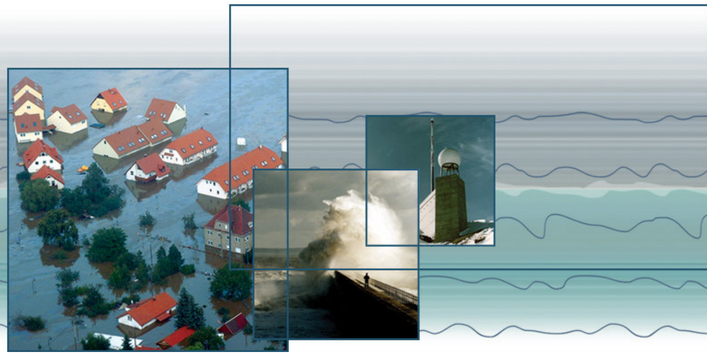
Integrated Flood Risk Analysis
and Management Methodologies



Task 10- Risk to Life

"GARD RIVER" CASE STUDY

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SUMMARY

The Gard River case study focuses on human behaviour and casualties during the September 8-9, 2002 flash floods in order to provide estimates of the potential loss of life for this type of flood and elements for a calibration of the proposed model. The study contributes to Actions 1 and 2 of Activity 1 in Task 10 in helping to identify the factors leading to risk to life and in understanding the relation of risks to people and hazards.

In terms of observed rainfall accumulation within hydrological watersheds, the return period of this 2002, event is over hundred years for the three major watersheds of the Gard administrative department. This rain event induced one of the most important floods ever reported of the three corresponding rivers (Gard, Cèze, Vidourle) and also produced remarkable flash floods in many upstream tributaries (Delrieu et al., 2005).

The characteristics of flash floods (space and time scales, intensity) have three consequences:

- Warning and communication is the central mean of prevention,
- The time available for communicating and reacting is dramatically short,
- Very little is known about the conditions in which casualties occur and about the behaviour of the public under such extreme conditions.

In consequence, this case study proposes to contribute to an understanding of the loss of life following the two steps below.

To identify the hydrometeorological circumstances of casualties
The accurate time and location of casualties is simply not available in this type of extreme situation. This information will be determined by crossing different sources (declarations of the families to the administration, a detailed list of rescue missions, reports in local newspapers). This positioning in time and space will allow defining the physical circumstances leading to casualties.

To describe the behaviour of road users as deaths appear to be heavily attributed to flash floods
The usefulness of flood warning depends on the communication to the public and on the capacity of the public to adapt its behaviour to the situation. In order to gain some first understanding of the different ways and steps of the warning communication and the different behavioural responses interviews were conducted and analysed.

Results: The expected results are mainly the following:

To define the size of the watersheds responsible for casualties

- To relate this size to the characteristic scales of the phenomenon.
- To compare these characteristic times to the chronology of the existing warning procedures.
- To propose a typology of the most prominent behaviour.
- To draw preliminary conclusions regarding the effective use of warning messages by road users.

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1. Introduction

The present study was conducted in the Gard, a flash flood prone *département* located at the foothills of the Cévennes mountains close to the Mediterranean sea, in Southern France. In this area, Jacq (1994) inventoried 144 rain events between 1958 and 1994 with daily precipitation greater than 190mm. According to Delrieu at al. (2005), Gard's climate is strongly influenced by three different factors: (i) the proximity of the Mediterranean sea as a reservoir of energy and moisture, especially at the end of summer and beginning of fall, (ii) a southerly flow that both advects and destabilises air masses from the Mediterranean sea toward the coast, (iii) the surrounding relief of the Alps, Pyrenees and Massif Central mountains slows down and enhances perturbations. Those elements may trigger large amounts of precipitation during several days but also within a few hours in the case of a Mesoscale Convective System (MCS). These situations result in very localised or much larger disastrous flash flood events. Between 1316 and 1999, Antoine et al. (2001) recorded 27 fatal flood episodes and 277 deaths in the Gard. As in most flash flood events, motorists represent 40% of the people who lost their lives in the last fifty years (Antoine et al., 2001; Lescure, 2004).

The Gard *département* counts 623,139 inhabitants and welcomes 4.5 millions of visitors, including 40% of foreigners (Institut National des Etudes Statistiques, 1999). Among the Gard's 353 municipalities, 298 are prone to floods. These flood-prone municipalities include 37% of the population; 29% of whom live in watersheds prone to flash floods (Conseil Général du Gard, Wateau and Ségala, 2006). In this context much of the French initiative gathering flash flood research and operational implementation is focused on this area where local government agencies have developed their own expertise. One of the main difficulties they face is the spatial and temporal variability of rainfall events that poses problems in terms of warning and protection of distributed targets as dispersed habitat, road users and tourists. As flash floods concern small catchments with very short response times, warnings at small scales are still not possible.

This report aims at providing data about casualties and public awareness of flash flood events in the Gard département in order to contribute to the development of the Risk to life model being developed in Task 10, Activity 1. The study contributes to Actions 1 and 2 in helping to identify the factors leading to risk to life and in understanding the relation of risks to people and hazards. Much of the research relating to this case study was conducted for a PhD thesis for one of the authors, see Ruin, 2007.

The first part deals with the available data sets collected in the context of the Gard River case study that may used in the model. In the second part, we analyse the hydrometeorological circumstances leading to fatalities during the September 2002 flash flood event in the Gard. In the final part, we focus on social vulnerability factors and especially on risk awareness linked to motor vehicle usage in heavy rain conditions.

2. Risk to life model application

Table 1 gives the data available in the Gard River case study used to help develop the risk to life model. Some difficulties have to be underlined concerning its application in the context of flash flooding. As stated earlier, the Gard Département is characterized by very quick and intense events. In fact, flash flood events mainly affect small watersheds that are also ungauged basins. It is one of the reasons that may explain the lack of data. Since the 1999 flash flood event in the Aude département, post flood investigations are now conducted to better understand the causes of disasters. But casualties are not investigated in this context and data are still sparce.

Even if the number of injuries and fatalities is known, it is very difficult to be precise in terms of geographical location and time. People affected at home represented only one part of the casualties. 60% of them were not at home during the flood and it is sometimes difficult to understand the circumstances of these casualties. The age factor does not seem to be significant in the case of road fatalities in flash flood events. Risk awareness on roads is not necessary related to global awareness of risk. When dealing with motorist fatalities, behaviour seems to be more relevant but also difficult to investigate. In a previous study (Ruin and Lutoff, 2004) we have shown that mobility in the context of flash floods is mostly linked to commuting. Therefore, it may be interesting to investigate road users' everyday itineraries and their spatial representations. From these observations, we decided to conduct two kinds of studies.

The first study aimed at understanding the circumstances of casualties in flash flood contexts, especially on roads (hydrometeorological circumstances). The second study focused on road users' spatial representation of risk in their usual itinerary. What are the factors leading to human adaptation of daily activities in heavy rain conditions? A survey based on mental maps was conducted to collect data on this particular aspect.

