D3.3
Case studies – Issue 3

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List of Acronyms

ACA	Agència Catalana de l'Aigua (Catalan Water Agency)
ARPAL	Agencia Regionale per la Protezione Ambientale Ligure
ARPSI	Áreas con Riesgo Potencial Significativo de Inundación (Areas of Potential Significant Flood Risk)
CA	Consortium Agreement
CECOPAL	Centre for Municipal Emergency Coordination
CHE	Confederación Hidrográfica del Ebro (Ebro Hydrographic Confederation)
CIMA	Centro Internazionale in Monitoraggio Ambientale – Fondazione CIMA (CIMA Foundation)
CRI	Associazione della Croce Rossa Italiana (Italian Red Cross)
CTTC	Centre Tecnològic de Telecomunicacions de Catalunya (Catalan Tecnological Telecommunications Centre)
DEMA	Danish Emergency Management Agency
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center)
DUPROCIM	Document Únic de Protecció Civil Municipal (Municipal Civil Protection Plans)
EC	European Commission
EKUT	Eberhardt Karls Universität Tübingen
EMA	Automatic Meteorological Station
FBBR	Frederiksborg Brand og Redning (Frederiskborg Fire and Rescue Service)
FRS	Fire and Rescue Service
GA	Grant Agreement
GLRP	Grampian Local Resilience Partnership
GRAF	Technical Unit of the Forest Actuations Reinforcement
ICGC	Institut Cartogràfic i Geològic de Catalunya (Catalan Institute of Cartography and Geology)
ICP	Incident Command Post
IDESCAT	Institut d'Estadística de Catalunya (Statistical Institute of Catalonia)
INUNCAT	Special Plan of Floods Emergencies of Catalonia
INT-FRS	Ministry of Home Affairs – Fire and Rescue Service
IPR	Intellectual Property Right
MoM	Minutes of Meeting
ODIN	Online Data Reporting System
OMIRL	Osservatorio Meteo Idrologico della Regione Liguria

PAP	Priority Action Points
PB	Project Board
PC	Project Coordinator
PCF	Fundació d'Ecologia del Foc i Gestió d'Incendis Pau Costa Alcubierre (Pau Costa Foundation)
PG-ME	Policia de la Generalitat de Catalunya – Mossos d'Esquadra (Police of the Generalitat of Catalonia – Troopers)
PPT	Precipitation
RBD	Risk Based Dimensioning
RESCAT	Radio communications of Emergencies and Security of Catalonia
SFRS	Scottish Fire and Rescue Service
SMC	Servei Meteorològic de Catalunya (Catalan Weather Service)
SPH	Space Hellas S.A.
TL	Task Leader
TM	Technical Manager
ToC	Table of Contents
TSYL	Tecnosylva S.L.
TV3	Televisió de Catalunya (Catalan television)
UNISTRA	Université de Strasbourg (University of Strasbourg)
VE	Vulnerable Elements
WP	Work Package
WPL	Work Package Leader
WUI	Wildland-Urban Interface

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Executive Summary

This document provides a comprehensive collection of data and information about seven different case studies gathered by the end-users of the HEIMDALL project. These case studies and the ones that were presented in the previous deliverable are aimed to populate the HEIMDALL databases and catalogues, as well as to prepare HEIMDALL demonstrations exercises through the definition of *storyboards*.

1 Introduction

The document is organised as follows:

- Section 2 summarises the allocation of case studies per each consortium end-user.
- Section 3 analyses the case study of the Garonne river Floods;
- Section 4 analyses the case study of the Entella river Floods;
- Section 5 provides further analysis on the Ballater Floods - Storm Frank introduced in the previous deliverable (D3.2);
- Section 6 the case study of the Roskilde Fjord Floods - Storm Ingolf;
- Section 7 analyses the case study of the Artés Fire;
- Section 8 analyses the case study of the Tisvilde Hegn Fire.
- Finally, Section 9 analyses the case study of the Mati Fire.

2 Case studies

In total, five case studies will be analysed during the course of the project: two of them based on forest fires, two based on floods and flash floods, and one based on a landslide. These case studies will be led by a responsible project end-user, as listed in brackets:

- Forest fire case 1 (SFRS)
- Forest fire case 2 (INT-FRS)
- Flood, flash flood case 1 (FBBR)
- Flood, flash flood case 2 (CIMA)
- Landslide case 1 (CRI)

Notably, this deliverable collects **7 different case studies: four based on floods, and three based on forest fires.** The data and information collecting process has been led by the end-users of the consortium (INT-FRS, FBBR, SFRS, CIMA) with the support of PCF. Following are the main case studies collected for this deliverable:

- Flood case 2 (FBBR) – Roskilde Fjord - Storm Ingolf (Frederikssund, Denmark)
- Flood case 1 (CIMA) – Entella river floods (Liguria, Italy)

This deliverable gathers not only the case studies that *storyboards* and demonstration exercises will use to get data, but also other minor case studies that consortium end-users found relevant to expand the catalogue of scenarios in future steps of the platform. In this sense, two case studies have been added in this document:

- Garonne river floods (Catalonia, Spain)
- Ballater floods – Storm Frank (Scotland, United Kingdom)
- Artés Fire (Catalonia, Spain)
- Tisvilde Hegn (Frederikssund, Denmark)
- Mati Fire (Attica, Greece)

3 Garonne river Floods

The floods of the Garonne River in Vielha e Mijaran (Vall d'Aran, Catalonia, Spain) took place between 17th and 18th of June, 2013. The Garonne river and its tributary, the Nere river, overflowed in numerous points on their way through Vielha, causing considerable damage to houses, roads, bridges and sanitation systems, and leaving part of the population isolated and without supplies of gas or electricity. The numerous damages caused by the floods were quantified economically in approximately twenty million of euros. The overflow of the river and the great danger that it represented forced to evacuate more than four hundred people. Fortunately, the incident did not leave any fatalities.

The case study will present not only data referring to the meteorological and hydrological causes, but also a review of the management of the emergency, pointing out the different steps in the management and the different actors involved.

3.1 Data collection

Data collected and sources for the Garonne River flood are shown in Table 3-1.

Table 3-1. Data sources for Garonne River flood.

Type of data	Source	Time of collection
Cartography (topography, infrastructure, population, roads, bridges, powerlines, vegetation, geology, soil use, ortophotos…)	SMC, ACA, CHE, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, Vielha e Mijaran Municipality	2007-2013
Operational cartography on topography (critical assets, routes, soil use, housing)	SMC, ACA, CHE, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, Vielha e Mijaran Municipality	2007-2013
Flood extension	SMC, ACA, CHE, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, PG-ME, Local Police, Vielha e Mijaran Municipality	2013
Affected area	SMC, ACA, CHE, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, PG-ME, Local Police, Vielha e Mijaran Municipality	2013
Weather data	SMC, ACA, CHE, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, PG-ME, Local Police, Vielha e Mijaran Municipality	1982-2013

Images and videos	TV3, Fire Service, ICGC, Vielha e Mijaran Municipality	2013
Logistics and means deployed	PG-ME, Local Police, Vielha e Mijaran Municipality	
Population within area of interest and citizens affected	PG-ME, Local Police, Vielha e Mijaran Municipality, IDESCAT	2013
Fieldwork to validate flood behaviour	PG-ME, Local Police, Vielha e Mijaran Municipality	2013-2018
Social media and relevant information	TV3, SMC, ACA, CHE, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, PG-ME, Local Police, Vielha e Mijaran Municipality	2013

3.2 Data processing

This section aims to offer some maps, graphics and images collected and processed before and after the flood event. This data is essential to understanding the magnitude and the impact of the floods as well as the factors that triggered it. This combines cartographic data, which locates the study area and shows the characteristics of the terrain, and meteorological data, which defines the weather conditions influencing the development of the flood incident. The impact of flood on the region of Vielha e Mijaran, caused by a number of simultaneous factors, will be discussed later.

3.2.1 **Cartographic data**

The cartographic data that is presented below provides information on the location of the study area (Figure 3-1), land-uses (Figure 3-2), topography (Figure 3-3), geology (Figure 3-4), hydrogeological characteristics (Figure 3-5), and erodibility of the terrain (Figure 3-6).

This data allows first responders to perform a better assessment of the hazard and plan for a more efficient emergency response.

Figure 3-1. Ortophoto of the study area.

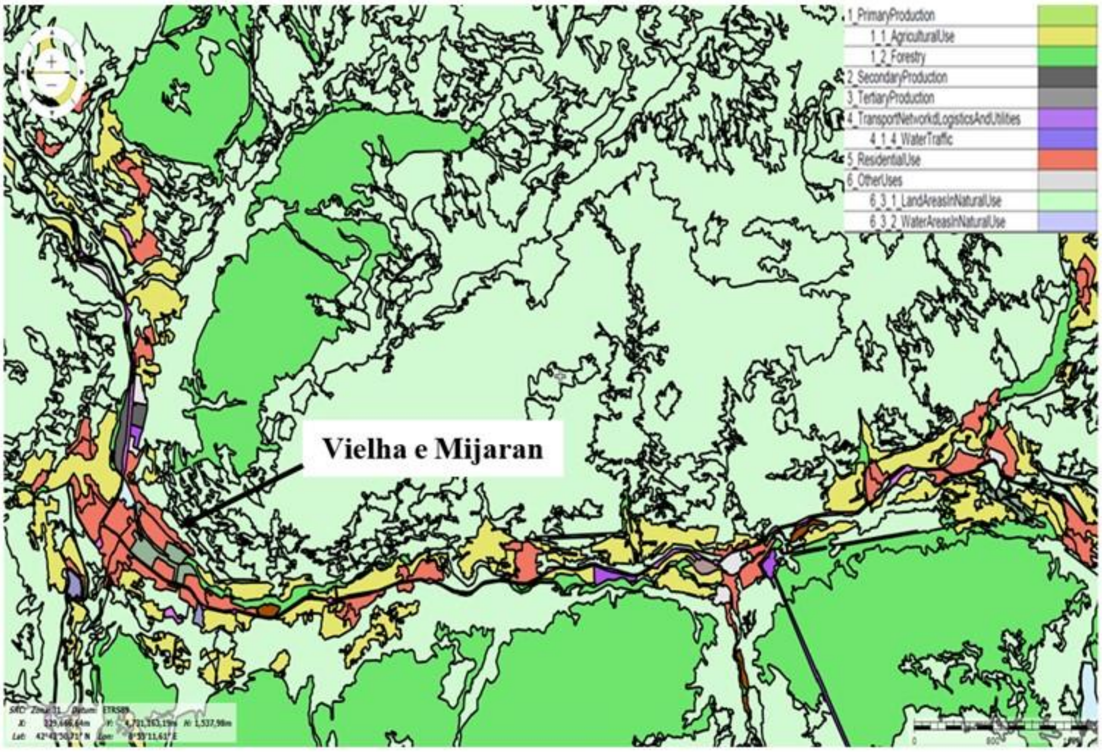


Figure 3-2. Land-uses in the study area.

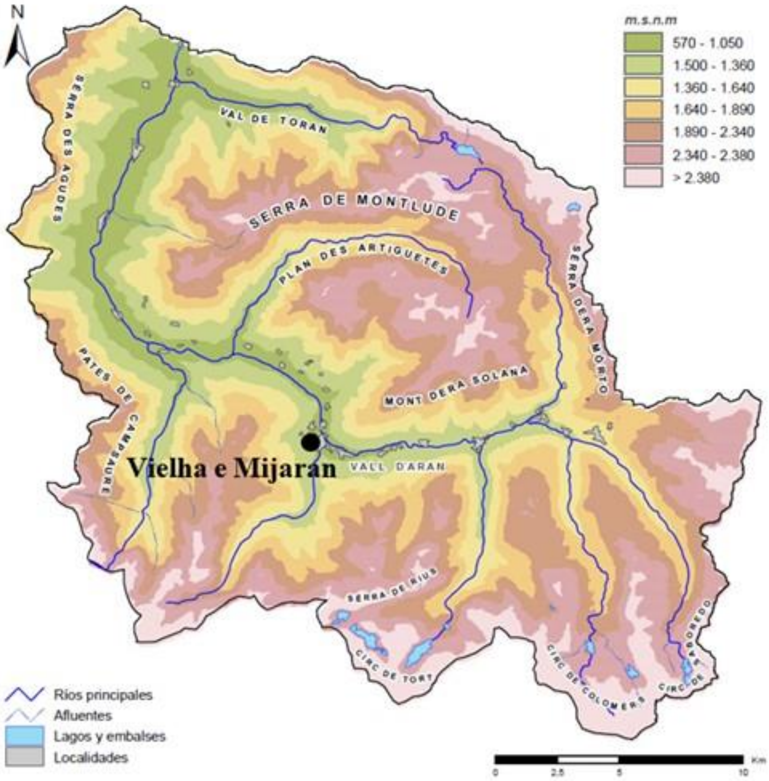


Figure 3-3. Topographic map of the headwater of Garonne river.

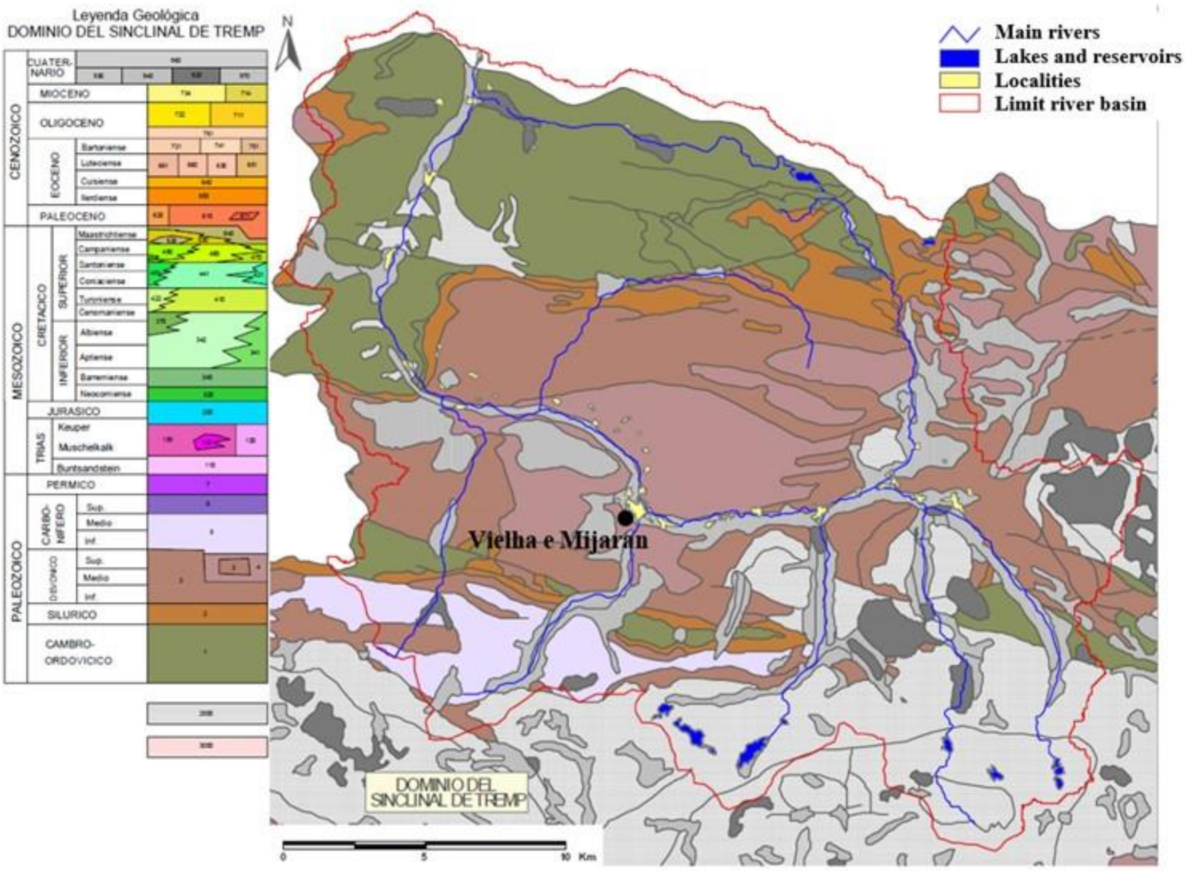


Figure 3-4. Geological map of the headwater of Garonne river.

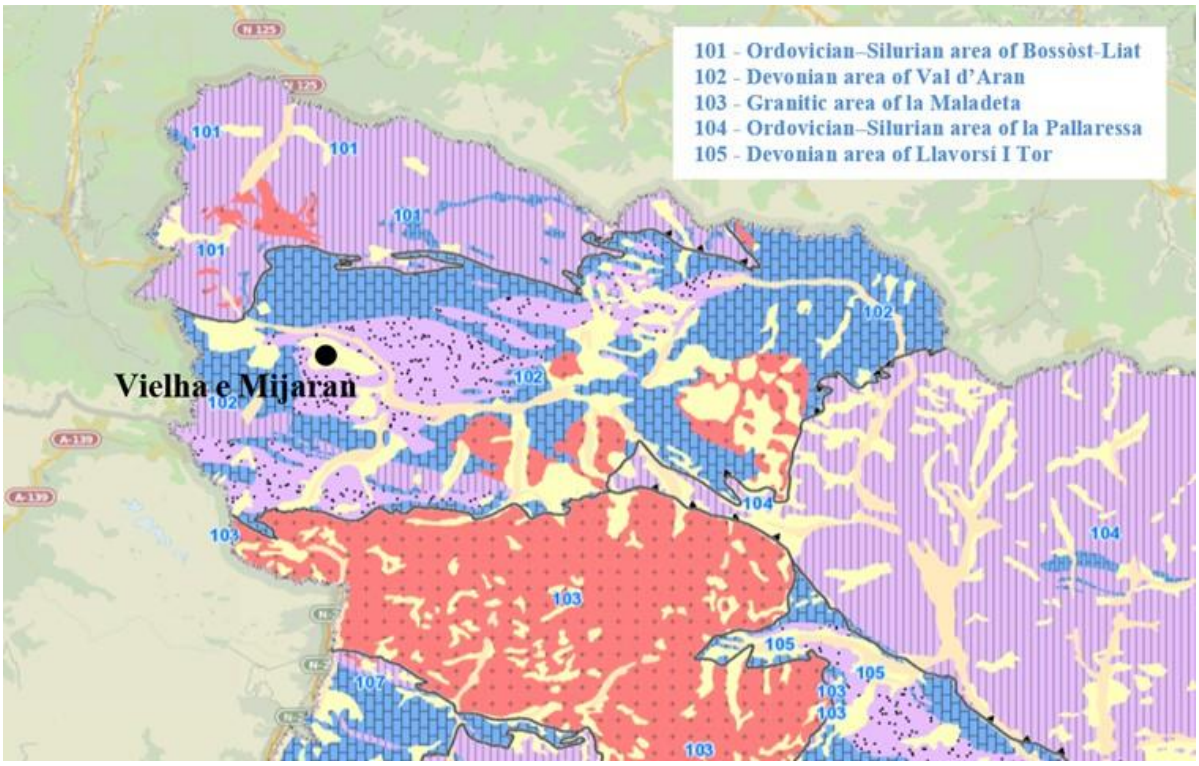


Figure 3-5. Hydrogeological map.

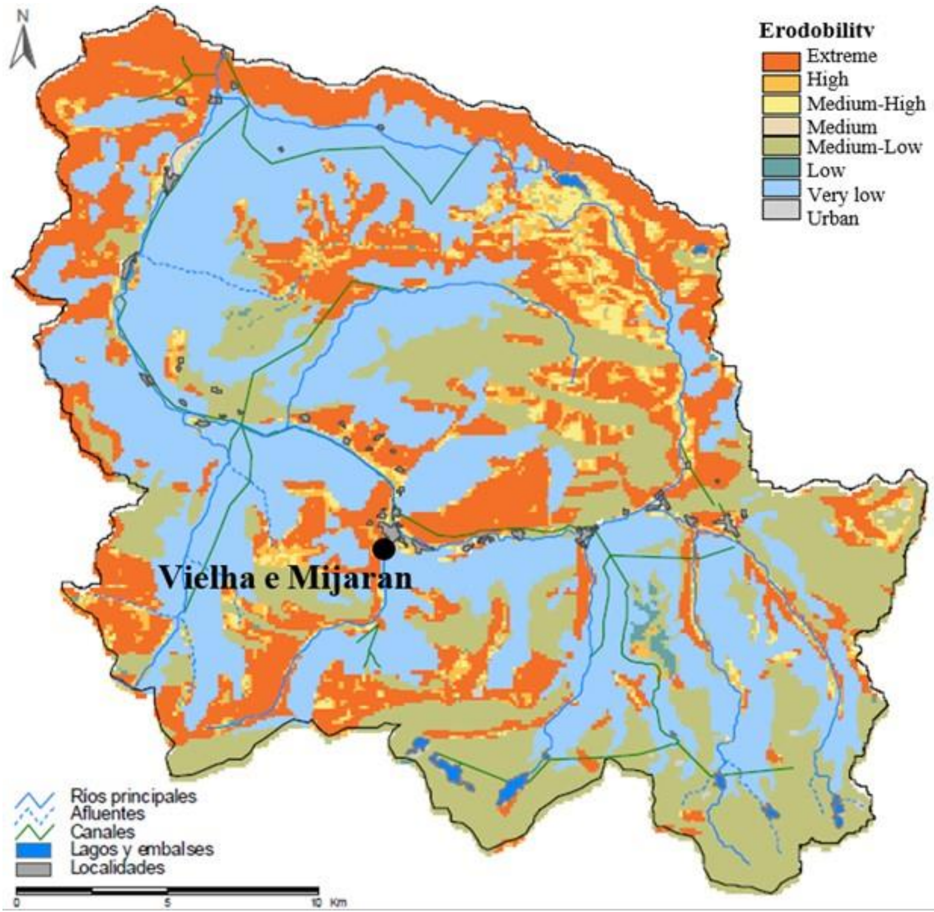


Figure 3-6. Erodibility map of the study area.

3.2.2 **Meteorological data**

3.2.2.1 Rainfall

One of the casual factors that led to the flooding of the Garonne River was the heavy rains that fell between the 17th of June at 17:00 h and the 18th of June at 15:00 h (see Figure 3-7).

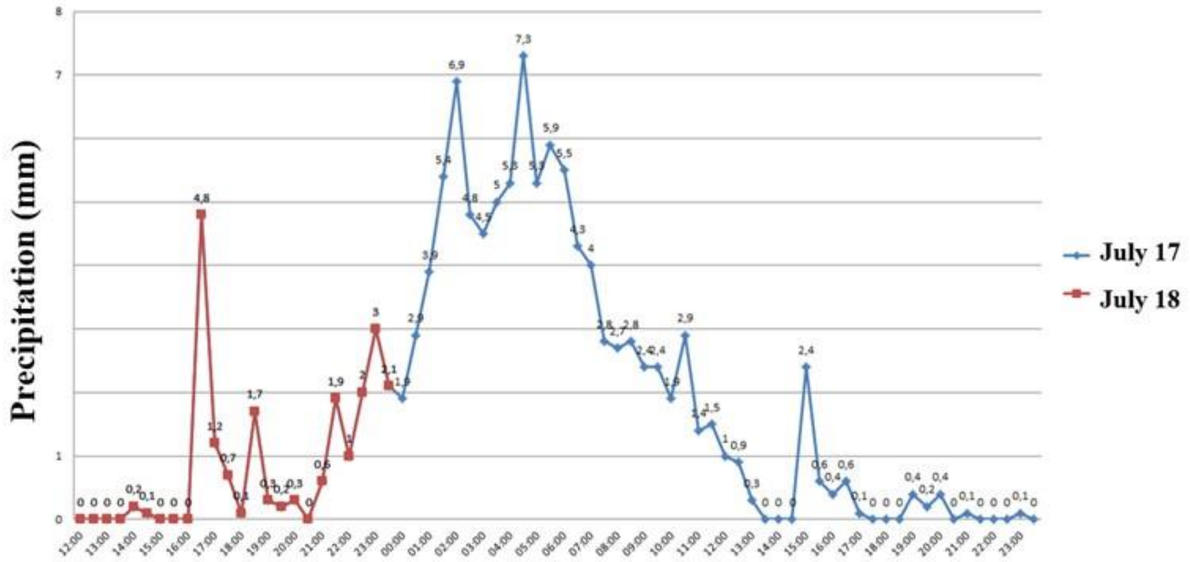


Figure 3-7. Rainfalls in Vielha e Mijaran between the 17th of June at 17:00h and the 18th of June at 15:00h.

In the following, rainfall-specific data is shown to better understand the magnitude of the rains and their consequences in the overflow of the Garonne River.

Figure 3-8 shows the distribution of the total annual precipitation across Catalonia revealing an exceptional pluviometric year around the study area.

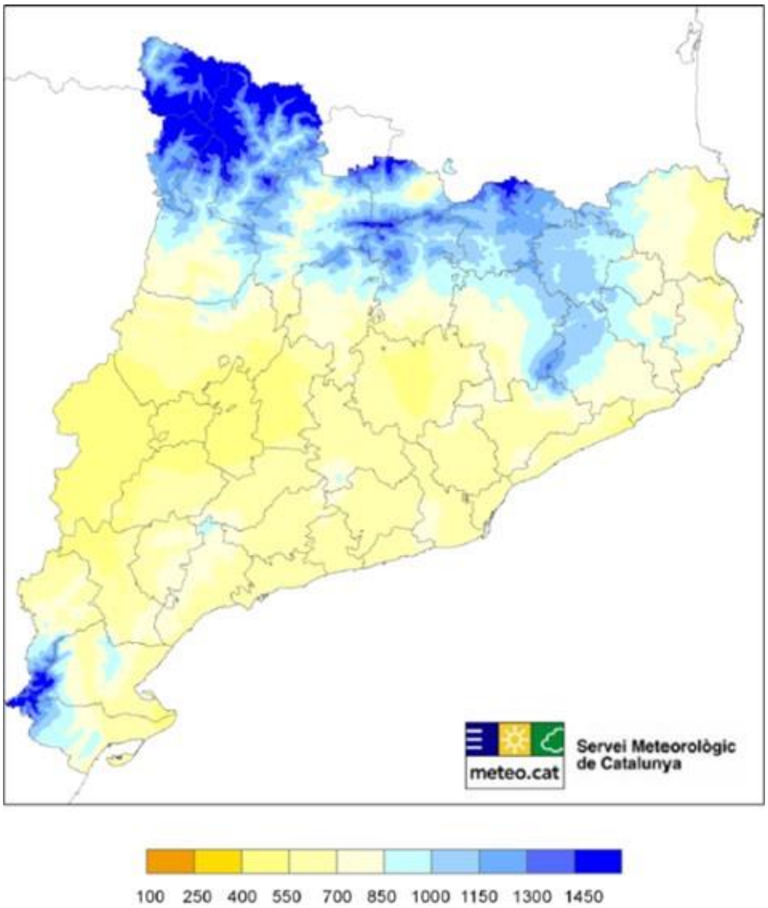


Figure 3-8. Total annual precipitation in mm across Catalonia during the pluviometric period 2012-2013.

Rainfall-specific data for the area of study was registered by the Automatic Meteorological Station located in Vielha e Mijaran. The total accumulated precipitation that was recorded for the period 2012-2013 was 1,216.7 mm. Such levels had not occurred since the period 1907-1908, when a total of 1,286.8 mm were registered. Moreover, during the period 2007-2016, the maximum daily precipitation (PPTx24h) was 101.2 mm, on the 18th of June 2013 (see Table 3-2).

Table 3-2. Maximum daily precipitation (PPTx24h) in Vielha e Mijaran during the period 2007-2016.

Variable	GEN	FEB	MAR	ABR	MAI	JUN	JUL	AGO	SET	OCT	NOV	DES	ANY
TMm	2.3	2.2	5.2	8.7	11.5	15.2	17.5	17.3	13.9	10.5	5.4	2.6	**9.4**
TXm	8.0	8.9	12.4	15.7	18.5	22.6	25.3	25.5	21.9	18.0	11.3	7.9	**16.3**
TNm	-1.2	-1.8	0.6	3.4	6.0	9.4	11.5	11.7	8.7	6.0	1.8	-0.6	**4.6**
TXx	18.1	20.9	23.3	27.8	32.1	34.7	36.3	37.1	33.6	28.7	24.2	20.8	**37.1**
d TXx	08-01-14	16-02-07	13-03-09	09-04-11	13-05-15	30-06-15	08-07-10	18-08-12	07-09-16	06-10-09	08-11-15	24-12-12	**18-08-12**
TNn	-12.3	-16.5	-11.6	-3.4	-1.2	2.2	3.6	5.0	-1.2	-4.2	-10.0	-10.8	**-16.5**
d TNn	10-01-10	08-02-12	11-03-10	17-04-12	26-05-13	02-06-07	10-07-07	31-08-10	28-09-07	29-10-12	16-11-07	26-12-10	**08-02-12**
dG	19.2	19.1	12.5	3.3	0.5	0.0	0.0	0.0	0.2	2.7	9.5	15.7	**82.7**
dEstiu	0.0	0.0	0.0	0.8	4.5	11.2	17.1	16.3	8.2	1.8	0.0	0.0	**59.9**
dCàlids	0.0	0.0	0.0	0.0	0.3	1.9	6.5	6.7	0.7	0.0	0.0	0.0	**16.1**
nTropical	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	**0.1**
HRMm	75	72	68	69	71	72	70	71	74	73	76	72	**72**
PPT	73.4	67.6	75.8	94.5	105.6	87.7	70.2	54.8	51.1	77.9	131.0	51.3	**940.7**
PPTx24h	63.8	50.4	43.1	43.1	37.8	101.2	64.2	37.6	32.2	68.3	59.4	33.6	**101.2**
d PPTx24h	24-01-14	25-02-15	21-03-12	07-04-09	15-05-13	18-06-13	12-07-08	01-08-10	07-09-13	19-10-12	02-11-08	20-12-11	**18-06-13**
PPTx1h	6.5	5.6	7.1	9.4	8.1	18.5	14.6	13.6	12.7	18.4	7.4	5.8	**18.5**
d PPTx1h	24-01-14	12-02-07	25-03-10	01-04-07	19-05-11	11-06-14	12-07-08	01-08-10	08-09-14	04-10-13	02-11-15	24-12-09	**11-06-14**
dPPT>0.2	12.6	12.0	12.3	14.6	16.0	13.6	10.5	9.2	9.4	10.0	11.9	9.4	**141.5**
dPPT>5.0	4.4	4.2	4.2	6.2	6.5	5.3	4.1	3.5	3.7	4.1	6.1	2.8	**55.1**
dPPT>10.0	2.5	1.8	2.7	3.0	3.2	2.2	2.1	2.0	1.7	2.7	3.9	1.6	**29.4**
VVm	1.4	1.6	1.7	1.7	1.7	1.6	1.7	1.8	1.6	1.6	1.5	1.6	**1.6**
VVx	21.2	37.6	20.2	25.0	22.7	19.9	19.1	18.6	18.5	22.4	24.3	24.6	**37.6**
d VVx	08-01-11	27-02-10	04-03-14	26-04-12	13-05-07	17-06-07	23-07-09	01-08-14	16-09-15	24-10-11	05-11-13	24-12-12	**27-02-10**
GNm	3.5	11.6	2.2	0.1	0.5	0.0	0.0	0.0	0.0	0.0	1.1	2.0	**1.8**
GNx	66.9	69.2	38.5	6.8	10.0	0.0	0.0	0.0	0.0	1.3	45.8	28.4	**69.2**
d GNx	16-01-13	10-02-13	05-03-08	07-04-09	01-05-07					28-10-12	23-11-13	01-12-13	**10-02-13**

The Automatic Meteorological Station (EMA) of Vielha, which is managed by the Meteorological Service of Catalonia and has been operating since 1996, registered for the first time a daily rainfall of more than 100 mm (101.2 mm) on the 18th of June 2013, a record that had not been recorded since 1982. Until then, the rainiest day recorded by the EMA station in Vielha was on the 1st of August 1998 with 94.0 mm.

The amount of rainfall registered during the incident (days 17th, 18th and 19th of June 2013) reveals that the floods analysed in this study case have been one of the most remarkable rainfall episodes in recent years.

Altogether, during the period 17th-19th of June the total accumulated rain was of 125.7mm (see Figure 3-9).

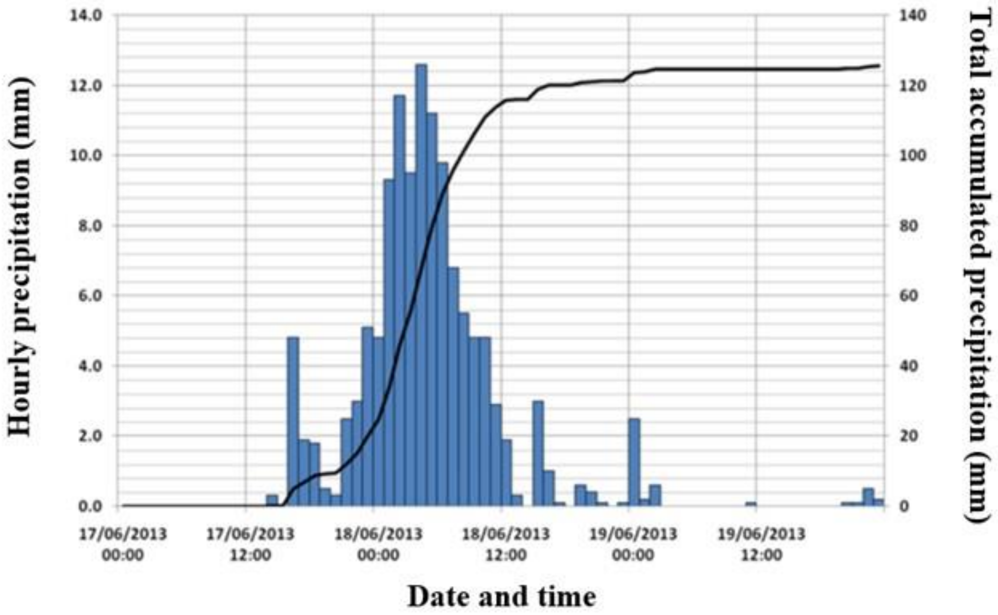


Figure 3-9. Hourly precipitation and total accumulated precipitation from the 17th of June to the 19th of June.

3.2.2.2 Temperature

The temperature is another factor that influenced the overflow of the Garonne River. The significant raise of temperatures during the month of June, especially the heat wave that affected Catalonia during the days prior to the flood event (between the 11th and 16th of June), caused rapid melting of deep layers of snow that had been accumulated during the winter and the spring (see Figure 3-10).

The 11th of June the raise of temperatures began to be noticeable in the region, and the 17th of June air masses of up to 20 ºC were recorded up to 1,500 m above sea-level.

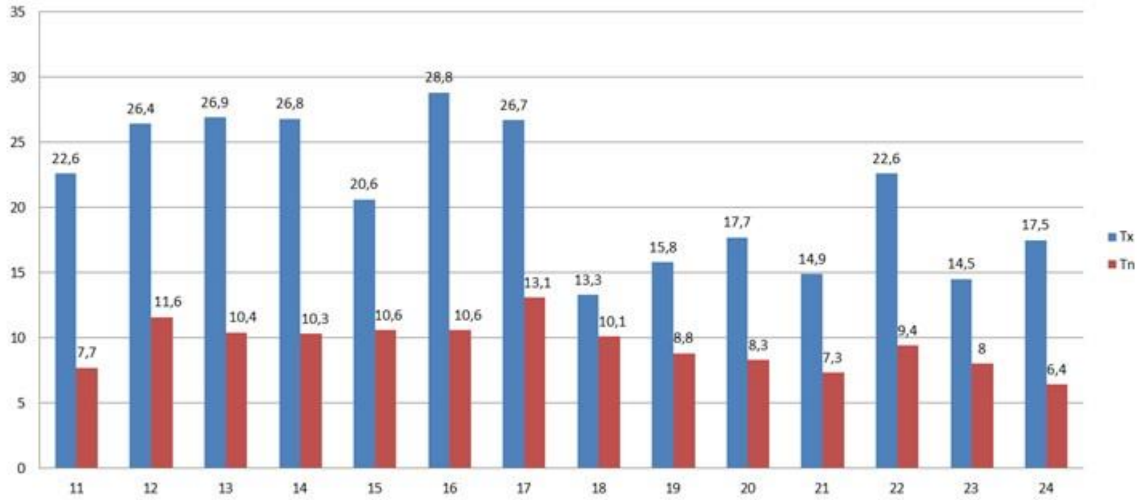


Figure 3-10. Maximum and minimum temperature values between 11th and the 24th of June 2013.

3.2.2.3 Snow melt and river´s flow

As mentioned in the previous section, the temperature was decisive so that the snow that had accumulated quickly melted. Post-disaster studies have determined that the snow layer decreased between 10 and 30 cm per day between the 17th and the 18th of June [3]. Hence, the automatic station of Bonaigua, which is a mountain station in the Catalan Pyrenees at 2,266 m above sea-level, recorded the data shown in Figure 3-11 and Figure 3-12.

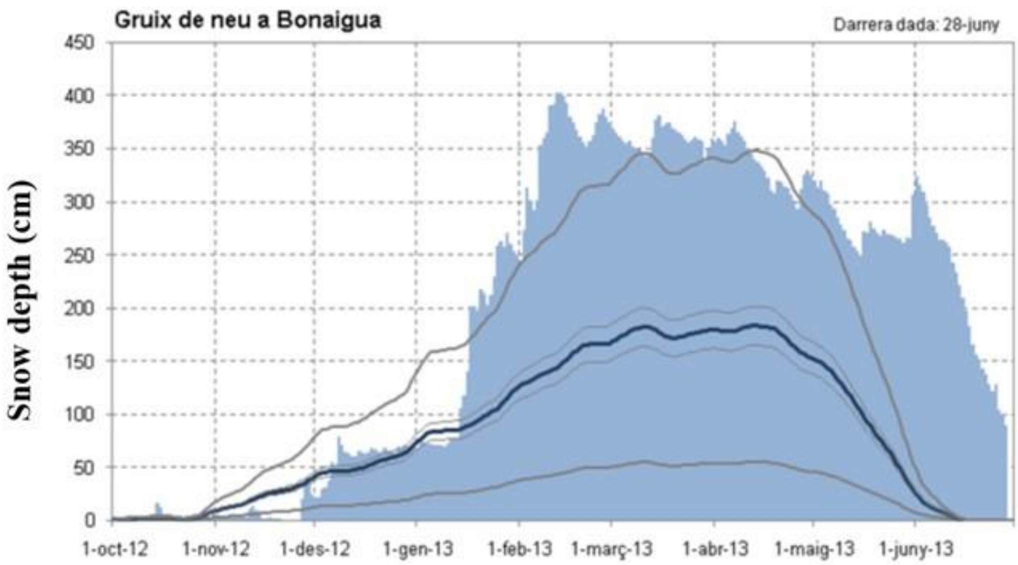


Figure 3-11. Daily snow depth recorded by the automatic station of Bonaigua during the 2012-2013 season, compared to the values of its series.

An an example, in Vielha on the 14th and 15th of November the snow depth was 50 cm at high altitude levels, and about 30 cm at the bottom of the valleys. However, in February the snow depth had exceeded 50 cm at the bottom of the valley, and 69 cm on the 10th of February in Vielha e Mijaran (1,002 m).

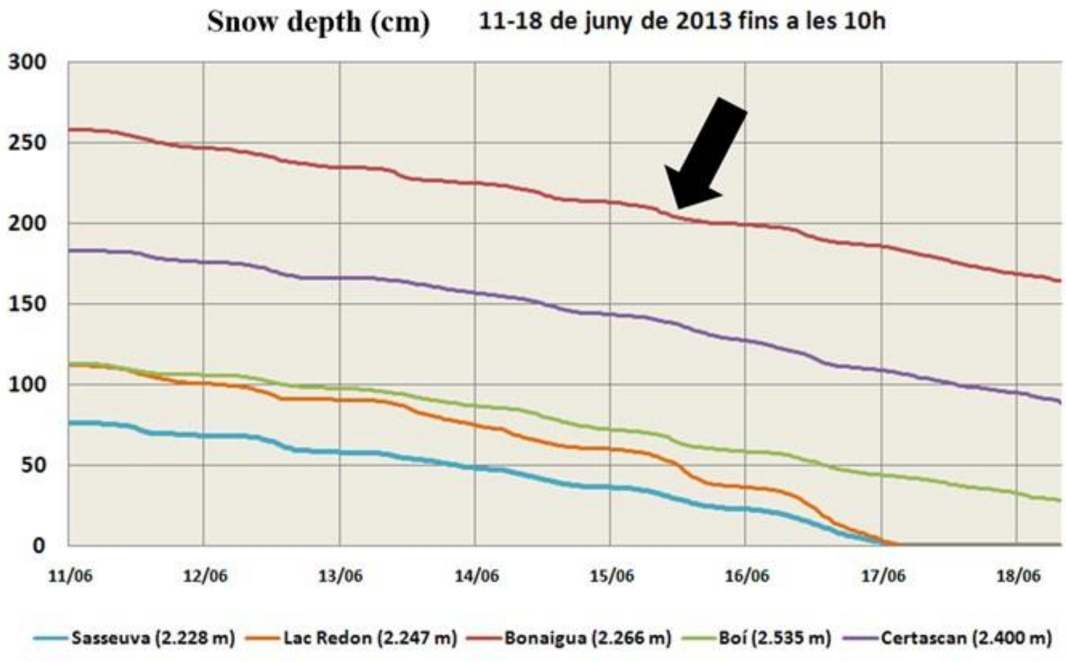


Figure 3-12. Layer of snow in the automatic station of Bonaigua compared to other automatic stations between the 11th and 18th of June at 10:00h.

Another significant fact is that in 2013 the town of Vielha e Mijaran was covered by snow during 106 days (i.e. more than three and a half months), twice the time in comparison to 2012. The difference between both years can be observed in Figure 3-13.

