exit point is then assigned to the nearest zone, and the ratios are recalculated. This procedure continues until all the zones have been given an exit point. The optimised assignment is presented below in Figure 6.20. This assignment is comparable to the traffic management option in EC.

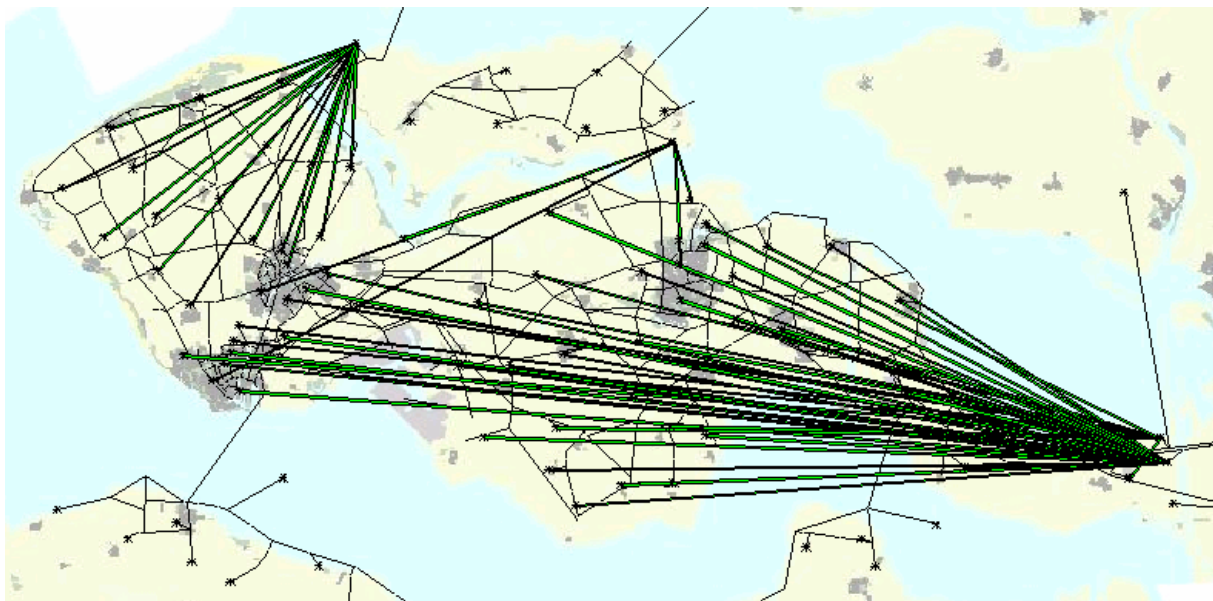


Figure 6.20 Optimised assignment using all the exits points

Departure profiles

The departure profile represents the percentage of departed evacuees as a function of time. During the first simulation, S-curve departure profiles were used. This is shown in Figure 6.21. The 16-hour S-curve is based on previous research on evacuee departures resulting from hurricanes. The 8-hour S-curve is essentially the same as the 16 hour S-curve only the evacuee response time is twice as fast. The 8-hour S-curve was used to evaluate how a faster evacuee response time affects the total evacuation time. The 16-hour S-curve can be considered representative of response times in the event

of a foreseen flood, while the 8-hour profile is more representative of the response time for a more sudden flood event. Figure 6.21 shows an 8-hour S curve departure profile.

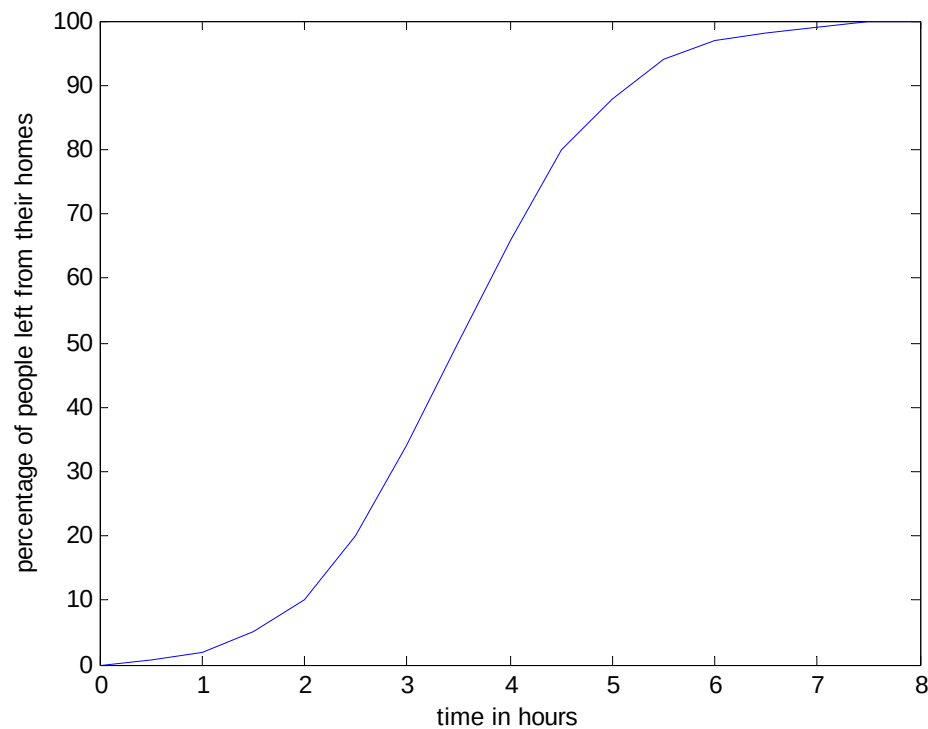


Figure 6.21 S-curved departure profile over eight hours

Parameters

When applying INDY a number of parameters have to be set. First the required OD matrix is selected. The departure profile is entered using departure fractions. For example when choosing an evenly divided 8 hours departure profile for each hour a fraction of 0.125 of the original OD matrix is taken.

The basic scenarios

The basic scenarios are based on the scenarios simulated earlier with Escape and the Evacuation Calculator. A total of 12 basic scenarios were created using combinations of the following factors:

- *Departure profile*: An eight hour or a 16-hour S-curve;
- *Exit points*: All of them (excluding the tunnel) or only those leading to Noord Brabant;
- *Assignment zones-exits*: Zones are divided over the exit point according to the reference method, coupled to their nearest exits or assigned in an optimised manner.

6.5.4 Results of the application of INDY on the Schelde pilot

In this section the results of the INDY simulation are presented and discussed. With OmniTrans it is possible to review the completed simulations both dynamically and statically. Table 6.11 gives the resulting evacuation times for the 12 basic scenarios. Table 6.12 compares the resulting evacuation times for the different assignment methods, and Table 6.13 compares evacuation times for different exits used.

Table 6.6 INDY evacuation times for the 12 basic scenarios

Exits used	Assignment	8h S-curve	16h S-curve
All*	Reference	22h15	22h15
	Nearest	30h45	31h45
	Optimised	21h45	22h30
Roads toward Brabant	Reference	36h45	37h00
	Nearest	39h15	40h15
	Optimised	36h30	37h00

*With the exception of the tunnel

It was expected that the 16-hour S-curve departure profile would result in faster evacuation times, due to the load on the road network being spread over more hours. Table 6.11 shows that in fact the 8 hour S-curve resulted in faster evacuation times, although the difference was not significant. The maximum difference in resulting evacuation times was 3.5 percent. The 8-hour departure profile proved more effective because during the first hours of evacuation, when the road networks are not at capacity, twice as many evacuees had departed in the 8-hour scenario as in the 16-hour scenario.

Table 6.12 Scenarios compared by the assignment used.

Exits Used	Assignment	Reference	Nearest	Optimised
All	8h S-curve	22h15	30h45	21h45
	16h S-curve	22h15	31h45	22h30
Roads toward Brabant	8h S-curve	36h45	39h15	36h30
	16h S-curve	37h00	40h15	37h00

Comparing the results on basis of the exit-assignment method cannot be done easily. The difficulty is that crossing flows of traffic are not accounted for when applying INDY. These conflicting flows may appear at junctions (flows cross each other) or at merging roads (two flows become one). The first has the most notable delaying effect. The method of assigning exit points has great impact on the number of crossing flows that may appear. While in the optimised and nearest assignments these crossing flows are minimised, they are not minimised in the reference assignment shown in Figures 6.18 to 6.20. Owing to the fact that INDY does not account for these cross flow, the evacuation times for the case of reference assignment may be significantly underestimated. Therefore, only the nearest and optimised assignments are currently able to be compared, since they are comparable in their minimised number of crossing flows.

The evacuation times resulting from the optimised assignment were significantly shorter than those resulting from the nearest assignment. As shown in Figure 6.19, in the nearest assignment almost all of the evacuees are routed towards the two northern exit points. This is because the area is relatively horizontally stretched, and north-south distances are notably shorter than east-west distances. As a result, two exit points were scarcely used, including the exit point with the largest capacity. This result enforces the reasoning for a tactical assignment done prior to the evacuation. This would require that inhabitants be informed of their exit point prior to the evacuation.

Table 6.13 Scenarios compared on the exits used.

Departure profile	Assignment	Only towards Brabant	All exits*
S-curve over 8h	Reference	36h45	22h15
	Nearest	39h15	30h45
	Optimised	36h30	21h45
S-curve over 16h	Reference	37h00	23h30
	Nearest	40h15	31h45
	Optimised	37h00	22h30

*With the exception of the tunnel

A decrease in the number of exits increases the evacuation time significantly. Differences in evacuation times for scenarios where only the number of exits was varied ranged from 21% to 39%. This is because the same numbers of evacuees are using a smaller part of the road network at the same time. When only using the eastern exits, congestion occurs very early near the exit points where all the evacuation paths join each other. The congestion then spreads throughout large portions of the road network, as shown 12 hours after the evacuation began in Figure 6.22 below. Roads highlighted in red represent congestion in the network; roads highlighted in green represent traffic moving at (approximately) the speed limit.

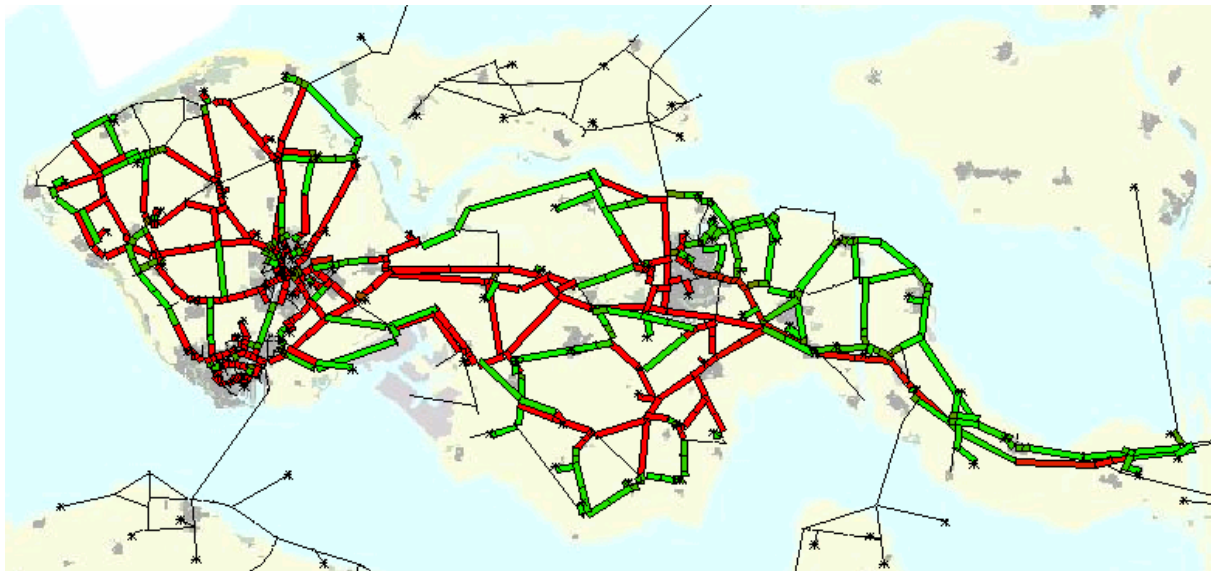


Figure 6.22 Congestion appears everywhere when only using the eastern exits

6.5.5 Extensions to basic scenarios using INDY

Various extensions to the basic scenarios were investigated using INDY. Some of these extensions aimed to minimise the evacuation time. These included application of a different departure profile structure, the use of shelters, and the use of the tunnel as an escape route. Other extensions attempted to simulate in more detail the behaviour response of inhabitants in the case of an evacuation. Below is a description of the extensions that were applied:

- *Linear departure profile*: Instead of using realistic S-curves, it may be more advantageous for the throughput of traffic to use a linear departure profile.
- *Tunnel*: The Schelde tunnel that serves as the link between Terneuzen and Zuid Beveland is added to the list of exit links.
- *Prescribed routes*: While INDY tries to spread the evacuees over multiple routes, in reality most people will tend to use the shortest route known to them.

- *Shelters*: By assigning shelters in certain parts of the area (safe spots, critical areas) the number of cars that need to evacuate can be reduced, and thus also the evacuation time.
- *Coupled to a flood scenario*: Delft Hydraulics is able to give prognoses on possible dike breaches and their consequences. By determining the most probable flood scenarios, the evacuation process can be altered such that the most critical areas are evacuated first.

These extensions were applied and evaluated by comparing them to one or more of the basic scenarios.

Linear departure profile

Although the S-curves used in the basic scenarios represent a more realistic departure profile, the people are entering the network in a non-linear way. For example, in the case of the 16-hour S-curve departure profile, approximately 80% of evacuees depart over a span of six hours. This is shown in see Figure 6.21. It seems logical that when a more linear departure profile is applied this will lead to a more balanced use of the network and thus a reduction in the evacuation time. Therefore two linear departure profiles, an 8-hour and a 16-hour, were created. Figure 6.23 presents the 16-hour linear and S-curve departure profiles. The comparison of the evacuation times are presented in Table 6.14.

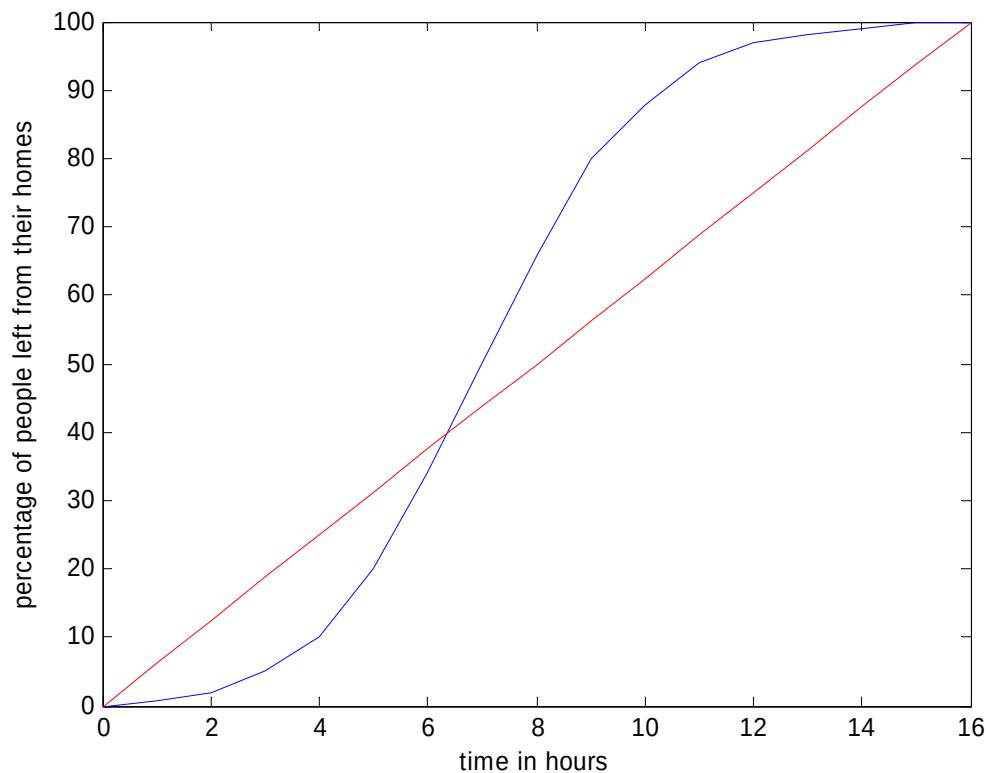


Figure 6.23 Linear (red) and S-curved (blue) departure profile over 16 hours

Table 6.14 Comparison of evacuation times using linear and S-curve departure profiles

Assignment	Exits used	Curve Extent	S-Curve	Linear
Optimised	All*	8-hour	21h45	20h45
		16-hour	22h30	21h00

The use of a linear departure profile results in a decreased evacuation time. This is because with a linear departure profile, the load of traffic is transferred onto the available infrastructure in a more

balanced way than when using the S-curve. However, a linear departure profile is impossible to achieve whereas the S-curve represents a realistic (uncontrolled) departure profile.

Use of the Westerschelde tunnel

Figure 6.24 shows a photograph of the Westerschelde tunnel. In the evacuation simulation done with the models of EC and Escape, the exit possibility of the Westerschelde tunnel was not explored. This is because the possibility of inundation while within the tunnel is considered too dangerous at the moment flooding begins. However, it can be argued that the use of bridges or roads along dams is more dangerous due to the fact that storm weather conditions, such as heavy rain and strong winds, can make it difficult for drivers to maintain control of their vehicles. Within the tunnel drivers are sheltered from storm conditions. Additionally, the tunnel leads to an area south of Terneuzen which is safer than Noord-Beveland and Noord Brabant. Thus it is considered realistic to add the tunnel to the set of exit links. The network including the Westerschelde tunnel as an exit point, with the optimised exit assignment used, is shown in Figure 6.25. The evacuation times resulting from the INDY simulation with and without the tunnel as an exit link are compared in Table 6.15.



Figure 6.24 Entrance Westerschelde tunnel at Terneuzen

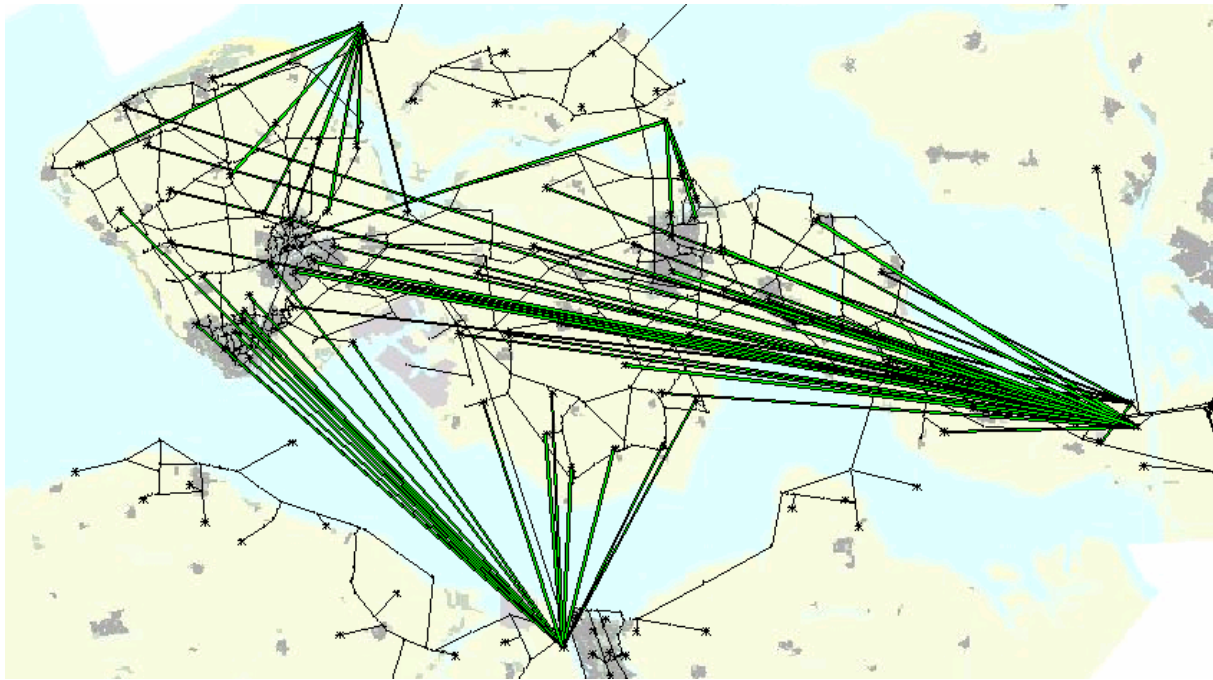


Figure 6.25 OmniTrans network with the Westerschelde tunnel (optimised assignment)

The tunnel is added as an exit link to the second basic scenario, and a comparison is done in the following in Table 6.15.

Table 6.15 Outcomes of INDY with the addition of the tunnel

Departure profile	Assignment	Tunnel exclusion	Tunnel inclusion
8h S-curve	Optimised	21h45	19h15

The evacuation time is reduced with the inclusion of the tunnel, as the added exit allows for a better spread of traffic. However, given that the tunnel has the second largest capacity (3,200 vehicles per hour), which considerably lessens the load of traffic on the other exit points, the reduction in evacuation time (~11%) was less than expected.

Prescribed routes

In the event that inhabitants are assigned an exit point, but no specific route is assigned, it is likely that the shortest route, which is often the fastest route, will be chosen by the evacuees. INDY attempts to improve the individual travel times by assigning them to alternative routes. The user defines how many of these routes are explored with the iteration parameter. In the current study, this parameter was set to ten, meaning that at most ten different routes are considered. If this parameter is set to one, only the shortest route is available to the drivers. Thus, the case in which the iteration parameter is set to one is considered representative for actual conditions in the event that no route is assigned to the evacuees, while the case in which the parameter is set to ten represents conditions in the event that routes were prescribed along with the exit point. These two scenarios were investigated with INDY and the resulting evacuation times are presented in Table 6.16.

Table 6.16 Outcomes of INDY with the shortest path

Departure profile	Assignment	Exits used	Prescribed routes	No prescribed routes
8h S-curve	Optimised	All exits	21h45	23h15

The shortest-route simulation, in which no routes were assigned to the evacuees, resulted in a longer evacuation time than the case in which ten alternative routes were employed. This is because in the shortest-route simulation, the traffic is confined to one route per exit point, instead of ten. This leads to more congestion which results in a longer evacuation time. This confirms the importance of prescribed routes in the evacuation process.

The degree of improvement is dependent on the road use in the study area. In the area of Walcheren and Zuid-Beveland, most of the traffic uses the highway as part of their route. Even if more paths are considered, a large portion of the traffic will eventually make use of this highway. Thus the advantage of employing multiple routes may be somewhat limited. Traffic conditions 15 hours after evacuation began, for the case of multiple routes and shortest route only, are presented in Figures 6.26 and 6.27, respectively. Routes shown in red indicate congestion in the network and routes shown in green indicate traffic moving at almost the speed limit. It can be seen that during an evacuation, the highway serves as the bottleneck in the area, remaining congested until approximately 15 km before the exit points, when it splits into multiple paths. Thus it may be concluded that because of the use of the highway in so many of the alternate routes in the study area, an increased number of routes does not significantly affect the evacuation time. In the case that there are multiple (independent) paths leading toward the exit points, the effect of increasing the number of alternate routes will be more significant.