Table 1: Gard River data for risk to life model application

<table>
<tr><th>Characteristics</th><th>Data requirement variables</th><th>Data</th><th>Data quality and uncertainty – source of data and if taken from a model, is measured or estimated data.</th></tr>
<tr><td rowspan="6">Area(s) characteristics</td><td>Type of land use/ spatial development</td><td>Gard department :
Area: 5853 km^2 , Population : 623125 inhab.; densité = 106 inhab./ km^2
Mixed land use, mostly rural in the mountain area (23 inhab./km^2) and urban and industrial in the plain area.
Two main agglomerations: Nîmes (128 471 inhabitants; density = 806 inhab./km^2) and Alès (41037 inhabitants;1527 inhab./ km^2)</td><td>Data source : INSEE, 1999 population census
Measured data</td></tr>
<tr><td>Flood warning systems</td><td>Fair : the first meteorological warnings were given on Monday 9th in the night at 1h27 whereas some areas were already flooded.
None : no official flood warnings</td><td>Post flood official investigations (Huet, 2003)
Measured data</td></tr>
<tr><td>Type of buildings</td><td><table><tr><td>multi-storey apartments</td><td>multi-storey houses</td><td>single storey houses</td><td>commercial/ industrial prop.</td><td>mobile-homes</td><td>campsites</td><td>schools</td></tr><tr><td>123 530</td><td colspan="2">161 397</td><td>34192 January 2004)</td><td>329</td><td>190</td><td>712</td></tr></table></td><td>Data source : INSEE, 1999 population census
Measured data</td></tr>
<tr><td>Rate of rise/speed of onset</td><td>Medium (few hours) to high risk (few minutes) depending on watersheds sizes (large to very small))</td><td>Gaume, 2003
Measured data</td></tr>
<tr><td>Building collapse</td><td>Number of damaged homes: 7179 including 1500 flooded by more than 2 meters of water and 100 buildings totally destroyed.
Number of damaged commercial/industrial properties: 2592 including 49 campsites</td><td>Ledoux, B., 2003, "Estimation quantitative et qualitative des dommages économiques dans le Gard à la suite des inondations des 8 au 10 septembre 2002
Cas des entreprises et de l'habitat des particuliers », MEDD report.
Measured data</td></tr>
<tr><td>Evacuation</td><td>Data not available</td><td></td></tr>
<tr><td rowspan="7">Flood characteristics</td><td>Details of flood</td><td>September 8th and 9th, 2002 in the Gard department, France. The disaster area covered 297 municipalities (80% of the Gard department). Flash floods were triggered by major quasi-stationary Mesoscale Convective System (MCS) that came from the Mediterranean sea and stayed over the Gard region for 28 hours.</td><td>Delrieu et al., 2005
Measured data</td></tr>
<tr><td>Depth</td><td>It depends of the location and the shape of the flood plain, but the maximum recorded was around 14 meters.</td><td>Report from the French roads services (DDE 30)
Estimated data</td></tr>
<tr><td>Velocity</td><td>Very fast. Around the 600 mm rain line specific peak discharges even exceed 20 m^3 s^{-1} km^2 which is the most important values ever reported for watersheds of similar areas.</td><td>Delrieu et al., 2005
Measured data</td></tr>
<tr><td>Debris content</td><td>Cars, trees, caravans…</td><td>Photos
Estimated data</td></tr>
<tr><td>Time of Flood</td><td>Started Sunday 8th around noon and finished on monday 9th in the afternoon, but the start time of the flood and its duration were different depending on the size of the watershed and the location of it related to rainfall distribution.</td><td>Delrieu et al., 2005
Measured data</td></tr>
<tr><td>Duration</td><td>Hours and less</td><td>Gaume, 2003
Measured data</td></tr>
</table>

Table 1: Gard River data for risk to life model application(contd.)

People characteristics	Number of people affected in the area(s)/zones	2940 people were rescued, including 1260 persons by helicopters	Official report from Civil security services Measured data
	Number of deaths	23 deaths: 12 men (ages : 35, 42, 52, 55, 62, 70, 72, 74, 77, 84) 9 women (ages: 34, 46, 52, 54, 67, 71, 75, 84) , 2 children (2 and 6 years old) 9 died in their house (drownings and 2 heart attacks), 5 died on the road from motor vehicle usage, 5 victims were tourists in campsites	review of newspapers, municipality services, post-flood reports from the rescue missions Measured data
	Number of seriously injured	Data not available (probably none)	
	Age 75+	54 355 persons in the whole Gard department	Data source : INSEE, 1999 population census Measured data
	Health status	Data not available	
	Population with language constraints	Foreign nationalities inhabitants : From EU = 9872; non from EU = 21067 New French citizens : born in EU = 11754; non born in EU = 9930	Data source : INSEE, 1999 population census Measured data
	Awareness of flood risk	13,3% of second home 1551360 tourist bed-nights in September 2002	Data source : INSEE, 1999 population census and departemental comity of tourism Measured data

3. Hydrometeorological circumstances of casualties in flash floods[1]

In September 2002 a flash flood took 23 human lives and generated 1.2 billion of Euros of damages in less than 24 hours over an area of 20,000 km² located in the south of France. The Gard River basin was hit by a storm that locally received more than 600 mm in one day. The aim of this paper is to investigate the detailed hydrometeorological circumstances leading to accidental casualties and to understand better the prominent physical factors of risk.

Although intense storms and resulting flash floods are rather common in the considered region (Jacq, 1994 or Riverain, 1998), the knowledge about their physical characteristics and about their social consequences is still rather limited. Their reduced extension in space is ill captured by operational observation networks of rain and river gages. Their intensity often affects the reliability of the data and the integrity of the measurement devices, especially for discharge measurements. In spite of these difficulties, thorough analyses of the physics of such events have been published in recent years, relying both on available operational data and post-event investigations (Smith et al., 1996 or Ogden et al., 2000 for the United States ; Gaume et al. 2003 and 2004 for Southern France). A synthesis of the event considered in this study is also available (Delrieu et al., 2005).

The knowledge of the social consequences of flash floods is also rather limited. These consequences are related by public media during and shortly after the crisis. They are documented by relevant institutions like rescue services, medical care facilities, and insurance companies in the limit of their respective missions and of their means. It appears that during exceptional crises the classic reporting of rescue missions is very difficult because the pace of intervention is too fast. Social consequences are also partially summarized in reports produced in the framework of official investigations led by state institutions (Huet et al., 2003). At the end, the resulting information appears to be fragmented and heterogeneous.

The authors believe that the most appropriate way to define the forecasting tools needed for this type of risk is to understand the circumstances of the resulting accidents and the behaviour of populations during the crisis. Depending on these circumstances, the most sensitive scales in time and space must be identified.

After a brief review of the catastrophic event of September 2002, we propose to observe geographical and time circumstances of casualties in the Gard.

3.1 The catastrophic event of September 2002 in France

The 8 - 9th September 2002 catastrophic event was induced by a major quasi-stationary Mesoscale Convective System (MCS) that came from the Mediterranean sea and stayed over the Gard region for 28 hours. The MCS remained stationary for 14 hours then moved West, and finally interacted with a cold front moving East (Delrieu et al., 2005).

3.1.1 General description

The three following phases can be distinguished:

- <u>Phase 1</u>: September 8th from 08:00 UTC to 22:00 UTC

[1] Part of this section is to be submitted to *The Journal of Hydrology*.

After 09:00 the MCS became stationary and its convective part produced rain amounts greater than 200 mm in less than 12 hours in floodplain regions located in the lower parts of the Gardon and Vidourle watersheds (see figure 1).

- Phase 2: September 8th 22:00 UTC to September 9th 04:00 UTC

After 22:00 UTC, the MCS moved towards the upper part of the Gardon and Cèze watersheds and stayed near the Cévennes mountain crests where it produced heavy rainfall during a 6 hour period (average value of about 40 mm h^{-1}).