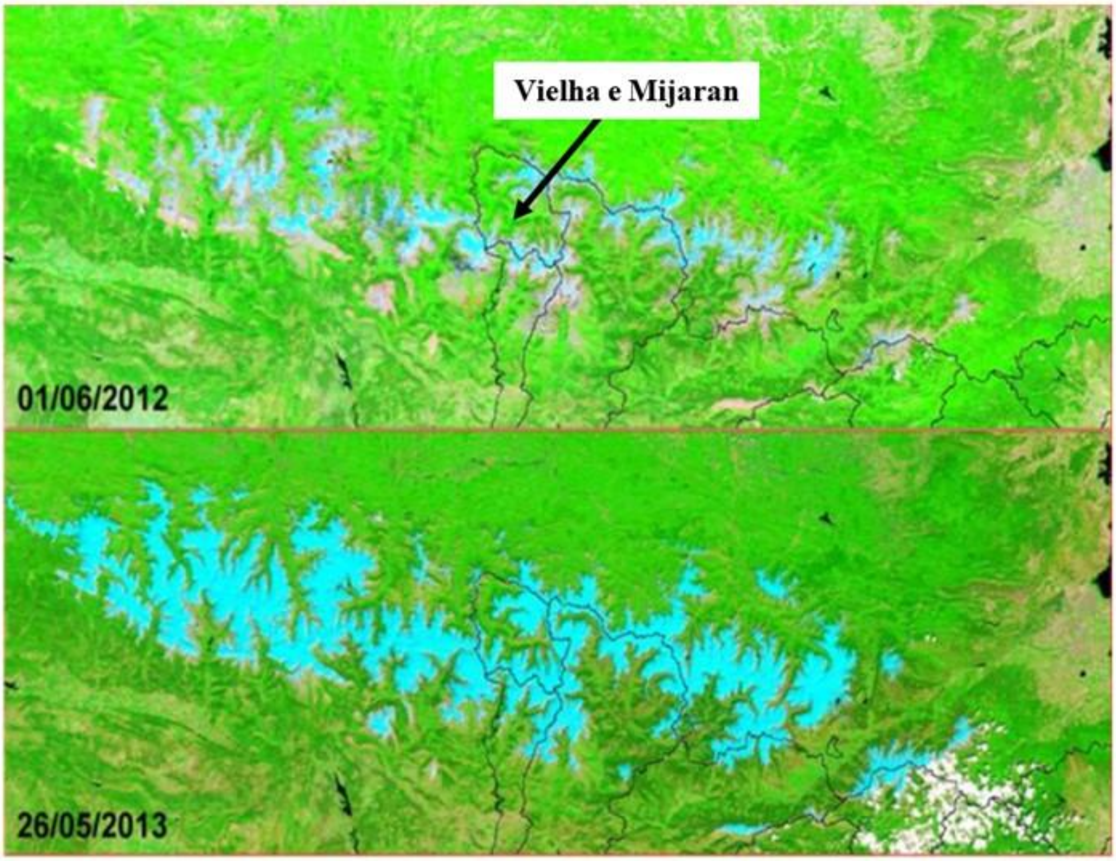


Figure 3-13. Extension of the snow mantle (MODIS-NASA satellite) compared between years 2012 and 2013 in the study area. The light blue color represents snow, the white color the clouds, the green the vegetation and the brown the bare ground.

The combination of high temperatures and large accumulations of snow resulted in a rapid thaw of approximately 51 hm3 between the 11^{th} and the 26^{th} of June (calculation made by the SWE - Snow Water Equivalent [8]), the same amount that is estimated that the rainfall contributed from day 17 to day 19 at 12:00h.

Likewise, analysing the meteorological data helps understand what happened in Arties, a town located to the east of Vielha e Mijaran, where the water power of the Garonne river and its flood also caused severe damage. This can be observed through Figure 3-14, which shows how the snow melt and the rainfall increased the river flow causing the floods, similarly to what happened in Vielha e Mijaran.

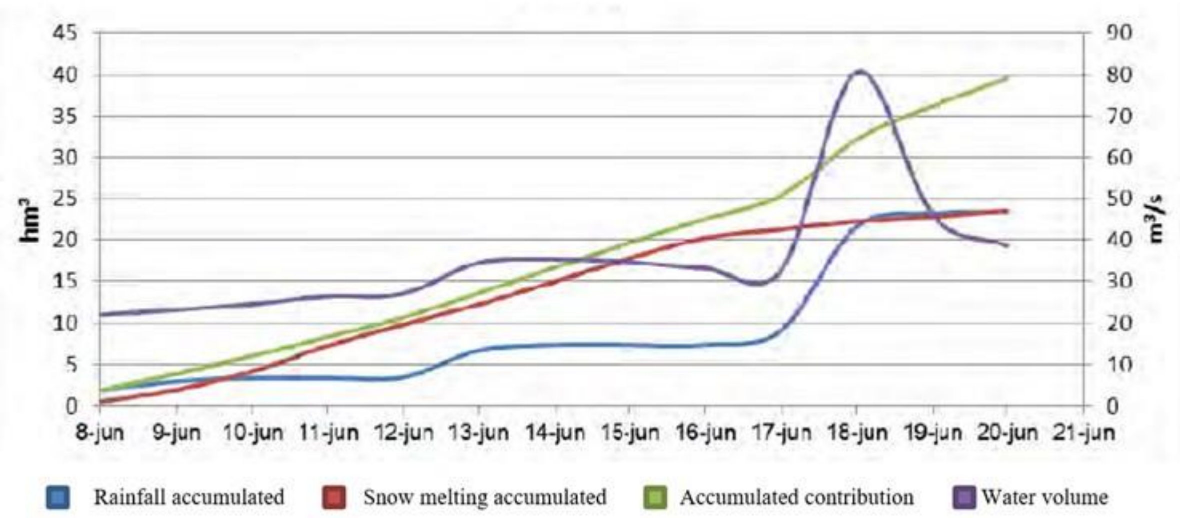


Figure 3-14. Amount of water in the River Garonne when flowing through Arties.

Therefore, the snow made it difficult to absorb the rain that, in addition to the raise of temperatures, caused an accelerated melting of the snow that contributed to increased water flow rate. Normally, the river has a flow rate between 20 and 60 m^3/s during the period April-June, with peaks of $100m^3/s$. However, on the 17th of June, the flow of the Garonne River had a high flow of $125m^3/s$ due to the late thaw. During the incident the river reached a peak flow of nearly 350 m^3/s in its way through Bossòst (Figure 3-15).

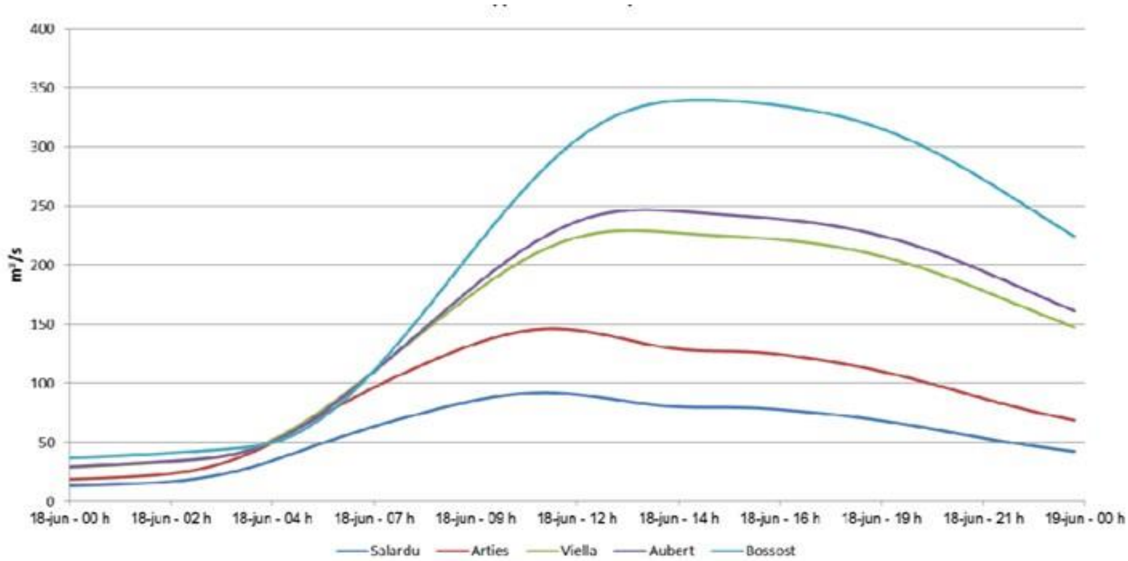


Figure 3-15. Hydrographs for each of the control points obtained with the Aster model.

On the other hand, the level of the sheet of water (water line) of the Garonne River running through Arties increased approximately one meter to 1.56 m (see Figure 5-23). In Valarties, a sheet water level of 1.40 m was recorded. In Vielha e Mijaran the sheet water level reached 2.17m (Figure 3-16).

A thaw higher than usual and an abundant rainfall caused the increase of the Garonne River flow causing an overflow, unleashing flooding and provoking the innumerable damages that will later discussed.

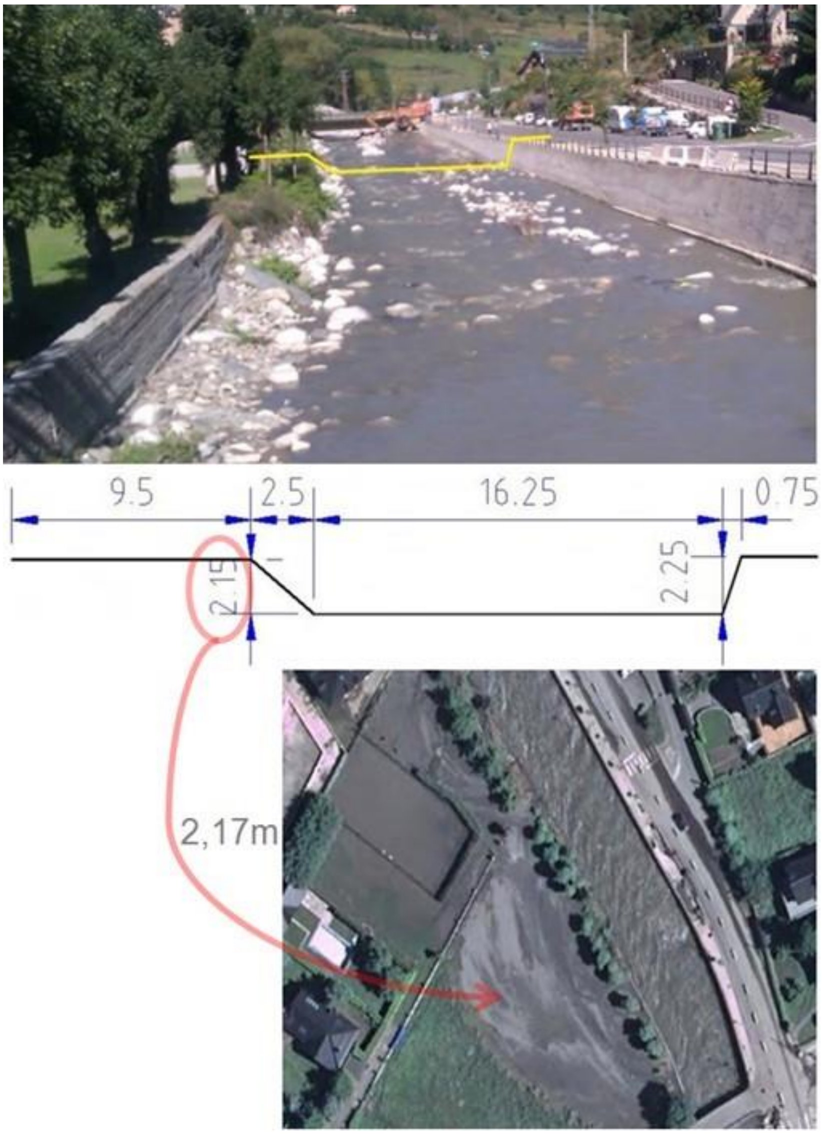


Figure 3-16. Increase in the sheet water level of the Garonne River passing in its way through Vielha e Mijaran.

3.2.3 **Videos of the flood incident**

The list below provides a collection of videos of the floods of the Garonne River that can be useful to grasp a better idea about the nature of its impacts:

- http://www.ccma.cat/324/un-any-de-les-inundacions-a-la-vall-daran/noticia/2428953/
- https://www.youtube.com/watch?v=3fvMXtFDybU
- https://www.youtube.com/watch?v=GInJJEo3Dj8
- https://www.youtube.com/watch?v=eyGCWVFOrmc&t=5s
- https://www.youtube.com/watch?v=Ph9VrUIaUTw&t=312s

3.3 Risk and behaviour analysis

The occurrence of flooding events can be seen as an opportunity to gain an understanding on the nature of hazard, and, as a result, plan, target, and prioritize actions to mitigate and manage the vulnerabilities identified in the territory. To that end, preliminary assessments performed on the area of interest are analysed to know analyse whether the flooding impact during the past incident in 2013 was actually greater on those areas that had previously been identified as areas of potential flood risk[1].

3.3.1 Analysis of data on flood causality

The causative factors of the exceptional growth of the Garonne and the resulting floodings are mainly due to the conjunction of two factors, thaw and precipitation:

- Winter precipitation in the 2012-2013 season exceeded by 200% the climatic average registered by the XEMA (SMC) resulting in remarkable accumulation of snow.
- May and June were relatively cold (average values of 2ºC below the climatic average) until the temperature suddenly rose grew from the 11th of June.
- Late thaw after a season with plenty of snow with still remains of snow at the beginning of summer at levels above 2000 m.
- A warm air mass of approximately 20ºC in levels of 1,500 m (850 hPa) on the 17th of June.
- Precipitation above the climatic average, especially on the 17th and 18th of June, with values greater than 100 mm.
- Anticipated high flow. Before the precipitations the river already presented a high flow of 125 m^3/s.

3.3.2 Areas of Potential Significant Flood Risk (ARPSI)

The Garonne River, as well as its confluence with the Nere River and the Ravine of Deth Meligar de Casau, is considered as an Area of Significant Potential Flood Risk (ARPSI) [1].

Table 3-3. Potential Significant Flood Risk Areas (ARPSI) along the Garonne River route.

Name of the ARPSI	ARPSI code	Length ARPSI (km)	Name of the ARPSI subsection	Code of the ARPSI subsection	Length ARPSI Subsection (km)	Municipalities
29.-Garonne	ES091_ARPS_GAR	17.151	The Rivers Malo and Ruda	ES091_ARPS_GAR-01	1.694	Naut Aran
			Confluence between the Garonne River and the Valartíes River	ES091_ARPS_GAR-02	2.905	Naut Aran
			The Garonne River and its confluence with the Nere River and the	ES091_ARPS_GAR-03	5.803	Vielha e Mijaran

[1] Instruments to support the management of emergencies due to natural disasters related to floods following the principles of DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007 on the assessment and management of flood risks on the assessment and management of flood risks (Chapters II, III and IV). Transposed to the Spanish legal system through the Real Decreto 903/2010, 9th of July, related to evaluation and management of flood risk.

			Ravine of Deth Meligar de Casau			
			Garonne River	ES091_ARPS_GAR-04	3,769	Es Bòrdes and Vielha e Mijaran
			The Garonne River and its confluence with the Ravine of Casteràs	ES091_ARPS_GAR-05	1,688	Bossòst
			Garonne River	ES091_ARPS_GAR-06	1,293	Les

The consideration of Garonne River as an ARPSI is due to the preliminary assessment of the flood risk made by the Ebro Hydrographic Confederation (

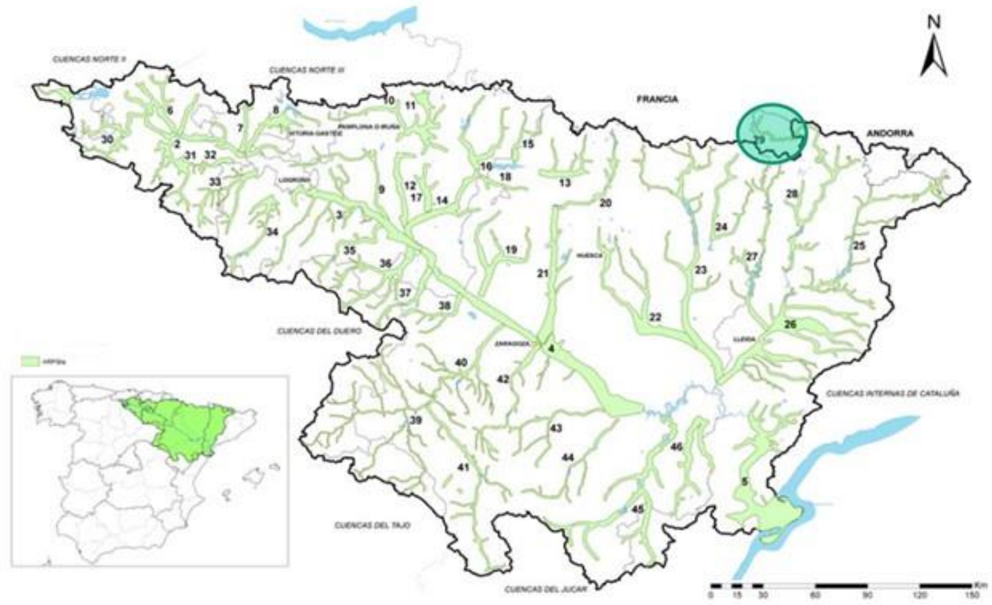


Figure 3-17) [2].

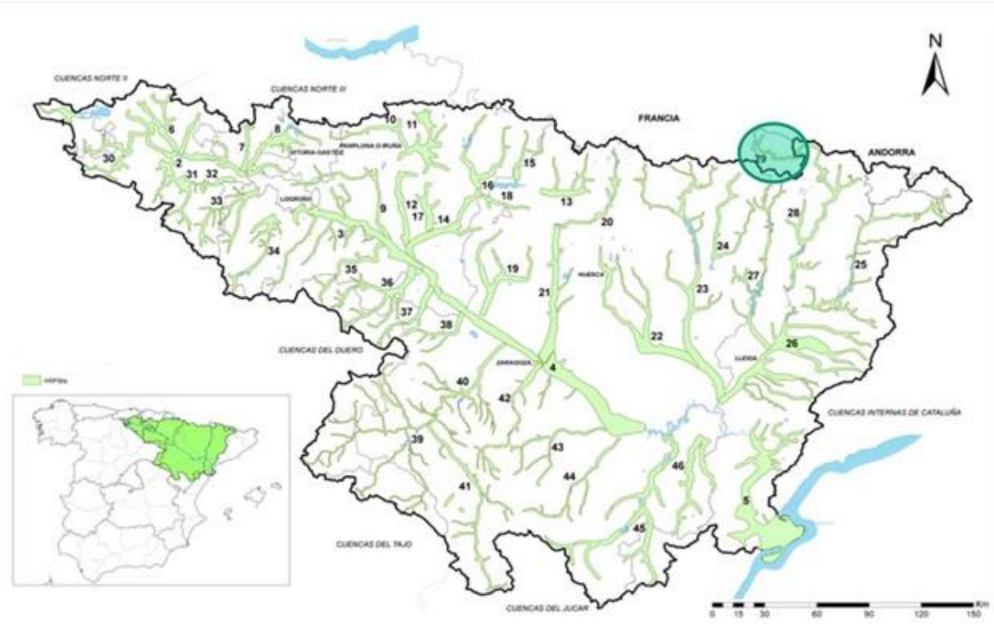


Figure 3-17. Areas of Potential Significant Flood Risk (ARPSI) within the Hydrographic Confederation of the Ebro.

To assess the risk of flooding it is necessary to combine and analyse the probability of a flood and the impact of potential negative consequences. A series of data were collected to that help in the prediction and the evaluation of flood behaviour, the identification of critical points, and the delimitation of flood zones:

- Meteorological data and other parameters: depth of water, speed, energy, flow, duration of the flood, level of the sheet of water, rainfall, level of snow at high altitudes, water temperature, humidity, environmental temperature, etc. Depending on the type of flood (flash floods, groundwater floods, coastal floods), some parameters will be more important than others. For instance, atmospheric pressure can be more useful for coastal floods.

- Frequency of flood-related catastrophic events: floodplains of past events can be mapped.

- Hydrogeology, hydraulics and hydrology: hydrological characteristics, statistics, return period, hydrological methods, hydraulic cartography...

- Geological and geomorphological data: morphological features and geological characteristics of the land, transfer data to topographic maps, geomorphological cartography.

- Simulated data: Dynamic water flow simulations use as an input data such as land use, soil moisture before rainfall, maximum flow, the height of the level of the water layer, etc.

- Negative impacts: evaluation of the possible negative impacts on human health, the environment, infrastructures, cultural heritage, economic activities, etc.

- Protective measures: Evaluation of protective measures to protect people against the risk of flood.

- Flood risk mapping: zoning of the fluvial spaces and creation of flood hazard maps and flood risk maps from different sources and types of data.

3.3.3 **Analysis of Return Periods**

The authorities that are responsible for civil protection, water resources, and spatial planning have mapped the areas defined as flooding points associated with a return period

(INUNCAT). The return period can be defined as the total time elapsed from the time a flood event occurs to the time another flood event of the same magnitude occurs again. Hydrological analysis in the study area available at INUNCAT special plan have determined different return periods for the Garonne River through the locality of Vielha e Mijaran (Figure 3-18).

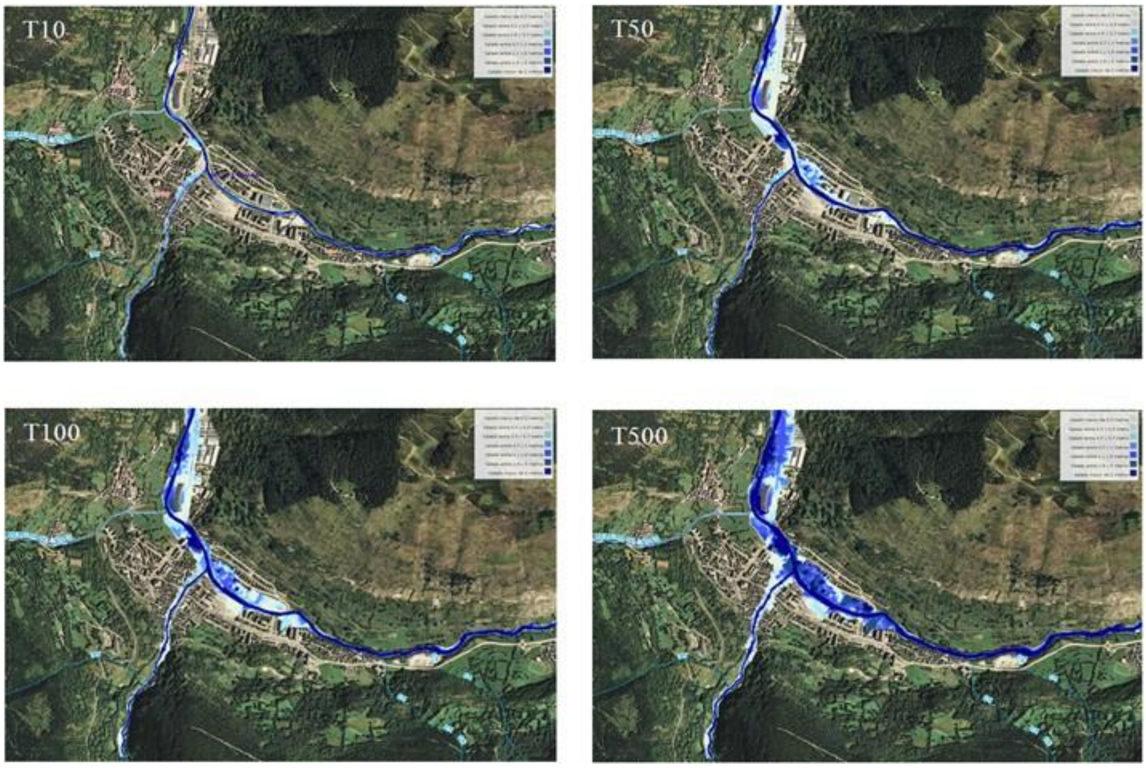


Figure 3-18. Flooding zones around Vielha e Mitjaran classified by return periods of 10 years (T10), 50 years (T50), 100 years (T100), and 500 years (T500).

Rainfalls can be associated with return periods in order to get a better understanding of the intensity of the flood event in the Garonne River in 2013. Along these lines, Figure 3-19 shows the maximum rainfall in 24 hours for return periods of 10 and 25 years. As exposed before, the maximum rainfall in 24 hours in Vielha e Mijaran was 101.2 mm (see Table 3-2), which took place on the 18th of June 2013. As observed in Figure 3-19, for a return period of 10 years, the maximum daily precipitation in the town of Vielha e Mijaran ranges between 83 and 88 mm, which is significantly lower than the precipitation recorded on the 18th of July Whereas for a return period of 25 years, the maximum daily precipitation ranges between 103 and 108 mm, which is slightly more than the precipitation recorded on the 18th of July. As a conclusion, the return period for the occurrence of heavy precipitations that gave rise to the floods of 2013 in Viella and Mijaran is nearly 25 years.

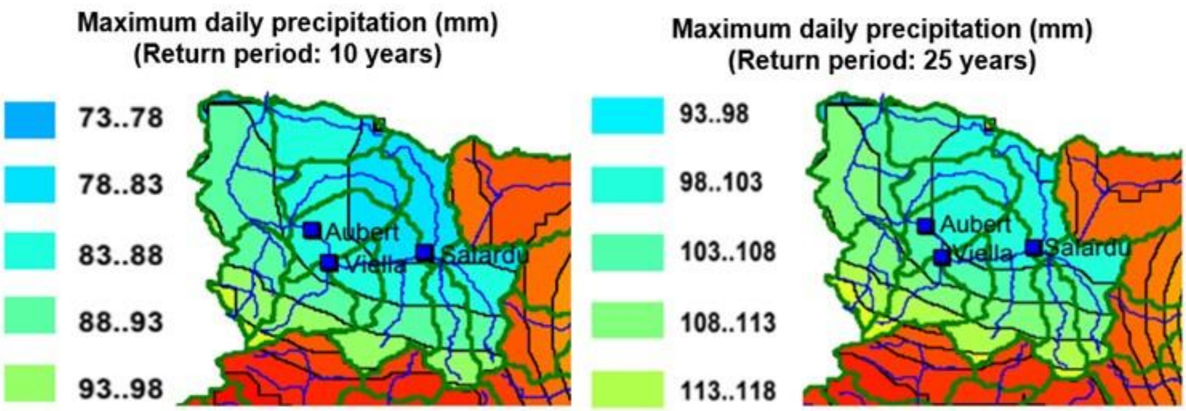


Figure 3-19. Maximum daily precipitation estimates (mm) in the area of Vielha and Mijaran for a return period of 10 years (left) and 25 years (right).

3.3.4 Critical flooding points, vulnerable elements and priority action points

While the Areas of Potential Significant Flood Risk allow to assess the risk of flooding at the river basin scale, the critical flood points do the same at a smaller (town) scale. Table 3-4 lists the critical flooding points along the Garonne River that affect the municipality of Vielha e Mijaran [1].

Table 3-4. Critical flood points in the Garonne River affecting the municipality of Vielha and Mijaran.

Code	Municipality	River	Potential danger	Level of risk
CA-L25243-55-01	Vielha e Mijaran	Barranc de Casau	**Flood in an urban area** River with a steep slope and abundant material transport. In 1982 there were problems of overflows in Vielha.	High
GA-L25243-55-01	Vielha e Mijaran	Garonne	**Flood in an urban area** Bed of the river with low drçainage capacity.	High
GA-L25243-55-02	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	High
GA-L25243-55-03	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction..	High
GA-L25243-55-04	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	High
GA-L25243-55-05	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	High
GA-L25243-55-06	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	High
GA-L25243-55-07	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	High
GA-L25243-55-08	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of	High

			obstruction.	
GA-L25243-55-09	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	High
GA-L25243-55-10	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	Medium
GA-L25243-55-11	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	High
GA-L25243-55-12	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	Low
GA-L25243-55-13	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	Low
GA-L25243-55-14	Vielha e Mijaran	Garonne	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	Low
NE-L25243-55-01	Vielha e Mijaran	Nere	**Flood in an urban area** From the lock on the Nere river until its flows into the Garonne River, the conditioning is not adequate. In case of avenue can cause damage in the urban area of Vielha.	High
NE-L25243-55-02	Vielha e Mijaran	Nere	**Flood in a communication route** Structure with a capacity less than a flood flow for the return period of 500 years and/or potential danger of obstruction.	High

Critical flooding points allow for the identification of Vulnerable Elements (VE) present in the study area. Hence, the study area corresponds to a zone prone to be affected by flooding of the Garonne River, or its tributaries (e.g. Nere River). Most of the inhabitants of the municipality and infrastructures are concentrated within this zone.

The Vulnerable Elements within the study area are listed below in Table 3-5 and located in the map in Figure 3-20:

Table 3-5. List of Vulnerable Elements in the town of Vielha e Mijaran. In green, VE that were impacted by the Garonne River floods in 2013. In red, VE that required higher priority warnings as their occupants are not self-sufficient in case of evacuation/confinement.

Code	Vulnerable Element	Code	Vulnerable Element
VE-17	Pompièrs-Bombers - Firefighters	VE-49	Association of the mentally handicapped in Aran (ADDA)

VE-18	Riding school	VE-51 (Figure 3-21)	Hotel Acevi-Val d'Aran
VE-20 (Figure 3-21)	Football field	VE-52	Hotel Eth Solan
VE-21	Cinema	EV58	Hotel Orla
VE-22	Era Cunhera School	VE-59	Hotel Aran
VE-25	Multipurpose room of Vielha	VE-60	Hotel Urugallo
VE-26	General Council of Vielha e Mijaran	VE-61	Hotel Sol Melià
VE-28	Vielha Hospital	VE-68	Aparthotel Refugi deth Aran
VE-29	Vielha Town Hall	VE-69	Hotel Baricauba
VE-31	Nursing home	VE-70	Hotel Ribaeta
VE-32	Sports hall	VE-71	Hotel Fonfreda
VE-33	Sports Centre	VE-72	Hotel Albares
VE-35	General Library of Vielha	VE-73	Hotel Anglada
VE-36	Aran IES High School	VE-74	Val d'Aran Museum
VE-38	Nusery School – CEIP Garonne		

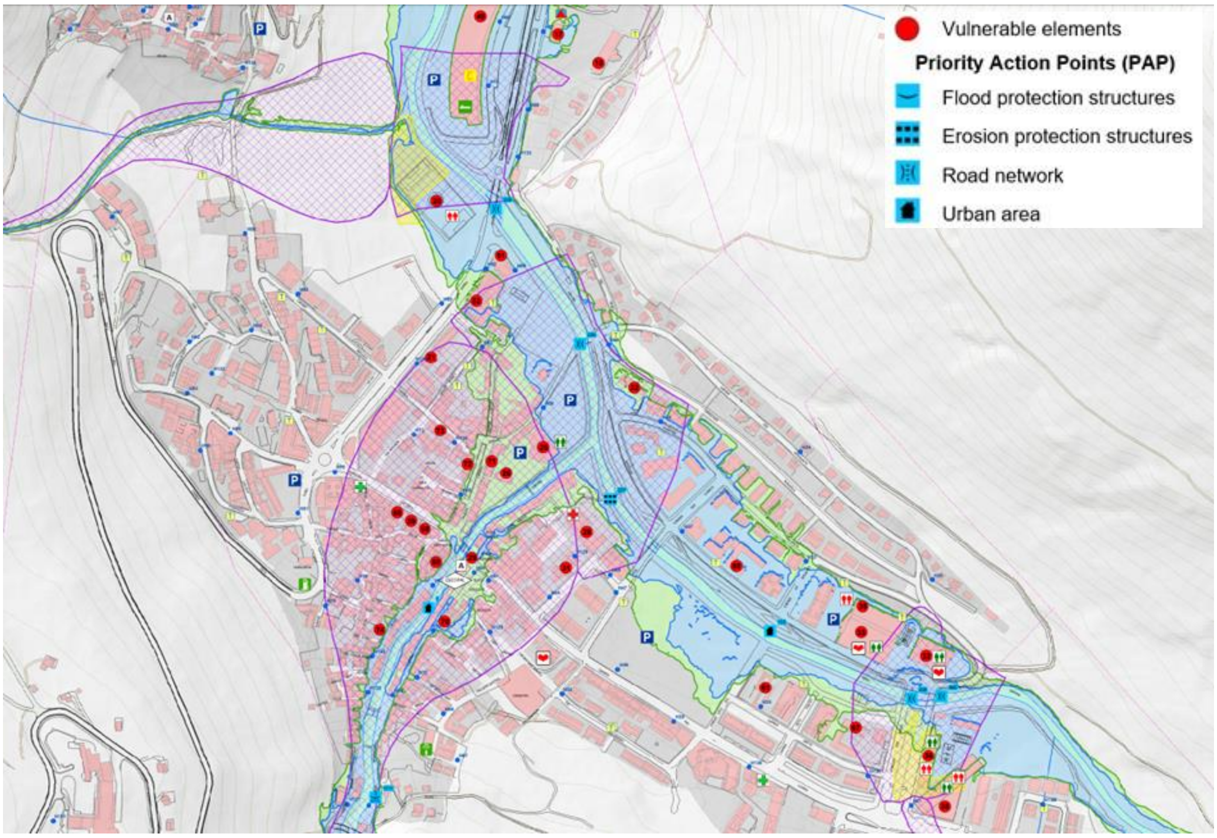
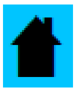
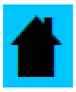
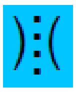


Figure 3-20. Location of Vulnerable Elements and Priority Action Points in Vielha and Mijaran.

Finally, identifying VE allows for the allocation of Priority Action Points (PAP), i.e. target areas where river avenues and landsclides can affect people, structures, critical infrastructures, basic services... Due to their intrinsic risk, PAP are meant to be used operationally to derive emergency management actions (e.g. road blockage, evacuation, increase of drainage, etc.). Therefore, emergency response services need to focus their attention on these areas in the event of floods. Table 3-6 lists the PAP within the study area, whose symbols serve to locate them on the map of Figure 3-20 and in the image of Figure 3-21.

Table 3-6. List of Priority Action Points (PAP) in the town of Vielha e Mijaran. In green, PAP that were implemented during the Garonne River floods in 2013.

Priority Action Point (PAP)	Symbol	Name	Description	Typology
PAP 1		Nere Basin. Nere River	Floods in urban areas	Urban area
PAP 133		Garonne Basin. Garonne River	Floods in urban areas	Urban area
PAP 226		Bridge on the Av. deth Solan (east) in Vielha on the Garonne River	Bridge Av. deth Solan	Communication routes

PAP 227		Pedestrian footbridge to Vielha (hospital area) on the Garonne	Pedestrian footbridge access to Vielha	Protection structures against erosion
PAP 228 (Figure 3-21)		Bridge C. Querimònia in Vielha on the Garonne River	Bridge C. Querimònia	Communication routes
PAP 229 (Figure 3-21)		N-230 national road (bridge between Vielha and Mijaran on the Garonne River)	N-230 national road	Communication routes
PAP 964		Route inside Betren	Route inside Betren	Communication routes
PAP 965		Bridge Av. deth Solan (west) in Vielha on the Garonne River	Bridge Av. deth Solan (west)	Communication routes
PAP 1711		Lock of Vielha. Nere River.	Critical point due to lack of connectivity. (ecological quality of the fluvial space)	Flood protection structures
PAP 1839		Garonne and Nere river on their way through Vielha	The occupation of floodable areas	Flood protection structures

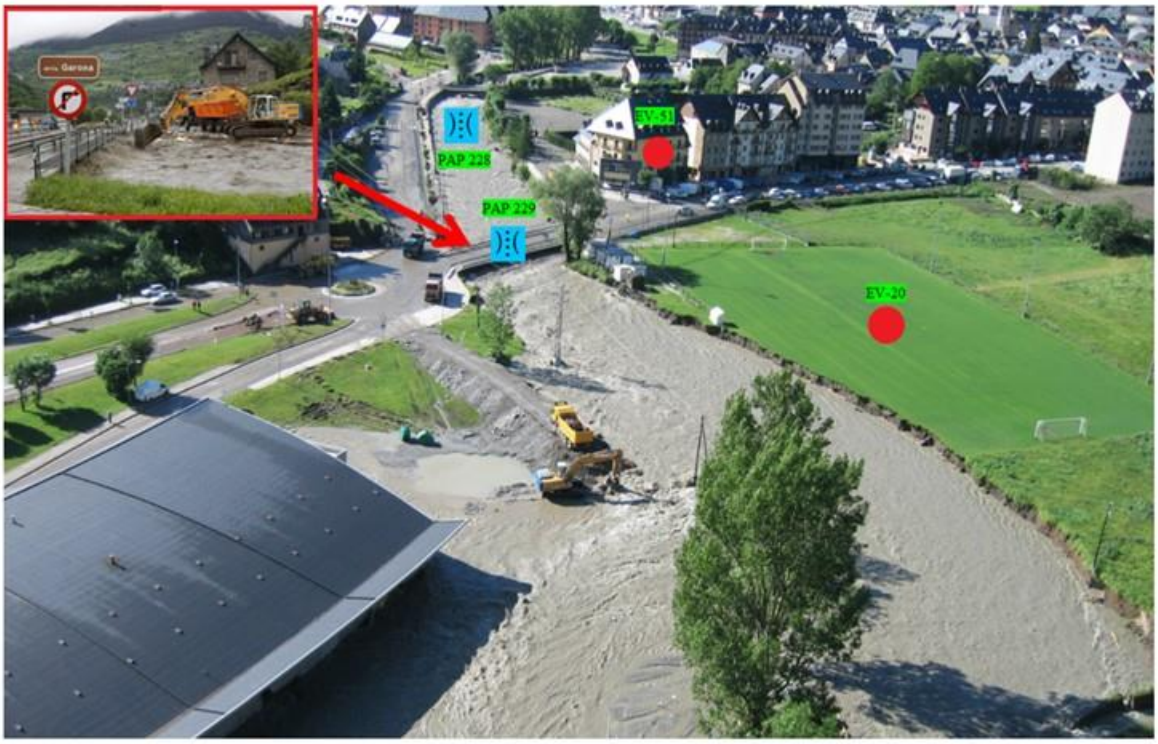


Figure 3-21. Vulnerable Elements affected and Priority Action Points implemented during the Garonne River floods in 2013.

3.3.5 **Landslides**

The floods were not the only risk affecting the area. The copious rainfall triggered other hazardous event in a cascade effect; namely, landslides, torrential mass movements (especially debris flows) and an increase in the alluvial fan activity (see Figure 3-22). The geological characteristics of the terrain and the soil, in combination with the power of rainfall, had influence on the occurrence of these events [7]. The cascading effect had a greater impact on areas with high erodibility (see Figure 3-6).

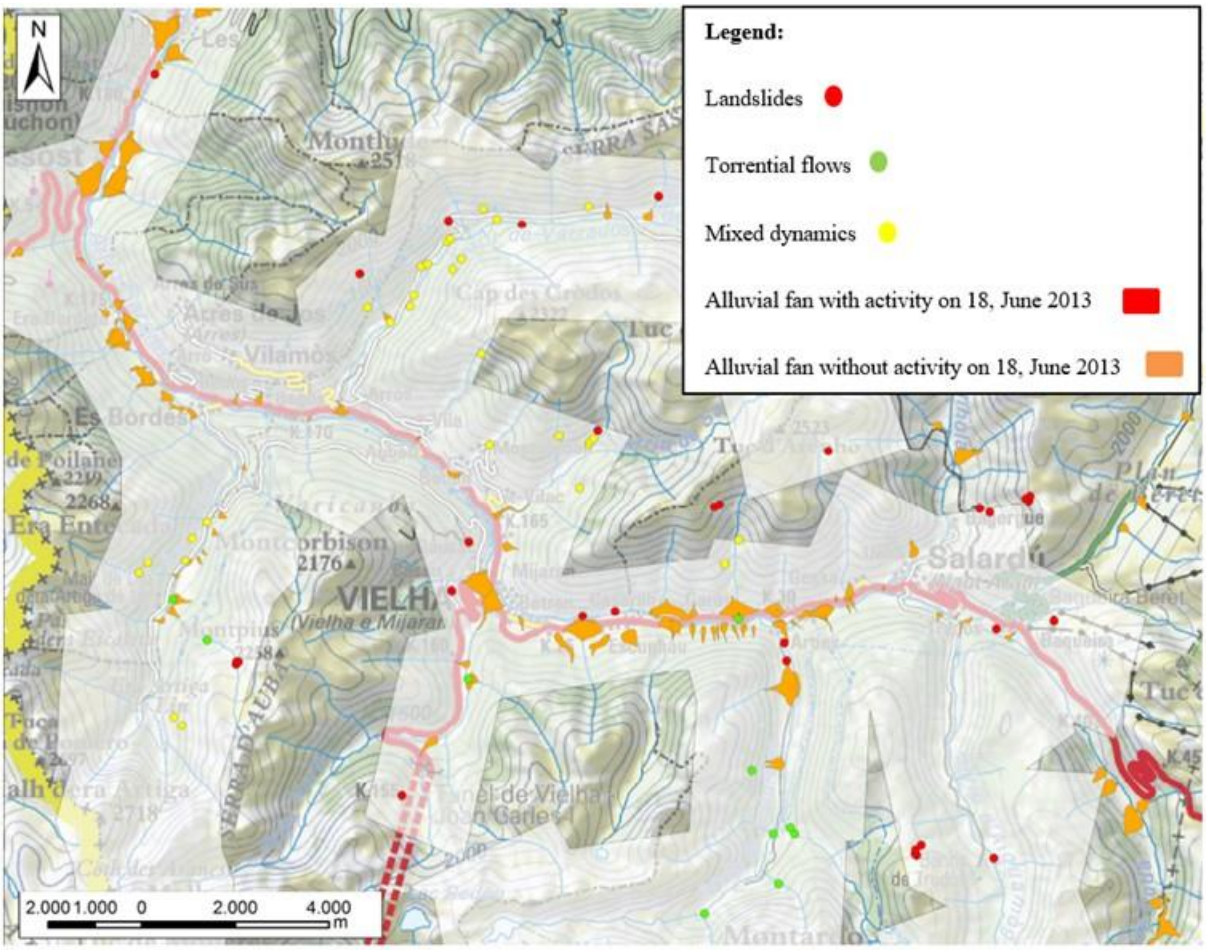


Figure 3-22. Landslides, torrential flows, and activity of alluvial fans triggered by the Garonne floods on the 18th of June 2013.

3.4 Operations and impacts

On the 14th of June, Civil Protection activated the **Pre-Alert** phase of INUNCAT (The basic structure of the INUNCAT plan is described in Annex A. The INUNCAT plan) due to persistent rains and the swelling of Garonne River in the region of Val d'Aran. The flow of the river had increased by 60% in just one week.

Preventive and operating tasks that were carried out during the Garone river floods, associated with each of the response levels defined by INUNCAT, are outlined below:

Tracking information:

1. CECAT communications.
2. Weather information: http://www.meteo.cat/prediccio/.
3. Gauging stations[2] along the Garonne River managed by the General Council of the Aran Valley: Tredòs, Betren, Aubèrt, Pònt deth Lop, and Les. Live monitoring of these gauging stations can be accessed at the following link: http://www.conselharan.org/nivel-de-los-rios/.

[2] Gauging stations are strategically located along the river to obtain systematic observations of gauge height (water level) or discharge.

4. Gauging stations along the Garonne River managed by the CHE: A200, A143, and A019. Live monitoring of these gauging stations can be accessed at the following link: http://195.55.247.237/saihebro/index.php?url=/datos/mapas/tipoestacion:A/localizar:A143
5. State of the road network: http://cit.transit.gencat.cat.

Interactive communication:

Telephone and radio communications via the RESCAT network (Radio communications of Emergencies and Security of Catalonia), and information exchange with the CAT112 emergency centre.

Surveillance:

Increase of surveillance in the following special risk areas (based on risk maps of INUNCAT):

- Urban areas under high flooding risk: Vielha, Mijaran, Casarilh, Aubèrt and Pont d'Arròs.
- Urban areas under risk by alluvial fans: Vielha, Mijaran and Pont d'Arròs.

Identification of VE:
Warn and report other VE affected by flood risk based on forecasts for the incident area.

Actions at PAP:

The following preventive actions were planned as part of the "pre-alert" phase of INUNCAT:

- Signage at critical flooding points.
- Road closures to control vehicle access to certain areas.
- Dissemination of warnings across the critical flooding points to encourage public to take appropriate protective actions.

During the early hours of the 18th of June, Civil Protection activated the **Alert** phase of INUNCAT due to occasional overflows of the Garonne because of the rain. Emergency services issued preventive evacuation in some campsites of the area. Also, the N-230 was closed to traffic from Vielha up to the French border. The region of Val d'Aran was at that time isolated by road due to floods and traffic restrictions. In Vielha water level had overflowed the bridge of the road N-230. The Incident Command Post was located at the Pompiers d'Aran (fire and rescue services of Aran) headquarters. That afternoon, Civil Protection activated the **Emergency** phase of INUNCAT.