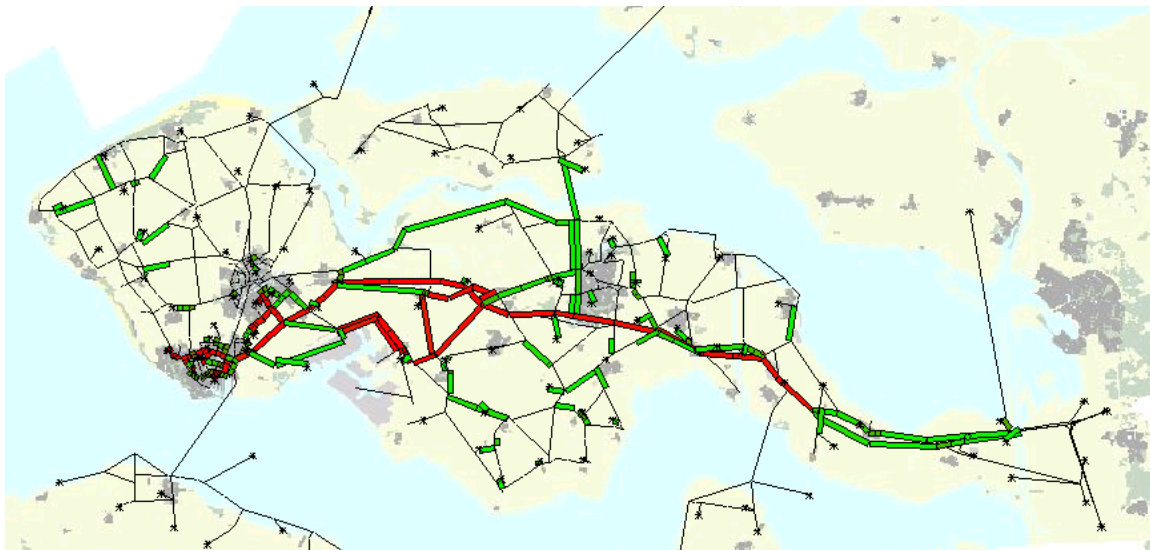


Figure 6.26 Traffic flows after 15 hours of evacuation

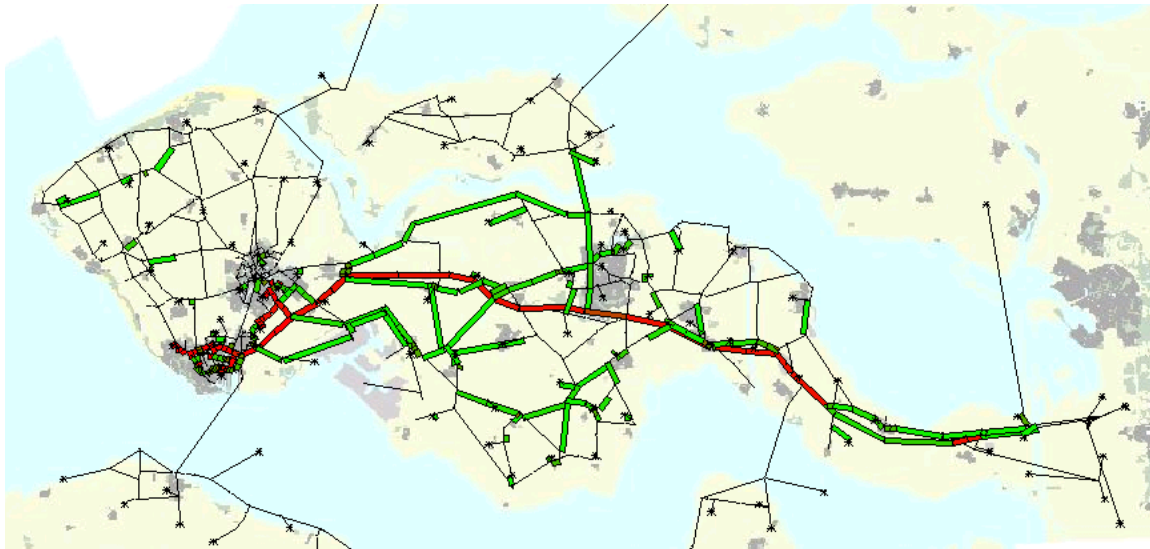


Figure 6.27 Traffic flows after 15 hours of evacuation with only the shortest route used

Shelters

This extension serves to investigate if directing evacuees to shelters significantly reduces the total evacuation time. During the evacuation process, evacuees may be advised to go to nearby safe locations within the risk area if the time is too limited to for everyone to evacuate. Examples of such locations are taller buildings (four or more floors), dunes, secondary embankments or non-flooded areas. Because flood events typically coincide with storm conditions, remaining out of doors for an extended period of time presents a danger for evacuees. As a result it is considered better and safer to send people to shelters such as schools, apartment buildings or hospitals, instead of dunes and embankments where they have no protection against the weather. The decision makers should know where these shelters are located and what their capacities are. These shelters must be prepared with food, water and facilities (e.g. beds). For the organisation process prior to the evacuation (assignment of exit points, etc.) these shelters play an important role. The more people are sent to shelters, the less traffic there is on the road network. This means that people are only routed to shelters in their direct neighbourhood; they must be able to reach them without the use of a car. Because of the relief shelters provide to the road network, the use of shelters should reduce the total evacuation time.

Table 6.17 presents a list of the shelters used in the simulation. Vlissingen has the largest shelter capacity due to a large number of apartment buildings located along the coast. A total of 9,500 people can be directed to the shelters. This is approximately 4.5% of the total number of inhabitants in the area at risk. The resulting evacuation times in the case with and without shelters are compared in Table 6.18.

Table 6.17 Overview of shelter capacity

City	Shelter capacity
Vlissingen	6,000
Middelburg	2,000
Goes	1,000
Kapelle	500
Total	9,500

Table 6.18 Resulting evacuation times - simulations with and without the shelters

Departure profile	Assignment	Exits used	Shelters	No shelters
8h S-curve	Optimised	All	20h45	21h45

The resulting evacuation time is reduced in the case where shelters are employed. The 4.5% decrease in evacuees using the road network resulted in a comparable decrease in the total evacuation time. Thus, it is expected that to achieve a significant reduction in the evacuation time, the shelter capacity would need to be significantly larger.

Coupling the model to a flood scenario

If flooding occurs due to an embankment failure, a part of the area will become flooded. Which area becomes flooded depends on the breach location and the amount of water which flows through the breach. Figure 6.28 shows possible flooded areas due to a large number of failure locations along the Westerschelde Estuary (De Bruijn et al, 2008). In most circumstances only one or a few of these locations will breach at the same time. However, in the case of a serious flood threat, it is not known where the first breach will be. Figure 6.28 also shows the importance of the secondary embankments. These secondary embankments limit the flood extent, leaving large parts of the area to remain dry.

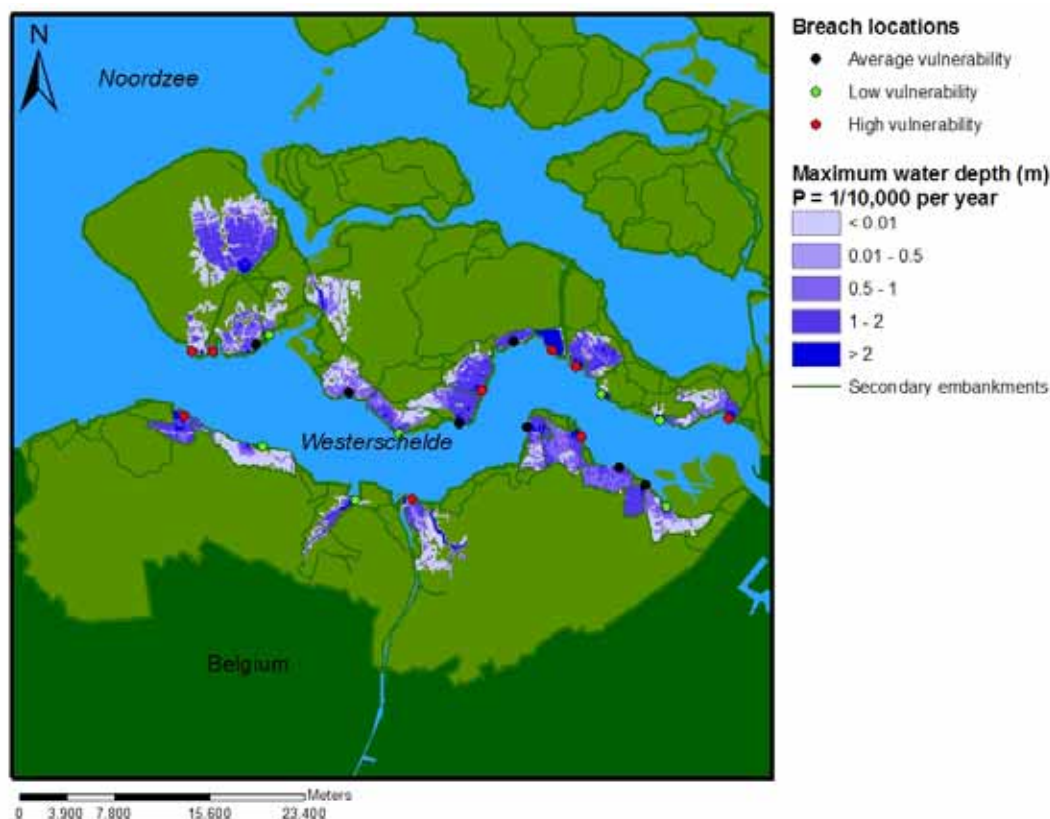


Figure 6.28 Possible flood scenario

As part of the area is expected to remain dry, it might not be necessary to evacuate the whole area. The critical areas, denoted in Figure 6.28 by red and blue colours, should be evacuated in case of a real flood threat. In this extension only these critical areas are evacuated and the evacuees are routed outside the research area using the same four exits as before. Approximately 107,000 people reside in the critical areas shown in Figure 6.28, representing 53.5% of the total population of the study area.

Table 6.19 presents the evacuation time for the case of only the critical area being evacuated compared with the evacuation time for the entire study area.

Table 6.19 Comparison of evacuation times – Evacuation of whole area and critical area

Departure profile	Assignment	Exits used	Evacuation of the whole area	Evacuation of the critical area
S-curve over 8h	Optimised	All	21h45	12h00

Evacuating only the critical area reduces the total evacuation time by 45%, comparable to the reduction in the number of evacuees. When time available for evacuation is limited, it is advisable to begin evacuating inhabitants from the critical areas first.

6.6 Model comparison

6.6.1 Technical comparison

A technical comparison of the tested evacuation models gives insight into which evacuation times may be compared. Technical differences can be found in the spatial scale, input parameters, management of the evacuation routes, and output. INDY is unique in that it shows where congestion is most likely to occur as a result of merging roads. However, none of the models take into account the congestion due to crossing flows at intersections. This leads to an underestimation of the evacuation time in all models. The model differences are summarised in Table 6.20. The simulation time of ESCAPE and EC is about a minute. INDY, however, needs almost half an hour to complete a simulation, depending on the number of generated routes.

Spatial scale

Both the Evacuation Calculator (EC) and ESCAPE can only be used at a macro scale. The road network is simplified to one straight road between origin and destination in the case of EC, or to a set of connected lines with an average capacity in the case of ESCAPE. INDY spatially works at meso scale as it allows multiple routes between origin and destination. The user defines which roads are taken into account by choosing the scale of postal code zones.

Input parameters

The most important input in the estimation of evacuation time are the population density, the departure profile, the road capacity and the exit assignment.

Population Density

The detail of the population density is comparable in all three models. EC takes into account elderly and disabled inhabitants and distinguishes between self-evacuation, public transport and assisted evacuation. The EC also takes into account the amount of cattle to be transported. ESCAPE distinguishes between self-evacuating inhabitants, who are assumed to evacuate by car and inhabitants requiring help, who are assumed to evacuate by bus. The application of INDY only takes cars into account. In the case of EC and ESCAPE, larger vehicles are converted into car-equivalents. These different levels of detail are not expected to influence the results significantly.

Departure Profile

All three models rely on departure profiles, which give the evacuee departures over time. However in EC and INDY these profiles can be adjusted by the user prior to a simulation, whereas ESCAPE optimises the departure profile for each zone at the start of the simulation. Because the user has no insight into the optimised ESCAPE departure profiles, it is difficult to determine how the results can be compared with the other two models.

Table 6.20 Comparison of Evacuation Calculator with ESCAPE

	EC	ESCAPE	INDY
Model Features			
Evacuation time calculated	✓	✓	✓
Postal codes used as spatial scale	✓	✓	✓
Models the movement of traffic, not individuals	✓	✓	✓
Includes evacuation of people	✓	✓	✓
Includes evacuation of livestock	✓		
Capacity of exit user-determined by a reduction factor	✓		
Calculates evacuation from user-input departure profile	✓		✓
Includes dynamic traffic simulation			✓
Evacuation Time Dependent On:			
Population density	✓	✓	✓
Number of exit points	✓	✓	✓
Distance to exit point	✓	✓	✓
Departure profile	✓	✓ *	✓
Percentage of population requiring help	✓	✓	
Cattle population	✓		
Exit capacity	✓		✓
Average vehicle velocity	✓		
Organization of evacuation routes	✓		✓
Road capacity		✓	✓
Assumptions			
Preparation time lasts 13 hours	✓	✓	✓
Inhabitants are home at the time of evacuation	✓	✓	✓
Inhabitants respond to the evacuation call	✓	✓	✓
Congestion at the exit point	✓		
No traffic jams		✓	

*The departure profile is determined within ESCAPE, and cannot be input by the user

Road Capacity

The road capacity is most comparable between INDY and ESCAPE, which both take into account realistic road capacities. The EC only allows for a capacity at the exit point and the travel velocity is given by the user.

Exit Points

In all three models the user defines the location. In EC this choice is limited, because the exit point location depends on the scale of the zoning, which is fixed. INDY and ESCAPE show a realistic road network to choose the exit point from. In ESCAPE the network scale is fixed, only INDY allows for a more detailed road network.

Traffic management options

Both INDY and EC allow for different route-assignment options: reference, nearest exit and traffic management/optimised.

Reference

The nature of the reference assignment slightly differs between the two models. In the reference option people from each zone are distributed over all exits. This is done to increase evacuation times to compensate for cross flows not being taken into account. In EC, the reference option results in each exit receiving the same number of people. INDY, however, takes into account the distance to each exit when dividing the evacuees over the exits. This means that a larger fraction goes to the nearest exit. This is not expected to significantly affect the total number of people that each exit point receives. However, it does significantly affect the average travel distance. Because INDY routes a higher proportion of the evacuees to their nearest exit than EC does, the average travel distances in INDY are expected to be shorter.

Nearest Exit

In both models, the nearest-exit assignment routes all inhabitants within a zone to their nearest exit.

Optimised/Traffic Management

In the optimised (INDY) or traffic-management (EC) assignment the traffic is managed such that the outflow at the exits is maximised. In both models, this results in a higher proportion of the evacuees being routed to the exit with the highest capacity than in the case of the nearest-exit and reference assignments.

ESCAPE does not allow user-input route assignments, but rather optimal routes are assigned internally. This optimisation takes place at the start of the simulation, and is based on the fastest route towards an exit point for each zone, assuming maximum road capacity. It is unknown whether these routes remain optimal during the simulation, when more cars occupy the road. Because the method used by ESCAPE to determine the exit routes is unknown, and because the route assignment has a significant impact on the evacuation time, the results from ESCAPE cannot be readily compared with the other models.

Output

The output of the EC is given as figure in which the number of cars that arrive at the exit point and the outflow of cars through the exit is plotted as a function of time, from which the total evacuation time is derived.

The output of ESCAPE consists of a table in which the number of inhabitants still present in the area is given as a function of time. The time at which this number reaches zero is taken as the evacuation time.

The output of INDY is given as the total estimated evacuation time and the individual travel times for each route. The output can also be visualized such that the locations where congestion occurred are indicated.

6.6.2 Comparison of results

Table 6.21 shows the resulting evacuation times to evacuate the entire study area according to all three models for the optimised/ traffic management option. The results of the ESCAPE simulations are included in Table 6.23. However, because the internal departure profile and route management used by ESCAPE are unknown, the results can not be reliably compared with EC or INDY. EC and INDY evacuation times were compared for each assignment option. The results are discussed below.

Table 6.21 Comparison of the outcomes of the three models

Departure Profile	Exits	Assignment	EC**	INDY	ESCAPE***
8h S-Curve	All	Reference	22h00	22h15	-
		Nearest	32h00	31h45	-
		Optimised*	12h00	21h45	44h00
	Roads to Brabant	Reference	39h00	36h45	-
		Nearest	16h00	39h45	-
		Optimised*	13h00	36h30	54h00
16h S-Curve	All	Reference	23h00	23h30	-
		Nearest	33h00	31h45	-
		Optimised*	21h00	22h30	44h00
	Roads to Brabant	Reference	40h00	37h00	-
		Nearest	25h00	40h15	-
		Optimised*	22h00	37h00	54h00

* The optimised assignment it referred to as Traffic Management in EC.

** For the EC results shown, it was assumed that the average velocity is 30 km/hour and there is no reduction on the capacities of the exit links (reduction factor = 1).

*** An explicit departure profile is not used in ESCAPE; the departure times are set from within the model.

Reference assignment

EC and INDY show comparable evacuation times when all exits are used. Two aspects can cause a difference in evacuation times, if all other input parameters are kept the same: merging flows and distance. INDY accounts for congestion caused by merging flows, leading to a higher estimation of the evacuation time. However, the reference option in EC, which is defined differently than in INDY, results in a higher average travel distance than in INDY, which in turn leads to an increase in evacuation time. Thus, the reference option in EC compensates for the lack of congestion due to merging flows, and the results of the two models are comparable.

When only roads to Brabant are used, INDY estimates lower evacuation times. This has to do with the different road capacities and the fact that they are used in parallel. The exit points in EC receive the same number of people, while in INDY the exit with the highest capacity (the highway) receives more people. This is due to the nature of the assignment algorithm in INDY, in which more people go the road that is closer by. Although both roads lead to Brabant, the highway is defined as closer to most of the zones. This leads to a faster evacuation with INDY.

Nearest exit

EC and INDY again show comparable evacuation times when all exits are used. When only roads to Brabant are used, the difference in resulting evacuation times is significant. In EC, the evacuation time decreases when only the roads to Brabant are in use. This is because when all exits are available, the nearest assignment routes an excess of evacuees to exits with low capacity. When only the roads in Brabant are in use, more evacuees are routed to the highway, which has a higher capacity, and thus the evacuation time is reduced. Contrarily, the evacuation time increases in INDY when only the roads to Brabant are in use. This is assumed to be due to the increase in merging congestion that occurs when all evacuees travel in the same direction.

Optimised/traffic management

The EC results in evacuation times as low as 12 hours, while INDY results indicate the fastest evacuation can be accomplished in 22 hours. The reason for this discrepancy is likely due to the inability of EC to simulate traffic. It estimates evacuation times based on the capacities of the different road links together with a user-input average travel speed. Because the INDY model does incorporate congestion, traffic speeds can be significantly reduced, resulting in an increased evacuation time. In earlier applications of EC, a reduction factor on the outflow capacity was introduced to account for congestion. The discrepancy in the results between EC and INDY could be used to better estimate an appropriate reduction factor.

6.7 First response of end user group

On 5 September 2007 potential end users of the ESS were asked to give their feedback to the preliminary results obtained in both Tasks 17 and 19. Representatives of the province of Zeeland as well as the local water board were present.

Two activities were undertaken:

1. Presentation and discussion of the initial results from the application of EC and ESCAPE on the Schelde pilot; this research was carried out under task 17.
2. Presentation and discussion of the prototype evacuation support system (ESS); this system was developed under task 19.

The findings from the first activity are summarized below, whereas the findings of the second activity can be found in the task 19 report (Mens et al, 2007). 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. Before that, some people will individually decide to evacuate, leading to chaos on the roads.

6.8 Conclusion and recommendations for the Schelde pilot

Three existing traffic or evacuation models have been applied on the Schelde pilot:

- Macro scale Evacuation Calculator (EC)
- Macro scale ESCAPE DSS
- Meso scale INDY

The aim was to draw conclusions on the reliability of the model results and the suitability of the models to support the planning of an evacuation. This study focused on the technical aspect of evacuation management.

The models have been compared in four aspects:

- Scale they can be applied on;
- Suitability for evacuation planning;

- Resulting evacuation times;
- Reliability of the resulting evacuation times.

The conclusions are summarised below.

Scale

The evacuation models EC and ESCAPE are not very detailed, being applied at a macro-scale. INDY presents an improvement in detail, being applied at a meso-scale. None of the models model individual movement of persons, instead they model the flows of total number of inhabitants from each postal code zone.

INDY takes into account the actual road network and allows for congestion due to merging traffic flows. Both EC and ESCAPE are simplified versions of INDY. The road network in ESCAPE is simplified to a static network, but still incorporates the various road capacities. In EC the road network is simplified to an origin-destination matrix coupled with the use of average velocities. In both EC and ESCAPE the simulation takes only one route into account, whereas INDY dynamically calculates several routes between origin and destination. Moreover INDY is able to simulate congestion due to decreasing road capacities and time-varying traffic load.

From the flood risk analysis carried out in Task 14 of FLOODsite it becomes clear that the flood extent is limited to the areas close to the primary dike. It can be concluded from this that evacuation plans should focus on local displacement of people and cattle instead of evacuating the large areas. It is important to know where congestion occurs and where alternative routes exist. This could be done by applying INDY on a more detailed network than was done in the current study.

Suitability

The EC can be used for a quick estimation of the evacuation time, if the whole area is to be evacuated. However, due to the amount of parameters that must be estimated by the user, it is advisable to validate the EC with the INDY model.

ESCAPE is not very user-friendly, as it gives little insight in the calculation algorithms. The order in which the evacuees leave their homes is derived within the simulation. The model does not give insight in this. Therefore the results could not be compared with the other models.

INDY is the most realistic of the three models and gives the most reliable results. Besides evacuation time estimates, it gives insight in the site-specific causes of congestion. However, the duration of the model set-up and simulation run-time are considerably longer.

The problem with macro-scale models, like EC and ESCAPE, is that they do not help the decision-maker to prepare evacuation plans for one specific part of the area. INDY could be used for this purpose, but the choice of area would have to be based on the six digit postal code zones. In the current study we chose to use the less detailed four digit postal code zones.

Because of the coarse resolution of the models, all three were unable to accurately estimate the evacuation time in the case in which only the areas along the Westerschelde were to be evacuated. In this scenario, evacuation times would be short and no timing problems are expected. It would be more interesting to use micro scale models for these situations to obtain insight into local congestion problems. This could only be modelled by INDY with six postal-code zones or a micro-scale model like LSM BC HYDRO as discussed in Chapter 5.

