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Emergency Management

2019 Annual Report

European Flood Awareness System

Analisys on the CEMS hydrological data collection

CEMS HYDROLOGICAL DATA COLLECTION CENTRE

soologic® TECHNOLOGICAL SOLUTIONS

Junta de Andalucía
Regional ministry of agriculture, livestock, fisheries and sustainable development
ENVIRONMENTAL AND WATER AGENCY OF ANDALUSIA

Rediam

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Acknowledgement

The EFAS team, and particularly the HDCC, would like to thank the EFAS Partners and Data Providers that contributed to the CEMS hydrological data collection. We would like to acknowledge their dedication to the EFAS project, their commitment and the sharing of their hydrological data. We thank them for their cooperation with the HDCC, both in the provision of data and for their proactive role in responding to the questions and solving issues. Without their collaboration the delivery of this report would not be possible.

Introduction

This report contains an analysis of the hydrological data received by the CEMS Hydrological Data Collection Centre (HDCC) for the year 2019. The HDCC is contracted by the European Commission and operated by the Agencia de Medio Ambiente y Agua de Andalucía in collaboration with Soologic Technological Solutions S.L. The HDCC is responsible for the collection, quality control, harmonisation and internal distribution of hydrological observations to various components of the Copernicus Emergency Management Service (CEMS), mostly to the European Flood Awareness System (EFAS).

By the end of 2019, 43 data providers contributed with near real-time hydrological data at 1,792 stations to the CEMS Hydrological Data Collection, covering 31 countries and 49% of all the European water basins.

In the following section we first highlight the growth of the HDCC database in 2019, before introducing the hydrological analysis of data within the EMS HDCC in the next section, which will in turn occupy the rest of the document.

Figure 1. Spatial distribution of data providers to the CEMS (full list in Annex 1).

Update the HDCC database in 2019

During 2019, three additional hydrological data providers contributed with their hydrological data to the HDCC. Those are:

- the Institute of GeoSciences, Energy, Water and Environment of Albania with 16 stations,
- the Regional Civil Protection (ARPA) of Lombardy, Italy with 55 stations,
- the National Environmental Agency under the Ministry of Environmental Protection and Agriculture of Georgia with 5 stations.

In addition to those new data providers and stations, a number of existing data providers (DP) increased the number of stations providing real-time hydrological data to the HDCC. Those are:

- the Ministère de l'Ecologie et du Développement Durable Service Central d'Hydrométéorologie et d'Appui à la Prévision des Inondations with 161 additional stations,
- the Icelandic Meteorological Office with 28 additional stations,
- the Finnish Environment Institute with 11 additional stations,
- the Estonian Environmental Agency with 5 additional stations, and
- the Rijkswaterstaat, Rediam and the Croatian Meteorological and Hydrological Service with each 1 additional station.

This makes a total of 284 new stations in the HDCC database since 2018. In addition, some existing EFAS data providers uploaded new historic data sets during 2019.

An overview is given in *Table 1*.

Table 1. Historic data received during 2019

Country	Hydrological data provider	Dataset received during 2019. (year/s)
Poland	Institute of Meteorology and Water Management Wroclaw Branch	2018
Belgium	Hydrological Information Centre	2018
Switzerland	Federal Office for the Environment	2017
Ireland	Office of Public Works	from 1955 to 2019 for station Ballyduff (EFAS ID 1410)
Israel	Israel Hydrological Service - Water Authority	several years
Romania	Institutul Național de Hidrologie Si Gospodarire A Apelor	2017
Serbia	Republic Hydrometeorological Service of Serbia	2018
Ukraine	State Emergency Service of Ukraine - Ukrainian Hydrometeorological Center	2016-2017
Spain	Government of Andalusia - Regional Ministry of Agriculture, Fisheries and Environment	1991-2020
Hungary	Hungarian Hydrological Forecasting Service, General Directorate of Water Management	2017-2018

Table 2 provides the most important statistics summarising all the changes to the HDCC database in 2019.

Table 2. Number of data providers, stations and values managed during 2019.

	Before 2019	New since 2019	Total	Increment
Data Providers	59	8	67	14%
Active Data Providers (Portugal provides historical data)	40(+1)	3	43(+1)	8%
No Of Stations Registered	3,138	197	3,335	6%
No Of Active Stations	1,724	66	1,790	4%
No Of Near Real-Time Values	303 Mill.	60 Mill.	363 Mill.	20%
No Of Stations with defined threshold levels	886	206	1092	23%
No Of Historic Values	114 Mill.	3,2 Mill.	117 Mill.	3%

Analysis of the data in the HDCC database

In order to extract conclusions and then propose improvements in the process, it is necessary a further analysis of the total data managed by the HDCC. This entails a selection of stations and a division of the analysis in four sections according to the most relevant aspects.

