European Flood Awareness System

DETAILED ASSESSMENT REPORT

"THE DECEMBER 2019 EVENT IN NORTHERN SPAIN"

EFAS DISSEMINATION CENTRE

EFAS HYDROLOGICAL DATA COLLECTION CENTRE

Specific Contract No.5

Table of content

Acronyms

AEMET	Agencia Estatal de Meteorología (Spanish State Meteorological Service)
CEMS	Copernicus Emergency Management Service
CET/CEST	Central European Time/Central European Summer Time
CHE	Confederación Hidrográfica del Ebro
CHMS	Confederación Hidrográfica Miño-Sil
COSMO-LEPS	Limited Area Ensemble Prediction System
DELFT FEWS	Hydrological Forecast and Warning System
ECMWF	European Centre for Medium-Range Weather Forecasts
ECMWF-ENS	Ensemble forecast of ECMWF
EFAS	European Flood Awareness System
EFAS-IS	EFAS Information System
ERA-5	Climate reanalysis produced by ECMWF,
ERCC	European Response and Coordination Centre
NVI	Normalized Variation Index
REDIAM	Environment and Water Agency of the Regional Ministry for the Environment and Spatial Plann

1 Introduction

Floods are one of the most destructive natural hazards worldwide that causes severe economic damages and human losses. The European Flood Awareness System (EFAS) operated by the Copernicus Emergency Management Service (CEMS) since 2012 is the first monitoring and operational forecasting and warning system that provides a service that significantly increases the efficiency in decision-making and flood situation response, particularly in the large trans-national river basins throughout Europe. It provides complementary, added-value information (e.g. probabilistic, medium range flood forecasts, flash flood indicators, and impact forecasts) to the relevant national and regional authorities. Furthermore, EFAS keeps the Emergency Response Coordination Centre (ERCC) informed about ongoing and possibly upcoming flood events across Europe.

In December 2019 severe weather events in South-Western Europe caused severe floods and consequently damages. This EFAS detailed assessment report focuses on this event in three river basins in Spain. The report is targeted on the situation in the Spanish Minho, Douro and Ebro basins for the event in December 2019. The detailed assessment aims to provide a thorough understanding of the EFAS forecasts in terms of accuracy, timely availability and effective communication of the forecasts. In addition to the hydrological forecasting skill, the report provides information about the hydrological model performance over the regions of interest, meteorological forecasts and antecedent conditions (i.e. soil moisture). The flood and flash flood generation drivers are stated for each region together with the number of EFAS notifications sent to the partners. Overall, this assessment allows to evaluate of the accuracy of the EFAS forecasts and affiliated notifications, with the aim of shaping suggestions for further service evolutions.

The report is organized as follows: Chapter 2 gives a general description of the study area. Chapter 3 describes the hydro-meteorological conditions during the event. Chapter 4 describes the EFAS forecasts and information. Chapter 5 presents a detailed hydrological analysis of the flood events and Chapter 6 reconstructs the flood events based on media reports. Chapter 7 evaluates how EFAS performed during the event in terms of spatial-temporal accuracy of the predictions as well as the timeliness and accuracy of the EFAS notifications. The final chapter of the report contains a synthesis and some conclusions.

2 General description of the study area

2.1 Basin descriptions

The study area chosen for this Detailed Assessment Report comprises of four basins located in Northern Spain: Minho, Limia, Douro and Ebro. These basins are adjacent to each other, being Minho and Limia the most western and Ebro the most eastern. Because those four basins comprise a large territory within Spain, with important differences, their characteristics will be explained separately. The basins considered for the detailed assessment are shown in Figure 1.

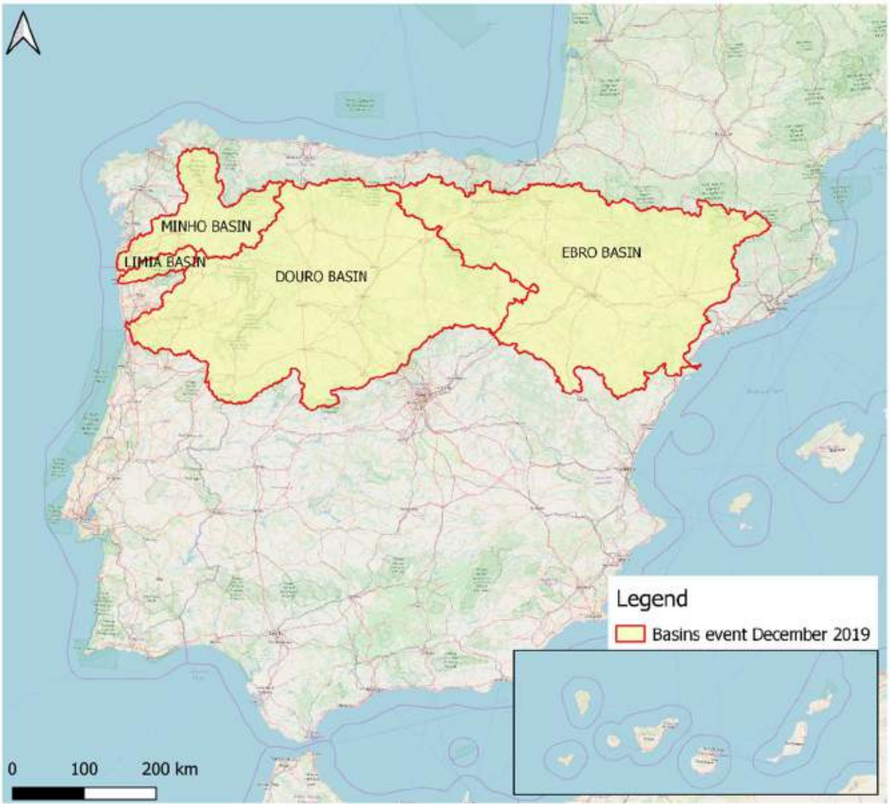


Figure 1 Map of the basins studied in this report, for the flood event of December 2019.

2.1.1 Minho

The Minho basin is situated in the northeast of the Iberian Peninsula, encompasses 8.288km^2 and drains the autonomous communities of Galicia, Castilla y León and Asturias and the north of Portugal. In the Minho basin, together with Limia and Sil basins live approximately 858.000 inhabitants. [123]

The climate of the Minho basin is characterized by light winters, cool summers, humid air and frequent clouds. Precipitation is usual within all the basin, especially due to the influence of the Atlantic sea and the morphology of the basin. There are spatial differences of rainfall within the Minho basin. Whereas in the western mountains the rainfall reaches up to 1.500mm per year, the Sil valleys are characterized for their lower rates of around 800mm per year.[4]

[1] https://www.chminosil.es/es/chms/informacion-de-interes/informacion-publica/concesiones-de-agua/80-chms/699-
[2] https://www.chminosil.es/es/chms/demarcacion/marco-fisico/descripcion
[3] http://www.cadc-albufeira.eu/es/cuencas-hidrograficas/cuenca-minio/
[4] https://www.chminosil.es/es/chms/demarcacion/condicionesclimaticas

Within the Minho basin, the strong erosion produced by the rivers has created deep, narrow and steep valleys. The water use of this river basin is focused on agricultural, urban and industrial water use and energy production.[2,3]

2.1.2 Limia

The Limia basin is situated in the northeast of the Iberian Peninsula. This basin has a total surface of 2.387km^2, among which 1.329km^2 fall within Spanish territory. In the Limia basin, together with Minho and Sil basins live approximately 858.000 inhabitants.[15]

The climate in the Limia basin is moderate, with light winters, cool summers, moist air and frequent precipitation in all the seasons. Furthermore, it is influenced by the Atlantic sea. The annual precipitation is varied along the basin. In Buscalque the average annual precipitation reaches 1.435mm, whereas in Arzoa valley the annual amount is on average less than 900mm. The average annual precipitation within the basin is 1.175mm.[45]

In the Spanish part of the Limia basin, there are no main urban or industrial areas. The largest water use of the basin focuses on the production of energy.[5]

2.1.3 Douro

The Douro basin is situated in the northeast of Spain, comprises around 98.073km^2 and is the largest basin of the Iberian Peninsula. 80% of the basin falls in Spanish territory (78.859km^2), whereas 20% falls within Portugal. Within Spain, the basin extends through the autonomous communities of Castilla y León, Galicia, Cantabria, Castilla La-Mancha, Extremadura, La Rioja, Madrid and Asturias, and it has approximately 2.205.123 inhabitants.[6]

The Douro basin has a Mediterranean climate, although on the most western side of the basin the Atlantic influence softens the climate. Within the Douro basin, the main rainfall periods are autumn and spring, whereas in summer periods there is barely no rainfall, and droughts can affect up to 90% of the watershed. The average annual precipitation is of around 600mm. However, there is a large spatial variability of precipitation. The heaviest rainfall events happen in the mountains surrounding the basin, with values larger than 1.800mm per year. The lowest values occur between Salamanca, Zamora and Valladolid, with annual rainfall around 400mm.[6]

The basin of the Douro is mainly flat, although it is elevated and is surrounded by mountains. The river Douro has created a deep canyon along 100km of border between Spain and Portugal.[6]

2.1.4 Ebro

The Ebro basin is situated in the northeast of the Iberian Peninsula and comprises around 85.534km^2. This is the largest basin of Spain, occupying 17% of the Spanish territory[7]. The Ebro basin drains the autonomous communities of Cantabria, Castilla y León, La Rioja, País Vasco, Navarra, Aragón, Cataluña, Comunidad Valenciana and Castilla-La Mancha.[8] Within the basin there are approximately 3.200.000 inhabitants.[7]

This watershed has a Mediterranean climate, although it is also influenced by the ocean in the northwest and the inner mountains of Spain. Furthermore, within the basin there are large precipitation contrasts as well. The precipitation is concentrated in the mountainous areas, especially in the Pyrenees, where the average annual precipitation exceeds 1000mm. On the other hand, on the inner valley average annual rainfall does not exceed the 400mm, and the climate is semiarid.[7]

The Ebro basin's main river is Ebro, which is fed by many tributaries on its right and left sides. Furthermore, on the landscape of the basin, there are large number of mountain lakes called

[5] http://www.cadc-albufeira.eu/es/cuencas-hidrograficas/cuenca-limia/
[6] https://www.chduero.es/la-cuenca-del-duero
[7] http://www.chebro.es/contenido.visualizar.do?idContenido=2001&idMenu=2004
[8] https://es.wikipedia.org/wiki/Ebro

"Ibones". Regarding the water use of the watershed, most water is destined for urban purposes, industry, agriculture and energy production.[7]

2.2 Data providers

The Data providers for those basins are: ES-1012 (Confederación Hidrográfica del Ebro), ES-1036 (Confederación Hidrográfica del Miño-Sil) and ES-1039 (Confederación Hidrográfica del Duero). These providers send hydrological data from Ebro, Miňo-Limia and Douro basins from 130 gauging stations. Most of them provide discharge and water level values, but to make a comparison between all the stations it is better to use discharge values because it does not depend on the river morphology. So, for the analysis the 103 stations with discharge values where selected. See the stations location in Figure 2, Figure 3 and Figure 4.

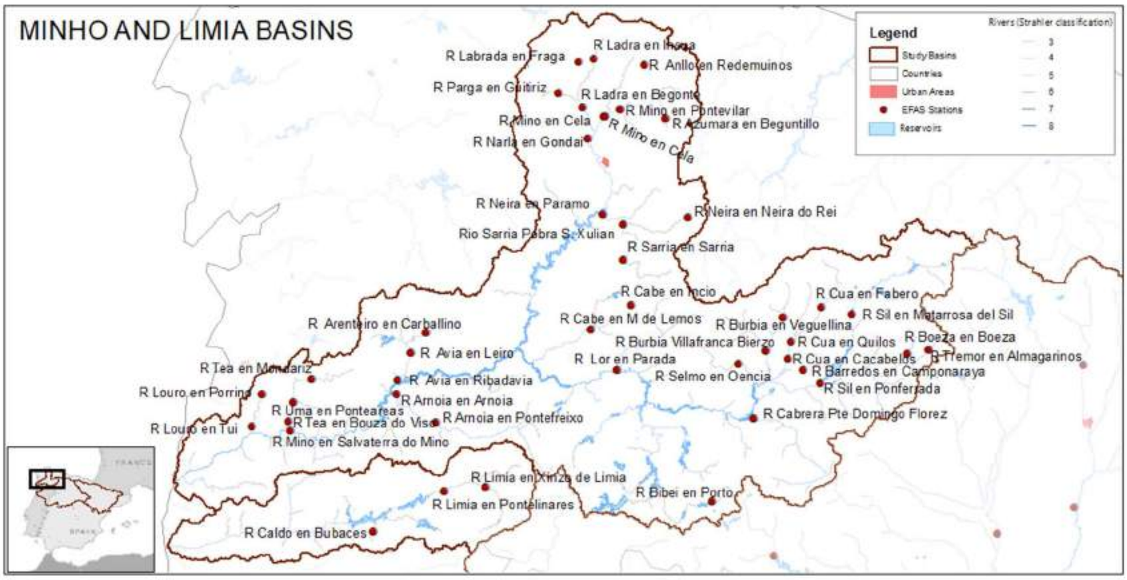


Figure 2 The 44 selected EFAS Stations located in Miňo and Limia basins.

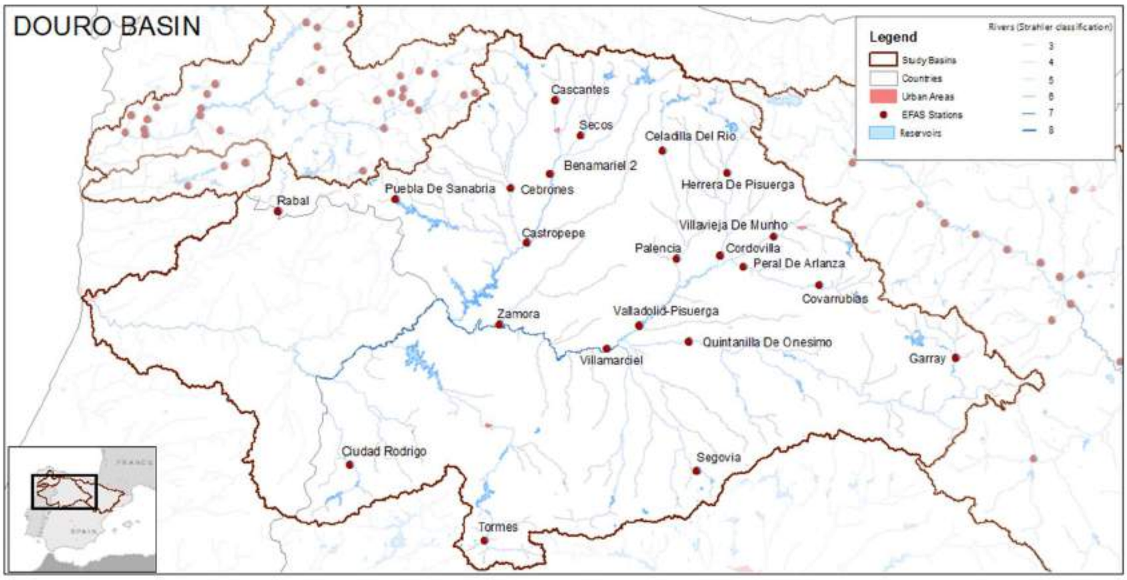


Figure 3 The 22 selected EFAS Stations located in Douro basin.

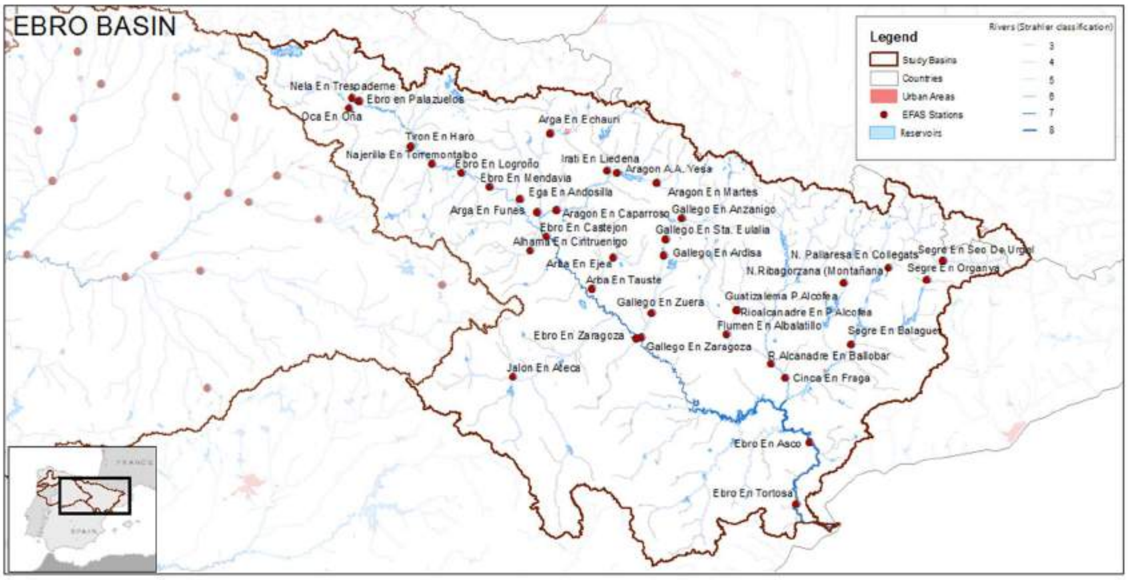


Figure 4 The 37 selected EFAS Stations located in Ebro basin.

3 Description of the hydro-meteorological conditions

For the detailed assessment the flood period at the end of 2019 in Northern Spain was selected. During the period of this detailed assessment (1st – 31st December 2019), three meteorological events occurred in the northern area of Spain. In this section the specifications of these events will be explained separately.

Storm Daniel (16th December)

The first event that occurred was storm Daniel. It formed on the 15th of December, few hundred kilometers west of Portugal. On the 16th of December, the event reached the Peninsula, and affected the western side of Spain. However, its life span was short and within 48 hours the storm dissipated[9]. The event was characterized by strong winds, precipitation and snow. The largest daily accumulation of rainfall occurred in Riaño, with 108.8mm accumulated on the 16th of December[9].

Storm Elsa (18th – 20th December)

The next event that occurred within northern Spain was storm Elsa, which was formed in an *atmospheric river* over the Atlantic. This corridor provided high concentrations of moisture over western Europe. Storm Elsa started to have effects in Spain on the 18th of December and had impact until the 20th of December over almost all the country. The 21st of December, its life cycle ended, when it was absorbed by the next storm, Fabien.[10]

This event was characterized by intense rainfall and strong winds and waves. The intense rainfall events together with the thawing of accumulated snow resulted in the increase of the discharge and overflow of several rivers (Pisuerga, Minho, Júcar among others). The largest 24-hours accumulated precipitation of this event was recorded between the 19th and 20th of December and took place in Grazalema, with 286.9mm of accumulated rainfall.[10]

During the storm Elsa, six weather related fatalities were reported between the 19th and 21st (start of storm Fabien), due to diverse causes, in several places of Spain. Furthermore, there were large damages in the infrastructures of the country. Several roads and railways were closed, and the electricity supply in Galicia was interrupted.[10]

Storm Fabien (21st – 22nd December)

The storm Fabien was formed as well in the *atmospheric river* over the Atlantic. Fabien was observed in Terranova the 19th of December, and reached Spain on the 21st, through Galicia. Its stay in Spain was short but intense. The 22nd of December Fabien, its life cycle ended, when it dissipated between the Netherlands and Denmark.[11]

The event was characterized by an intense storm surge in Galicia and the Cantábrico, and strong winds. Precipitation occurred in a large part of the country. However, there was only one location where the 24-hour accumulated precipitation exceeded the 60mm. In the station of Grazalema (Cádiz), 145.2mm were registered the 21st December.[11] Although during the storm Fabien there were no casualties, the damages were considerable.[11]

When looking at the three events (16th to 22nd December) as a single phenomenon, precipitation occurred within all the country. Table 1 depicts the total precipitation registered in several regions of Spain.[11]

[9] http://www.aemet.es/en/conocermas/borrascas/2019-2020/estudios_e_impactos/daniel
[10] http://www.aemet.es/en/conocermas/borrascas/2019-2020/estudios_e_impactos/elsa
[11] http://www.aemet.es/en/conocermas/borrascas/2019-2020/estudios_e_impactos/fabien

Table 1 Total precipitation collected by the automatic stations of AEMET during the week 16th - 22nd December[11]

Region	Accumulated precipitation (mm) from 16th - 22nd of December
Grazalema (Cádiz)	532
Puerto El Pico (Ávila)	455
La Hoya – La Covatilla (Salamanca)	379
Garganta la Olla (Cáceres)	348
Madrigal de la Vera (Cáceres)	337
Navasfrías (Salamanca)	302
Tornavacas (Cáceres)	280
Piornal (Cáceres)	270
Hoyos (Cáceres)	265
Nuñomoral (Cáceres)	261

3.1 Precipitation

The succession of three storms in the north of Spain in the month of December 2019, brought high intensity rainfall, as well as wind and surges. These events caused the death of six persons (storm Elsa) and large material damages. The river basin with the largest 24-hour accumulated precipitation was Douro, followed by Limia, Minho and Ebro.

Table 2 depicts the maximum 24-hourly accumulated rainfall and the precipitation accumulated during the three storms, in each basin.

Table 2 Maximum 24-hour accumulated precipitation of the event and accumulated precipitation throughout the event, per basin, calculated with Delft-FEWS and ERA5 reanalysis data.

Basin	Maximum 24-h accumulated precipitation (mm) during the event	Precipitation accumulated throughout the event (16th – 22nd Dec) (mm)
Minho	100	354
Limia	100	320
Douro	161	521
Ebro	98	249

Precipitation in all north of Spain was spread and with high intensity. The 20th of December, the largest accumulated precipitation occurred. In areas surrounding León, Valladolid and Salamanca, values around 10mm of rainfall were measured within one hour. Furthermore, in Salamanca and Porto (Portugal), 24-hour accumulated precipitation exceeded 100mm. Figure 5 and Figure 6 depict the ERA5 reanalysis observed precipitation, accumulated in one and 24 hours respectively, on the 20-12-2019 00:00:00UTC.