- Phase 3: September 9th 04:00 UTC to 12:00 UTC

A cold front passed over the area. It produced high rain rates and pushed the MCS towards the East and out of the region. Total rain amounts were not higher than 100 mm.

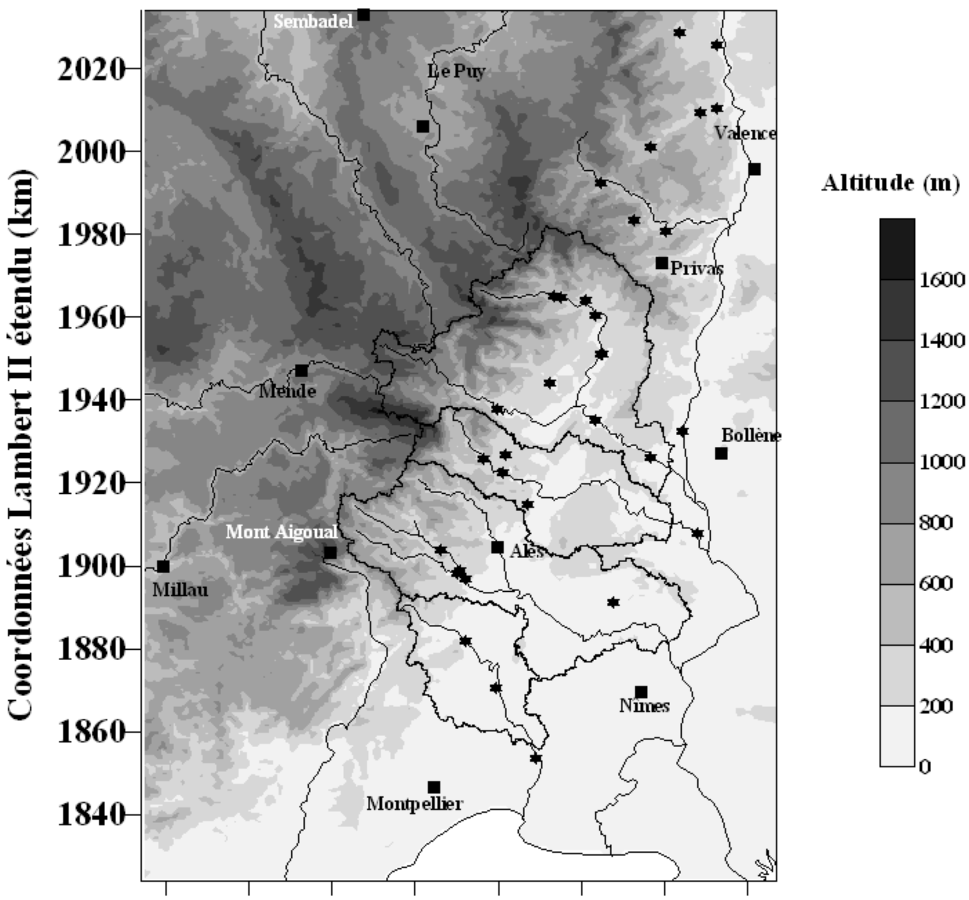

Figure 1 : The September 2002 event's area.

This storm event triggered catastrophic flash floods on many upstream tributaries as well as the most important flood ever reported of the major rivers (Gard, Ceze and Vidourle). Post-event hydrological investigation using interviews of witnesses and river cross-section surveys allowed estimation of peak specific discharges of 17 watersheds of sizes from 10 to 100 km^2. It is noticeable that most of the estimations give peak specific discharges of at least 5 m^3 s^{-1}

km^2 when the 10 year return period discharges are about 2 m^3 s^{-1} km^2 for such watershed areas in this region. Around the 600 mm rain line peak discharges even exceed 20 m^3 s^{-1} km^2 which are the most important values ever reported for watersheds of similar areas (Delrieu et al., 2005).

The disaster area covered 297 municipalities, i.e. the major part of a French administrative department (80% of the Gard department). The event took 23 human lives including 22 in the only Gard department mainly inside the Gardon watersheds. Victims were mostly old and disabled people (9 of them died in their house), and road users (5 persons). During this event tourists also appeared to be vulnerable with a total of 5 victims (people on holidays or in campsite) (Huet et al., 2003). According to the rescue services report, 18,000 phone calls were registered in three days including 10,000 for the day of September 9th. About 600 vehicles involved in the operation rescued 2,940 persons. 40 of these vehicles were lost and 200 were damaged. 1,260 persons were rescued by 20 helicopters. The event started on a Sunday night when less people were on the roads compared to weekdays. Considering simply that more than 200 school buses transporting 4,000 children circulate on week days in this sector this gives an indication of the potential risk. The event happened at the beginning of September when many less tourists are on holiday in the region.

3.1.2 Data sets available

The meteorological and hydrological data used here were collected in the context of the "Cévennes-Vivarais Mediterranean Hydrometeorological Observatory" (OHM-CV). This observatory is a research initiative aimed at understanding the intense Mediterranean storms that frequently result in devastating flash floods in southern France. A primary objective is to bring together the skills of meteorologists and hydrologists, modellers and instrumentalists, researchers and practitioners, to cope with these rather unpredictable events. Due to the difficulty in observing extremes, the OHM-CV observation strategy is made up of three complementary means: (i) detailed, long-lasting and modern hydro-meteorological observation over part of the region of interest, the Cévennes-Vivarais region, (ii) post-flood investigation after the major events occurring over the entire French Mediterranean region and (iii) use of historical information available on past floods. Within a window of 160 x 200 km2 the OHM-CV benefits from data from (i) three weather radars of the Météo-France ARAMIS network located in Nîmes, Bollène and Sembadel i.e. areas 100 to 150 km apart (Figure 2), (ii) a network of about 400 daily rain gauges and 160 hourly rain gauges and (iii) 45 water level stations.

In terms of vulnerability, data were collected by crossing different sources. The victim list was first established from a review of the newspapers following the event. The precise place and time of fatal accidents were given by municipality services where accidents happened and sometimes confirmed by the detailed post-flood reports from the rescue missions (Table 2). From our data collection, it turned out that only a few accidents could have been documented precisely and in a coherent manner. The difficulty in collecting this type of data is that their accuracy depends on the presence of witnesses. In some cases, data registered corresponds to the location and time where and when individuals have been reported missing or bodies have been found, which is often different from the precise time and place of the accident.