Out of the 1,792 stations that the HDCC currently collects hydrological data from, only 1,558 stations will be analysed in this report. This is due to the fact that only stations were selected that actively delivered data throughout the entire year 2019 and that had a stable data provision to the HDCC before January 1 2019. Out of these 1,558 stations, 290 deliver exclusively discharge data, 370 only water level data and 898 stations provide discharge and water level data. *Figure 2* shows the geographical distribution of those stations.

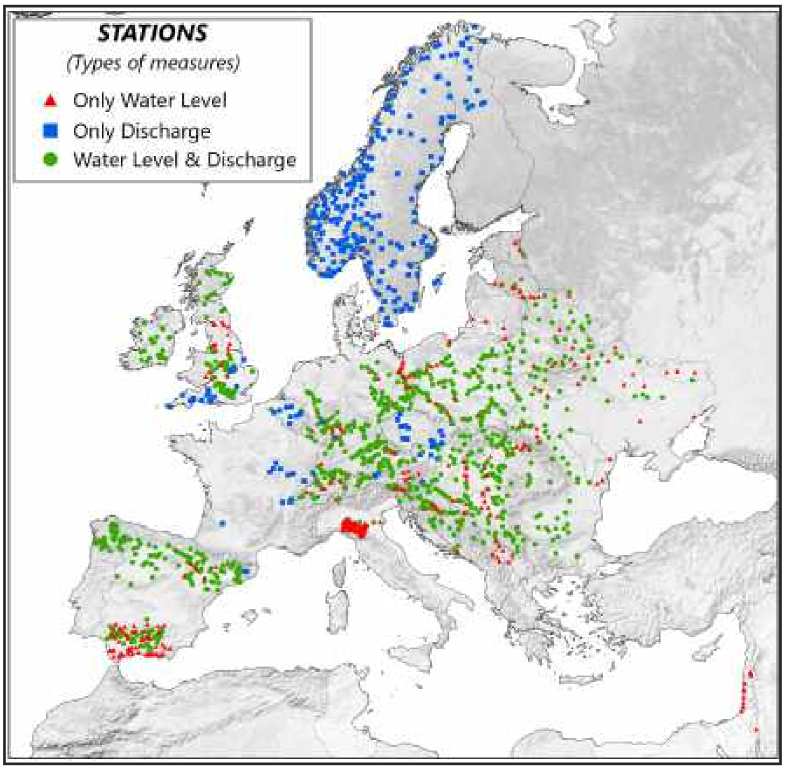


Figure 2. Spatial distribution of the 1558 selected stations and variables measured.

Beside the final conclusion chapter, this report is divided in the following main chapters, each of them containing the analysis of a certain aspect of the HDCC hydrological data collection for the year 2019. Those are:

- Chapter 2: An analysis on the general hydrological conditions across Europe, focusing on important deviations of average discharge.
- Chapter 3: An assessment of the HDCC Data Collection in terms of gaps and outliers, including a classification according to causes, duration, length and distribution.
- Chapter 4: An evaluation on the threshold level exceedances, looking at the duration, magnitude, number and distribution of exceedances according to the threshold levels.

In addition, the HDCC analysed the 2019 flood events in Northern Spain, in the Ebro, Minho-Limia and Douro basins. The floods were analyzed from a hydrological point of view, focusing on the evolution of the flood events in terms of intensity and duration. The complete detailed assessment of those flood events has been carried out as a cooperation between the HDCC and the EFAS Dissemination Centre and can be accessed under the following link: https://www.efas.eu/report/assessment-report-flood-events-northern-spain-december-2019

1 Hydrological conditions of EFAS gauging stations

Introduction

This chapter describes the hydrological conditions for the year 2019 across the entire EFAS domain, by comparing near real-time data of 2019 with near real-time data from 2018 and historical data (1991-2016) respectively.

Although the CEMS Hydrological Data Collection Centre (HDCC) collects water level and discharge values, the analyses in this chapter have been carried out on the discharge data only. This is because, unlike water level, discharge does not depend on the river's geometry and hence allows for a comparison of the hydrological behaviour between stations.

The mean daily values have been used to calculate all the statistics for the analyses: the annual mean, minimum and maximum for 2019, as well as the percentiles of the year 2018 and the period 1991-2016 respectively. The average of the annual mean is an indicator of the annual water contribution at the gauging points, whereas the percentiles allow comparing the annual minima and maxima in 2019 to the reference periods in order to determine their variations.