Evacuation modelling in which inhabitants are routed to safe havens or shelters was not possible in any of the models. In ESCAPE the algorithms were too simplistic, and EC and INDY are not detailed enough in that the scale of the zones does not allow for defining shelters in a realistic way. However, INDY can simulate the use of shelters by reducing the number of inhabitants that are routed onto the

road network. INDY results indicate that the total evacuation time can be significantly reduced if the number of evacuees is reduced.

Resulting evacuation times

In EC some scenarios combine the above-mentioned assumptions: a fast departure profile, no reduction factor (this means no congestion at the outflow) and optimal traffic management. This result of this scenario, which was an evacuation time of approximately 12 hours, is considered highly underestimated and unreliable.

Because ESCAPE algorithms are not understood in detail, it could not be properly compared to EC and INDY. However, because it assumes an optimal departure profile and an optimal traffic management (no congestion), ESCAPE is also expected to underestimate the evacuation time.

All models predict that it will take at least 22 hours to evacuate the whole study area, when the evacuation is managed and no unexpected events (like accidents) happen and people leave very efficiently. While this is an underestimation of the actual evacuation time, it is still too long to complete the evacuation within the lead time of the event-forecast, which is usually 6 hours in this region.

Reliability

Because the model results were not compared with actual evacuation times from a historical event, it is difficult to conclude which model produces the most reliable results. It seems intuitive that INDY would produce more reliable results than EC and ESCAPE, because INDY simulates the actual road network in a dynamic way, whereas EC simulates the network based on assumptions regarding the departure profile and evacuation velocities, and ESCAPE assumes an optimal departure profile and fixed road capacities. All three models are expected to underestimate the evacuation time due to the assumptions that no congestion occurs from cross flow traffic, that no accidents will occur, and that residents will respond to an evacuation call in an ideal and optimal way.

End user consultation

From the end-user consultation carried out in September 2007 it was noted that besides the technical aspect, evacuation management deals with important political issues. These include:

- The possibility that an evacuation which turns out to be unnecessary will influence the response for the next evacuation call;
- The possibility that people start evacuating before the official order is given. This will lead to chaos on the roads.

Recommendations

The following recommendations have been

- If INDY is used in future evacuation modelling of Zeeland, it is recommended to look into potential obstruction locations due to crossing of roads. This is not taken into account, while in reality this will cause a delay. Currently the evacuation time is considered underestimated.
- Flood simulations show 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;
- In the evacuation planning, it is recommended to focus on local displacement of people and cattle. By making use of flood simulations the most risky areas can be pointed out. For these areas detailed evacuation plans can be developed, making use of meso- or micro-scale models.

- When local evacuation plans are developed, the traffic from other parts of the region needs to be considered. Congestion at a certain location also depends on people's displacement from other areas.
- Instead of evacuating the whole of the pilot area, it is worth looking into the use of shelters within the area at risk. Hazard maps provide insight in which areas are higher or will most likely stay dry.

7. Pilot application for the Gard Region of France

7.1 Introduction

This chapter details the development of a flash warning system for roads in the Gard Region of France. There has been little work undertaken to develop flash flood warning systems for road networks. Such tools are of interest for the following reasons:

- (i) Many victims of flash floods are car passengers trapped in their vehicles on roads that are suddenly inundated. Lives could be saved if the relevant authorities were informed on the probable status of the road network and could prevent traffic entering areas at risk;
- (ii) The emergency services need to have a clear overview of the road conditions during a flood and to programme their interventions efficiently and to identify the safest access or evacuation routes.

The objective of the Task 17 of the FLOODsite project, as far as flash floods are concerned, was to define the specifications of such a flood warning system devoted to the road network and to develop a prototype system for the Gard Region in France. The development of this prototype has been divided into three phases as follows:

1. The identification of the road inundation potential based mainly on local geographical information.
2. Developing rainfall-runoff models on the catchments located upstream the identified points prone to flooding.
3. Combining the flooding potential of roads with the estimated flood discharges, to provide an integrated tool able to forecast in real time the flooding of roads.

This chapter summarises the development of the prototype flood road warning tool.

7.2 The choice of the Gard pilot area

The Gard Region, shown in Figure 7.1, is located in the French Mediterranean area. It has been selected as the pilot area for the development of the proposed prototype for the following reasons:

1. It is being used as a flash flood pilot site for Task 23 of FLOODsite.
2. It is exposed to frequent and intense flash floods. It has experienced a series of damaging flash floods during recent years, particularly in 2002. A large amount of data, in particular hydrological data but also information on road water depths, is available.
3. In this area, 40% of the victims of flash floods during the last fifty years were motorists (Antoine, 2001). During 8 to 9 September 2002, five people were been drowned in their cars and about two hundred emergency services vehicles were trapped on inundated roads and destroyed or seriously damaged. An improvement of the road network management during flash floods has therefore become a major concern for the Gard local authorities.
4. An inventory of the road sections flooded during the last 40 years in parts of the Gard Region. This inventory is in the form of The PICH (Plan d'Intervention Crises Hydrologiques). PICH is a database that sets the conditions for the calibration and validation of the proposed approach.

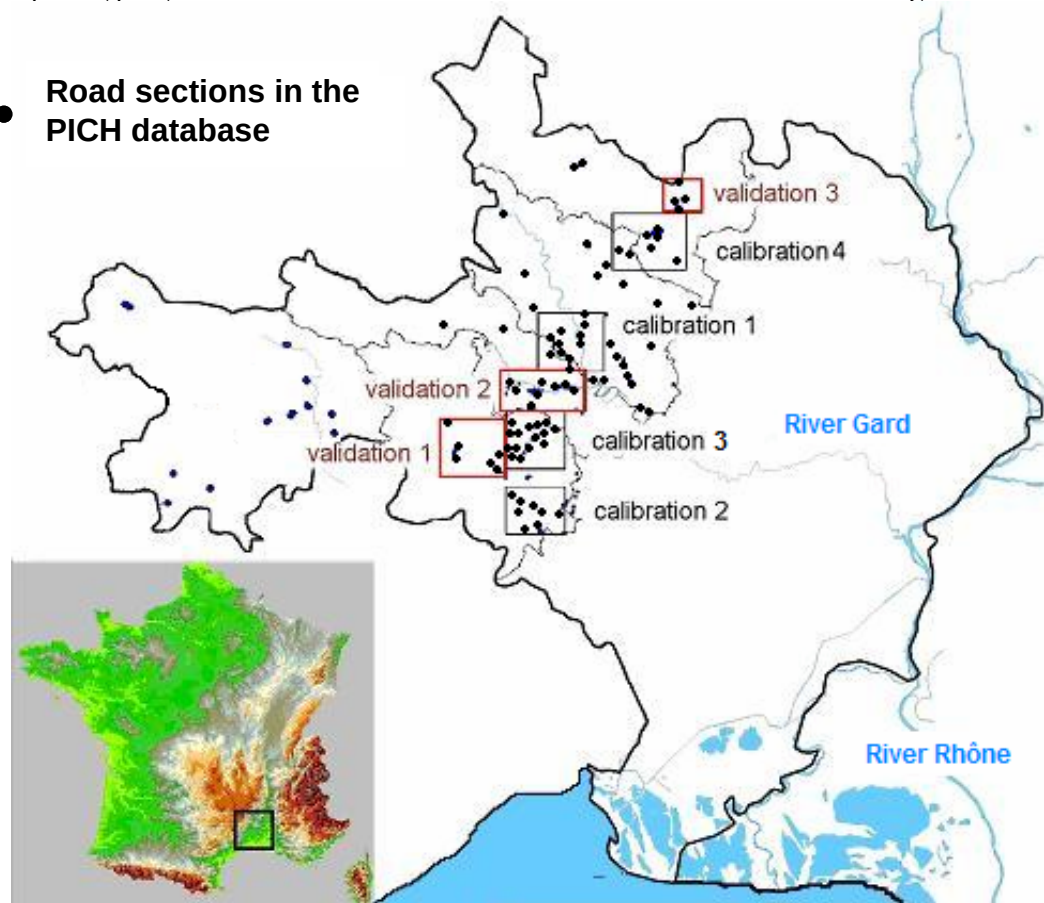
The rest of this section describes the PICH and the other databases available in the Gard Region that have been used.

7.3 Description of the PICH inventory

The PICH (Plan d'Intervention Crises Hydrologiques) is an inventory of the road inundations over the last 40 years. It has been developed by the state services in charge of the maintenance and management of the road network (Lignon, 2000). The objective of the PICH was to collate the experience gained by the employees of these services that would be useful for the management of the

road network during flood events. This inventory mainly covers the western and central part of the region, shown in Figure 7.1. This is the most populated part of the region. However, it is still mainly rural area in nature with a mean population density of 106 people/km². The PICH lists 167 locations on the 2,500 km of the road network, the majority of which are intersections between roads and rivers. Low points where runoff water accumulates during storm events and road sections located in flood plains are also included in the PICH. Four areas have been selected for the development and the calibration of the prototype system and three others for its validation. These are shown in Figure 7.1.

- **Road sections in the PICH database**



Note: The PICH road sections are shown by black points
The calibration areas are shown by black rectangles
The validation areas are shown by red rectangles

Figure 7.1 The Gard Region, the four calibration and the three validation areas and the location of the road flooding based on the PICH database

The PICH inventory provides a comprehensive database. It contains the exact locations of the roads that flood and in 75% of the cases, the number of observed floods during the last 40 years. It only covers the western part of the Gard Region shown in Figure 7.1. This comprises the upstream parts of the river catchments in the region. These are the areas that are exposed to flash floods. The PICH inventory lists frequently submerged road sections, i.e. the weakest points of the road network. Almost half of the listed road sections have suffered more than 20 floods during the last 40 years, which means a flooding frequency higher than one per two year. The frequency of flooding is shown in Figure 7.2. The number of PICH road sections and their inundation frequencies are related to the very high flood hazard in the region. The peak discharge of the mean annual flood for a 10 to 500 km² catchment is about 1 m³/s/km² (Gaume et al., 2004, Gaume et al., 2004b, Payrastre et al. 2005). This is much higher than the 1 in 100 year return period flood of catchments with equivalent areas in other regions of France or Europe. Most of the road sections in the PICH database do not correspond to poor design of river crossing. The flooding frequency of the road sections listed in the PICH inventory is the result of the combination of general design practices and local unfavourable

characteristics. The first phase of the proposed approach analysed the PICH road sections and compared them with other sections of the road network that have not been flooded in the recent past, to identify the characteristics that could help to measure the vulnerability of the road sections to flooding.

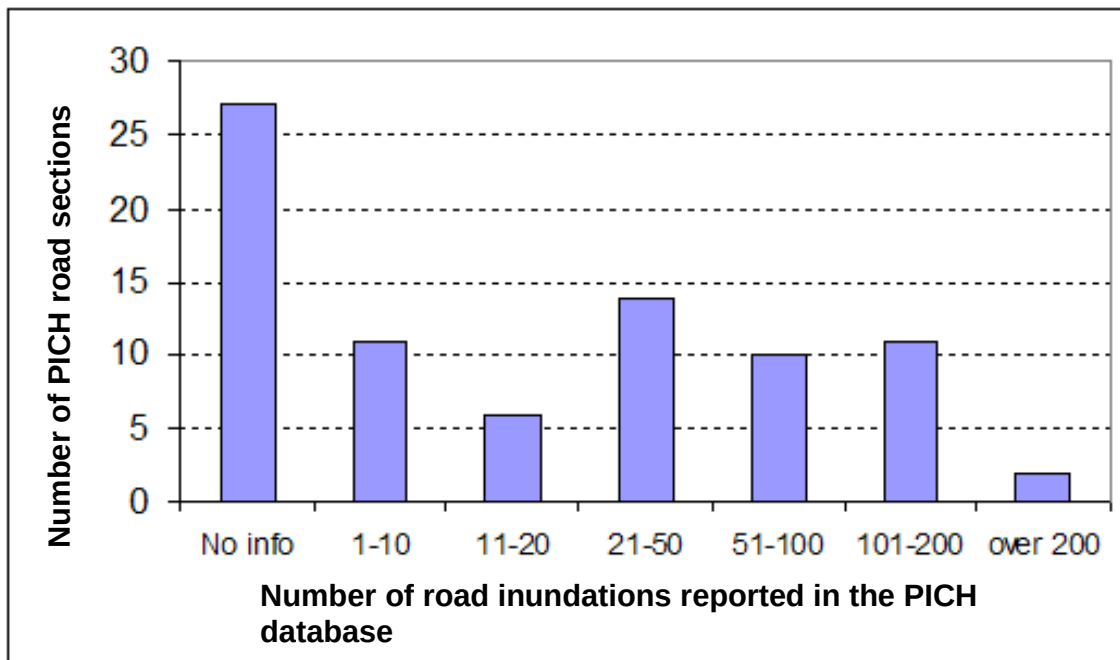


Figure 7.2 Number of flood events in the PICH database during the last 40 years for the calibration and verification areas

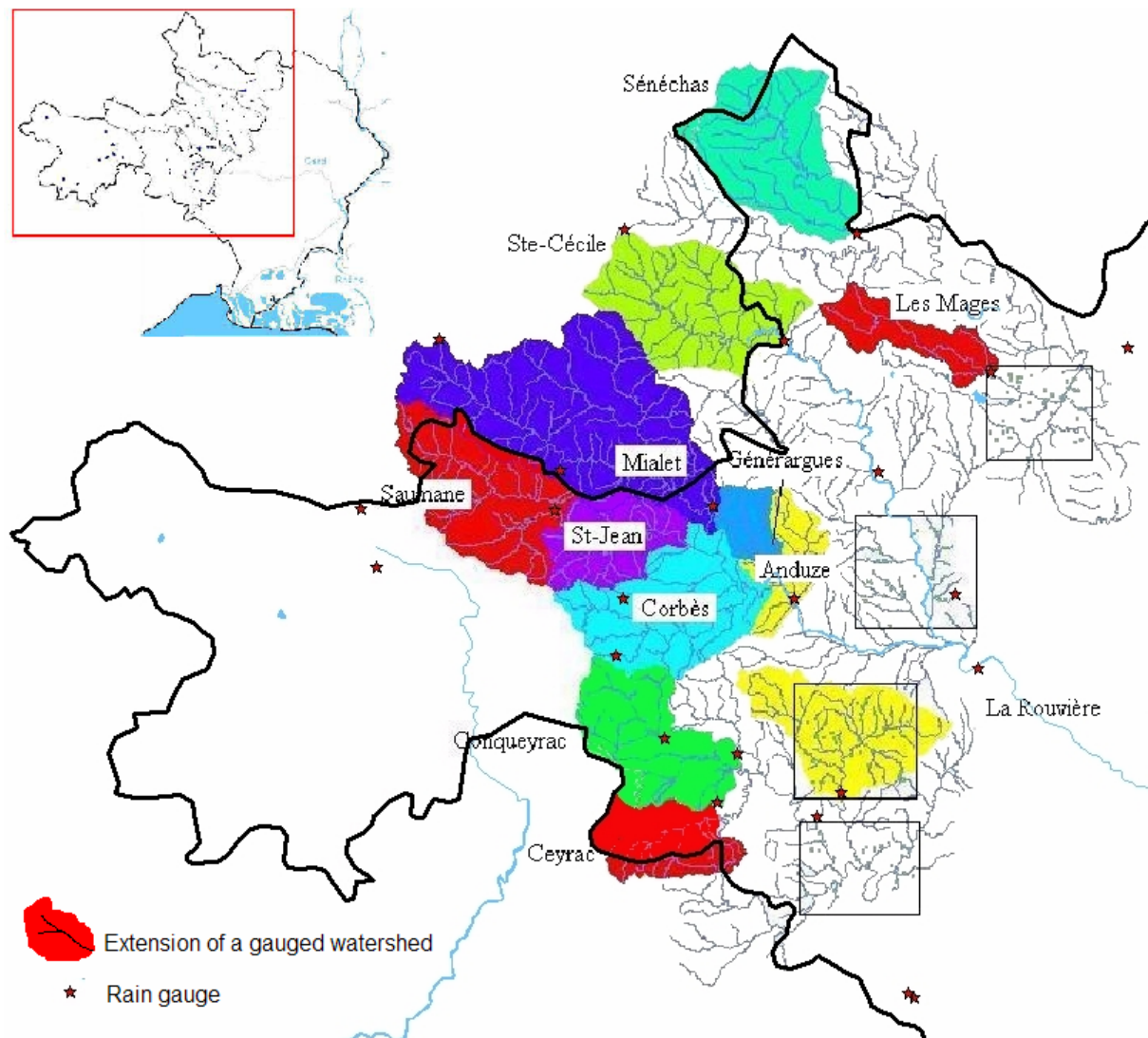
In addition to the PICH, the inundated roads were mapped by the state technical services after four recent major recent flash floods that occurred in the Gard Region in December 2002, November 2003, December 2003 and September 2005. In some cases details are available on these maps about the timing of the road flooding. This information complements the PICH data and was useful in evaluating the ability of the proposed tool to forecast road flooding. These four events as well as the September 2002, which is the 1 in 100 year return period flood for the PICH area, were used for validating the outputs of the prototype system.

7.4 Hydrological data

The second phase of the proposed approach comprised the development of a distributed rainfall-runoff model that was able to simulate and forecast the flood discharges of the catchments located upstream of the road sections that are prone to flooding. Three types of hydrological data are available in the Gard Region and have been used to calibrate and validate the rainfall-runoff model. These are:

- Hourly rain gauge data;
- Gauged river data;
- Hydrological statistics concerning peak rainfall intensities and discharges over the region.

Some of these data are also presented in Task 23 of the FLOODsite project. It has been possible to obtain a complete set of data for the major flash floods over the period 2000 to 2005, including the September 2002 flood. The location of the calibration areas, and rainfall and flow gauges is shown in Figure 7.3.



Note: The gauged catchments are those shown in colour

Figure 7.3 Gauged river basins in the Gard Region showing the location of the calibration areas

Rainfall intensity data

There are 35 hourly rain gauges located in or close to the Gard Region. This rain gauge network has been set up for flood forecasting purposes. It is denser in the upstream part of the main river catchments corresponding to the PICH area. This is shown in. In the upper part of the catchments it is relatively dense with about one gauge per 100 km², compared to the average density of hourly rain gauges in France of one per 500 km². However, such a density does not enable an accurate estimate of mean areal rainfall rates for time steps up to a few hours and hence is a major factor limiting the accuracy of rainfall-runoff simulations especially for small catchments. The Gard Region is also covered by two C-band weather radars. However, the radar data available was not sufficient accurate and hence it was not been considered in this study. A Kriging method was used to interpolate the point rainfall measurements and obtain hourly rainfall rates for a 1 km x 1 km grid of the project area.

Other rainfall intensity information

The 1 in 10 and 1 in 100 year rainfall intensities have been mapped for the whole region (CNRS/INPG, 1997). An empirical formula, the Crupedix formula, has been calibrated all over France to estimate the 1 in 10 year peak discharge of a catchment depending on the 1 in 10 year daily rainfall amount and the catchment area (Cemagref, 1980). This formula has been used to compute one of the road vulnerability criteria. It has also been used to rate the magnitude of the simulated floods in each river basin.

Discharge data

Discharge measurements were obtained for 12 river gauging stations of the Gard Region from the “Direction Départementale de l’Equipement du Gard” (DDE30) and from the “Direction Régionale de l’Environnement Languedoc Roussillon” (DIREN). Flow data were available at an hourly time step over the period 2000 to 2005. The upstream river catchments correspond to those stations are shown on Figure 7.3.

7.5 Geographical data

A 50 m x 50 m Digital Terrain Model (DTM) has been used to compute the properties of the road sections. The DTM has been re-interpolated to a 25 m resolution with a Regularised Spline with Smoothing and Tension (RST) method (Mitasova, 1993). The new DTM has been further improved by removing flat areas and “steps” that result as a result of the discrete nature of elevation data (basically integer values).

Roads and hydrological networks are both available and represented by vector data from the Institut Géographique National (IGN) topographic database. Every type of road is documented, from national major roads to small local roads. Perennial and ephemeral streams have been extracted from the DTM.

Soil properties and bedrock information were also available on the Institut National de la Recherche Agronomique (INRA) soil database at a 1:25.000 scale (INRA, 2000). Data consist of polygons representing different categories of soils and bedrocks. For the sake of simplicity, the initial complex classification has been simplified to define five main categories of bedrocks and associated soils in the Gard Region. These are:

- Alluvium;
- Impervious (marl, clay);
- Pervious (calcareous, conglomerate);
- Metamorphic (schist, gneiss);
- Karst.

A land cover geographical database, the Corine Land Cover database (Institut Français de l’ENVironnement (IFEN), 2000) was available at a 1:100,000 scale. The land use classification was simplified to reduce the number of land use types to five. These are:

- Urban and industrial areas;
- Agricultural;
- Forest;
- Natural environment;
- Water bodies.

The vulnerability of a road section to flooding did not appear to be significantly linked to the dominant land use type in its upstream catchment, nor to the soil and bedrock types. However, this information was used to inform the choice of the values of some of the parameters of the rainfall-runoff model. The geographical information was processed and visualised using the open source GIS GRASS (Neteler & Mitasova, 2004).

7.6 Evaluation of the road vulnerability

7.6.1 Introduction

The first phase of the proposed approach comprised identifying the potentially flooded sections of a road network cross-comparing available geographical data: DTM, topology of the road and hydrographic networks. It was important to identify if it was possible to identify all the PICH road sections in the Gard Region using these data.

The second step was to assess if there are some criteria that can help to discriminate between PICH and non PICH sections and to rate the road section vulnerability. The PICH sections, the most vulnerable sections, show a general tendency to be located in the lowest and flattest areas as well as downstream of the largest catchments. The elevation, the slope value, the upstream catchment area values were linked to the probability of a road section having been flooded during the last 40 years and to the flooding frequency for the PICH road sections.

The third step aimed to test if a combination of the various identified criteria can lead to a better discrimination between road sections exposed to flooding.

7.6.2 Step 1: identification of the potentially flooded road sections

Based on the PICH inventory, three different types of road sections that flood were identified. These are:

1. Intersections, road sections where the road crosses a watercourse. These represent the majority (77%) of the road sections known to have flooded.
2. Low points where runoff water accumulates during rain events.
3. Road sections located in inundated floodplains i.e. where road are located in the river bordering road sections.

Based on the DTM and the hydrographical and road network data bases, a set of road sections that have the potential to flood have been automatically extracted. It contains:

- (i) All the intersection points between the road network and the drainage network.
- (ii) All the low sections of the road network identified on the DTM.
- (iii) All the sections of the road network bordering a river: i.e. located at a distance lower than 75 m from a watercourse.

These are shown in Figure 7.4.

The analysis conducted on the calibration areas reveals that almost all the PICH road sections are included in this extracted set (62 out of 69). However, it is not surprising to note that the sample contains more road sections than the PICH database. This is shown in Table 7.1 and Figure 7.5.