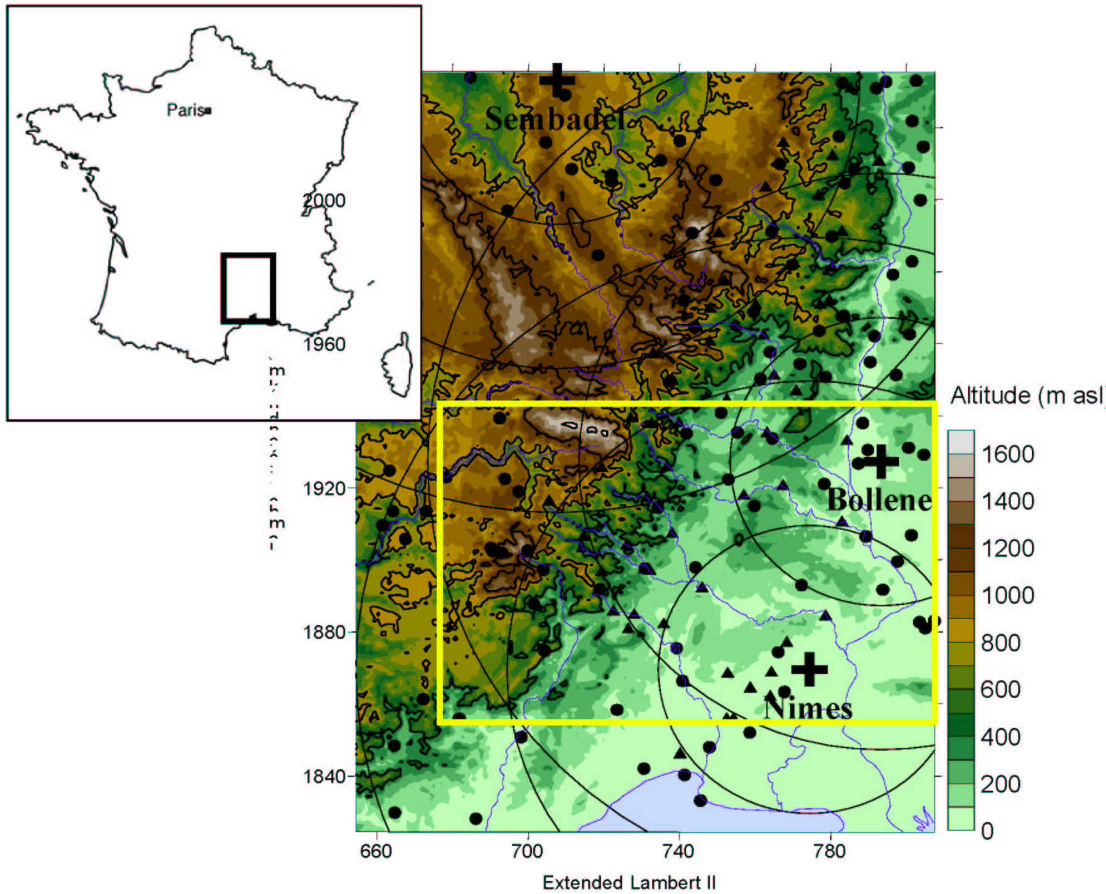

Figure 2 : The Météo-France ARAMIS network in the studied area.

The correct position of accidents in time and space is a first step to defining the physical circumstances leading to casualties and raised the importance of good and accurate data collection.

Watersheds involved in fatal casualties are spatially distributed in the department. In terms of dynamics, small watersheds react in two peak discharges whereas Gard plains rivers (Cèze, Gardon) have only one. Downstream tributaries of the Vidourle (10), Cèze (3) and Gard river (9, 6,11) as well as one of the Vistre tributary in Nîmes (12) and the Nizon in Saint Laurent les Arbres (7), reacted first during the phase 1 rain peak between 16:00 and 22:00 UTC on the 8th. Discharge of upstream watersheds of the Gardon river (1, 4 and 5) occured later between 23:00 on the 8th and 03:00 UTC on the 9th as a response to the phase 2 rain peak. As a consequence of the phase 3 rainfall, a second peak discharge occured between 05:00 and 11:00 UTC on the 9th in all tributaries beginning with the ones upstream. The Gard plains rivers discharge resulted both from the delayed contribution of tributaries and flash floods associated with phase 3 of downstream tributaries.

Table 2: Circumstances of fatalities in September 2002 flash flood event (Gard, France)

Municipaly where casualties happened	Number of victims	Gender	Age	Deaths circumstances	Date of the accident
Fons	1	M	52	driver outside	08/09 11:00 pm
St Laurent les Arbres	1	F	46	pedestrian outside	Reported missing on 09/08 8:00 - 10:00 pm
Domazan	1	F	46	driver outside	Reported missing on 09/08 10:00 pm
St Quentin la Poterie	1	M	62	driver outside	Body found 09/09 7:30 am
Rousson	1	M	42	campers late evacuation	Bodies found 9/09 11:56 am
	2	Children	2 & 6		
St Martin de Valgualgues	1	M	35	pedestrian outside (animal rescue)	No data
Quissac	1	F	52	inside house HLRW	09/09 9:00 am
St Christol les Alès	1	M	55	driver outside	09/09 6:00 am
Nimes	1	M	70	driver inside	9/09/2006 1:00 pm ou 4:00 pm (journal)
Aramon	1	F	84	inside house HLRW	dike break on 9/09 9:50 pm
	1	F	54		
	1	F	67		
	1	F	75		
	1	M	77		
Vers Pont du Gard	1	F	71	inside house HLRW	09/09 5:00 pm
Bagnols / Cèze	1	M	84	inside house HLRW	10/09 7:03 am
Montfrin	1	M	72	inside house	Body found 09/10 9:00 am
Chusclan	1	M	74	campers late evacuation	Death certificate 10/03 6:40 pm
	1	F	34		Body found 09/13 5:46 pm
Vezenobres	1	M	52	inside house, indirect cause	No data
Remoulins	1	M	?	pedestrian outside (animal rescue)	Reported missing on 09/09

3.1.3 Brief comparison to previous flash flood events in the area

In terms of rain accumulation, the event of September 2002 is among the three most devastating rain events that occurred in the south of France during the last fifty years. In September 2002, the areas where the rain accumulation exceeded the 200, 400 and 600 mm thresholds are respectively equal to 5,500, 1,600 and 170 km^2. For a previous event on 29-30th September 1958 on the Gard basin, the areas exceeding the thresholds 200 and 400 mm were respectively 2800 and 30 km^2. 37 people lost their lives in this flash flood. More recently, a storm that occurred on 12-13th November 1999 in the neighboring basin of the Aude river exceeded the thresholds of 200 and 400 mm over respectively 4,000 and 1,800 km^2. This event was responsible for 35 fatal casualties.

Recent paleoflood investigations show that four or five floods reached considerably higher levels (17m instead of 14m) on the La Baume River, an important tributary of the Gardon

River since the 14th century (Sheffer et al., 2003). Over the same period of 6 centuries, 67 floods were reported in the Languedoc-Roussillon area with the number of victims established around 1,000 by Antoine et al. (2001). According to these authors, most of the fatal floods that resulted in more than 10 victims occurred between September 10th and October 25th and mostly between 12:00 and 18:00 hours. Analyzing the circumstances of casualties, 50% of the victims died by drowning or burial in buildings, mostly in their homes. Another important cause is due to the use of motor vehicles during the crisis period, which represents 40% of the known causes if considering events of the last fifty years (Antoine et al., 2001). Vulnerability analysis focusing on Mediterranean flash floods in the twentieth century also shows that the circumstances of deaths could be equally distributed in five categories (Lescure, 2004). The three first represent 60% of the total loss and concern fatalities occurring in open space mostly on public land, as for pedestrians and drivers inside or outside their car. The last 40% happened inside buildings, with no influence of running water, directly from the higher level of raised water or from indirect causes.

3.2 Scales and intensity of interest

A first important issue is to feature the scales at which the risk occurs. In the following we focus on the basins where accidental casualties occurred in 2002.