As part of the **Alert** and **Emergency** phases of INUNCAT, the following actions were carried out during the incident:

- Activation of the flood plan included in the DUPROCIM (Municipal Civil Protection Plans) and communicate the action to the CECAT.
- Permanent communication with CAT112.
- Formation of the municipal Emergency Committee and the CECOPAL (Centre for Municipal Emergency Coordination). Activation of local Action Groups.
- Interactive communication through the platform RESCAT.
- Permanent monitoring of the situation, surveillance operations, and communication with the CECAT.
- Protective actions by the fire brigade at the VE based on forecasts for the endangered area.
- Development by firefighters of PAP included in the INUNCAT plan (see Figure 3-20).
- Blockage or control the access to the following roads:
    - Road access to areas near the River Varradòs.
    - Areas near the Joèu River in coordination with the municipality of Es Bòrdes.
- Closure of urban footpaths by the river.
- Suspension of outdoor events near the river.

- Public warnings to walk away from flood areas and move to safe place.
- Withdrawal of at-risk elements that can be dragged by water, such as vehicles...
- Warnings at the VE and request for special needs.
- Cleaning of the local road network (remove clay and broken trees).
- Notification of evacuations, definition of shelter locations, and assistance to evacuees.
- Registration and organization of occasional volunteers.
- Implementation of actions plans for sectors of risk (e.g. Municipal Action Plan) and communication to the CECAT and to the members of the Municipal Emergency Committee.

3.4.1 **Socioeconomic impacts**

While there were no fatalities resulting from the flood, these caused severe damages in the town that led on to widespread socioeconomic impacts. Notably, the floods caused an impact on: exposed population; urban or industrial areas; road network; means of transport; cultural heritage; social and economic assets.

Some of these impacts are illustrated in the maps and images below:

Figure 3-23. Map of flood impacts on an industrial area.

Figure 3-24. Image of flood impacts on an industrial area.

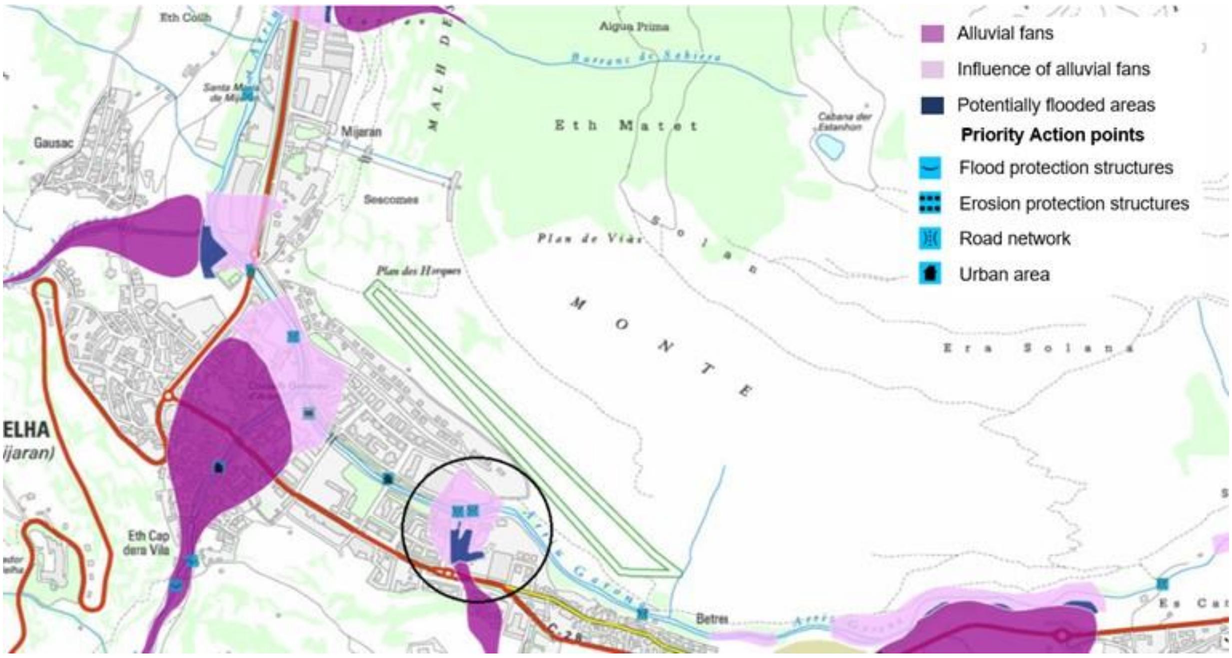


Figure 3-25. Map of flood impacts on a school area.

Figure 3-26. Image of flood impacts on a school area.

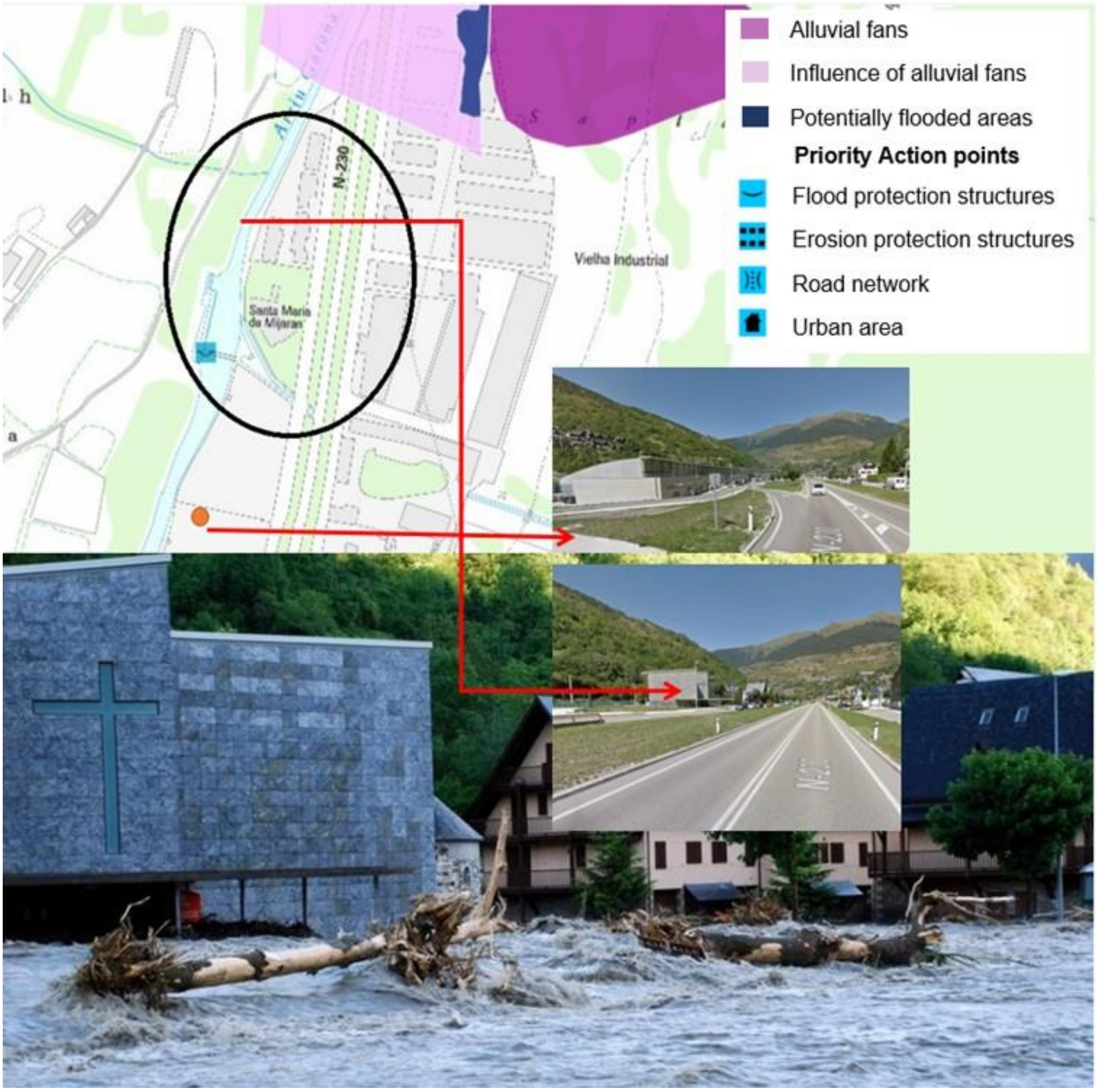


Figure 3-27. Map and images of flood impacts on the road network.

Figure 3-28. Map and images of flood impacts on the road network.

3.4.1.1 Economic costs of the flood incident

Across the municipality of Vielha and Mijaran, different urban areas on either side of the Garonne River were severely affected by flooding. Along these lines, the civil council is responsible for repairing damage. Post-flood recovery costs derived from restoring those affected areas were estimated by the civil council at approximately 517,980.38€ (Table 3-7).

Table 3-7. List of affected areas in Vielha e Mijaran and the approximate repair cost.

Locality	Affected area	Estimated repair cost
Vielha	Maladeta Avenue area	51,712.73€
	Gardens	39,331.93€
	Areas between bridges	41,367.64€
	Mijaran neighbourhood area	Unspecified
	Bridge in Camin Reiau	77,209.01€
	Upper area in Sarriulera Street	13,547.16€
	Garonne Avenue and bridges	55,272.80€
	Access to the municipal services centre	110,800.30€
	Vielha water collection	1,954.15€
	Moncorbison street area	Unspecified
Escunhau	Water harvesting structures	14,452.76€
Vilac	Water harvesting structures	79,176.53€

Aubert	Prats de Mont street area	33,155.37€
Total (approx.)		**517,980.38€**

Moreover, according to the *Consorcio de Compensación de Seguros* (Insurance Compensation Consortium), an instrument that services the Spanish insurance sector, the flooding event affected 275 houses, 145 establishments, 58 vehicles, 21 industrial plants, 11 infrastructures.

Flood damages to industrial plants and infrastructure is remarkable due to considerably high restoration costs. In this case, economic damages were quantified by the *Consorcio de Compensación de Seguros* at approximately 39 million euros. The responsibility to repair these post-flood damages falls on the organisation responsible for the management of the infrastructure in question (Table 3-8).

Table 3-8. Damages to specific infrastructure, their associated repair cost, and the organisation responsible for covering these cost.

Infrastructure	Repair cost	Responsible
Purifiers, water treatment plants, sanitation networks, and electricity supply	7 million euros	Insurance companies; Town council; Government of Catalonia
Regional Roads	5 million euros	Government of Catalonia
National Roads	23 million euros	Ministry of Public Works of the Government of Spain
Defensive walls along the Garonne river basin	4 million euros	CHE (Ebro Hydrographic Confederation)
Total repair costs	**39 million euros**	

4 Entella river Floods

The flood event that affected the Italian region of Liguria from the evening of the 9th November until the morning of the 13th of November, 2014 was due to the passage of a deep trough coming from the West and bringing large quantities of humidity from Africa.

The intense wet advection brought intense and widespread rainfall across the region of Liguria, these being favourable to thunderstorm activity. Copious rainfalls up to 240 mm in 24 hours occured in the localities of Piampaludo and Alpicella.

The long rainfall activity culminated in the overflow of the Entella river basin at several places on its way through Liguria giving rise to a dramatic flood event that collapsed the region in the evening of the 10th of November and caused considerable damage in the municipality of Chiavari and a number of towns in the Entella basin (San Colombano, Leivi, Borzonasca and Carasco). Moreover, the floods triggered numerous landslides that caused damages to homes and infrastructures resulting in the death of two people.

It was also reported an intense downdraft (sudden and violent wind reinforcement as a consequence of the front thunderstorm) that hit the area between Voltri and Prà in the afternoon of the 10th of November, causing the fall of heavy containers full of material. Fortunately this episode did not cause harm to people.

4.1 Data collection

The information collected for the preparation of this case study has been consulted/extracted from the following sources:

Weather data was collected from:

- MetOffice
- EUMETSAT
- Arpal (*Agencia Regionale per la Protezione Ambientale* Ligure)
- OMIRL (*Osservatorio Meteo Idrologico della Regione Liguria)*

Images and videos were collected from:

- Youtube
- Youreporter
- Digital press:
    a. Oggi newspaper: http://www.oggi.it/attualita/notizie/2014/11/11/piove-e-la-liguria-e-di-nuovo-alluvionata-chiavari-e-in-ginocchio-smottamenti-e-frane/.
    b. Savonanews: http://www.savonanews.it/2014/11/15/leggi-notizia/argomenti/finalese/articolo/finale-ligure-frane-in-tutto-il-territorio-chiusa-laurelia-al-porto-e-la-provinciale-del-melogno.html.
    c. Valigliabu: https://www.valigiablu.it/litalia-tra-alluvioni-frane-e-valanghe-i-numeri-di-un-continuo-disastro-annunciato/.
    d. Riviera 24: https://www.riviera24.it/2018/11/frane-e-alluvioni-liguria-tra-le-regioni-piu-a-rischio-e-elevato-in-provincia-di-imperia-575856/.

4.2 Data processing

This section presents the weather data that helped emergency services anticipate the adverse effects of flood hazard, prepare to mitigate its impact and protect the population at risk. This weather data that is presented in this section will be analysed in section 4.3 as part of the risk analysis and behaviour of the flood events.

4.2.1 **Weather data**

In order to present the meteorological data associated with the level of flood risk in Liguria, the emergency services divided the territory into five warning zones as shown in Figure 4-1.

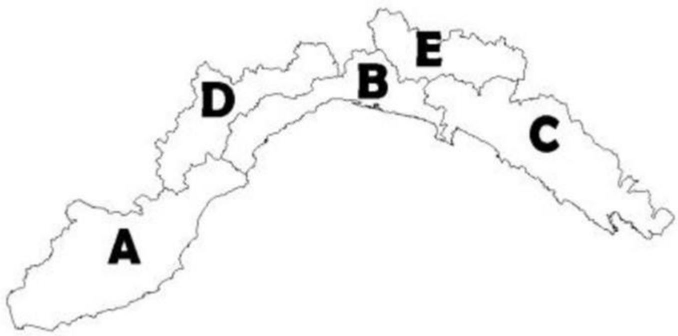


Figure 4-1. Map of Liguria: territorial limits of the five warning zones.

Wetting conditions before the incident

A period of heavy rainfall in the region of Liguria preceded the start of the flood events. When the flood events started, on the 9th of November, the wetting conditions across the region had medium-high values, as shown in the map of the saturation level in the soil generated by the OMIRL (Figure 4-22).

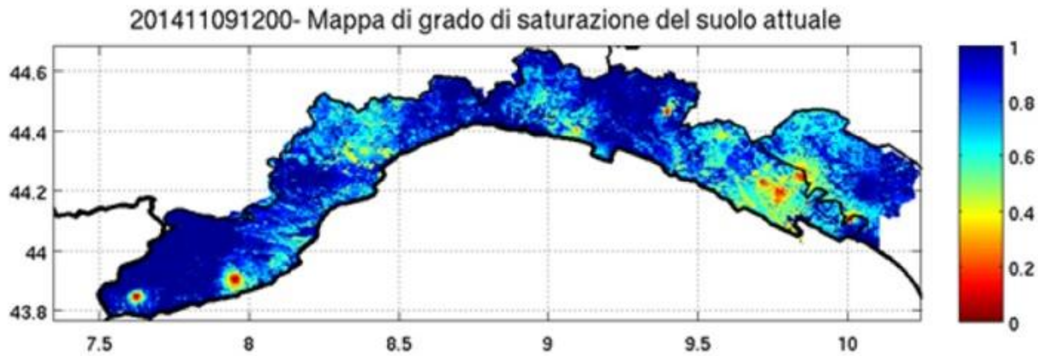


Figure 4-2. Degree of saturation of the soil across the region of Liguria during the 30 days prior to the flood events.

The highest saturation values were identified in areas between Genoa and Savona, particularly in Tigullio/Fontanabuona and its hinterland areas (Trebbia, Aveto) as a consequence of abundant rainfall in the previous days (Table 4-1).

Table 4-1. Average rainfall values 30, 15, and 5 days prior to the start of the floods recorded in the warning zones and in the whole regional territory.

	30 days before	15 days before	5 days before
Zone A	212.4 mm	187.8 mm	135.5 mm
Zone B	294.6 mm	134.1 mm	113.5 mm
Zone C	305.8 mm	161.2 mm	130.7 mm
Zone D	240.8 mm	156.1 mm	110.6 mm
Zone E	493.0 mm	212.6 mm	165.8 mm
Regione Liguria	*286.6 mm*	*170.6 mm*	*130.6 mm*

Rainfall analysis

During the course of the flood events it was possible to distinguish different episodes, each with a different part of the region being affected. To understand that,

Table 4-2 reports the rainfall values recorded on a daily basis over the incident period measured in a number of OMIRL weather stations:

Table 4-2. Daily and total accumulated rainfall for the period 9-12 of November 2014. Provinces: IM-; GE-Genova;

Zona	Stazione	Provincia	09/11/2014	10/11/2014	11/11/2014	12/11/2014	Totale
A	Colle D'oggia	IM	39.6	45.4	153.8	43.2	282.0
A	Castellari	SV	31.0	41.2	141.6	6.8	220.6
A	Albenga - Isolabella	SV	27.0	39.0	140.0	9.2	215.2
A	Colle del Melogno	SV	27.0	21.6	156.0	9.2	213.8
B	Monte Pennello	GE	49.4	63.8	113.6	113.2	340.0
B	Genova - Pegli	GE	71.4	37.4	84.4	119.0	312.2
B	Alpicella	SV	27.0	17.2	237.8	21.6	303.6
B	Stella S. Giustina	SV	22.8	25.0	230.6	11.2	289.6
B	Madonna delle Grazie	GE	36.2	34.2	112.0	102.8	285.2
B	Il Pero	SV	27.6	15.2	222.0	19.6	284.4
B	Viganego	GE	37.8	89.4	65.0	86.6	278.8
B	Genova - S.Ilario	GE	44.0	86.2	60.4	87.0	277.8
B	Sanda	SV	20.8	19.8	217.0	18.6	276.2
B	Fiorino	GE	29.6	22.0	163.0	61.4	276.0
B	Colonia Arnaldi	GE	34.6	137.2	51.0	49.0	271.8
B	Genova - Pontedecimo	GE	44.6	43.6	77.0	83.8	249.0
C	Giacopiane - Lago	GE	32.6	192.4	33.0	24.2	282.2
C	Cichero	GE	23.6	171.4	49.6	30.6	275.2
C	Panesi	GE	27.0	194.2	27.4	26.2	274.8
C	Borzone	GE	33.2	192.8	23.8	15.4	265.2
C	Ognio	GE	34.8	102.6	56.0	57.0	250.4
C	Chiavari - Caperana	GE	27.2	162.0	22.8	23.6	235.6
C	Statale	GE	25.6	166.0	26.4	14.0	232.0
C	Sella Giassina	GE	33.0	95.0	57.4	43.2	228.6
C	Pian dei Ratti	GE	27.2	116.0	53.0	31.2	227.4
C	Croce Orero	GE	27.4	98.8	51.2	36.4	213.8
C	Rapallo	GE	27.8	83.2	64.4	33.6	209.0
D	Urbe - Vara Sup	SV	42.2	22.6	213.4	47.4	325.6
D	Piampaludo	SV	32.4	21.8	234.4	27.2	315.8
D	Praì	GE	36.8	20.6	177.6	52.2	287.2
D	Sassello	SV	18.8	24.2	168.2	12.8	224.0
D	Rossiglione	GE	21.8	16.4	133.4	37.4	209.0
E	Cabanne	GE	28.8	174.4	48.2	29.0	280.4
E	Barbagelata	GE	31.6	134.4	61.6	34.6	262.2
E	Brugneto Diga	GE	30.0	100.4	66.6	31.8	228.8
E	Loco Carchelli	GE	28.6	110.0	50.6	32.8	222.0
E	Torriglia	GE	31.0	89.2	56.2	38.2	214.6
E	Busalla	GE	28.0	59.8	56.6	57.6	202.0

Real-time weather data

The hazardous situations deriving from heavy rainfalls varied amongst the warning zones. For instance, while the Entella river basin received less amount of rain than other basins in central and western parts of the region, it was affected to a great extent by landslide impacts, especially in the area of Chiavari.

The maximum precipitation values recorded during the incident are shown in Table 4-3 in time windows of 1, 3, 6, 12, 24, and 96 hours for each of the warning zones.

Table 4-3. Accumulated amount of rainfall [mm] in the warning zones from the start until the end of the incident.

Warning Zone [UTC]	mm/1 h	mm/3 h	mm/6 h	mm/12 h	mm/24 h	mm/96 h
A	10 [2014/11/11 20:00]	27 [2014/11/11 21:00]	46 [2014/11/11 23:00]	59 [2014/11/12 04:00]	88 [2014/11/12 02:00]	165 [2014/11/13 00:00]
B	10 [2014/11/09 22:00]	28 [2014/11/09 22:00]	39 [2014/11/11 08:00]	66 [2014/11/11 12:00]	115 [2014/11/12 02:00]	225 [2014/11/13 00:00]
C	13 [2014/11/10 21:00]	31 [2014/11/10 22:00]	50 [2014/11/10 23:00]	71 [2014/11/11 02:00]	88 [2014/11/11 07:00]	142 [2014/11/13 00:00]
D	10 [2014/11/11 21:00]	27 [2014/11/11 22:00]	50 [2014/11/12 00:00]	76 [2014/11/12 01:00]	128 [2014/11/12 02:00]	173 [2014/11/13 00:00]
E	11 [2014/11/09 22:00]	29 [2014/11/10 19:00]	52 [2014/11/10 22:00]	73 [2014/11/11 02:00]	120 [2014/11/11 06:00]	205 [2014/11/13 00:00]

The following series of figures display maps of accumulated rainfall for each of the four days of the event, with the last map showing the total accumulated rainfall.

Figure 4-3. Accumulated rainfall from the 9th of November at 00h UTC to the 10th of November at 00h UTC (24h).

Figure 4-4. Accumulated rainfall from the 10th of November at 00h UTC to the 11th of November at 00h UTC (24h).

Figure 4-5. Accumulated rainfall from the 11th of November at 00h UTC to the 12th of November at 00h UTC (24h).

Figure 4-6. Accumulated rainfall from the 12th of November at 00h UTC to the 13th of November at 00h UTC (24h).

Figure 4-7. Accumulated rainfall from the 9th of November at 00h UTC to the 13th of November at 00h UTC (96h).

As said before, the most hazardous situations in terms of landslides occurred during the flood events in the city of Chiavari. This can certainly be notice by observing Figure 4-4, which shows intense rains in this area during this particular day.

River basins whose total accumulated precipitation was reported to the Regional Operations Room during the incident are presented in Table 4-4.

Table 4-4. Maximum amount rainfalls (mm) recorded at different river basin in different time windows (1h, 3h, 6h, 12h, and 24h) between the 9th of November at 00 UTC and the 13th of November at 00 UTC.

Warning Zone	River basin	Max 1 h	Max 3 h	Max 6h	Max 12 h	Max 24 h
A	Nervia alla foce	22 [2014/11/10 14:00]	33 [2014/11/10 14:00]	37 [2014/11/12 01:00]	52 [2014/11/10 15:00]	74 [2014/11/12 02:00]
A	Argentina alla foce	13 [2014/11/11 23:00]	34 [2014/11/11 23:00]	54 [2014/11/12 01:00]	66 [2014/11/12 03:00]	90 [2014/11/12 02:00]
A	Centa a Molino Branca	13 [2014/11/10 15:00]	31 [2014/11/11 21:00]	59 [2014/11/11 23:00]	75 [2014/11/12 04:00]	100 [2014/11/12 02:00]
A	Varatello alla foce	21 [2014/11/11 20:00]	56 [2014/11/11 21:00]	78 [2014/11/11 23:00]	96 [2014/11/11 21:00]	132 [2014/11/12 02:00]
B	Letimbro alla foce	13 [2014/11/11 20:00]	32 [2014/11/11 22:00]	56 [2014/11/11 20:00]	77 [2014/11/11 23:00]	142 [2014/11/11 23:00]
B	Sansobbia alla foce	20 [2014/11/11 04:00]	45 [2014/11/11 21:00]	77 [2014/11/11 22:00]	106 [2014/11/11 21:00]	198 [2014/11/12 01:00]
B	Teiro alla foce	25 [2014/11/11 04:00]	46 [2014/11/11 04:00]	68 [2014/11/11 09:00]	122 [2014/11/11 13:00]	217 [2014/11/12 01:00]
B	Cerusa alla foce	29 [2014/11/12 03:00]	58 [2014/11/12 03:00]	79 [2014/11/12 04:00]	94 [2014/11/12 05:00]	181 [2014/11/12 03:00]
B	Leira alla foce	30 [2014/11/12 03:00]	66 [2014/11/12 03:00]	88 [2014/11/12 04:00]	109 [2014/11/12 09:00]	164 [2014/11/12 03:00]
C	Boate alla foce	26 [2014/11/10 21:00]	47 [2014/11/10 22:00]	75 [2014/11/11 01:00]	93 [2014/11/11 03:00]	130 [2014/11/11 04:00]
C	Entella a Panesi	26 [2014/11/10 21:00]	65 [2014/11/10 21:00]	95 [2014/11/10 23:00]	128 [2014/11/11 03:00]	159 [2014/11/11 07:00]
D	Erro al confine regionale	17 [2014/11/11 04:00]	42 [2014/11/11 22:00]	71 [2014/11/11 22:00]	105 [2014/11/12 01:00]	184 [2014/11/12 01:00]
D	Orba a Tiglieto	19 [2014/11/11 11:00]	36 [2014/11/12 01:00]	64 [2014/11/12 03:00]	104 [2014/11/11 15:00]	200 [2014/11/12 03:00]
D	Stura a Rossiglione	21 [2014/11/12 03:00]	47 [2014/11/12 03:00]	72 [2014/11/12 04:00]	89 [2014/11/12 06:00]	154 [2014/11/12 03:00]

Further rainfall data

Cumulative total values of precipitation recorded by the weather stations show high levels of rainfall concentrated in the central parts of Liguria (Zones B, E, and western part of C). However, the severity of landslide impacts is not only due to the total accumulated rainfall, but also to the intensity of rainfalls lasting between 3 and 6 hours, which took place on the 10th of November and mostly occurred in the Entella basin and its surroundings. Maximum values were observed in Giacopiane, 129 mm/3h, and in Panesi, 166 mm/6h.

The following table shows the maximum values recorded by weather stations located in each of the 5 warning zones, for sub-hour durations (10min, 30min, 1h), for the usual durations of more than an hour (3h, 6h, 12h, and 24h), and for the total duration of the event (96h).

Table 4-5. Maximum precipitation values (mm) for different time durations recorded at the weather stations between the 9th of November at 00h UTC and the 13th of November at 00h UTC.

Zona	Max 10 min	Max 30 min	Max 1 h	Max 3 h	Max 6 h	Max 12 h	Max 24 h	Max 96 h
A	21.0 Seborga 10/11/2014 13:40	38.2 Ceriana 10/11/2014 14:05	46.8 Ventimiglia 10/11/2014 13:45	99.2 Colle Oggia 11/11/2014 22:35	140.6 Colle Oggia 12/11/2014 01:25	157.2 Colle Oggia 12/11/2014 02:45	176.4 Colle Oggia 12/11/2014 02:45	282.6 Colle Oggia 13/11/2014 00:00
B	26.4 Colonia Arn. 10/11/2014 10:25	49.2 Colonia Arn. 10/11/2014 10:30	64.6 Colonia Arn. 10/11/2014 10:35	104.8 Ge Pegli 12/11/2014 03:20	128.0 Ge Pegli 12/11/2014 03:30	150.6 Stella S. Giustina 11/11/2014 21:25	241.6 Alpicella 12/11/2014 01:50	340.2 M. Pennello 13/11/2014 00:00
C	19.6 Bargone 10/11/2014 22:40	40.2 Statale 10/11/2014 21:55	67.2 Panesi 10/11/2014 20:30	129.0 Giacopiane 10/11/2014 20:35	166.0 Panesi 11/11/2014 00:05	198.8 Panesi 11/11/2014 01:50	211.2 Panesi 11/11/2014 13:10	282.4 Giacopiane 13/11/2014 00:00
D	11.8 Piampaludo 11/11/2014 10:20	21.2 Urbe Vara S. 11/11/2014 14:30	30.8 Urbe Vara S. 11/11/2014 14:30	57.4 Piampaludo 11/11/2014 10:30	90.8 Monte Settepani 11/11/2014 23:20	132.6 Piampaludo 11/11/2014 18:30	242.4 Piampaludo 12/11/2014 01:30	329.0 Urbe Vara S. 13/11/2014 00:00
E	19.6 Cabanne 10/11/2014 18:20	46.4 Cabanne 10/11/2014 18:20	58.0 Cabanne 10/11/2014 18:50	100.0 Cabanne 10/11/2014 20:50	131.4 Cabanne 10/11/2014 22:30	154.4 Cabanne 10/11/2014 22:30	194.8 Cabanne 11/11/2014 06:50	280.6 Cabanne 13/11/2014 00:00

Following are a series of histograms associated with the weather stations in each zone with the maximum precipitation values recorded by the end of the event (Max. 96h):

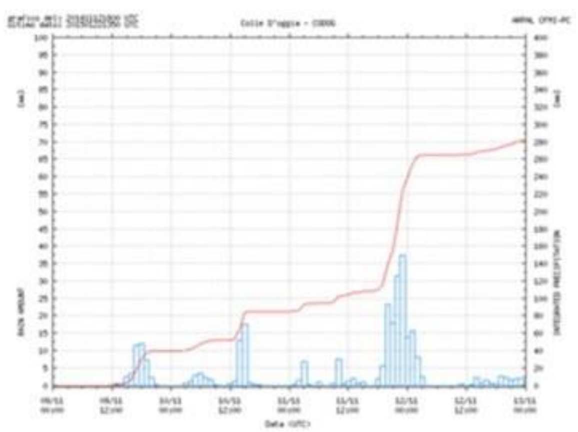


Figure 4-8. Rainfall data in Colle d'Oggia (Zone A). Blue bar: hourly accumulated rainfall; red line: total accumulated rain.

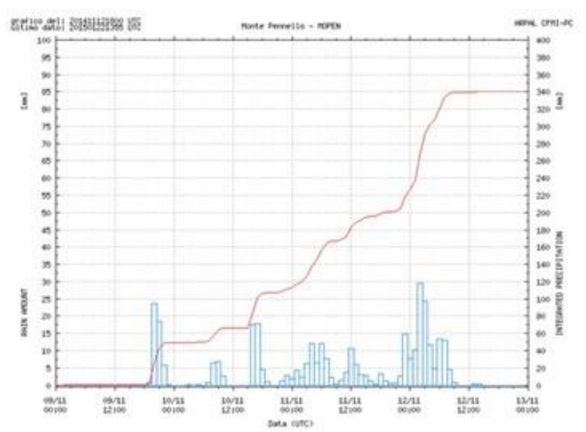


Figure 4-9. Rainfall data in Monte Penello (Zone B). Blue bar: hourly accumulated rainfall; red line: total accumulated rain.

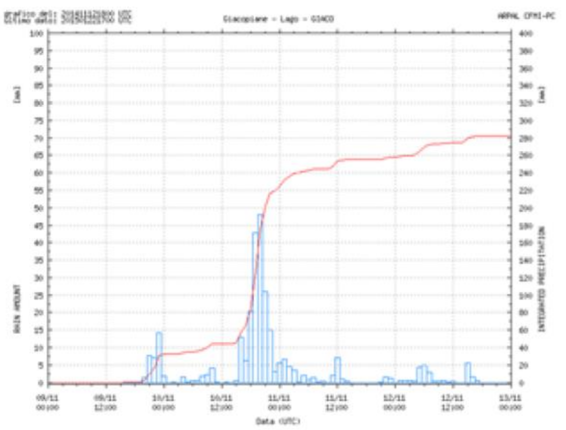


Figure 4-10. Rainfall data in Giacopiane Lago (Zone C). Blue bar: hourly accumulated rainfall; red line: total accumulated rain.

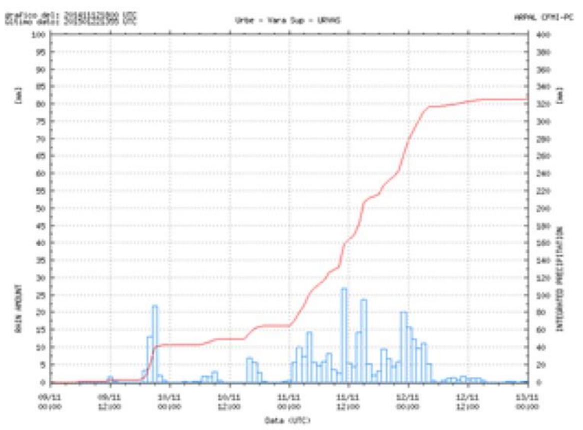


Figure 4-11. Rainfall data in Urbe Vara Superiore (Zone D). Blue bar: hourly accumulated rainfall; red line: total accumulated rain.

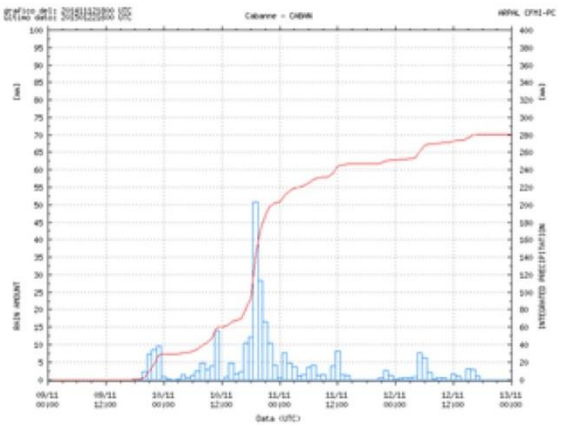


Figure 4-12. Rainfall data in Cabanne (Zone E). Blue bar: hourly accumulated rainfall; red line: total accumulated rain.

Hydrometric analysis

Hydrometric analyses are aimed at examining the levels of water along different river sections as a consequence of the rainfall episodes. In general, the increase in the level of water was notorious in a large part of the region of Liguria, with most of the peaks concentrated in the river sections where the floods occurred (in particular, the Entella river basin).

Table 4-6 shows the maximum level of water recorded at the flood peak and the increase in the water level for a selection of water courses that were monitored.

Table 4-6. Hydrometric data along different points of the water courses in Liguria.

Zone	Hydrometric station	Highest water level (m)	Time (UTC) of flood peak	Increase in the water level (m)
A	Nervia a Isolabona	2.53	11/11/2014 21:45	1.65
A	Armea a Valle Armea	2.02	10/11/2014 15:15	1.26
A	Arroscia a Pogli di Ortovero	5.51	12/11/2014 00:45	5.02
A	Neva a Cisano sul Neva	2.81	12/11/2014 01:15	1.73
A	Centa a Molino Branca	4.54	12/11/2014 01:45	3.66
B	Teiro a Il Pero	2.14	11/11/2014 10:15	1.76
B	Leira a Molinetto	2.63	12/11/2014 03:00	1.92
C	Sturla a Vignolo	4.52	10/11/2014 21:00	3.49
C	Lavagna a Carasco	8.33	10/11/2014 22:00	7.00
C	Graveglia a Caminata	2.41	10/11/2014 23:30	1.81
C	Entella a Panesi	6.39	10/11/2014 22:30	7.23
C	Gromolo a Sestri Levante	1.77	10/11/2014 23:45	1.83
C	Petronio a Sestri Levante Sara	2.32	10/11/2014 23:30	2.20
D	Bormida di Spigno a Piana Crixia	3.72	12/11/2014 01:30	3.07
D	Stura a Campoligure	2.81	12/11/2014 03:30	1.77
E	Aveto a Cabanne	1.49	10/11/2014 21:30	1.74

The figures below show the trend observed in the water level for the stations in Table 4-6 recording the highest increase in the level of water:

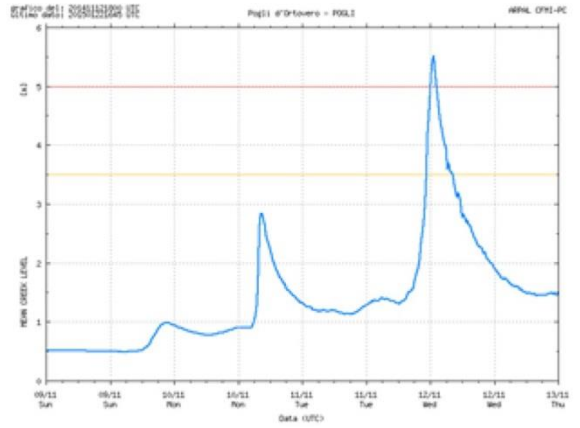


Figure 4-13. Evolution of the water level in Arroscia a Pogli do Ortovero.

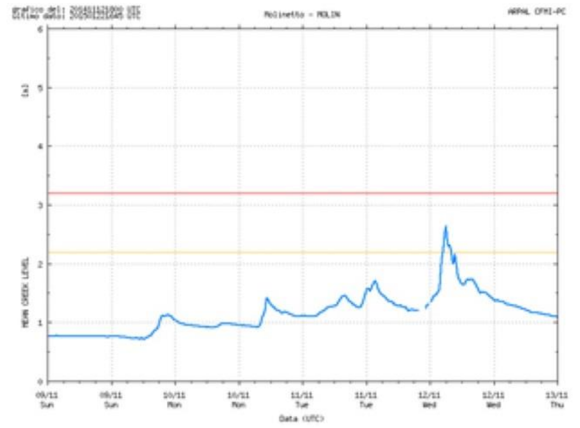


Figure 4-14. Evolution of the water level in Leira a Molinetto.

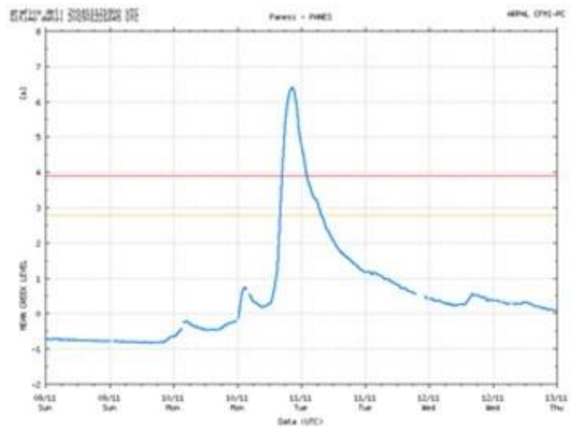


Figure 4-15. Evolution of the water level in Entella a Panesi.

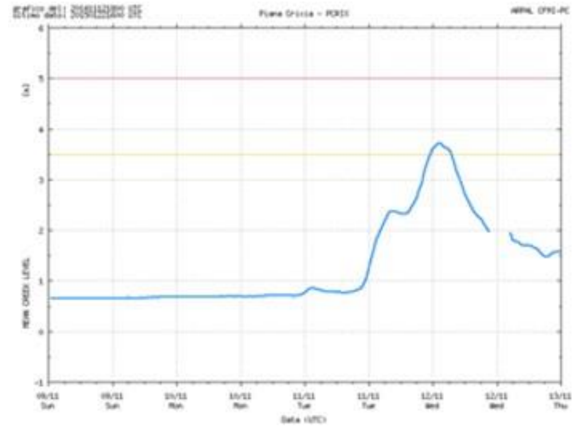


Figure 4-16. Evolution of the water level in Bormida di Spigno a Piana Crixia.

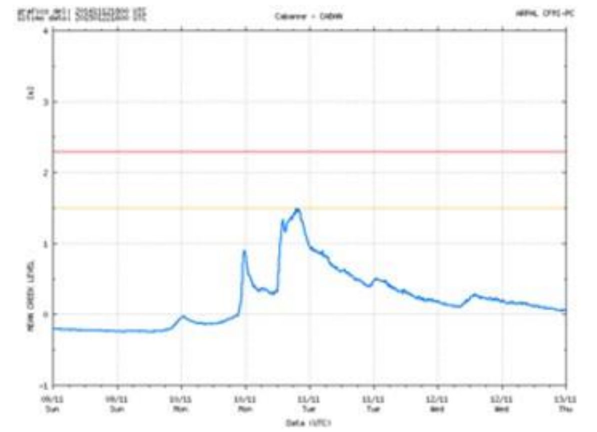


Figure 4-17. Evolution of the water level in Aveto a Cabanne.

Anemometric analysis

In the eastern part of Liguria winds were predominantly coming from the south, reaching strong intensities that were associated with a typical stormy trough patterns and significantly high gusts. On the other hand, in the central and western parts of the region winds were predominantly coming from the north with frequent gusts going from moderate to strong.

Sustained air masses coming from the north converged with southern air masses and rose together in an updraft leading to cloud formation, as happened in the evening of the 10th of November in Tigullio (Figure 4-18).

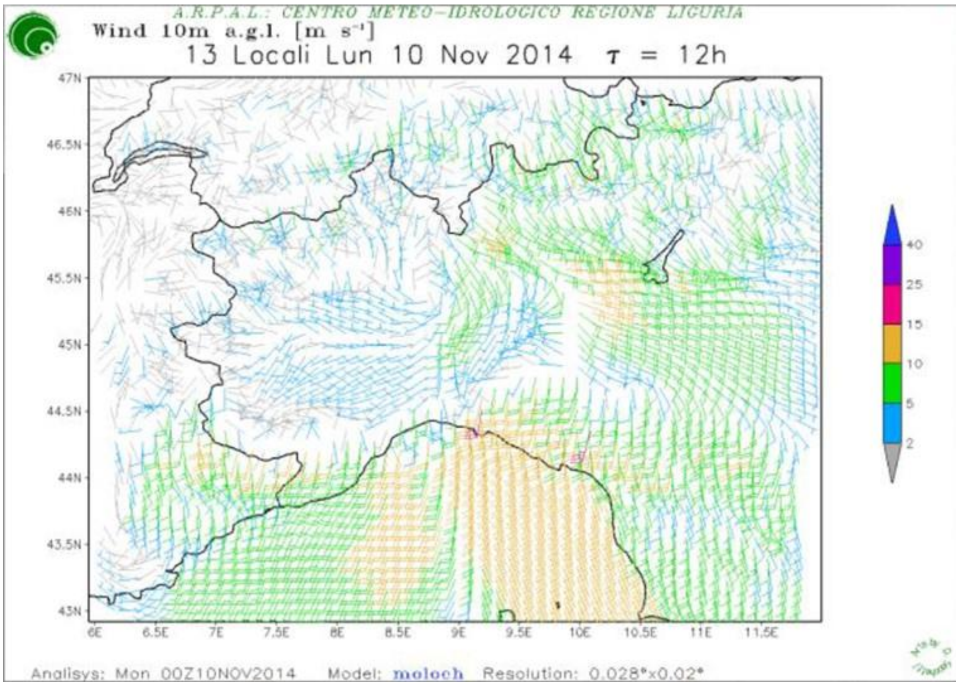


Figure 4-18. Wind map at 10 meters high on the 10th of November 2014 at 00h UTC.