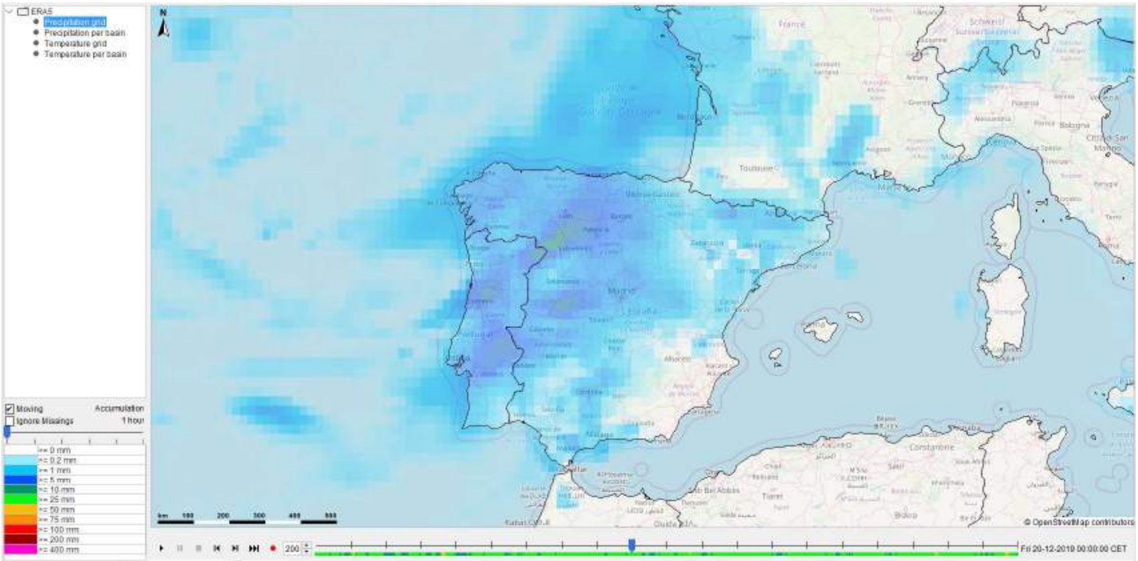


Figure 5 The 1-hour accumulated rainfall (mm) on the 20-12-2019 00:00:00CET, derived from ERA5 in Delft-FEWS

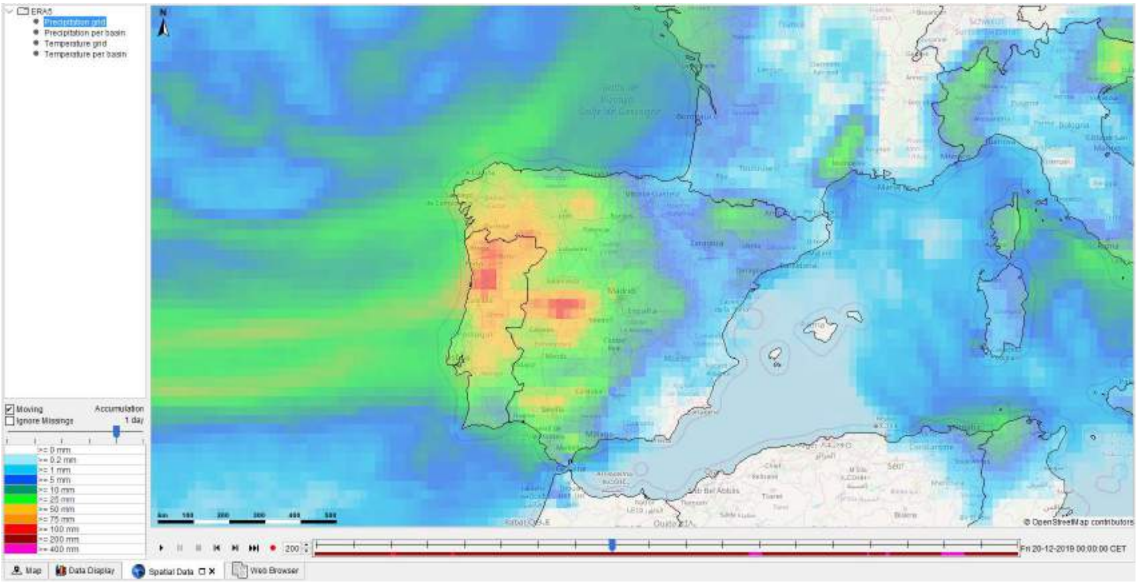


Figure 6 The 24-hour accumulated rainfall (mm) on the 20-12-2019 00:00:00CET, derived from ERA5 in Delft-FEWS

Figure 7 depicts the observed 24-hour accumulated precipitation on the 20th of December 06:00:00UTC, based on interpolated precipitation. This map and the maps based on ERA5 data (Figure 5 and Figure 6), show the intense rainfall that occurred during storm Elsa, in northern Spain. For this specific day, large peak events can be observed in all basins.

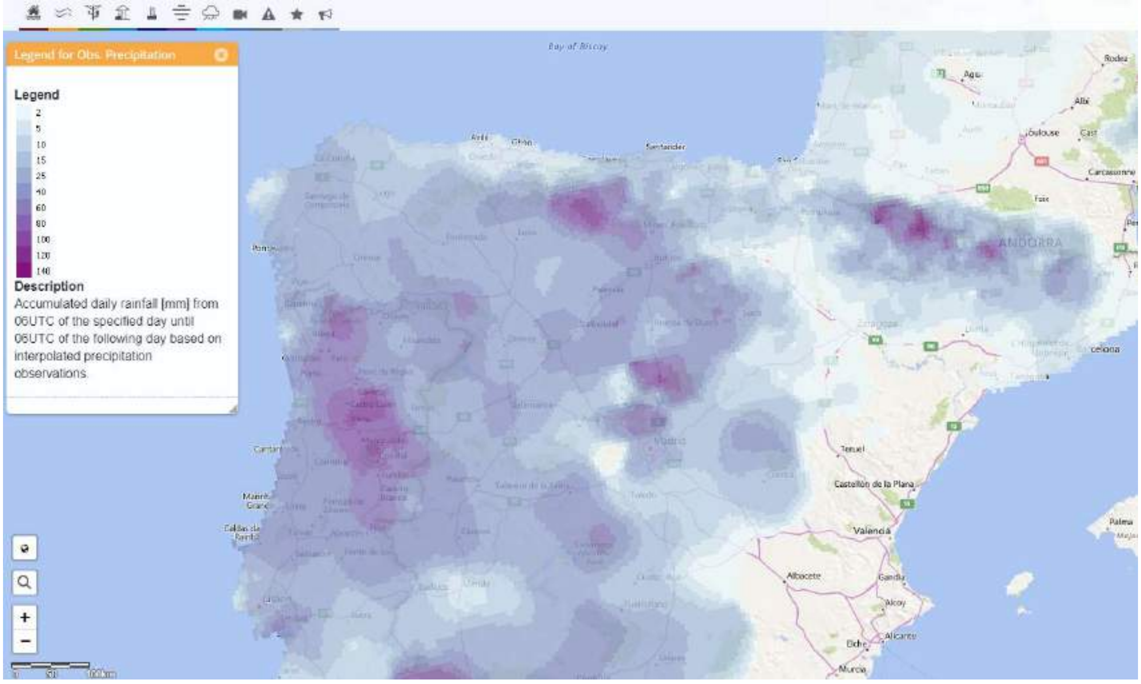


Figure 7 Accumulated daily precipitation (mm) from the 20-12-2019 06:00:00UTC until the 21-12-2019 06:00:00UTC, based on interpolated precipitation observations.

The probabilistic models of EFAS COSMO-LEPS and ECMWF predicted the probability of exceedance of 150mm accumulated during the entire forecast range (5 and 10 days respectively). COSMO-LEPS predicted probabilities of more than 50% over large parts of the study area (Figure 8), from the model run of 15-12-2019 00:00:00UTC. On the other hand, ECMWF predicted probabilities larger than 50% in Minho, Douro and Ebro basins (Figure 9) from the 11-12-2019 00:00:00UTC.

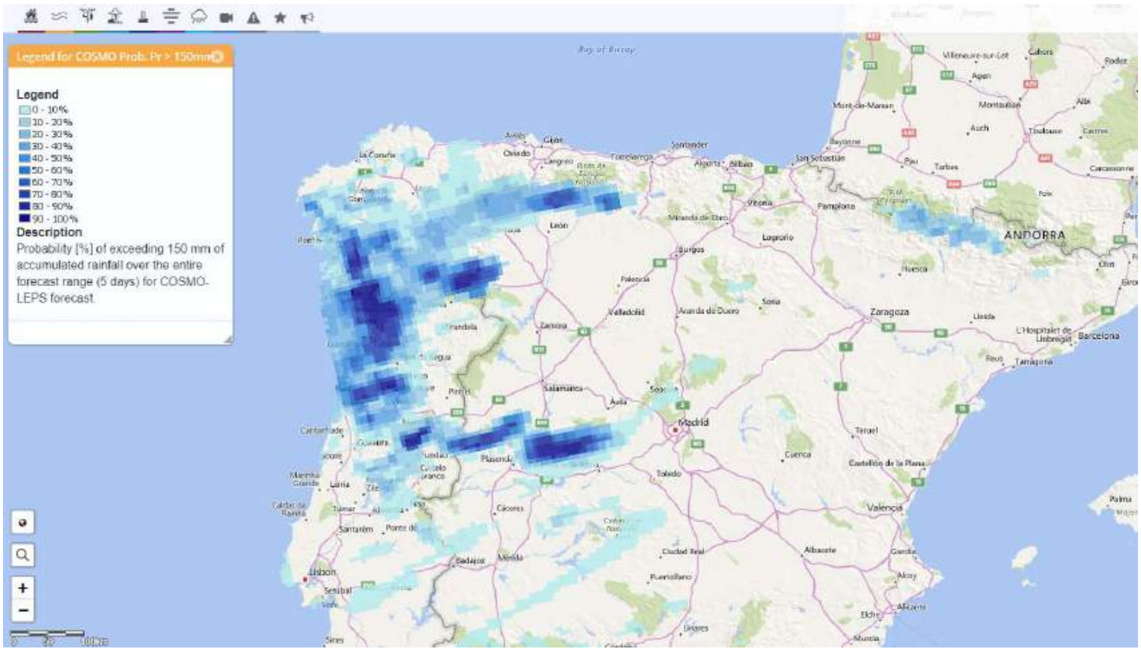


Figure 8 Probability (%) of exceeding 150mm of accumulated rainfall over the entire forecast range (5 days) for COSMO-LEPS forecast on the model run of 15-12-2019 00:00:00UTC, obtained from EFAS.

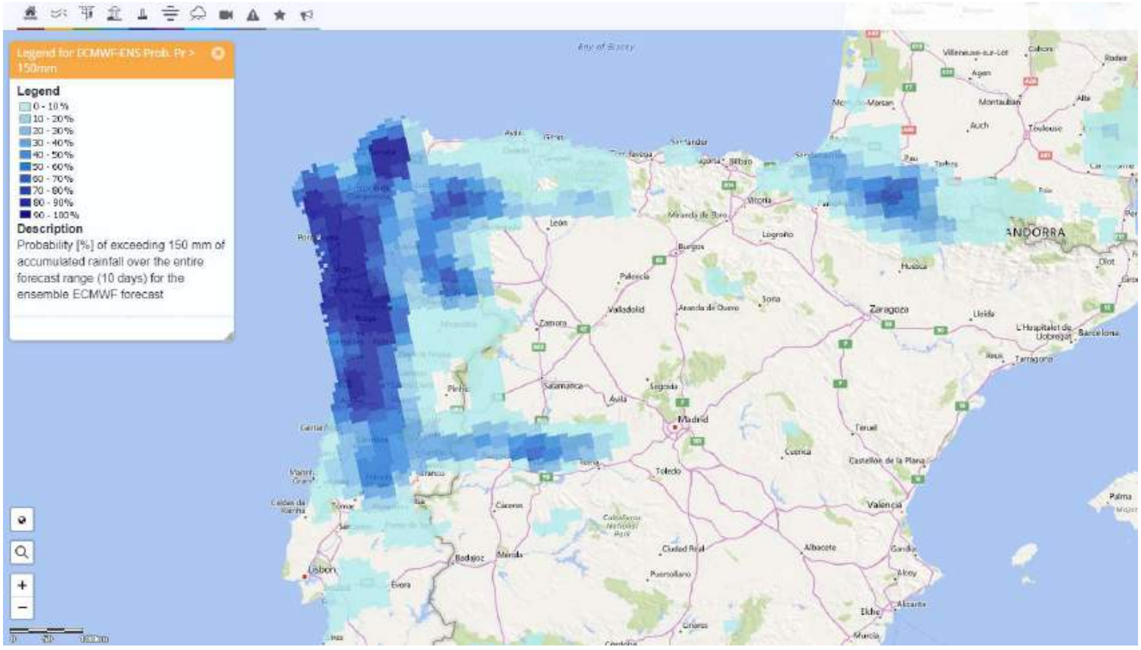


Figure 9 Probability (%) of exceeding 150mm of accumulated rainfall over the entire forecast range (10 days) for the ensemble ECMWF forecast on the model run of 11-12-2019 00:00:00UTC, obtained from EFAS.

3.2 Soil moisture

The soil moisture just before the first event (storm Daniel) started in most parts of northern Spain were near normal conditions (Figure 10), where normal conditions have been derived using the simulated soil moisture from a 26 year model climatology (1990-2016). Only in the surroundings of *Cordillera Cantábrica* and *Sistema Central*, which are mountainous areas, the soil was wetter than normal and even being categorized in some points as “highly wetter than normal”. On the other hand, when observing the soil moisture anomaly at the end of the event (21-12-2019), large areas of northern Spain had areas wetter than normal. The Douro and Ebro basins were wetter than normal, and in the mountainous areas like the *Cordillera Cantábrica, Sistema Central, Sistema Ibérico* and Pyrenees, the soil moisture conditions were highly wetter than normal (Figure 11).

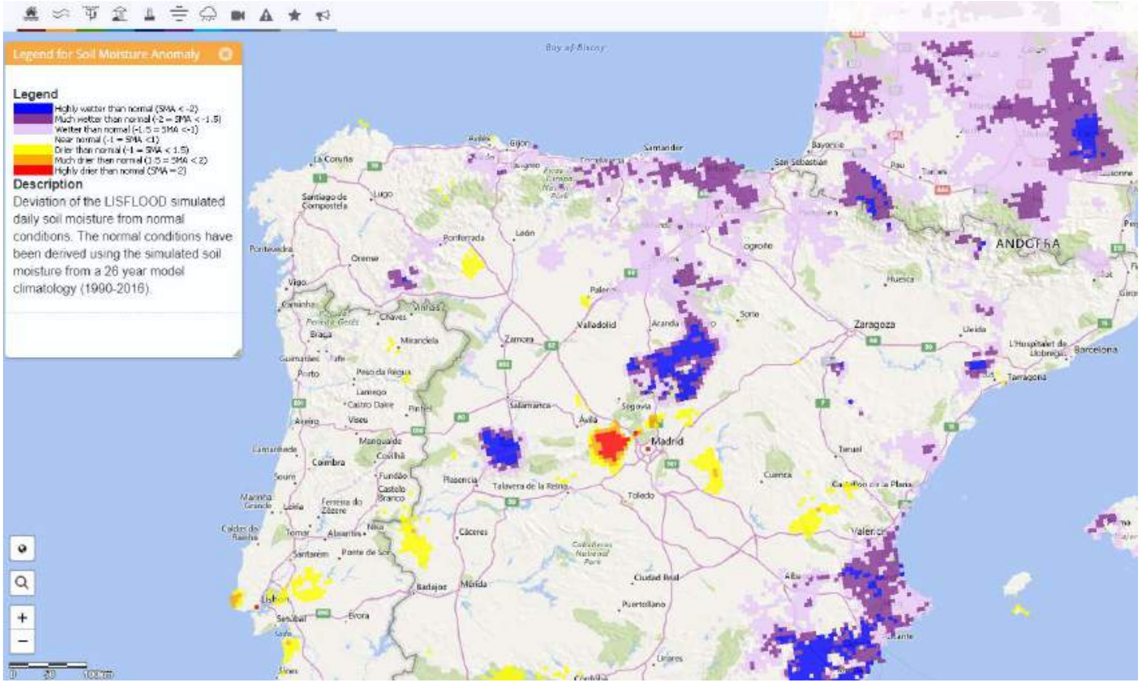


Figure 10 LISFLOOD simulated deviation of daily soil moisture from normal conditions, for the model run 11-12-2019 00:00:00UTC.

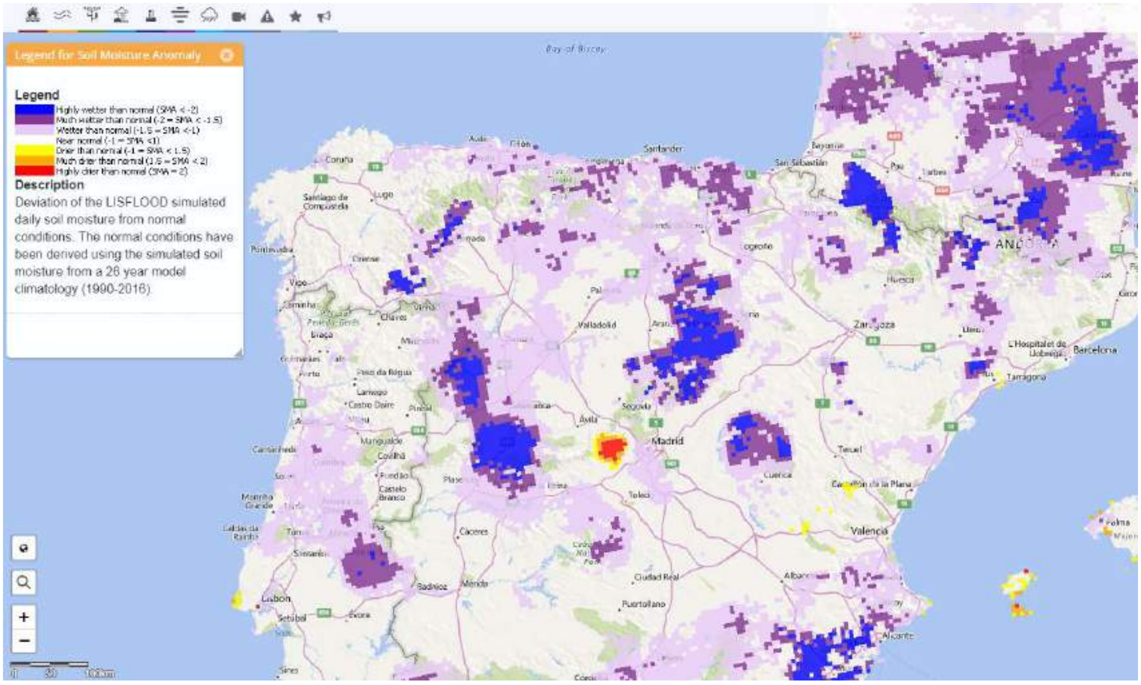


Figure 11 LISFLOOD simulated deviation of daily soil moisture from normal conditions, for the model run 21-12-2019 00:00:00UTC.

4 EFAS forecasts & information

In Figure 12 an overview of the issued Informal, Formal and Flash Flood Notifications is presented for the period of the event for the three different basins. In this chapter, the EFAS forecast information is presented per basin.

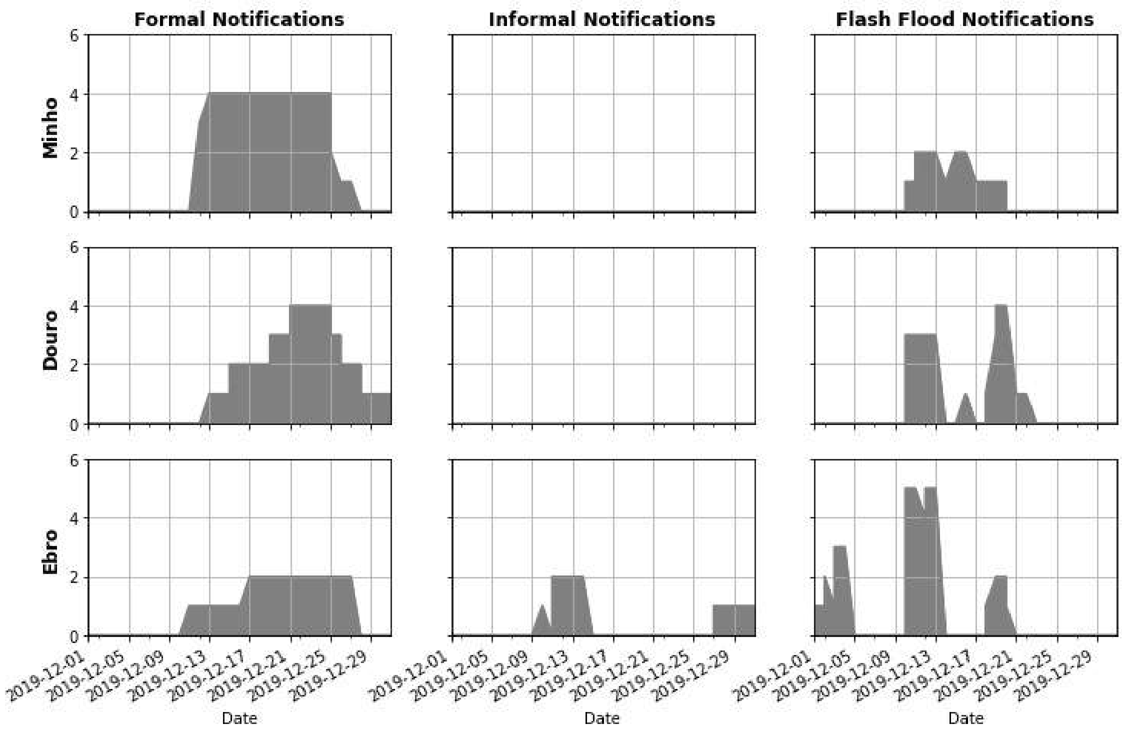


Figure 12 Overview of the active notifications (Formal, Informal and Flash Flood) per basin over the period of the events.

4.1 Flood probability

A large number of rivers in the three basins of this study showed high probabilities of exceeding the EFAS 5-year return period threshold, for the ECMWF-ENS forecasts 0-48 hours ahead, on the 20-12-2019 00:00:00UTC model run, depicted in Figure 13. The rivers located on the North-Western side of Spain, had especially large probabilities, of more than 70%.

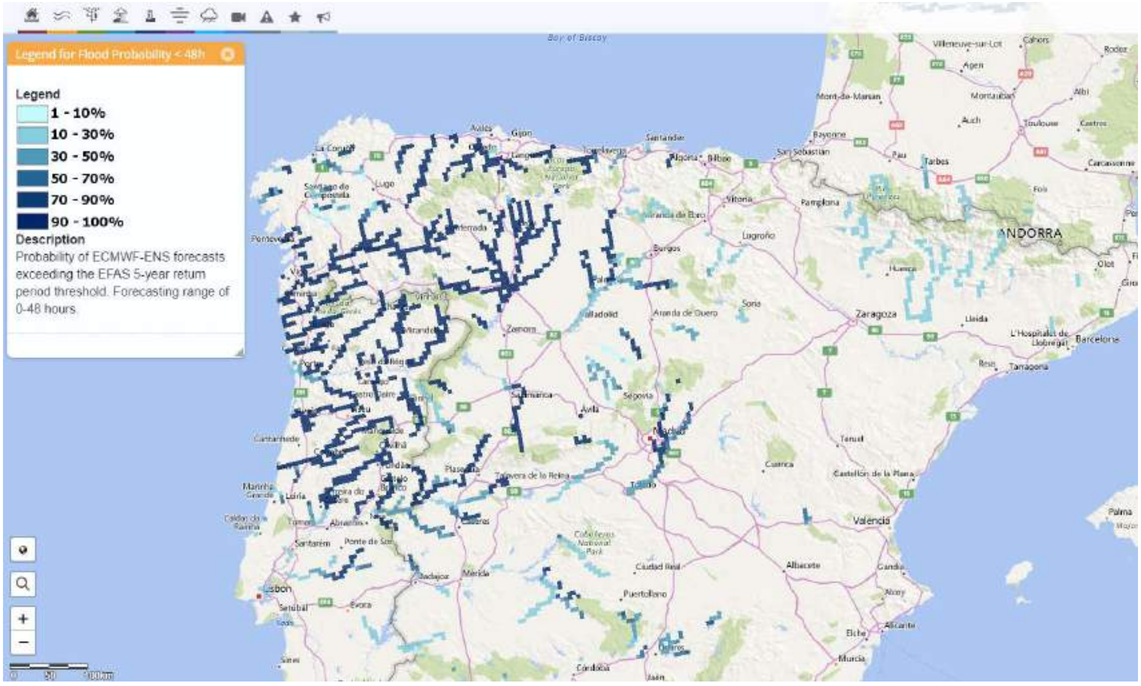


Figure 13 Probability of ECMWF-ENS forecasts exceeding the EFAS 5-year return period threshold, for the forecasting range 0-48 hours, on the 20-12-2019 00:00:00UTC.