We like to point out that the analysis covered by this section is based only on discharge measures collected from gauging stations. As an increasing number of stations are strongly regulated upstream by hydraulic infrastructures, many of these stations show discharge values that are not according to their natural discharge regimes. For this reason, it's not uncommon to find discharge variations that are not caused by meteorological factors. Any interpretation of the results presented in this section should consider this point.

Assessing stations and data for analysis

In order to guarantee a good quality analysis, only stations with good temporal coverage have been selected for the analyses. For 2018 and 2019 only stations that were fully operational and active throughout the reference period, and received more than 75% of their expected annual discharge observations were selected. For the 1991-2016 period, only stations with at least two years of data were included. As a result, a total of 1,149, 1,119 and 929 stations were chosen for 2019, 2018 and 1991-2016, respectively.

Figure 3 (left) shows the spatial distribution of the hydrological gauging stations chosen for this analysis, including the length of their historical time series. More than 50% of the stations have more than 20 years of historical data. The longer the time series, the more representative are the derived statistical parameters. Henceforth, we expect the accuracy of the assessment to be higher in areas with long historical time series (such as Norway, Sweden, the Ebro River basin in Spain, and stations across the Rhine and Danube river basins).

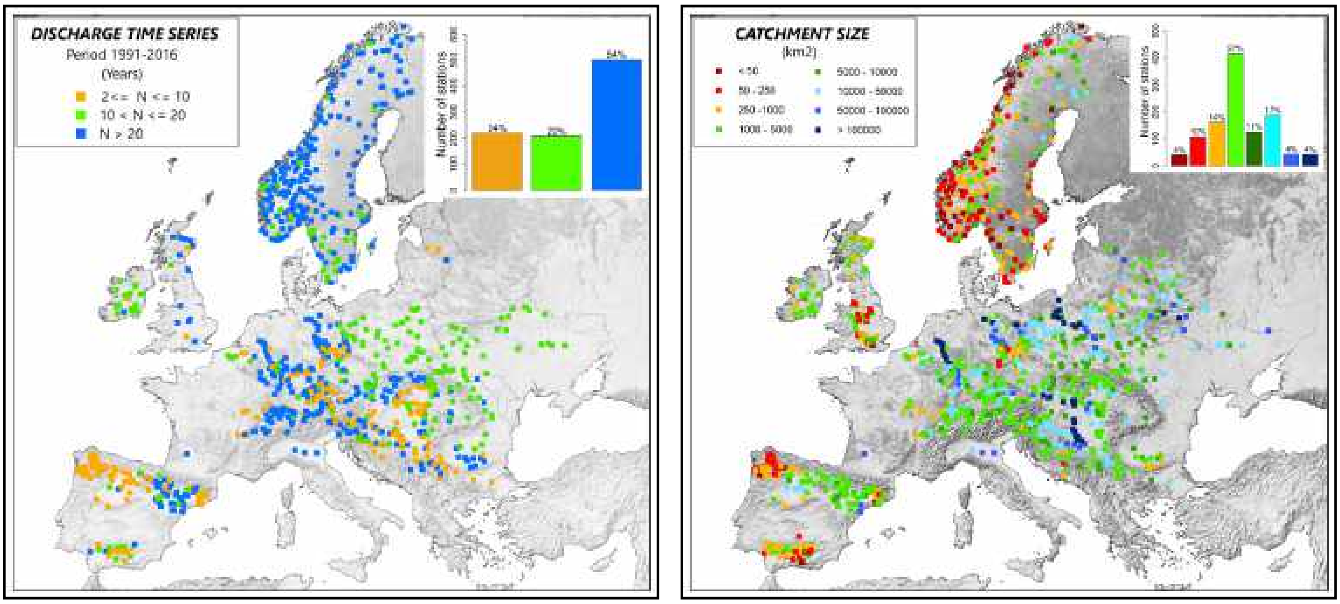


Figure 3- Spatial distribution of stations according to the length of their historical time series (left) and catchment size (right).

Figure 3 (right) shows the upstream areas of all the selected stations. Many of the stations from the Scandinavian peninsula, Spain, England and across the Elbe river basin have small catchment areas (< 250 km^2), whereas many of the stations from the Danube, Vistula, Ebro and Rhine river basins hold large upstream areas (>1,000 km^2). The distribution of catchment areas of the stations is partly a result of hydrological features, and partly a result of where hydrological services want to observe and which of the observations they are willing to share. We have normalized the discharge values with the upstream area to get a normalised discharge, as this index allows comparisons between stations. Nevertheless, differences in catchment areas is still likely to have an effect on the minimum and maximum values (smaller catchments typically have a larger difference between minimum and maximum specific discharge than larger catchments) and on annual variability (smaller catchments typically have larger annual variability). The units for this index are millimetres of water per year (mm/year), which is the same as litres per square meter and per year [l/(m^2· year)].