In the evening of the 10th of November, wind gauges in Genoa recorded moderate gusty winds from the north (e.g. in Monte Cappellino and Fontana Fresca, and weaker intensity but the same direction in Genoa S. Ilario), while wind gauges in La Spezia recorded winds from the southeast with intensities from moderate to strong and typically stormy gusts (e.g. in Corniolo and Framura, and less sustained winds in Monte Rocchetta).

Numerous wind gauges recorded wind squalls from the east, whereas less sustained air flows were recorded the west. The most intense wind values were recorded on the 10th and 11th of November, while local and temporary wind episodes also occurred during the rest of the days (Table 4-7).

Table 4-7. Maximum average wind speed and peak gusts observed in some wind gauges installed across the regions.

Wind gauge [Zone]	Maximum wind speed (km/h)	Date and time (local)	Prevailing direction at maximum speed	Peak gusts (km/h)
Poggio Fearza [A]	32	14:10 del 10/11	SE	65
Monte Maure [A]	40	14:00 del 10/11	ESE	64
Imperia-Oss. Meteosismico [A]	40	22:40 del 11/11	NW	55
Fontana Fresca [B]	70	17:10 del 10/11	SSW	90
Fontana Fresca [B]	44	22:50 del 09/11	NW	87
Monte Pennello [B]	50	11:20 del 11/11	SE	80
Monte Portofino [B]	35	02:20 del 12/11	E	75
Genova-Punta Vagno [B]	44	17:20 del 10/11	ESE	52
Framura [C]	60	10:40 del 10/11	E	95
Casoni di Suvero [C]	60	10:40 del 10/11	SSE	90
Casoni di Suvero [C]	66	12:20 del 10/11	S	81
Corniolo [C]	50	10:10 del 10/11	SE	70
La Spezia [C]	50	10:50 del 10/11	SSE	63
Monte Settepani [D]	42	05:40 del 13/11	NW	-
Giacopiane Lago [E]	45	11:50 del 10/11	SSE	83

Winds from the east and southeast exceeded 90 km/h, which were recorded in the locality of Framura, and winds from the north and northwest were gusting up to 90 km/h, which were recorded in the locality of Fontana Fresca (Figure 4-19 and Figure 4-20).

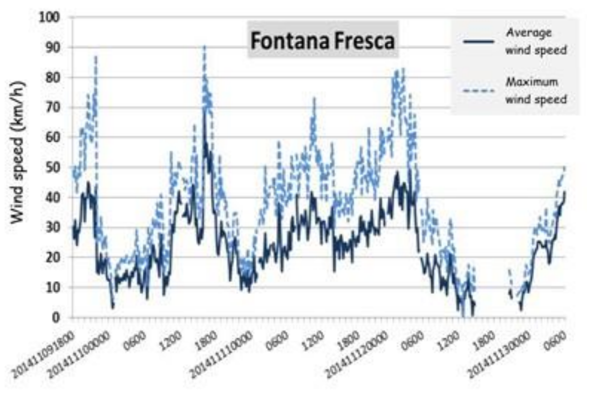


Figure 4-19. Average and maximum wind speed recorded by the station of Fontana Fresca during the course of the event.

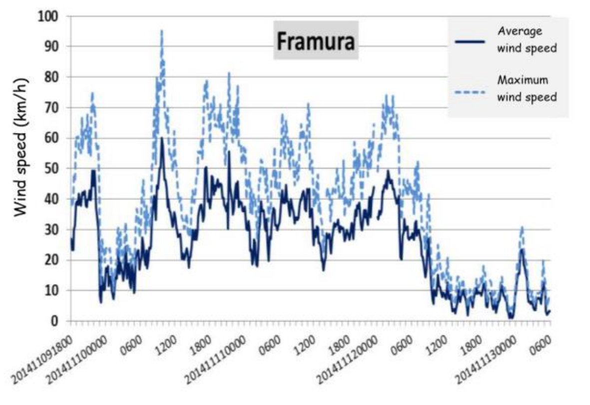


Figure 4-20. Average and maximum wind speed recorded by the station of Framura during the course of the event.

Sea waves

Persistent winds from the south led to an increase in wave motion. The state of the sea became very rough both on the western and on the eastern coast. In the western part of the region of Liguria, between the 9th and the 10th of November, maximum wave heights of 1.6 meters were recorded at “Capo Mele” buoy during the night; whereas in the eastern part of the region, between the 10th and the 11th of November, maximum wave heights of 1.8 meters were recorded at “La Spezia” buoy (Figure 4-21).

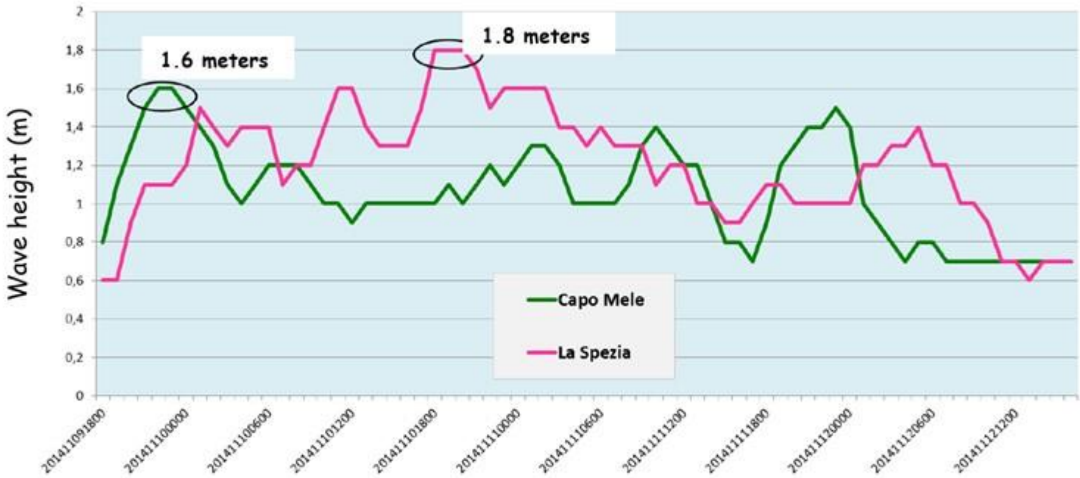


Figure 4-21. Maximum wave heights recorded in Capo Mele and in La Spezia during the course of the event.

4.2.2 **Images and videos**

Images:

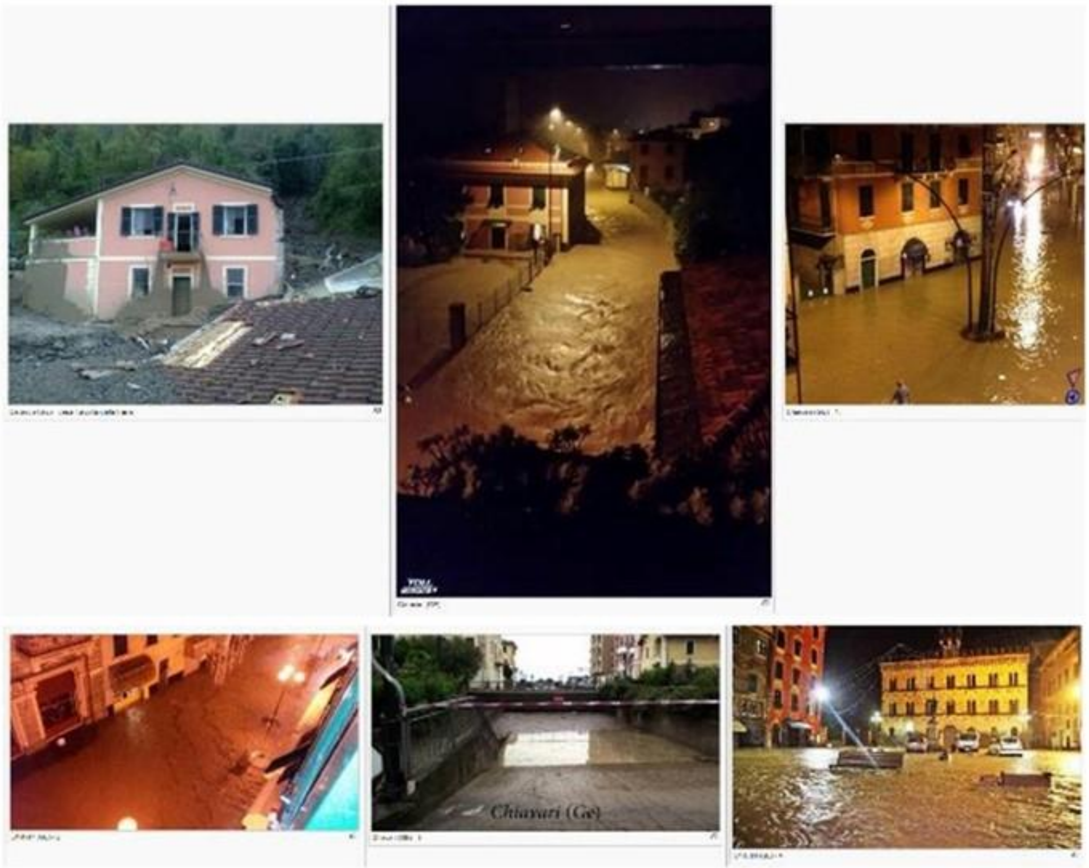


Figure 4-22. Flood images in Tigullio.

Figure 4-23. Images of landslides during the Tigullio floods.

Videos:

- https://www.youtube.com/watch?v=qw6PXV5C534.
- http://www.oggi.it/video/attualita/2014/11/11/chiavari-alluvionata-guarda-lacqua-e-dappertutto/.
- http://www.oggi.it/video/attualita/2014/11/11/la-liguria-e-sottacqua-ancora-dispersi-due-anziani-a-leivi-le-immagini-dei-vigili-del-fuoco/.

4.3 Risk and behaviour analysis

Following, the evolution of the flood risk and the impact derived from it are presented in a chronological order. The weather data that was processed to anticipate the risk scenario (see section 4.2) can be frequently consulted to better understand the nature of the flood-related impacts that hit the region of Liguria from the 9th of November until the 13th of November.

4.3.1 **Weather analysis and impact of flooding events**

The flood events presented in this study case were preceded by other episodes of intense and heavy rains accompanied by heavy storms that hit not only Liguria but also the region of Tuscany between the 3rd and the 6th of November.

The adverse weather scenario during the first days of November reached its peak on the 5th of November, when the high amounts of water flowing in the Parmignola stream led to flooding in the eastern part of Liguria in the Lunense plain (in particular the municipality of Ortonovo and the area of Marinella in the Magra basin) causing extensive property damage.

Three days later a new rain front approached from the west bringing widespread rainfall that started in the evening of the 9th of November and lasted until the early hours of the 13th of November.

The synoptic conditions on the 9th of November were dominated by a frontal system (Bracknell front) with a centre of deep trough (991 hPa) in Scotland that extended to the

African coasts and further east. On the other hand, a large area of high pressure (1033 hPa) stationed in western regions of Russia (Figure 4-24).

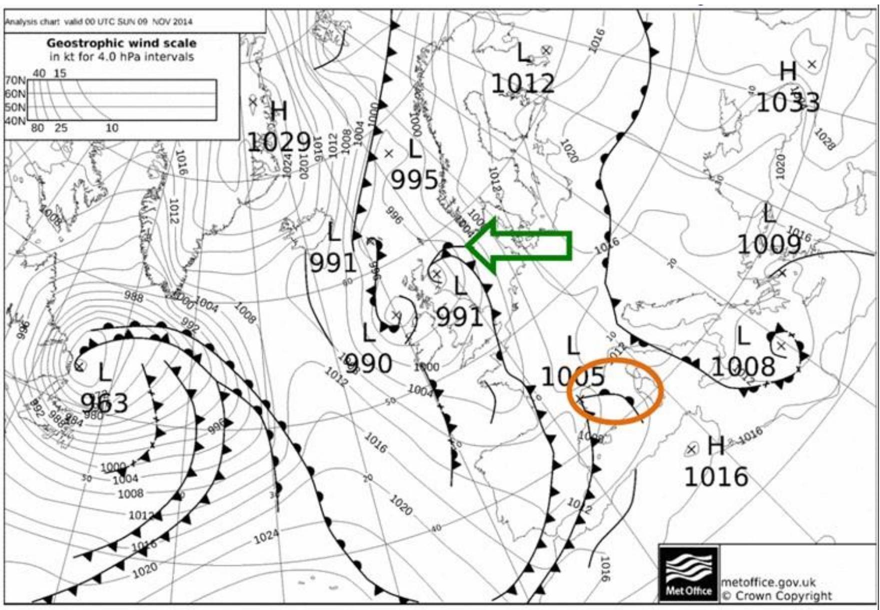


Figure 4-24. Bracknell Fronts Analysis on the 9th of November 2014 at 00 UTC.

This situation determined a southern humid flow that in the early hours of the day affected some regions of southern France (where rainfall was also observed along with strong temporal storms) and during the afternoon in the Italian region of Tyrrhenian.

Winds from the north met the passage of the frontal system and brought a mass of cold air to the northern regions of Italy that collided with the intense wet advection. These conditions persisted until the 12th of November maintaining a marked instability in Liguria.

During the afternoon of the 9th of November, precipitations became widespread, and in the early hours of the night of the 10th of November the first strong thunderstorms started. The following precipitations were recorded:

- Framura: 48 mm/1 hour and 70 mm/3 hours
- Genoa Pegli: 40 mm/1 hour and 70 mm/3 hours
- Genoa Castellaccio, Genoa Bolzaneto, Genoa S. Ilario and Sanctuary Monte Gazzo: 30 and 35 mm/1 hour).

It was in the Genoa area, and in particular in the districts of Cornigliano and Staglieno, where the first flooding events took place.

On the 10th of November the hot part of the frontal system affected the region of Liguria by strengthening the wet advection from the southeast (Figure 4-25) and maintaining widespread precipitations (Figure 4-26) in the form of thunderstorms during the morning in Golfo Paradiso and Tigullio. Maximum rainfalls of 65 mm/1 hour were recorded in the area.

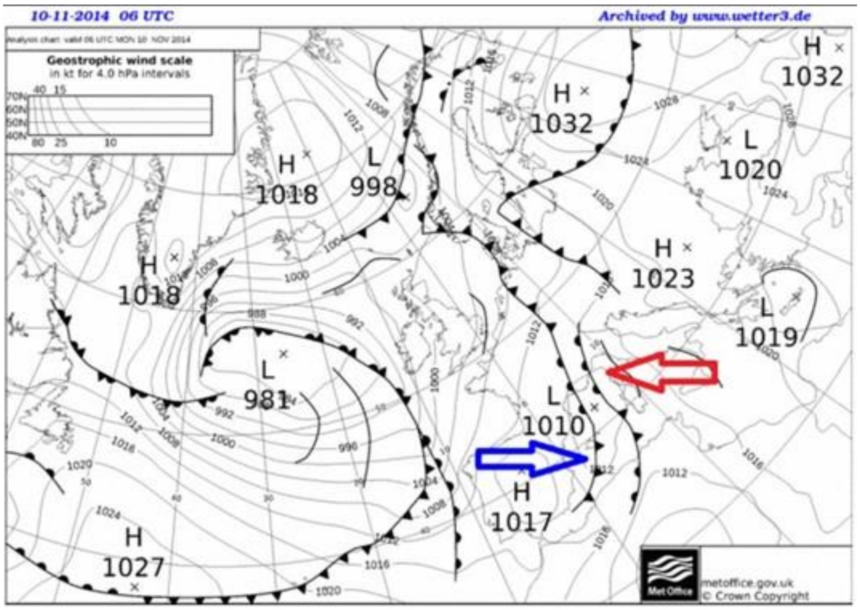


Figure 4-25. Bracknell Fronts Analysis on the 10th of November 2014 at 06 UTC.

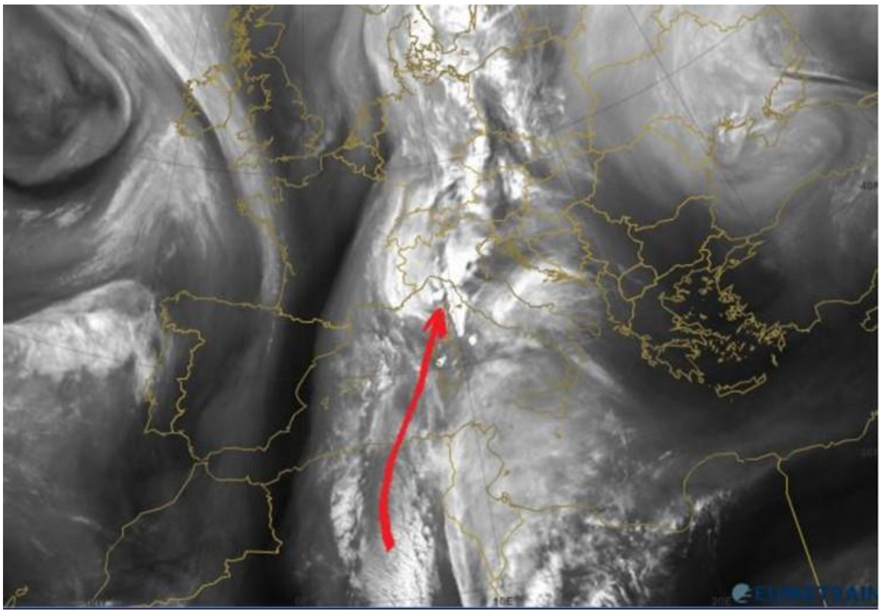


Figure 4-26. Image from the MSG satellite in the Water channel Vapor (WV6.2) on the 10th of November 2014 at 06 UTC.

From midday the rainfall stopped in the areas that had been affected during the morning. However, in the west the rains intensified due to the presence of a thunderstorm with southwest-northeast axis in rapid eastward movement. Significant rainfall intensities were recorded in Ceriana, Ventimiglia, Passo Ghimbegna, Mount Maure, Seborga with values between 40 and 45 mm in 1 hour.

During the afternoon the thunderstorm moved towards the area of Genoa giving rise to a downdraft (descending current) between Prà and Voltri as a result of the strong instability and the rotation of the winds: the force of the wind was so strong that caused the fall of some containers full of material. In the centre of the region, precipitations reached strong intensities but were not persistent as the storm front kept moving quite quickly towards the east.

From late evening the presence of northern winds in the centre of the region and winds from southeast led to the formation of a convergence line (Figure 4-27), again with southwest-northeast axis (Figure 4-28), with very strong storm precipitations that lasted for 3-4 hours in the Entella basin thus giving rise to severe flood events. Furthermore, intense lighting activity occurred as a result of the development of the storms (Figure 4-29).

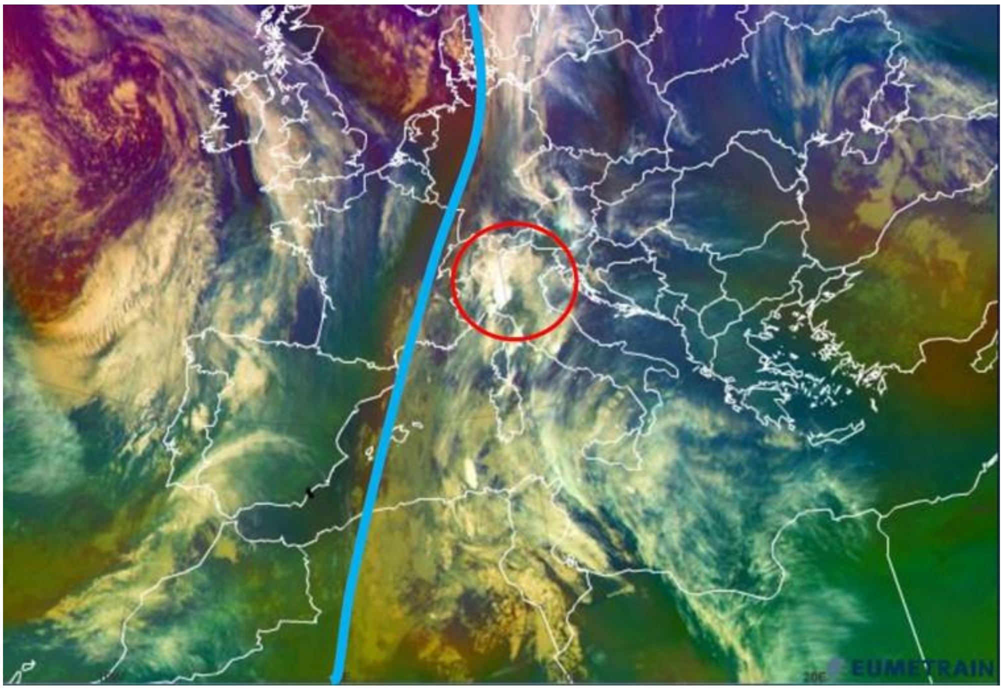


Figure 4-27. MSG satellite image (RGB combination AIRMASS) on the 10th of November 2014 at 18 UTC.

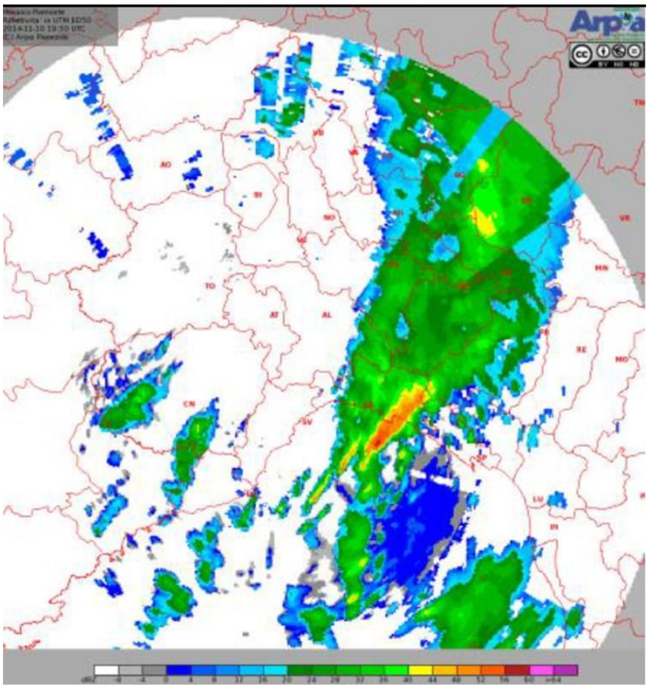


Figure 4-28. Reflectivity map on the 10th of November 2014 at 19:50h UTC. The structure of the thunderstorm with southwest northeast axis is displayed in red-orange colour.

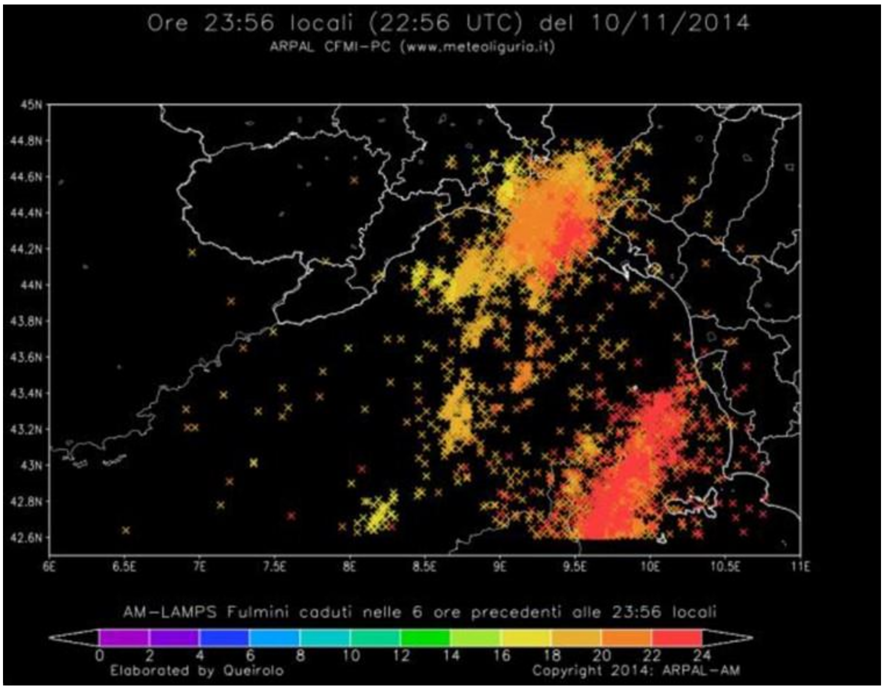


Figure 4-29. 6-hour lighting map until 22:56h UTC local time on the 10th of November 2014.

At this point, precipitations reached strong intensities with peaks of 67 mm/hour in Panesi, and were persistent in time with peaks that exceeded 100 mm/3 hours in several weather stations of Tigullio (e.g. Panesi, Giacopiane-Lago, Cichero). In Borzone, the total amount of precipitation recorded exceeded 120 mm in 3 hours.

The presence of the convergence line and the intensity of the precipitations in the evening of the 10th of November provoked floods along the drainage basin, affecting especially water courses like Entella, Sturla, and the Lavagna.

In Tigullio the precipitations continued until the first hours of the night of the 11th of November, however they became less intense during the night. On the 11th of November Liguria was affected by the presence of an occluded front (Figure 4-30) which led to unstable weather due to the persistence of the southern wet advection and wind flows coming from north.

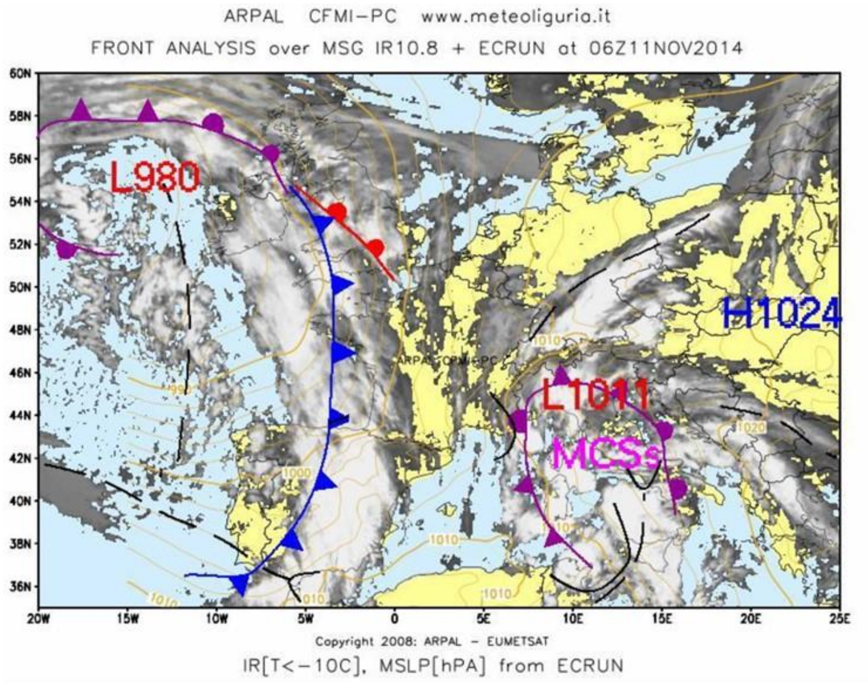


Figure 4-30. Occluded front on the 11th of November at 06h UTC.

The high pressure on Eastern Europe likewise continued to favour the occluded front by hindering the shift towards the east. In the early hours of the 11th of November, while the rainfall in Tigullio was ceasing, it became more intense in the city of Savona with rainfalls that reached 39 mm/hour in Stella S. Giustina, and 33-35 mm/1 hour in Sanda, and Manie and Fiorino. The rains persisted in Savona and in the area of Varazze and Cogoleto during all morning and part of the afternoon (Figure 4-31) to the point of provoking floods in Savona, Celle and Varazze, and compromising the viability of the road network.

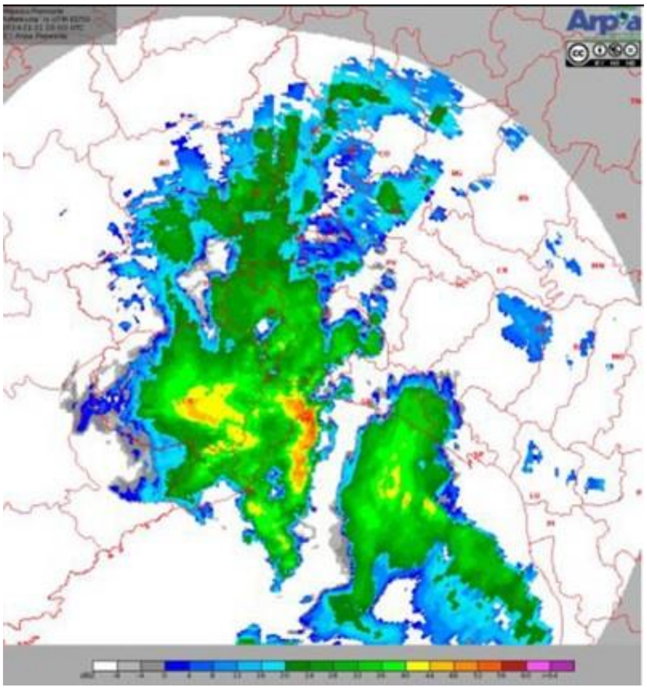


Figure 4-31. Reflectivity map on the 11th of November 2014 at 10:00h UTC. The structure of the thunderstorm with southwest northeast axis is displayed in red-orange colour.

During the afternoon and in the evening a new thunderstorm band with a Southeast-Northwest axis formed on the sea and affected the western part of the Savona area (the Albenganese and its own inland).

Later on in the evening the maximum rainfalls were recorded in Albenga-Isolabella, with 40 mm/hour and 83 mm/3 hours), and in Cisano sul Neva, with 38 mm/1 hour and 80 mm/3 hours).

The heavy rains provoked flooding in Albenga and many critical issues were recorded: the Arroscia river reached the guard level in Ortovero; the levels of the river Empire, Neva, Argentina and Armea had rapid rates of rise.

In the early hours of the 12th of November, rainfalls resumed abundantly across the area of Genoa area, being particularly intense in the west. A band of precipitation with a southeast-northwest axis initially involved the city centre and then move towards the west (Figure 4-32), where it gave rise to heavy and long-lasting showers that recorded high accumulations of water: 117 mm/6 hours in Genoa-Pegli, 100mm/6 hours in Sanctuary Monte Gazzo, 90mm/6 hours in Monte Pennello, and 80 mm/6 hours in Apples and Madonna delle Grazie about.

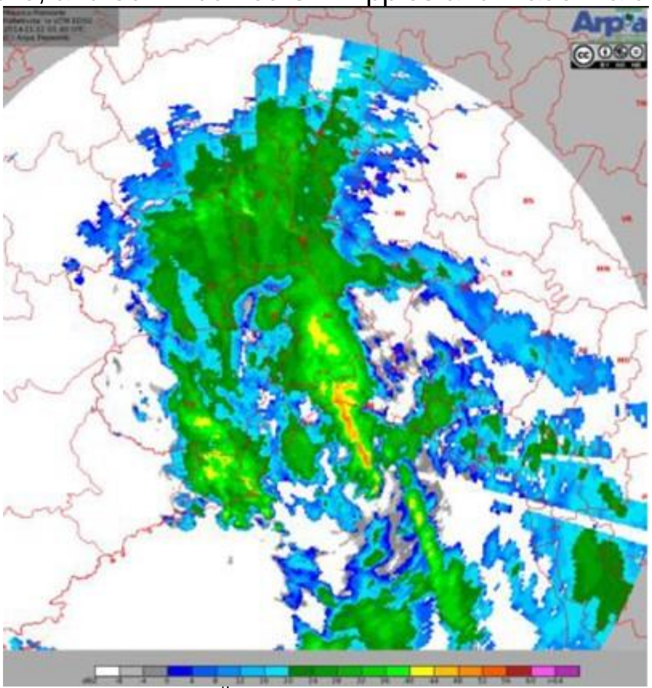


Figure 4-32. Reflectivity map on the 12th of November 2014 at 01:40h UTC. The structure of the thunderstorm with southwest northeast axis is displayed in red-orange colour.

Around 4:00 am local time the band of precipitation moved eastwards, allowing the water levels progressively drop below the critical values.

During the morning of the 12th of November, moderate and some strong showers still fell in Genoese and Tigullio provoking some isolated floods events. In the evening rainfalls became less intense and scattered over the region and finally ceased in early hours of the 13th of November.

4.3.2 **Landslides and related impacts**

After the heavy rainfalls that took place in Liguria new levels and types of risk emerged, particularly landslides, in areas that become completely saturated by heavy rainfall. This situation involved secondary impacts on the population posing a significant risk to life and major challenges for emergency rescue services.

Numerous interventions were made by the fire brigades to rescue people stranded in cars, swept away by water, or trapped in areas affected by landslides. Rescue efforts were hampered by a blackout that lasted about two hours.

The damage caused by rainfall-induced landslides caused particular impact on houses, road infrastructure, and railways. Hundreds of people were evacuated to various municipalities in the region as a result of landslides that fell on built-up areas. The balance of landslides on homes was particularly tragic as two people died when a landslide ruined a house between Carrasco and Leivi. For safety reasons, the exit toll of motorway A12 in Chiavari was closed, as so was the Caperana bridge between Chiavari and San Salvatore, making it more difficult the evacuation of people. Furthermore, a landslide between the stations of Chiavari and Zoagli interrupted the railway Genoa-Rome, blocking an intercity train for about two hours with about a hundred people on board.

5 Ballater Floods - Storm Frank

On 29 December 2015 a Met Office amber warning was issued for heavy rain for large parts of Scotland including Aberdeenshire valid from 00:15 am to 3p.m. on 30 December 2015. SEPA issued a Flood Guidance Statement with an amber warning for flooding affecting the River Dee and concerns for the southernmost River Spey catchment area. Ballater had been identified as a potential for flooding. In response to these warnings the Grampian Local Resilience Partnership (GLRP) was activated and a meeting was held at 4 pm on 29 December in order to plan for the potential impacts of the severe weather.

5.1 Data collection

The information collected for the preparation of this case study has been consulted/extracted from the following sources:

SEPA – Scottish Environment Protection Agency: Potential flooding risk areas.

SFRS – Scottish Fire and Rescue Services: incident response, means deployed, operations and impacts.

OS – Ordnance Survey National Mapping Agency for Great Britain: geographic GIS data for the area around of Ballater.

Digital press (The Press and Journal, Telegraph): images.

Netweather: weather charts.

Scottish Flood Forecasting Service: weather forecast maps.

5.2 Data processing

5.2.1 **Weather data**

A situation of low pressure on the United Kingdom on 29th of December was the precursor of Storm Frank, a quickly deepening area of low pressure (Figure 5-1). During the following days (30th and 31st of December, heavy rains during the two following days (Figure 5-2).

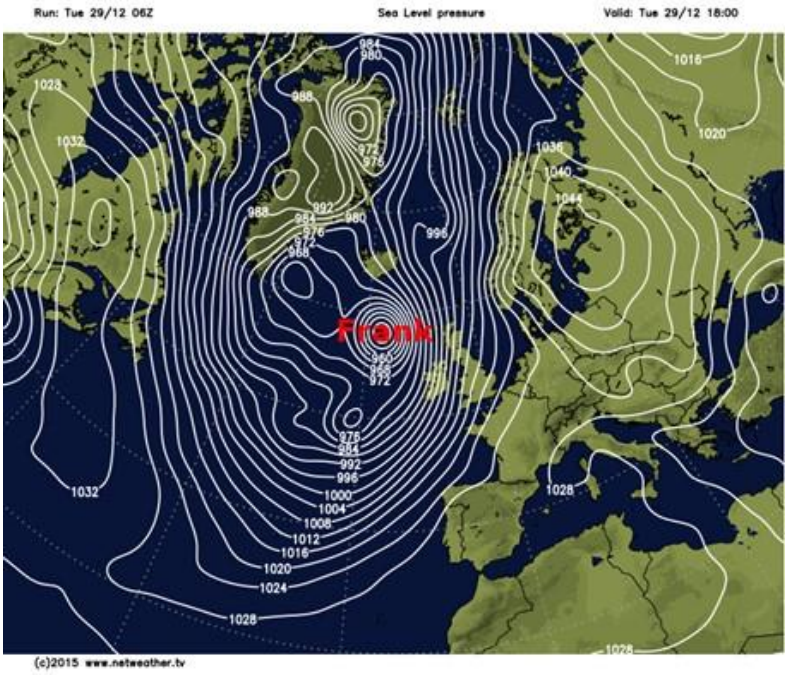


Figure 5-1. Deep area of low pressure the day before the flood events.

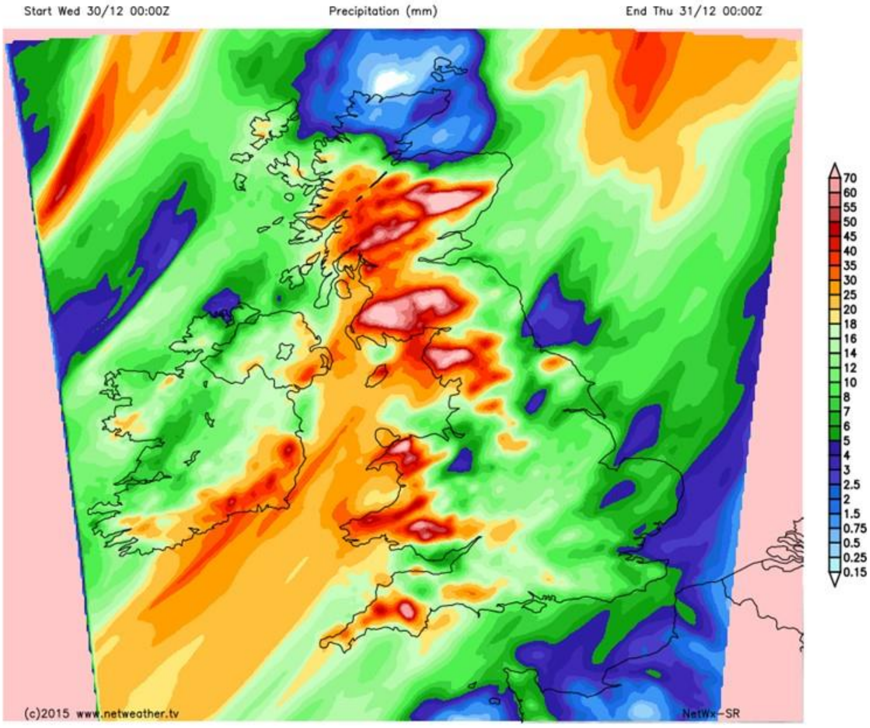


Figure 5-2. Rainfall in the UK between the 30th and the 31st of December 2019.

The daily flood risk forecast for the UK is determined by means of the Flood Guidance Statement (FGS), a document that produces flood risk levels at county level across several days. Figure 5-3 (a) shows how the FGS anticipated likely severe weather the days before to the flood event. On the other hand, Figure 5-3 (b) shows the areas that were more affected by the rain episodes. This information has been extracted from the “Scottish Flood Forecasting Service and is available at: https://floodforecastingservice.net/2016/03/15/storm-frank-short-range-forecast-performance/.

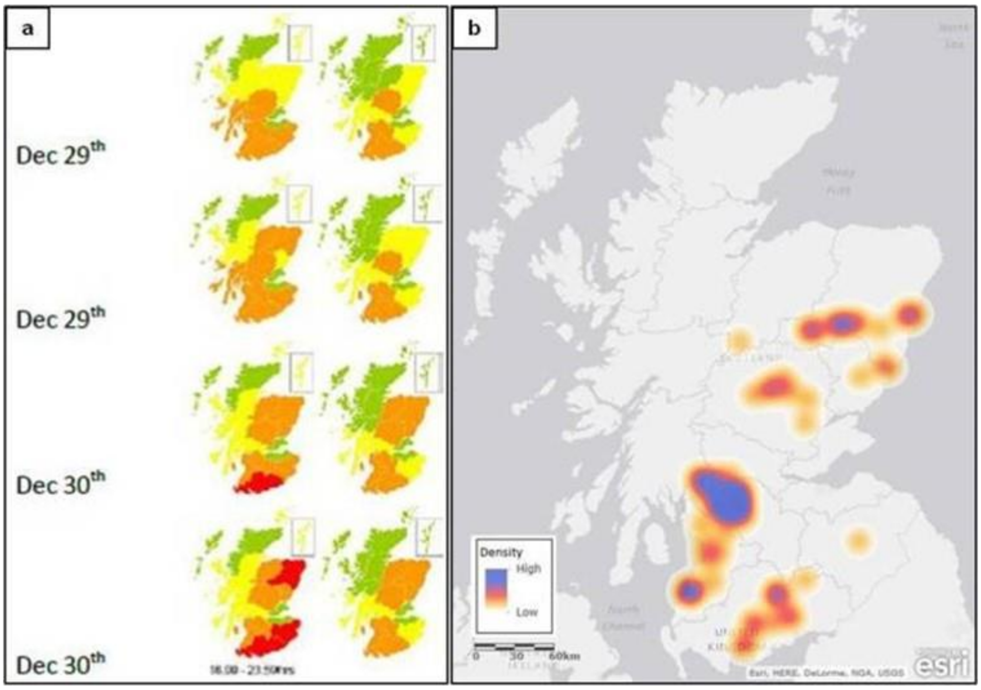


Figure 5-3. (a)The Flood Guidance Statement (FGS) maps issued ahead of the event on the 29th-30th December, and a map (b) of public reported incidents of flooding associated with storm Frank.

5.2.2 **Roads and houses**

Specific data relevant to the roads and houses/structures around the village of Ballater were download from the Ordnance Survey for Great Britain, processed in a GIS and maps were prepared. The road network around Ballater is displayed in Figure 5-4.

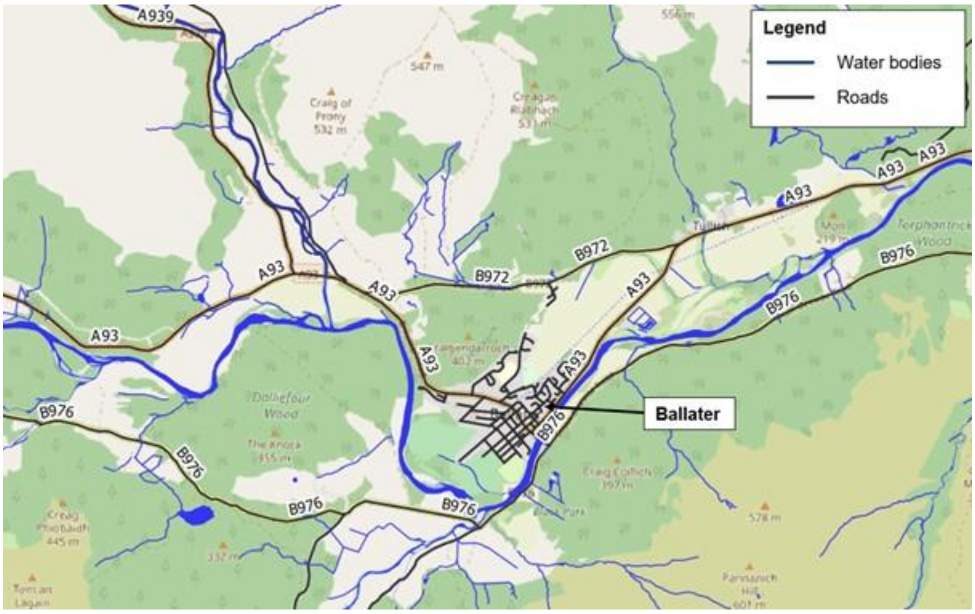


Figure 5-4. Road network and water bodies around the town of Ballater.