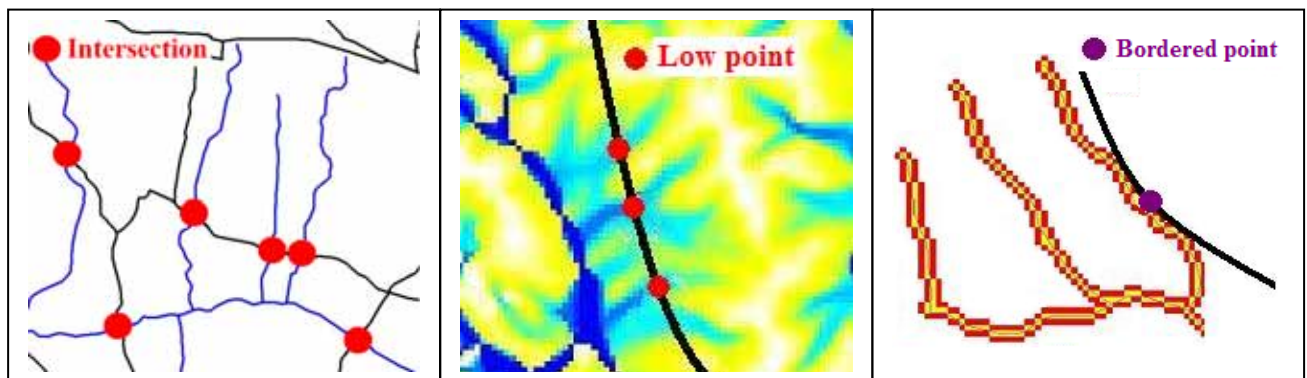


Figure 7.4 The three types of inundation mechanisms and their identification based on geographical data: intersections, low road sections and bordering road section

Table 7.1 Results of the initial analysis

	Number of identified road sections	Number of PICH road sections	Number of PICH road sections in the identified set
Intersections	293	54	54
Low points	158	9	7
Bordering points	81	6	1

The identification of roads in the floodplain (“bordering points”) was an issue, 81 points were identified but only one of them corresponded to a PICH point. This is because inundation of road in the floodplain (“bordering points”) requires a higher resolution DTM to identify them accurately. A detailed field study in the calibration areas revealed that blocked or partially filled ditches are generally responsible for the flooding of the low points of the road network. This information is not included in the geographical databases. Hence it can be concluded that site information is important to detect low points or roads in the floodplain that are exposed to flooding.

7.6.3 Identification of road flooding vulnerability indicators

Methodology

The objective of this step of the analysis was to identify characteristics in the form of indicators linked to the vulnerability of the road sections to flooding. Two types of indicators have been studied:

- (i) The local characteristics of the road section (e.g. altitude, slope, shape).
- (ii) The characteristics of its upstream catchment (e.g. area, peak discharge, land use, topographic Topmodel index, bed rock type).

The results concerning the indicators for which a significant difference appeared between PICH and non PICH road sections are presented below.

The separation between the PICH and non PICH sets, based on indicator values, is generally not perfect. However, the distributions of the indicator values will be different for both sets if the indicator is significantly linked to the sensitivity of the road point to flooding. Figure 7.6 shows a theoretical example. There may be for instance a general tendency of the PICH road sections to be located on the steepest or flattest roads.

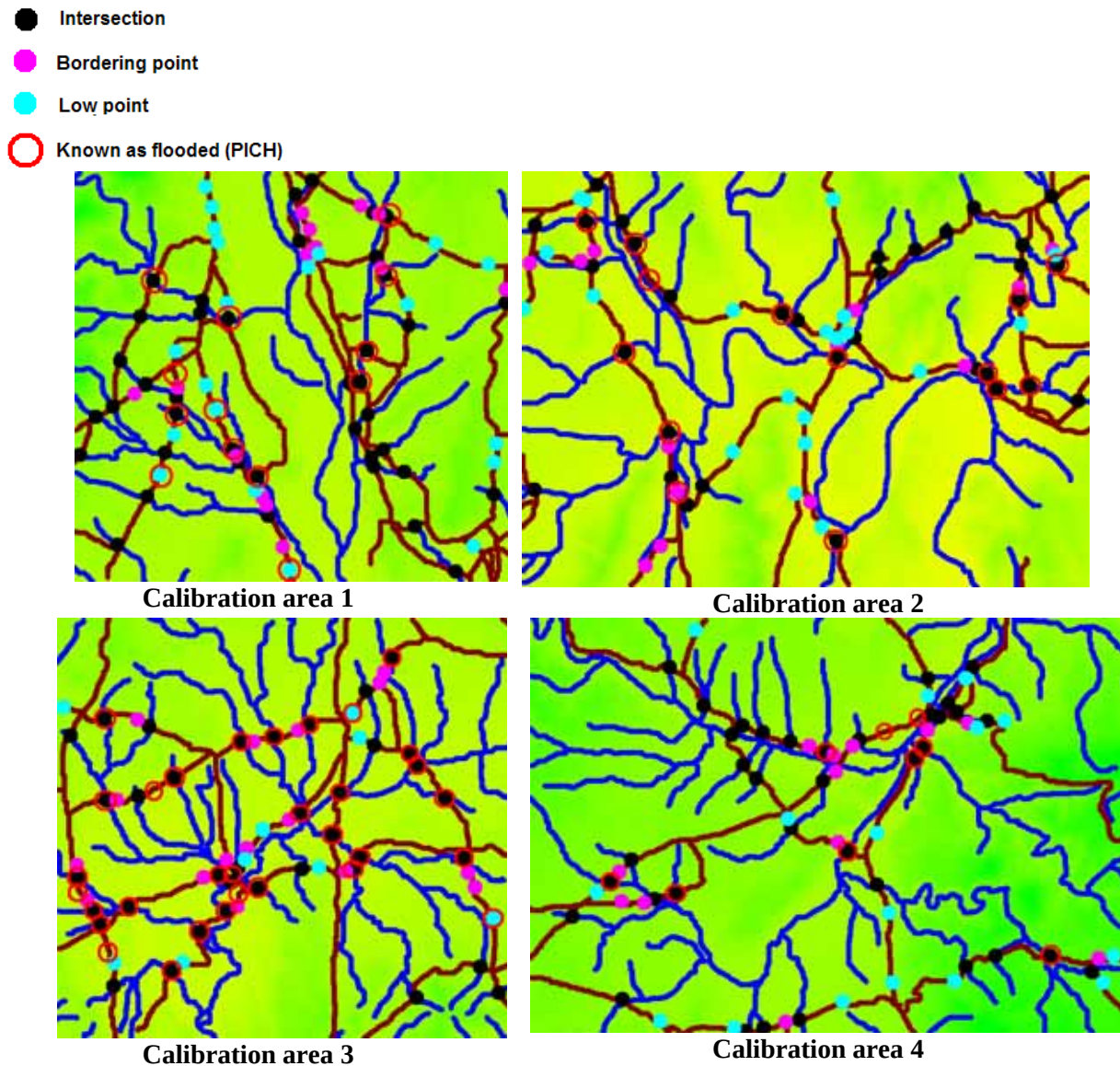


Figure 7.5 Result of the extraction of the sections of the road network sensitive to flooding on the four calibration areas

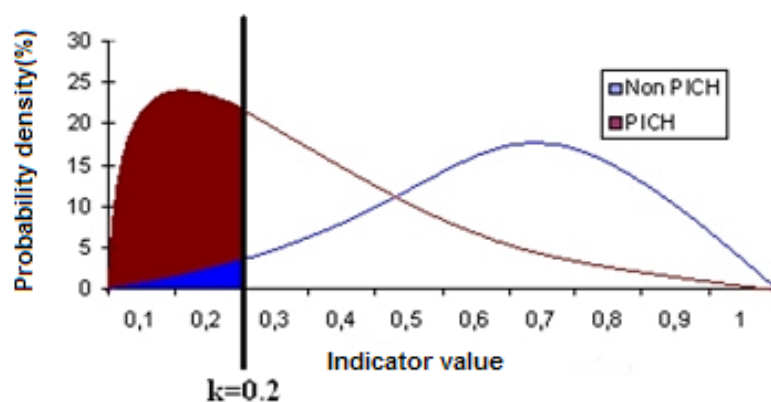


Figure 7.6 Theoretical densities of an indicator value for the PICH and non PICH set and separation efficiency based on a threshold (0.2 in this case)

In such a case, based on the indicator threshold values, empirical probabilities for a road section of being a PICH road section can be evaluated or classes of point can be defined with variable (growing

or decreasing) proportions of PICH, vulnerable road sections. To evaluate the discrimination efficiency of each tested criterion, the density and distribution functions for the criterion values of the PICH and non PICH sets will be compared and the proportion of non PICH road sections in four classes will be computed. The four selected classes are:

- **Red:** class containing 20% of the PICH road sections.
- **Orange:** class containing the next 30% of the PICH road sections.
- **Yellow:** class containing the next 50% of the PICH road sections.
- **Green:** class containing no PICH road sections.

Finally, the range of the values taken by each characteristic (e.g. altitude, slope) depends on the study area. The vulnerability indicator should, if possible, be case independent. Therefore, the indicator chosen is not the direct characteristic value but a normalised value. The simple normalisation method chosen consists of taking as indicator the value of the empirical distribution function of the considered characteristic for the extracted potentially flooded road sections in each considered region. It takes its values in the interval 0 to 1. Its density function is uniform for the whole extracted set of points and its distribution function is linear.

Impact of the road altitude

An analysis has been carried out to assess whether the vulnerable road sections are located mainly in the valleys or on the slopes. The distribution of the normalised altitudes of PICH road sections in the four calibration regions differs significantly from a uniform distribution. This is shown in Figure 7.7. The PICH road sections appear to be located in the lowest zones. Around 40% of the PICH road sections lie in the 20% lowest parts of the calibration areas. Table 7.2 shows the sorting efficiency based on the altitude indicator value.

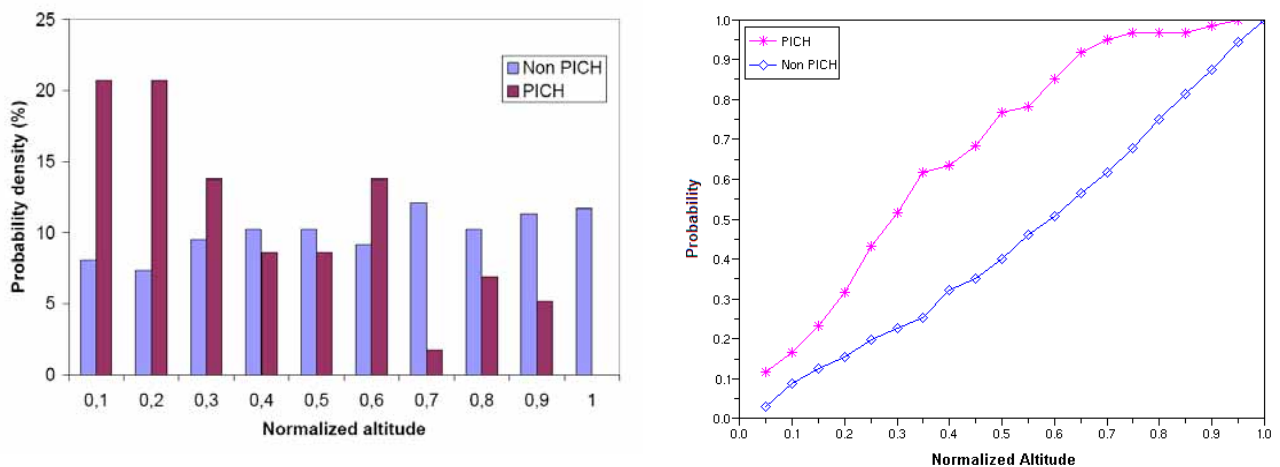


Figure 7.7 Density and distribution functions of the normalised altitudes for the PICH and Non PICH sets in the four calibration areas.

Table 7.2 Sorting efficiency based on the altitude indicator value

Flooding potential	Threshold	Selected sub-set			
		Selected PICH	Selected non PICH	Selected Total	PICH/Total class
Red		20%	11 %	13%	36%
	0.12				
Orange		30%	12%	16%	44%
	0.29				
Yellow		50%	70%	65%	18%
	0.94				
Green		0%	7%	6%	0%

However, this tendency is not pronounced enough to enable an efficiency separation between PICH and non PICH indicators based on an altitude indicator threshold as shown in Figure 7.8.

Impact of the local slope

The second characteristic extracted from the DTM that appeared to be linked to the vulnerability of the road is the local maximum slope around the considered road pixel. This slope indicates if the road section is located in a valley or a hillside. It is therefore partly linked to the altitude. It also indicates local runoff capacities, the flow velocities and hence the through flow capacity of culverts may increase with the slope.

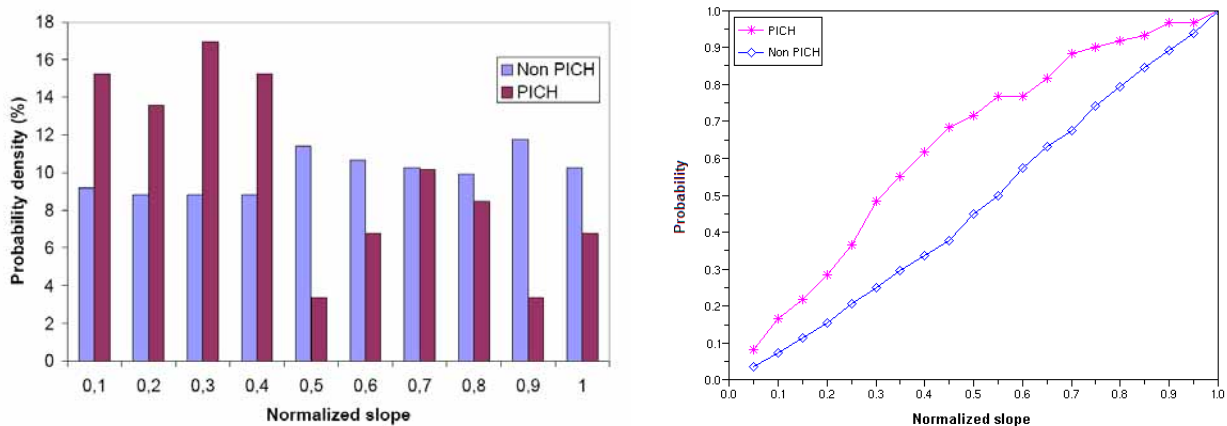


Figure 7.8 Density and distribution functions of the normalised slope for the PICH and Non PICH sets in the four calibration areas

Figure 7.8 shows that a large number of the PICH road sections are located in flat areas. Approximately 60% of the PICH road sections lie in the 40% areas with the lowest slopes. As is the case of the altitude, this tendency is not pronounced enough to enable an efficiency separation between PICH and Non PICH based on a slope indicator threshold as shown in Table 7.3.

Table 7.3 The sorting efficiency based on the slope indicator value.

Flooding potential	Threshold	Selected sub-set			
		Selected PICH	Selected non PICH	Selected total	PICH/total class
Red	0.11	20%	7%	10%	47%
Orange		30%	21%	23%	31%
Yellow	0.33	50%	70%	65%	18%
	0.9				
Green		0%	2%	2%	0%

Impact of the upstream catchment area

For each road section that has been identified at risk of flooding, the DTM has been used to delineate the upstream catchment area. The runoff processes and hence the flood hazard and the probability of the road flooding risk may vary from one catchment to another depending on its characteristics: topography, soil, geology, land use, and density of the existing stream network. Various characteristics of the upstream catchments have been computed and evaluated, but only two were significantly linked to the road flooding vulnerability: the upstream catchment area and when available, the ratio between the theoretical 1in 10 year discharge and the maximum free surface discharge of the bridge or culvert.

The catchment areas have been sorted in decreasing order so that the largest areas correspond to the lowest values of the normalised area indicator. The upstream catchments draining to the PICH road sections are generally larger than the catchments draining to the non PICH road sections. This is shown in Figure 7.9. The average area of the PICH catchments is 30 km² whereas a non PICH catchment has an average area of 10 km².

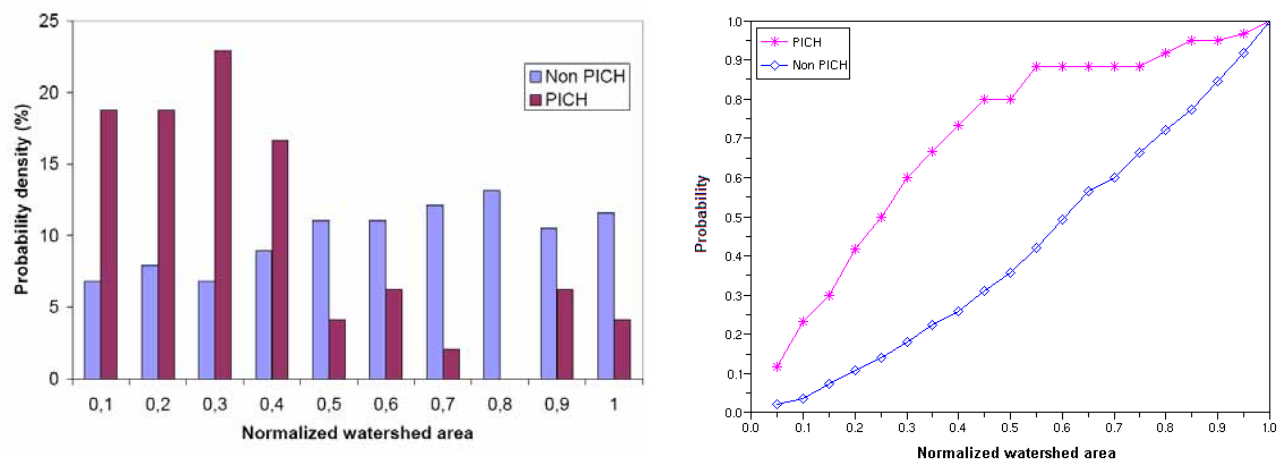


Figure 7.9 Density and distribution functions of the normalised catchment area for the PICH and non PICH sets in the four calibration areas

The sorting out of the PICH road sections based on the value of the upstream catchment area indicator is far from perfect but appears much more efficient than in the two previous cases. The red and orange classes contain for instance 50% of the PICH road sections but less than 15% of non PICH road sections. Table 7.4 gives the sorting efficiency based on the area indicator value.

Table 7.4 Sorting efficiency based on the area indicator value

Flooding potential	Threshold	Selected sub-set			
		Selected PICH	Selected non PICH	Selected total	PICH/total class
Red		20%	2%	6%	76%
	0.08				
Orange		30%	12%	16%	44%
	0.25				
Yellow		50%	82%	74%	16%
	0.98				
Green		0%	4%	4%	0%

Impact of the ratio between 1 in 10 year flow and design discharge of the road crossing

This indicator is based on a comparison between the road 1 in 10 year design flow upstream of a structure and the estimated design capacity of the structure (i.e. bridge and culvert) that crosses the road. Ideally, if both the design discharge and the 1 in 10 year flow could be accurately computed, the ratio between these two values should provide a good measure of the vulnerability of the watercourse crossing the road sections. It should be noted that both values cannot be accurately computed on the basis of the available data. The capacity of the culvert was computed based on free flow. Depending on the local configuration of a crossing, water can flow through a culvert under pressure without the road being inundated.

Two discharge values can be estimated on the basis of the available data: the maximum free surface flow through the structure based on its geometry and the 1 in 10 year flow. The Manning-Strickler formula has been used to derive an approximate free surface maximum flow through the culverts or the bridges that cross the road. This equation is of the form:

$$Q_c = K \cdot R h^{\frac{3}{2}} \cdot I^{\frac{1}{2}} \cdot S$$

Where:

Q_c is the design capacity of the crossing

K is the roughness coefficient;

Rh is the hydraulic radius;

I is the local slope;

S is the cross-sectional area of the structure.

The Crupedix formula (CEMAGREF, 1980) used to estimate the 1 in 10 year flow for small catchments in France has been used to compute the 1 in 10 year discharge:

$$Q_{10} = S^{0.8} \cdot \left(\frac{P_{j10}}{80} \right)^2 \cdot R$$

S is the catchment area in km^2 ;

P_{j10} is the 1 in 10 year 24 hour rainfall in mm;

R is a regional parameter equal to 1.5 for the Gard Region.

The ratio Q_c/Q_{10} has been computed for all the road sections for which the dimensions of the watercourse crossing structures were available. This is 75% of the PICH road sections and 25% of the non-PICH road sections. This is shown in Figure 7.10.

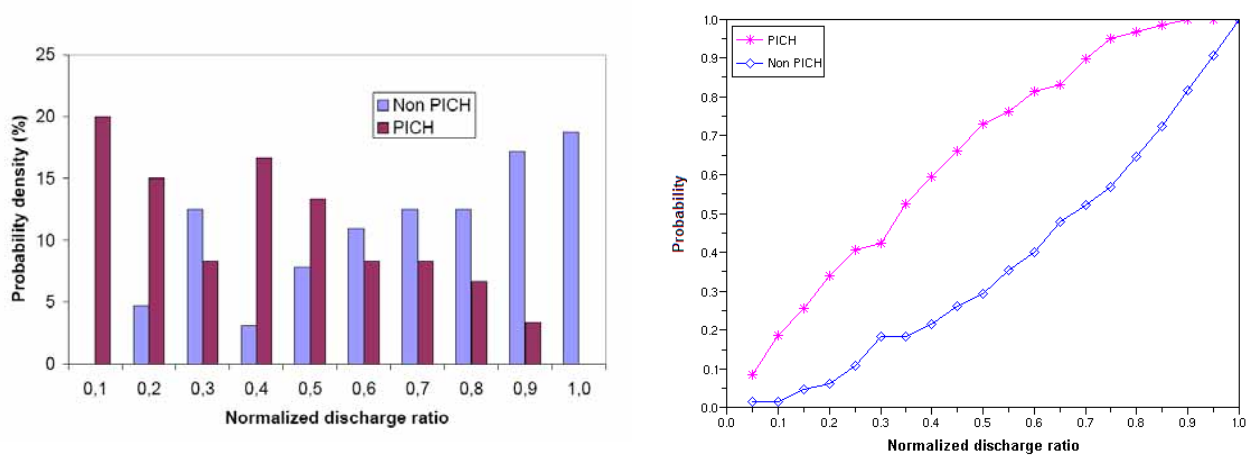


Figure 7.10 Density and distribution functions of the normalised discharge ratio for the PICH and non PICH sets in the four calibration areas

The potential flooding potential is clearly linked to the dimensions of structures that carry the watercourses under the road. The lowest ratio values correspond exclusively to PICH road sections and the highest, corresponding to the larger structures, to non PICH road sections. The use of the discharge ratio appears more provides amore useful indicator than some of the previous ones. This is shown in Table 7.5 for the higher values of the indicator (i.e. the yellow and green classes).