Hydrological conditions in 2019

Figure 4 shows the normalized mean discharge values for 2019. 17% of the studied stations present values below 100 mm/year. These are mostly present in Spain, Elbe, Oder, Vistula, Dnieper, Neman, Daugava and the Northern and Central Danube river basins. These values usually belong to regulated or overexploited streams and/or dry meteorological regimes. The highest values (over 1,000 mm/year) occur for stations in Norway, the upper Rhine and Danube basins and usually occur in relatively small catchments with high precipitation.

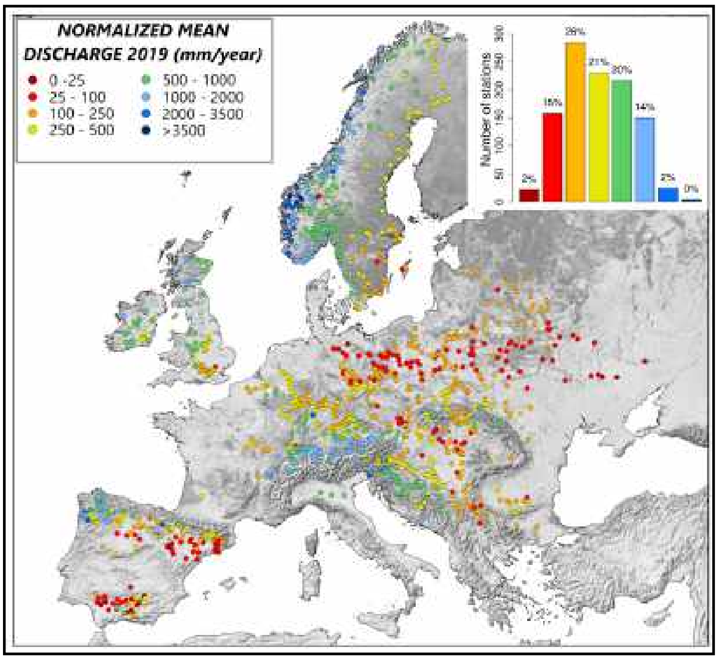


Figure 4. Spatial distribution of normalized mean discharge values in 2019.

Comparative analysis

In this section the hydrological situation of 2019 is compared to the previous year (2018) and to the historical reference period (1991-2016). This is to assess if and how the hydrological conditions of 2019 differ from the past. The comparison of the relative variation of the average values is done through two indexes: the Streamflow Variation Index (SVI) and the Normalized Variation index (NVI).

SVI is applied when comparing 2019 and the period 1991-2016. It is adapted from the Streamflow Drought Index (SDI) (Nalbantis and Tsakiris, 2009):

$$SVI_H = \frac{\bar{X}_{2019} - \bar{X}_H}{S_H}$$

X_{2019} and X_H are the mean discharges for 2019 and 1991-2016, respectively. S_H is the standard deviations of the annual mean discharge for the period 1991-2016. This index is a standardization of annual mean discharge in 2019 according to the annual mean and the standard deviation of the annual mean discharge in the period 1991-2016.

The Normalized Variation index (NVI) is applied when comparing the 2019 and 2018 mean discharges as the SVI is not applicable when the reference period covers only one year:

$$NVI = \frac{\bar{X}_{2019} - \bar{X}_{2018}}{\bar{X}_{2019} + \bar{X}_{2018}}$$

Where and are the mean discharges for 2019 and 2018 respectively.

Table 3 defines quality classes based on the distribution of the resulting SVI and NVI values.

On the other hand, the percentile of the minimum and maximum daily mean values of 2019 are calculated according the to the time series of daily mean values from 2018 and the period 1991-2016 respectively. These percentiles are used to indicate how close the minimum and maximum river flows of 2019 are to the minimum and maximum for those periods. The extreme values of 2019 are then classified according to their percentile in the periods 2018 and 1991-2016. The percentiles intervals are shown in the *Table 4*.