Figure 5-5 displays the structures and houses located around the basin of river Dee through Ballater.

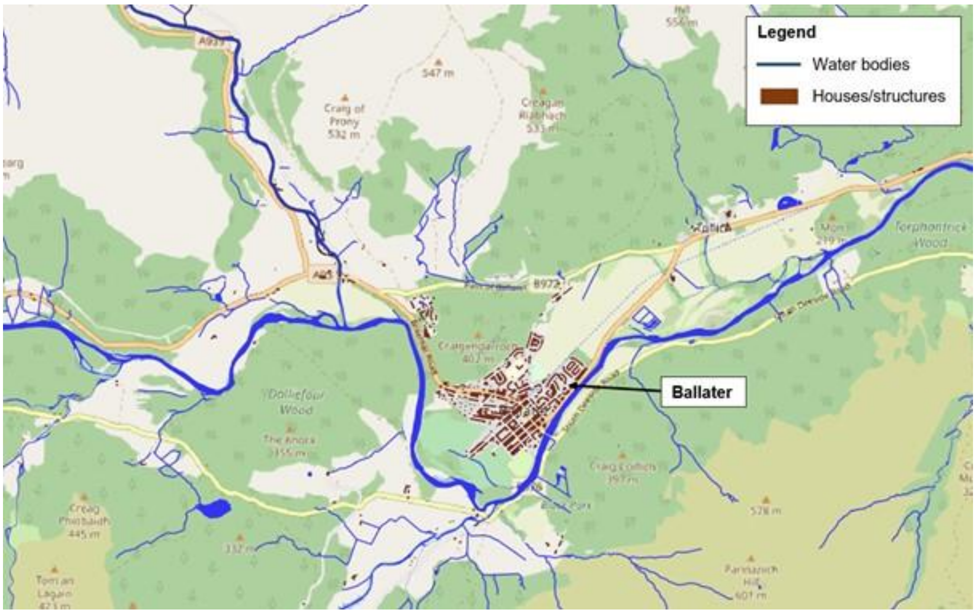


Figure 5-5. Houses/structures and water bodies around the town of Ballater.

5.3 Risk and behaviour analysis

5.3.1 **Potentially Vulnerable Areas and Potential Flooding Areas**

The entire village of Ballater is inside the Potentially Vulnerable Area “06/22”, with an extension of approximately 7km^2, as defined by SEPA (Scottish Environment Protection Agency).

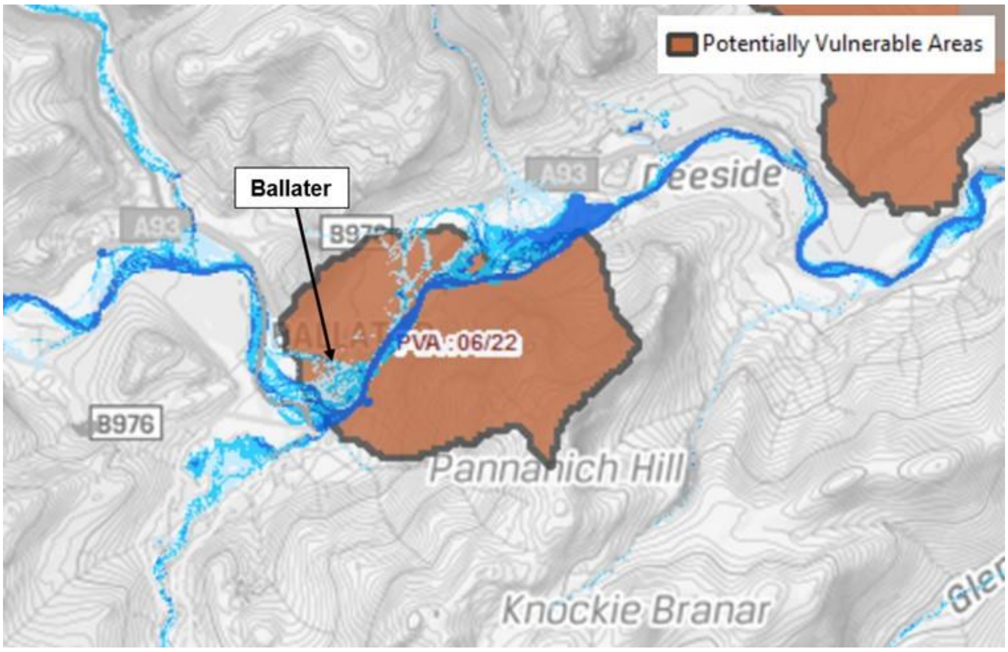


Figure 5-6. Potentially Vulnerable Areas

Flood risk mapping is likewise provided by SEPA in terms of likelihood of flooding. As observed in Figure 5-7 nearly the entire village of Ballarat is exposed to flooding risk. In the northern part the likelihood of flooding is mostly low, whereas in the central and southern part of the village the likelihood of flooding is medium and high.

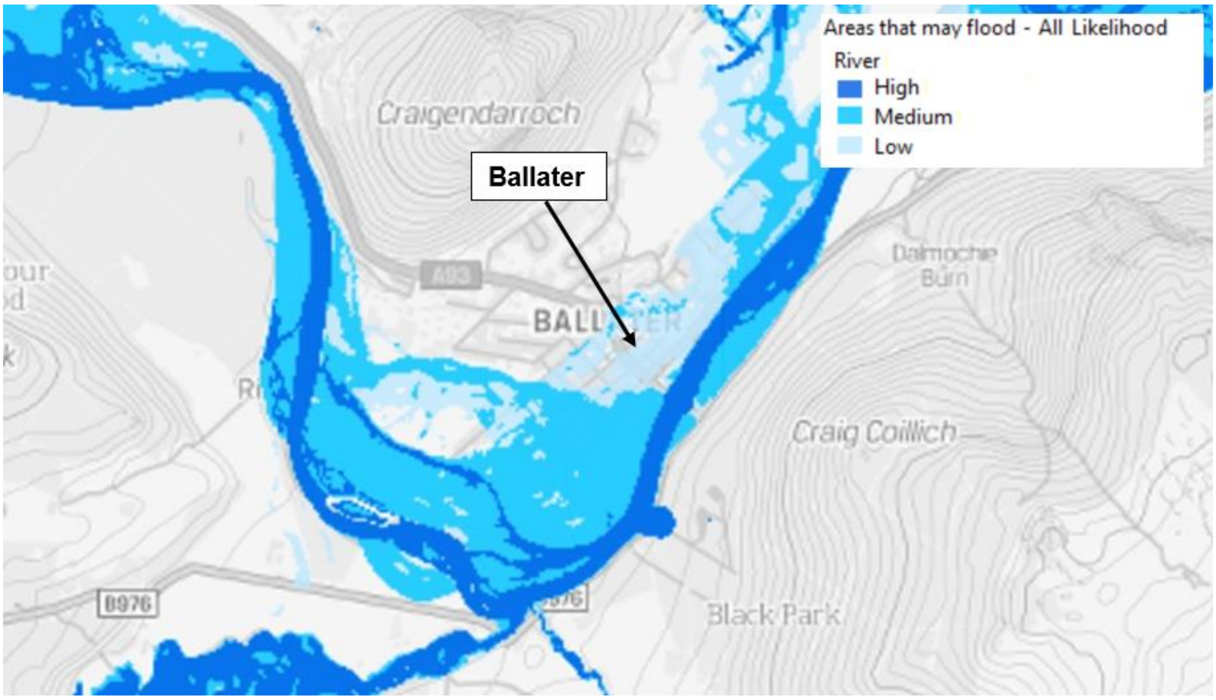


Figure 5-7. Potential flooding areas around Ballarat.

5.3.2 **Flood risk assessment during the event**

The weather impacted as forecasted on 30 December and significant flooding was experienced in Deeside and Aberdeen. Police Scotland consequently declared a Major Incident for the Deeside area in light of the fact that Ballater was badly affected with access routes closed and much of the town under water. There were significant evacuations and rescue of persons from fast flowing floodwater, and the Police, Fire and Ambulance stations in the town were flooded. The GLRP continued to meet regularly throughout 30 and 31 December and the Major Incident was stood down on the afternoon of 31 as the critical response phase had passed.

On 1st January 2016 Met Office issued a further amber warning for more heavy rain likely to impact the Grampian area from 2pm on 2 January. The GLRP met to plan for the potential impacts considering the forecast. Aberdeenshire Council continued to coordinate the recovery phase for the Deeside area. In response to the ongoing severe weather, emergency flood protection plans were activated to prevent further flooding within Ballater.

On 4th January 2016 further SEPA Flood warnings and Alerts were issued across the Grampian area with concerns for the Rivers Don, Dee, North Esk and Spey. This was followed on 6 January by a Met Office amber warning of rain valid for the whole of 7 January. The key areas of concern from the SEPA Flood Guidance Statement on 7 January were the Rivers Don and Deveron with likely impacts on Inverurie, Kintore and Huntly. River levels continued to rise, and significant flooding was experienced across the forecast area and given the situation in Kintore and Inverurie a Major Incident was declared by Police Scotland at the GLRP meeting. Agencies continued to respond to widespread consequences of the flooding for the following period with the weather eventually abating on 9 January and moving from the response phase to recovery.

5.4 Strategy, priorities and tactical objectives

On Wednesday 30 December 2015 an initial call was received reporting flooding in the Ballater area and the Ballater appliance was mobilised at 08:44 a.m. An assistance message was sent to control at 09:38 a.m. asking for level 2 and level 3 flood response units to attend, and units from Stonehaven, Huntly and Elgin were mobilised to the incident.

Due to the severity of the flooding the main A93 road coming into Ballater from Aberdeen and Braemar was totally cut off (see Figure 5-4), and there was only one road accessible into the village via Strathdon, which added a 40-mile diversion for the oncoming appliances.

The first 1st call officer was on scene at 10:57 a.m., and due to access difficulties into the village the first 2nd call officer did not get on scene until 3:44 p.m.

Incident operations involved the evacuation of residents from their homes utilising all level 2 water rescue personnel and level 3 water rescue personnel and the rescue boat (Figure 5-8). These crews were assisted by police water rescue teams, their rescue boat as well as mountain rescue teams, and two coastguard helicopters.

Figure 5-8. Rescue effort during the Ballater floods. Source: The Press and Journal.

All operations were coordinated from the rest centre in the centre of the village where a silver command team had been set up.

The stop message for the incident was sent at 09:33 a.m. on Thursday 31 December with the last involvement of SFRS personnel concluding at 9 p.m. on 4 January 2016.

5.5 Operations and impacts

5.5.1 **Operations and emergency organisation**

- Ballater level 2 flood response crew – involved in initial evacuation of residents from flooded property and subsequent pumping out operations in flooded property.
- Ballater Forestry unit – Polaris forestry unit used to assist with the evacuation of residents from their homes to the rescue centre.
- Stonehaven level 2 flood response pump - involved in initial evacuation of residents from flooded property and subsequent pumping out operations in flooded property.
- Huntly level 2 flood response pump – involved in initial evacuation of residents from flooded property and subsequent pumping out operations in flooded property.
- Elgin level 3 swift water rescue pump and boat crews - involved in initial evacuation of residents from flooded property using boat.
- Banchory appliance – used for pumping out flooded homes and businesses and responding to fire calls in the area.
- Strathdon appliance - used for pumping out flooded homes and businesses and responding to fire calls in the area.
- One 1st call Officer
- One 2nd call Officer
- Due to the firefighters station at Ballater being totally destroyed by the flood, the RDS in Ballater rendered inoperable, and for relief purposes, a whole time appliance was sent to cover the Ballater area during the night. This continued for several days after the event until normal communications were restored.

Figure 5-9. Flooded cars in Ballater. Source: The Press and Journal.

Other agencies involved

- Police Scotland – assisted fire service with evacuation of residents and processing those affected at the casualty rest centre.
- Police Scotland water rescue team – assisted fire service with evacuation of residence from flooded property.

- Braemar Mountain Rescue – assisted fire service with evacuation of residents from flooded property.
- Scottish ambulance service – assisted in the care of residents displaced by the flooding at the rest centre and the transport of vulnerable residents to hospital.
- Coastguard – two coastguard helicopters assisted in the evacuation of fire service personnel and local residents from flood water (Figure 5-10).

Figure 5-10. Coastguard helicopter rescuing people in Ballater. Source: The Press and Journal.

- Aberdeenshire council – initial assistance in the set up and co-ordination of the rest centre and subsequent rehousing of displaced residence.
- SSE – assisted fire service and other agencies in the shutting down of power to the affected properties and subsequent re-instalment of power once the flood water had receded.

5.5.2 **Socioeconomic impacts**

The physical impact on the village of Ballater was severe. The flooding experienced was unprecedented, with 365 houses and 54 businesses severely flooded.

The local caravan park which had 100 static caravans on it was totally destroyed (Figure 5-11). Not one caravan survived the flood with many being either washed away into the River Dee or totally destroyed by the flood water.

Figure 5-11. Caravan park damaged by the storm Frank. Source: Red Kite Media Scotland.

The local fire, police and ambulance stations were totally destroyed by flood water and 4 main hotels in the area severely damaged by flood water.

The estimated cost of the damage for the Ballater area was GBP 1.5 million, and due to the impact of the river on the bridges from Braemar down to Aboyne the estimated cost to repair to those bridges was GBP 2 million.

The main A93 linking Ballater to Crathie was washed away and this also meant a substantial cost to repair and reinstate that road.

The psychological impact to the residents of the village was also severe. Many of those residents whose homes had been destroyed in the flood had to be re-homed many of them out of the village itself. Many residents were in temporary accommodation for up to a year following the flood.

Following the flood event all residents within the village of Ballater were given flood defence measures if they wanted them. These were in the form of flood gates and flood covers for outside vents.

A local resilience plan was developed and put in place for the community of Ballater, Crathie and Braemar.

5.6 Lessons learned

Table 5-1 outlines the lessons identified in the aftermath of the Ballater floods and the actions considered to be required to overcome them:

Table 5-1. Lessons identified and actions required.

	Topic	Lessons identified/Issue	Proposed Action Required	Suggested lead
1	Command Control & Coordination	The multiagency Resilience Room was only utilised for the second phase of the response.	Review the requirement for the Multy agency resilience room.	GLRP
2	Command Control & Coordination	Oversight of the widespread nature of the incidents across the North area was not achieved.	Need to consider wider Resilience Partnership involvement when impacts are wider than just Grampian whilst still ensuring principle of subsidiarity.	GLRP
3	Command Control & Coordination	Some aspects of the LRP meetings were found to be less effective including meeting etiquette, agency updates and effective use of sub groups such as Care for People.	Ensure LRP members are aware of importance of use of 3 minute brief or similar in providing updates and remind of need for good meeting etiquette. Also brief Lead Coordinating Agency of importance of establishing Response subgroups to ensure detailed arrangements are not resolved at LRP (i.e. CfP, coordination of assets, etc.)	GLRP

4	Care for people	There were conflicting views on the activation of the CfP Groups and their role.	Care for People Groups to clarify their response role and ensure they have the appropriate membership identified to deliver the response role. Also ensure coordination of CfP activities across the Grampians area.	Grampian CfP Group
5	Care for people	There was a lack of coordination and common understanding of the vulnerable persons list.	Ensure that the Care for People Group/s are established to ensure effective coordination of the vulnerable persons list/s.	Grampian CfP Group
6	Plans	There were a number of issues raised around dealing with widespread flooding incidents.	Consider establishments of a Flood Group for the LRP to oversee Flood planning and response arrangements including training and exercising requirements.	GLRP
7	Recovery	The GLRP structures were not utilised during the recovery phase.	Review the Recovery guidance and asses against local arrangements and capability. Ensure awareness of Guidance across LRP membership.	GLRP
8	Communities/ Volunteers	Incidents highlighted value of community resilience and scope for enhanced engagement with volunteers.	Explore how experience of these incidents can be utilised to enhance engagement with communities and coordination of volunteers.	GLRP WG

6 Roskilde Fjord Floods - Storm Ingolf

This study case is based on a flood incident that started on the 29th of October 2017 at 11:28 am (Danish Emergency Management Agency's [DEMA] statistical bank: www.odin.dk) in a coastal area within the FBBR Frederikssund Municipality (Figure 6-1). It is one of FBBR's representative scenarios related to climate change in cooperation with the Risk Based Dimensioning (RBD), which is part of the Comprehensive Preparedness Planning (CPP). A detailed analysis of this scenario has been made and is included in the FBBR RBBD-plan 2019 (www.fbbr.dk).

Figure 6-1. Coastal area (harbour) in the municipality of Frederikssund Municipality.

Frederikssund is a town located on the eastern coast of Roskilde Fjord, about 45 km northwest of Copenhagen, 20 km south of Hillerød and 30 km north of Roskilde. The fertile land surrounding Frederikssund is used for mixed farming, notably cereals, root crops and pigs.

The recent development of the town, as well as the old commercial harbour, have given Frederikssund a new look thereby becoming a sought-after residential area with enhanced connections to Copenhagen and surroundings. Today Frederikssund has all the facilities associated with a modern Danish town: museums, a public library, supermarkets, a hospital and sports and recreation centres. West-facing zones on the shore of Roskilde Fjord have many footpaths. The local rail and bus services are well developed.

Due to the incident, the Frederikssund Municipality prepared a series of maps showing a rise in water surface of 140 cm in the coastal part of the city causing an increase of flood risk. In addition to this, they prepared cards with protective measures to mitigate flood losses during the events (e.g. installation of watertubes and depots with sandbags). Watertubes were installed at Færgevej/J.F. Willumsensvej, in Frederikssund, and at the Kignæshallen, in Jægerspris. Current and planned watertubes across the municipality can be consulted on the Frederikssund Municipality website (www.frederikssund.dk).

It is important to note that the cards are subject to wind direction, wave stroke, etc. can mean both higher and lower water levels than the maps show, so they are only indicative.

Finally, it is worth mentioning that the area is highly populated as it is popular destination for many tourists and visitors during the year, with the peak season being during the summer months.

6.1 Data collection

All relevant data and information related to this scenario can be found in Danish Emergency Management Agency´s (DEMA) data base www.brs.dk (www.odin.dk, www.statistikbank.brs.dk) e.g. incident report, ODIN-GIS.

Other relevant information sources such as Frederikssund Municipality, www.frederikssund.dk, Danish Metrological Institute (DMI), www.dmi.dk has been used in this case as well as other relevant sources, resource persons, and information from FBBR.

Table 6-1. Data sources for Roskilde Fjord – Storm Ingolf Flood

Type of data	Source	Time of collection
Cartography (ortophotos of the study area)	Google Earth	2017
Analysis of fire risk	FBBR - Plan for Risk Based Dimensioning	2017, 2019
Systems and tools used for crisis management situations	FBBR (www.fbbr.dk)	2017, 2019
FBBR RBD-plan 2019	FBBR	2019
Incident report, ODIN-GIS	DEMA (www.brs.dk)	2017
Information and statistics	DEMA's statistic bank (www.brs.statistikbank.dk)	2017
Contextual description about the affected area Preparedness plan Crisis management plan	Frederikssund Municipality (www.frederikssund.dk)	2017
Weather data	DMI	2017
Images of the flood incident	FBBR	On the incident location
Logistics and means deployed	FBBR, DEMA (Odin-Statistic Bank)	2017
Social media and relevant information	www.frederikssund.dk	2017

6.2 Data processing

All the available sources of data and information were used for the design of this scenario. This mainly concerns previous FBBR RBD-plans and incident reports, but also, emergency response activities that were reported to the Danish Emergency Management Agency's Online Data Registration and Reporting System (ODIN) (www.fbbr.odin.dk), ODIN-GIS module (www.brs.odinGIS.dk), and municipality maps. Furthermore, information and statistics have been drawn from DEMA´s Statistic BANK (www.brs.statistikbank.dk), which retrieves and processes data from ODIN. This means that if an emergency report is incorrect, it will affect the statistics. Nevertheless, only very few emergency reports tend to contain incorrect information. Therefore, for the overall statistics it only gives a small margin of error.

Extracts have been made and validated on the basis of emergency responses from the 1st of January 2013 to the 31st of December 2017.

6.2.1 **Available photos**

A few photos during the flood incident have been retrieved from the FBBR data base.

Figure 6-2. Flood protection measures – installation of the water tubes (1/2).

Figure 6-3. Flood protection measures – installation of the water tubes (2/2).

Figure 6-4. Flooded area in the municipality of Frederikssund during the flood events in 2017.

6.3 Risk and behaviour analysis

The risk scenario is described in Table 6-2:

Table 6-2. Risk scenario for the Roskilde Fjord - Storm Ingolf flood.

Scenario title	Roskilde Fjord - Storm Ingolf flood
Time	2017, October 29th, 11:28 am.
Location	112 - address:, Strandvej 36, 3600 Frederikssund; Easting - 690590, Northing - 6193369, Municipality code: 250; Street code: 1210)
Distance to the nearest fire stations	Frederikssund fire station: 1.6 km, approx. 4 minutes Jægerspris Fire station: 7 km, approx. 11 minutes Slangerup Fire Station: 9.4 km, approx. 15 minutes Højager Volunteer Fire Station: 10.9 km, approx. 15 minutes Stenløse Fire Station: 15.2km, approx. 19 minutes Helsinge Fire Station: 31.5 km, approx. 28 minutes Gilleleje Fire Station: 47.3 km, approx. 41 minutes
Meteorological conditions	Temperature: 7.8 ^{0}C Wind direction: NW Wind speed: over 18 m/s Constant strong winds from the northwest.
Description of risk	High water level in Roskilde Fjord. 30 hours before elevated water level occurs. Warning from DMI. Increased water level throughout Roskilde Fjord. Water rise of 1.6 meters above the normal water level.

	
Composition of the first response team	4 team leaders + 8 firefighters + 1 water diver The Fire Department moves their fire and rescue teams into position: FBBR Volunteers and DEMA - Sjælland (BRSS)
Other	The scenario was prepared according to the “Municipality´s Contingency plan for the notification of elevated water level", which is based on the method detailed in the FBBR Risk Based Dimensioning Plan – 2019 (RBD Plan 2019 - www.fbbr.dk). The analysis is solely based on Frederikssund harbour area, and Frederikssund City centre consisting of a rise of the water level that impacts the entire area and around the areas of Roskilde Fjord and Isefjorden. Activation of the FBBR's Crisis Management Unit (CMU). The focus is placed on information management/sharing, communication, coordination and operational efforts. Collaboration with municipal Crisis Management Unit is strengthened. The causes of increased flood risk in the area is linked to climate change.

6.3.1 **Storm Ingolf flood risk estimation**

The estimation of risk was performed using the Risk Matrix (Table 6-3).

Table 6-3. Risk estimation on people (P), environment (E), property (Pr), and society (S).

			Very low risk	Low risk	Medium risk	High risk	Very high risk
			Impacts				
Frequency	Very probable: >10 per year	**5**					
	Mostly probable: 1-10 per year	**4**					

	Probable: 0.1-1 per year	**3**	**P & M**			**Scenario:** Roskilde Fjord - Storm Ingolf flood **Pr & S**	
	Mostly improbable: 0.01-0.1 per year	**2**					
	Very improbable:< 0.01 per year	**1**					
			Limited	**Moderate**	**Serious**	**Very serious**	**Critical**
			Consequences				
People (P)			Insignificant impact	Less injuries, few people	More than 5 injured	Few deadly injured/few dead	Many injured /many dead
Property (Pr)			<1,500 €	1,500-15,000 €	15,000-150,000 €	150,000-1.5 mil. €	>1.5 million €
Environment (E)			Insignificant impact	Greater impact	Risk of permanent damage	Minor lasting damage	Big lasting damage
Society (S)			No/minor disturbance. Delays in operation <1 day	Shorter disturbance. Delays in operation <1 week	Significant disturbance. Delays in operation >1 month, firing of employees	Serious disturbance. Delays in operation >3 month, loss of customers	Critical for maintaining of functions. Termination of business operations.

Based on the FBBR data (FBBR-ODIN Statistic bank), the frequency of flood risk is estimated between 0.1 and 1 per year. In the RBD-plan the probability scale is shown in the risk matrix that is made on the FBBR-DEMA-ODIN database (DEMA-ODIN – statistic Bank).

The estimation of the consequences is distributed as follows:

- People – **Limited** (Insignificant impact);
- Property – **Very Serious** (approx.1,000,000 Euros);
- Environment – **Limited** (Insignificant impact); and
- Society – **Vey serious** (Serious disturbances, delays in operation, and potential loss of customers).

Notice: This estimation refers to FBBR´s predefined risk level in the pick list. But the Risk analysis i.e. estimation of the consequences places this scenario in the risk matrix as shown – based on the highest consequences, which in this case are “property” and “society”.

Altogether, the risk associated with the scenario “Roskilde Fjord - Storm Ingolf flood” is estimated at **High Risk**.

6.4 *Emergency response management*

6.4.1 Incident management organization at municipal level

Decision-making structure and organization management is shown in Figure 6-5.

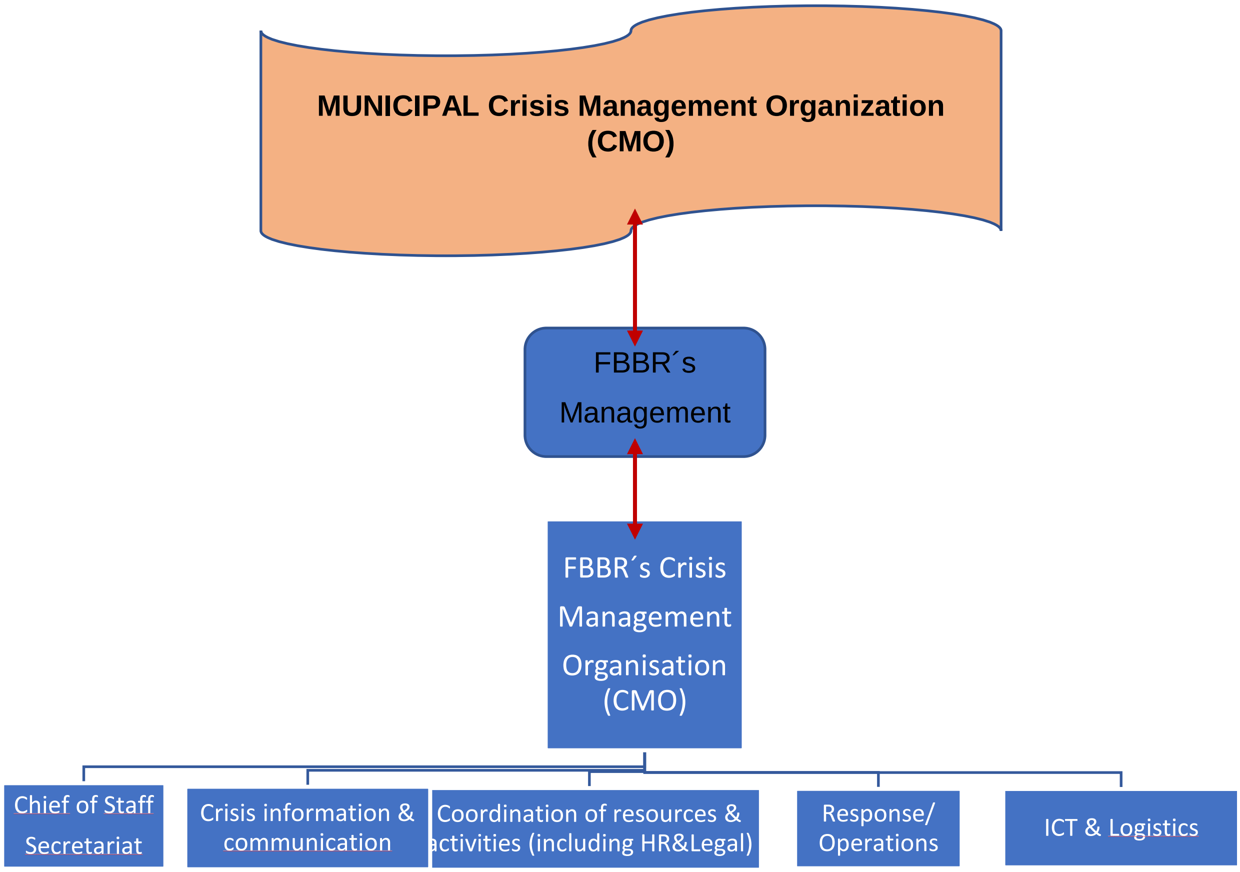


Figure 6-5. Crisis management in Denmark at municipal/FBBR level.

6.4.2 Communication systems, dissemination methods, and decision support tools

A series of communication systems, dissemination methods, and decision support tools were employed by the fire and rescue services during the ongoing emergency.

The following **communication systems** were utilised to facilitate interagency coordination, communication and decision making:

- **UMS module (Unified Messaging Systems).** To avoid confusion with other SMS templates (Mobile phone text message), FBBR has made SMS Preparedness as a separate module that can handle a given emergency situation immediately and effectively. When you open the module to turn on alarm, the entire screen turns red to alert that everyone (Figure 6-6) from the established list gets the message.

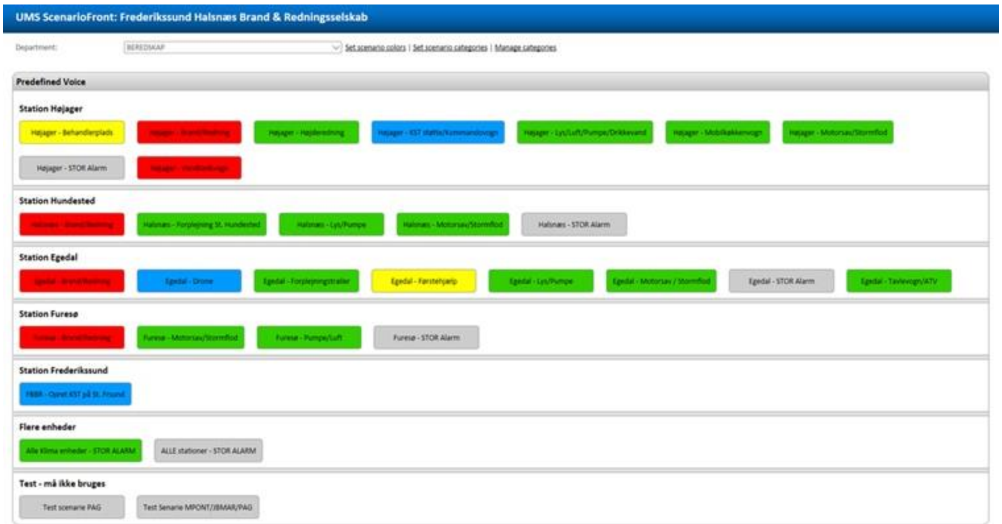


Figure 6-6. Example of UMS – Module to turn on the alarm for volunteers.

- **TETRA (Terrestrial Trunked Radio)**
- **Mobile phone (GSM)**
- **Pager**
- **Landline phone**

The following **dissemination methods** were utilised for the delivery of warning messages to the at-risk population**:**

- **Siren – warning**
- **TV - national**
- **FM-Radio**
- **Website (www.frederikssund.dk).** (A written statement issued by the Municipality of Frederikssund through their website can be seen in Annex B. Public statement (Roskilde Fjord Floods).)
- **Facebook**
- **SMS alerts**

The following **decision support tools** were utilised for risk assessment and emergency planning:

- **DMI (Danish meteorological Institute) – (weather forecast: updates every 6 hours)**

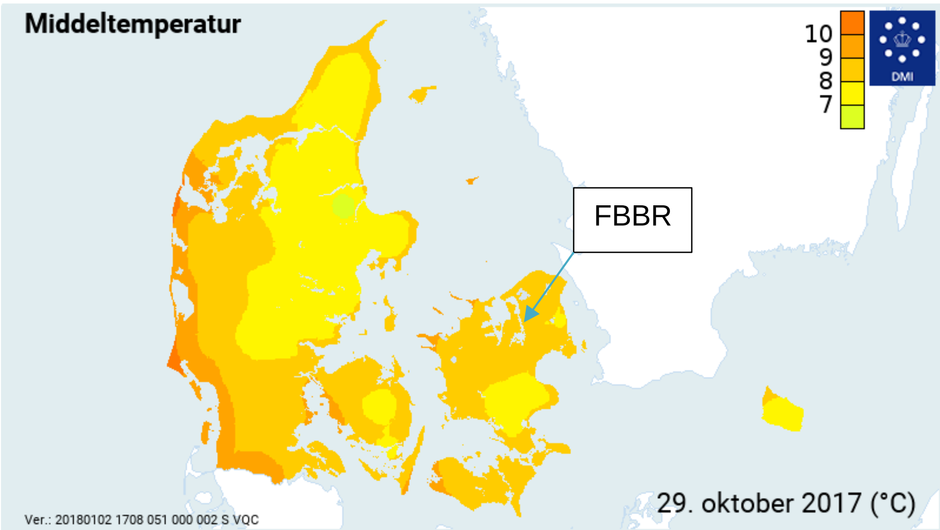


Figure 6-7. Temperature map for the 29th of October 2017 from the DMI.

- **Maps for the Response and action plans**

Figure 6-8. Overview map of the response in connection with the storm Ingolf and the elevated water level - sandbags and water tubes in the municipality (www.frederikssund.dk).

- **Maps of the municipality (e.g. map of Frederikssund Municipality)**
- **GIS tools**

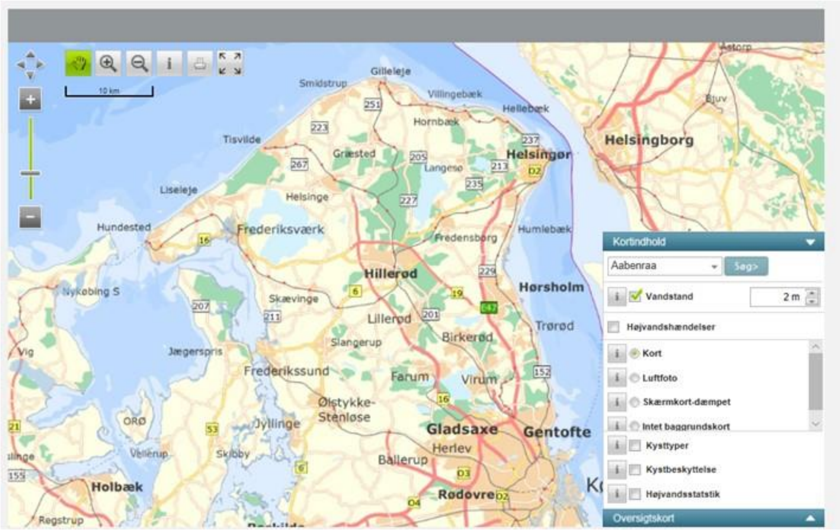


Figure 6-9. Forecast of the flooded area in a GIS tool (http://www.klimatilpasning.dk/vaerktoejer/havvandpaaland/havvand-paa-land.aspx).

6.4.3 **Strategy, tactics and operations**

Strategy, tactics and a chronology of the operations undertaken in response to the flood incident in Roskilde Fjord are shown in Table 6-4.

Table 6-4. Response operations for the Roskilde Fjord - Storm Ingolf flood.

RESPONSE FLOW	**DESCRIPTION**
T1 (0-5 min)	Elevated water level is detected and Municipal and FBBR Crisis Management Unit (CMU) is notified. FBBR first response team is notified.
T2 (5-60 min)	FBBR and municipal CMU, as well as FBBR first response team,

	are dispatched.
T3 (1-3 hours)	Fire services of different fire stations meet at Frederikssund Fire Station.
T4 (3-5 hours)	Novofos (supply Company) closes the sewer under the road in Hyllingeriis. Frederikssund part time firefighters call Toldboden fire team to install water tubes. Leader in Hyllingeriis requires municipal people to disseminate information about the ongoing incident to the citizens. IC requests firefighters from the National Guard.
T5 (5-7 hours)	Fire and rescue teams drive to critical locations, i.e. the harbour and the bridge, with equipment (pumps, hoses…) to assist in managing flood mitigation and protection actions. Toldboden starts the layout of water tubes.
T6 (7-9 hours)	More emergency units are dispatched to act at the bridge. Additional equipment is requested by the units working at the scene of the incident. Sand filling machine needs to be picked up in Egedal by an external trolley that performs tasks of crane. Kælskør fire team is warned about a ship by the quay.
T7 (9-11 hours)	External hauler delivers 30 packs of sandbags at the bridge. Service trolley with 2 fuel canisters is requested at the bridge. Mazda vehicle drives to the bridge with additional equipment (cable to the shelves and rescue rope). The layout of water tubes starts at Føtex and Stænværksvej.
T8 (11-13 hours)	Highways authority and Police notifies that MP-bridge closes at 8 pm. Ferry road with water tubes is ready. Additional units of the National guard arrive at the scene. Layout of water tubes at Enebærvej and Gyvelvej.
T9 (13-15 hours)	Vehicle with 1 team leader + 2 volunteers drives to Hyllingeriis because of the bridge closing. More voluntary fire brigade units arrive. External haulier arrives with sandbags at Strandvej. Hose tender is requested by Højager Fire Team. The IC requests 25 sandbags for Gyvevej.
T10 (15-16 hours)	IC visits the drainage on Tuevej in Jægerspris. Fire and rescue teams drive back home.

6.4.4 **Conclusion on response**

The following table serves to evaluate the degree of difficulty experienced to manage the flood emergency to as well as the outcomes of the management practices carried out.

Table 6-5. Evaluation the Roskilde Fjord – Storm Ingolf flood management outcomes. Green: easy; yellow: moderate; red: difficult.

Person rescue		Not relevant
Water supply		Not relevant
Firemen/crew		Sufficient firemen/crew of the first response
Response time		Response time of the first firetruck is less than 15 minutes
Management		Incident commander must arrive during 5 minutes after the first
Chemical		Not relevant

6.5 Lessons learned

Early warning to citizens is paramount in the event such crisis situations. Along these lines, communication, coordination, and information management can be improved using the new tools and technologies, training, exercises, and education.

With regards to prevention measures, the following aspects were identified:

- Existing prevention: Follow DMI guides on the weather forecast. Dialogue with municipal responsible sectors and other science resource persons. Contingency plans/action plans need to be updated.
- Future prevention: Drone monitoring and drone alert. Preparation of special vehicles at Danish Metrological alert.
- Remarks: Communication and coordination in a crisis situation is very important.

7 Artés Fire

The Artés forest fire started on the 5th of August 2017 at 14:30 h. Firefighters eventually managed to stabilise the fire around 17:20h on the 6th of August, after the sunshine peak hours and the wind shifts brought on by sea breezes during the day. Finally, the fire was fully controlled on the 7th of August around 21:20 h.

The fire started in area known as Les Planes (east of the B-431 road) and initially burned across 400 ha of agricultural and forest land in a plain between the localities of between Artés and Masia Roqueta.

The right flank advanced towards the northeast, crossing the gorge of the *Seco* river in the direction of San Joan d'Oló. The left flank was surrounded by many forest tracks and agricultural fields that favoured the tasks of extinction. Therefore, the Firefighters of the Generalitat de Catalunya concentrated their efforts on the right flank.

Figure 7-1. Aerial image of Artés fire.

The tasks of suppression involved 41 terrestrial units and 17 aerial means of the Firefighters of the Generalitat, as well as ADF volunteers, heavy machinery, and local farmers in tractors. Moreover, the Ministry of Agriculture, Food and the Environment of the Spanish Government sent additional aerial support: two hydroplanes, and one airplane for coordination and water-bombing support.

Two roads, the transversal road in Sallent, in the direction of Girona, and the B-431 road in Artés, were cut off to transit by the police. Two houses were burnt in Artés, but fortunately nobody was injured.

Several evacuations were performed during the incident. Firstly, emergency services evacuated around 50 people from the village of San Joan d'Oló and took them to an indoor sports pavilion in the nearby village of Santa Maria d'Oló. Once there, they were assisted by volunteers, the Red Cross and the local councils of neighboring towns that offered their help to the people affected. Also, 51 children and 7 monitors were evacuated from the farmhouse *The Clapers* and were taken to another sports pavilion in Artés. Finally, the Police of the Generalitat of Catalonia (PG-ME) preventively evacuated various houses and farmhouses in the vicinity that were affected by smoke: Masía La Vall and Masía El Pla, Ca la Ponsa, Masia Oliveras, house of the Muntanyola, Cal Cases, Can Plana, Cal Fuster, Cal Po, Ca la Mestressa, Ca l'Abellà, and Casanova del Tonet.

The 112 emergency telephone number received a total of 191 calls for this forest fire and Civil Protection was able to contact numerous municipalities in the area to keep them informed and aware of the situation.

7.1 Data collection

Data collected and sources for the Artés fire are shown in Table 7-1.

Table 7-1. Data sources for the Artés fire.

Type of data	Source	Time of collection
Cartography (topography, infrastructure, population, roads, bridges, powerlines, vegetation, geology, soil use, ortophotos…)	SMC, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, Artés Municipality	2017
Operational cartography on topography (critical assets, routes, soil use, housing)	SMC, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, Artés Municipality	2017
Fire extension	SMC, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, PG-ME, Local Police, Artés Municipality	2017
Affected area	SMC, IDESCAT, Civil Protection of Catalonia, ICGC, Fire Service of Catalonia, PG-ME, Local Police, Artés Municipality	2017
Weather data	SMC, ICGC, IDESCAT, Civil Protection of Catalonia, Fire Service of Catalonia, PG-ME, Local Police, Artés Municipality, Wetterzentrale, Wetter3	2017
Images and videos	TV3, Fire Service, ICGC, Artés Municipality, ElNacional, Youtube, ADFs, Regio7, Ara, Naciodigital, EFE	2017
Logistics and means deployed	PG-ME, Local Police, Artés Municipality, ADFs, Fire Service	2017
Population within area of interest and citizens affected	PG-ME, Local Police, Artés Municipality, IDESCAT	2017
Fieldwork to validate fire behaviour	ADFs, Fire Service of Catalonia, PG-ME, Local Police, Artés Municipality,	2017

Social media and relevant information	TV3, Fire Service, ICGC, Artés Municipality, ElNacional, Youtube, ADFs, Regio7, Ara, Naciodigital, EFE, Local Police and PG-ME	2017

7.2 Data processing

7.2.1 **Available photos**

A number of photos of the Artés fire have been collected from INT-FRS and other open sources and added to Annex C. Images of the Artés Fire. This collection of photos has the purpose to help fire experts from INT-FRS to know better about the fire behaviour.

7.2.2 **Weather data**

Weather charts are used by fire experts to define the weather scenario of each forest fire (level of humidity of air mass, atmospheric instability, pressure levels, etc.). This kind of information, in conjunction with the historical data and empirical information from crews, is used to predict the evolution of the fire behaviour and to reconstruct past fire events.

Specific forecasted weather charts were obtained for Artés Fire from the 5th until the 6th of August 2017:

- Temperature and Relative Humidity during the Artés fire.
- 500hPa Geopotential on the 5th of August 2017.
- 850hPa Geopotential on the 5th of August 2017.
- Precipitation on the 5th of August 2017.
- Temperature at 2m on the 5th of August 2017.
- 500hPa winds on the 5th of August 2017.