3.2.1 Corresponding space and time scales involved

The space scale of flood risk is represented by the drainage surfaces which have clear relationships with flood time response. Several studies on watershed responses have shown a logarithmic relationship between the surface of the basin and its time response (Creutin, 2001). Looking at historical average data of watershed time responses in the function of drainage surface for watersheds located in the south of France where the hydrological dynamic is similar to the Gard region, it appears that the smaller the drainage area the quicker is the response to rainfall. For instance watersheds up to 10 km^2 react mostly with a slight delay of less than 20 minutes, which is extremely short to warn population. Those time responses are typical of small watersheds in flash flood prone zones and help us to understand that the time factor is particularly decisive, especially concerning human response in the face of an event.

In order to compare flood parameters and vulnerability data concerning individual physical vulnerability and social response issued from the September 2002 flash flood, post flood investigations data are represented on spatio-temporal scale in figures 3 and 4. Thanks to data collection of casualties' precise localization, it is possible to determine the sizes of the fatal watersheds involved. The surfaces of those watersheds spread out between 2 km^2 and 2000 km^2, with a majority of 10 victims within watersheds of less than 15 km^2. If considering those watersheds react following the square root regression fitted to historical average data, their time responses are mostly globally included between 19 and 52 minutes. Nevertheless 8 other victims died within a drainage area larger than 1000 km^2 with a time response of more than 7 hours, but it is important to notice that 5 of them were struck by a dam break wave.

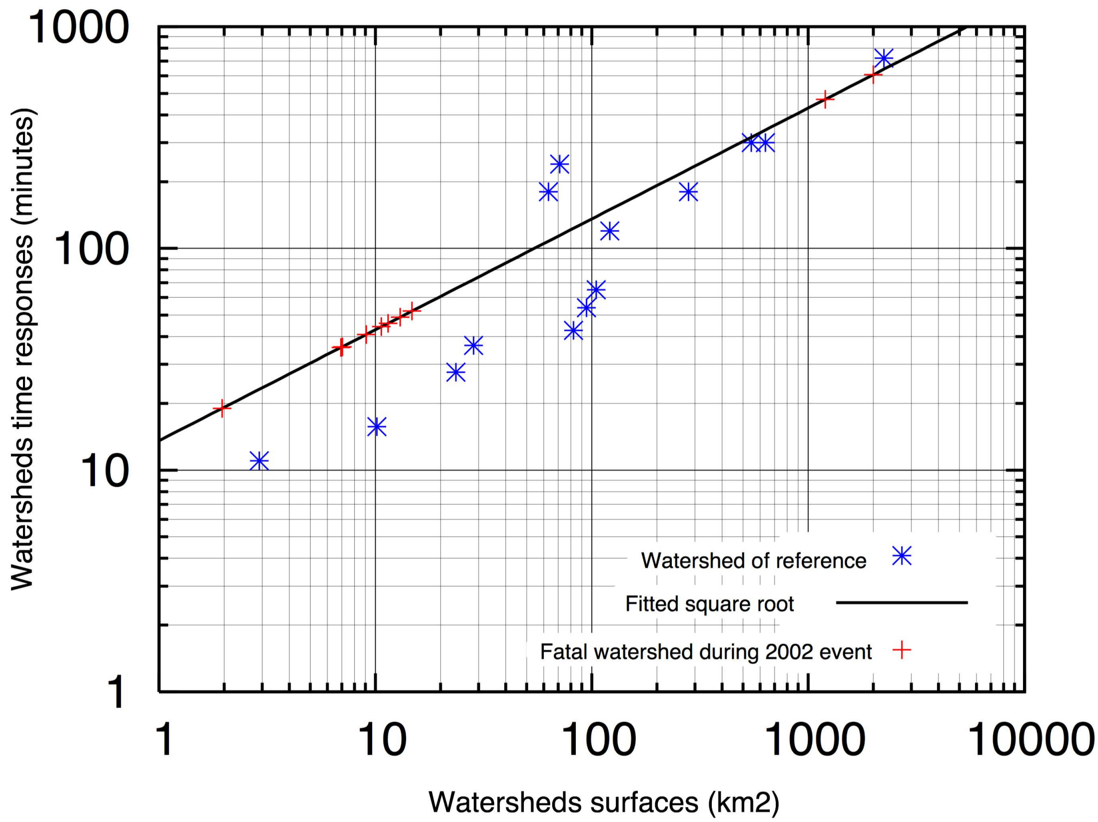

Figure 3:Time of watershed responses in function of the drainage surface

As an example of scales involved in the case of flash floods, figure 3 presents historical average data of watershed time responses in function of drainage surface for watersheds located in the south of France, where the hydrological dynamic is similar to the Gard region. This figure shows that on a logarithmic scale, the relationship between watershed size and time response fits to a square root regression ($f(x) = 13{,}57*\sqrt{x}$).

3.2.2 Size and specific outflows of the basins

When studying flash flood vulnerability another important parameter lays in peak specific discharge. The problem is that the smallest basins are mostly un-gauged basins where peak discharges are difficult to evaluate. Post flood investigations often show higher peak specific discharge for smaller basins. For instance, for the 2002 event, peak specific discharge of the smallest investigated basin ($11km^2$) was evaluated at $27m^3.s^{-1}.km^2$. The data collection of the 2002 post flood investigation estimations, together with other historical data for several Cevennes and Gard watersheds, gives a representative sample of peak specific discharges for watershed with a surface within 4 km^2 to 2000 km^2. This sample shows a logarithmic relationship between peak specific discharges and the surface of the basins (cf figure 4). This relationship allows estimating peak specific discharge values for the 2002 fatal watersheds where the only data available are the watersheds surface area. If considering this relationship, peak specific discharges of small basins (2 to $15km^2$) where 10 accidental casualties occurred in 2002 vary between $55m^3.s^{-1}.km^2$ and $20m^3.s^{-1}.km^2$ which is rather exceptional. For bigger watersheds as the Gard (2000 km2) and Cèze (1200km2) rivers, values are around $2m^3. s^{-1}. km^2$.