Table 7.5 Sorting efficiency based on the discharge indicator value

Flooding potential	Threshold	Selected sub-set			
		Selected PICH	Selected non PICH	Selected total	PICH/total class
Red		20%	2%	11%	90%
	0.09				
Orange		30%	16%	23%	63%
	0.34				
Yellow		50%	62%	56%	42%
	0.89				
Green		0%	20%	10%	0%

7.6.4 Conclusions

The three types of road sections liable to flooding were defined as follows:

- Intersections with the watercourses (i.e. the majority of the inundated sections);
- Low sections;
- Road sections bordering rivers.

Based on the DTM of the region and on the hydrological network, a sample of the potentially flooded road sections could be defined. This sample contains 90% of the road sections that actually flooded during the last 40 years and were reported in the available PICH inventory. The origins of the flooding of the 10% remaining road sections appeared to be linked to local features that cannot be detected by the DTM.

A test has been carried out to asses if additional indicators could help to refine the identification of the potentially flooded road sections. The comparison of the PICH and non PICH sub-sets of the identified potentially flooded road sections set revealed that four indicators where significantly linked to the flooding potential of a section of the road network. These were:

- Altitude;
- Local slope;
- Area of the upstream catchment;
- The ratio between the 1 in 10 year discharge and the design discharge of the structure that crosses the road.

It has been found that the PICH road sections have a tendency to be located in low and flat areas, with large upstream catchments.

7.6.5 Combination of flood vulnerability indicators

The discharge ratio indicator has been shown to be the most useful indicator. However, information concerning the geometry of the structures crossing the roads is only available for a limited number of locations. The possibility of combining the other three identified indicators has been investigated. A sensitivity analysis has been conducted to calibrate the combination method. All the three indicators take their values in the range 0 to 1. For sake of simplicity, the same value has been taken for the three indicators in each test. Two logical connectors have also been tested for the combination of the selection threshold of each indicator: AND and OR. The results of the sensitivity analysis are presented in Figure 7.11 and Table 7.6.

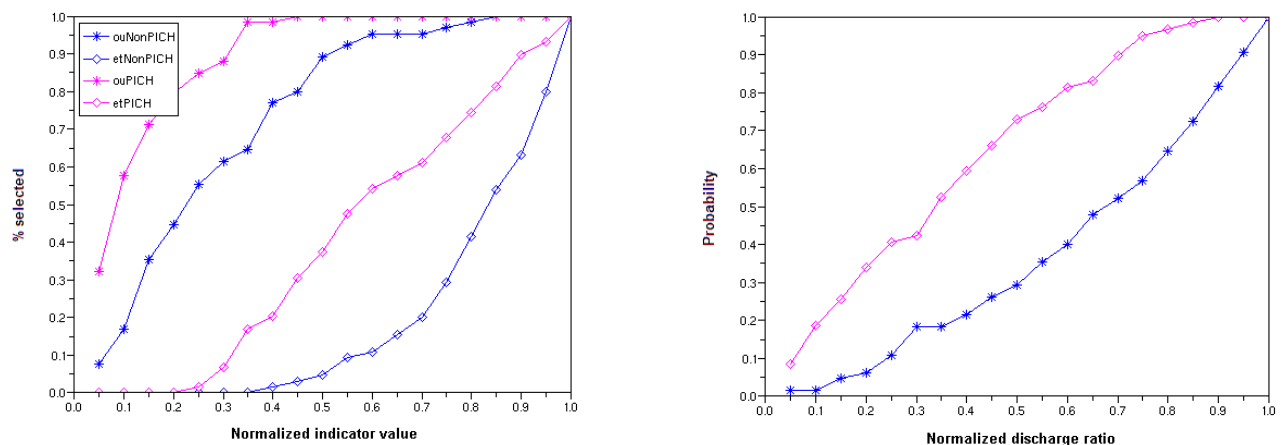


Figure 7.11 Distribution functions of the combined index value for the two tested connectors (left) and of the normalised discharge ratio (right) for the PICH and Non PICH sets in the four calibration areas

Table 7.6 Sorting efficiency based on the proposed indicator combination

Flooding potential	Threshold	Selected sub-set			
		Selected PICH	Selected non PICH	Selected total	PICH/total class
Red	AND	0.3	20%	1%	6%
Orange			30%	15%	18%
Yellow	OR	0.1	47%	51%	50%
Green			3%	33%	26%

Table 7.6 illustrates the effect of combining the three indicators. The selection ratio of the PICH road sections is higher than if only one indicator were used. It is particularly noticeable for the higher values of the indicator (yellow and green classes) where the sorting efficiency of the combined index

shown in Table 7.7 outperforms the sorting efficiency of the discharge ratio indicator shown in Table 7.5.

The discharge ratio is probably the best possible indicator of the road vulnerability that can be computed for “crossing road sections”. However, the information necessary for its computation is generally not available. It may be possible to replace it by an index based on the DTM with a comparable efficiency as far as the characterisation of the vulnerability of road sections to inundation is concerned. The efficiency of this index on the validation areas has been tested in the sections below.

7.6.6 Validation and conclusions

Two methods the combined index method and the discharge ratio indicator, have been tested on three other areas of the PICH region. In each area, the following steps were applied:

- Construction of the samples of potentially flooded road sections (intersection and low road sections);
- Calculation of the indicator values for each road section (i.e. altitude, slope, area, discharge ratio);
- Statistical classification of these indicators and computation of normalised values;
- Use of the thresholds and definition of the categories.

Table 7.7 Validation results of the flooding potential index computation method – method 1, combination of geographical indicators and method 2, index based on a discharge ratio

Flooding potential	Selected sub-set			
	Selected PICH	Selected non PICH	Selected total	PICH/total class
Red	10%	5%	25%	2%
Orange	33%	15%	32%	20%
Yellow	51%	52%	43%	63%
Green	6%	28%	0%	15%

For the three validation areas, whatever the method, the results are very similar to the ones obtained in the calibration areas shown in Table 7.7. About 50% of the flooded road sections (PICH) are in the RED and ORANGE categories. The Green category contains almost no PICH road sections, and the results obtained with the methods 1 and 2 are similar to one another. The proposed approach could be extrapolated, at least to the whole of the Gard Region and probably more generally the French Mediterranean area.

The classes identified on the basis of the proposed combined index differ by the proportion of PICH road sections they contain but also by the frequency of inundation of their PICH road sections as shown in Figure 7.12. The red PICH road sections are on average more frequently submerged than the orange ones which are more frequently submerged than the yellow ones.

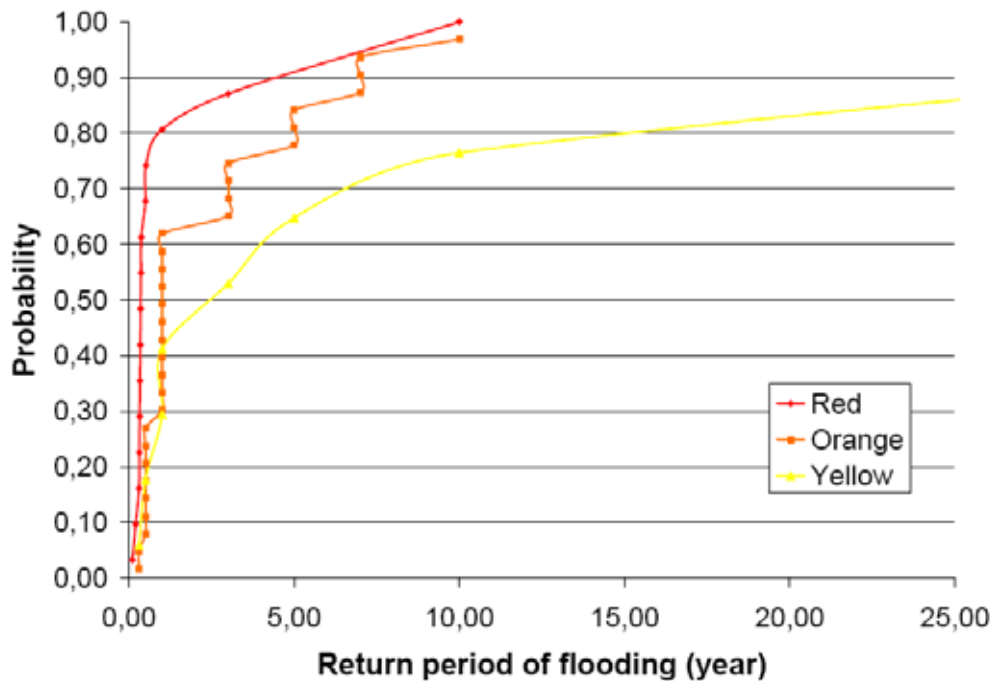


Figure 7.12 Distribution function of the inundation return period of the PICH road sections in the Red, Orange and Yellow classes

7.7 Distributed rainfall-runoff simulation

7.7.1 Specification of the rainfall - runoff model

The next step comprised linking the vulnerability indicators to the hydrological hazard. During a storm, the discharge of the rivers that intersect the road network needs to be estimated. A rainfall-runoff simulation was conducted for each catchment located upstream of the identified road sections prone to flooding in order to calculate the discharge. The selected rainfall - runoff model had to have the following properties:

- To be able to estimate a discharge for a large number of locations, i.e. on every vulnerable section of the road network;
- To use the available rainfall and land use data.

A distributed rainfall-runoff model was best suited to fulfil the above criteria.

The CINECAR model was selected to compute the flood discharges (Gaume et al., 2004). It has been developed specifically to model flash floods and has been used to simulate the extreme flood that occurred in 2002 on the Gard River (Gaume et al., 2004b; Delrieu et al. 2004). The characteristics of the model are follows:

- The flood flows are assumed to comprise essentially surface runoff water;
- The US Soil Conservation Service (SCS) Curve Number (CN) model is used to calculate the mean runoff coefficient on each sub-catchment;
- The kinematic wave model is used to route the flood flows through the catchment.

In the model, a catchment is represented by a network of river reaches having a rectangular cross-section connected to two rectangular slopes as shown in Figure 7.13. The division of the Gard Region into sub-catchments and river reaches was dependent on the location of the vulnerable road sections.

The largest sub-catchment area was 10 km². The average area of a sub-catchment was 2 km². Average areal hourly rainfall intensity was computed for sub-catchment using the Kriging method.

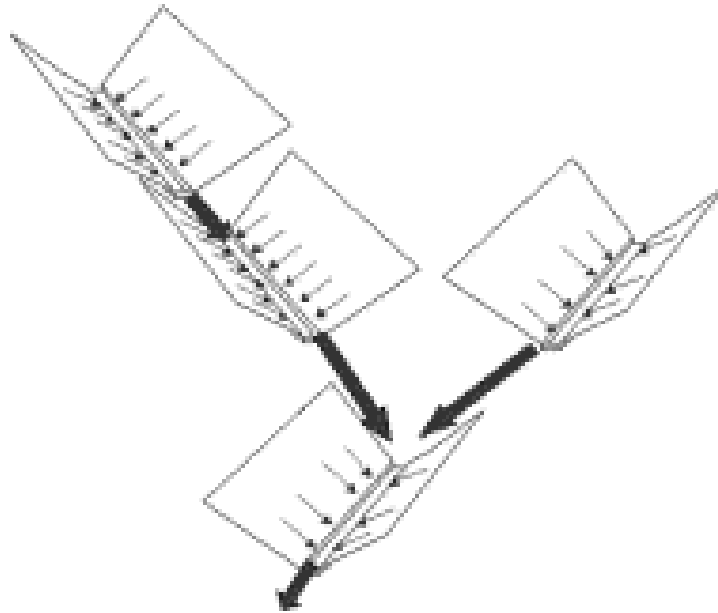


Figure 7.13 Representation of a catchment in the CINECAR model

The SCS model was selected among others because of its simplicity, in estimating the rainfall contributing to the runoff. The evolution of the runoff coefficient value during the storm event depends on a single coefficient as follows:

$$V_t = \frac{(P_t - 0.2S)^2}{(P_t + 0.8S)}$$

Where:

V_t is the total runoff volume from the beginning of the storm event in millimetres;

P_t is the total rainfall amount in millimetres;

S is the retention capacity of the catchment, also in millimetres, given by the equation:

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right)$$

Where:

CN is the “curve number”, and has a value ranging from 0 (constant runoff coefficient equal to 0%) to 100 (constant runoff coefficient equal to 100%).

7.7.2 Model parameterisation

The CINECAR model comprises two sub-models:

- A rainfall – runoff model based on the SCS-CN model;
- A flow routing model.

The main parameter of the rainfall – runoff model is the Curve Number for each slope of the catchment. In the flow routing model, the dynamics of the flood propagation depends the following:

- Sub-catchment area;
- The average slope;
- The slope length;
- The Strickler's roughness coefficient.

These parameters affect the routing of the flood through the catchment. Some of the above data (e.g. length, average slope) can be derived from the DTM. The roughness coefficient and the reach widths play a similar role in the kinematic wave model and the dynamics of the flood propagation is dominated by the transfer times in the river reaches when slopes with reduced area are used as is the case in the present application. It was thus decided to fix the values of the Strickler's roughness coefficients of the slopes and reaches respectively to 10 and 15 m^{1/3}/s. These values led to satisfactory results for the simulation of the 2002 flood (Gaume et al., 2004 and 2004b ; Delrieu et al. 2004). The only remaining calibration parameters of the routing model are the equivalent widths of the river reaches. These equivalent widths comprise the river bed width where the flow is confined for moderate floods and the floodplain widths that are inundated during larger floods.

7.7.3 Choice of Curve Numbers (CN)

Firstly, a single CN parameter was implemented on all the sub-catchments without considering their geographical characteristics (e.g. dominant land cover or soil type). The study conducted on previous flash floods (Gaume et al., 2004 and 2004b ; Delrieu et al. 2004) has shown the most appropriate value of the curve number is between 50 and 70 for rural catchments that are exposed in autumn to intense storm events. This corresponds to a total storage capacity S of 100 to 250 mm.

In a second test, a specific CN value has been calibrated for the dominant land cover and soil types. Three land cover types (i.e. CNagr for agricultural, CNfor for forest and CNurb for urban areas) and five soil and corresponding bed rock types (i.e. CNall for alluvial soils , CNimp for impervious, CNper for highly pervious, CNmet for metamorphic bedrock covered by shallow soils and CNkar for karstic areas) have been considered.

7.7.4 Choice of river reach widths

The width of the reaches, have been linked to the Strahler order of the stream. Figure 7.14 shows a theoretical example of Strahler ordering.

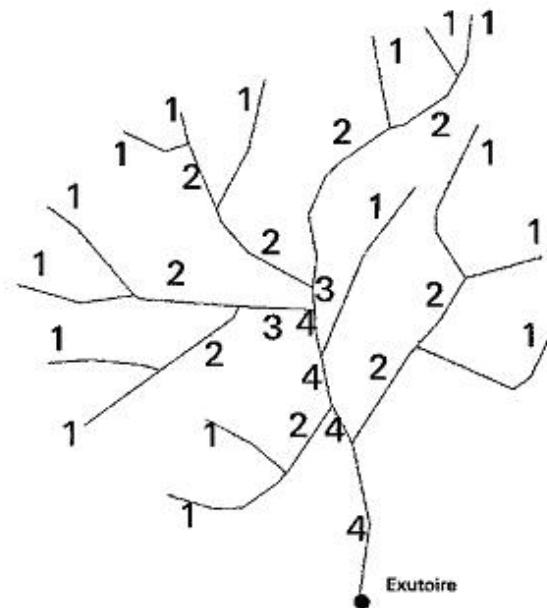


Figure 7.14 A theoretical example of Strahler ordering of a river network

Three different widths have been used depending on the magnitude of the flood. These are shown in Table 7.8. Owing to the simplicity of the flood propagation model implemented in CINECAR, (it is only possible to define rectangular cross-sections), it appeared not to be possible to define a single set of river cross-section width for the whole range of simulated discharges. To obtain a reasonable flood peak timing, it has been necessary vary these widths with the magnitude of the flood. Owing to the expansion of the flow in the floodplains, the effective river cross-section widths have a general tendency to increase for larger floods. Three sets have been defined as follows:

- Set 1: Minor flood, flow confined in the river bed. Typically peak discharge values are lower than the 1 in 2 year return period peak discharge.
- Set 2: Medium floods. Typically a peak discharge return period higher than the 1 in 2 year return period;
- Set 3: Larger floods.

Table 7.8 Sets of widths based on the Strahler orders and the flood magnitude.

	Order 1	Order 2	Order 3	Order 4	Order 5
Set 1	4 m	16 m	36 m	64 m	100 m
Set 2	8 m	32 m	72 m	128 m	200 m
Set 3	12 m	48 m	108 m	192 m	300 m

7.7.5 Calibration procedure

To measure the performances of the model, the simulated discharges were compared to the observed ones using a Nash criterion computed for each flood event separately. The Nash efficiency criterion ranges from minus infinity to 1. A value of 1 indicates a perfect agreement between the simulated and observed values and a value lower than 0 means that the model does not perform better than the simple model simulating the average discharge value over the whole flood event.

The calibration of the rainfall – runoff model consisted of varying the values of key parameter value adjustment an optimisation procedure. The optimal set of parameters appears to vary significantly

from one flood event to the other and from one catchment to another. The objective of the calibration was to determine a range of parameter values for each storm event which leads, if possible, to an acceptable mean Nash criterion on the calibrated catchments. For each flood event, the three sets of width as well as seven CN values, ranging from 30 to 90, were tested. The results of the two best combinations of CN and widths sets are shown in Table 7.9. These were tested on the validation catchments.

The calibration was carried out on eight gauged catchment for nine recent storm events for which the total mean rainfall exceeded 100 mm. Four remaining catchments were used to test the potential of the using the rainfall – runoff model on ungauged catchments. It is important to evaluate this potential since the majority of the catchments located upstream the vulnerable road sections of the road network are ungauged.

7.7.6 Calibration results

For sake of clarity, the results obtained with an average calibrated CN value and variable CN values with the land cover will be presented. The results obtained where the CN was based on the soil type were found to be similar. Table 7.9 summarises for each flood event the adjusted CN and widths as well as the corresponding average Nash values for the eight calibration catchments. The average values of the Nash criterion may appear modest for the majority of the events, however, the following should be taken into account:

- The Nash criteria were computed only for the flood periods, which is more selective than a criterion computed over a long period of time including low flows generally available in the literature.
- The selected model was not adapted to the simulation of the recession curves after the flood, dominated by processes with slower dynamics than surface runoff. This part of the flood hydrograph reduces the Nash criterion value.
- The data used for the calibration are operational data and have a high degree of uncertainty in them. A highly negative value on one single catchment affects the average Nash value.
- The estimation of the mean areal rainfall based on the spatial interpolations of the measured road section rainfall is relatively uncertain. For instance the estimated average rainfall over the St Jean catchment seems not to be in accordance with the measured discharges. This is probably due to a very localised rainfall event that lasted less than one hour and was captured by one rain gauge and to which the interpolation method gave too much weight to for this catchment.

Figures 7.15 to 7.22 illustrate the variability of the obtained results on different catchments and the significance of the Nash criterion values. The intensities are average cumulated rainfall depths over the catchments area during 15 minutes. It must be multiplied by a factor of four to obtain intensity values in mm/hour.

Table 7.9 Results of the rainfall - runoff model adjustment

Date	Rainfall (mm)	CN	Width	Nash	Cnagr	Cnfor	Cnurb	Width	Nash
19 Sept2000	100	40-50	Set 1	0,01/-1,7	80-90	30-40	70-80	Set 1	-0,06/0,14
27 Sept 2000	164	40-50	Set 2	0,30/-0,99	80-90	30-40	70-80	Set 2	0,41/-0,15
17 Oct 2001	193	30-40	Set 2	-0,15/-0,08	80-90	30-40	70-80	Set 2	0,14/-0,06
8 Sept 2002	335	40-50	Set 2	0,47/0,43	80-90	30-40	70-80	Set 2	0,60/0,62
30 Sept 2003	98	40-50	Set 2	0,10/0,12	50-60	40	80	Set 2	0,11/-0,77
15 Nov 2003	120	50-60	Set 3	0,08/0,27	80-90	50-60	70-80	Set 2	0,15/-0,43
21 Nov 2003	165	50-60	Set 3	0,35/0,20	80-90	50-60	70-80	Set 2	-0,14/-0,65
29 Nov 2003	230	70-80	Set 3	0,67/0,51	90	60-70	80	Set 2	0,70/0,72
25 Oct 2004	161	40-50	Set 2	0,35/-0,11	70-80	40-50	80	Set 2	0,57/0,53

The results are variable, but acceptable if compared to simulation results obtained on comparable case studies where more effort was put into model calibration (e.g. FLOODsite Task 16). The initial conclusions are presented below.

The model with CN values that vary with the land cover or the soil types do not have significantly better performances than the model with a global average CN value. They actually have a general tendency to have lower Nash values on the validation data set. This is shown in Table 7.9. It appears difficult to calibrate a specific CN value for each land cover or soil type on the basis of input-output (i.e. rainfall - discharge) information only. The variability in the land covers of the various catchment is not pronounced enough to enable a specific calibration of each CN. The problem is one of “over-parameterisation” and the calibrated models are too sensitive to specific parameters and have therefore lower performances when used on other catchment. This led to the selection of the simplest model with a global CN value.

One single set of parameters does not match all the calibration events. However, the variations of the adjusted sets are logical. The river channel widths have to be increased for the largest floods. Moreover, the CN values increase during the autumn indicating a recharge of the soils and the groundwater. Two ranges of values have: 40 to 50 in September and October and 50 to 60 in November and probably the same values during the winter and spring season. The very large value used for the event of the 29 of November 2003 is probably linked to the high rainfall volumes of the just preceding events.

The performance of the model is generally better for the highest rainfall events. The hydrological response to smaller rainfall events appears a little more erratic and probably linked to the non-linearity of the rainfall-runoff relationship and slight variations of the initial conditions

The interpolation of rainfall rates based on a even relatively dense rain gauge network seems to be a major source of uncertainty limiting the performances of rainfall runoff models. This is particularly true when the storm event is localised and not widespread over the region.

The model chosen has a general tendency to overestimate the flood peak discharges. This will lead to a pessimistic forecast of the road network state which may be better than an optimistic one for a warning system.