One example of each of this parameters is shown in the following figures:

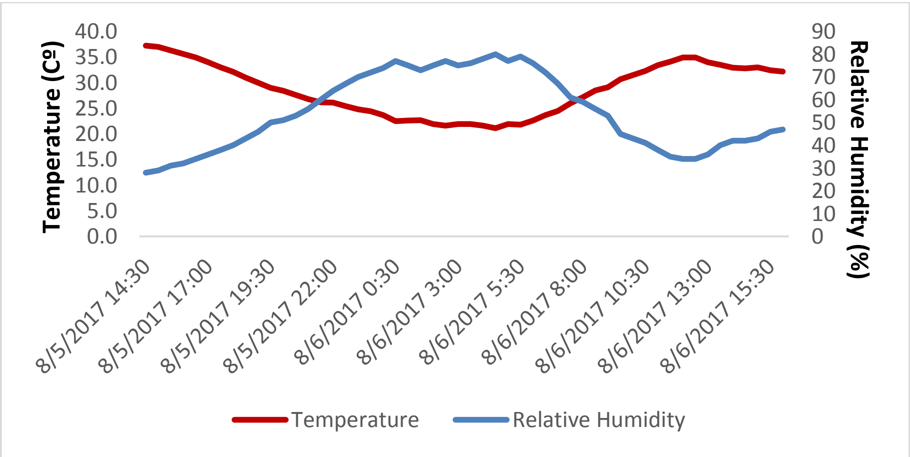


Figure 7-2. Temperature and Relative Humidity during the Artés fire.

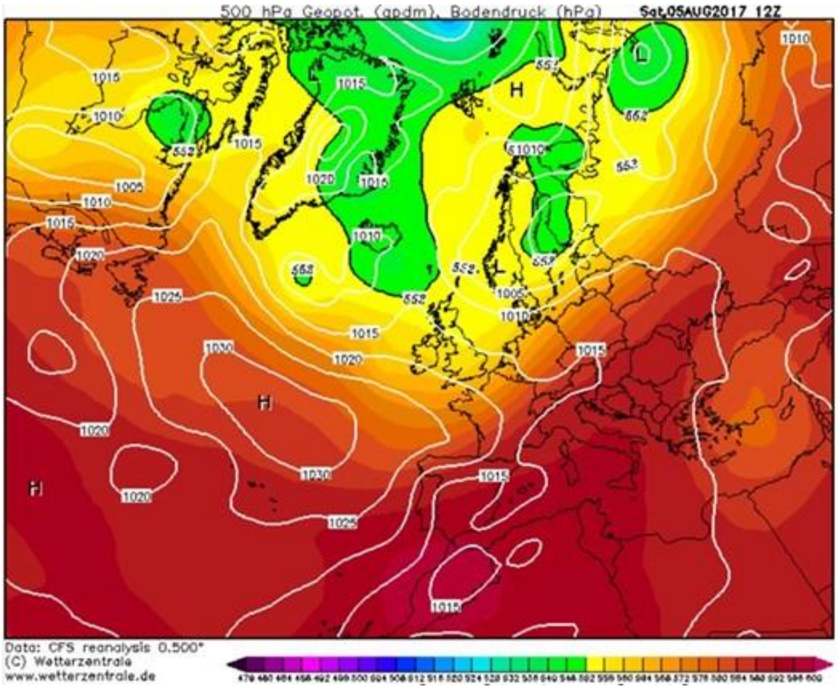


Figure 7-3. 500hPa Geopotential on the 5th of August 2017.

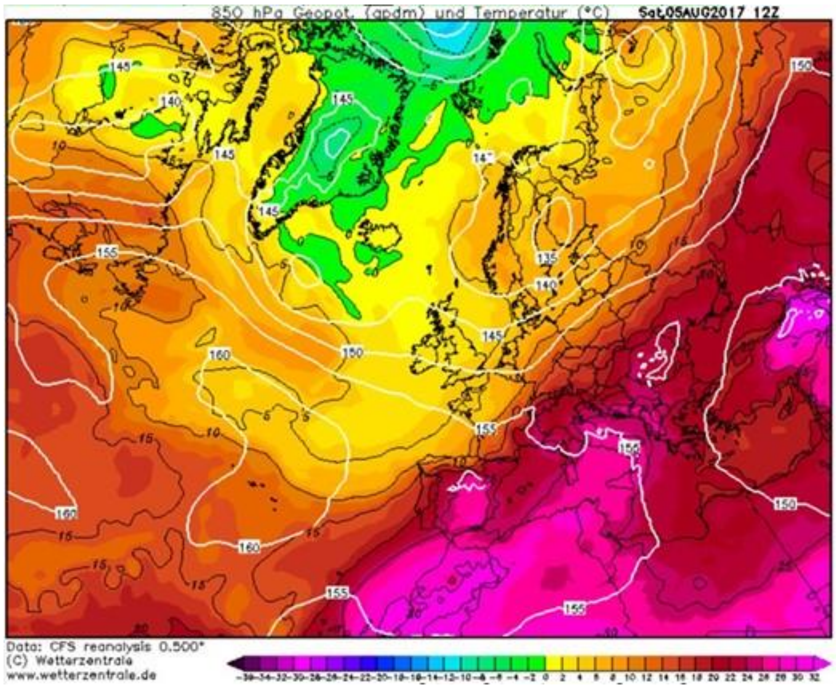


Figure 7-4. 850hPa Geopotential on the 5th of August 2017.

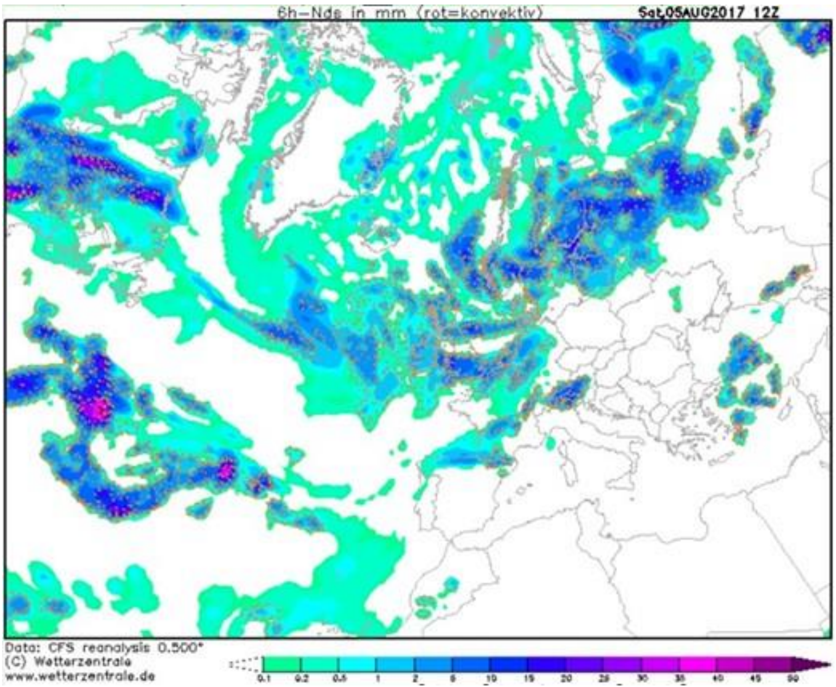


Figure 7-5. Precipitation on the 5th of August 2017.

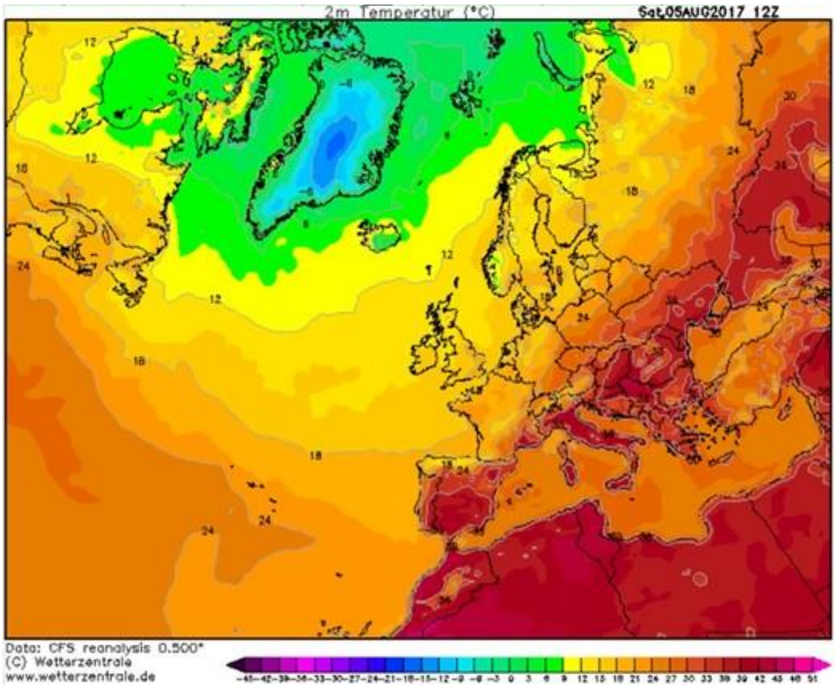


Figure 7-6. Temperature at 2m on the 5th of August 2017.

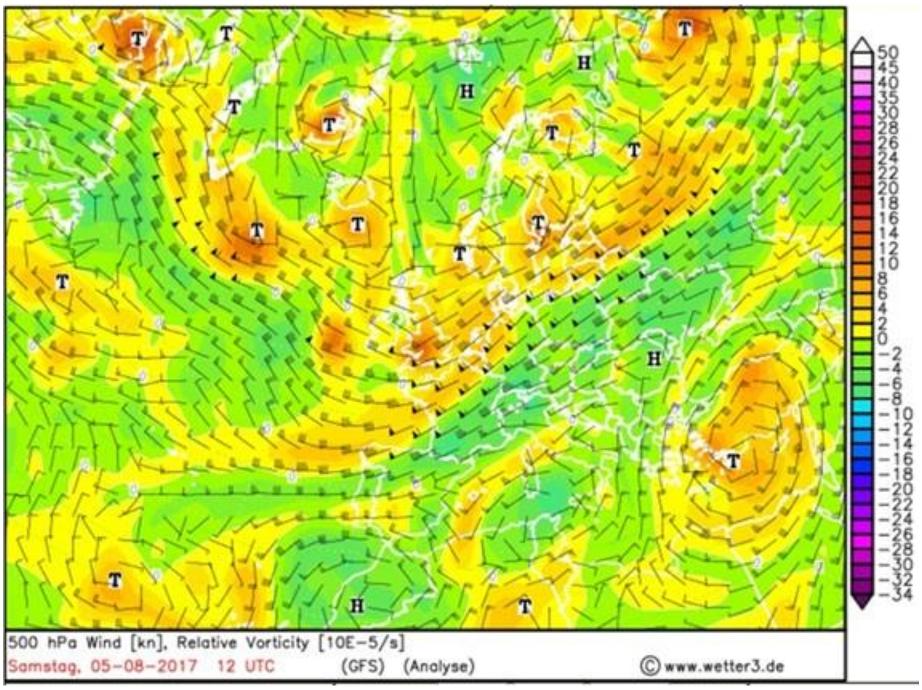


Figure 7-7. 500hPa winds on the 5th of August 2017.

Weather forecasts from the SMC

In addition to this information, the SMC (Meteorological Service of Catalonia) disseminates graphic information that enables to know the synoptic situation or the meteorological peculiarities for a given period of time.

Following is relevant weather data collected from SMC for the month of August 2017, when the Artés fire occurred:

- Difference (ºC) between the average and climatic temperature in August 2017.
- Accumulated rainfall (%) with regard to the climate average in August 2017.
- Monthly solar irradiation anomaly (%), August 2017.
- Estimated accumulated rainfall (mm) for the 5th and 6th of August.
- Topography of 500 hPa on the 5th of August at 12:00h UTC
- METEOSAT image from day 5th of August at 12:00h UTC
- Real accumulated rainfall from the 5th to the 6th of August 2017
- Absolute maximum temperature in August 2017

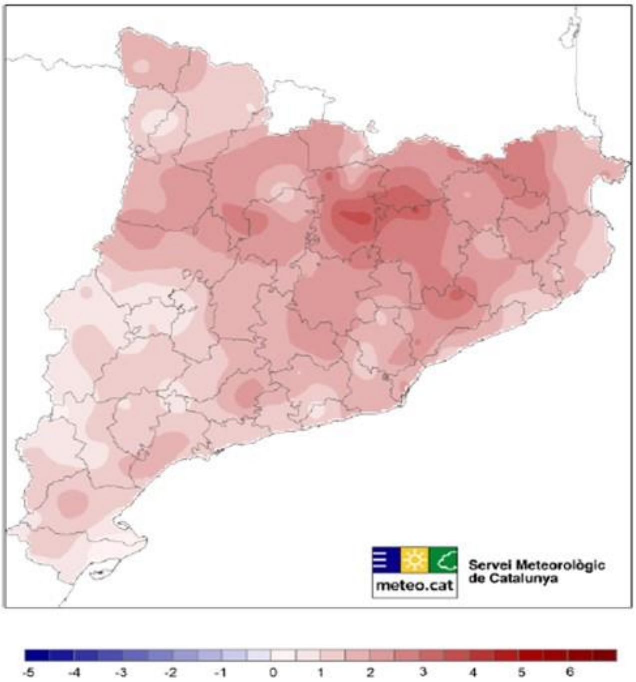


Figure 7-8. Difference (ºC) between the average and climatic temperature in August 2017.

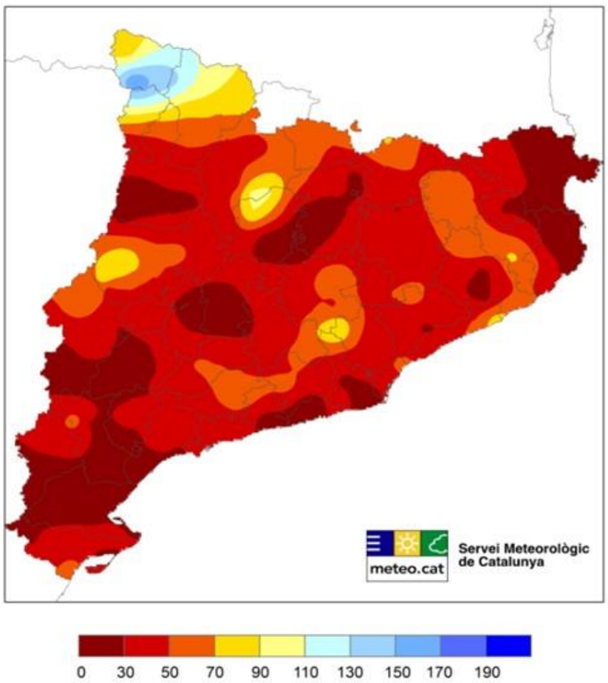


Figure 7-9. Accumulated rainfall (%) with regard to the climate average, August 2017.

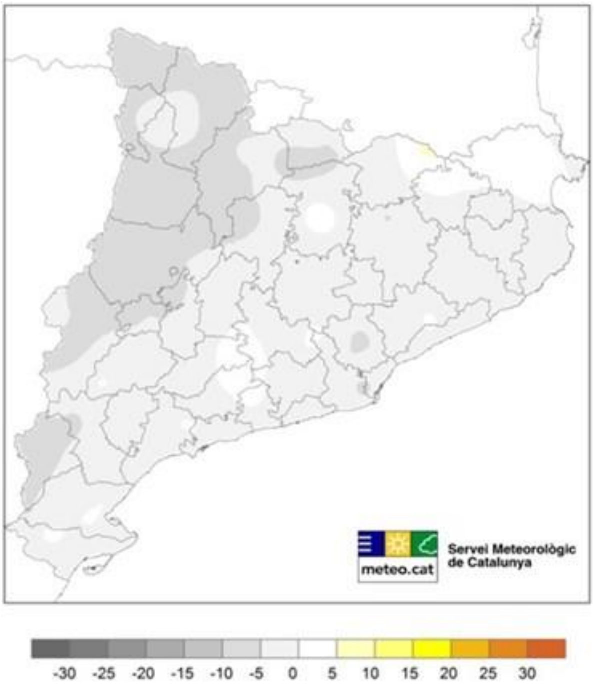


Figure 7-10. Monthly solar irradiation anomaly (%).

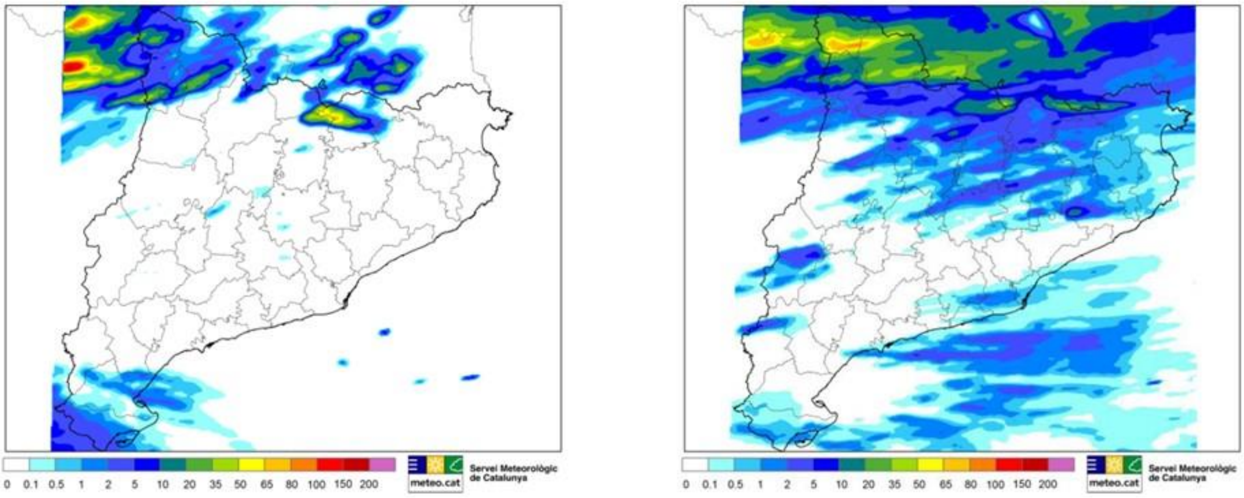


Figure 7-11. Estimated accumulated rainfall (mm) from the 5th to the 6th of August.

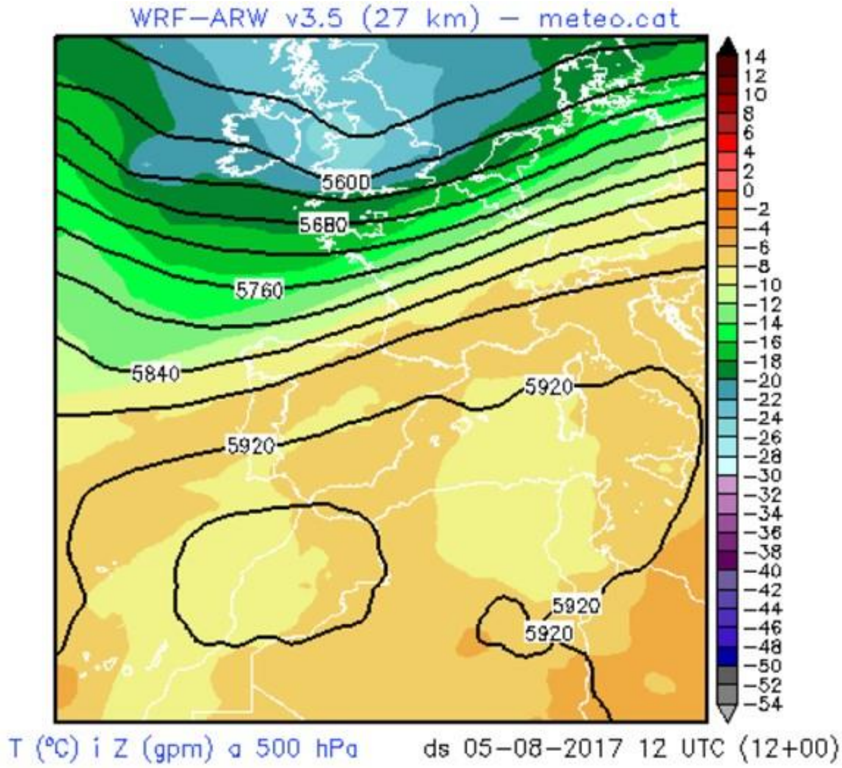


Figure 7-12. Topography of 500 hPa for the 5th of August at 12:00h UTC.

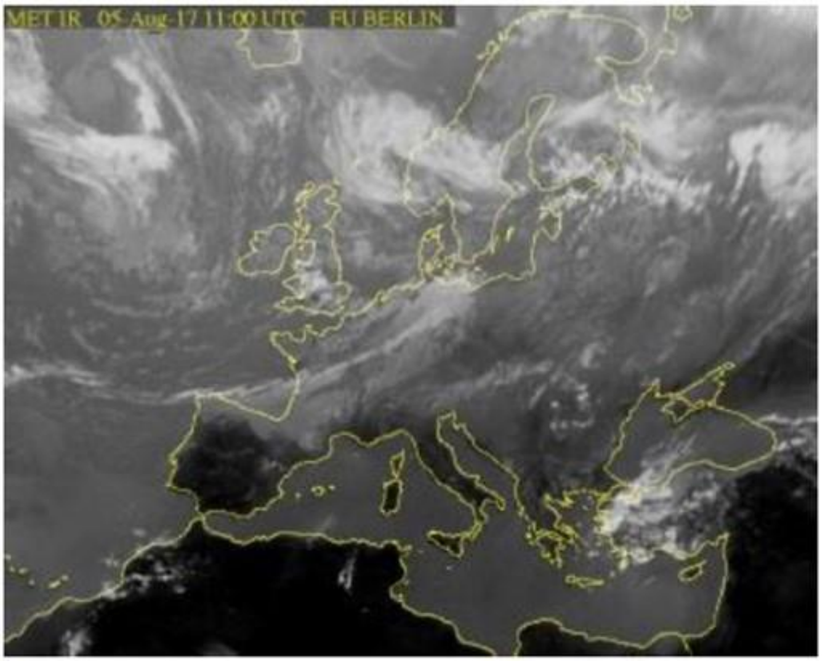


Figure 7-13. METEOSAT image for the 5th of August at 12:00h UTC.

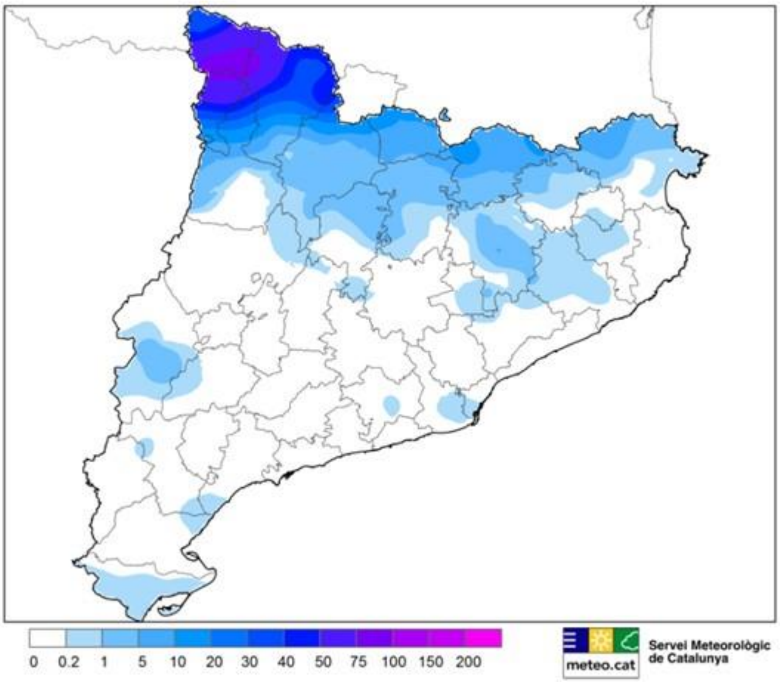


Figure 7-14. Real accumulated rainfall from the 5th to the 6th of August 2017.

The meteorological data at the beginning of August of 2017 in Artés presented high temperatures, and this is why the vegetation was dry.

Table 7-2. Thermopluviometric values of the Artés station managed by the SMC (August 2017).

Region	EMA	TMm (°C)	TXm (°C)	TNm (°C)	TXx (°C)	Day	TNn (°C)	Day	PPT (mm)	PPTx24h (mm)	day
Bages	Artés	24,6	34,4	16,5	41,2	4	11,0	11	30,3	12,4	31

EMA: Automatic weather station
TMm: Average daily temperature (°C)
TXm: Mean daily maximum temperature (°C)
TNm: Mean daily minimum temperature (°C)
TXx: Absolute maximum temperature (°C)
TNn: Absolute minimum temperature (°C)
PPT: Accumulated rainfall (mm)
PPTx2: Maximum daily rainfall registered (mm)

7.2.3 **Fire perimeter and operations**

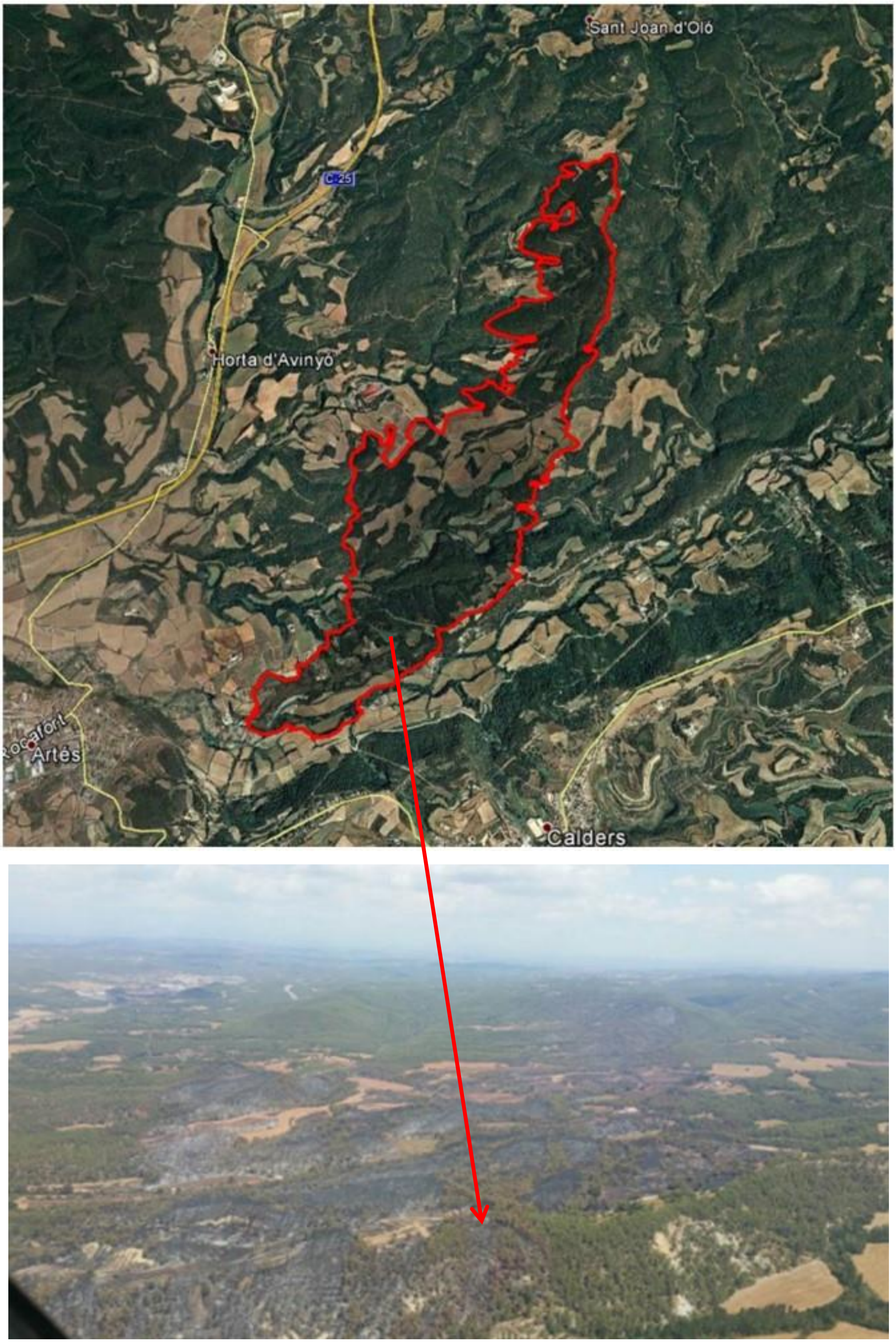


Figure 7-15. Perimeter of the Artés fire on the 5th August 2017 from a helicopter of the Catalan FRS.

Table 7-3. Surface burned and rate of speed in the Artés Fire.

Date	Name and region	Surface burned (ha)	Average of rate of spread (km/h)

05/08/2017	Artés (REC)	378	>1

REC: Central Region of Fire Emergencies in Catalonia.

Table 7-4. Symbology of fire suppression operations.

Name	Symbology
Hose line executed	
Hose line planed	
Hand line	
Hose line + hand line	
Aerial means executed (water bombings)	
Aerial means planed (water bombings)	
Aerial means (retardant)	
Back fire planed	
Back fire executed	
Bulldozer line executed	
Bulldozer line planed	
Fire perimeter	

7.3 Risk and behaviour analysis

7.3.1 **Trigger Points and Vulnerable Elements**

Figure 7-16 shows the situation of the fire perimeter on the 5th of August at 19:30 h. At this point 90% of perimeter was stabilized, a small part of the left flank close to the head was still active, and only a very small part was controlled. The estimated surface burnt was 440 ha, while the first estimates had concluded that the fire had potential to spread over 3.000 ha.

The fire propagated as a wind-driven fire in the planes and as a topographic fire in the mountainous area. It was not as a plume-dominated fire, although spotting across the plain reached distances up to 300 m. The maximum rate of spread was estimated at 2km/h.

As observed in Figure 7-16, Trigger Points were located along both flanks: Trigger Point A is on the right flank; Trigger Point B is further up on the left flank; whereas Trigger Point C is at some distance from the right flank. If the fire reached one of these points it would led to a sudden change in fire behaviour resulting in increased potential of spread. This would also increase the possibilities for the fire to reach the Vulnerable Elements located along the fire perimeter. In this case, Vulnerable Elements correspond to populated areas that become a priority in terms of fire protection. To protect Vulnerable Elements A and B firefighters need to stop the progression of the left flank, whereas to protect Vulnerable Elements C and D, firefighters need to stop the progression of the head before the main fire front reaches them. Finally, Element E, which is at some distance from the Right Flank, could only get affected if fire reached Trigger Point A and met favourable conditions to propagate towards it (e.g. shift in the direction of the wind towards the east).

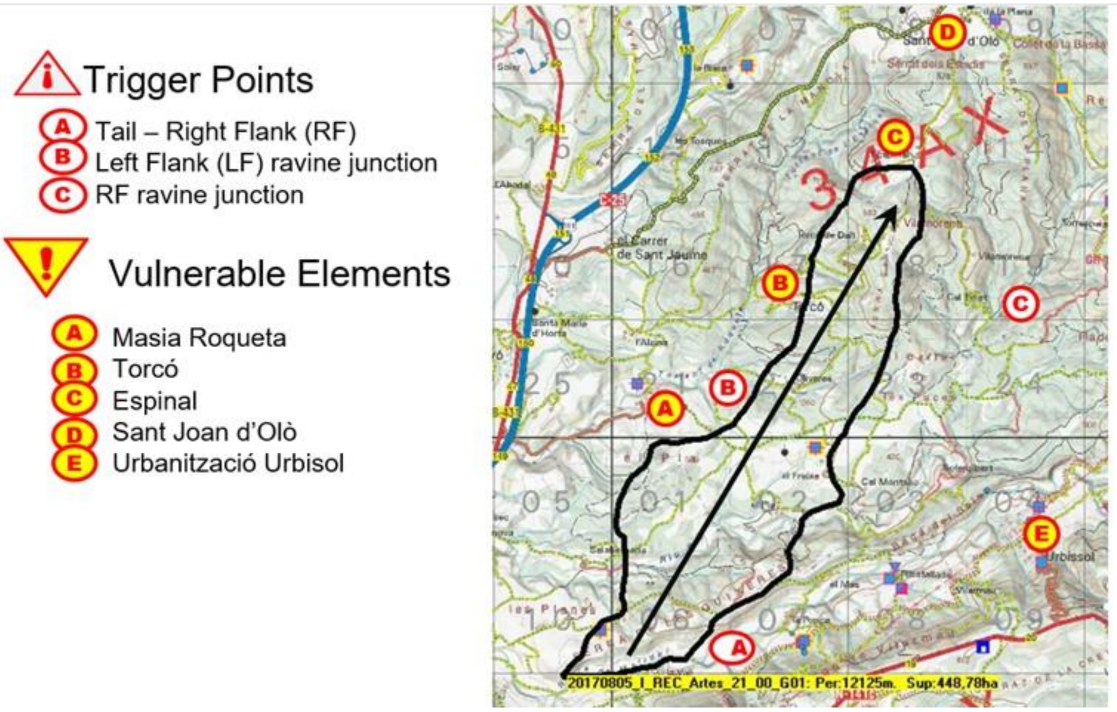


Figure 7-16. Fire perimeter, Trigger Points, and Vulnerable Elements.

7.3.2 **Drones for the detection of hot spots**

During the first night the firefighters tested a drone that was provided by the MAPAMA (Ministry of Agriculture, Fisheries and Food of the Spanish Government) to track the hot spots and capture a set of aerial images that allowed them to make a better assessment of the development of fire. All the data obtained from the drones was geo-referenced and transferred into a GIS system for a more detailed analysis on the fire situation. Early next morning that information became very useful for the management of aerial firefighting resources and the definition of priority points to perform the fire suppression actions.

The information provided by the drones (Figure 7-17) was used in combination with the field observations made by the ground personnel to have a complete picture of the fire perimeter, including both the contour and the area inside [5].

Figure 7-17. Perimeter of the fire made up of drones images obtained during the drone flight during the night on the 5th of August 2017 for the location of hotspots.

7.4 Strategy, priorities and tactical objectives

7.4.1 General strategy

The overall strategy was to narrow as much as possible the fire perimeter on the plain (between Artés and Masia Roqueta) as well as keep it with reduced intensity and slow rate of spread in order to stop the spread of fire towards the mountainous area of Sant Joan d’Oló.

7.4.2 Strategic scenario

The strategic scenario is underpinned by the analysis of potentials displayed in Figure 7-18, which shows the maps of potential fire spread and the initial strategies planned to confine the fire perimeter.

Securing both flanks from the back is crucial due to the following factors:

- Rapid rate of spread of 2 km/h;
- important spotting distances across the plain reaching 300 m; and
- evolving storms in the area of Berguedà generating erratic movements on both flanks.

Operations in the mountainous area ahead of the front of the fire are limited to protecting vulnerable elements between Masia Roqueta and Sant Joan d´Oló (Figure 7-18). It should be noted that this area has very few safe areas, and the work of fire and rescue services is subject to risk conditions caused by the storm.

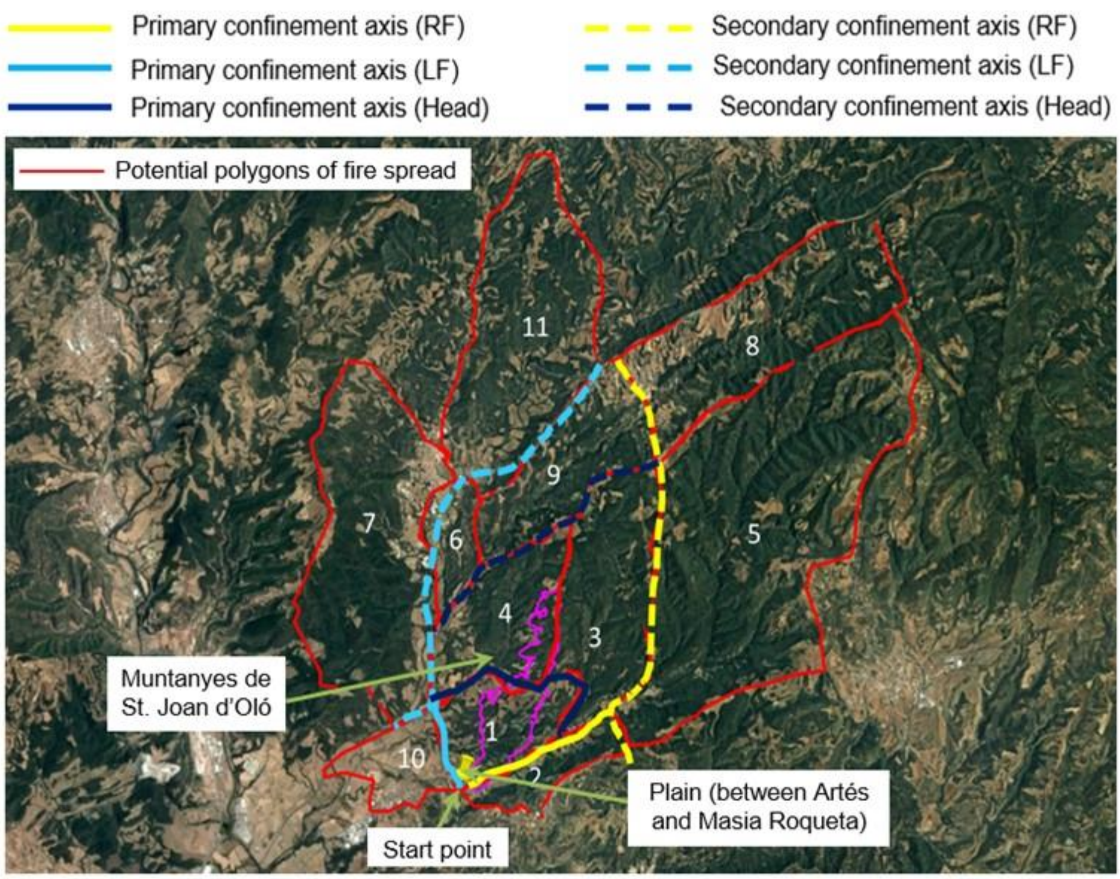


Figure 7-18. Potential polygons of fire spread and axis of primary and secondary confinements of the fire.

The probabilities of fire spread to the potential polygons of fire spread in the diagram in Figure 7-18 are displayed in Figure 7-19.

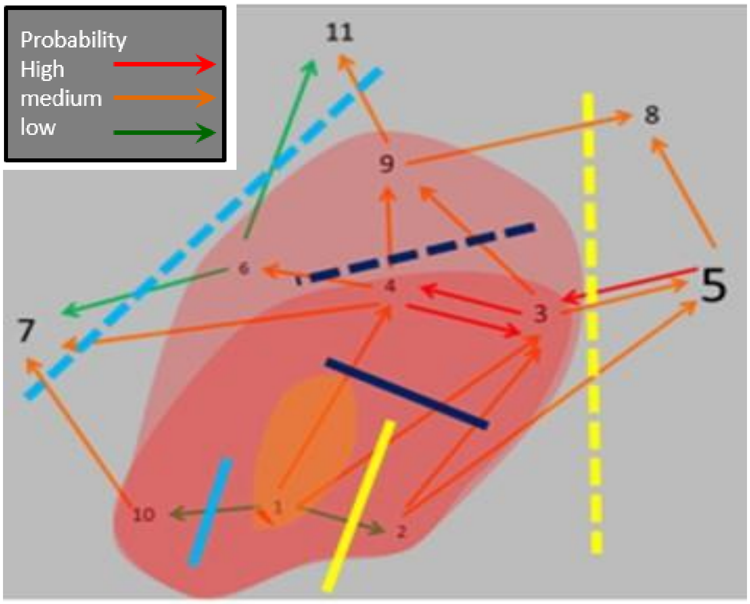


Figure 7-19. Diagram of potential polygons of fire spread.

7.4.3 **Tactical objectives, actions and operations**

	Tactical Objectives When and Where. Opportunities	Actions and Operations Actions / Operations / Description	Commandment	Division / Resource
1	Stabilize the tail to prevent the Right Flank from spreading to the east, and reduce the spread of fire towards the north. (14:30 to 16:00)	Defence of houses Tractors digging fire lines in wheat fields. Hose lines and aerial means working. Backfires in the flanks.	Delta 100	ECHO0 GRAF Division Aerial Means Division
2	Stabilize both flanks to keep the fire as narrow as possible. (14.30 to 19:30)	Tractors tearing lines in wheat fields. Hose lay and aviation resources. Backfires on the flanks. Allocation of water resources.	Bravo 0 Delta 100	Ecos GRAF Div. MAER Div.
2	Reduce the spread of the head and minimise potential damages in this area. (15:30 to 19:00)	Identification of opportunities and vulnerable elements ahead of the head. Backfires in the discontinuities perpendicular to the main spread direction. Evacuation, confinement, and tractors digging fire lines to protect houses and infrastructures in danger.	Graf 03	GRAF Div. MAER Div.
1	Work both flanks to narrow the fire perimeter. (19:30 to 22:00)	Allocation of water resources. Tractors tearing lines in wheat fields. Hose lay and aviation resources. Backfires on the flanks.	Bravo 0 Delta 100	Echos GRAF Div. MAER Div.
2	Stabilize and control the perimeter (Day 1 at 19:30 to day 2 at 16:00)	Hose lays, Bulldozers. Manual tools, aerial means.	Bravo 0 Delta 1 Delta 100	Echos GRAF Div. MAER Div

7.4.4 **Constraints and opportunities**

Following are a list of constrains and opportunities that fire suppression services encountered during the fire suppression actions and operations. Fire-fighting operations carried out during the fire events are illustrated in Figure 7-20.

- Given the uncertainty of the track and conditions of the storm, operations should be always well anchored, with a safe zone nearby, and progression along the flanks should always have its back well consolidated. Terrestrial movements in the area between the Masia Roqueta and Sant Joan d'Oló, with few safe areas, are limited to firefighters preserving the safety of vulnerable elements and tracking possible opportunities to stop head runs in clear discontinuities, slowing down the fire with indirect attack by aerial means and technical fire. Back fires anchored in fields and roads.
- Works in both flanks are carried out at the same time, by direct and parallel attack.
- The deployment of fire engines depends on the need for protecting the endangered houses on the Left Flank.
- To contain the spread of fire the priority is to contain both flanks:
    - Firstly, prevent the Tail-Right Flank (trigger point A) from reaching the Serrat de la Creuata, lee-wind area. This is achieved with the aid of hose lines, tractors, and aerial means.
    - Secondly, prevent the Left Flank from reaching the Roqueta Torrent towards Serrat de l´Alzina (trigger point B). This is achieved by stabilizing spots across

vineyards and well-managed forest with aerial means, hose lines, and hand lines.