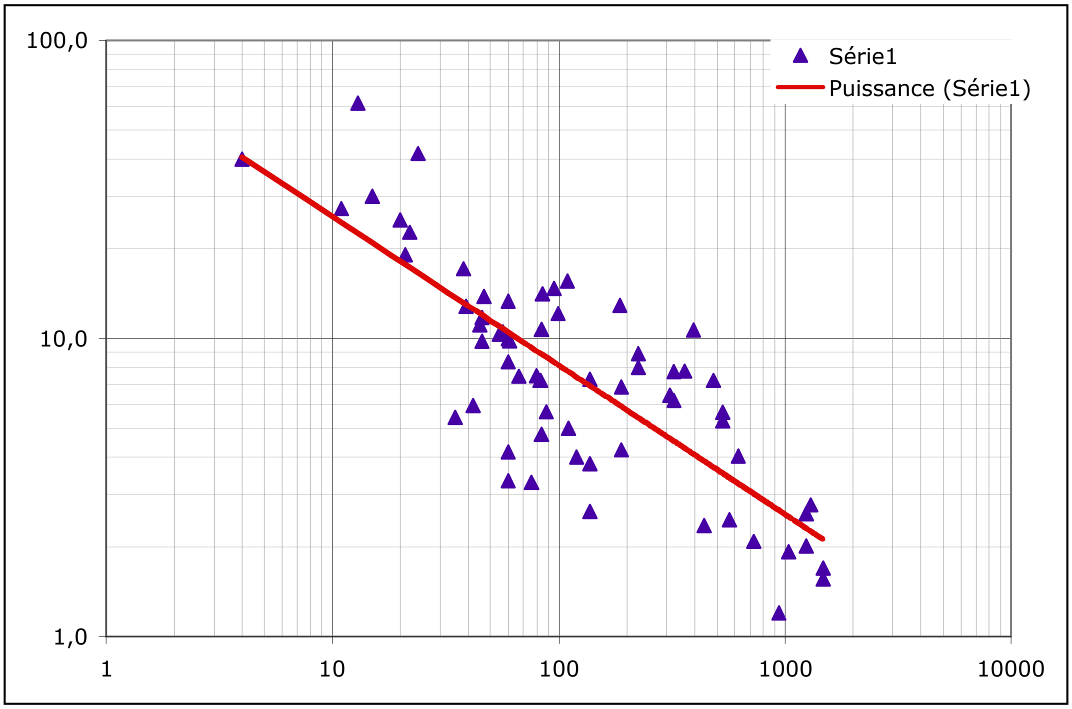

Figure 4: Peak specific discharge in function of watershed surface

For both space and time scales and peak discharge intensity, watersheds involved in fatal accidents seem to be classified into two very distinct groups. On the one hand, 10 very small watersheds between 2 to 15km2 responsible for 12 deaths react drastically rapidly with extremely high peak specific discharges. Those are really what we can call "the flash flood basins". On the other hand, 3 large watersheds (>1000km2) cause 11 fatalities although they have several hours of time response and a smaller intensity in terms of specific outflows. In order to better understand how people are exposed to those different risky situations and their vulnerability to the situations our next section will analyze what were the dynamics of the event in each location and what were the circumstances of the well-documented fatal casualties.

3.2.3 Dynamics of the event and its consequences

The dynamic of the event has to be understood in both space and time dimensions in order to compare it to the victims' activities at the time they were struck.

The fatalities spread across the whole Gard department may be compared to the rainfall distribution in reference to the three phases identified in section 2. Thanks to the time recollection of when the fatal accident happened, individuals have been reported missing or bodies have been found. Rainfall phases characterized by their own extension, intensity and duration can be associated with different accidents. Thus, during phase 1, three people died respectively in Fons, Saint Laurent les Arbres and Domazan. During phase 3, seven fatalities occurred in five localities drained by different watersheds. It appears that no fatality record was related to phase 2 of the rain event.

3.3 First conclusions

This first study shows that considering vulnerability points, the range of scales where improvements are needed is in our understanding and forecasting capabilities. Small watersheds (less than 100 km²) are responsible for the majority of accidents. The expected improvement implies first to investigate in meso-b scale meteorology (Orlanski, 1975) in terms of detection of convective cells. This improvement implies secondly an investigation of triggering runoff in headwater basins.

This study also shows the need to constitute specific data sets including information on both physical and human aspects of fast developing floods. In the case of the human aspects of flash floods we have to focus on risks associated with motor vehicle usage in heavy rainfall conditions. Hydro-meteorological circumstances have to be investigated in more detail but risk awareness of road users in their daily itineraries may also be of importance. This last aspect is one of the objectives we addressed with the use of a mental maps survey in 2005.

4. Awareness of risk in particular on roads[2]

During the last two major flash flood events in September 2002 and 2005, extreme weather warnings were not sufficient to avoid great dysfunctions for transportation and road networks. In 2002, 75% of the road network was impassable for nearly two days, hundreds of motorists were trapped because of the flood on the road joining the two main cities of Nîmes and Alès (Lescure, 2004) and five deaths occurred among motorists. Among the 600 vehicles involved in rescue missions, 40 were lost and 200 were damaged (MEDD, 2004). The main network is being redesigned to become flood-resistant (DDE30, 2003), but secondary roads are still subject to regular floods. The present study particularly focuses on a 10km-wide area around the main road (RN106) linking Nîmes (capital of the *département*) and Alès (figure 5).

In 1999 (before the 2002 devastating flash flood), 169,508 people lived in this area (Institut National des Etudes Statistiques, 1999). The study area also includes a dense secondary road network and 96 smaller rural and urban municipalities.

4.1 Survey methods

Cognitive mapping is one of the common tools for perception assessment of the spatial environment. It usually refers to "a process composed of a series of psychological transformations by which an individual acquires, stores, recalls and decodes information about the relative locations and attributes of the phenomena in his everyday spatial environment" (Downs and Stea, 1973a). Yet, there is a theoretical debate about the meaning and scope of the term 'map' (Kitchin, 1994). Psychologists tend to consider cognitive maps as mental and hypothetical constructs and representations (Moore, 1979). On the other hand, geographers mostly relate cognitive mapping to actual cartographic representation of one's perception of space and environment (Gould and White, 1974). The second approach will be the one used in the following paragraphs.

[2] Part of this section has been submitted to the journal Environmental Hazards.

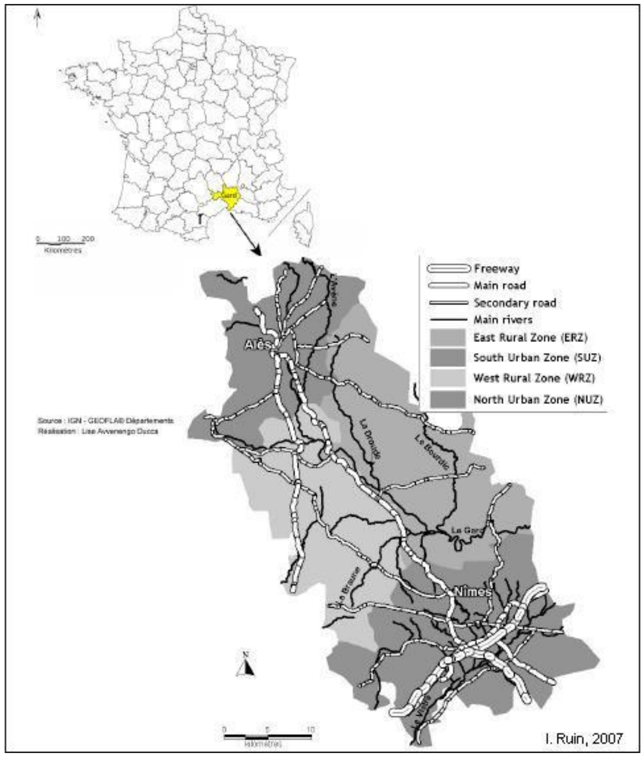

Figure 5: Study area in the Gard département in Southern of France

Cognitive mapping is often used with two goals in mind. First, it intends to evaluate how people perceive, remember and describe spatial features and relationships at scales that vary from their immediate surroundings to the whole earth (Gould and White, 1974). It also serves as a basis to understand how an individual decides to move within places (Kitchin, 1994). This second use of cognitive maps directly relates to the purpose of the study described in the present paper. Cognitive mapping is indeed particularly useful in understanding why people choose: 1) to stay or to go; 2) where to go; 3) which route to take; 4) how to get there (Cadwallader, 1976; Gärling et al., 1985). It is widely assumed that those decisions strongly depend on people's spatial representation, experience, knowledge and personality among other factors (Gärling, 1989). These factors inevitably vary from one individual to another and thus introduce discrepancies between people's representation of their environment and the real world. Distortions are particularly evident in relation to distances and directions as well as map recognition and construction (Tversky, 1992).