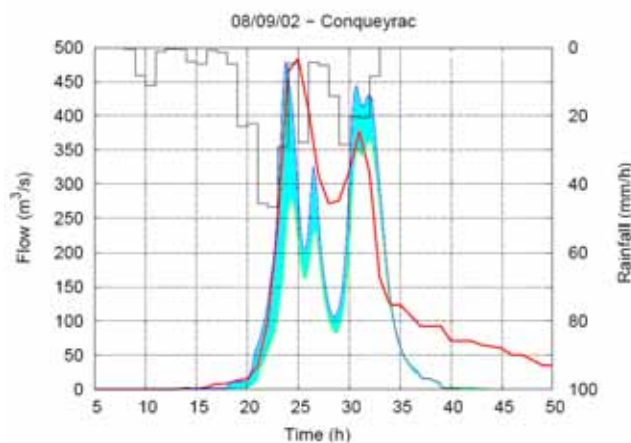


Figure 7.15 Conquerac, 08/09/02, Nash [0.65,0.77]

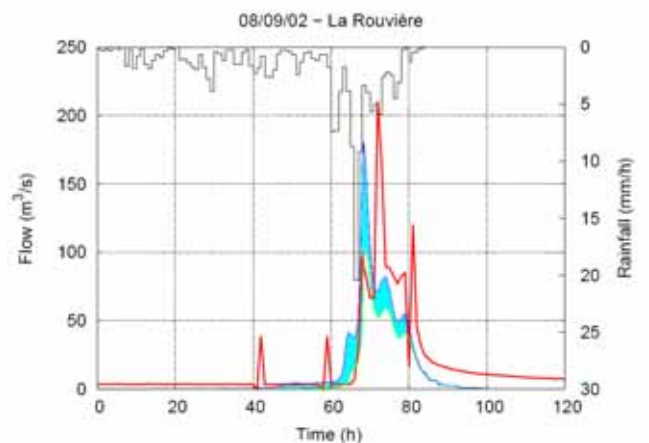


Figure 7.16 La Rouvière, 21/11/03, Nash [0.49,0.51]

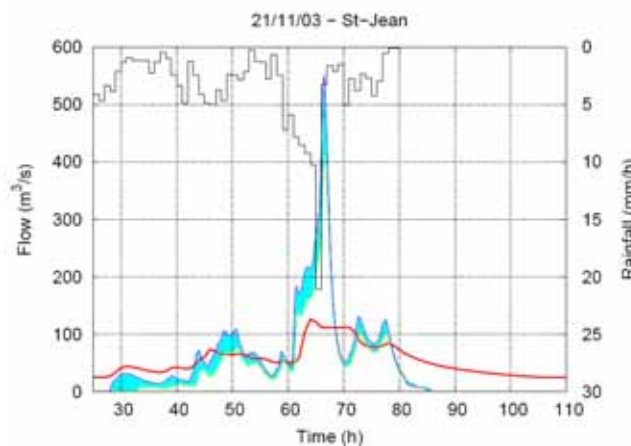


Figure 7.17 St-Jean, 21/11/03, Nash [-0.52,-2.32]

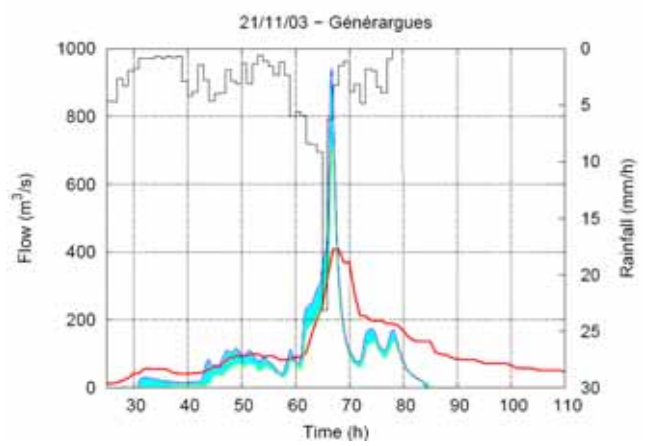


Figure 7.18 Generargues, 21/11/03, Nash [0.31,0.32]

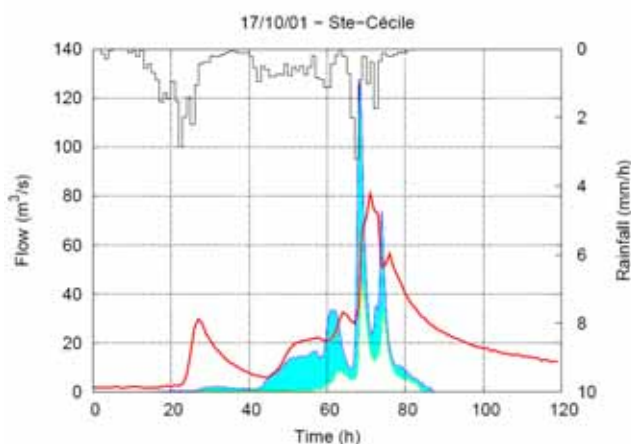


Figure 7.19 St-Jean, 21/11/03, Nash [-0.62,-0.30]

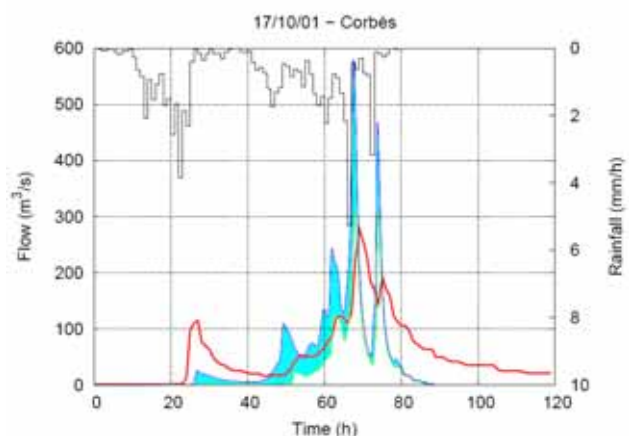


Figure 7.20 Corbes, 17/10/01, Nash [0.29,-0.30]

Comparison between the simulated and the measured hydrographs :

Observed discharge



Rainfall



Simulated discharge

high hypothesis



low hypothesis



7.7.7 Validation of the results

The results obtained on the four validation catchments appear very similar to the calibration results. The severe storm of 8 September 2002 has been modelled well with the calibrated parameters used on other catchments. This is also the case, to a lesser extent, for the events of 27 September 2000, 30 September 2003 and 25 October 2004 events. For other events, especially for the 29 November 2003 event, the model tends to over-estimate the flood peak discharge. In some cases (i.e. the 19 September 2002 and 30 September 2003 flood) the calibration average results are even better than the validation results. These validation results reflect a certain robustness of the selected rainfall - runoff model and indicate that it can be applied, with its limits, on ungauged catchments over the Gard Region. Figures 7.21 to 7.23 show the results. Table 7.10 shows the results of the rainfall runoff validation.

Table 7.10 Results of the rainfall – runoff model validation

	CN	Width	Nash	CNagr	CNfor	CNurb	Width	Nash
19 Sept 2000	40-50	Set 1	0,38/-1,2	80-90	30-40	70-80	Set 1	0,08/0,30
27 Sept 2000	40-50	Set 2	0,34/0,31	80-90	30-40	70-80	Set 2	-0,02/-0,23
17 Oct 2001	30-40	Set 2	-0,04/-0,41	80-90	30-40	70-80	Set 2	0,1/-0,5
8 Sept 2002	40-50	Set 2	0,82/0,65	80-90	30-40	70-80	Set 2	0,74/0,84
30 Sept 2003	40-50	Set 2	0,47/0,66	50-60	40	80	Set 2	0,56/0,59
15 Nov 2003	50-60	Set 3	-0,2/0,07	80-90	50-60	70-80	Set 2	-0,13/0
21 Nov 2003	50-60	Set 3	-1,3/-2,11	80-90	50-60	70-80	Set 2	-1,17/-2,35
29 Nov 2003	70-80	Set 3	-0,27/-0,41	90	60-70	80	Set 2	-0,42/-0,75
25 Oct 2004	40-50	Set 2	0,31/0,34	70-80	40-50	80	Set 2	0,5/0,2

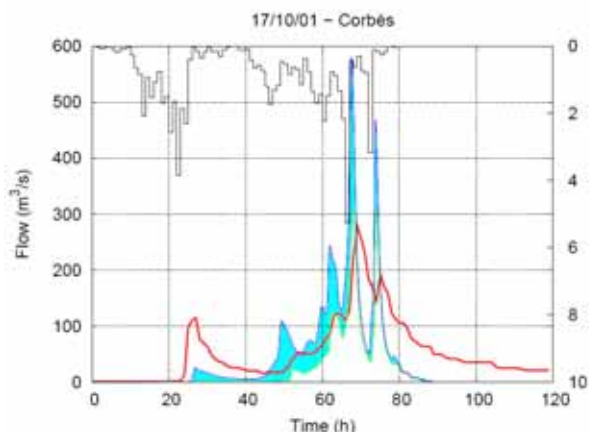


Figure 7.21 Comparison between the simulated (global CN) and measured hydrographs. Anduze, 30/09/03, Nash [0.70,0.56]

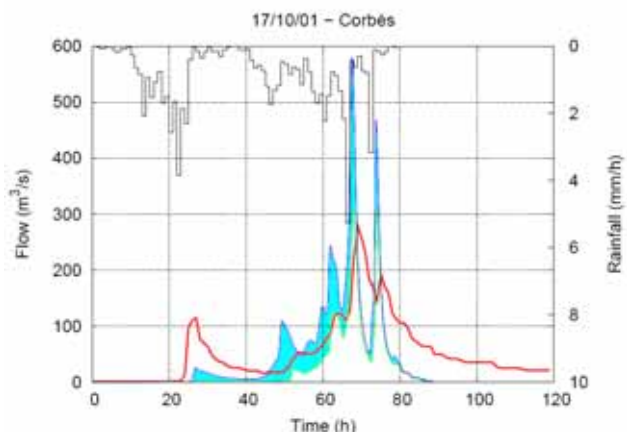


Figure 7.22 Comparison between the simulated (global CN) and measured hydrographs. Mialet, 08/09/02, Nash [0.83,0.51]

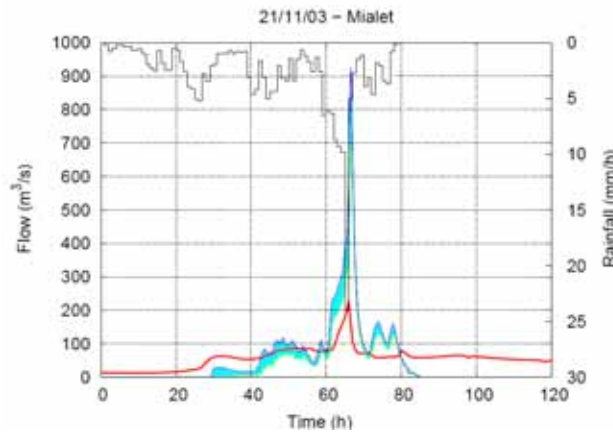


Figure 7.23 Comparison between the simulated (global CN) and measured hydrographs. Mialet, 21/11/03, Nash [-3.61,-6.27]

7.8 Conclusions

Based on the geographical and hydrological information, it has been possible to identify most of the points of the road network sensitive to flooding in the Gard Region pilot area and to rate their vulnerability. The proposed method has been calibrated on the Gard Region pilot area; hence its application to another region will require further validation. Some information is required on the past road inundations in order to develop a road vulnerability assessment tool.

A simple distributed rainfall-runoff has been calibrated and validated on the hydrological database available in the region. The validation results appear relatively satisfactory and provide an acceptable method to estimate peak discharges for the ungauged catchments in the Gard Region.

Both model outputs, i.e. vulnerability index and estimated discharges, have now to be combined to compute submersion risk indexes for the various vulnerable points of the road networks at various instants of a storm event. The maps obtained will be compared to the available maps of observed road submersions for four recent flash floods (i.e. December 2002, November 2003, December 2003 and September 2005).

7.9 Development of a road inundation forecasting prototype

7.9.1 Objectives and evaluation criterions

The objective was to develop a tool that delivers accurate information about the possible state of the road network to assist emergency services making decisions during flood events. The forecasting prototype must be able to identify a large proportion of the “hot spots” and the number of “false alarms” should be limited.

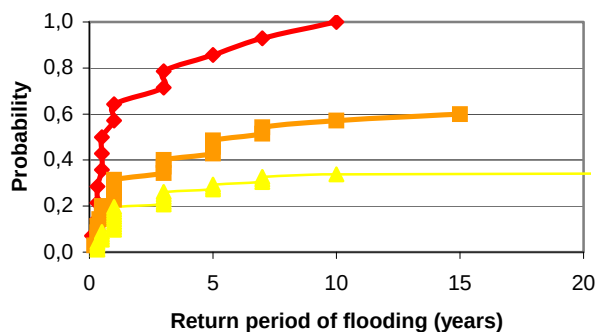
This section is divided into two parts. The first one presents how the vulnerability evaluation and the hydrological simulations were combined to assess the risk of road inundation. The second part presents the validation of the proposed approach based on road inundation data collected in the Gard Region during five recent flash flood events that occurred on 21 November 2003, 29 November 2003, 17 December 2003, 17 November 2004 and 8 September 2005. Three qualitative and quantitative evaluation criteria were used:

1. The proportion of the inundated road sections identified as high risk sections;
2. The effectiveness of identifying safe routes;
3. The accuracy of the forecast road inundations.

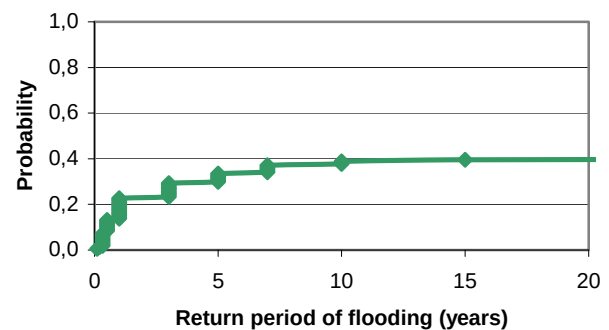
7.9.2 Definition of a submersion risk index

Based on the geographical information, it was possible to rate the vulnerability of road flooding at river crossing. A rainfall-runoff model has been selected to estimate the discharges produced by the catchments located upstream of these road sections. To be able to evaluate the risk of the road inundation, it was necessary to combine the vulnerability and hazard estimates.

Four vulnerability classes have been defined. The proportion of PICH road sections for which a road inundation has been reported in the last 40 years and also the frequency of the inundation of the PICH road sections are varying between these classes is shown in View 1 Figure 7.24. The distribution function of the inundation probabilities or return periods will be selected as the vulnerability measure of each class. To evaluate the usefulness of the vulnerability characterisation of the road network river crossing sections and their repartition into vulnerability classes, submersion risk computations will be also conducted without defining vulnerability classes. In this case, all the road network river crossing sections have the same statistical distribution of flooding return periods. This is shown in View 2 of Figure 7.24.



View 1



View 2

Figure 7.24 Distribution of the return period of flooding with and without the definition of vulnerability classes

To be able to compare return period probabilities and simulated discharges, it is necessary to evaluate a theoretical return period of these discharges. To do so, a regional discharge quantile estimation method, the Crupedix method presented was used. Three reference quantiles were considered: the 1 in 10 year discharge computed with the Crupedix formula, the 1 in 2-year discharge and the 1 in 50 year return period discharge. It should be noted that in the Gard Region the 1 in 50 year discharge is generally twice the 1 in 10 year discharge and the 1 in 10 year discharge is generally twice the 1 in 2 year discharge.

$$Q_{10} = S^{0.8} \cdot \left(\frac{P_{j10}}{80} \right)^2 \cdot R \approx 6.8 S^{0.8} \Rightarrow Q_2 \approx 3.4 S^{0.8}$$

As illustrated in Table 7.11 the Crupedix formula, as well the 1 in 2 year return period discharge estimation formula, seem to deliver very satisfactory quantile estimates in the Gard Region for a large range of catchment areas.

Table 7.11 Verification of the Crupedix and 1 in 2 year return period discharge estimation formula on gauged catchments of the Gard region.

	Les Mages	Saumane	Corbès	Généralgues
Area (km ²)	43	119	262	315
Q ₁₀ empirical (m ³ /s)	130	270	580	610
Q ₁₀ Crupedix (m ³ /s)	138	311	584	678
Q ₂ empirical (m ³ /s)	65	150	310	340
Q ₁₀ Crupedix/2 (m ³ /s)	69	256	293	340

Depending on the simulated discharge Q , five cases were considered: $Q < Q_2/2$, $Q_2/2 < Q < Q_2$, $Q_2 < Q < Q_{10}$, $Q_{10} < Q < 2Q_{10}$, $2Q_{10} < Q$. In each case the proportion of sections with inundation return periods comprised between the boundaries of the class can be computed for each vulnerability level. The first case ($Q < Q_2/2$) defines the lower discharge limit for which the risk is computed. The results are shown in the double entry Table 7.12.

Table 7.12 Probability of flooding with or without the hazard information

Vulnerability	Probability of flooding			
	Q < Q₂	Q₂ < Q < Q₁₀	Q₁₀ < Q < 2×Q₁₀	Q > 2×Q₁₀
High	65%	35%	0%	0%
Moderate	33%	22%	4%	41%
Low	20%	13%	1%	66%
Safe	0%	0%	0%	100%
Without vulnerability	24%	14%	2%	60%

The limit proportions to define the inundation risk classes were defined as follows:

1. The high submersion risk class (**red**) corresponds to a probability of inundation higher than 65%. Inundation of the road is almost certain. This will affect the highly vulnerable sections as soon as $Q > Q_2$, and the moderately vulnerable sections if $Q > 2Q_{10}$.
2. A significant risk class (**orange**) when the probability of submersion exceeds 33%. The inundation probability is high. It corresponds to the high vulnerability sections as soon as $Q > Q_2/2$, the moderately vulnerable sections if $Q > Q_2$, and the low vulnerability sections if $Q > Q_{10}$.
3. A moderate risk (**yellow**) occurs when the probability is higher than 20%. This corresponds to a “vigilance state”. Inundation is far from sure but possible. It will also affect safe cross-sections if $Q > 2Q_{10}$.
4. Almost safe (green or no colour).

The definition of these thresholds is arbitrary and adapted to the considered case study. If the vulnerability classes are not considered and with the same thresholds, the risk will be considered as moderate if $Q > Q_2$ and significant if $Q > 2Q_{10}$. The inundation risk is not as precisely rated in this last case.

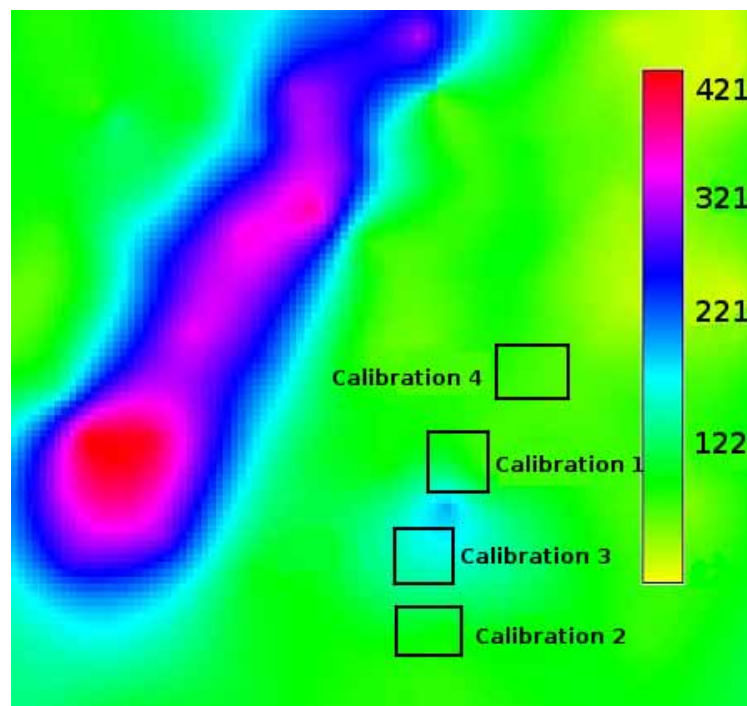
7.10 Evaluation of the proposed approach

7.10.1 Detection of the hot spots

Example 1 - 21 November 2003

This event was a typical autumn flash flood with an average cumulative rainfall exceeding 100 mm within a few hours over the considered area. The graphical outputs are shown for test area 4 where most of the inundations occurred. The results obtained for the four testing areas are summarised in Table 7.13. Figure 7.25 shows the cumulative rainfall over the Gard Region on 21 November 2003.

Figure 7.26 shows the warnings in Area 4 for the 21 November storm (low and high hydrological



modelling hypotheses).

Figure 7.25 Cumulative rainfall over the Gard Region on 21 November 2003 in millimetres and location of the test areas

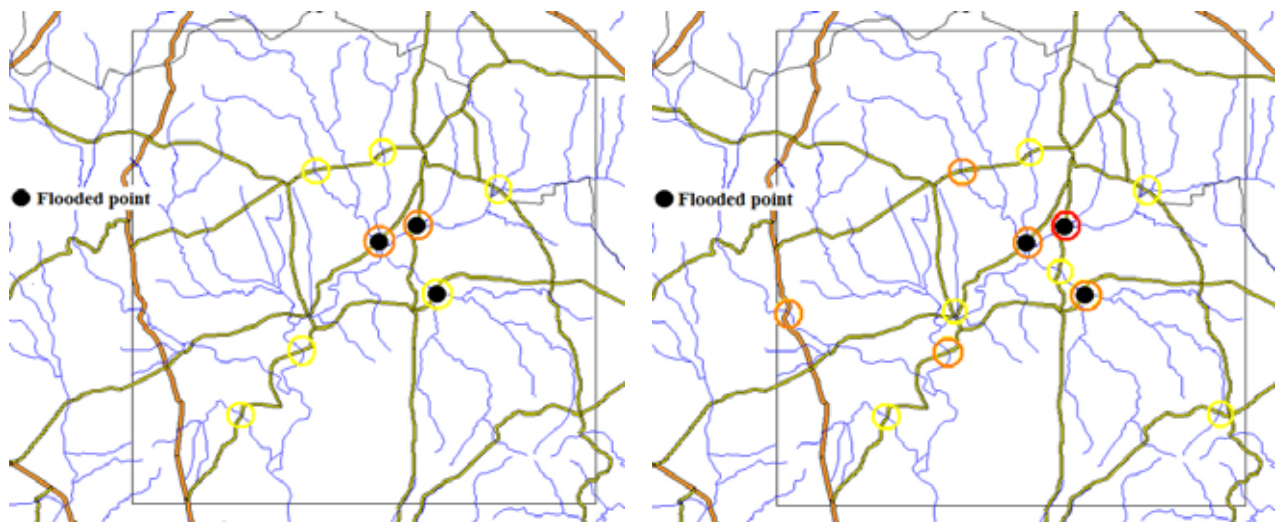


Figure 7.26 Warnings for Area 4 for the 21 November storm (low and high hydrological modelling hypotheses)

The results appear very satisfactory. The three effectively flooded sections are all identified as potentially flooded sections with the low or high hydrological modelling hypothesis. Moreover two of the three submerged points are rated with an orange colour with the low hypothesis and all these points are rated at least as orange (high risk) with the high hypothesis while at the same time only three other points are also rated as orange. The road and physiographic networks are shown on Figure 7.26 to give an idea of the total number of river crossing sections in this area. The discrimination efficiency of the proposed approach is high. A large proportion of the river crossing sections of the area are not identified as risky or affected by a moderate level of risk, leaving many possibilities for

the rescue services to define safe routes, even in the central and apparently most affected area. Table 7.13 shows a synthesis of the results for the 21 November 2003 storm.