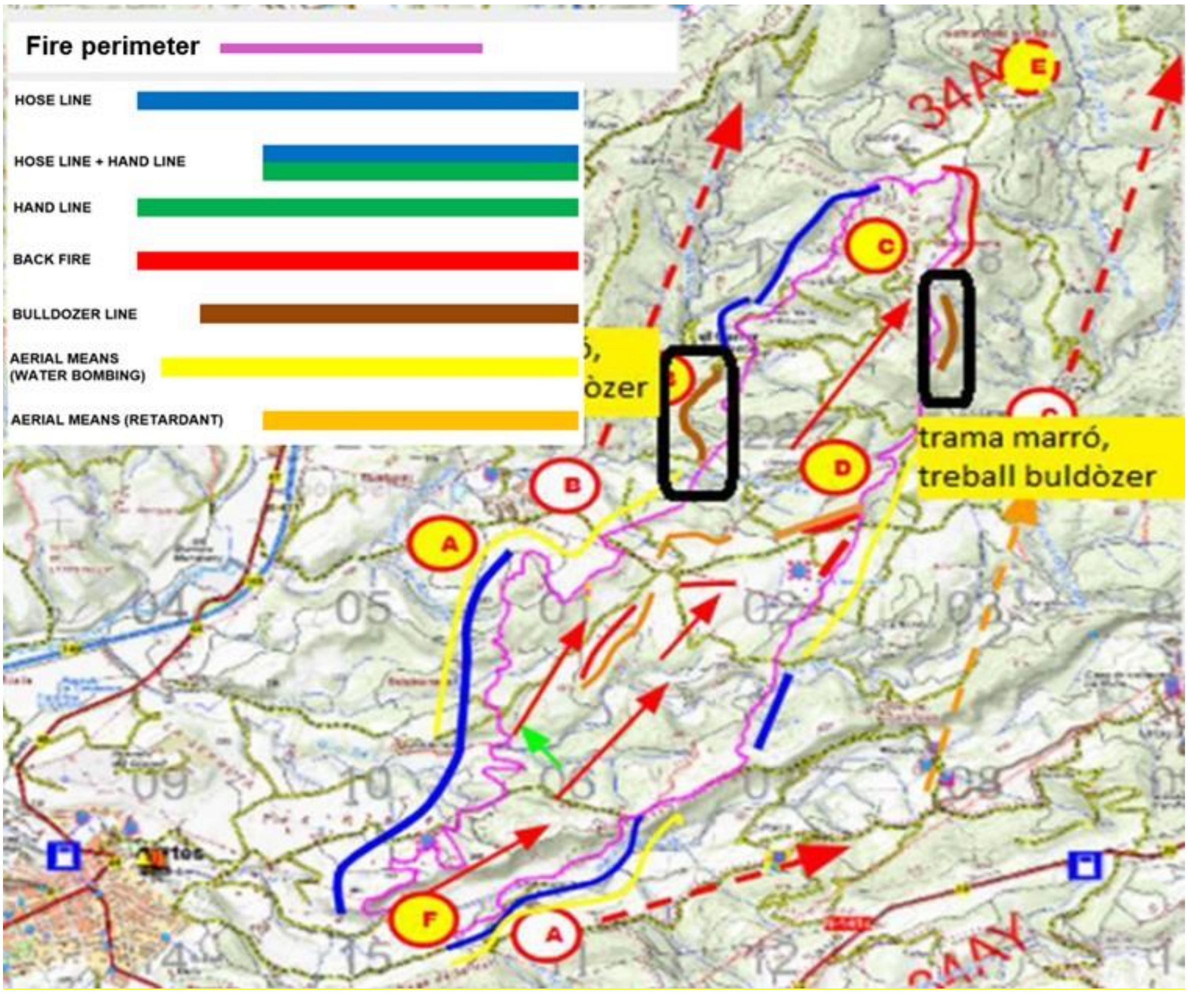


Figure 7-20. Fire suppression operations.

7.5 Operations and means deployed

This sections describes the operations carried out by each of the acting groups, as well as the means deployed, sequentially from the start of the incident (5^{th} of August at 14:00) until (6^{th} of August at 16:00).

Operational period: 05/08/2017 14:30-19:30h

Strategy: to protect vulnerable elements between *Masia Roqueta* and *Sant Joan d´Oló* and prevent the fire from reaching the forest area.

Common objectives

- Extinguish the fire and protect isolated houses from *Artés*.
- Narrow as much as possible the fire perimeter on the plain (between Artés and Masia Roqueta) in order to prevent the fire from reaching the mountainous area of Sant Joan d'Oló.
- Protect the vulnerable elements from the General Operations Area (GOA), and evacuate people.

Means deployed

List of means deployed by action organisations (Table 7-5):

Table 7-5. List of means deployed on the 5th of August from 14:30 to 19:30h.

Organisation	Means deployed
FRS (Fire and Rescue Services)	• Material means: - 15 aerial means - Heavy machinery/equipment - 15 command vehicles - Incident Command Post • Human means: Dispatch: - Commands - Delta 100, Bravo 0, GRAF 00, GRAF 02, GRAF 03 - 148 firefighters (approx.) Situation Report: - 15 fire engines - 2 GRAF units - 4 helicopters - 2 air tractors (small airplanes)
Police	Material and human means deployed in the emergency under the command of the organisation responsible leaders: the Mayor and the Local Police Chief of Artés. The deployment of these resources were done in coordination with the rest of the authorities involved in the emergency. • Material means: - 1 SUV 4X4 DACIA DASTER model police vehicle. - 1 HONDA 125cc scooter police motorcycle. • Other material resources that are not owned by the Police: - 1 bus which is not a property of the Local Police but was used to evacuate a group of children. - 1 private vehicle of one of the commissioned police officer. • Human means: - 1 local police officer in service. - 2 local police officers and 1 senior management local police officer as an emergency contingent (they were on vacation period).

	- A complete list of the volunteers of Artés.
CP (Civil Protection)	N/A
MS (Medical Services)	1 ambulance

Command and control (Table 7-6)

Table 7-6. Command Organigram Chart on the 5th of August from 14:30 to 19:30h.

Position	Name and Surname	Agency	Hierarchy	Location
Incident Commander (IC)			1	On field & ICP
Fire Strategic Analyst	GRAF 00	FRS	-	On field
Operations Chief		FRS	2	On field
Aerial Operations Coordinator		FRS	3	On field
Sector Chief 1		FRS	3	On field
Sector Chief 2		FRS	3	On field
Tactical Fire Operations Chief	GRAF 03	FRS	3	On field
Planning & Logistics Chief		FRS	2	ICP
Tactical Fire Analyst	GRAF 02	FRS	4	ICP
Logistics Coordinator		FRS	2	ICP
Tactical Advisor		FRS	4	ICP
Weather Analyst		SMC	-	ICP
Hazard Analyst		SPIF	-	ICP
Local Police Chief		Local Police	2	ICP
PG-ME Chief		PG-ME	2	ICP
Civil Protection Chief		CP	2	ICP
Medical Resources Coordinator		MS	2	ICP

Constraints

- The presence of electrical power lines generates a problem for the work of aerial means.
- The meteorology was uncertain because of a storm front passing through.
- Initial runs of the fire end up with various houses burned, so suppression efforts were focused on that area.

Organisation Specific Actions

FRS (Fire and Rescue Services):

- Protect houses and control fire spread in the area.
- Direct attack on the flanks of the fire with the support of the Forest Defence Aid (FDA). Also, direct attack on the head of the fire with the support of the FDA and tractors.
- Activation of GRAF Group of the FRS.

Police:

- Evacuate inhabitants of the fire zone and nearby areas of high risk.
- Isolate and protect the area.
- Establish checkpoints at the accesses of the area (the perimeter of the fire) in order to prevent the public access to the emergency zone.
- Surveillance of the affected area to protect the assets (particularly houses) in the area.
- Confine people in the villages of *Santa Maria d'Oló* and *Roqueta*. Evacuate three country houses, one of them called *"Els Clapers"* (in the natural setting of *Santa Maria d'Oló*) and the summer camp called *"La Ruca"* in *Horta d'Avinyò* where there are a group of children. A bus is facilitated the evacuation.
- Accompany other emergency services who are less familiar with the area so they can act faster, and be more efficient.
- Request reinforcements to the local police of *Sant Fruitós de Bages*.
- Provide refugee locations and support/help for evacuees.
- Traffic control.
- Call for solidarity asking resident population for help in distributing water and food to emergency services, as well as firefighting activities (firewalls) under the leadership of firefighters and ADF.

CP (Civil Protection):

- Activate phase of Alert of the INFOCA emergency plan.
- Confine people in *Masia de Roqueta* and evacuate people from Holiday Home.
- Guide the evacuating people; coordinate with the municipality to define and manage the refuge locations and the logistic support.

MS (Medical Services):

- Assist and evacuate injured people from burned houses.
- Place an ambulance at the ICP as a preventive measure.

Notifications

Who?	What?	To whom?	Why?
Local Police officer	Fire alarm and emergency plan.	Local Police Chief and Firefighters.	Fire detection is confirmed by a police officer. He warns and reports the firefighters and the local police chief so they make decisions.
Local Police Chief	Fire alarm and local action plan	The chief commander of each agency (Firefighters, PG-ME, ADF) the mayor of PG-ME, the municipal technician, and all police officers of Artés.	Inform about the fire detection and activate the local action plan.
Local Police Chief	Set up the CECOPAL and the crisis cabinet	To whom it may concern internally in each agency (ADF, Police, the municipal technician responsible of the emergency plan, the mayor, etc).	Necessity to quickly set up the CECOPAL and the crisis cabinet.
Firefighters	Point of transit - coordination	The chief commander of each	Provide a meeting point for the coordination of the

	point	agency.	involved organisations.
Support Tactical Analyst (GRAF 01)	Situational Report 1	Incident Commander	Support the Incident Commander in the decision making process.
Support Tactical Analyst (GRAF 01)	Situational Report 2	Strategic Analyst (GRAF 00)	Support the Strategic Analyst in the decision-making process.
Strategic Analyst (GRAF 00)	Report on the current situation, the expected evolution of the incident, and response actions agreed with the IC.	Support Tactical Analyst (GRAF 01)	Communicate the response actions and other decisions.
FRS Command Centre (on site)	Situational Report 3	The chief commander of each organisation in ICP's meetings.	Report on actions to be taken.
		FRS Central Control Room, located in the region where the incident occurs.	Report on actions and tasks to be taken.
Chief commanders of each organisation on field at the ICP.	Situational Report 4	To whom it may concern internally in each agency.	Report on actions and tasks to be taken.
FRS Central Control Room		Coordination Centre Room (CECAT)	Report on actions and tasks to be taken.

Operational period: 05/08/2017 19:30h - 06/08/2017 16:00h

Strategy: narrow the fire perimeter as much as possible and stabilize and control the fire as the storm activity is likely to decrease during the night because by night, the storm will probably decrease leading to more favourable conditions.

Common objectives

- Limit the fire spread on the left flank in order to stop the progression of fire towards *Sant Joan d'Oló*.
- Limit the fire spread on the right flank to prevent fire from reaching dense forest stands.
- The fire sector that burned houses at the beginning of the incident is not totally extinguished by the start of the second operation period. Thus, one of the priorities is to cool this area down with water to insure that the fire is out, and check the state of the burned structures.

Options and contingency

Figure 7-21 shows the fire perimeter and the polygons of potential fire spread at 18:30-19:00h. At this point the fire could potentially enter the polygons 1 and 4.

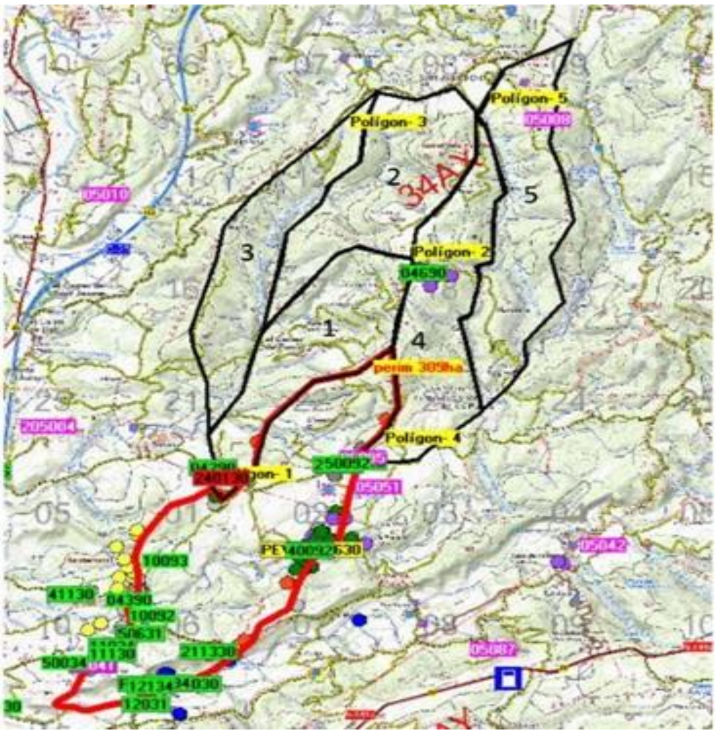


Figure 7-21. Artés fire perimeter (in red), and potentials polygons of fire spread (in black).

The scheme of potential as depicted in Figure 7-22 helps define the “what-if” analysis which will in turn help the incident commander to make the final decision with regards to the best strategy.

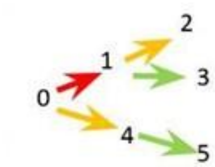


Figure 7-22. Scheme of potential polygons of fire spread.

Following is the “what-if analysis” derived from the identification of potential polygons of fire spread:

What if the fire spreads to polygon 1?

The fire will have potential to run to polygons 2 and 3 thereby reaching the village of *Sant Joan d’Oló.*

What if the fire spreads to polygon 4?

The fire will have potential to run to polygon 5 thereby reaching dense forest stands.

Final decision made by the Incident Commander after the “what if” analysis: polygon 1 will be attacked first as the primary issue is to guarantee the safety of the at-risk population.

Means deployed

List of means deployed by action organisations (Table 7-7):

Table 7-7. List of means deployed from the 5th of August at 19:30h to the 6th of August at 16:00h.

Organisation	Means deployed
FRS (Fire and Rescue Services)	• Material means: - 15 aerial means - Heavy machinery/equipment - 15 command vehicles • Human means: Dispatch: - Commands - GRAF 00, GRAF 02, GRAF 03 - 255 firefighters (approx.) Situation Report: - 15 fire engines - 2 GRAF units - 4 helicopters - 2 air tractors (small airplanes)
Police	Material and human means deployed in the emergency under the command of the organisation responsible leaders: the Mayor and the Local Police Chief of Artés. The deployment of these resources were done in coordination with the rest of the authorities involved in the emergency. • Material means: - 1 SUV 4X4 DACIA DASTER model police vehicle. - 1 HONDA 125cc scooter police motorcycle. • Other material resources that are not owned by the Police: - 1 private vehicle of one of the commissioned police officer. • Human means: - 1 local police officer in service. - 2 local police officers and 1 senior management local police officer as an emergency contingent (they were on vacation period). - A complete list of the volunteers of Artés.
CP (Civil Protection)	N/A
MS (Medical Services)	1 ambulance

Constrains

- Aerial means cannot operate during the nighttime and the work of terrestrial means becomes more difficult than during the day.

Command and control (Table 7-8)

Table 7-8. Command Organigram Chart from the 5th of August at 19:30h to the 6th of August at 16:00h.

Position	Name and Surname	Agency	Hierarchy	Location
Incident Commander (IC)			1	On field & ICP
Fire Strategic Analyst	GRAF 00	FRS	-	On field
Operations Chief		FRS	2	On field
Aerial Operations Coordinator		FRS	3	On field
Sector Chief 1		FRS	3	On field
Sector Chief 2		FRS	3	On field
Tactical Fire Operations Chief	GRAF 03	FRS	3	On field
Planning & Logistics Chief		FRS	2	ICP
Tactical Fire Analyst	GRAF 02	FRS	4	ICP
Logistics Coordinator		FRS	2	ICP
Tactical Advisor		FRS	4	ICP
Weather Analyst		SMC	-	ICP
Hazard Analyst		SPIF	-	ICP
Local Police Chief		Local Police	2	ICP
PG-ME Chief		PG-ME	2	ICP
Civil Protection Chief		CP	2	ICP
Medical Resources Coordinator		MS	2	ICP

Organisation Specific Actions

FRS (Fire and Rescue Services):

- Limit the spread of both fire flanks.
- Stabilize and control the perimeter.

Police:

- Evacuate people in the area affected and nearby high-risk areas.
- Isolate and protect the areas at risk.
- Establish checkpoints at the accesses of the area (the perimeter of the fire) in order to prevent the public access to the emergency zone.
- Surveillance of the affected area to protect the assets (particularly houses) in the area.
- Confine people in the villages of *Santa Maria d'Oló* and *Roqueta*. Evacuate three country houses, one of them called *"Els Clapers"* (in the natural setting of *Santa Maria d'Oló*) and the summer camp called *"La Ruca"* in *Horta d'Avinyò* where there are a group of children. A bus is facilitated the evacuation.

- Accompany other emergency services who are less familiar with the area so they can act faster, and be more efficient.
- Request reinforcements to the local police of *Sant Fruitós de Bages*.
- Provide refugee locations and support/help for evacuees.
- Traffic control.
- Call for solidarity asking resident population for help in distributing water and food to emergency services, as well as firefighting activities (firewalls) under the leadership of firefighters and ADF.
- Maintain checkpoints at the accesses to the fire area.
- Support firefighters and ADF agents in their tasks.
- Traffic control.
- Perimeter surveillance.
- Surveillance of the area affected to protect the assets (particularly houses) in the area.
- Assistance in the transportation of people and means from and to the "point of transit" (Figure 7-23).

Figure 7-23. Point of Transit in Artés fire.

- Police patrols to assist the local community and the evacuees as long as it does not jeopardise their operations.
- Collaborate in the investigation of the causes of the start of fire (particularly the person suspected of being the author of the fire) in cooperation with the PG-ME investigation unit.

CP (Civil Protection):

- Continue to assist in the guidance of evacuation people, managing the refuge locations and the logistic support in collaboration with the municipality.

MS (Medical Services):

- Place an ambulance at the ICP as a preventive measure.

ADF (Forest Protection Association)

- Assist FRS with the direct attack on the flanks and on the head of the fire.
- Stay away from the area between *Sant Joan d'Oló* and the head of the fire.

Notifications

Who?	What?	To whom?	Why?
Support Tactical Analyst (GRAF 01)	Situational Report 1	Incident Commander	Support the Incident Commander in the decision making process.
Support Tactical Analyst (GRAF 01)	Situational Report 2	Strategic Analyst (GRAF 00)	Support the Strategic Analyst in the decision-making process.
Strategic Analyst (GRAF 00)	Report on the current situation, the expected evolution of the incident, and response actions agreed with the IC.	Support Tactical Analyst (GRAF 01)	Communicate the response actions and other decisions.
FRS Command Centre (on site)	Situational Report 3	The chief commander of each organisation in ICP's meetings.	Report on actions to be taken.
		FRS Central Control Room, located in the region where the incident occurs.	Report on actions and tasks to be taken.
Chief commanders of each organisation on field at the ICP.	Situational Report 4	To whom it may concern internally in each agency.	Report on actions and tasks to be taken.
FRS Central Control Room		Coordination Centre Room (CECAT)	Report on actions and tasks to be taken.
Police Officer	Assist in the investigation of the causes of fire ignition.	Local Police chief	Report on the progress and results of the investigation.
Local Police chief	Assist in the investigation of the causes of the start of fire.	PG-ME Chief	Assist in the investigation of an alleged crime.

7.6 Lessons learned

Table 7-9 gathers the lessons learned from the Artés fire and describes the actions to overcome them.

Lesson Learned	Level of Command	Positive/ Negative	Lessons learned Capability	Landscape Scenario's Challenge	CCC Result	Description
A strategy based on polygons of potential is followed in front of a scenario of forest mass and instability. It allows ordering priorities **and elaborating an Action Plan for Intervention (PAI)**. The Action Plan for Intervention is elaborated by the Support to Command Team and distributed to all the commands.	G00 + CI	Positive		Incident Command Organisation	Focus on sustainability safe operations	- Identify quickly, zone and plan safe access in hostile environment, and maintain situation awareness. - Adapt efforts and tempos to forecasted available capacities, forecasted changes in the scenario, and to sustainability of operations. - Build trust inside crews with different specialities, between crews and with commanders. - Appoint a safety officer at highest level of decision.
The absence of a protection area around the houses burnt implies both the capture of resources and a change of priorities. This **causes the need to give explanations to politics, neighbours and the task to raise awareness afterwards**.		Negative	High flow of effort in hostile environment	Community involvement	Develop public self-protection	- Focus on prevention, self-protection and risk awareness of population. - Pact with public and private stakeholders on accepted risk and self-protection measures. Mandatory exercises funded by owners of high risk activities. - Train general population from 0 and with basic language, exercise with those more exposed. Address all phases of emergency. - Disseminate instructions in case of risk, in order to strengthen the appropriate reactions from population.
Presence of volunteers (Forest Defence Aid Group, ADFs) at the head of the fire although at the Forward Command Point (FCP) and at the Transition Point (PT) it was previously said that it was not necessary. Therefore it is **detected as necessary to implement plan procedures** (PAGI) **at the local units and to do public talks about it to raise awareness**.		Negative		Guidance instruments and standards	Establish procedures and guides	- Procedures and guides for fast response to minimize total damages in a time-efficient way (mobilization, arrival, command, transfers and turn-overs, work-rest balance, briefings, documentation, logistics, communication, coordination, cross—border procedures…) - Standardize response in front of specific hostile environments (divide into zones, safety, techniques…) - Build techniques for planning and adjusting the use of resources with time, to maintain the work effort sustainability for long periods of time.

Table 7-9. Lessons learned from the Artés fire.

Lesson Learned	Level of Command	Positive/ Negative	Lessons learned Capability	Landscape Scenario's Challenge	CCC[3] Result	Description
A strategy based on polygons of potential is followed in front of a scenario of forest mass and instability. It allows ordering priorities **and elaborating an Action Plan for Intervention (PAI)**. The Action Plan for Intervention is elaborated by the Support to Command Team and distributed to all the commands.	G00 + CI	Positive	High flow of effort in hostile environment	Incident Command Organisation	Focus on sustainability safe operations	- Identify quickly, zone and plan safe access in hostile environment, and maintain situation awareness. - Adapt efforts and tempos to forecasted available capacities, forecasted changes in the scenario, and to sustainability of operations. - Build trust inside crews with different specialities, between crews and with commanders. - Appoint a safety officer at highest level of decision.
The absence of a protection area around the houses burnt implies both the capture of resources and a change of priorities. This **causes the need to give explanations to politics, neighbours and the task to raise awareness afterwards**.		Negative		Community involvement	Develop public self-protection	- Focus on prevention, self-protection and risk awareness of population. - Pact with public and private stakeholders on accepted risk and self-protection measures. Mandatory exercises funded by owners of high risk activities. - Train general population from 0 and with basic language, exercise with those more exposed. Address all phases of emergency. - Disseminate instructions in case of risk, in order to strengthen the appropriate reactions from population.
Presence of volunteers (Forest Defence Aid Group, ADFs) at the head of the fire although at the Forward Command Point (FCP) and at the Transition Point (PT) it was previously said that it was not necessary. Therefore it is **detected as necessary to implement plan procedures** (PAGI) **at the local units and to do public talks about it to raise awareness**.		Negative		Guidance instruments and standards	Establish procedures and guides	- Procedures and guides for fast response to minimize total damages in a time-efficient way (mobilization, arrival, command, transfers and turn-overs, work-rest balance, briefings, documentation, logistics, communication, coordination, cross—border procedures…) - Standardize response in front of specific hostile environments (divide into zones, safety, techniques…) - Build techniques for planning and adjusting the use of resources with time, to maintain the work effort sustainability for long periods of time.

[3] Common Capability Challenges.

8 Tisvilde Hegn Fire

This study case is based on a fire incident that started on the 7th of July 2010 at 14:13 (Danish Emergency Management Agency's [DEMA] statistical bank: www.odin.dk) in a FBBR forest area called Tisvilde Hegn (Figure 8-1). It is one of FBBR's special objects/risks and representative scenarios in cooperation with the Risk Based Dimensioning (RBD), which is part of the Comprehensive Preparedness Planning (CPP). A detailed analysis of this scenario has been made and is in the FBBR RBBD-plan 2019 (www.fbbr.dk).

Figure 8-1. Forest area in Tisvilde Hegn.

The forests of Tisvilde Hegn (Figure 8-1) consist of a big pine plantation covering about 1,400 ha in the northern coast of Zealand island, in Denmark. Tisvilde Hegn is part of the European Natura 2000 network as it contains rare and valuable habitats, protected by the EU Habitats Directive, as well as plants, animals, and an important birdlife that is protected by the EU Birds Directive. The area is dominated by pine forest and open pine forest, also including scattered beech and oak. The birch has managed to dominate sites where conifers have been felled without being re-seeded. The popular Troldeskov grows, along the coastal shore on dune hills, are formed by ancient 200-year-old pine trees heavily growth-inhibited, low and distorted, due to the harsh wind. The forest is essentially the nature of a true mid-Scandinavian coniferous forest, which (as well as the area's close location to Sweden) has provided a breeding ground for a unique collection of animals and plants that otherwise are not found in the rest of Denmark. The variegated collection of landscapes in the Tisvilde area, including heath and high bogs, heathlands, heather heaths, overgrowth, meadow swamps, large sun-exposed open hills, sandy surfaces and dunes, have also made it possible for many rare species, linked to a wide range of different habitats, to establish a solid foothold in the area (www.naturstyrelsen.dk).

Finally, it is worth mentioning that the area is very populated as it is attractive to many tourists and visitors throughout the year, being the peak season during the summer months.

8.1 Data collection

Table 8-1. Data sources for Tisvilde Hegn wildfire.

Type of data	Source	Time of collection
Cartography (ortophotos of the study area)	Google Earth	2010
Analysis of fire risk	FBBR - Plan for Risk Based Dimensioning	2007
Systems and tools used for crisis management situations	FBBR (www.fbbr.dk)	2010
FBBR RBD-plan 2019	FBBR	2019
Incident report, ODIN-GIS	DEMA (www.brs.dk)	2010
Information and statistics	DEMA's statistic bank (www.brs.statistikbank.dk)	2010
Description about the affected area	Nature agency of the Ministry of Environment and Food of Denmark (www.naturstyrelsen)	2019
Weather data	DMI	2010
Logistics and means deployed	FBBR, DEMA (Odin-Statistic Bank)	2010

This use case describes a fire in a FBBR forest area called Tisvilde Hegn and it is one of FBBR's special objects/risks and representative scenarios in work with the Risk Based Dimensioning (RBD) which is as a part of the comprehensive preparedness planning (CPP). A detailed analysis of this scenario has been made and is in the FBBR RBD-plan 2019 (www.fbbr.dk). This scenario is based on the reel incident happened 07th July 2010 at 14:13 (DEMA statistical bank - www.odin.dk).

All relevant data and information related to this scenario can be found in Danish Emergency Management Agency´s (DEMA) data base www.brs.dk (www.odin.dk, www.statistikbank.brs.dk) e.g. incident report, ODIN-GIS.

Other relevant information sources such as Ministry of Environment and Food of Denmark, Nature agency www.naturstyrelsen, Danish Metrological Institute (DMI), www.dmi.dk has been used in this case as well as other relevant sources, resource persons, and information from FBBR.

8.2 Data processing

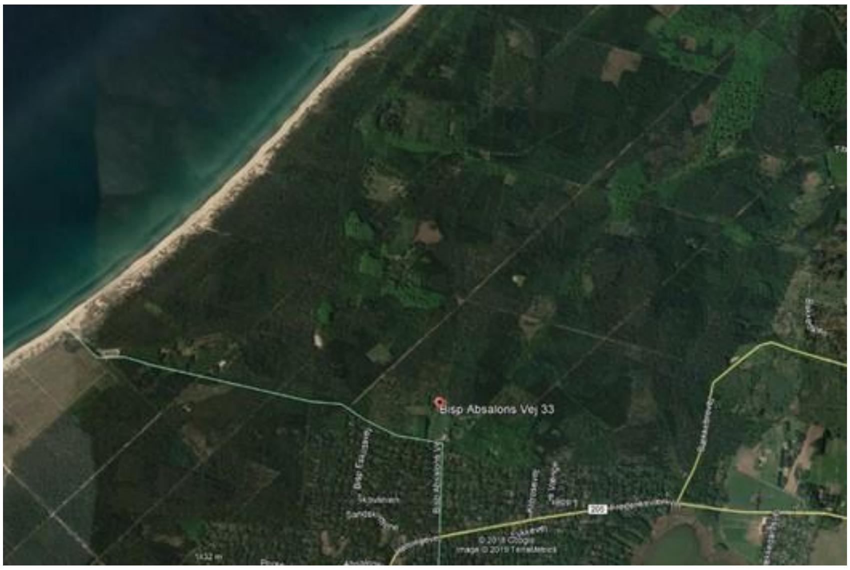
All available sources of data and information were used for the design of this scenario. This refers to previous FBBR RBD-plans and incident reports. Also, emergency response activities that were reported to the Danish Emergency Management Agency's Online Data Registration and Reporting System (ODIN) (www.fbbr.odin.dk), ODIN-GIS module (www.brs.odinGIS.dk). Furthermore, information and statistics in this section have been drawn from DEMA´s Statistic BANK (www.brs.statistikbank.dk) which retrieves and processes data from ODIN. This means that if an incorrect report is provided in an emergency report, it will affect the statistics. It is estimated that only a few of the emergency reports are where the information is not correct. As far as possible these are also isolated. For the overall statistics, it gives only a small margin of error.

Extracts have been made and validated on the basis of emergency responses from the 1st of January 2013 to the 31st of December 2017.

8.3 Risk and behavior analysis

The risk scenario is described in Table 8-2:

Table 8-2. Risk scenario for the Tisvilde Hegn fire.

Scenario title:	Tisvilde Hegn Wildfire
Time	2010, July 7th, 2:13 pm.
Location	112 - address: Tisvilde Hegn, (Bisp Absalons Vej 33, 3300 Frederiksværk; Easting - 690130, Northing - 6213144, Municipality code: 270; Street code: 134)
Distance to the nearest fire stations	Helsinge fire station: 12.4 km, ca. 14 minutes Frederiksværk 1 Fire station: 14.1 km, approx. 22 minutes
Meteorological conditions	Temperature: 27 ^{0}C (Warm and sunny) Wind direction: SW Wind speed: 7 m/s
Description of risk	Forest, primarily conifers. Attractive beach with many summer visitors. 
Fire behaviour and spread	Situation on arrival at the incident: high-intensity fire through the forest area; vegetation prone to burn due to dry weather conditions; conditions make it difficult to get an overview of the fire. Rate of spread: fire is spreading rapidly at approximately 7m/min. Spread direction: SW.

	Flame height: up to 20 m.
Composition of the first response team	2 Incident commanders + 2 Team leaders + 10 Firefighters - This composition is due to the episode of drought. Standard response team would be composed of 1 Incident leader + 1 Team leader + 5 Firefighters. Here, the Fire Department takes part in Helsinge, Frederiksværk and DEMA - Sjælland (BRSS)
Pick-list	BNSP, Wildfire – Forest/Plantation (Naturbrand-Skov/Plantage) Pre-defined Risk Level: High – due to special object in the RBD-plan.
Other	More information in the FBBR RBD- plan 2019

8.3.1 **Wildfire risk estimation**

The estimation of risk was performed by using the Risk Matrix (Table 8-3).

Table 8-3. Risk estimation on people (P), environment (E), property (Pr), and society (S).

			Very low risk	Low risk	Medium risk	High risk	Very high risk
			Impacts				
Frequency	Very probable: >10 per year	**5**					
	Mostly probable: 1-10 per year	**4**					
	Probable: 0.1-1 per year	**3**	**S**	**P**	**Pr**	**<u>Scenario:</u> Tisvilde Hegn Wildfire** **E**	
	Mostly improbable: 0.01-0.1 per year	**2**					
	Very improbable:< 0.01 per year	**1**					
			Limited	**Moderate**	**Serious**	**Very serious**	**Critical**
			Consequences				
People (P)			Insignificant impact	Less injuries, few people	More than 5 injured	Few deadly injured/few dead	Many injured /many dead

Property (Pr)	<1,500 €	1,500-15,000 €	15,000-150,000 €	150,000-1 mil. €	>1 million €
Environment (E)	Insignificant impact	Greater impact	Risk of permanent damage	Minor lasting damage	Big lasting damage
Society (S)	No/minor disturbance. Delays in operation <1 day.	Shorter disturbance. Delays in operation <1 week.	Significant disturbance. Delays in operation >1 month, firing of employees.	Serious disturbance. Delays in operation >3 month, loss of customers.	Critical for maintaining of functions. Termination of business operations.

Based on the FBBR data (FBBR-ODIN Statistic bank), the frequency is estimated to be 0.1-1 per year.

The estimation of the consequences is distributed as follows:

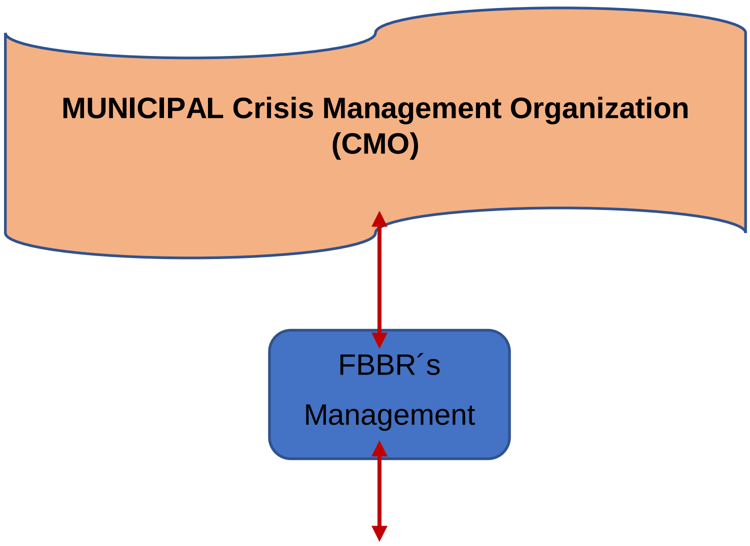
- People - **Moderate** (few injured);
- Property - **Serious** (appox.100,000 Euros);
- Environment – **Very serious** (minor lasting damage); and
- Society as a whole – **Limited** (no significant).

Altogether, the risk associated with the Tisvilde Hegn wildfire is estimated as **High Risk**.

8.4 Emergency response management

8.4.1 **Incident management organization at municipal level**

Decision-making structure and organization management is shown in Figure 8-2.



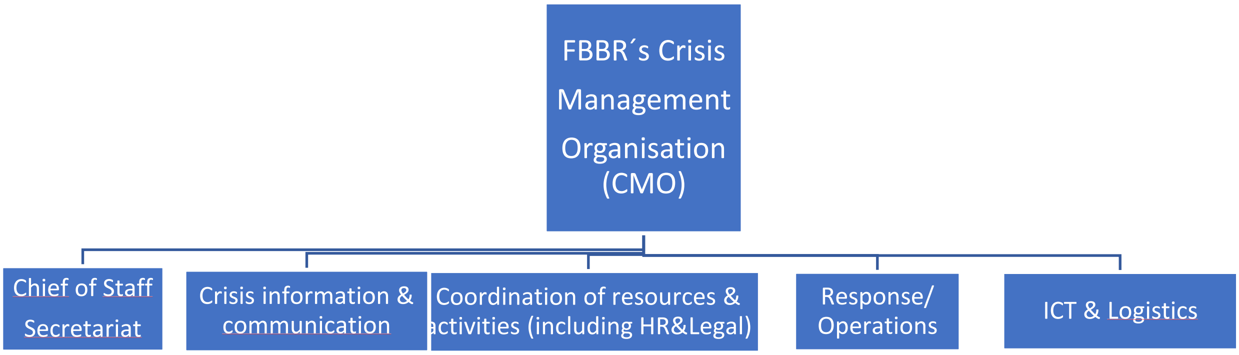


Figure 8-2. Crisis management in Denmark at municipal/FBBR level.

8.4.2 Communication systems, dissemination methods and decision support tools

A series of communication systems, dissemination methods, and decision support tools were employed by the fire and rescue services during the ongoing emergency:

The following **communication systems** were utilised to facilitate interagency coordination, communication and decision making:

- **UMS (Unified Messaging Systems) module.** To avoid confusion with other SMS (mobile phone text message) templates, FBBR has made SMS Preparedness as a separate module that can handle a given emergency situation immediately and effectively. When you open the module to turn on alarm, the entire screen turns red to alert you that everyone (Figure 8-3)– from the established list - gets your message.

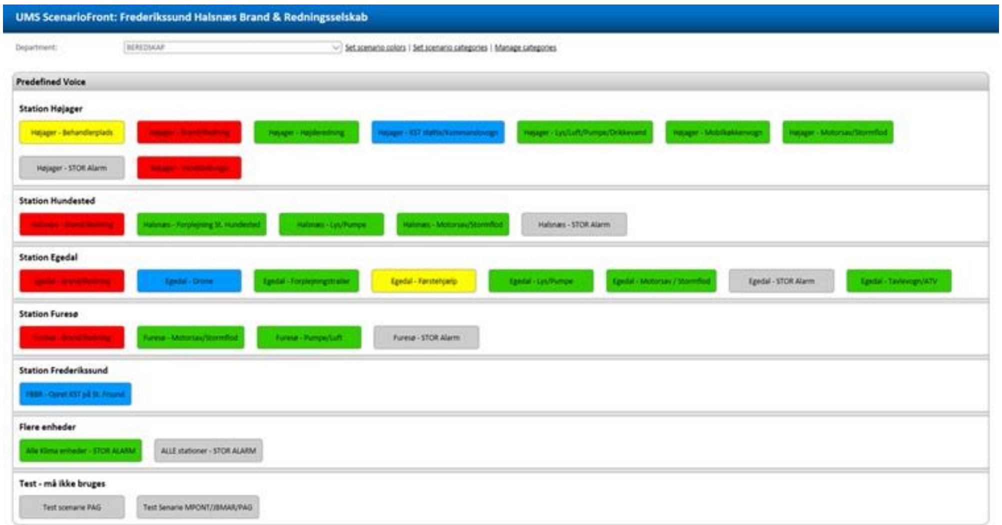


Figure 8-3. Example of UMS – Module to turn on the alarm for volunteers.

- **Alarm call centre**

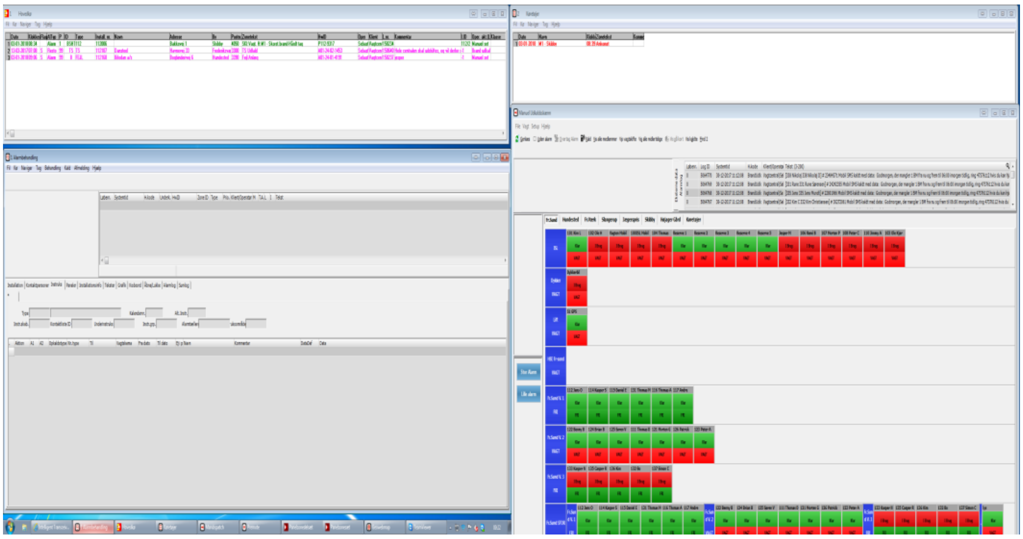


Figure 8-4. Example of FBBR´s dispatch centre to activate firefighting resources. Alarm treatment (left) and call-out screen (right).

- **TETRA (Terrestrial Trunked Radio)**
- **Mobile phone (GSM)**
- **Pager**
- **Landline phone**

The following **dissemination methods** were utilised for the delivery of warning messages to the at-risk population**:**

- **Siren – warning**
- **TV - national**
- **FM-Radio**

The following **decision support tools** were utilised for risk assessment and emergency planning:

- **DMI (Danish meteorological Institute) – (updates every 6 hours)**
- **Maps for the Response and action plans**
- **Maps of the municipality (e.g. map of Tisvilde Hegn forest)**
- **GIS tools**

8.4.3 **Strategy, tactics and operations**

Strategy and tactics in response to the wildfire incident in Tisvilde Hegn is shown in Table 8-4.

Table 8-4. Response operations for the Tisvilde Hegn wildfire.

RESPONSE FLOW	**DESCRIPTION**
T1 (0-5 min)	Fire is detected. Multiple alerts are received on the 1-1-2 emergency number.
T2 (5-10 min)	No response. Incident commander receives additional messages from 1-1-2. Fire Station Gilleleje and DEMA - emergency level 2.

	BRSS Sjælland declares additional voluntary preparedness required.
T3 (10-15 min)	Incident commander, a fire engine and a water tank from Helsinge fire station are on the way to the scene of the incident.
T4 (15-20 min)	Incident commander arrives. Helsinge fire station arrives with a fire engine and a water tank. Start with the B / C lay-outs and fire engines on the right and left flank.
T5 (20-25 min)	Frederiksværk Fire station arrives with a fire engine and a water tank. Suppression efforts on H + V flank. Lay-outs and water supply are continued.
T6 (25-30 min)	The second deputy leader arrives and creates Incident Command Post. Suppression efforts, lay-out and water supplies is continued
T7 (30-35 min)	Gilleleje fire Station arrives with a fire engine and a water tank. Fire units start to build a firebreak in order to set a backfire in front of the head on the fire.
T8 (35-90 min)	Operations to build the firebreak carry on, after which backfire is initiated. Fire suppression efforts on both flanks carry on.
T9 (90-120 min)	More voluntary fire brigade units arrive. Gilleleje fire station drives home.
T10 (120-240 min)	DEMA arrives, establishes water supply for open water as well as after extinguishing in the burned area.
T11 (240 min-end of the incident)	A watchman assigned by DEMA stays on-site until the fire is completely extinguished.

8.4.4 Means deployed

The table below provides a list of the resources deployed at the wildfire incident and their timing of deployment:

Table 8-5. Means deployed in fire suppression for the Tisvilde Hegn wildfire.

Task	**Response flow**												
Time (min)	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**	**Material**	**Vehicles**
Incident commander & Incident Command post				1	1	2	2	2	2	2		HT-tubes, thermic camera + Material from volunteers + material from DEMA	1-comm. car 3-Fire engines 3-water tanks + vehicles of volunteer fire services + vehicles of DEMA
Team leader		1	1	1	2	2	3	3	2	DEMA			
Pumper		1	1	1	2	2	3	3	2	DEMA			
Water supplies (for fire suppression)					1	1	1	1	1	DEMA			
Fire Extinguishing		4	4	4	7	7	11	11	7	DEMA + Volunteers			
Air support										DEMA			
Food and water supplies										DEMA	DEMA		

Watchman										DEMA	DEMA		
Total		6	6	7	13	14							
Total crews	1+5			1+1 +5	1+2+1 0	2+2 +10	2+3+15		2+2+10 + Volunteers +D EMA				
Water supplies (l/min)		400	800	800	800	800	800	800	800	800	800		
Total water supplies (l)		2,000	6,000	10,000	14,000	18,000	22,000	66,000	90,000	186,000			

8.4.5 **Conclusion on response**

The following table serves to evaluate the degree of difficulty experienced to manage the wildfire emergency to as well as the outcomes of the management practices carried out.

Table 8-6. Evaluation the Tisvilde fire management outcomes. Green: easy; yellow: moderate; red: difficult.