Some rivers in the three basins of this study showed probabilities of exceeding the EFAS 5-year return period threshold, for the ECMWF-ENS forecasts 2-10 days ahead, on the 20-12-2019 00:00:00UTC model run. Figure 14 presents the large probabilities for the Douro river, with values reaching more than 70% probability of exceeding the 5-year return period of EFAS. Also, in the Minho basin there were high probabilities of more than 70%, whereas in the Ebro basin the flood probability was lower.

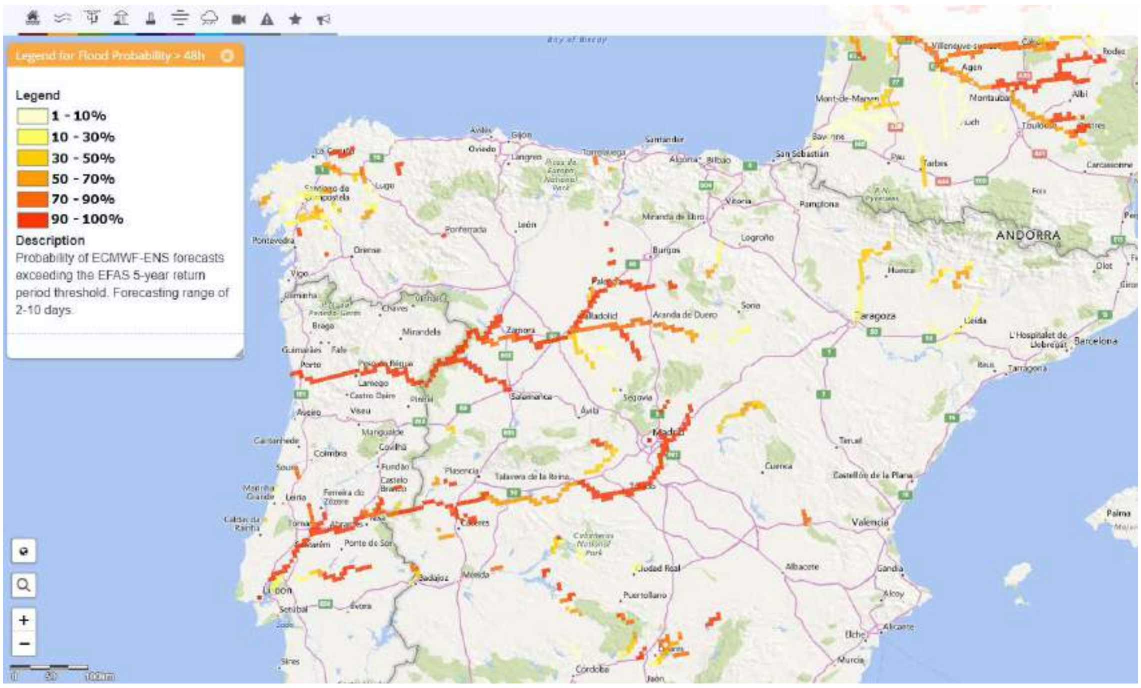


Figure 14 Probability of ECMWF-ENS forecasts exceeding the EFAS 5-year return period threshold, for the forecasting range 2 – 10 days, on the 20-12-2019 00:00:00UTC.

4.2 Minho basin

For the Minho basin, three EFAS Formal Flood Notifications were sent out in total during December 2019. Of those, two on the 13th of December and one on the 14th of December (see Figure 15 for the location of those notifications). The detailed information on the timing of the notifications and the forecasted probabilities is shown in Table 3.

In addition to the three Formal Flood Notifications, four EFAS Flash Flood Notifications were sent out between 10th and 20th of December for the same basin. The detailed information on timing of the notifications and the forecasted probabilities is shown in Table 3.

No Informal Flood Notifications were sent for the Minho basin.

Figure 16 shows the by EFAS predicted hydrographs for the Formal Flood Notifications for the ECMWF and COSMO ensembles.

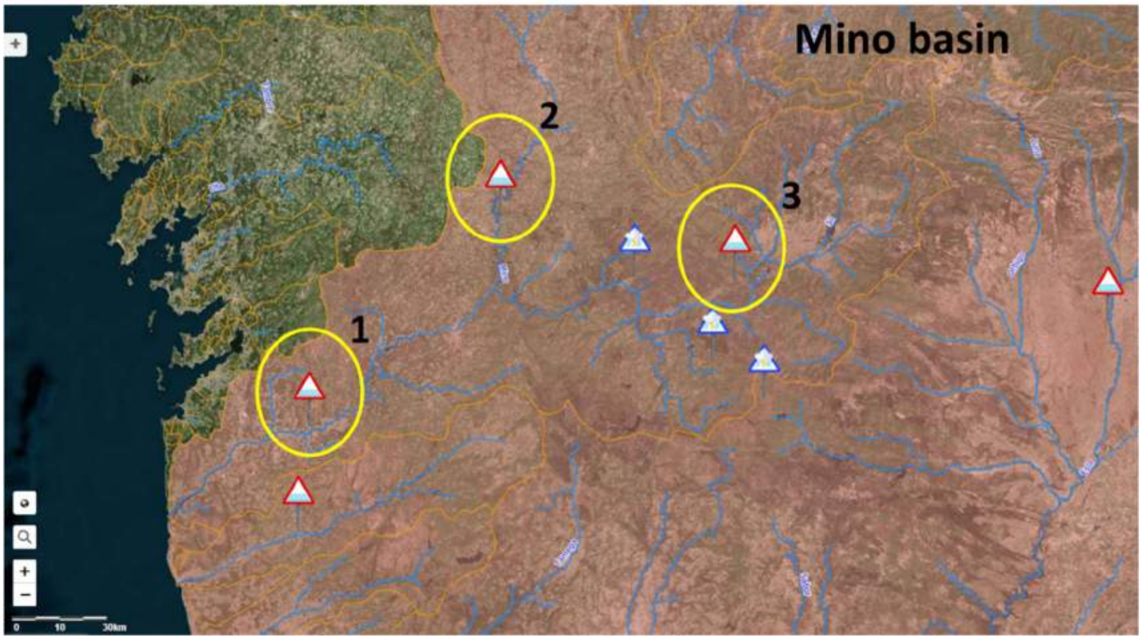


Figure 15 Geographical overview of the Formal Flood Notifications from the 12th of December 00:00 hour forecast for the Minho basin.

Table 3 Detailed information related to the sent information from EFAS for the Minho basin.

Type	Basin	River/Region	Date sent	Forecast	Earliest Peak	Prob. 5y	Prob. 20y	Deactivated
Flash	Minho	Lugo	11-12-2019	10-12-2019	13-12-2019	35%	13%	13-12-2019
Flash	Minho	Sil	12-12-2019	11-12-2019	13-12-2019	39%	0%	13-12-2019
Formal	Minho	Minho (ES)	12-12-2019	12-12-2019	21-12-2019	55%	24%	25-12-2019
Formal	Minho	Minho (PO)	12-12-2019	12-12-2019	21-12-2019	55%	24%	25-12-2019
Formal	Minho	Sil	13-12-2019	13-12-2019	16-12-2019	100%	14%	26-12-2019
Flash	Minho	Lugo	15-12-2019	15-12-2019	16-12-2019	28%	13%	17-12-2019
Flash	Minho	Ourense	17-12-2019	17-12-2019	19-12-2019	18%	0%	19-12-2019

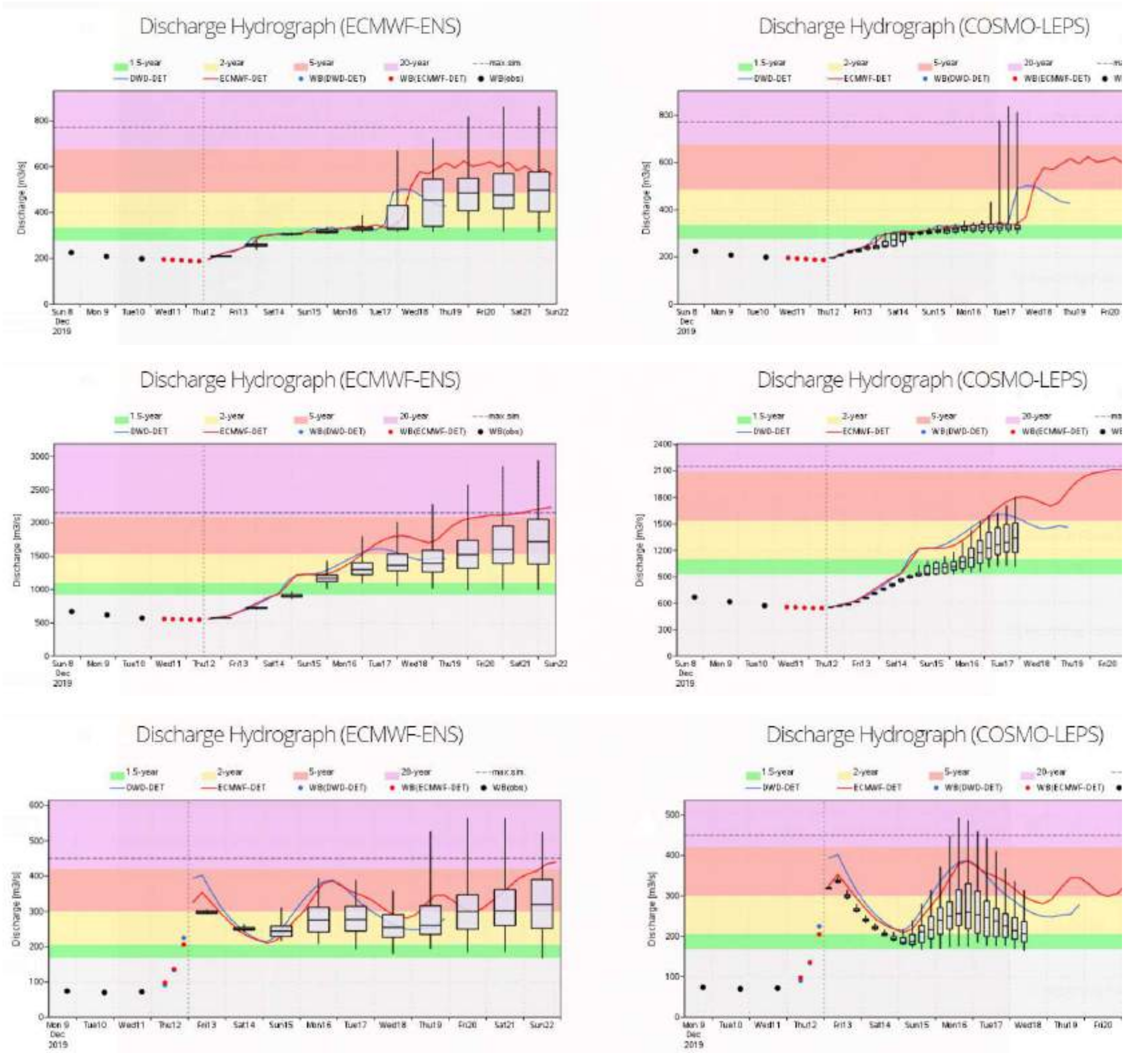


Figure 16 Forecasted hydrographs for the Formal Flood Notifications in the Minho basin. From top to bottom: Minho (ES), Minho (PO) and Sil rivers.

4.3 Douro basin

For the Douro basin the first Formal Flood Notifications were sent out at the 13th of December. The earliest peak was predicted for the 18th of December (number 1 in Figure 17). On the 15th of December a second Formal Flood Notification was sent (number 2 in Figure 17). EFAS predicted the peak to be on the 22nd of December. On the 19th of December another Formal Flood Notification was sent out (number 3 in Figure 17). The predicted peak of the event was for the 24th of December. Finally, another Formal Flood Notification was sent on the 21st of December (number 4 in Figure 17), predicting a peak on the 24th of December also. The number of active notifications drops after the 25th of December. Details on the Formal Flood Notifications are shown in Table 4.

In the time between 10th and 22nd of December, six Flash Flood Notifications were sent out, as is shown also in Table 4.

No Informal Flood Notifications were sent for the Douro basin.

Figure 18 shows the by EFAS predicted hydrographs for the Formal Flood Notifications for the ECMWF and COSMO ensembles.

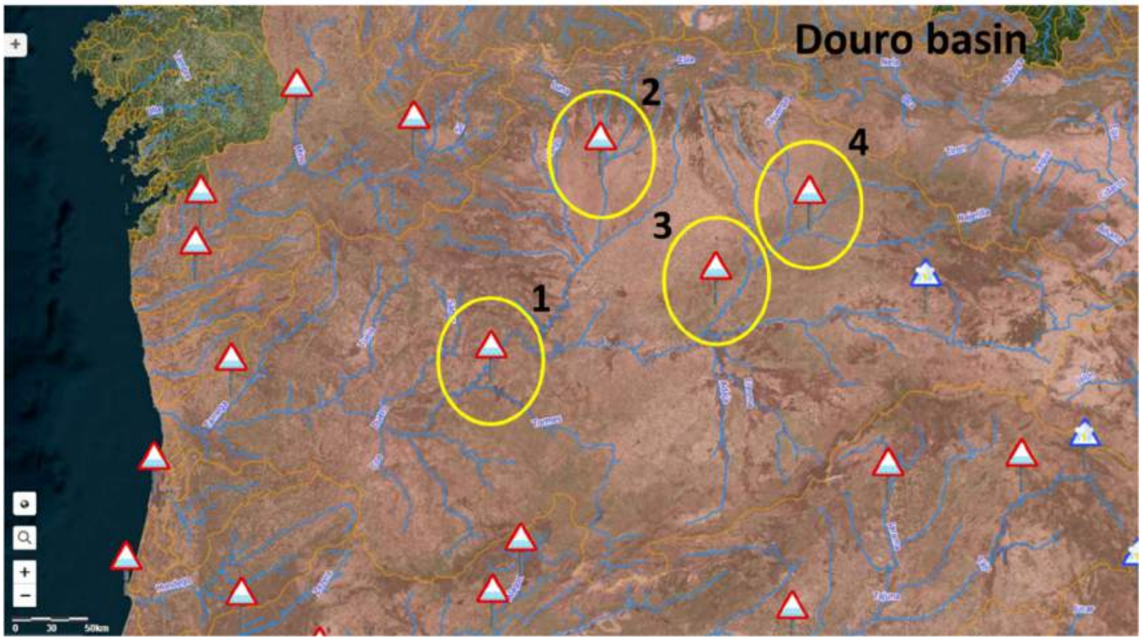


Figure 17 Geographical overview of the Formal Flood Notifications from the 25th of December 00:00 hour forecast for the Douro basin.

Table 4 Detailed information related to the sent information from EFAS for the Douro basin.

Type	Basin	River/Region	Date sent	Forecast	Earliest Peak	Prob. 5y	Prob. 20y	Deactivated
Flash	Douro	Esla	11-12-2019	10-12-2019	13-12-2019	14%	0%	13-12-2019
Flash	Douro	Duoro	11-12-2019	10-12-2019	13-12-2019	15%	0%	13-12-2019
Formal	Douro	Esla	13-12-2019	13-12-2019	18-12-2019	57%	33%	25-12-2019
Formal	Douro	Arlanza	15-12-2019	15-12-2019	22-12-2019	45%	25%	26-12-2019
Flash	Douro	Zamora	16-12-2019	16-12-2019	17-12-2019	12%	0%	17-12-2019
Flash	Douro	Soria	18-12-2019	18-12-2019	20-12-2019	95%	72%	21-12-2019
Flash	Douro	Douro	19-12-2019	19-12-2019	20-12-2019	55%	17%	21-12-2019
Flash	Douro	Adaja	19-12-2019	19-12-2019	20-12-2019	22%	0%	21-12-2019
Formal	Douro	Douro	19-12-2019	19-12-2019	24-12-2019	100%	100%	29-12-2019
Formal	Douro	Pisuerga	21-12-2019	21-12-2019	24-12-2019	100%	100%	28-12-2019

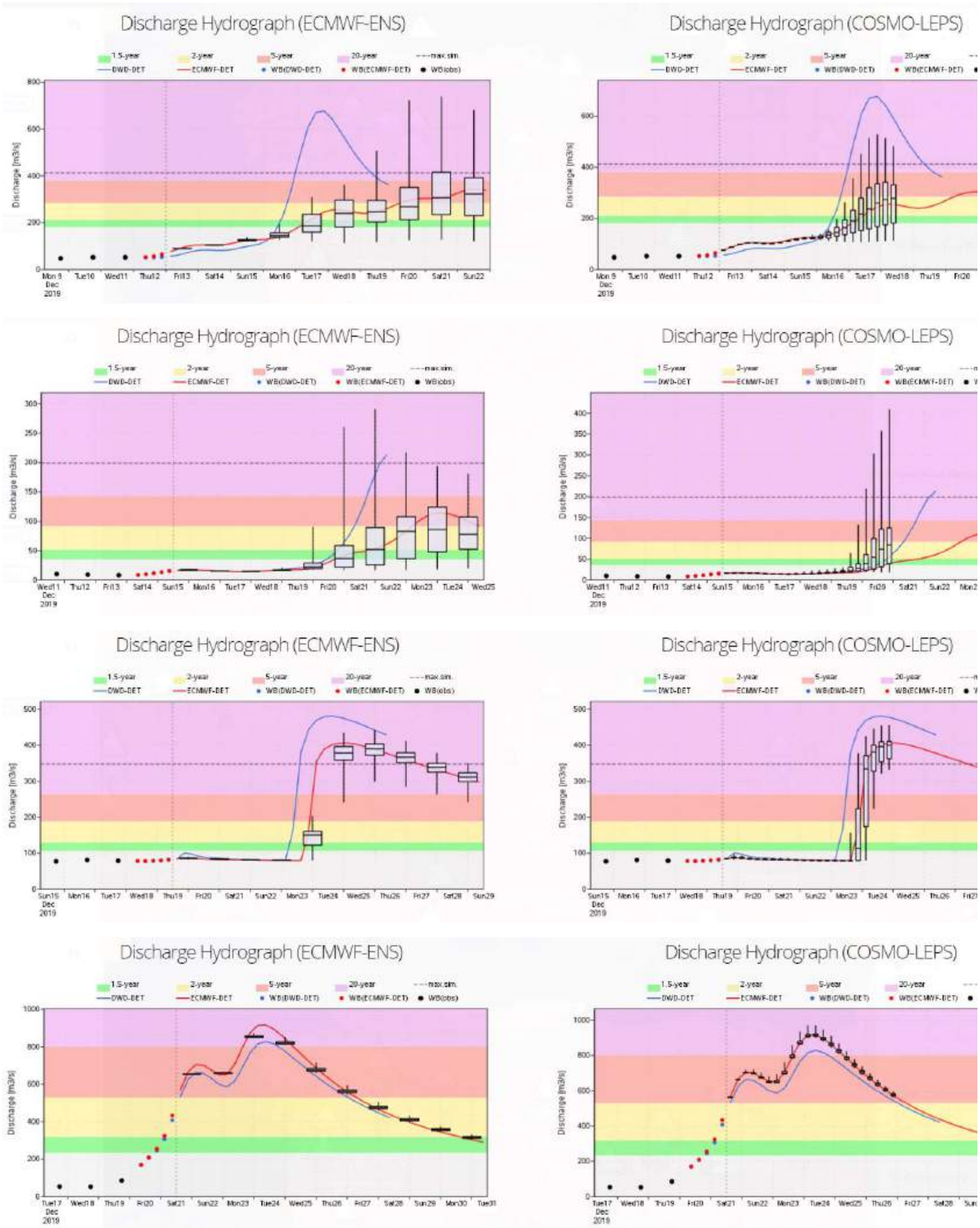


Figure 18 Forecasted hydrographs for the Formal Flood Notifications in the Douro basin. From top to bottom: Esla, Arlanza, Douro and Pisuerga rivers.

4.4 Ebro basin

For the Ebro basin the first Formal Flood Notification was sent out at the 11th of December. The start of the event was predicted for the 14th of December with the earliest peak at the 15th of December (number 1 in Figure 19). A second and third notification (Figure 20) were sent for a second event, for which EFAS predicted the start for the 20th of December, with the earliest peak on the 22nd of December.

The number of active Formal Notifications for the Ebro basin in December was three, divided over two separate events. The last Formal Flood Notification was de-activated on the 28th of December (see Table 5).

In the Ebro basin, three Informal Flood Notifications were sent in the period between 10th and 27th of December. None of the Informal Flood Notifications were changed into Formal Flood Notifications.

In the time between 1st and 21st of December, seven Flash Flood Notifications were sent out, divided over three separate events.

Figure 21 shows the by EFAS predicted hydrographs for the Formal Flood Notifications for the ECMWF and COSMO ensembles. In Figure 22 the real-time hydrograph at the moment of sending out of the Formal Flood Notification is shown for the Navia river.

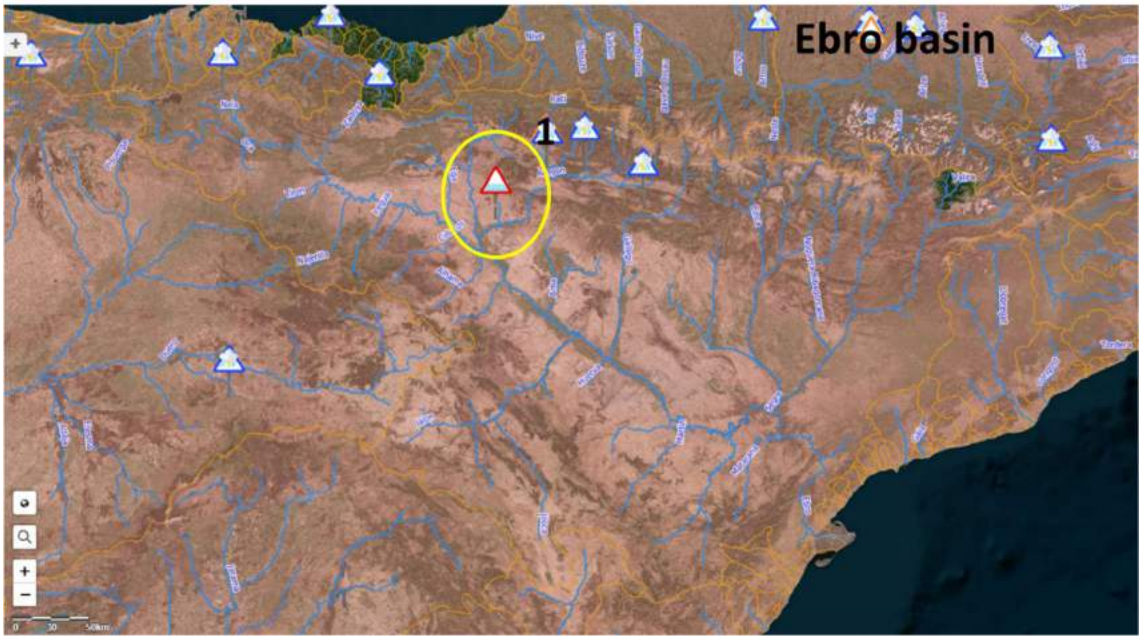


Figure 19 Geographical overview of the Formal Flood Notifications from the 10th of December 12:00 hour forecast for the Ebro basin.