Table 7.13 Synthesis of results obtained for the 21 November 2003 storm on for the test areas

	Low hypothesis				High hypothesis			
Risk	Yellow	Orange	Red	Efficiency	Yellow	Orange	Red	Efficiency
With vulnerability	2/7	4/5	0/0	100%	0/16	3/8	3/4	100%
Without vulnerability	0/0	0/0	0/0	0%	5/16	0/0	0/0	83%

Note: x/y means x effectively submerged number of points and y total number of identified point in the risk category

Table 7.13 shows that the results obtained on the other testing areas are comparable. Six sections have been inundated. They are all detected by the model with the low or high hypothesis. Moreover they are rated with the highest risk levels and represent almost 50% of the total number of identified road sections in the highest risk level categories. The approach appears to be far less satisfactory if the vulnerability classes are not considered, indicating that the effort devoted to vulnerability quantification was a necessity.

Example 5 - 6 September 2005

The storm on 6 September 2005 was one of the most intense flash floods of the recent years over the region with rainfall accumulations exceeding 250 mm over less than 12 hours in the selected validation areas. The cumulative rainfall is shown in Figure 7.27. However, on many of the catchments, the simulated peak discharges did not exceed the theoretical 1 in 10 year discharge. The whole validation area was badly affected by the storm event: i.e. homogeneous computed hazard or return period values for the discharges. The detection efficiency of the hot spots is therefore particularly highly linked to the vulnerability rating accuracy in this application. Many road sections were submerged over the region, including almost all the PICH road sections but also other sections, and the majority belonged to the low vulnerability class. This explains the relatively lower discriminating efficiency for this major flood event if compared to the previous one. Figure 7.28 shows the warnings for Area 1 for the storm on 6 September 2005. Table 7.14 gives the results for the 6 September 2005 storm

A very high number of potentially flooded road sections were identified: from 43 to 56 for a total validation area of about 150 km² depending on the hydrological hypothesis. Almost all the submerged sections were retrieved by the model with the high hypothesis, but a majority belong to the yellow (moderate) risk class. During major events, it is not unusual that a large proportion of the road network is affected at one instant or another of the storm event by a warning. However, these warnings, depending on the spatial and temporal repartition of the rainfall, may not be delivered simultaneously, leaving some intervention possibilities to the rescue services.

Road inundation detection and reopening times have been noted by the road management services during this extreme event. It was important to see if the time sequence of the computed warnings gave a useful overview to the operational services and whether it could help them to manage the road network and programme their interventions. It was also important to see if the warnings would be delivered in advance or at least on time.

Table 7.14 Results for the 6 September 2005 storm

	Low hypothesis				High hypothesis			
Risk	Yellow	Orange	Red	Efficiency	Yellow	Orange	Red	Efficiency
With vulnerability	12/31	2/5	4/7	69%	18/44	6/13	5/9	90%
Without vulnerability	6/21	0/0	0/0	26%	22/64	0/0	0/0	74%

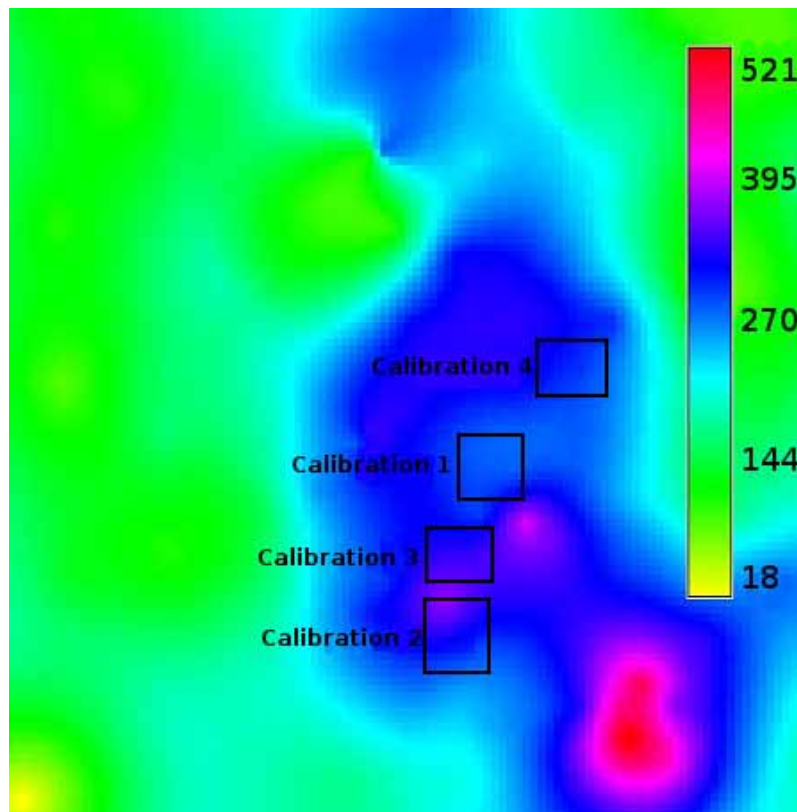


Figure 7.27 Total cumulative rainfall accumulation over the Gard region on 6 September 2005 and location of the testing areas

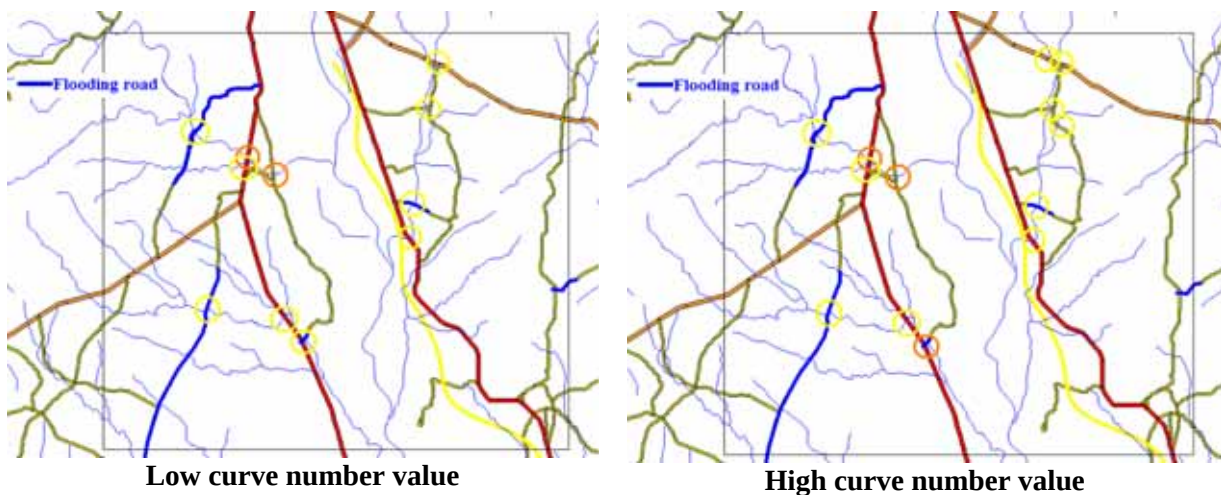


Figure 7.28 Warnings for Area 1 for the storm on 6 September 2005 (low and high hypothesis)

7.10.2 Time sequence of submersion warnings

Figure 7.29 shows the evolution of the warnings in time in the validation Area 2 between 6 and 8 September 2005, as well as the road inundation reports. It should be noted that generally there is a delay between the inundation of the road and its detection by the road network management services. Likewise, the roads are generally re-opened to traffic some hours after the water has subsided. The results obtained with the hydrological high hypothesis are shown. The two hydrological simulations that have been tested rapidly converge as the total rainfall amount increases.

The first phase of the September 2005 flood

The first initial rainfall event gave rise to localised road inundation. At 11 o'clock on the 6 September 2005 more than 100 millimetres fell in the preceding hours. Five significant alarms were issued by the model, these are shown in Figure 7.29. Three of them correspond to road inundations that were later noticed by the road technical services between two and three o'clock in the afternoon. They were detected during the period when the rainfall had temporarily ceased. This is probably the period when the services were able to make their first round tour of the road network.

The model was effectively able to detect the major problems that have occurred during this first rainfall burst on the road network before they could be reported. This is a satisfactory outcome. Moreover, a large part of the road network of the area was affected by an alarm at 11 o'clock, which is a sign of a high probability of submersion that was later confirmed by observations. This was not the case at 9 o'clock. According to the model, until 9 to 10 o'clock, it was still possible to use the majority of the road network despite the high rainfall amounts and intensities. No data exist that could validate the timing of road inundations given by the model, but it is interesting.

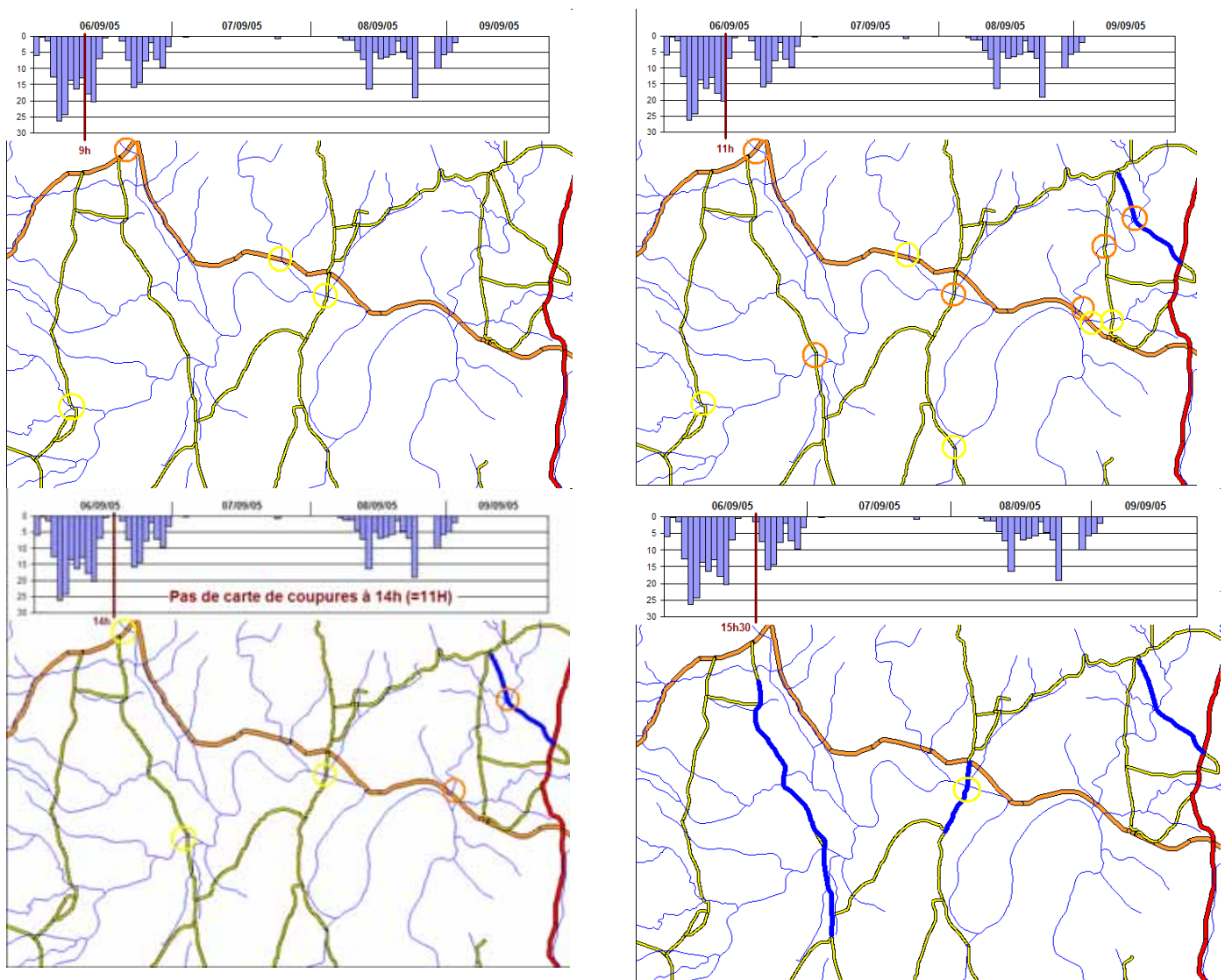


Figure 7.29 The first phase of the September 2005 flood

The second phase of the September 2005 flood

The three inundated road sections were not reopened to traffic until the 7 September at 6 o'clock in the afternoon and no reports were made between 18:00 on the 6 September and 6:00 on the 7 September.

The roads were probably not inundated over all this period. The reports of the road management service do not help to validate the model for this second phase. However, even if the recession period since the preceding storm was quite short (e.g. about three hours), the risk levels grow progressively during this second rainfall event to reach a maximum at midnight on the 6 September. This is shown in Figure 7.30. This delay is due to the progressive saturation of the catchments and also due to their time of concentrations. This would certainly appear to be realistic and can be used by the rescue services to assess what is going to happen. It is also interesting to note that the maximum risk level is not reached at the same time for all the road sections. This can be seen by comparing Figure 7.30 at 20:00 with Figure 7.30 at 0:00. This is a result of the spatial and temporal distribution of the rainfall, as well as of the variability of the time of concentration of the catchments. The delays between the response of the various catchments of the area, depicted by the model, may also be evaluated by the operational services.

Third phase of the September 2005 flood event

During the third rainfall event, two road sections are shown to be rapidly affected by a red colour (very high risk) at one o'clock in the afternoon on 8 of September. This is shown in Figure 7.31. The inundation of one of them will be only reported by the operational services at 5 o'clock as shown in Figure 7.31. For this situation the model provides important information. Other vulnerable road sections in the area are not highlighted at the same time. This is a sign that the rainfall seems to be concentrated on the north-western of the area at this moment of the storm and the model is able to value this information about the spatial rainfall heterogeneity. The western part of the area does not seem to have been affected by any inundations and the model indicates this area was relatively safe during this last storm.

7.11 Use of emergency routing techniques developed by the Orchestra project piloted in the Gard Region

7.11.1 Introduction

The overall aim of the Orchestra Integrated Project is to provide an Information Technology (IT) based framework for risk management based on distributed services and open standards. This development is seen as important in for example the context of the INSPIRE directive. Within the context of the Orchestra project, work has been carried out on the development of a pilot on risk assessment in the French Italian border region using internet based services. As part of this pilot a routing routine has been developed to finding alternative routes when a road is cut off by flooding, landslides or some other natural disaster.

Road closures can have a dramatic impact on the economic, social and functional life of a region and these impacts can spread far from the site of the blockage and, even, across international borders. The region chosen for the pilot project is especially prone to hazardous events and also, due to the lack of redundancy in the road network within the region, disruption to a major route can have a large effect (Douglas et al).

This routing routine was implemented in a web based demonstrator. Within this demonstrator users can interact with the client choose start and end point and simulate the disruption of the road network. As part of this work the Joint Research Centre (JRC) has worked with ENPC to utilise the routing algorithm together with the prototype flash flood forecasting model for roads in the Gard Region of France. By combining this with the Orchestra routing method, the original algorithm has been used in order to provide a demonstration of the support that can be given to the emergency services in the planning of their operations.

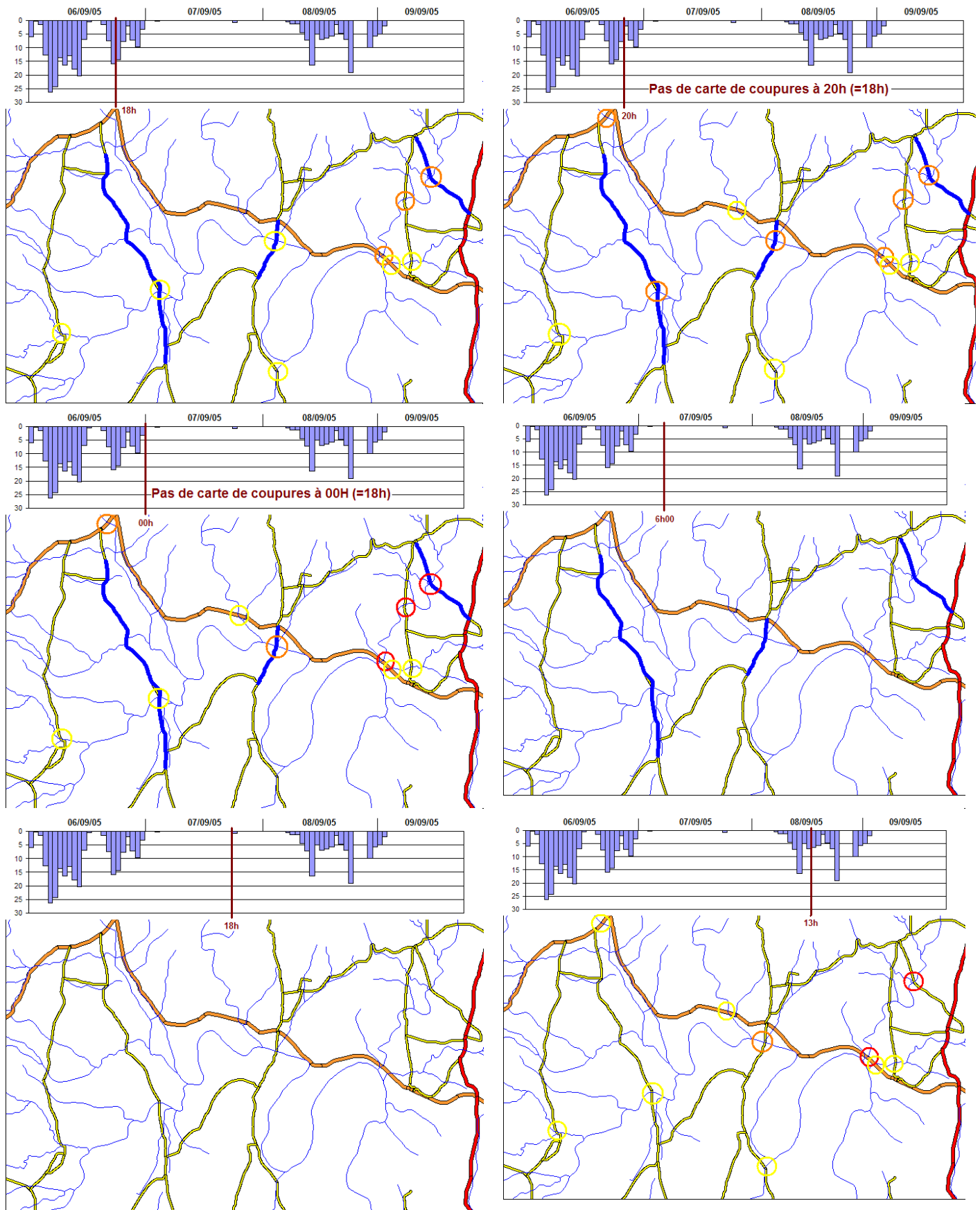


Figure 7.30 Second phase of the September 2005 flood

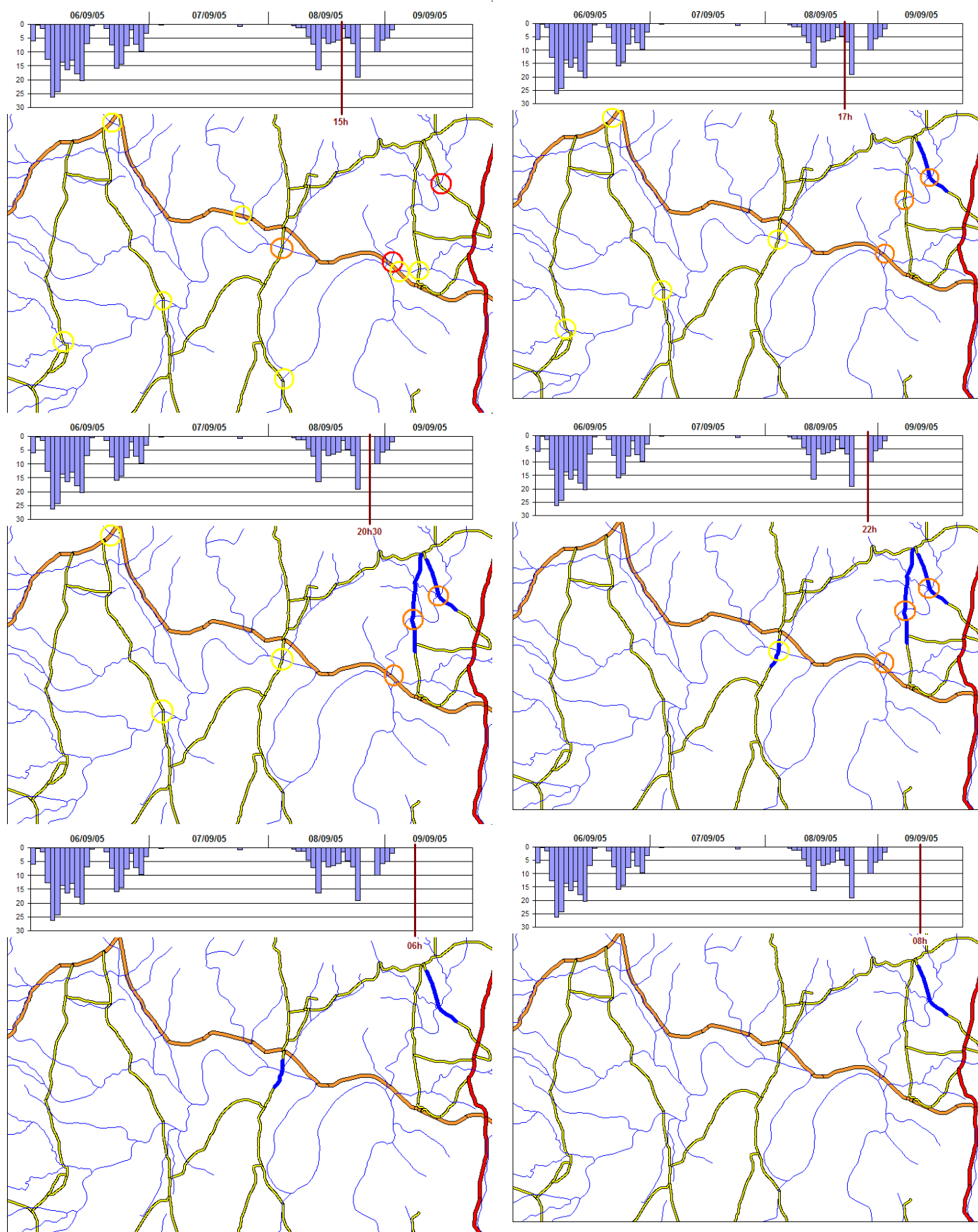


Figure 7.31 Third phase of the September 2005 flood

7.12 Background to the internet based routing services developed under Orchestra

The routing is done using web services, algorithms have a “wrapper” around them that make them callable through http requests. The display of items on the map is also done using Open Geospatial Consortium (OGC) compliant services. The OGC is an international industry consortium of 346 companies, government agencies and universities participating in a consensus process to develop publicly available interface specifications. This means that any application can point to the layers in his or her application. The routing demonstrator for the Orchestra project was established based on the TeleAtlas road network data and open source software solutions. More information is available from the Orchestra website (<http://orchestra.brgm.fr/OrchestraClient/viewer.jsp>).