Person rescue		Not relevant
Spread of fire		Fire spreading
Water supply		No water shortage
Firemen/crews		Sufficient firemen/crew of the first response
Response time		Response time of the first fireengine is less than 15 minutes
Management		Incident commander must arrive during 5 minutes after the first
Chemical		Not relevant

8.5 Lessons learned

Generally, the information reported in the previous sections reveals poor communication during the incident. Firstly, portable radios, car-radios and mobile phones had very limited coverage in the forest area. Moreover, DEMA, which used SINE terminals (EADS or MOTOROLA), could not use them in TMO-mode in the forest. All these constraints created a situation in which collaboration and disaster mitigation became difficult. Communication, coordination, and information management can be improved by using the new tools and technologies, training, exercises, and education.

With regards to prevention measures, the following aspects were identified:

- Existing prevention: Follow drying index and DMI guides on the use of open fire. Dialogue with e.g. forest fodder and other science resource persons. Contingency plans / action plans must be updated.
- Future prevention: Drone monitoring and drone alert. Preparation of special vehicles at Danish Metrological alert.
- Remarks: Undisturbed communication and coordination in the forest is very important. Training of firefighters in forest fire technology. Timely fire detection and alarming is of crucial importance.

9 Mati Fire

On July 23rd 2018 16:40 a fire outbreaks in Daou Penteli (Figure 9-1), a small residential area within the Northeast part of Attica region, Greece. Pushed by strong winds, unexpectedly blowing from the West, the fire front rages through well cured high grass and quickly affects some structures, escaping through a mild rugged terrain covered with pine forest regeneration and sparse shrubs. In less than one hour the intense fire front impacts on the first houses in the West part of a residential area, Neos Voutzas.

The fire front continues a downslope fast run through ravines, engulfing dense pine stands and finally jumping perpendicularly over Marathon Avenue, a four lane highway which separates Neos Voutzas from the densely populated area of Mati. Showing indicators of extreme behaviour, the fire continues burning through a mixed pattern of houses and vegetation, mostly and particularly thanks to the projection of massive shower of firebrands.

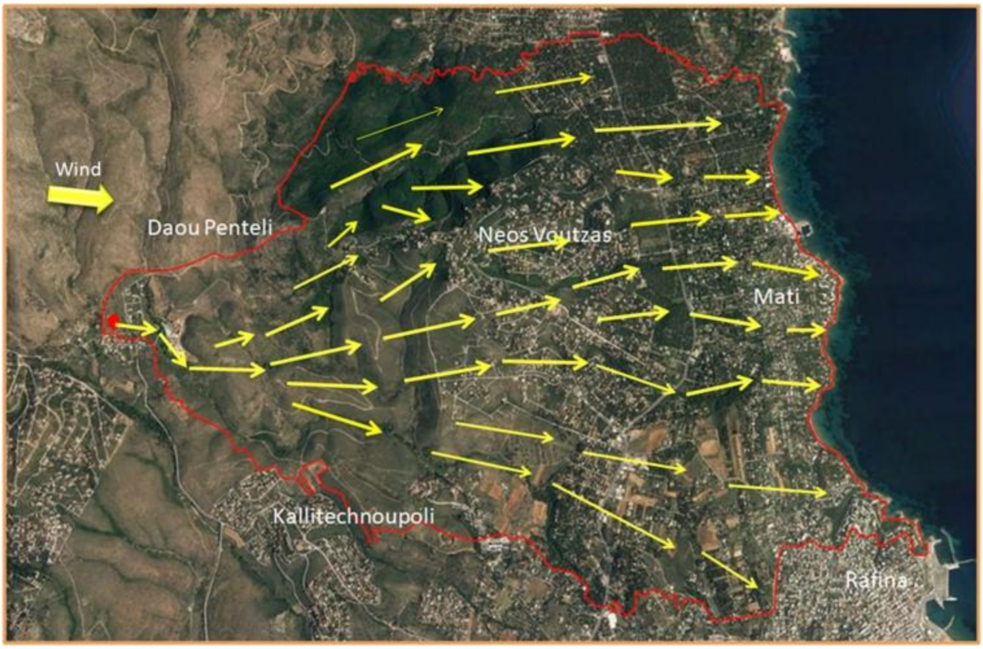


Figure 9-1. Final perimeter of the Mati fire and the suggested vectors of propagation. Point of origin is marked in red at the left.

Nearly 4000 people are involved in the event, out of which a majority manages to escape on their own through the narrow streets and roads, as no evacuation order is set out. Others run for their lives towards the sea as a last resource, both by car and by foot, but only 700 could make it as there were just a few access points to the safety of water in a coastline mainly dominated by a cliff. One of the access points is collapsed by cars in their attempt to quickly reach the sea, creating a deadly traffic jam across the neighbouring streets. Simultaneously, a group of 26 persons are trapped between fire and the cliff in their attempt to find a safe exit, finally perishing on the spot embracing each other. Some hours later, a small fleet of volunteering vessels rescue most of the people who waited helplessly in the water, some of them badly injured, for some sort of aid. As a consequence, more than 80 people are reported dead in the same day, Around 200 people are injured, some of them severely, who later died in hospital raising the dead toll up to 102 victims confirmed.

The area visited by fire affects nearly 2000 structures, out of which around 600 are totally destroyed or severely damaged. Despite the efforts of the firefighters and police, little could be done, primarily due to the speed of the unfolding events. Given the seriousness of the episode, the complete Greek firefighting air fleet is deployed to the place, and more than 200 fire units are allocated in the area, who see, with a feeling of impotence, that the raging fire front is quickly crossing over the Mati area.

This event is the deadliest wildfire affecting Wildland-Urban Interface areas (WUI) second to Black Saturday in Australia 2009, and the most serious in Europe in the last decades. Several lessons observed (to be learned) are highlighted in section 9.4.

9.1 Data collection

Three types of sources and means of data collection were combined for this study case:

1. **Fieldwork.** A dedicated three-day visit to the Mati aftermath took place a week after the fire outbreak with the purpose of gathering testimonies and data on the event. A photographic camera (Nikon D810) with a GPS antenna (Phottix Geo One) was used to gather as much graphical geo-tagged information as possible. In some cases, a 360º camera was used to take surroundings of some of the destroyed structures so to proceed with an in depth analysis later in the office with a VR set.

   A general purpose tablet (iPad) was used as the main source of geographical information and geo-referencing the survey. Google Earth was the preferred application for on-site referencing the data gathering. Complementary, Tracks of the different surveys were recorded using OruxMaps application on a cellular phone. Some of the testimonies audio were recorded on the cellular phone.

   The field work was assisted by Dr. Gavriil Xanthopoulos (Demeter), an expert on forest fires, and Miltiadis Athanasiou, an expert on Civil Protection Greece. Besides, assessment was provided by the police and military personnel deployed in the area.

   Some of the zones, still under forensic investigation during the days the visit took place, were access-restricted.

2. **Media.** Interaction with local and national mass media took place, particularly with the “Ethnos“ newspaper. This included a thorough review of most of the main newspapers and most of the TV news.

3. **Internet.** A systematic survey and gathering of testimonies, photos and videos was performed. This was particularly useful to get a better grasp of how fire impacted on the landscape, on populated areas, and the actual threat posed to hundreds of people:

   a. Video footage from Alpha channel, which deployed journalists on the very places while the fire was still running.

   b. Photos available on Twitter, Facebook and Instagram done by particulars, although in general lack of enough quality.

   c. Aerial video performed by the National Kapodistrian University of Athens (NKUA) over the aftermath of the fire area with a drone.

   d. A security camera in one of the houses located close to the fire starting point, which a timestamp overimposed.

   e. Footage recorded by the particular Konstantino Gkikas, who accidentally exposed himself to an approaching fire front near his house in Neos Voutzas (Riga Fereou St. with Agiou Gerasimou St.) and who bravely used his phone to grab the moment.

   f. The orthophoto provided by Airbus on the fire area taken a few months later was particularly helpful for the assessment of structural loss. An image of the area in a date previous to the fire (november 2017) was extracted from Google Earth as a reference.

   g. Street View photographs provided by Google as a means of understanding the vegetation, streets and structures arrangement prior to the fire event.

9.2 Data processing

The data processing procedure was set up in order to assist primarily to the structural loss assessment and, as far as possible, reconstruct the fire behaviour as observed. The GIS platform used to achieve that is ArcMap 10, and the reference system selected is WGS84 UTM 34N. The following work was undertaken as part of the data processing phase:

- The orthophoto from Airbus reflecting the situation just after the fire event was geo-referenced. Resolution was 50 cm.
- A detailed georeferencing of an orthophoto extracted from Google Earth was performed as well to exactly match the previous one. This before-after layers helped tremendously in analysing possible factors of house affectation.
- A house by house assessment was performed at the office using mainly the most recent orthophoto and checked with the in-field photos, the 360º images, the NKUA drone aerial videos and other photos and media found in the Internet. In parallel, assessment was also reinforced with the Street View photos of the situation prior to the fire.
- Most of the photos and videos obtained in the Internet were analysed to deduce the location and time in which they were made. Corresponding tags were included in the maps. Four general analysis zones were established: Daou Penteli (D), Neos Voutzas (V), Mati (M), North (N) and South (S).
- For some of the zones, a set of sectors were established to facilitate a systematic survey. In particular, in Mati area 12 sectors were described (Figure 9-2), mainly using streets as separators. A 6-digit naming convention was used (ZSSHHH) to label the structures, where Z is a letter addressing the zone, SS is the sector and HHH the number of house within the sector. Each house was then identified in the orthophoto, the map and the existing photos in the database.

Figure 9-2. Sectors used in Mati area to help in the systematic survey for structure loss assessment.

- A subjective assessment of structure loss was performed using a four-level code: 1=No damage, 2=Minor affection, 3=Severe damage, 4=Total destruction.
- For the sectors in Mati that were most affected by fire (sectors 8, 9, 10, and 11), a detailed map of vegetation was obtained from the orthophoto previous to the event, digitized at 50cm resolution. A map of the houses was also obtained and both corresponding raster layers at 1m resolution. Then, a friction-continuity risk index was obtained and correlated to the degree of destruction for each house. As a complement, some of the known times of fire pass were recorded as points in the map to deduce fire front spread speed and position over time.

- A number of Points Of Interest (POI) were also recorded in the map, including the fire starting point, the position of the security camera, the position of Kostas Gkikas house, the location of the group entrapment, or the position of the traffic bottleneck amongst others.

9.3 Risk and behaviour analysis

9.3.1 **Fire behaviour**

In the same day of 23rd of July 2018, around noon, a first wildfire outbroke near the city of Kineta, in West Attica, potentially threatening its population. This event entailed the deployment of firefighting forces and aerial means to that area, which is located 70 km West of Mati.

In Mati area, the days before the incident, several episodes of rain were observed. The forest fuel, both live and dead, presented an unusually high moisture content for the moment in the fire season in Greece (end of July usually presents much lower fuel moisture content readings), with readings of around 100% in most of live fuels [9]. Besides, the wind pattern was unusual as well: in this period of the year the local Meltemi wind is blowing from Northeast or North, but not from the West or West-Northwest, as observed on that day. Strong winds, between 80 and 100 km/h, cancelled most of the benefits of a relatively high moisture in the fuel bed.

The Mati fire started at 16:40 in the residential area of Daou Penteli[4], as a consequence of a reported negligence by a man burning some vegetal debris. Video footage shows strong winds and an accelerating fire front building up steadily, developing initial flame lengths of 2 to 3 m. A first propagation of around 150 m took place, running over a grass-dominated plot with some sparse pine trees that torched with easiness. This initial fire head quickly impacted onto the first row of houses (confirmed by the same video footage) in about 7 minutes from fire outbreak, while the right flank was barely being held by the streets and the left flank was steadily opening. The head and right flank of the incipient fire managed to jump the streets and enter new lots, while leaving a house and a van in flames under a couple of pine trees. Another three structures were affected as well. This triggered the initial concern of first responders on the affected houses, which consequently displaced the preliminary centre of gravity of operations towards this area.

In these initial moments (first 15 minutes) the fire progressed very narrow and directional, crossing a second row of perpendicular streets and hitting the West border of a small urban development corresponding to the Pantokrator Monastery, intercalating olive trees fields with almost no fuel in the surface. This 100 meter-wide area could have been enough to stop the fire, but the right flank managed to progressively enter a small ravine full of flammable fuels, dead vegetal materials, shrubs and some trees. Based on the marks left, the intensity developed by fire in this point was high. Pushed by the wind, the fire eventually managed to escape the ravine into an open field without restriction, heading Eastbound towards the west part of the urban interface of Neos Voutzas. Indeed, the presence of two immediate gullies added channelling of winds and entailed the development of two fingers, one heading East towards Neos Voutzas and the other running Southeast towards Neos Pontos. Video footage taken by neighbours at Kallitechnoupoli shows the intense progression of this right flank that developed afterwards.

The head of the fire encountered several patches of young pine stands along the way (Figure 9-3), which were part of the reforestation works done after the 2005 wildfire to recover the

[4] Coordinates are WGS84 UTM34N 758239.75 E, 4214336.81 N

burned areas and protect soil. At that moment the wind, the topography (particularly the axis of the E-W ravine) and the fuel availability aligned together, thus entailing a remarkable increase in fire activity.

Figure 9-3. First run of the fire front. The first run took place over a young pine stand. In the background (looking towards West) the Pantokrator Monastery and Daou Penteli, the origin of the fire.

The fire front continued this intense run for about 1600 meters until hitting the first set of houses at the West limit of Neos Voutzas residential area around 17:30 h (that means, roughly speaking, two kilometres in 50 minutes rendering an average rate of spread of 40 m/min). Once there, the fire front progressed fiercely downslope through the different ravines within the settlement (Figure 9-4), mainly helped by the existing very dense and flammable pine stand and the channelling of the wind, creating tracks of propagation and secondary impacts with houses, roads and installations inside. Some houses were destroyed and many others were just affected (Figure 9-5).

Figure 9-4. Interpreted main fire runs through ravines within Neos Voutzas settlement, following the main wind component (West).

Figure 9-5. View of the aftermath in Neos Voutzas, looking West. Observe the intensity of some of the fire runs. In this area just few structures were destroyed, but many others were affected.

One of these fire runs continued steadily through the ravine in Ekavis street, building up the heat release and fire spread rate. Google Street View in such point depicts a remarkable accumulation of forest fuel and dead vegetation debris prior to the fire. At the end of the street another pine stand interlaced with dense shrub, placed in between Attalou Str. and Marathon Av., was in the trajectory of the fire head (Figure 9-6).

Figure 9-6. Street View from Google of one of the ravines within Neos Voutzas, packed with fuel in a dense pine stand. Observe the dead fine materials laying in the ground.

That dramatically helped in the new increase of fire activity, the production and projection of firebrands and, eventually, the fire jump into Mati area at around 18:10. This was the central, and most likely the first, entry point of fire into Mati.

Figure 9-7. Moment in which the fire jumps from Neos Voutzas (to the right) into Mati area (to the left), strongly pushed by winds. Both sides presented dense pine stands. The traffic in Marathonos Avenue (depicted) was still present. Photo is taken looking South.

The right flank opened and created a parallel run through the ravine close to Efkalipton Str., in the South part of Neos Voutzas. This eventually helped to an effective jump of fire front into Mati area in the South, involving a ravine parallel to Panos Str. leading to a massive destruction of houses.

The left flank in Neos Voutzas had already opened and reached the base of another ravine, just by the foot of the slope leading to a set of isolated houses of the settlement and the Orthodox Childhood Village of Lireio Idruma, running up and causing the affectation and destruction of several buildings. Later on, by the time the fire head was nearly reaching Marathon Avenue in the central part (as deduced from pictures of that moment), the left flank in Neos Voutzas continued a slow but steady descent through a dense pine stand towards the canyon parallel to Manou Katraki Rd., with the main axis practically running in the same direction as the wind was blowing (Figure 9-8).

Figure 9-8. Progression of the left flank. The left flank slowly entered a deeper ravine at the North and slowly but steadily progressed downslope. The projection of firebrands created spot fires which eventually developed oblique topographic runs.

Projection of firebrands along this slope were observed, which most likely produced several intense oblique topographic runs uphill of high intensity, as it is recorded in the video footage by Kostas Gkikas.

Several houses in that area were affected and some completely destroyed (Figure 9-9). As observed in some other video footage (i.e. Alpha Channel, recorded from km 14 of Marathon Av.), the fire was running fast an intense all the way down Manou Katraki, finding at the end a new area with dense pine stands mixed with some sparse housing just prior to the jump of flames over Marathon Av. into the North part of Mati area. As a conclusion, the fire created several entry points into the Mati area, with firebrands projection (seen in the video) and severe fire behaviour, widening the affection all across Marathon Avenue and reducing opportunities for a safe evacuation and fire suppression.

Figure 9-9. House impacted by fire in Neos Voutzas. Some of the houses receiving the impact of these oblique runs. One of them (close to the house depicted here) is Kostantinos Gkikas house, who managed to record a front progression with his cellular phone.

The pictures gathered show a very intense fire and an almost horizontal smoke plume, a typical indicator of a wind-driven wildfire (Figure 9-10). The video footage (Alpha Channel) show a very active spotting fires inside Mati area, due to the shower of firebrands produced mainly in the pine stands near Marathon Avenue. Analysis of the aftermath orthophoto also indicates numerous spot fires, as several parts of vegetation were left unaltered.

Figure 9-10. Left flank is ready to enter the ravine at North. Some spotting is observed which eventually gave intense runs upslope. The head has already progressed up to Marathon Avenue. Photo is taken looking South to Southwest.

Once in Mati, a densely populated area intermixed with a pine stand, the fire found plenty of available fuel in the long and narrow lots as a result of a continuous, persistent lack of management over the years, particularly in the undeveloped lots. This fact was particularly notorious in the central part of Mati, near Marathon Avenue, where the first fire jump most likely took place. Indeed, it seems that the long plot of pine stand (350x110 m^2), located between Pefkalis and Akropoleos streets, played a prominent role in transferring an intense fire propagation (particularly in the first 200 m), and entailing the destruction of the houses placed on both sides.

Figure 9-11. Fire progression inside Mati area. Spotting took place over dry fine fuels and quickly catching up surface fuels (the main fire carrier) and eventually pine crowns. The long plots helped in transferring the fire inside the settlement.

A visual analysis on Google Street View -courtesy of Google- of the situation previous to the fire makes it patently clear the fuel buildup, particularly dead fine fuels, the continuity of such fuel bed, the presence of ladder vegetation, the overall accumulation of vegetal debris –resulting from the gardening activity-, and the abandonment of all types of objects (even old cars) (Figure 9-12). This all generates a fuel structure ready to receive firebrands, generate spot fires, produce flashy and highly energetic runs, entail crown fires, and eventually cause the destruction of houses.

Figure 9-12. View from inside Mati prior to the fire. Narrow streets, remarkable fuel load both sides and vegetal debris, amongst other factors, contributed to the rapid spread of the fire. Most likely, many fire outbreaks progressed and interacted inside the settlement.

Many of the streets in Mati run from West to East, as long, narrow corridors flanked by dense and relatively tall vegetation and lineations of houses in the very direction that wind was blowing that day. It is just a matter of speculation amongst specialists that this particular street layout could have had some degree of influence on the channelling and acceleration of winds (both meteorological and fire-induced), and also on the possible interaction of several flame fronts running closely and parallel to each other. However, these hypotheses must be corroborated or dismissed with models and laboratory studies.

As observed in pictures of that moment, and according to testimonies gathered from survivors, the last run of the fire front was very quick and destructive. The nearly one kilometre that goes from Marathon Av. to the coast was covered in about 15 minutes. Several pictures of the moment show that the smoke plume stayed mostly attached to the ground, creating what was looking as a ‘pyroclastic flow’, as referred to by some firefighters (Figure 9-13). In fact, the analysis of the aftermath orthophoto shows clear indications of massive production of firebrands, the setting of numerous spot fires, which eventually interacted between them and increased the overall rate of spread (when compared with a regular frontal spread rate of fire).

Figure 9-13. View from Nea Makri port. The image shows a dramatically tilted smoke plume, dominating the low atmosphere of Mati area. Photo is taken looking South.

The presence of many cars, objects and materials contributed to the production of dense and unbreathable smoke. This also contributed to the latency of the passing fire and the post-frontal slow combustion and destruction of houses. This latent post-fire frontal combustion entailed several domino effects, particularly the explosion of gas vessels and the ignition of other hydrocarbon fuels, among other things that were reported. The environment, after the passage of the fire, was not safe but destructive. This continued over the following five hours after the main fire run.

9.3.2 **Human factor**

Mati area in summer is populated mainly by elders and their grandchildren. Many of the houses were erected by themselves in the 60s and 70s; by that time was no regulation at all about urban development that was finally established in 1974.

On the following years to come no real management of the forested area took place; indeed, the Mati area was known as “the jungle”. The sons of these elders were at Athens, most of them, at their jobs. Hence, should this occur on Saturday or Sunday, the days the area is overpopulated by visitors and tourists enjoying the coastline, the catastrophe could have been much worse.

The social structure, as well as the uses and traditions, played a key role in the whole event. Elder people had an established perception of the risk, accustomed to North winds and the fire not crossing the main road; besides, they have a very limited capacity of escaping an approaching fire, many without cars, and even more limited skills and preparation for an active shelter in place. In their panic-dominated final runaway, people left most of the houses with open windows and doors. Many of the people who sheltered in place found themselves surrounded by fire and smoke and they did very little to fight back.

By the time the fire was entering Mati area the evacuation with cars, trying to reach the coastline, was chaotic. A tremendous traffic jam took place in one of the few access points to the coastline, the remaining affected streets trapped dozens in their cars. The traffic jam forced many people to run on foot, several of them carrying small children. The smoke and the fire did the rest. Many other run on feet looking for the sea, but found a cliff of about 10 meters height with just a few accesses, narrow and difficult to transit. Some others didn't found them and got trapped in groups, perishing on the very spots just some meters away from the water. Several dozens (around 700) were more successful and managed to reach the water, and wait there for hours for a rescue.

According to testimonies, the smoke covering the area was thick and toxic. They reported the falling of flying embers, burning branches and other large pieces of debris. They said that the flames were reaching the very edge of the cliff, and that the radiation was affecting them even staying in the water. The strongest young ones managed to swim away several dozen meters for a safe place, but many others didn't manage to do so.

9.3.3 **Structure loss assessment**

Most of the structures present in the area of Neos Voutzas-Mati are residential, with a few other buildings used as warehouses, sheds, garages and secondary cottages within the same parcel. In the area all types of buildings is found, mostly single homes erected by owners in the 60's and 70's but also new villas, hotels, blocks of flats, camp cottages or military barracks. Despite of the used building materials, shape and methods, there is no clear relationship between these factors and the degree of destruction. Indeed, almost all types of structures present were affected at a certain degree.

In this area, the type of roofing varies greatly. The most frequent are flat and gable roofs, with a variety in shapes found in villas (hipped, cross gabled, simple hip, etc.). Roof coverage also varies from clay tile shingles, slate tiles, flat concrete or metal roofing amongst others. Roof structure is frequently made of wood, particularly in single houses. Glazing is generally generous in size, mounted on plastic, metal or wood frames. It is frequent to see single pane glazing as a reminiscent from the 60's and 70's, while new villas and blocks of flats frequently have double pane for thermal and noise insulation.

In Daou Penteli, where the fire outbroke, just four buildings were affected, one of them severely. In Neos Voutzas just a few houses were totally destroyed, particularly in the lower part of the settlement near Marathon Av., but many others were affected. It was in Mati where the destruction took place in a more generalised pattern. Particularly where the fire made the three entrances in Mati as a consequence of the downslope runs along ravines in Neos Voutzas a higher degree of destruction is observed. In the central part (sector 8), as mentioned, along Pefkalis and Akropoleos streets, where a long plot of pine and shrubs burned violently; in the South part (sector 10) all the area between Fisiolatron and Panos street, mostly due to the fire run along the ravine ending in Psiloriu street, which affected the EOF Fisiolatron residential area, with several cottages inside. This area had another jump into sector 11, near the coast, with several houses destroyed and where the group of people was trapped; in the North part along Egeou and Mikras Asias streets, which received the fire run from Manou Katraki ravine; and all around the area where buildings are destroyed or affected separately.

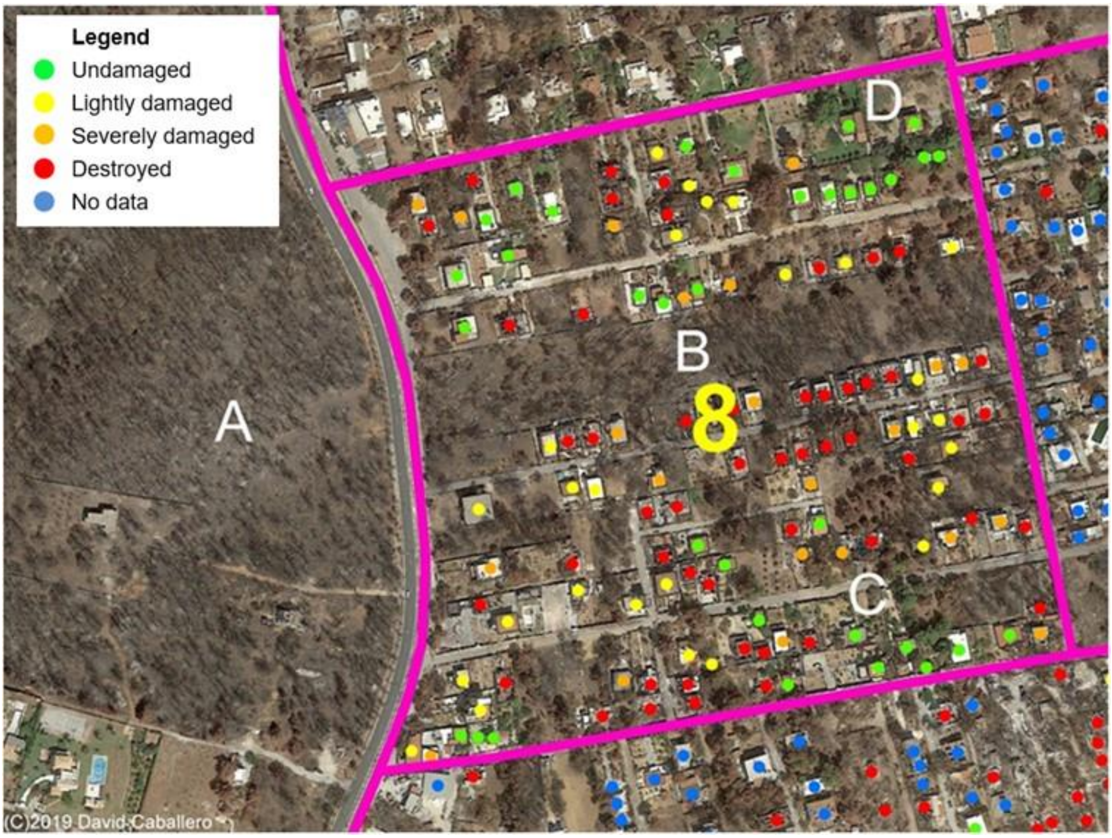


Figure 9-14. Structure loss assessment in sector 8 of Mati area. The pine stand to the other side of Marathon Avenue (A) provided enough flame length and firebrands so to allow fire catch the long plots of land packed with shrub and pines (B). These created fire runs which mostly affected houses lined up along the streets. Some patches of nearly untouched vegetation are observed (C, D) indicating active spotting by firebrands.

According to the fire patterns observed, most of the destruction happened by local burnings of fuels due to ignitions caused by firebrands. Local fuels had a direct and clear role, particularly those touching or near the structures. But several other buildings were affected without any vegetation in the surroundings, or particular flats in a block; this points at open windows left in the run away, the presence of other flammable materials or a combination of the two. Also, there are indications that firebrands played a key role in the ignition of houses through the roofing.

9.3.4 **Strategy, priorities and tactical objectives**

This event posed a big challenge to first responders and other civil protection practitioners, who were clearly overwhelmed by the enormity of the situation. As a result of consultation, gathering of testimonies and survey on media, a number of points are presented here for further analysis and reflection.

- There were complaints about the 20% reduction of budget for firefighters, which according to them lowered the capacity of response in such a day with several active fires.
- While weather forecasts indicated that strong winds blowing from West should show up in that day, it seems that this was not taken into account for the operations. The

weather conditions were known, but the strategy, if any, was not concordant to such data.
- About 15 fire outbreaks were reported that day, one of them was a serious event in Kineta, in the West part of Attica, where a refinery and a populated city were under threat. This fire displaced a large section of firefighting capacity 70 km away from the Northeast coast of Attica, where Mati is located.
- The first response for Mati fire was pointing at Daou Penteli, where there were some houses affected, and then Neos Voutzas. The high speed of the unfolding events gave little options to the firefighters to properly design and implement a defence strategy and fire suppression tactics.
- The fire developed intense firefront and flanks, which continued as such through Neos Voutzas as the WUI area did not reduced noticeably the fire spread rate or intensity. The only chance seemed to be, as done in other occasions, trying to stop the fire at Marathon Avenue, where most of the efforts were deployed both by ground and by aerial means.
- There was a relatively large population in Neos Voutzas and Mati affected by a rapidly evolving fire, many of which were old people with children. This reduced dramatically the chances of a timely, ordered and safe evacuation.
- At no time a proper evacuation order was set out to the population, which decided, frequently in the last minute, to leave the area under threat on their own means.
- As the fire was approaching Marathon Avenue, there were confusing orders, some of them diverting the incoming traffic of the highway into Mati, as this area was considered safe according to the experience in previous fires. Other called later for an evacuation towards Marathon Avenue, as it became clear that the fire would definitely enter the area. Most of the people managed to escape some way or other, particularly those who reacted quickly. Others got trapped between the incoming fire and the coastline.
- Much of the firefighting efforts concentrated in stopping the fire as it was reaching Marathon Avenue. According to video footage, the firefront was clearly out of suppression capacity, converting this tactic into a dangerous one.
- While the complete firefighting air fleet was deployed in that place, the type of fire, the presence of thick smoke tilted almost horizontally and the strong winds made these efforts almost useless.
- It is reported by the media that some firefighters were engaged in rescuing people from their houses, although it is not clear if this was part of an agreed or planned operation or individual decisions.
- There was no organised firefighting as the fire entered Mati area, just random protection of some houses. Most of the effective operations took place at the flanks and rear and after the main fire passage.
- Oblivious to the dramatic situation at Mati, the harbours of Rafina and Nea Makri continued operation, and several ferries unloaded people and cars into the streets of Mati complicating the situation.
- After the fire passage, and once it was clear to firefighters that there were dozens of victims, there was a poor management and handling of the situation. Out of the nearly 700 people waiting in the water for a rescue, around 15 died on the spot due to severe burnings, suffocating or drowning. The rescue operation took place five to eight hours after the fire reached the coastline, performed by a fleet of 21 vessels whose owners volunteered in setting up such an operation.
- During the ongoing disaster, the little or no presence at all of local, regional or national authorities was strongly criticized by citizens and media.
- Days after, no official investigation on the fire behaviour, operations, structure loss and victims in Mati was conducted by the national or regional authorities.

9.4 Lessons learned

1. We are facing unexpected weather patterns leading to fast-moving, energetic and rather unpredictable fire behaviour. We must look carefully and ask ourselves to what extent our indexes and risk analysis are really addressing this new reality.
2. Every time, more and more vulnerable people, without any sense of risk awareness and unprepared for self-protection are exposed to more and more dangerous wildfire scenarios in the WUI. Even though we have houses which are built with unburnable materials, the created environment results fatal in a wildfire event.
3. Living backwards to fire risk, being permissive with illegal constructions, allowing the surrounding fuel to build-up, do not taking care of the objects and materials accumulated, all this cost lives. And without a proper reaction, this is the first of a dramatic series of similar events in the future.
4. The intermix pattern must be strongly regulated and transformed. As it is today, the intermix offers the best combination of factors for a tragedy, as we had in Mati. If people decide to live in an intermix, the vegetation has to be transformed dramatically, preserving the tree overstory at a given density, removing all understory, keeping the ground covered with lawn, providing proper street network and ensuring access to the safe points. In short, the intermix should look like a city park.
5. Owners play a key role in creating a safer environment. Reducing the amount of fine fuels to avoid fast and energetic propagation, minimizing the outbreak of spot fire but also the presence of large pieces of vegetation and other materials and objects that provide a long latency of slow combustion and smouldering in the post-fire front scenario.
6. Long, aligned streets to the prevailing winds contribute to the acceleration and channelling of smoke, firebrands and fire front, leading even to the attaching of the convection column to the ground, creating a sort of “pyroclastic flow” with deadly consequences. A less linear, less aligned road and street network should be designed for that purpose.
7. For large and densely populated intermix areas, a local first-responding force may be of paramount importance. In private areas, owners may think about contracting this private service of prevention, survey, first response and support in fire events.
8. In these rapidly developing catastrophic events, firefighting operations are both dangerous and ineffective; hence, the population must know a basic set of self-protection procedures, whether this accounts for proper and safe evacuation or perform active shelter in place. Closing windows and doors, for example, is a basic manoeuvre for house survivability before leaving to a safe place.
9. In certain dangerous areas, a limitation of the number of people and vehicles is recommended. This could be achieved through entry control points, in which, among other things, certain information about self-protection and good behaviour in case of forest fires is provided.
10. In the intermix settlements by the coast, it is of utter importance to design alternative escape routes, even if they are available just for emergencies. Escape through the sea using boats should be pre-planned and trained beforehand.
11. Some of the existing buildings should be prepared, conditioned and labelled as fire shelters. The routes to such shelters should be marked and of a certain distance of the surrounding houses.
12. Coastline perimetral firebreak is strongly recommended. This could be planned to improve accessibility, vigilance, escape or ingress route (firefighters), as defence line (using sea water) and as a means of separating the fuel from the seaside. This also could be applied to other points on the coast, such as small beaches.

13. It is recommended to count with basic autonomous breathing systems so to be used by elder people, children or persons with health difficulties.
14. It is utterly recommended to inform visitors and tourists about the particularities of the area and the dangers. The touristic installations and facilities, including hotels, should count with a prevention and self-protection plans and the guest to be accordingly informed of that. Tourists very rarely know the dangers they are exposed to.

10 Conclusion

This document provides a description of different case studies relevant to floods and wildfire emergencies that have taken place over the last few years across Europe. The different types of data collected have allowed to have a closer approach about the nature of the hazard and the most effective ways to cope with it. Hence, collecting information about the risk and behaviour analysis has been useful to understand the hazard dynamics and anticipate the potential adverse impacts during the ongoing event; the strategies and tactics planned during the emergency, as well as the operations and means deployed, have all allowed to grasp a better idea on how the emergency is managed to mitigate adverse impacts and guarantee public safety; finally, the lessons learned have allowed to highlight deficits in the incident management activities and explore new pathways to improve them.

The collection of incident data published in this deliverable shows that, even though each hazard event is unique, similarities can be found in the way how the risk assessment is performed or how the management resources are deployed as the event unfolds. The recognition of common dangers and management challenges posed by different incidents may require the implementation of similar practices to face up the hazard scenario. Therefore, end-users can benefit from the data collected from past incidents to better cope with future incidents of similar characteristics. This is perfectly aligned with the main goal of the HEIMDALL project to develop a system that enables to search for and retrieve specific data relevant to hazard scenarios.

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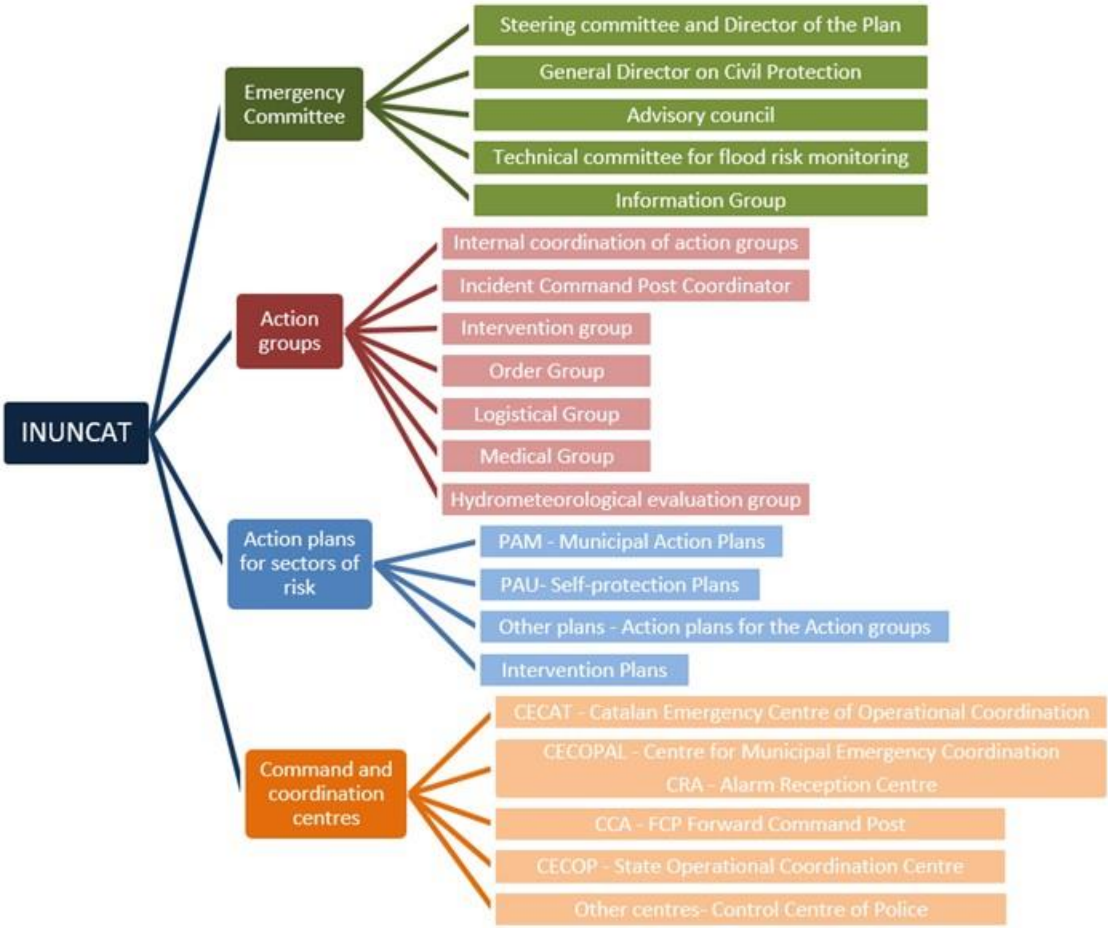
12 Annex A. The INUNCAT plan

The special plan of floods emergencies in Catalonia is called INUNCAT. The plan provides a management system for flood-related events that aims to facilitate the coordination of all activities, by all the organisations involved, in the resolution of the emergency. Thus, the warning system, the organisation, and the procedures of performance are all defined [4].

As for the organisation, INUNCAT defines actors participate with a different role. Figure 7-1 provides an overview of the organization of the emergency and the different actors who are involved.

INUNCAT provides an organizational command structure during the emergency that defines the emergency committee, actions groups and their specific roles, action plans for specific sectors of risk, and command and coordination centres.



Emergency Management Structure as defined by the INUNCAT plan.

INUNCAT is composed of three emergency response levels:

- Pre-alert: Potential situations in which flooding can occur, which require close and timely monitoring of the action.
- Alert: Situations in which the establishment of preventive and control measures is necessary.
- Emergency 1: Serious emergency situations. Floods that have significant impact but limited to specific areas in the territory.
- Emergency 2: Serious emergency situations. Large floods or simultaneous flooding that affect a large areas in the territory.

13 Annex B. Public statement (Roskilde Fjord Floods)

The following public statement was uploaded on the Frederikssund municipality´s website (www.frederikssund.dk) to keep citizens informed about the evolution of flooding risk and the protection measures that had been carried out**:**

Forecast of elevated water level

DMI announces strong winds during the weekend with the risk of gusts of storm force and a preliminary forecast of elevated water levels in the fjords of up to 120 cm on Sunday evening.

With heavy weather on the road this weekend, the municipality and the preparedness follow the forecasts from DMI. Today Thursday, DMI - based on an English forecast - informs that the water level in Roskilde Fjord on Sunday evening 29 October can rise to 120 cm. above normal level. The forecast is subject to uncertainty.

When DMI can warn more securely during Friday, we will inform you about this on the page including any action if it turns out that a more secure notice says 120 cm or more. There is nothing to indicate that the elevated water level comes close to what the storm Urd caused in the Christmas days of 2016.

Important about elevated water levels in the fjords

(Sunday at 9.27) DMI's latest forecast for elevated water levels in the fjords is now 153 cm in Roskilde Fjord and 165 cm in Isefjord. Filled sandbags have been laid out at the depots, and water tubes are laid out in Frederikssund, Hyllingeriis and Jægerspris during Sunday.

DMI reports 153 cm elevated water level in Roskilde Fjord (the meter at Frederikssund South) and 165 in Isefjord (the meter at Kyndbyværket) on Sunday evening.

Important about elevated water levels in the fjords:

(Sunday at 9.27) DMI's latest forecast for elevated water levels in the fjords is now 153 cm in Roskilde Fjord and 165 cm in Isefjord. Filled sandbags have been laid out at the depots, and water tubes are laid out in Frederikssund, Hyllingeriis and Jægerspris during Sunday.

DMI reports 153 cm elevated water level in Roskilde Fjord (the meter at Frederikssund South) and 165 in Isefjord (the meter at Kyndbyværket) on Sunday evening

The municipality's and the emergency preparedness's common crisis staff have met this morning. It has been decided that water tubes be added in the following areas:

Two water tubes are laid out in Frederikssund at J.F. Willumens road towards Strandvej and Færgevej, respectively. Water tubes are also laid out in the harbor area along the north quay at Toldboden and at Stenværksvej.

Two water tubes are laid out in Hyllingeriis, and one water tube is laid out in the area at the Kignæshallen in Jægerspris.

On Saturday, filled sandbags were added at the following depots:

Over Dråby Strand - Lille Strandvej by the parking lot.

Dalby Strandvej at the parking lot at the end of the road.

Ball houses - at the end of Barakvej by the bus square.

Tørslev Hage - corner of Granbrinken / Old Farmyard Road).

Frederikssund - parking lot at the entrance to Skyllebakkehavn.

Frederikssund - corner of Fasanvej / Slåenbakke avenue.

By Road and Park, Smedetoften 4 in Frederikssund.

Notice: The municipality's staff and preparedness follow the situation closely. If you have any questions, the emergency preparedness can be contacted at 47 37 61 12. The municipality's staff can be contacted via the municipality's main number 47 35 10 00.

14 Annex C. Images of the Artés Fire

Following is a number of images displaying the impact of the flood event extracted from digital media:

Images	Description
	Smoke plume from the village of Artés.
	Aerial photograph of Artés fire from a helicopter of Agents Rurals (Rural Agents of the Government of Catalonia).
	Aerial photograph of Artés fire from a helicopter of the Catalan Fire Service of the Government of Catalonia.

	Retardant dropping operations from an aircraft of the Fire Service of the Government of Catalonia.
	Heavy machinery assisting in suppression tasks.
	Decision-making at the Incident Command Post.

	Aerial image of the Incident Command Post.
	Medical group.

	Firefighthers of the Fire and Rescue Service of the Government of Catalonia extinguishing hot spots.
	House catching fire in Artés.
	Indoor sports centre in Santa Maria d'Oló used as a refuge for evacuated people.

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