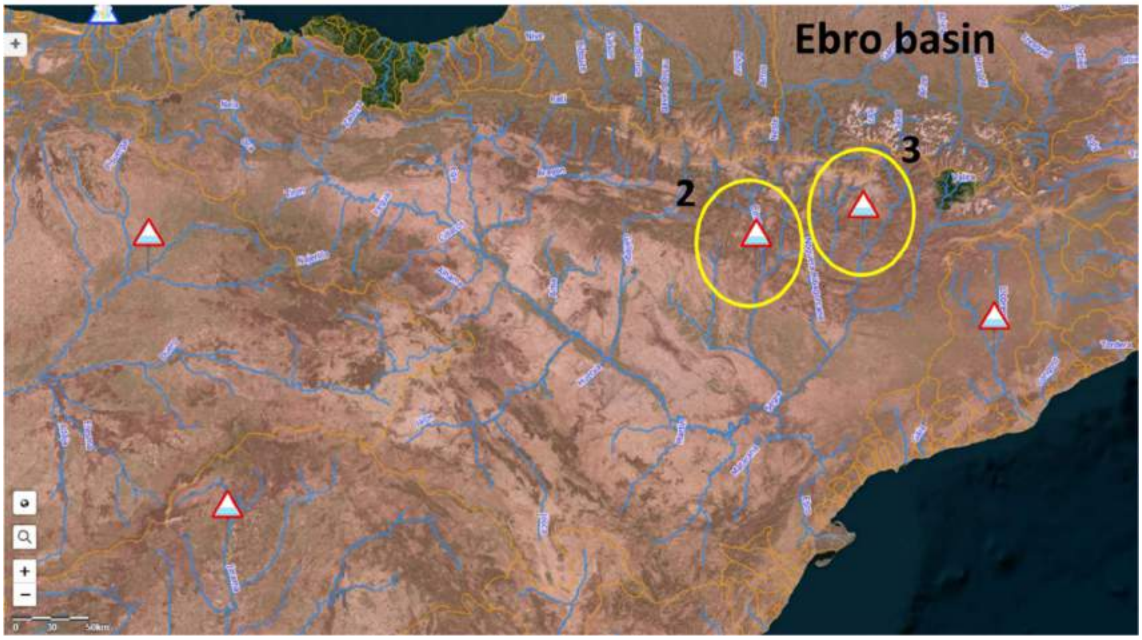


Figure 20 Geographical overview of the Formal Flood Notifications from the 18th of December 00:00 hour forecast for the Ebro basin.

Table 5 Detailed information related to the sent information from EFAS for the Ebro basin.

Type	Basin	River/Region	Date sent	Forecast	Earliest Peak	Prob. 5y	Prob. 20y	Deactivated
Informal	Ebro	Irati	10-12-2019	10-12-2019	14-12-2019	80%	30%	15-12-2019
Flash	Ebro	Navarra	10-12-2019	10-12-2019	13-12-2019	92%	44%	14-12-2019
Flash	Ebro	Zaragoza	10-12-2019	10-12-2019	13-12-2019	92%	62%	14-12-2019
Flash	Ebro	Araba/Alava	10-12-2019	10-12-2019	13-12-2019	28%	0%	14-12-2019
Flash	Ebro	Burgos	10-12-2019	10-12-2019	13-12-2019	38%	0%	14-12-2019
Flash	Ebro	Huesca	10-12-2019	10-12-2019	13-12-2019	33%	7%	14-12-2019
Formal	Ebro	Navia	11-12-2019	11-12-2019	17-12-2019	65%	15%	17-12-2019
Informal	Ebro	Aragn	11-12-2019	11-12-2019	14-12-2019	90%	0%	15-12-2019
Formal	Ebro	Gllego	17-12-2019	17-12-2019	22-12-2019	85%	60%	28-12-2019
Formal	Ebro	Noguera Pallaresa	17-12-2019	17-12-2019	22-12-2019	85%	60%	28-12-2019
Flash	Ebro	La Rioja	18-12-2019	18-12-2019	20-12-2019	76%	43%	21-12-2012
Flash	Ebro	Huesca	19-12-2019	19-12-2019	20-12-2019	42%	0%	20-12-2019
Informal	Ebro	Noguera Ribagorzana	27-12-2019	27-12-2019	28-12-2019	100%	100%	02-01-2020

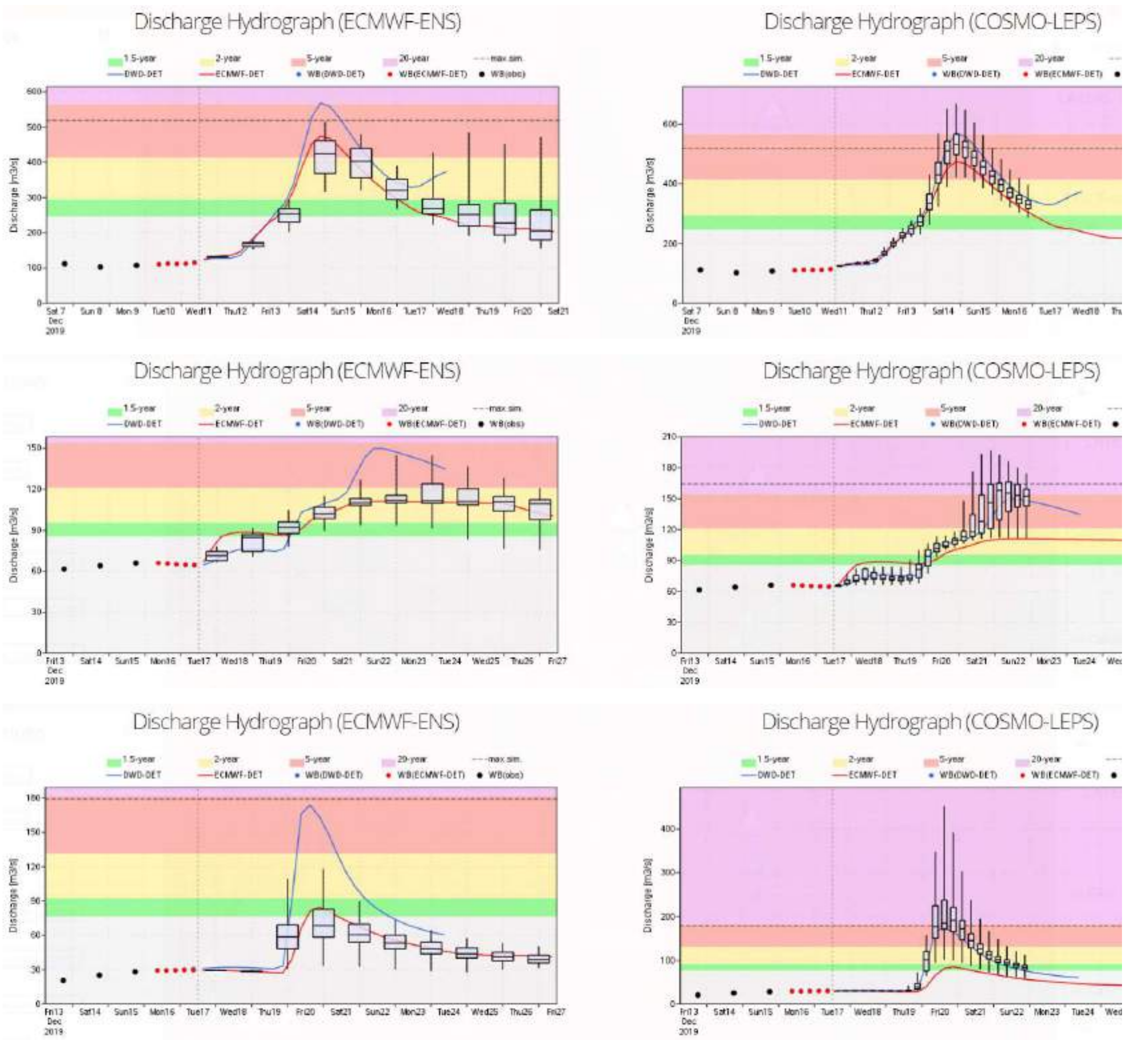


Figure 21 Forecasted hydrographs for the Formal Flood Notifications in the Ebro basin. From top to bottom: Navia, Gllego and Noguera Pallaresa rivers.

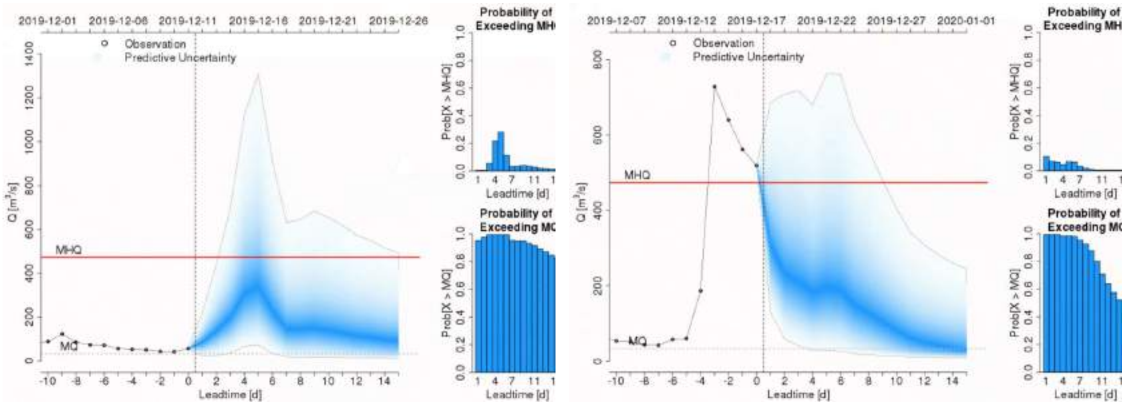


Figure 22 Real-time hydrograph for the Navia river as presented in EFAS. Left panel shows the predicted hydrograph at the moment of sending the notification (11-12-2019), the right panel shows the hydrographs at the moment of the predicted peak (17-12-2019).

5 Hydrological analysis of the in-situ observations

In this section the flood events in the Ebro, Minho-Limia and Douro basins will be analyzed from a hydrological point of view focused on the evolution of the floods in terms of intensity and duration. The analysis is based on the national hydrological data collected by the CEMS Hydrological Data Collection Centre, led by the Environment and Water Agency of the Regional Ministry for the Environment and Spatial Planning (REDIAM) and Soologic. Hydrological data for this area is provided by the Confederación Hidrográfica del Ebro, del Miño-Sil and del Duero. Data from 130 hydrological stations was used for the analysis, covering the time period from 11 December 2019 till 5 January 2020 (see Figure 23).

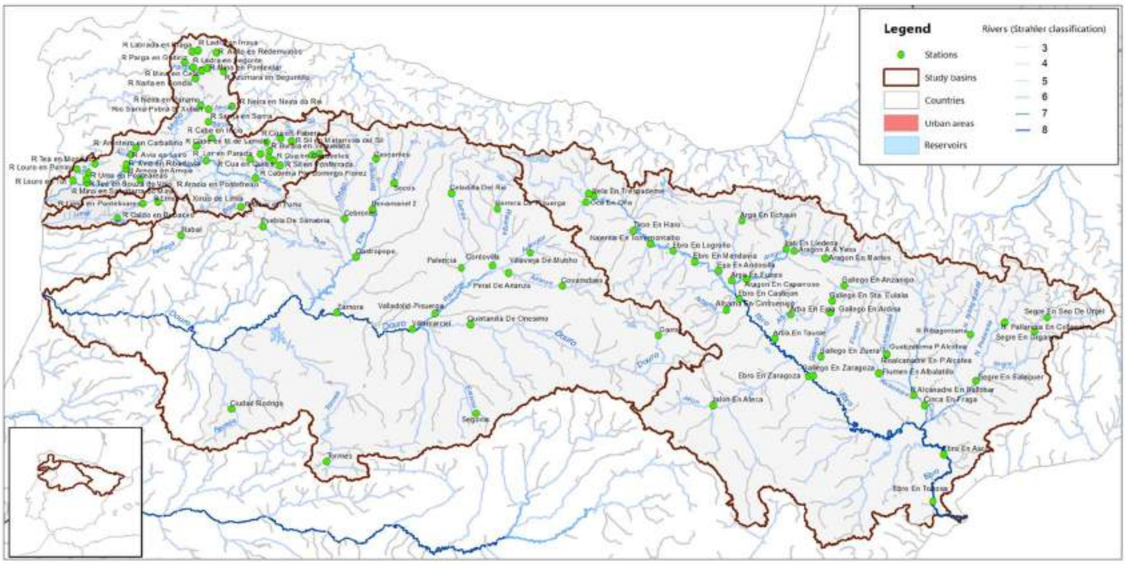


Figure 23 Spatial distribution of EFAS station along Ebro, Douro, Minho and Limia basins.

The hydrological in-situ information available varies across the study area. For some stations discharge and water level information is available, while for others only one of the two is available. Threshold levels were only available for the stations in the Minho and Limia basins. Return periods are not available for any of the stations. This excludes a traditional hydrological analysis, and we will present a statistical analysis comparing the observations of the recent flood with observations from the last years.

5.1 Methodology

The hydrological analysis is based on three different indicators. To make it easier to interpret the results, we present maps and calendar matrices, showing the indicators for each basin and their evolvement in time.

Normalized Variation Index (NVI)

The NVI is an indicator for the daily evolution of the event. It is for each day f calculated as a difference between the maximum observed discharge of day f of the event (D_{max}^{f}) and the maximum discharge on the day before the event starts (D_{max}^{i}), divided by their sum:

$$NVI = \frac{D_{max}^{f} - D_{max}^{i}}{D_{max}^{f} + D_{max}^{i}}$$

The NVI provides values between -1 and 1, allowing a relative comparison in a simple and objective way. “0” represents the non-variation between the initial date and the day being compared with, while positive and negative values represent increasing and decreasing flows, respectively.

For the present flood analysis, the NVI is grouped into four classes: <0, 0-0.3, 0.3-0.7 and >0.7. Negative values were grouped into a single class since this analysis focuses on floods, hence positive values. See Figure 24 for an example of an NVI analysis. Also, for each station the number of days per NVI class were computed and the highest class (NVI >0.7) was grouped into five classes to represent the maps: 0 days, 1-3 days, 4-7 days, 8- 10 days and >10 days (see e.g. Figure 28).

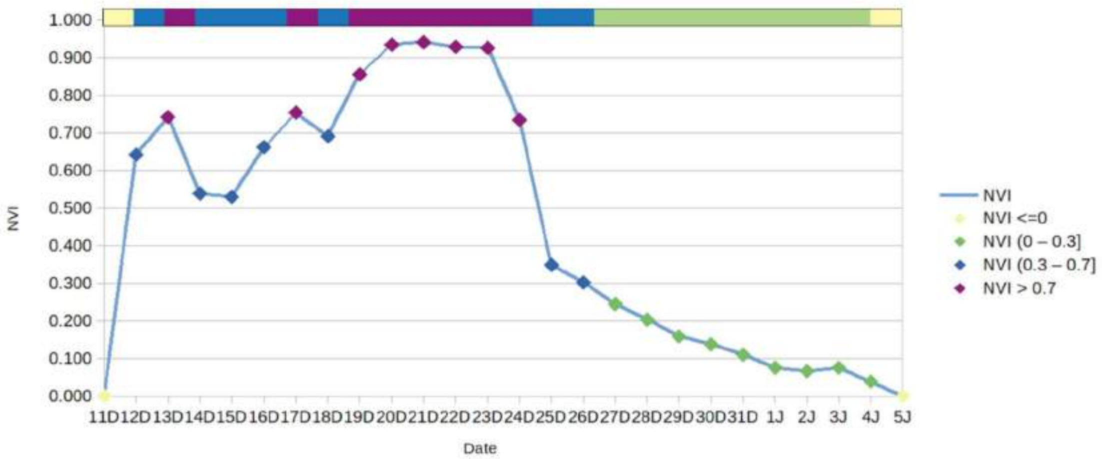


Figure 24 Example of NVI analysis. “Rio Louro en Tui” gauge station.

Percentiles

Percentiles are useful to assess the severity of the flood event in a historical perspective. Five levels were chosen, i.e., the 90th, 95th, 99th and Max. In the figures these levels are referred to as < P90, P90-P95, P95-99, P99-Max, > Max. The first three levels represent floods that are exceeded on average 36, 18 and 4 days per year, respectively, and the Max represents the value that has never been exceeded before. Also, the 99th percentile is not necessarily exceeded every year, although the annual frequency of exceedances will depend on catchment size. The percentiles for each station were obtained from the real time data (aggregated hourly) since 2012 for Ebro and 2014 for Minho and Douro.

Figure 25 shows an example of the percentile evaluation. As for the NVI, also here the number of days per percentile was computed, the number of days exceeding the 99th percentile and the Maximum were plotted on a map per basin (see e.g. Figure 29).

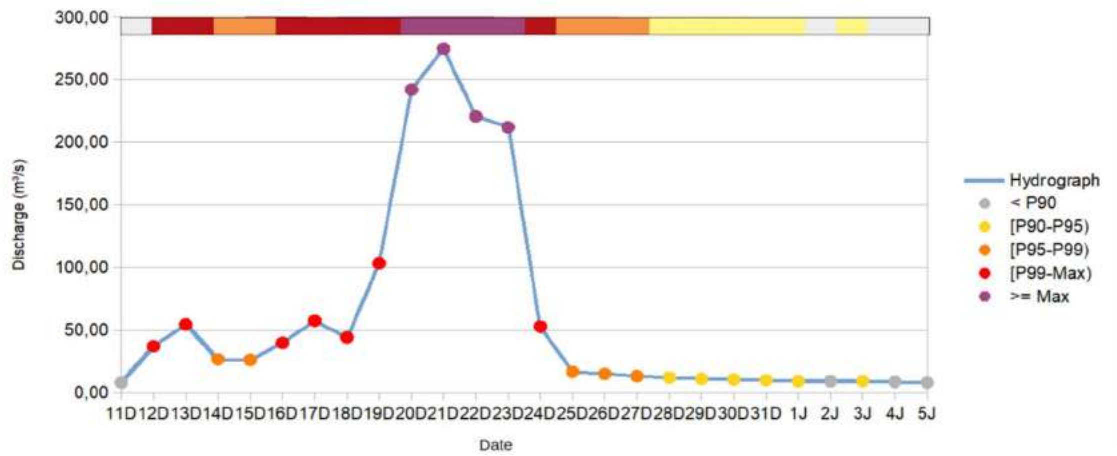


Figure 25 Example of percentile analysis. "Rio Louro en Tui" gauge station.

In addition to the analysis of the percentiles, a visual comparison is done between the December 2019 event and the most extreme event recorded before this, i.e., since 2014 for the Minho-Limia and Douro basins and since 2012 for the Ebro basin. To facilitate the visual comparison, the hydrographs of both events were overlaid with each other and aligned at their respective peaks (event time = 0). Negative and positive values of "event time" represent time before and after the peak discharge was reached, respectively (see Figure 26 as an example, where the comparison is an event from 2016).

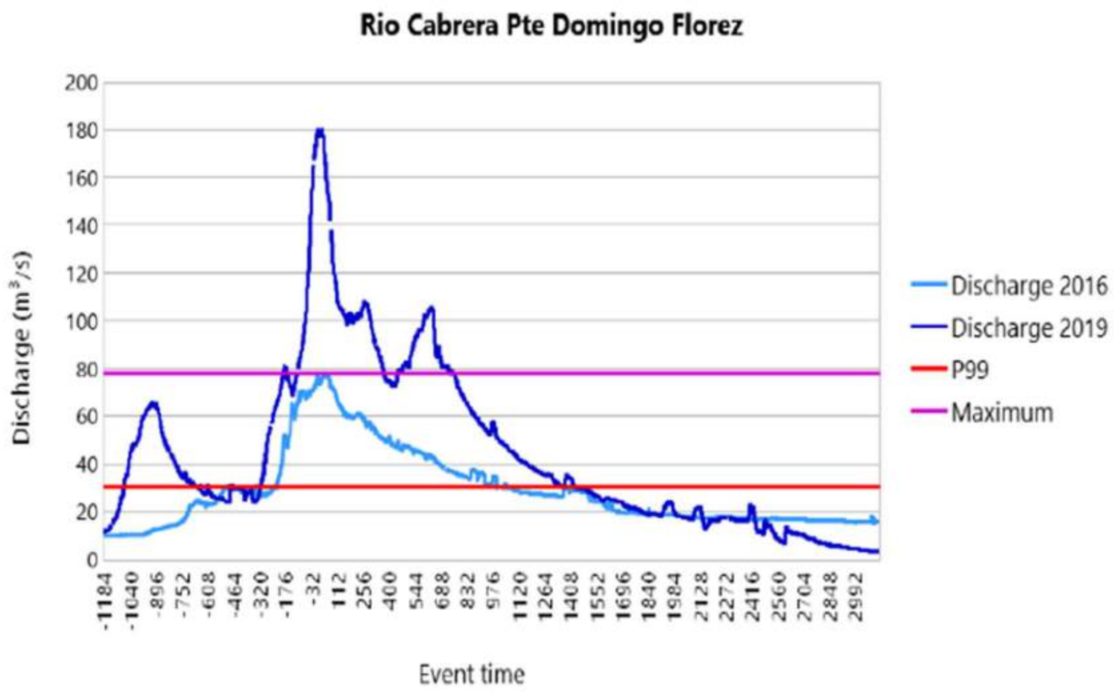


Figure 26 Example of an event comparison at hydrograph-level.

Exceedance of station-specific thresholds

The threshold exceedance analysis was done only for the Minho and Limia basin, as only for those basins station-specific thresholds were delivered by the respective data provider. The threshold levels are defined for water level values, so the comparison must be done with the maximum daily water level values. There are four threshold levels defined in the EFAS System, but this Provider only uses three levels. The System then orders them as Level 1, Level 3 and

Level 4 (TL1, TL3 and TL4). The three levels can be referred to as: Activation, Pre-alert and Alert Threshold, respectively.

Figure 27 shows an example of threshold exceedance. The number of days above each threshold is later on used as an indicator for the severity of the event. As for the two indicators above, also this indicator for the highest class (Days with Max WL >TL4) is presented in a map-diagram composition (see e.g. Figure 31).

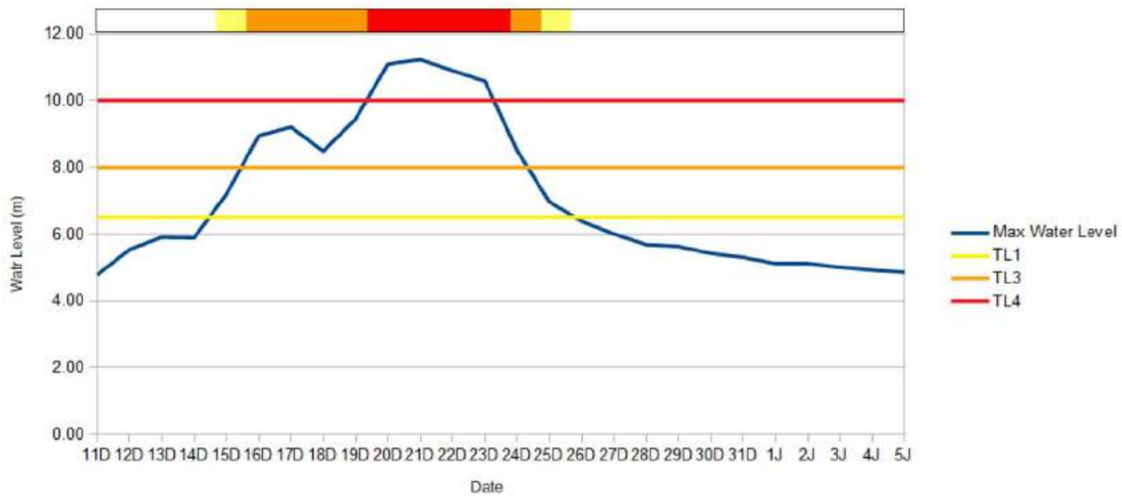


Figure 27 Example of a threshold exceedance evaluation. “Río Miño en Salvaterra do Miño” gauge station.

5.2 Results

To facilitate the analysis and interpretation of each indicator (NVI, percentiles and threshold levels) on a basin level a map-diagram composition was created. Each diagram is composed of three parts: 1) a calendar matrix showing the indicator value for each day and stations, 2) the number of days within the highest indicator class per station, as well as 3) a map with this last value for each station.

5.2.1 Minho and Limia basins

A total of 41 stations (Minho: 38; Limia: 3) have been analyzed for the time period between 11 December 2019 and 5 January 2020. Both basins are regulated by reservoirs. This influences the rivers behavior during flood events, with a typically more abrupt increase in discharge upstream of the reservoirs than downstream.