Using the web based risk assessment for road networks developed under Orchestra users are able to:

- Simulate events leading to road blockage or disruption;
- Calculate estimated traffic, alternative routes and their level of traffic;
- Estimate additional costs (in terms of time and money) caused by the disruption, and the subsequent Gross Domestic Profit losses for the affected region;
- Run these simulations to identify pinch points within the road network and improve planning and prevention.

An example of a screen of the web based system is shown in Figure 7.32.

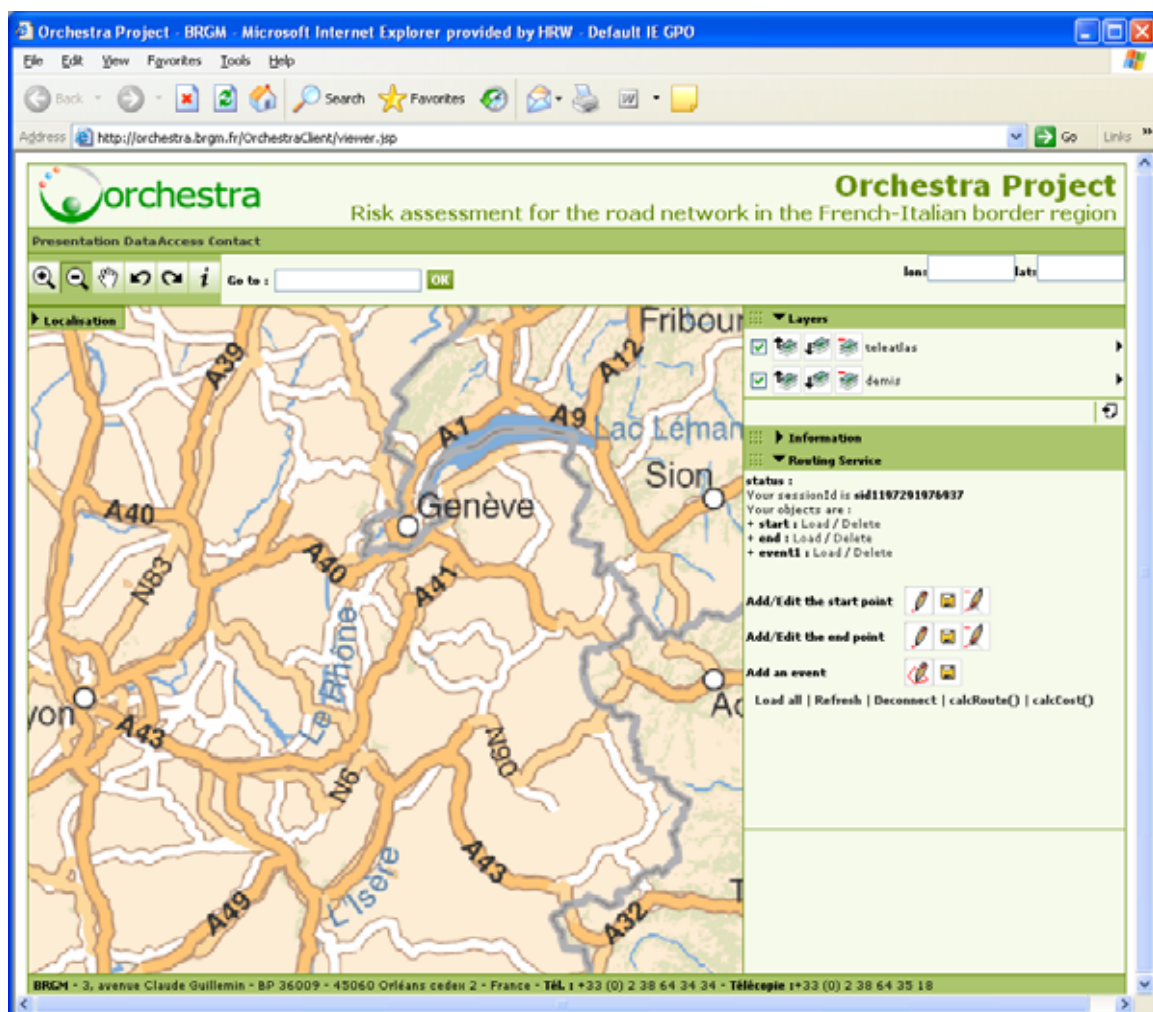


Figure 7.32 Example of the Orchestra project web based system for risk assessment for road networks on the French – Italian border

7.13 Application of the web based routing services to the Gard Region

The Orchestra web based application has been applied to the Gard Region of France, this is shown in Figure 7.33. The blue circle in Figure 7.36 depicts one of the submerged roads, based on the output of the prototype model on flash floods developed for the Gard Region. The red line shows the road section that has become unavailable as a result of the flooding. The points labelled “A” and “B” indicate the start and the end point of the route. These can be selected by the user. After the user has chosen their start and endpoint they can request a “route calculation” and, if the route intersects with a submerged road the routing algorithm will calculate the next best route.

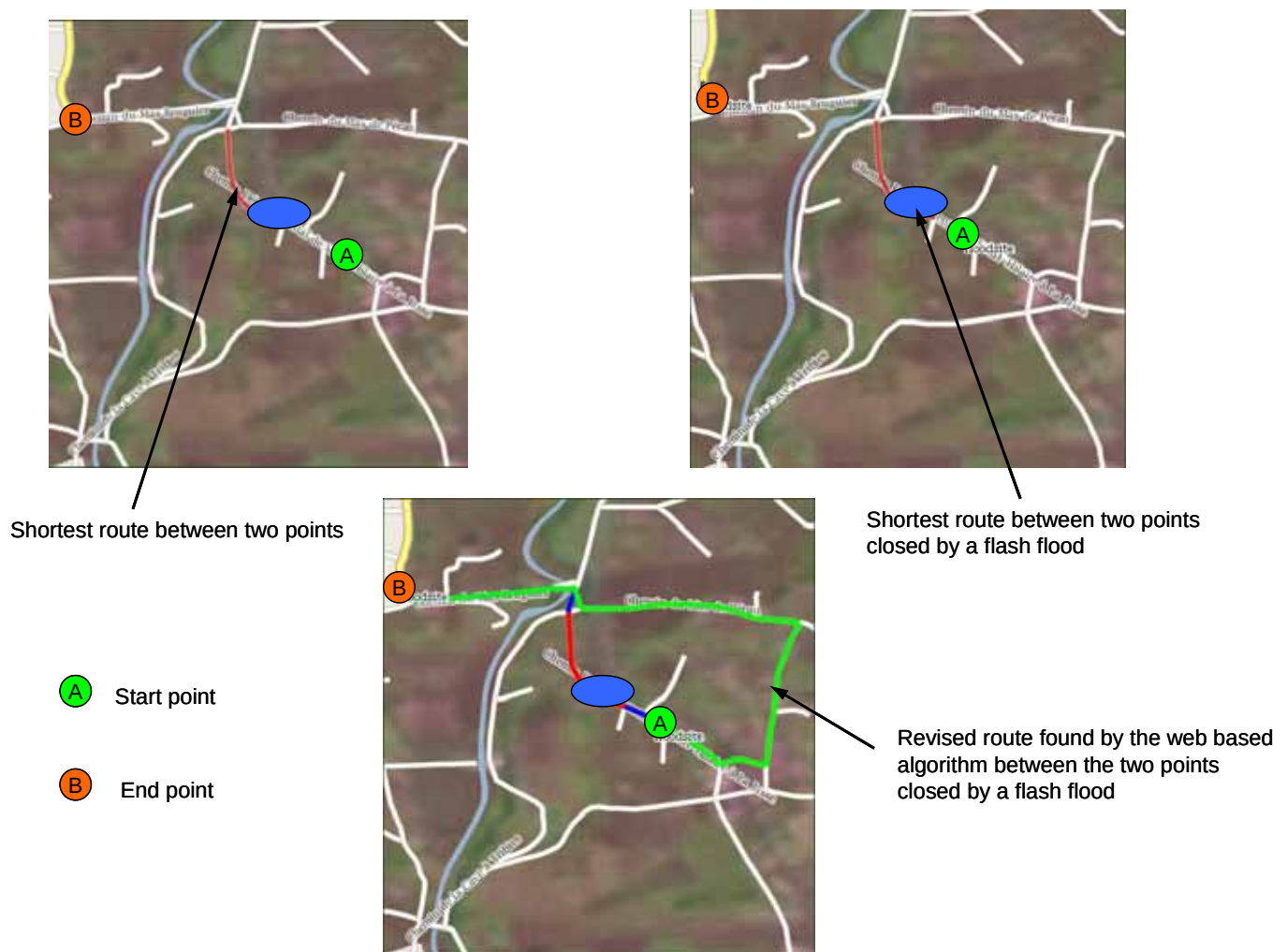


Figure 7.33 Application of the Orchestra web based application to the Gard Region of France

The work achieved by the collaboration between the Orchestra and FLOODsite projects was important because it illustrated that it was possible to form a link between two models that had been developed completely separately from each other and the possibility to combine these two in order to offer a risk management solutions. The work also demonstrate that if open standards are applied, added value can be created for the end user in terms of an easy “plug-in” of other modules.

7.14 End user consultation

7.14.1 Background

A meeting has been organised in Nîmes in the Gard Region on the 4 of December 2007 to present the prototype system and obtain the initial reactions of the potential end users of such a tool. The meeting, organised by the local flood forecasting service, comprised:

- Presentation the users' requirements with regards to road management during flood events;
- Presentation of the prototype and validation for five recent floods in the Gard Region;
- Discussion of the prototype, its results and its possible future development.

Seven people representing the regional administrations in charge of road network or emergency management were present as follows:

- François Bressand and Olivier Payrastre: resp. Chief and member of the flood forecasting service « Grand delta », Gard Region infrastructure State administration, Nîmes.
- Jean-François Loverat: Inter-regional road management, responsible of the Cevennes-Vivarais district, management of the national road network;
- Floriane Morena: Water and river service, Gard Region administration;
- Alain Jaffard: Head of the road network service, Gard Region administration;
- Captain Olivier Guillaume: Gard region fire and rescue service
- Magalie Pintard: Gard Region infrastructure state administration, coordination of the road management during emergencies;
- Pierre-Antoine Versini and Eric Gaume: CEREVE, partner 5 of the Floodsite project.

They are all interested in a road network inundation forecasting system at various levels. Captain Guillaume expressed the needs of the regional fire and rescue service. A forecasting or even monitoring system is needed for two main reasons:

1. During extreme flood events, the rescue teams should already be in place throughout the area before severe disruption to the road network occurs. This is currently carried out empirically with a homogeneous distribution of the teams over the region. The identification of the worst affected areas could help to build more effective “pre-positioning” strategies.
2. Information about the road network state is necessary for efficient rescue and evacuation operations. A forecasting or even monitoring system could be of great help.

7.14.2 User feedback

The prototype system and results was of interesting to all the participants. Such a tool is fundamental and essential according to Captain Guillaume. The validation results, indicating an almost 100% hit ratio and false alarm ratio generally lower than 25%, were impressive according to Mister Jaffard. Clearly the configuration and the performances of the prototype met the expectancies of the end users.

The discussion has been essentially focused on the future developments and the operational implementation of such tools. Mr Jaffard asked which service should support the development needed to produce an operational tool and which service should run it. The state flood forecasting service has the technical capacity. However, the development of “application oriented” forecasts is not in its mandate. Moreover the service does not have enough personnel to develop these capabilities.

The proposed forecasting tool operates at the regional level. The Gard regional road service would be the most natural organisation to operate such a tool, however, they do not have sufficient technical capacity. One possible alternative solution would be for the tool to be operated by a private company who could sell the service to local authorities.

The Gard regional road service appeared willing to financially support the future developments of the prototype. It was agreed to conduct an additional validation trial of the tool on a recent event that occurred on the 28 of September 2007¹⁶ in an area which lies outside the areas previously selected for the calibration and validation of the tool. In addition, radar data will be used rather than spatially interpolated rain gauge data. The Gard flood forecasting service will provide the radar data. CEREVE will conduct the computations and the results will be sent to the Gard regional road service

¹⁶ maximum local rainfall accumulations exceeded 300 mm within a few hours.

for comparison with the observed road inundations. If the prototype proves to be efficient through this rigorous test, it will be a significant step towards its transfer to operational use. It is expected that the outcome of this validation exercise will be delivered at the end of January 2008.

7.15 Conclusions

A road inundation warning prototype for flash flood prone areas has been developed and tested on some sub-areas of the Gard Region. The results obtained are promising. The prototype is able to rate the inundation risk in advance with an acceptable level of accuracy: i.e. relatively high hit ratios (proportion of actually flooded points affected by a high risk level between 70 and 100%), with a minimum false alarms (about 50% of the points with a high risk are not flooded).

The results are far from perfect and the prototype should not be considered as a decision support system but rather as a source of information, among others especially field observations that can help the emergency services during a flood event to improve their decision making. The prototype appeared to provide a relatively accurate and hence useful source of information. The emergency services in the Gard Region emergency services are to be consulted on the usefulness of this tool in the near future.

The development and the testing of the prototype has revealed that:

- A detailed vulnerability analysis was required for the approach to be successful. The most sensitive road sections must be identified in advance for the tool to be informative, otherwise only the spatial distribution of the rainfall will be reproduced. In the Gard Region the work on vulnerability benefited from the existence of the PICH inventory. The vulnerability indices developed may be of help if the same work has to be done in another region. However, they cannot be directly extrapolated. A road inundation risk computation tool must rely on some information concerning the road network vulnerability that is partly site specific.
- The key part of the prototype was the distributed hydrological model. The spatio-temporal distribution of the rainfall has a major influence on the road network state. The rainfall-runoff model must be able to take into account this distribution. The prototype model showed that despite their various sources of inaccuracy, the rainfall-runoff model delivered valuable hydrological information. The prototype model demonstrated that simple and approximate information about the intensity of the flood flows of various return periods (e.g. 1 in 2 year, 1 in 10 year and 1 in 50 year) can be very useful information for emergency managers.

8. Conclusions and recommendations

8.1 Conclusions

8.1.1 Introduction

A review of flood event management in the European Union (EU) indicated that most member states make a distinction between the organisations that are responsible for flood event management and the organisations that are responsible for emergency management and planning. The responsibility for the development of emergency plans often takes place at a local government level. Emergency plans are usually implemented by the emergency services (e.g. the police, ambulance service), the army and the local authority. Organisations responsible for flood risk management such as the Environment Agency in the UK and Rijkswaterstaat in the Netherlands carry out the flood forecasting and warning. The response to flood risk management in the EU has mainly focused on flood defence asset management, and forecasting and warning to reduce flood risk rather than on organised evacuation

Aside from the Netherlands there would appear to be limited experience within the European Union of employing systematic approaches and modelling tools to develop evacuation plans for flood event management. If the tools do exist then and are employed in practice they are often very generic and only applicable at a macro-level. The cost of evacuation is also not well documented. This is partly as a result of the fact that organised evacuation is only used as form of emergency response in Europe in very rare circumstances. In most of Europe the authorities have no powers to forcibly make people evacuate from an area at risk of flooding.

8.1.2 User requirements for evacuation planning

A review of user requirements in France, the Netherlands and the UK indicated that in terms of planning evacuation of an area at risk and the emergency response the following were important:

- The forecast of the flood extents, depths and velocities would assist with emergency response;
- Knowledge of the road network, location of the vulnerable receptors (e.g. old people, hospitals) and evacuation times are key to emergency planning.

In countries mass evacuations have been carried out in the past (e.g. the Netherlands in 1995 when 250,000 people were evacuated) the cost of evacuation is an important factor that needs to be taken into account. It is also important for emergency planners to understand what parts of the area at risk or what buildings can be used as shelters.

8.1.3 Evacuation modelling for flood event management

It has been found that there are three main scales at which evacuation models are employed for flood event management as follows:

- Micro – This corresponds to a scale where each individual receptor at risk is modelled;
- Meso – This corresponds to a scale that is between a micro and meso-scale
- Macro – A macro scale model provides an initial estimate of the evacuation time for a large area. (e.g. at a regional scale).

The type of evacuation model that is appropriate will depend on the level of risk and the processes which the evacuation modelling is seeking to inform. A densely populated urban area where the scale of potential evacuation is large may require a detailed simulation model where the traffic and flood hazard is modelled in a truly dynamic way.

8.1.4 Application of evacuation models in the Thames Estuary

Three evacuation models were tested in the Canvey Island and Thamesmead areas of the Thames Estuary. These were:

- BC Hydro Life Safety Model (LSM) – micro level model;
- A non-linear optimisation technique – meso scale model;
- A simple spreadsheet based model – macro scale model.

The following conclusions were reached on each model.

BC Hydro Life Safety Model (LSM)

- The LSM allows dynamic interaction between the receptors and the flood hazard;
- The LSM requires a significant amount of data including:
 - The location of individual properties, vehicles and people;
 - Flood depths and velocities from a two dimensional hydraulic model;
 - Details of the road network and other pathways;
- It has potential to be used to inform emergency plans for heavily defended areas (e.g. London, some coastal areas) and dam risk assessments in the UK. The effect of the following can be assessed for different flood events:
 - Location and the number of safe havens;
 - The effect of road closures;
 - Rate of dissemination of warning;
 - The time of day and the location of the population;
- The model also provides a scientifically robust method to estimate fatalities and injuries during a flood event;
- In its present state the LSM is not “user friendly” enough to be used by organisations such as the Environment Agency or the Emergency services without a significant amount of training;
- The LSM has the potential to be adapted in the future to provide estimates of the fatalities and evacuation times for other hazards (e.g. chemical or nuclear accidents).

Non-linear optimisation based evacuation model

A non-linear optimisation-based model for evacuation has several advantages for use at a meso-scale:

- It is relatively quick to set up such a model for small areas;
- It can be simply modified;
- Large areas can be modelled using relatively simple networks;
- A number of different evacuation routes and locations of safe havens can be tested quickly.

However, the non-linear optimisation models requires many assumptions to be made, although it could prove useful to establish initial evacuation times for relatively large areas of the UK e.g. the Thames Gateway.

Spreadsheet based evacuation model

A simple spreadsheet model was simple to set up to assess evacuation times. However, it can only usefully be employed at a macro-scale as it makes several simplifying assumptions such as assuming that all the traffic flows freely. However, if geo-referenced census road network data are readily available then a first order estimate of the evacuation time can be made very quickly.

8.1.5 Application of evacuation models in the Schelde Estuary

Three existing traffic or evacuation models were applied in the Schelde pilot as follows:

- Macro scale Evacuation Calculator (EC)
- Macro scale ESCAPE DSS
- Meso scale INDY

The aim was to draw conclusions on the reliability of the model results and the suitability of the models to support the planning of an evacuation. This study focused on the technical aspect of evacuation management. The models were compared with regards to:

- Scale they can be applied on;
- Suitability for evacuation planning;
- Resulting evacuation times;
- Reliability of the resulting evacuation times.

The conclusions are summarised below.

Scale

The evacuation models EC and ESCAPE are not very detailed, being applied at a macro-scale. INDY presents an improvement in detail, being applied at a meso-scale. None of the models model individual movement of persons, instead they model the flows of total number of inhabitants from each postal code zone.

Suitability

The EC can be used for a quick estimation of the evacuation time, if the whole area is to be evacuated. However, due to the amount of parameters that must be estimated by the user, it is advisable to validate the EC with the INDY model.

ESCAPE is not very user-friendly, as it gives little insight in the calculation algorithms. The order in which the evacuees leave their homes is derived within the simulation. The model does not give insight in this. Therefore the results could not be compared with the other models.

INDY is the most realistic of the three models and gives the most reliable results. Besides evacuation time estimates, it gives insight in the site-specific causes of congestion. However, the duration of the model set-up and simulation run-time are considerably longer.

Resulting evacuation times

In EC some scenarios combine the above-mentioned assumptions: a fast departure profile, no reduction factor (this means no congestion at the outflow) and optimal traffic management. This result of this scenario, which was an evacuation time of approximately 12 hours, is considered highly underestimated and unreliable.

Because ESCAPE algorithms are not understood in detail, it could not be properly compared to EC and INDY. However, because it assumes an optimal departure profile and an optimal traffic management (no congestion), ESCAPE is also expected to underestimate the evacuation time.

All models predict that it will take at least 22 hours to evacuate the whole study area, when the evacuation is managed and no unexpected events (like accidents) happen and people leave very efficiently. While this is an underestimation of the actual evacuation time, it is still too long to complete the evacuation within the lead time of the event-forecast, which is usually 6 hours in this region.

Reliability

Because the model results were not compared with actual evacuation times from a historical event, it is difficult to conclude which model produces the most reliable results. It seems intuitive that INDY would produce more reliable results than EC and ESCAPE, because INDY simulates the actual road

network in a dynamic way, whereas EC simulates the network based on assumptions regarding the departure profile and evacuation velocities, and ESCAPE assumes an optimal departure profile and fixed road capacities. All three models are expected to underestimate the evacuation time due to the assumptions that no congestion occurs from cross flow traffic, that no accidents will occur, and that residents will respond to an evacuation call in an ideal and optimal way.

8.1.6 Development of a prototype flash-flood warning system for roads in the Gard Region

A prototype flash-flood warning system for the Gard Region of France was developed to carry out the following:

- Identify road inundation potential based on local geographical information.
- Develop a rainfall-runoff models on the catchments located upstream the identified points prone to flooding.
- Combine the flooding potential of roads with the estimated flood discharges, to provide an integrated tool able to forecast in real time the flooding of roads.

Based on the geographical and hydrological information the sections of the road network that are most sensitive to flooding in the Gard Region pilot area were identified and their vulnerability to flooding rated. The proposed method has been calibrated on the Gard Region pilot area. Some information is required on the past road inundations in order to develop a road vulnerability assessment tool.

A simple distributed rainfall-runoff has been calibrated and validated on the hydrological database available in the region. The validation results appear relatively satisfactory and provide an acceptable method to estimate peak discharges for the ungauged catchments in the Gard Region.

Both model outputs, i.e. vulnerability index and estimated discharges, have now to be combined to compute submersion risk indexes for the various vulnerable points of the road networks at various instants of a storm event. The maps obtained were compared to the available maps of observed road submersions for four recent flash floods (i.e. December 2002, November. 2003, December 2003 and September 2005).

The results were far from perfect and the prototype should not be considered as a decision support system but rather as a source of information, among others especially field observations that can help the emergency services during a flood event to improve their decision making. The prototype provided a relatively accurate and hence useful source of information. The emergency services in the Gard Region emergency services are to be consulted on the usefulness of this tool in the near future.

8.2 Recommendations

The key recommendations that have come out of this research are as follows:

- There is a requirement for evacuation models. However, to be useful there is a need for them to model the individual receptors (e.g. people, houses, vehicles) and to be able to give decision makes other information other than just evacuation times (e.g. loss of life and injury estimates, effects of different management plans);
- More work needs to be carried out to make evacuation models more “user friendly” so that they are used more widely;
- The spilt of responsibilities between water management organisations and bodies that are responsible for emergency planning means that in some cases neither organisation wishes to be responsible for carrying out evacuation modelling. There is a need for flood risk managers to incorporate evacuation modelling as part of their flood event management work

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