Despite its evident interest and wide possible application, cognitive mapping has not been widely used in risk and disaster research or management. To our knowledge, no study based on cognitive mapping has yet focused on the way motorists perceive and behave in the face of natural hazards, especially flash floods.

Downs and Stea (1973b) assert that cognitive maps are a requisite both for human survival and for everyday environmental behaviour. Similarly, Kaplan (1973a) hypothesizes that cognitive maps develop as a means of quick and efficient mechanisms for handling information, thus giving people a selective advantage in a difficult and dangerous world. Based on these assumptions, the analysis of spatial products used in the meaning of external representations of cognitive map knowledge may be very fruitful to understand spatial decision-making and subsequent behaviour in everyday life but also in dangerous settings. The present study especially focuses on "which route to take" and "how to get there" among the four purposes of cognitive mapping listed by Cadwallader (1976) and Gärling et al. (1985). Nevertheless, it will not tell us about people's decision to stay at home safely or to travel following their usual patterns in extreme weather conditions.

The objective of this study is to explore either traditional hypotheses on factors influencing awareness of risk and spatial decision making, such as the experience of previous flash floods, knowledge of the local environment or socio-demographic and cultural factors, and hypotheses on spatial patterns of travel behaviour that may also influence perception of danger along road networks. Thus, we chose cognitive maps as the basis to assess the weight of hazard-related factors while the questionnaires are used for contextual factors. In addition to personal information, questionnaires deal with five different topics: usual travel behaviour and goals, previous flash flood experience, knowledge of the phenomena and protection means, drivers' perception of flood danger and sources of information. Interviewees were further asked to use a road map to highlight their usual itineraries and to localize the portions of the road network they think dangerous or safe for different extreme precipitation conditions (Figure 6).

In order to be representative both statistically and spatially, we used spatially stratified sampling. It enabled an equal representativeness of motorists from crowded urban municipalities and from rural ones. We divided our population sample into four groups corresponding to four areas with different population densities: South Urban zone of Nîmes (SUZ), North Urban Zone of Alès (NUZ), West Rural Zone (WRZ) and East Rural Zone (ERZ). 50 people were surveyed in each of the four selected areas or a total survey sample of 200 people. The sampling fractions were then established for each of the four areas and applied distinctly to each municipality population to determine the number of persons to be surveyed by municipality. For instance, the urban area around Alès (NUZ) obtained a sampling fraction equal to 0.063%. Within this area, applying this sampling fraction to each city census data, 26 persons were interviewed in Alès, the main city, and only one in the smallest municipalities gathering less than 200 inhabitants. 90 of the study area's 99 municipalities were surveyed, and our sample is spatially representative for each of the four selected areas (Figure. 5).

4.2 Data processing and major findings

All 200 questionnaires were analysed using SPSS software and MapInfo Geographical Information System for spatial data processing. The use of GIS is quite common in the field of risk and disaster management (Cutter, 2003; Montz and Evans, 2001) but quite rare when associated with cognitive maps (D'Ercole and Rançon, 1994).

4.2.1 Data processing

One of our first concerns was to build three spatial databases including respectively: (i) the usual itineraries of the interviewees, (ii) the road sections they think dangerous, named "dangerous roads" during a flash flood, and (iii) the ones they think safer, which they would use as an alternative itinerary called "safe roads". We proceeded to cartographic data entry of the different road sections cited by the interviewees on the basis of an existing GIS database of all the road sections of the area given by the *Direction Départementale de l'Équipement du Gard* (DDE30). This first data processing allowed mapping of the frequency of usage concerning the different usual itineraries of the 200 interviewers. Moreover it allowed mapping of the percentage of the constituting road sections that were perceived dangerous in heavy rain conditions.

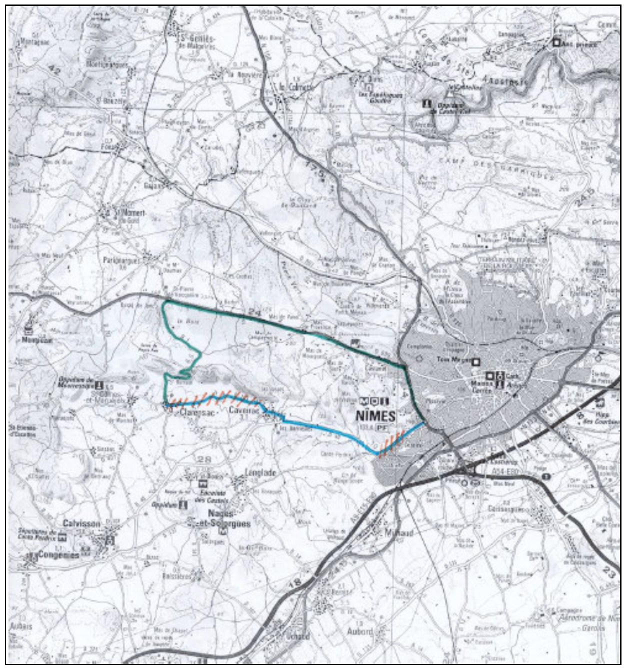

Figure 6 : Example of cognitive map used for the case study

In order to assess the quality of each road user's spatial perception of risk on their usual itinerary, we built a cartographic perception index. This index is based on the comparison of motorists' perceptions and road sections that were reported to be regularly flooded by the local department of transportation. The computation of the perception of risk index on the usual itinerary is shown in Table 3.

4.2.2 Results from spatial product analysis

Looking at usual itineraries, the National Road #106 (RN106) appears clearly to be the most used by the interviewees, then follows the RN110 and three other Départementale Roads (RD) in the surrounding of Nîmes or Alès. These observations well reflect road traffic counts given by transportation services for 2005. Then, comparing risk perception and road sections frequently flooded (figure 3), we notice that the objective flooded road sections are considered dangerous by most of the users (black diamonds overlying thick white lines). Nevertheless, there are still road sections where the risk is not appropriately perceived. Under-estimation depicted by black diamonds overlying thinner lines often concerns secondary roads that are also the less frequented (used by one to four interviewees) like in the south of Nîmes or along the "Droude" river for instance. This may be an interesting point but it is also questionable because these secondary roads often show a ratio too low to be considered as representative. However it is noticeable that risk is also under-evaluated on a large portion of the well-frequented RN106. Over-estimation of danger (large white lines with no diamonds on them) may be also a problem and this map shows a strong tendency for this.

It is mostly the case in the South Urban Zone (SUZ) on road sections that cross the "Vistre" tributaries but also along most of the RN106 track.