The NVI analysis shows three peaks with high increases in discharges: December 13 (before the three great storms), December 16-17 related to the Daniel Storm (December 16) and December 21 as an accumulation of the storms Elsa (December 18-20) and Fabien (December 21-22) (Figure 28).

79 % of the stations analyzed in the Minho basin have an NVI index value above 0.7. Of those, the stations with the longest durations are: R. Sil en Matarrosa de Sil (upstream Bárcena reservoir) with 23 days of exceedance, R. Cabrera en Puente Domingo Florez (upstream Eiros and Pumares reservoirs) and R. Tea en Bouza do Viso (on an unregulated tributary of the Minho river).

All stations in the Limia basin exceed the NVI of 0.7 for nine days. Two of those stations remain with an NVI of 0.3-0.7 till the end of the analyzed period (5 January 2020).

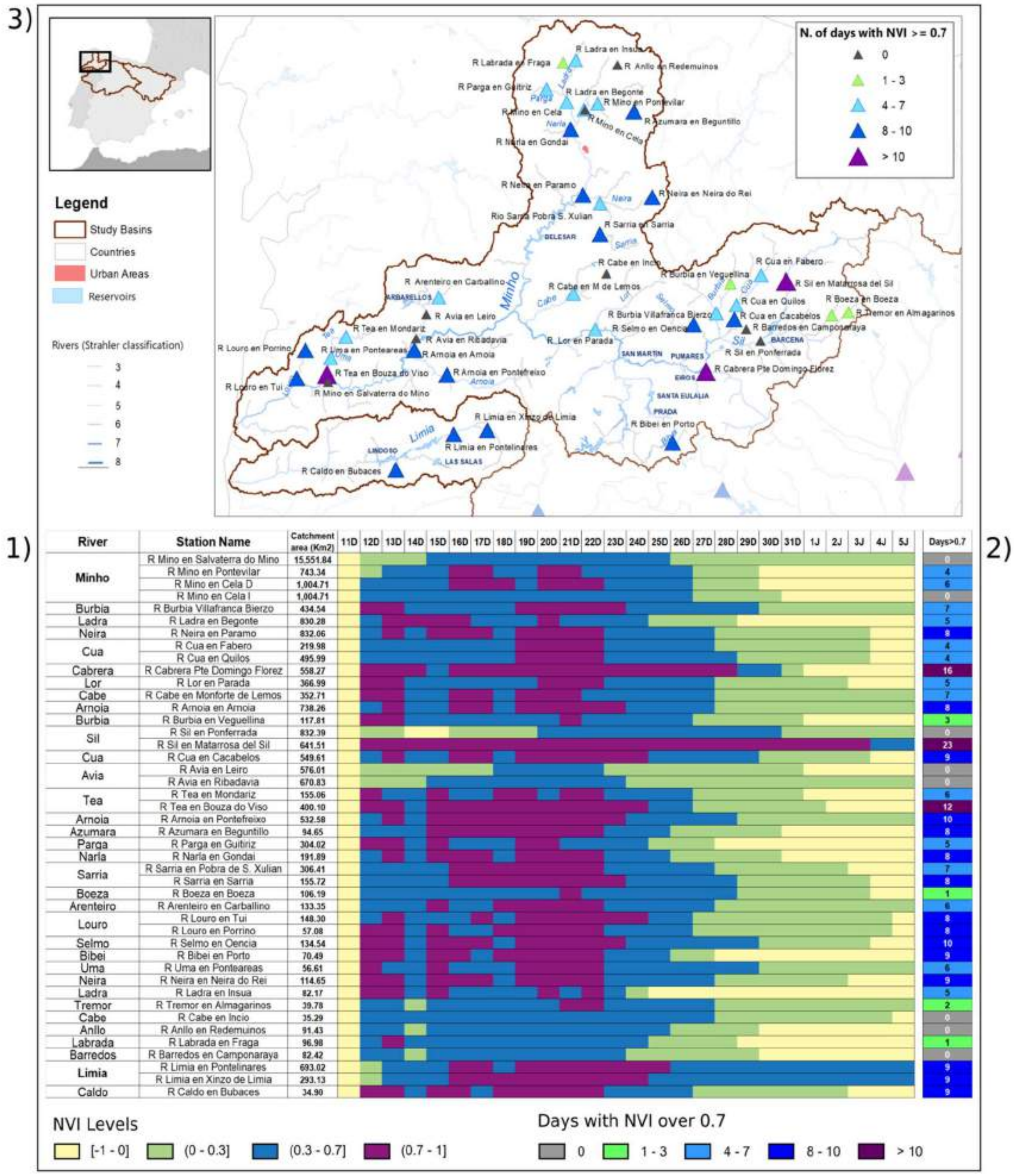


Figure 28 Minho and Limia basins. A) Map for stations representing the index for the number of days with NVI > 0.7 classified in 5 levels. B) Diagram by river and station showing the four NVI levels and to the right, the index for the number of days with NVI > 0.7 represented in A).

Figure 29 shows a map of the number of days with discharge above the 99th percentile and above the Maximum, and a calendar matrix showing the evolution of the percentiles. 24% of the stations analyzed in the Minho and Limia basins exceed the Maximum value. This indicates that the situation is exceptional compared to the past five years. An even stronger indication is that the stations with the largest catchment area in both basins exceed the maximum, for four days in Minho (R. Miño en Salvaterra do Miño) and for three days in Limia (R. Limia en Pontelinares). Also, all 41 stations exceed the 99th percentile for a minimum of three days; 15 of them for more than 10 days.

The station R. Sil en Ponferrada stands out with 21 days above the maximum (24 days as the maximum was already exceeded on December 8). This station is located downstream from the Bárcena reservoir and its hydrological behavior shows that the reservoir was at the limit of its capacity. The reason that it did not stand out during the NVI analysis was because the water level exceeded already the 95th percentile at the beginning of the study period (December 11). The station located upstream the reservoir (R. Sil en Matarrosa del Sil) stands out with 23 days with NVI above 0.7 and although it does not exceed its historical maximum, it remains for seven days above the 99th percentile.

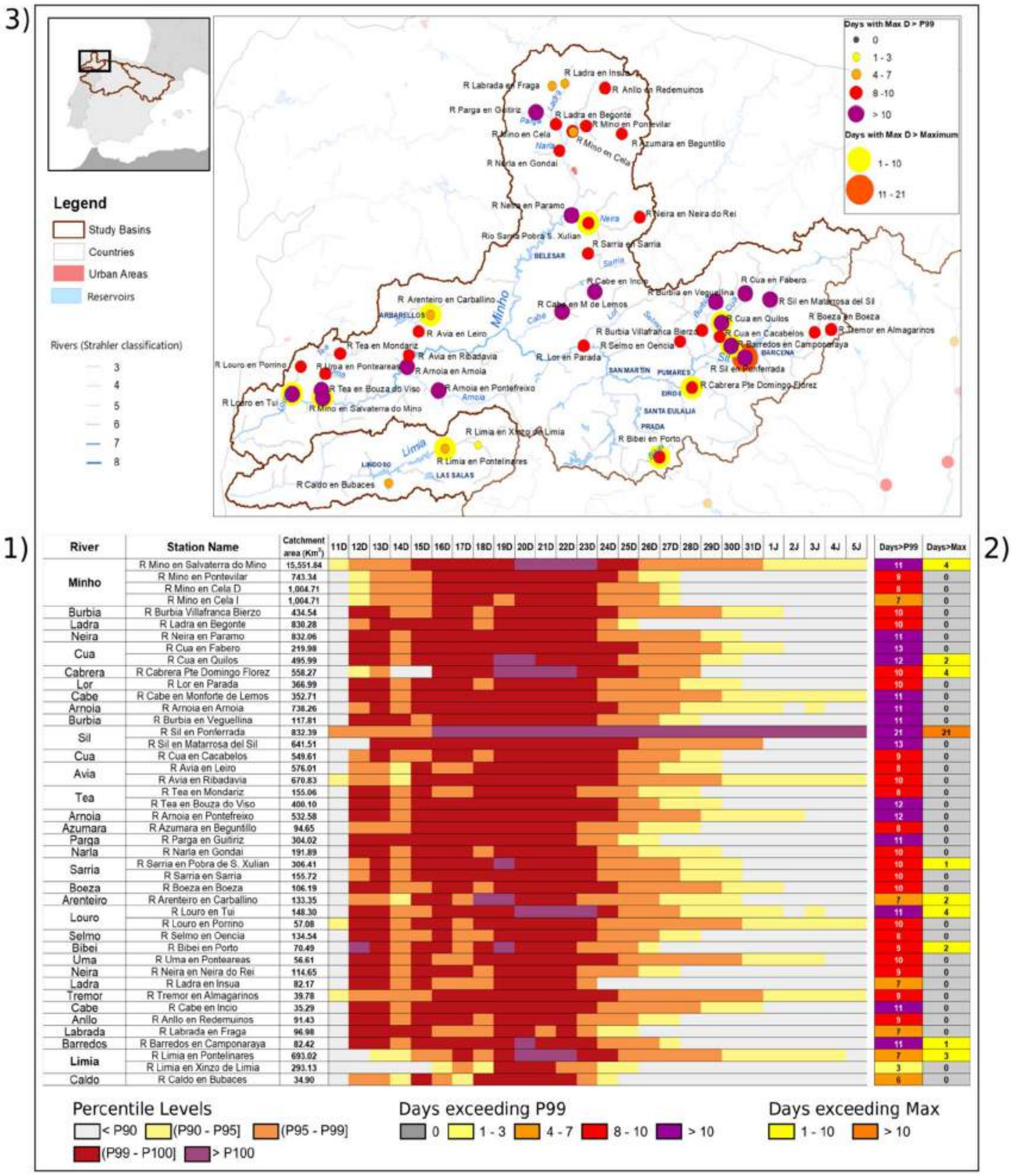


Figure 29 Minho and Limia basins. A) Map for stations representing the index for the number of days with Maximum Daily Discharge > P99 classified in 5 levels. B) Diagram by river and station showing the four Percentile levels and to the right, the index for the number of days with Maximum Daily Discharge > P99 represented in A).

The previously most extreme event in the Minho-Limia basin since 2014 occurred from 9 to 23 February 2016. Figure 30 shows the comparison of the 2016 and 2019 events at four selected stations, all located in areas without reservoirs influence. The observation frequency for these stations is five minutes.

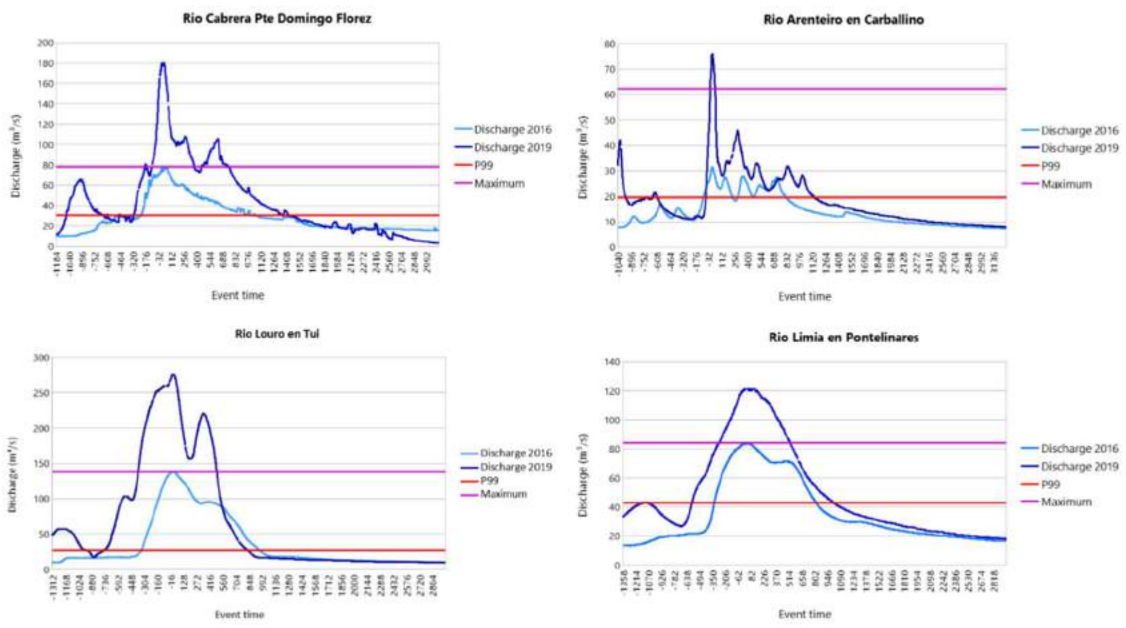


Figure 30 Comparison of the two largest events since 2014.

The plots show that the 2019 event was of considerably larger magnitude than the event in 2016. A comparison of the water levels with the threshold levels of the data provider (Figure 31) shows that all stations of the Minho river exceeded at least the lowest threshold level (TL1), while one station (R. Miño en Salvaterra do Miño) exceeded TL4 for 4 days.

TL4 was also exceeded in the following stations: Río Tea en Bouza do Viso, Río Ladra en Begonte, Río Neira en Páramo (the three exceed TL4 at the beginning of the flood event), Río Ladra en Insua and Río Labrada en Fraga (these two exceed TL4 between December 19 and 23). All the stations except Río Tea en Bouza do Viso are in the northern part of the basin, in the upstream tributaries of the Minho river and the Belesar reservoir.

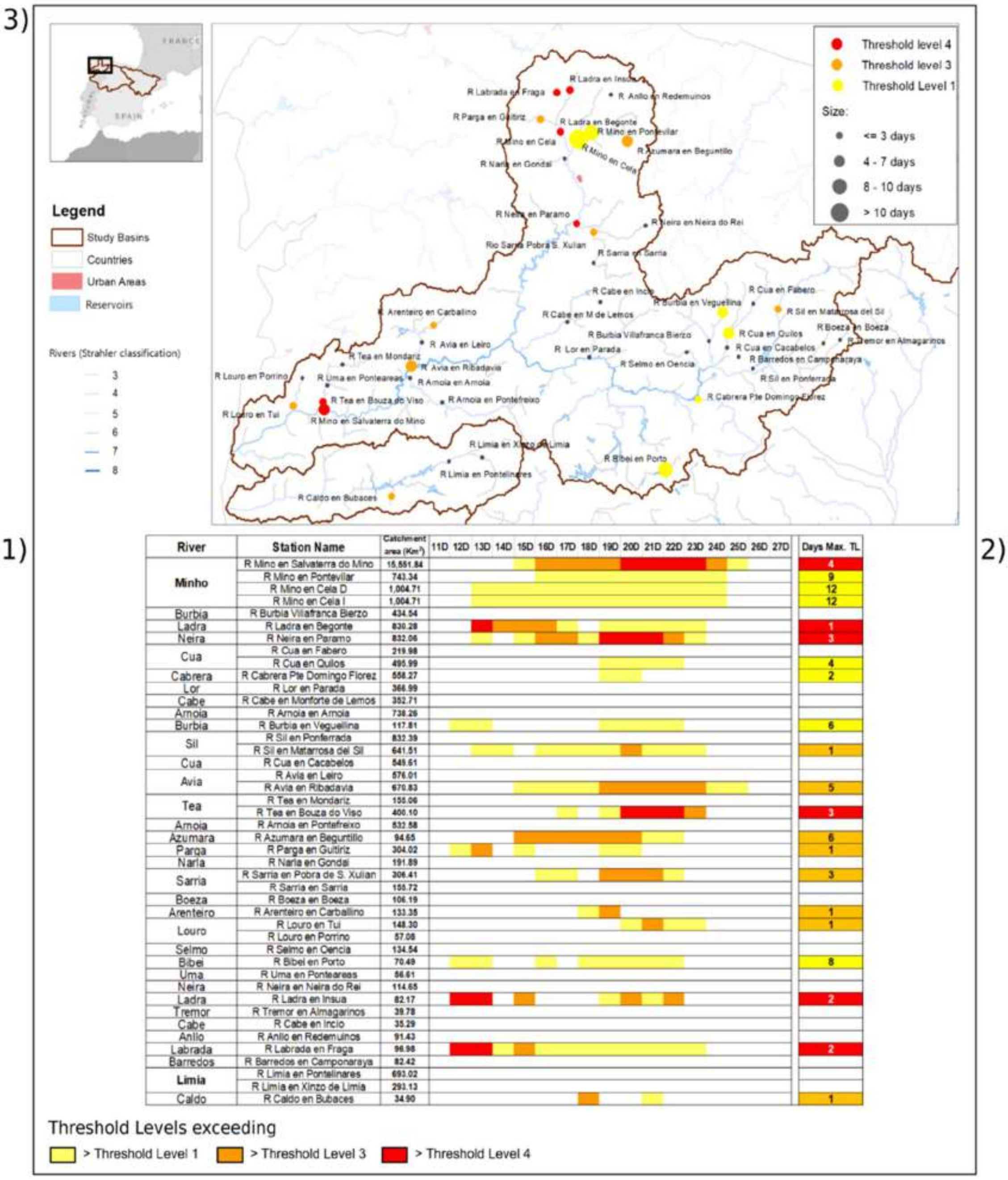


Figure 31 Minho and Limia basin. A) Map for stations representing the number of days exceeding the maximum threshold level reached. B) Diagram by river and station showing the days with thresholds exceedance and the number of days overpassing the maximum threshold.

5.2.2 Douro basin

22 stations were analyzed for the Douro basin for the time period 11 December 2019 till 5 January 2020 (with a data gap on 14 December). The Douro basin is regulated by reservoirs, which influences the hydrological response of the rivers, especially during flood events. The most important reservoir in the basin for this study is the Ricobayo reservoir.

The NVI analysis (Figure 32) shows that all 22 stations exceed an NVI value of 0.7, indicating a significantly increased flow compared to the start of the event. The duration of this event varies between 3 to 16 days across the basin, with longer durations upstream of the Ricobayo reservoir (Castropepe, Cebrones, Benamariel and Secos) as well as some remote stations located in the upstream Douro river (Ciudad Rodrigo and Garray stations).

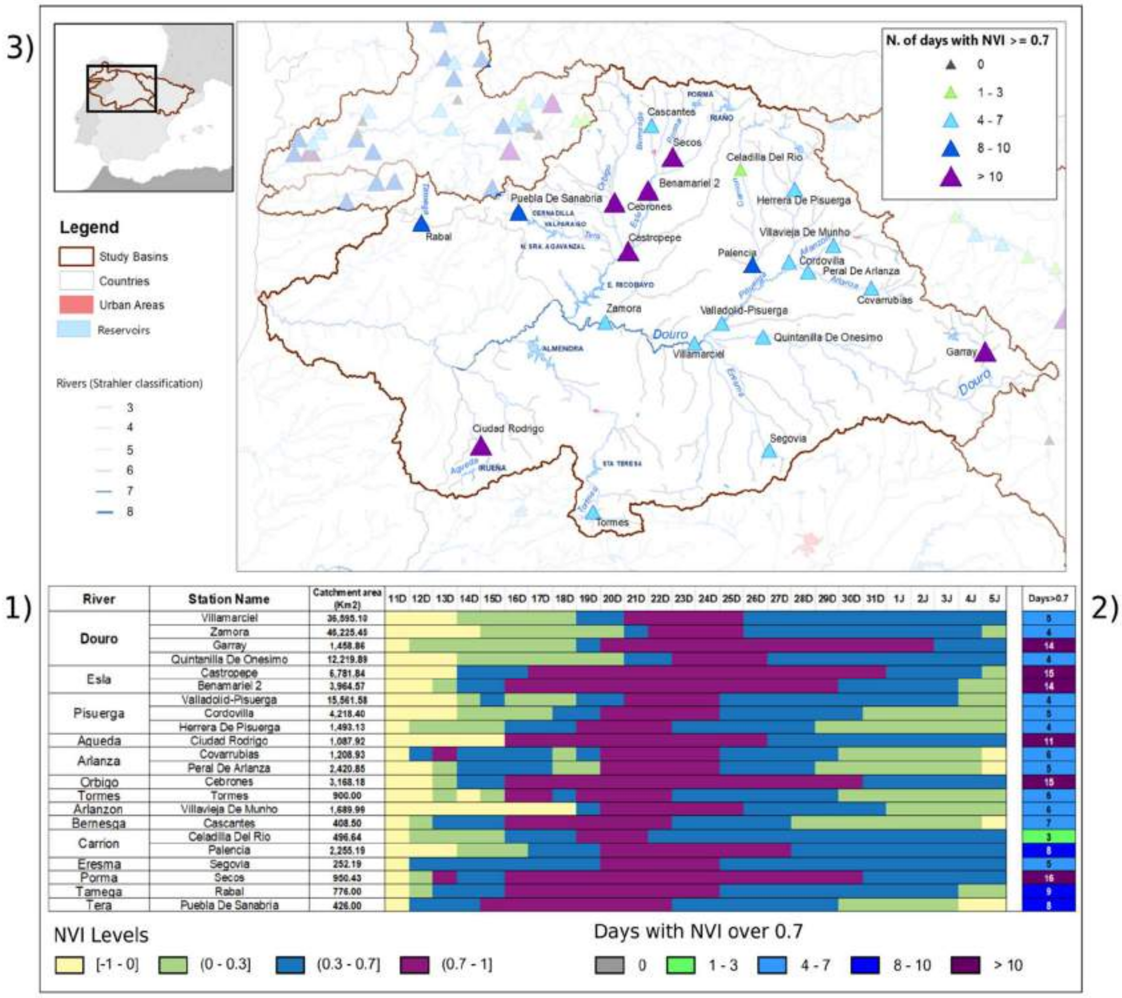


Figure 32 Douro basin. A) Map for stations representing the index for the number of days with NVI > 0.7 classified in 5 levels. B) Diagram by river and station showing the four NVI levels and to the right, the index for the number of days with NVI > 0.7 represented in A).

A comparison of this event with the data from the past seven years shows that it was one of the largest observed during this period. 73% of the stations analyzed in the Douro basin surpassed the Maximum, and the stations that did not exceed their maximum are located in the upstream basin, with small catchment areas. All stations exceeded P99 for at least three days.

The timing of the peak flows varies depending on the relative location within the basin. The earliest exceedances occurred in the upstream sections of the Esla river and tributaries, starting around 16-17 December as a consequence of the Daniel storm and highlighting Secos (with five days of exceedance, see Figure 33), Cascantes (for four days), Benamariel2 (for three days) and Castropepe (for four days). The second peak occurs around December 19-20, related to the Elsa storm and can be seen in 55% of the seasons. The last peak is observed on December 21-22, because of the previous storms and the Fabien storm. The stations that are downstream, with the largest catchment areas, stand out with the latest Maximum exceedances: Zamora for two days (December 23 and 24), Villamarciel and Valladolid-Pisuerga for three days (from December 22 to 24) and Quintanilla de Onesimo for three days (from December 23 to 25).

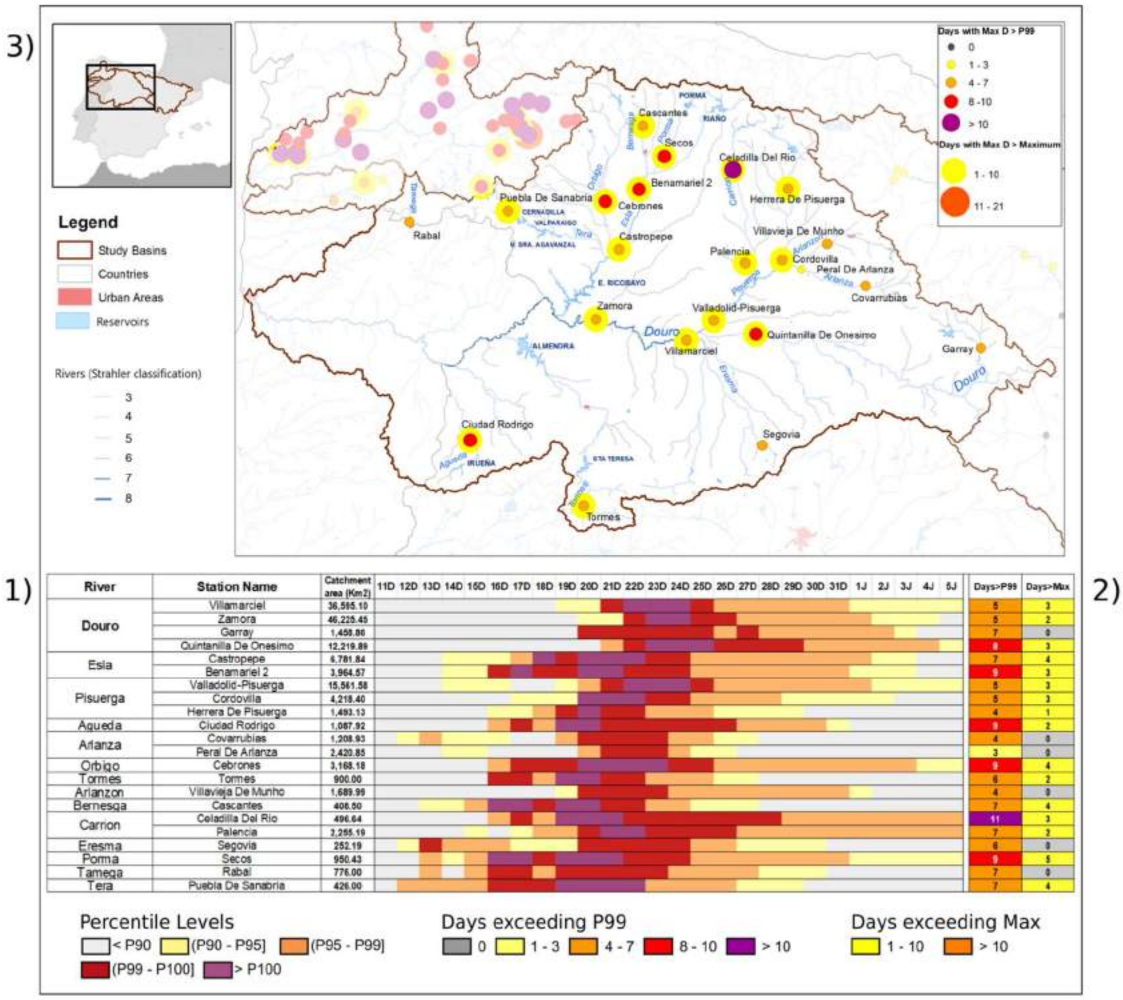


Figure 33 Douro basin. A) Map for stations representing the index for the number of days with Maximum Daily Discharge > P99 classified in 5 levels. B) Diagram by river and station showing the four Percentile levels and to the right, the index for the number of days with Maximum Daily Discharge > P99 represented in A).

Figure 34 shows the comparison of the December 2019 event with the previously largest event recorded since 2014 at four selected stations. At each of those the event of 2019 is more extreme than the one in 2016 (10 April to 4 May 2016).

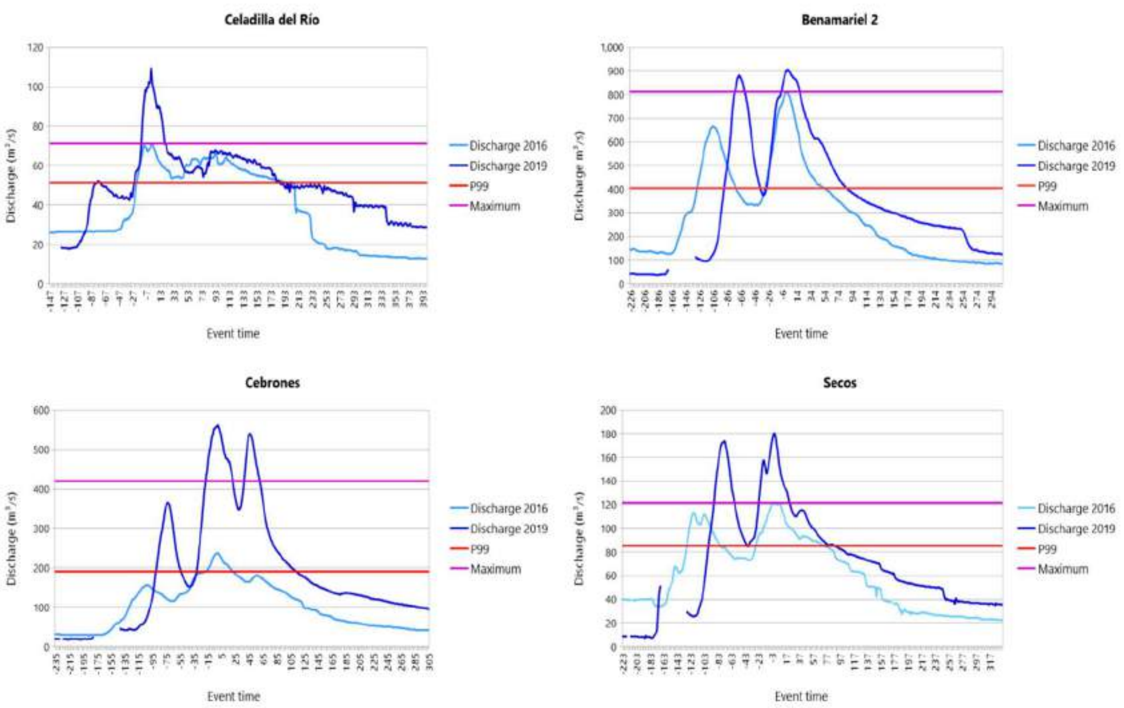


Figure 34 Comparison of the two largest events since 2014.

5.2.3 Ebro basin

37 stations have been analyzed in Ebro basin for the time period 11 December 2019 till 2 January 2020. Note that there is a data gap on the 22 December, which affects the index calculations for all the stations, as it is the central day of the flood event.

The analysis shows that all the stations present two peaks of high values, the first one around December 14, at the beginning of the storm Daniel, and the second one around December 21 representing the hydrological response to storms Daniel and Elsa. Two stations located along Gallego river (Gallego en Zaragoza and Gallego en Zuera stations) show a third peak from December 28 onwards as response to storm Fabien.

86% of all the stations have an NVI value above 0.7 (Figure 35). The duration of the high intensities decreases from upstream to downstream. The longest durations are found in upper sections of the Ebro river (Ebro en Palazuelos station) with 13 days; followed by 10 days in the upper central sections of the basin along the Alhama, Arba and Gallego rivers, and three days in the middle sections of the Ebro river. On the other hand, there are no high intensities (NVI > 0.7) in the lower sections.

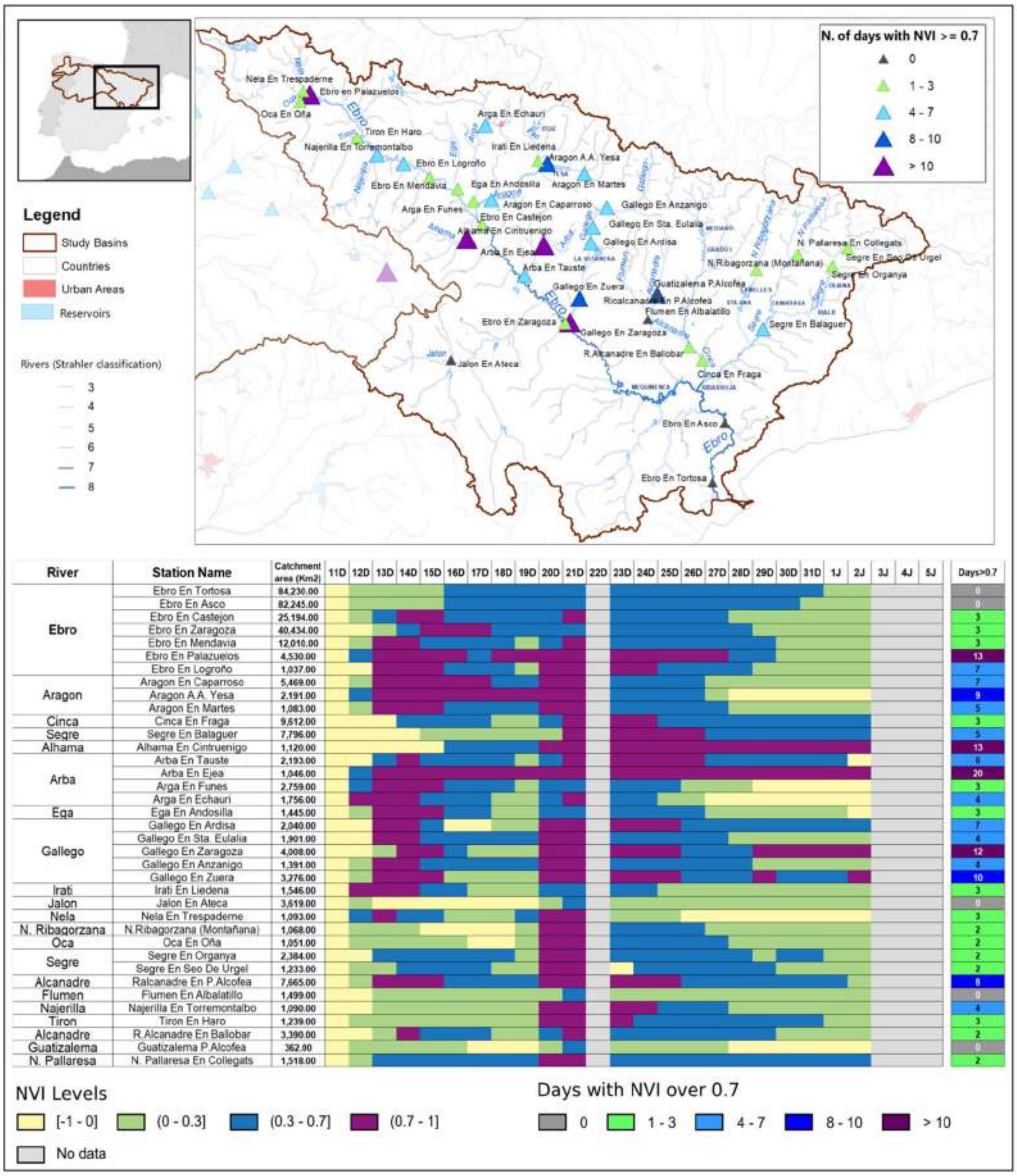


Figure 35 Ebro basin. A) Map for stations representing the index for the number of days with NVI > 0.7 classified in 5 levels. B) Diagram by river and station showing the four NVI levels and to the right, the index for the number of days with NVI > 0.7 represented in A).

A comparison of this event with the observations from the past five years (since 2014) shows that 75% of all stations exceeded the P99 threshold. The duration of those exceedances is with a maximum of six days, mostly shorter than the ones observed in the other basins. Only four stations exceed the Maximum values: Aragon A. A. Yesa for three days, and Gallego en Anzanigo, Irati en Liedena and N Pallaresa for one day. The remaining 25% of the stations did not exceed any of the percentiles considered, indicating that this was not an extreme event in these sub-catchments.

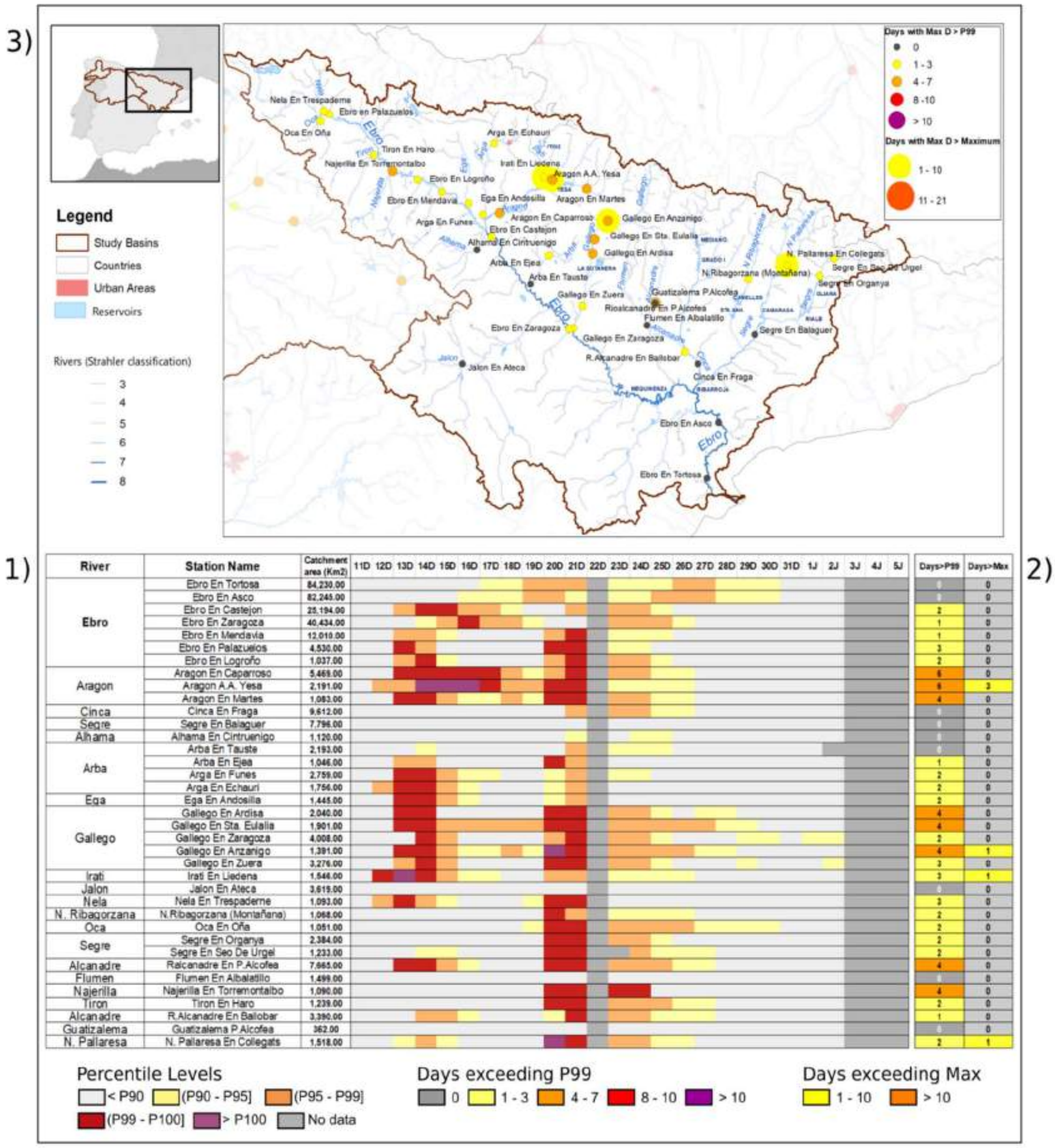


Figure 36 Ebro basin. A) Map for stations representing the index for the number of days with Maximum Daily Discharge > P99 classified in 5 levels. B) Diagram by river and station showing the four Percentile levels and to the right, the index for the number of days with Maximum Daily Discharge > P99 represented in A).

For the Ebro basin the largest event since 2012 (excluding the December 2019 event) occurred between 6 April and 8 May 2018. Figure 37 shows the comparison of hydrographs at four selected stations, which show that the 2019 event surpasses the 2018 event in only half of the cases. Combining that with information of Figure 36, which shows that the maximum discharge is only exceeded at four stations in total suggests that the 2018 event was of higher magnitude.

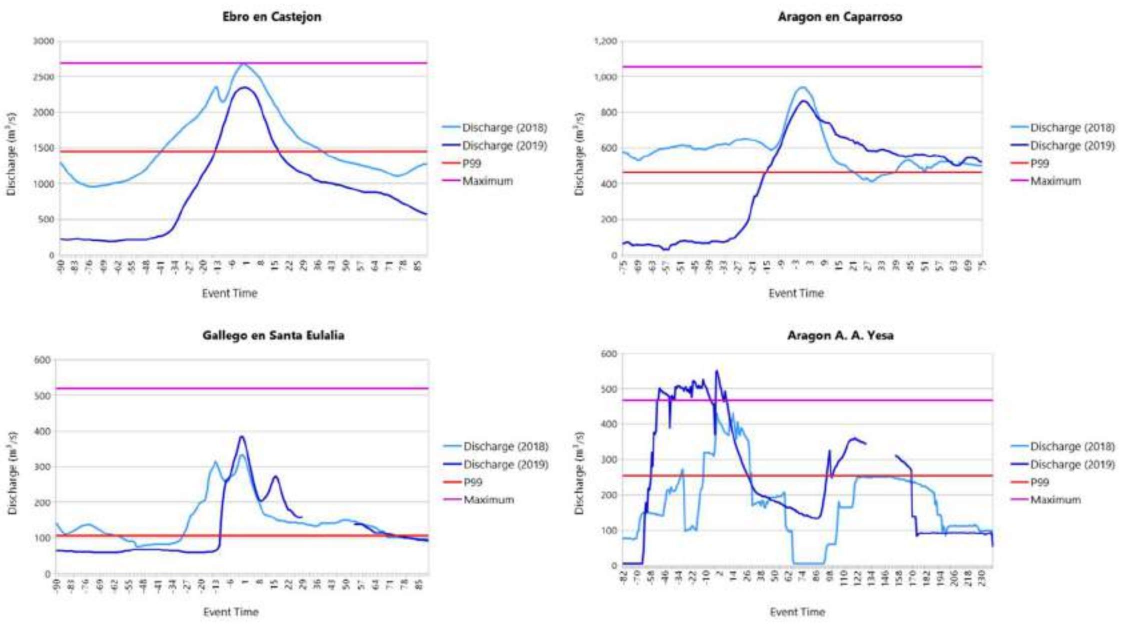


Figure 37 Comparison of the two largest events since 2012.

6 Media and government reports

6.1 Introduction

To support the analysis of the event an analysis was made of relevant media data and an overview of the flood event as it was reported in those media was derived. In this Chapter an account of the events in spatial overviews, timelines and day-to-day reports as it appeared in the media is presented.

As data source we used Twitter and links from Twitter. This includes observations of citizens but also news articles that were put on Twitter by news agencies.

Note that although we are confident that we provided a good overview of the flood event as covered by the media, there can be relevant media content on the flood event that we missed.

Figure 38 Screenshot of the FloodTags dashboard with data from the 1st of December 2019 to the 5th of January 2020, Spain

6.2 Flood events per river basin

FloodTags scanned through tens of thousands of English and Spanish flood related tweets between 1 December 2019 and 5 January 2020, finally to reach a selection of 1570 tweets and their hyperlinks that we drew our information from. Per basin this amounts to a total of 874 tweets on the Ebro basin, 425 on the Douro basin and 273 on the Minho basin.

In summary, Figure 39 shows the overview of the number of tweets per basin, annotated with the main observed flood events in the basins of the Douro, Minho or Ebro. It shows that the Minho caused severe flooding in and around Lugo, A Coruña and Pontevedra. In the Ebro basin the overflow of the rivers Agra and Ulzama (tributary of the Agra) caused floods in and around

Pamplona, while overflow of the river Híjar caused floods in and around Reinosa. Finally, the Douro basin had many different places of inundation, of which the province of Léon was most affected. In the next sections we discuss the rivers basins in more detail.

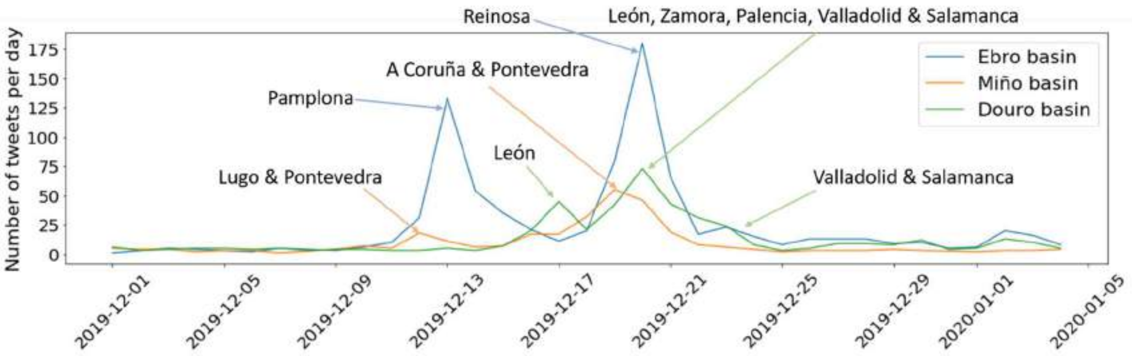


Figure 39 ***Number of tweets per river basin, annotated with the most affected locations.***

6.2.1 Minho basin (region of Galicia)

For orientation, the Minho flows through the region of Galicia, which is divided into four provinces, shown in Figure 40. In the further description of the events we refer to these four regions. The information below was drawn from a total of 273 flood related tweets and news articles.

The most affected areas in Galicia were around the cities of Pontevedra and Sada in the provinces of Pontevedra and A Coruña. A spatial overview of the flood impact as derived from the media is given in Figure 41. In total three people died and over 1000 flood incidents were reported.

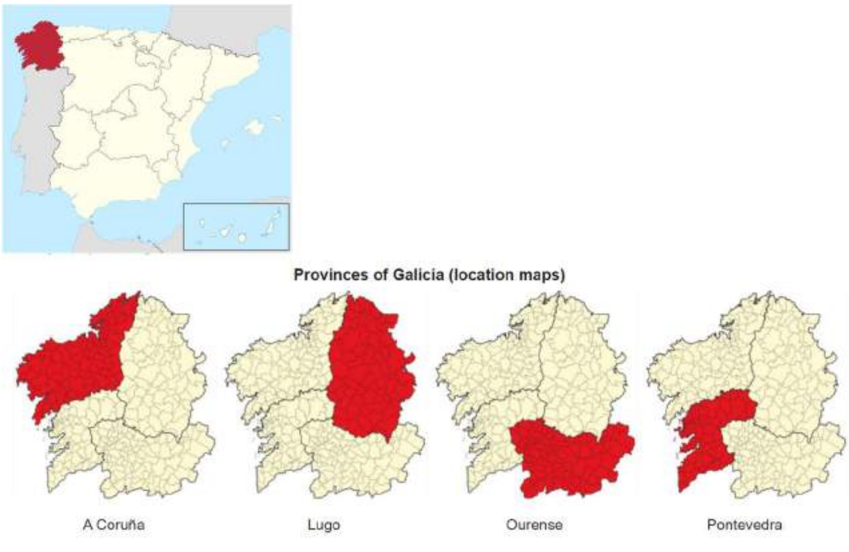


Figure 40 ***Provinces of Galicia***

Figure 41 ***Spatial overview of the floods in Galicia between 16 and 21 December 2019***

Timeline of events

The number of flood related tweets about Galicia (region of the Minho) from the first of December 2019 to the beginning of January 2020 is shown in Figure 42. The curve gives an indication of the state of the flood (surveillance (yellow), warnings and minor flood incidents (orange), flood (red) and the aftermath (brown)). The number of tweets gives an indication of the severity of the flood.