Table 3: Sample of the table of construction of cartographic indices

Inter-viewee Key #	Living area	Number of road sections used for usual itinerary **C**	Number of road sections prone to flood on usual itinerary	Number of road sections not prone to flood on usual itinerary	Number of road sections prone to flood and perceived as dangerous APPROPRIATE PERCEPTION **H**	Number of road sections not prone to flood and not perceived as dangerous APPROPRIATE PERCEPTION **I**	Number of road sections not prone to flood and perceived as dangerous INAPPROPRIATE PERCEPTION **J**	Number of road sections prone to flood and not perceived as dangerous INAPPROPRIATE PERCEPTION **K**
1	4	36	2	34	0	33	1	2
2	2	5	2	3	1	3	0	1
3	2	4	2	2	0	2	0	2

APPROPRIATE PERCEPTION RATIO (H + I)/C= M	**INAPPROPRIATE PERCEPTION RATIO** (J + K)/C = O	UNDER-ESTIMATION OF RISK RATIO K/C = P
0,92	0,08	0,05
0,80	0,20	0,2
0,50	0,50	0,5

Analyzing the results from the cartographic index, we found that 77% of our sample (154 persons) generally have an appropriate perception of potential flooded or non flooded road sections, which means that they localize more than 50% of the frequent road break points along their usual itinerary. The other 23% (46) localize 50% or less of the potentially flooded road sections. Among them, only 16 individuals (8% of the total sample) under-estimate the risk that is to say they do not know most of the sections prone to flood (Table 1, P>=0,5). Looking at the socio-demographic characteristics, three factors appear significant: area of living, previous flash flood experience and profession. Workmen (90%) or tradesmen and shopkeepers (87,5%) living in the ERZ (88%) or the NUZ (84%) with no experience of flash floods (87,5%) tend to have a better perception than intellectuals with flood experience living in SUZ or WRZ. In a less significant way, age seems also to have a little influence as people older than 65 (85%) generally display an appropriate perception of risk whereas people younger than 25 (67%) do not. In terms of road network usage, it seems that the longer the individual's riding distance the better they perceive the associated risk, as shown by more appropriate perception for drivers taking a high number of road sections for their usual itinerary. But there is no evidence of this in terms of frequency of usage.

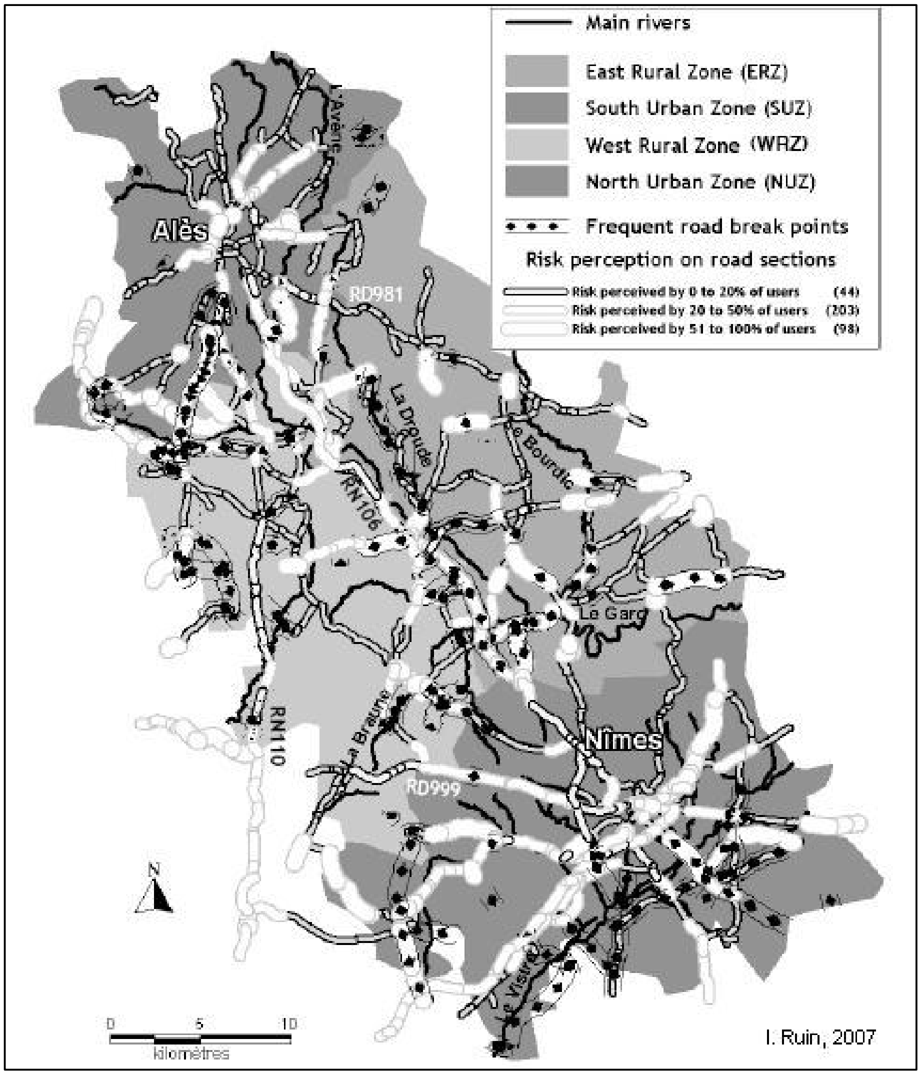

Figure 7: Risk perception on road sections in the Gard département (France)

4.2.3 Results from the questionnaire survey analysis

We identified several factors influencing flash flood risk perception. As similar studies have already revealed (Mileti, 1995; Drabek, 1986, 2000), socio-demographic characteristics influence public response to warnings. Here we particularly identify age as one of the prevalent factors on information source preferences and some of the questions on flash flood knowledge and risk perception. Not surprisingly, we also found that previous flash flood experience and length of residence in the area positively influence the knowledge of these hazardous phenomena and of the appropriate protection means. The type of population (urban or rural) seems to influence risk perception. For instance, urban people under-estimate the risk for a car to be swept away by running water and are relatively more threatened by walking than driving in flood conditions than people living in rural areas. The area of living tends also to influence the knowledge of protection means. As for the cartographic perception index, inhabitants from the NUZ and the ERZ show a better score than the ones from SUZ and WRZ.

5. Conclusions

Because of the suddenness, rapidity and violence with which flash floods occur, especially for small catchments, the risk to life model proposed is difficult to apply directly without detailed and reliable data. Flash floods are particularly difficult to forecast and allow little lead time for warning. Mobility is one of the main circumstances of casualties and a way should be found to include this in the risk to life model. In fact, on road networks, major danger is less localized along large rivers than at the crossing of minor tributaries often invisible in dry periods. We assumed that these flash flood hazard specificities may be one of the significant factors leading to difficulties for individuals and particularly motorists to perceive danger on their usual itinerary. At the same time, in the Gard *département*, people in charge of road networks and emergency managers struggle to protect road users in crisis situations. They have developed technical solutions and emergency plans but none of these addresses the question of peoples' perception and knowledge of protection means.

This case study gives three interesting perspectives. Firstly, the methods and tools used allow gathering of a common GIS database - the one used on a daily basis by the agency in charge of roads network management- information about physical vulnerability of the network but also its associated perception for each road section used. This method may lead to a better integration of social inputs in everyday road network management and gives the opportunity to really focus the effort on building an environment that takes into account propensity of users in the face of a flash flood. Secondly, this study is a helpful pre-requisite in the assessment of the local mitigation policies' usefulness or efficiency. It gives interesting insights about the present level of risk perception among motorists and the discrepancy between different geographical areas within the Gard *département*. This discrepancy may be due to several factors independent from individuals' personal characteristics and hazard features but in relation to the social, cultural, economic and political contexts. How local authorities deal with the flash flood problem may be of critical importance. Our results already display differences on individual's perception and level of information that may be a good starting point for further detailed studies on that aspect.

Finally, and on the same line, this case study is the necessary first step before investigating in depth the reasons of the differences between risk perception among individuals. For instance, on the basis of the road sections where danger was under-estimated or appropriately assessed, some future research may use the original "cognitive mapping" process to understand what are the key elements that lead to that particular perception. This would certainly have interesting implications for risk to life modelling.

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