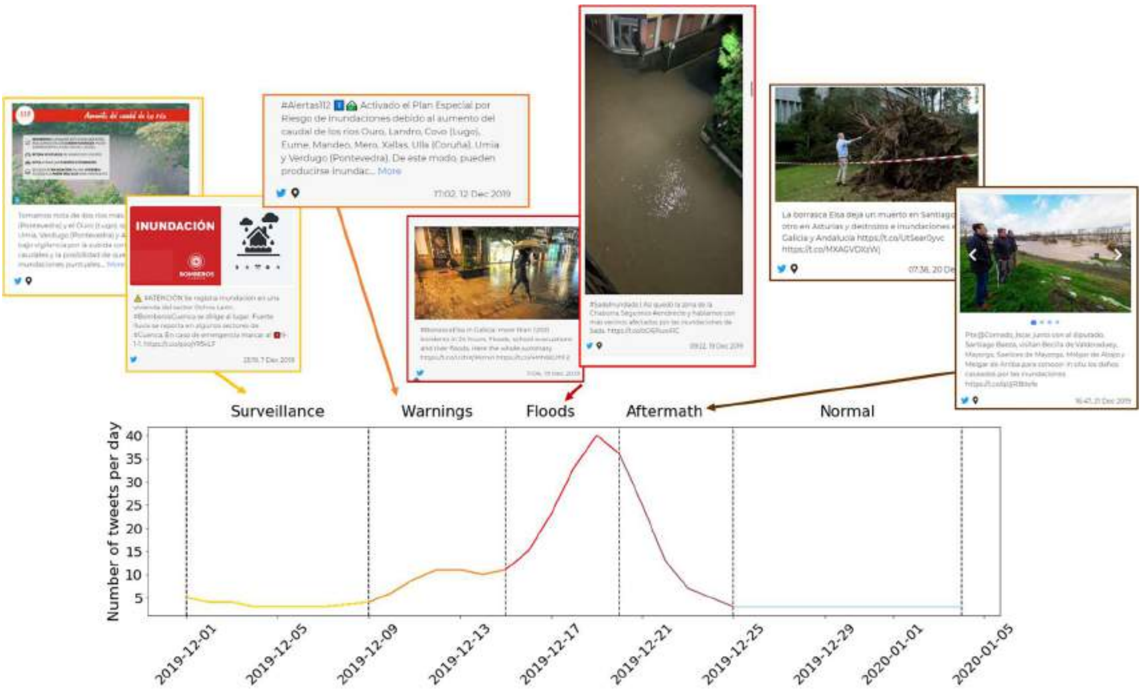


Figure 42 ***A timeline of the floods in Galicia***

The timeline in Figure 42 shows that the continuous rain experienced in the first half of the month of December resulted in multiple flood warnings and some flooded houses. As of 11 December, the number of tweets and articles increased, of which the majority was about emergency and flood actions plans. On the 16th the Minho started to flood and on the 18th and 19th serious flooding occurred in and around Santiago de Compostela, Pontevedra, Ferrol and Sana due to heavy rainfall. Below a more detailed account of the events.

On the 1st of December the rivers Lérez (province of Pontevedra) and the Ouro (province of Lugo) were put under surveillance because of a considerable rise in their flows with fear for possible flooding as result. The rivers Umia, Verdugo (Pontevedra) and Azúmara (Lugo) were already under surveillance.

On the 12th of December flows increased again in the rivers Ouro, Landro, Covo (Lugo), Eume, Mandeo, Mero, Xallas, Ulla (Coruña), Umia and Verdugo (Pontevedra). The special flood risk plan was activated. Minor flood incidents are reported.

On the 16th of December heavy rainfall and snow increased flows of the Minho river. The Minho overflowed its banks in the provinces Lugo and Pontevedra. In Lugo there were floods in Terra Chá, Outeiro de Rei and the city of Lugo. Facilities located on the banks of the river in the city Lugo flooded, including the Spa, the O' Miño Restaurant, the club 'Fluvial' and the parks. The same held for the Santa Isabel recreational area in Outeiro de Rei and the parks along the riverbank in A Canuda, Pontevedra. The Mayor of Becerreá confirmed that in the area of A Montaña and specifically in the municipality of Becerreá, the heavy rainfall had caused landslides which affected local roads.

The situation was expected to worsen since it reportedly still rained throughout the day. 112 tweets warned of flood risk in the basins of the Ouro, Landro, Labrada, Azúmara and Ladra rivers. An impression of the situation on the 16th is given in Figure 43.

Flooded parks due to river Minho in A Canuda, on the 16 December 2019

The Minho overflowed properties, parks and restaurants in the cities of Lugo and Terra Chá.

Multiple roads are blocked in Galicia promenade of Vilalba.

High flow in river Magdalena on the river

Figure 43 ***Overview of the situation on the 16th of December in the Minho basin***

On the 17th of December - The Minho river overflowed at various points in the province of Ourense, causing flooding.

On the 18th of December - The start of the heaviest floods in the area of Coruña due to the storm Elsa. Flooding occurred in the cities of Sada, Oleiros, Ferroll and Bergondoi. In Sada whole neighbourhoods were inundated, of which the Chaburra and the brañas areas most severely. Floods and heavy wind due to Elsa also occurred in Cuntis, Sanxenxo and the city Pontevedra in the province of Pontevedra. An impression of the situation on the 18th is shown in Figure 44.

Heavy rain caused floods in different places in Ferrol.

Areas of the Barañas flooded in Sada, A Caruña.

Wind gusts at 148 km/h and flooding in Cuntis and Sanxenxo in the province of Pontevedra.

Las Palmeras Park in Pontevedra, 19 Dec.

Figure 44 ***The situation in Galicia on the 18th of December 2019***

The 19th December - The floods on the 19th of December 2019 left one dead in Asturias and destruction in Galicia. In Sada sandbags were placed in preparation for the upcoming high tide and there were people without access to water. The river Tandre near Maceira caused some minor inundations due to its high flow. Cambados (Pontevedra) also got inundated. A total of 1000 incidents related to flood, landslides and fallen trees were reported on the 18th and the 19th of December.

On the 20th of December - The rain and wind became even worse overnight, with the result of one person dying in Santiago de Compostela due to a wall coming down. Two others were killed in Vegas del Condado. Winds were up to 160 km/h and floods got worse in multiple places.

From the 21st of December to the 5th of January - Aftermath of the floods in Galicia. On the 21st the storm had caused 30,000 homes to be without electricity in Galicia. Government officials visit places hit by floods from the 21st of December on to determine the damages. The places included Becilla de Valderaduey, Mayorga, Saelices de Mayorga, Melgar de Abajo and Melgar de Arriba.

6.2.2 Douro basin (region of Castilla y Léon)

The Douro flows through the region of Castilla y Léon in Northern Spain. The image below gives an impression of the worst affected areas in December 2019 in the Douro basin. The impression is based on the number and content of the messages about certain parts of the region.

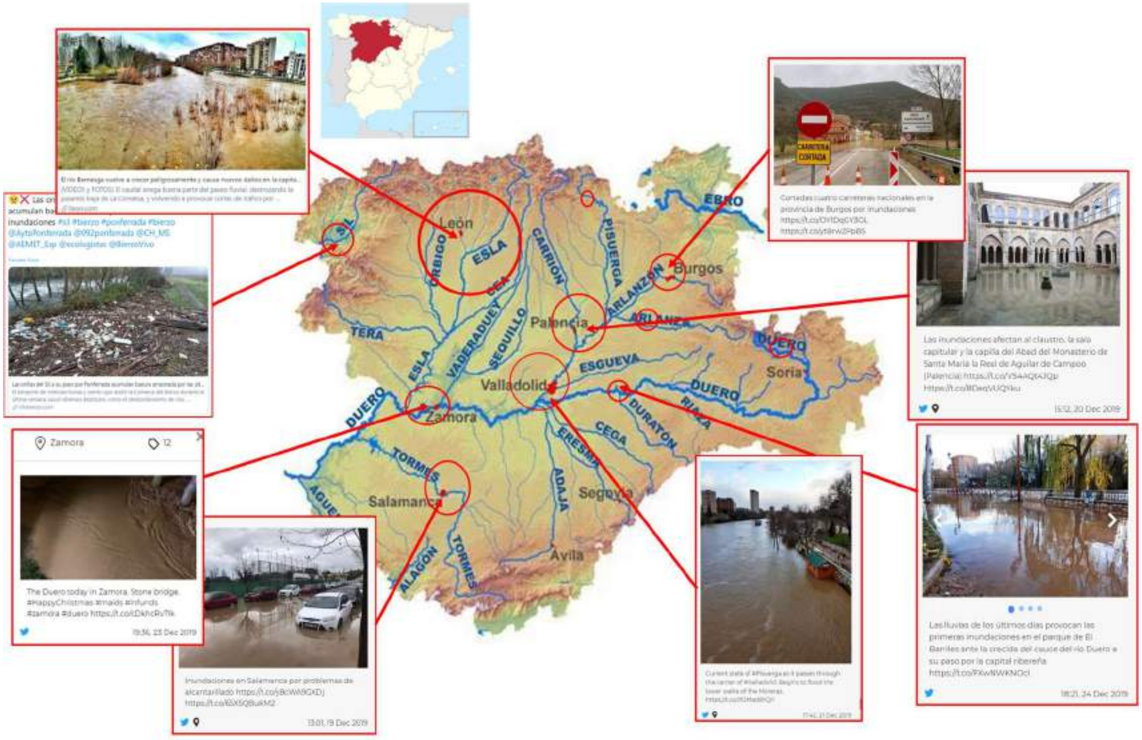


Figure 45 ***Spatial overview of affected areas in the Douro basin in the December 2019 flood events***

Timeline of events

There were multiple flood events in the Douro basin from the 1st of December to the 5th of January, with different timelines. The most affected area was Léon, followed by Palencia and Valladolid. Other areas affected were Burgos, Salamanca and Zamora. Their respective timelines with flood related tweets are displayed in Figure 46. Under the Figure is a more detailed description given of the time line of the events in the Douro basin.

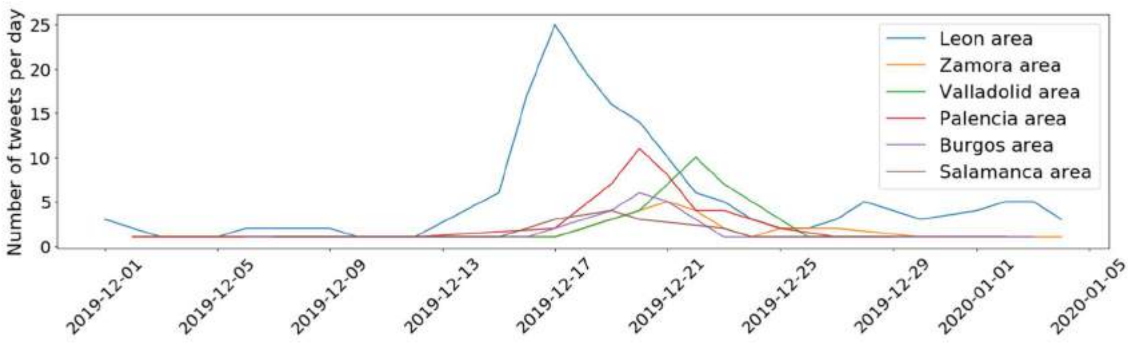


Figure 46 ***Number of flood related tweets per affected area in the Douro basin***

From 1st December to the 13th of December - Already in the beginning of December some hinder by heavy rainfall was reported. This includes Valladolid road being blocked because of a landslide caused by heavy rainfall.

From the 13th to the 14th of December a few warnings about high flow were posted, such as the warning that the headwaters of the Arlanza and Duero experienced high water on the 13th of December.

The 15th and 16th of December on the night of the 15th and the 16th of December heavy rain caused inundations in various places in the province of León. The city of Léon experienced the most damage.

At 11.30 on the 16th of December, **the Dueñas river** passed through the town of Leon with 29.7 m3/s and a height of 2.62 meters. The Dueñas also reached the alarm level in Crémenes. In addition, the Duero Hydrographic Confederation (CHD) warned that the trend is growing. Landslides caused by the intense rainfall on the 15th kept the roads between the towns of Salamón, Ciguera, Las Salas and Lois in the province of Léon cut off to traffic.

The **river Bernesga** in Villamanín, also in the province of León, reached the alarm level as well with a water level of 2.77 meters and a flow of 54.8 m3/s in Villamanín and 240 m3/s at the city of León. There were also alerts for the Bernesga river where it passes through the gauging station of Cascantes and Alija de la Ribera. In the city of León, the Bernesga forced the pedestrian walkways next to the river to be closed to ensure the safety of pedestrians. The overflow also caused damages to houses and bridges, including to the San Marcos Bridge and the Puente Castro.

Other rivers on alert on the 16th were **the Esla river** at Valencia de Don Juan, the **Curueño river** at the gauging stations of Olibia de Abajo and Caldas de Nocedo, the **river Luno** where it passed through Sena de Luna, the **Omaña river** at the Las Omañas gauging station, **the Porma river** where it passed through Camposolillo and the **Torío river** where it passed through Pardavé. In the province of Zamore, **the Tera River** in Puebla de Sanabria is on alert. Figure 47 gives an impression of the situation on the 16th of December 2019.

The Bernesga river forced closing of pedestrian walkways in the city of León

The Bernesga river overflowed and caused damage in the city of León

The river Torío at Hoces de Vegacervera, Léon area

River Esla at Valencia de Don Juan, Zamora area

Figure 47 ***Examples of tweets and articles in the Douro basin on the 16th of December***

On the 17th of December the Protección Civil called for the intervention of the EMU for the flooding in León. The city of La Robla in León was flooded by the Bernesga River and 43 soldiers were deployed to carry out bilge work and flood containment due to flooding of an old mine. Most of the province gradually regained normality after the rainstorm that caused the flooding. The Board maintained a level 2 alert to possible floods in the province of León.

Soldiers are deployed due to floods in La Robla, León

Image of the floods in the city of Léon

Figure 48 ***Examples of tweets and articles in the Douro basin on the 17th of December***

On the 18th of December - Parliamentarians of the region of León requested urgent aid to mitigate the damages caused by the floods in the province, new rains were expected to increase the still present problems of the floods in multiple places in the province of León.

On 19th of December - Heavy rains caused the Bernesga River to grow dangerously again with a water level of 4 meters and a flow of 275 m3/s at the city of León. Eleven roads were affected by the floods. In the city of León the flow destroyed the footbridge of La Condesa and the water rose to the level of the Los Leones car bridge. Inundations caused traffic jams under the San Marcos bridge. In and around the city La Pola de Gordón and the place Santa Lucía de Gordón (both province of León), numerous streets were flooded, and significant damage was caused to garages and low-lying buildings. Similarly, there were roadblocks in Manzaneda de Torío due to overflow of the Torío channel (also province of León). In Salamanca it flooded because of the high flow of the Tormes and because the sewage system could not cope with the heavy rain. Figure 49 gives an impression of the situation.

A landslide has cut the road that connects La Vida de Gordón with Villar del Puerto on 19 of December (province of León)

Saint Lucia de Gordón, several streets flooded due to overflow of river Torío on 19 December (province of León)

On the side of the Paseo de Salamanca, water has also flooded the entire space on 19 December

City of Léon, the gateway of La Condesa is again submerged and its structure completely damaged

Figure 49 ***The situation in the Douro basin on the 19th of December 2019 (source: https://www.ileon.com/actualidad/provincia/103901/el-rio-bernesga-vuelve-a-crecer-peligrosamente-y-causa-nuevos-danos-en-la-capital)***

On the 20th of December - The worst day of the floods. Even more rainfall fell on the night of the 19th/20th December. This resulted in more flood incidents and record flows. Initially some mountain areas such as the municipality of La Pola de Gordón were affected. The incidents then moved downstream causing damage and road blocks, of which the worst hit areas were in and around the city of Léon due to the Bernesga river, around Zamora due to overflows of the Douro river and around Palencia due to the Carríon river and in Burgos due to the Arlanzon river. Four national roads were cut in the province of Burgos.

Record flows were measured in Léon for the Bernesga river where it reached its historic record peak at 8.00 in the morning on the 20th with a water level of 4.23 meters and more than 303 m3/s. This caused flooding in many of the places around León, including Villamanín, Cascantes (Cuadros), Alija de la Ribera and Santa Maria del Páramа.

The river Esla exceeded the record flow of Monday on the 16th of December with a water depth of 5.55 meter and a flow of 780 m3/s at the town of Benamariel. Other rivers on high alert were numerous. Most significantly, the channel of the Besandino in Besande; the Cea in Villaverde de Arcayos; the Dueñas river in Crémenes and the Eria in Morla de la Valdería.

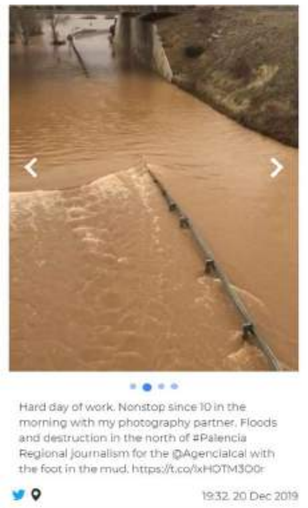
Also, on red alert were the Luna River in Sena de Luna; the Omaña in Castro de la Lomba and Las Omañas, the Órbigo river in the town of Cebrones del Río, the channel of the Orza in Vegacerneja, the Porma river in Camposolillo and the Yuso in Boca de Huérgano.

From the 21st to the 23rd of December the floods reduced in Léon. At the same time, the rivers Pisuerga and Valderaduey rose and caused flooding in Valladolid and Salamanca. The province of Palencia experienced floods too. The floods in Valderaduey were significant, but not as bad as the major floods experienced there in 2001. Five secondary roads got cut off around Valladolid and Salamanaca (including the VP-4017). On the 23rd the flood-plan in Valladolid got deactivated again.

On the 24th of December - The Duero caused flooding around Tordesillas (Valladolid) and Aranda (Burgos) due to high flow. At the same time, the mayor of Benavente, Zamora visited flood affected towns. Figure 50 shows a handful of examples of tweets from the 20th to the 24th of December.

25th - 5th of January - The aftermath of the flood. Messages were posted about costs and improved flood plans.

Floods in Palencia because of the Carrión river



Floods In Palencia (20th of December)

Mayers look at flood damage due to Duero (Zamora province) 24th of December

The river Duero caused flooding near Tordesillas on the 24th of December (Valladolid province)

Figure 50 ***The situation in the Douro basin between the 20th and the 24th of December***

6.2.3 Ebro basin

The basin of the Ebro covers multiple regions: Cantabria, Basque Country, Navarra, La Rioja, Aragon and Catalonia. The region of Navarra (around Pamplona) and the region of Cantabria (around Reinosa) experienced the most significant flooding events of the three river basins in December 2019, caused by overflow of the rivers Arga and Híjar respectively. Both are tributaries to the Ebro. A spatial overview of the situation as estimated from online media accounts is given in Figure 51. Next, we describe the timeline of the events is more detail.

Figure 51 ***Spatial overview of affected areas in the Ebro basin***

Timeline of events

There were two high impact events around Pamplona (province of Navarra) and Reinosa (province of Cantabria). The first peaked on the 13th while the latter peaked on the 20th, as can be seen from the number of flood related tweets shown in Figure 52. In Zaragoza were evacuations for possible flooding on the 15th of December, but the actual impact was very small. A more detailed timeline is described next.

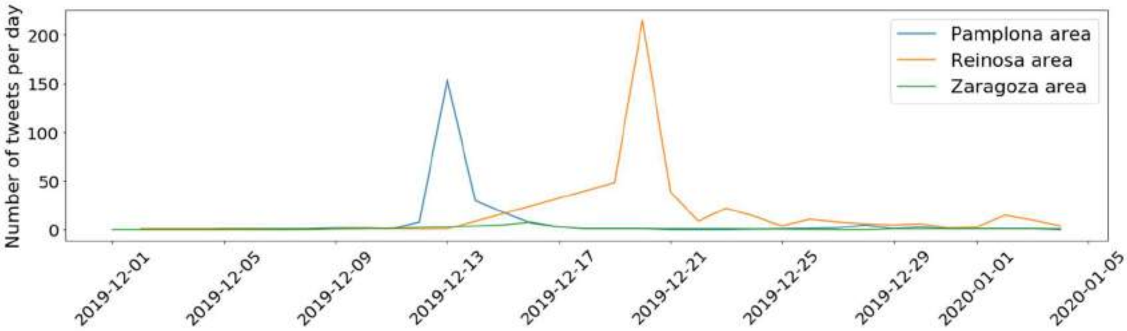


Figure 52 ***Flood related tweets over time per location in the Ebro basin***

From the 1st to 11th of December - Continuous rain but no flood events of importance.

On the 13th of December - The emergency flood plan was activated in Navarra. Four rivers recorded major flows and caused inundations; the Rio Ulzama, Arga, Burunda and Esca. The villages of Villava, Huare and the city of Pamplona were most affected by the resulting floods.

All these rivers are tributaries of the Ebro, which was expected to increase with 400% in one day. An overview of the flows of the Arga at multiple gauging stations was found in a tweet from the government of Navarra and is schematized in Figure 53.

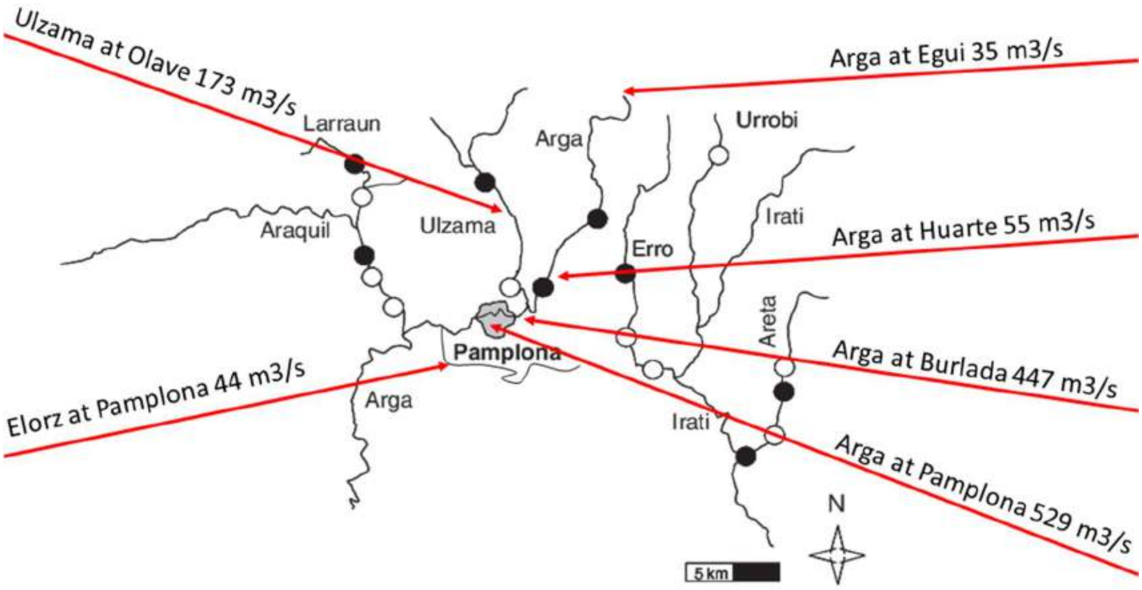


Figure 53 ***An overview of the flow of the rivers in the Navarra region on the 13th of December***

The Elgui reservoir, 22 km upstream of Pamplona, received an additional volume of 2,170,000 m3 between 21.00 and 9.00 on the night of the 12th to 13th of December. The reservoir was already filled from the continuous rain in the region since November. This resulted in a flow of 35 m3/s of the Arga at the Egui reservoir, with a water level of 0.87 m. The flow of 55 m3/s with a water level of 2.7 m of the Arga at Huarte caused great damage in the village of Huarte.

The flow of the Ulzama with 173 m3/s and a water level of 2.70 m caused inundations in the villages downstream. Villava (7 km downstream from Olave and close to Huarte) was badly affected. In Villava-Atarrabia a woman had to be rescued from her house by firefighters.

In Pamplona, the Arga had obtained a flow of 529 m3/s and a water level of 4.01 m, causing widespread inundations. Especially the Zonas de Las Oblates and Zonas Rochapea, Belcos and San Jorge next to the Arga river were inundated. A man had to be rescued from his car.

The Elorz joins the Arga a few km downstream of Pamplona and recorded a historical amount of flow with 44 m3/s and a water level of 2.02 meter. The Rio Arga continued to overflow on its way to the Ebro. The Ebro itself caused flooding in Tudela, downstreams of the inflow of the Arga.

An impression of the situation on the 13th is given in Figure 54.

The Arga at Huarte, one of the most affected villages.

Floods due to the Ulzama in Villava.

Area of San Jose, Pamplona.

Area de Las Oblatas, Pamplona on the 13th.

The river Arga overflowed the Puente de Berlada, Burlada, just above Pamplona.

Arga next to Rochapeo, Pamplona.

Figure 54 ***An impression of the situation in Navarra on the 13th of December***

On the 14th of December some flood problems were still recorded, but flows were reducing. Warnings were given out for floods in Castejón, next to the Ebro, but this passed without floods of importance. Figure 55 shows an image with water levels and flows recorded in the Ebro as reported by the radio station Ser Cinco Villas (https://twitter.com/SERCincoVillas/status/1206206885734604803) on the 14th of December, and of the tributary Abra (Note: this is not the same tributary as the Agra that overflowed on the 13th).

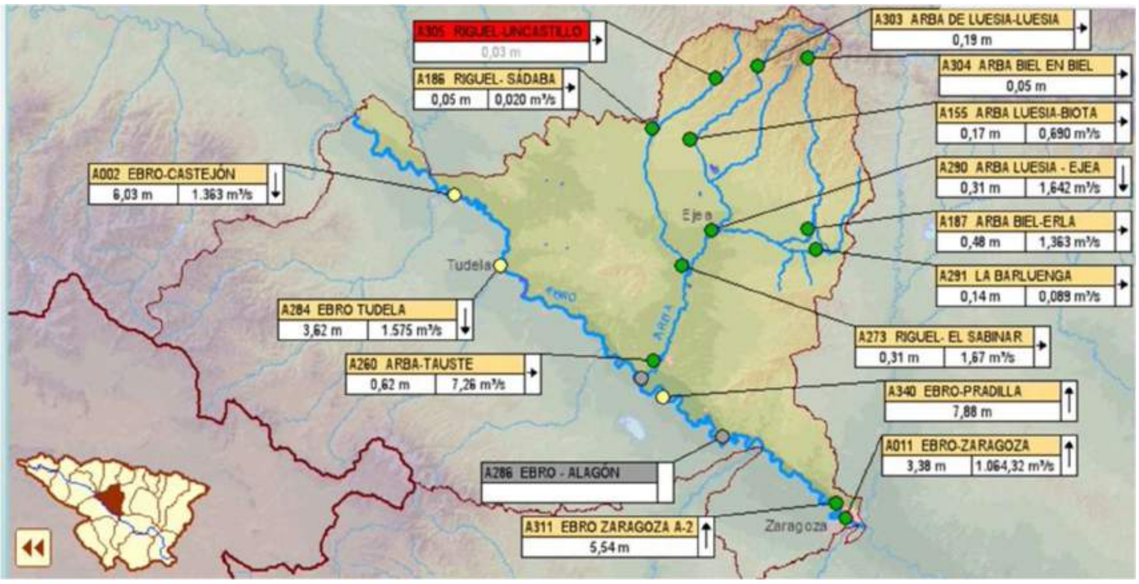


Figure 55 ***Flows and water levels of the Ebro and the Abra***

On the 15th of December - The emergency flood plan in Navarra was deactivated. On the other hand, in Zaragoza three neighborhoods were evacuated due to flood threats, but real damage stayed out.

On the 16th of December - Warnings for high flow in the Aragon river were given.

On the 19th of December – Worst floods in the history of Reinosa, province of Cantabria. Flood alerts were spread in anticipation of the storm Elsa. During the storm, 96.4 mm fell in the evening of the 19th to the 20th in some parts of the Cantabria region, which resulted in serious floods in the upper part of the Ebro basin. The city of Reinosa was most affected due to overflow of the

Híjar river, a tributary to the Ebro river. Four people were evacuated and 21 were trapped in their houses due to the floods. An impression is shown in Figure 56. Other villages affected were Cañeda and Matamorosa.

On the 23rd of December - The Ebro overflowed at Utebo (Zaragoza) with a flow rate close to 1200 m3/s, causing a few minor flood incidents.

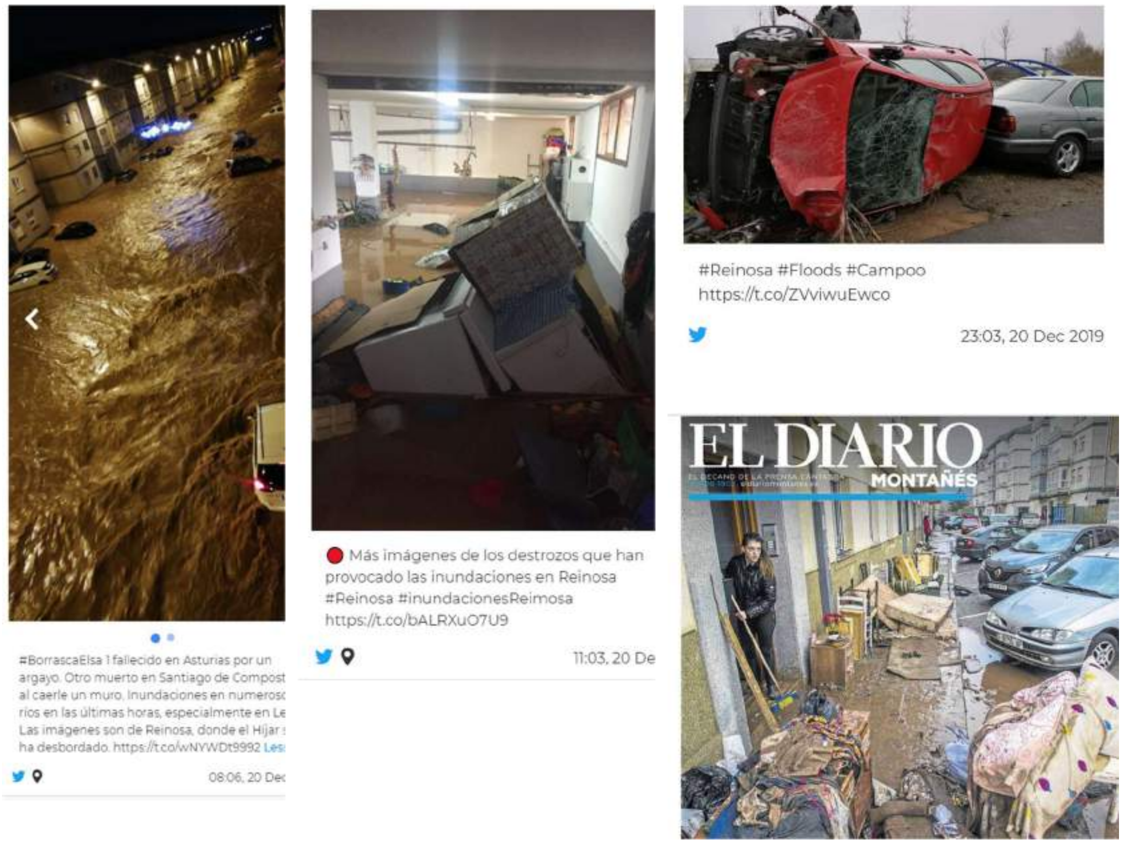


Figure 56 ***Images of the city Reinosa, in the flood from the 19th to the 20th of December***

7 Verification of EFAS forecast information

In this chapter we seek to verify the spatial-temporal (and magnitude) accuracy of the EFAS forecast information through comparison with the hydrological observations as well as Twitter information as proxy.

7.1 Minho basin

The temporal accuracy of the EFAS flood notifications sent out in the Minho basin is fairly high. The evaluation of the hydrological records shows (see Figure 31) that there were basically two events in this period that caused crossings of the threshold values. The first events around the 12th of December and a second event starting from the 20th of December onwards for the three stations. For the first event, two Flash Flood Notifications were sent out. For the second event two Flash and three Formal Flood Notifications were sent out.

This analysis is partly in line with the peak of the Twitter messages (Figure 42) which show a small peak around the 12th of December. However, the second and bigger peak in Twitter messages starts from the 17th of December onward, which is earlier than the actual timing of the threshold value crossings from the 20th of December onward.

The length of the event was predicted well as observations show that after December 24th, the levels dropped below the lowest threshold values for almost all stations in the basin. This coincides with the deactivation of most of the active notifications in EFAS.

Based on the analysis of the event and the analysis of the media reports, it can be said that EFAS predicted considerably well the event with a relatively long lead-time (9 days). The number of notifications and the timing of the predicted peaks seem to be well in line with the observed threshold values.

For the evaluation of the spatial accuracy of the EFAS notification, we compare the locations of the EFAS notifications with the location of in-situ stations where the observed threshold was exceeded. The comparison reveals some differences: 1) EFAS predicts a threshold exceedance downstream of the reservoir (number 2 in Figure 15), whereas the threshold was only exceeded upstream of the reservoir; and 2) a Formal Notification was sent for the Nis river (number 3 in Figure 15), where only the lowest threshold was exceeded for this station.

This also matches the analysis of the Twitter messages, which clearly show the one peak. It's also clear from the observations, that after December 24th, the levels dropped below the lowest threshold values for almost all stations in the basin.

In the time between 10th and 20th of December, several Flash Flood Notifications were sent out. From the analysis of the Twitter messages a slight increase can be observed over this period. In the observed thresholds exceedances, in this period three stations indeed show a short period for which the highest threshold values are exceeded.

Based on the analysis of the event and the analysis of the media reports, it can be said that EFAS predicted considerably well the event with a relatively long lead-time (9 days). Geographically, EFAS was able to capture reasonably well the event, although for one location EFAS seems to be over-predicting the event and for one other location the impact of the reservoir on downstream stations is not captured well in EFAS.

The *Confederación Hidrográfica Miño-Sil* (CHMS) valuates EFAS performance for this flood event as follows (for more details see Annex A; Chapter 9.1):

"During this event, it has been possible to verify the good performance of the hydrological models of the EFAS for the CHMS zone, showing precision both in the magnitude of the maximum flows and in the time of occurrence of the peak.

The alerts issued have been correct and issued sufficiently in advance for their analysis, complementing the information available in the CHMS for the management of the event.

In this sense, and as previously commented, it would be interesting to have access to model forecasts at more points in the hydrographic network, regardless of whether they generate a *hydrological alert or not. In this event, important flood waves for which no alert was issued by EFAS have been produced at different points of the CHMS, therefore, it is not possible to the information generated by the models for the points indicated."*

7.2 Douro basin

For the Douro basin the first Formal Flood Notifications were sent out at the 13th of December. The earliest peak was predicted for the 18th of December (number 1 in Figure 17). If we compare this with the timeline as presented in Figure 46, the first peak in the number of tweets is around the 17th of December, so one day before the predicted arrival of the peak. It must be noted that the peak in the number of Tweets doesn't necessarily need to coincide with the actual peak of the event.

On the 15th of December a second Formal Flood Notification was sent (number 2 in Figure 17). EFAS predicted the peak to be on the 22nd of December. If we again compare to the number of Twitter messages in this period, we see two smaller peaks around the 20th and 22nd of December, which matches with the predicted arrival of the peak.

Unfortunately, for the Douro basin no real threshold levels were available for the analysis, so in this case a virtual threshold level was derived, corresponding to the 99th percentile of the simulated discharges. When comparing the EFAS Formal Flood Notifications with these threshold values (see Figure 33), it is shown that based on observed crossings of the threshold values, this happened from the 16th of December onward and for six stations and from the 21th of December onward for all stations in the Douro basin. The first crossing (around the 16th of December) is in line with the first peak of the Twitter messages. In the number of Twitter messages, however, the situation seems to calm down after the 17th, while in EFAS the event seems to be worsening and spreading over the basin. The number of Formal Flood Notifications for the Douro basin is increasing from the 12th of December onward.

In the time between 10th and 22nd of December, several Flash Flood Notifications were sent out. From the Twitter analysis, as well as from the analysis of threshold crossings, it cannot easily be verified whether the Flash Flood Notifications were valid or not.

Based on the analysis of the event and the analysis of the media reports, it can be said that EFAS predicted the event well with a lead-time of around 5 days. Geographically, EFAS was able to capture the event reasonably well.

7.3 Ebro basin

For the Ebro basin the first Formal Flood Notifications were sent out at the 11th of December. The start of the event was predicted for the 14th of December with the earliest peak at the 15th of December (number 1 in Figure 19). Looking at the number of tweets in Figure 52, a peak in the number of tweets is observed at the 13th of December. Two more Formal Flood Notifications were sent on the 17th of December (numbers 2 and 3 in Figure 20). EFAS predicted the start for the 20th of December, with the earliest peak on the 22nd of December. In the number of tweets, a peak is observed on the 20th of December.

According to the hydrological analysis (see Figure 36) observations exceeded the 99P threshold values around the 14th and on the 20th -21st of December.

According to feedback received from the Confederación Hidrográfica del Ebro (CHE) (see Appendix A, Section 9.3) the magnitude of the event in the lower section of the Aragón River, was like that predicted on December 11. This was due to the reduction in peak flows made by the Yesa and Itoiz reservoirs. However, the event was larger than expected upstream of these reservoirs. The CHE said that EFAS predicted the event with a lead-time of around 3 days. However, according to the CHE the EFAS notifications could have been advanced by at least a day as there were signs of this event two days beforehand. Geographically, EFAS was able to capture the event reasonably well.

Compared to the national system the CHE states that for the Irati River, a tributary of the Aragón River, the forecast made by the basin organization was more accurate. However, for the Aragón river upstream of the Yesa reservoir, both forecasts remained below what was observed.

In the time between 1st and 21st of December, several Flash Flood Notifications were sent out, divided over three separate events. According to the CHE no flash floods occurred.

8 Synthesis and conclusions

In this detailed assessment of the EFAS forecast for the December 2020 event in Northern Spain, the quality of the EFAS forecast was verified. The assessment consists of 4 steps:

1) Summary of the provided EFAS forecasts & information
2) Detailed analysis of the hydrological observations
3) Detailed analysis of the media reports based on Twitter messages
4) Verification of step 1 based on the data from step 2 and 3

In summary for this event for the combined basins of the Minho, Douro and Ebro 30 notifications were sent out. For the Minho basin, seven notifications were sent: four Flash Flood Notifications and three Formal Flood Notifications. For the Douro basin, 10 notification were sent: six Flash Flood Notifications and four Formal Flood Notifications. For the Ebro, 13 notifications were sent: seven Flash Flood Notifications, three Formal Flood Notifications and three Informal Flood Notifications. The first notifications were sent out on the 10th of December, mainly in the Douro basin.

Based on the analysis and based on the data available for the analysis it can be concluded that the quality of the provided EFAS forecasts was fairly high. The events were detected by EFAS with a lead-time between 3-9 days, depending on the location of the affected rivers. This conclusion is supported by the analysis of the hydrological events and by the analysis of the Twitter messages.

For some rivers there seems be some problems in the model with e.g. reservoirs. This means that geographically EFAS predicted the event downstream, instead of upstream of the main reservoirs. Incorporating the operational usage of these reservoirs could potentially increase the accuracy of the EFAS forecasts.

The *Confederación Hidrográfica Miño-Sil (CHMS) and the Confederación Hidrográfica del Ebro (CHE) listed the following suggestions to improve the EFAS forecasts and notifications:*

- More permanent reporting points. During this event, significant floods have been observed at different points of the CHMS for which no EFAS alerts have been generated. It would be useful to know the model's forecasts at different points in the hydrological network, at least in situations of high rainfall, regardless of whether they meet the conditions to generate an alert.
- Incorporate or improve a reservoir module that improves forecasts downstream of these.
- Increase the spatial resolution of the products associated with the forecasts and the products associated with the observations: snow water equivalent, soil moisture and others.

9 Appendix A: Feedback from local authorities

9.1 Minho basin

Partner: Confederación Hidrográfica Miño-Sil (CHMS)

How did the EFAS forecasts for this event evolve?

1) When did EFAS start to forecast the first signs of flooding?

The first alert was received on 12/11/2019 and continued until 12/17/2019, highlighting on 12 that three alerts were received.

The notifications were of two types: EFAS Flash Flood Notification (5 notices) and EFAS Flood Notification Type Formal (3 notices, of which one is for the Portuguese part of the Demarcation).

The alerts received were as follows:

- EFAS Flash Flood Notification for SPAIN - Lugo Region 12/11/2019
- EFAS Flood Notification for Portugal - River: Lima - Type: Formal * 12/12/2019
- EFAS Flood Notification for Spain, Portugal - River: Miño, MINHO - Type: Formal * 12/12/2019
- EFAS Flash Flood Notification for SPAIN - Ourense Region 12/12/2019
- EFAS Flood Notification for SPAIN - River: Sil - Type: Formal * 12/13/2019
- EFAS Flash Flood Notification for SPAIN - Lugo Region 12/14/2019
- EFAS Flash Flood Notification for SPAIN - Lugo Region 12/15/2019
- EFAS Flash Flood Notification for SPAIN - Ourense Region 12/17/2019

2) Did the forecasts change over time?

The forecasts evolved but always remained consistent both in the range of maximum flows predicted and at the time of the peak occurrence.

3) Was the magnitude of the event always captured?

The alerts issued for points where they can be verified, points with a nearby CHMS gauging station, the predicted flows were consistent with the observed flows.

How good / bad were the EFAS forecasts compared to the national or basin forecasts and / or observations?

Both the forecasts made by EFAS and those of the CHMS (HEC-HMS model) showed very good performance throughout the event, both in predicting the magnitude and in the time of occurrence of flood peaks.

When were EFAS notifications sent for this event and what kind of EFAS notifications?

As previously mentioned, the notifications were received between December 11 and 17 and were of two types: EFAS Flash Flood Notification (5 notifications) and EFAS Flood Notification Type Formal (3 notifications, of which one is for the Portuguese part of the basin).

Should EFAS notifications have been sent earlier?

The warning time is considered correct, in most hydrological alerts it was 3-5 days before the start of the event, and in flash flood notifications, the warning time was 1-2 days in advance, Sufficient time for its management and developing decision-making.

If flash flood notifications were sent, were they correct?

These types of warnings could not be analyzed because they were forecast for areas where there are no nearby CHMS network gauging stations that provide information for their evaluation.

What was the delivery time for EFAS notifications?

In flash flood alerts, the notification period was 1-2 days in advance, while in hydrological alerts, Formal alerts, it varied between 3 and 5 days before the start of the event.

How did the national / regional EFAS partner use the notifications?

They were used as complementary information to that already used in the CHMS, information with which to contrast and evaluate the predictions of own production.

Were they useful?

All information that can extend the existing information, especially in emergency situations such as hydrological floods, are always helpful for management and decision-making.

Were they ignored?

All the alerts received are always consulted and evaluated in the CHMS to, as previously mentioned, expand the information available at all times and its possible use in managing the event.

Did the EFAS partner monitor the event on the EFAS interface?

For the monitoring and control of the event, the CHMS own tools were used

Would it be more useful for the EFAS partner to receive the actual EFAS data for entry into their system instead of looking at the EFAS web interface?

The current version of the EFAS website is enough since it allows a quick and agile consultation of the different alerts and the monitoring of the different flood events.

What additional information would the EFAS partner need?

The web interface offers complete information on the results of the forecasts at the points where alerts are generated. It would be interesting to have this same information available at a greater number of points on the network, regardless of whether the results generate an alert or not.

What should be done to improve EFAS forecasts and notifications?

During this event, significant floods have been observed at different points of the CHMS for which no EFAS alerts have been generated.

In line with the previous question, it would be useful to know the model's forecasts at different points in the hydrological network, at least in situations of high rainfall, regardless of whether they meet the conditions to generate an alert.

In this way, more information would be available in the management of the event and, at the same time, the performance of the different EFAS models could be verified in the areas where significant floods were also observed.

What are the lessons learned also for EFAS?

During this event, it has been possible to verify the good performance of the hydrological models of the EFAS for the CHMS zone, showing precision both in the magnitude of the maximum flows and in the time of occurrence of the peak.

The alerts issued have been correct and issued sufficiently in advance for their analysis, complementing the information available in the CHMS for the management of the event.

In this sense, and as previously commented, it would be interesting to have access to model forecasts at more points in the hydrographic network, regardless of whether they generate a hydrological alert or not. In this event, important flood waves for which no alert was issued by EFAS have been produced at different points of the CHMS, therefore, it is not possible to the information generated by the models for the points indicated.

9.2 Douro basin

No information was received yet from the local authorities.

9.3 Ebro basin

Partner: Confederación Hidrográfica del Ebro (CHE)

How did the EFAS forecasts for this event evolve:

1) *When did EFAS start to forecast the first signs of a flooding?*
   In the execution of 00:00 hours on December 8, 2019

2) *Did the forecasts change over time?*
   Between December 8 and 11, the severity of the event was increasing.

3) *Was the magnitude of the event always captured?*
   In the lower section of the Aragón River, the magnitude of the event was like that predicted on December 11. This was due to the reduction in peak flows made by the Yesa and Itoiz reservoirs. The event was larger than expected upstream of these reservoirs.

How good / bad were the EFAS forecasts compared to the national or basin forecasts and / or observations?

For the Irati River, a tributary of the Aragón River, the forecast made by the basin organization was more accurate. However, for the Aragón river upstream of the Yesa reservoir, both forecasts remained below what was observed.

When were EFAS notifications sent for this event and what kind of EFAS notifications?

A formal notification was sent on December 11 and an informal notification was sent on December 12.

Should EFAS notifications have been sent earlier?

There were signs of this event two days before, so that the notification could have been advanced at least one day.

If flash flood notifications were sent, were they correct?

A flash flood notification was sent, but this event did not occur.

What was the delivery time for EFAS notifications?

Three days in advance regarding the peak of the wave in the lower section of the Aragon River.

How did the national / regional EFAS partner use the notifications?

The Ebro Hydrographic Confederation regularly consults the hydrological forecast provided by EFAS for forecast horizons greater than 3 days.

Were they useful?

For this event, the notification was received when it was already known that an important event was going to occur in this sector of the basin, so that they served to confirm the agency's own forecasts.

Were they ignored?

No. They served as confirmation of the forecasts of the basin agency itself.

Did the EFAS partner monitor the event on the EFAS interface?

Both flood events and other information that could be consulted on the EFAS portal have been monitored.

Would it be more useful for the EFAS partner to receive the actual EFAS data for entry in their system instead of looking at the EFAS web interface?

Receiving EFAS data, in addition to being able to consult them through the portal, would facilitate the consultation and allow us to better contrast it with the results of our system.

What additional information would the EFAS partner need?

No other information is needed.

What should be done to improve EFAS forecasts and notifications?

- Incorporate or improve a reservoir module that improves forecasts downstream of these.
- Increase the spatial resolution of the products associated with the forecasts and the products associated with the observations: snow water equivalent, soil moisture and others.

What are the lessons learned also for EFAS?

1) It is necessary to improve the management of reservoirs to make a more adequate forecast downstream.
2) Review the return periods in various Reporting Points, since there are numerous cases in which flows that are relatively low are associated with very high return periods, so that false warnings are generated. In the case of the Ebro basin, it is almost generalized for the Pyrenees basins (Aragon, Gállego, Cinca, Nogueras and Segre).
3) The designations of zone names are not obvious and misleading. The descriptions should share at least the point of view of the national / regional partner. Sometimes, it is not possible to understand which zone or zones are exactly those affected by an event, for example, when a notification is received such as: "River (s): Ebro, section Aragon - Jalon (Ebro basin)", which Is the Aragón-Jalón sector ?. We can collaborate in the definition of the name of the sub-basins that EFAS manages and even make a sub-basin proposal based on the sections that we handle.