Table 3

Classes	SVI interval	NVI interval
Extremely positive	SVI > 2	NVI > 0.5
Moderately positive	2 ≥ SVI > 1	0,5 ≥ NVI > 0.25
Mildly positive	1 ≥ SVI ≥ 0.25	0.25 ≥ NVI > 0.02
Negligible	−0,25 ≤ SVI < 0.25	0.02 ≥ NVI ≥ -0.02
Midly negative	−1 ≤ SVI < -0.25	-0.25 ≤ NVI < -0.02
Moderately negative	−1.0 ≤ SVI < -2	−0.5 ≤ NVI < -0.25
Extreme negative	SVI < -2	NVI < -0.5

Table 4

Classes	Minimum	Maximum
Below / Exceeded	*	*
Very Low / High	P < 1%	P > 99%
Low / High	1% ≤ P < 2.5%	97.5% ≥ P ≤ 99%
Medium	2.5% ≤ P < 5%	95% ≤ P < 97.5%
High / Low	5% ≥ P ≤ 10%	90% ≤ P < 95%
Very High / Low	P > 10%	P < 90%

** The percentile is 0 for values lower than the minimum and 1 for a values greater than the maximum. We have added a separate class for such extremes.*

Variation of hydrological conditions

The spatial distribution of Normalized Variation Index for annual averages between 2019 and 2018, *Figure 5 (left)*, shows clearly a dominance of low variations, both positive and negative, in stations across Europe. Stations with the lowest annual mean discharge for 2019 compared to 2018 are mostly located in Spain in Guadalquivir, Ebro and Llobregat river basins. This situation also occurs in some stations in Norway, Sweden, Loire river basin in France, Elbe river basin in Germany, south-eastern Danube river basin in Bulgaria and Serbia, and Dnieper river basin in Belarus. On the other hand, the stations that registered the highest increases of discharge in 2019 compared to 2018 are located in the British Isles, Minho and Guadalquivir river basins in Spain, and southern Norway and Sweden. There are also a few stations with high increases in the Elbe and Danube river basin in Germany and Czech Republic, respectively. In summary, most of the stations Europe had a similar annual discharge in 2019 to what they had in 2018.

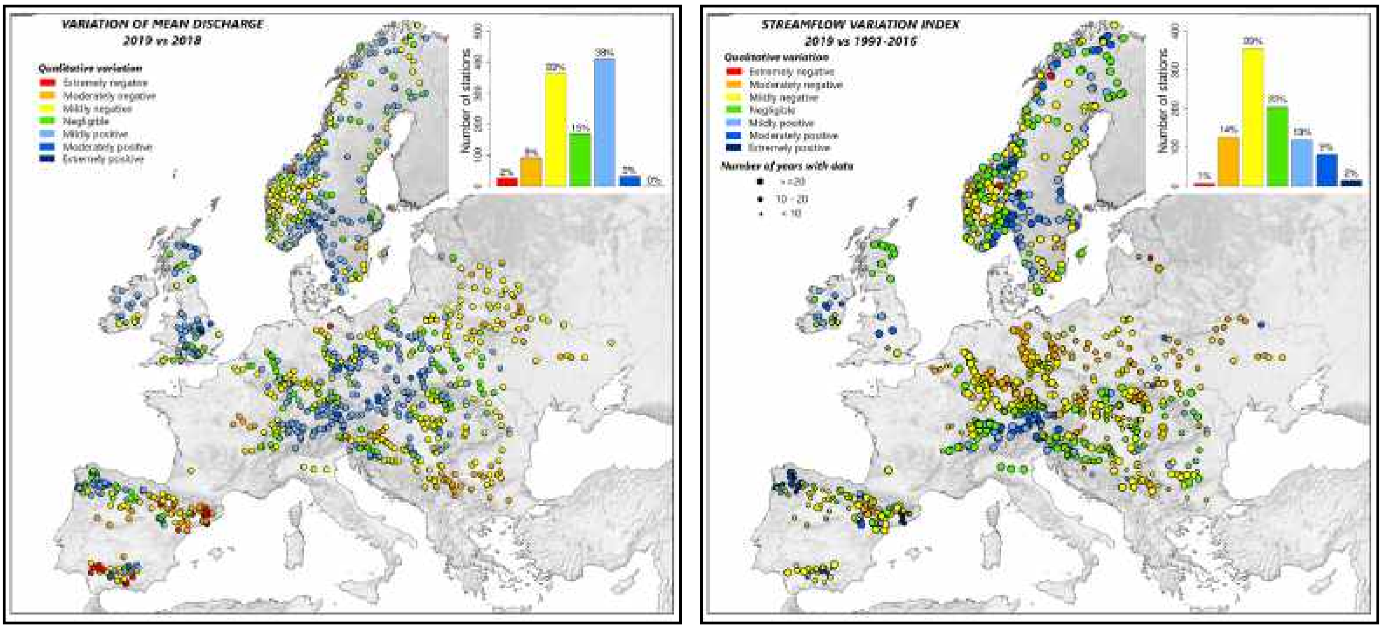


Figure 5. Spatial distribution of Streamflow Draught Index in 2019 with respect to 2018 (left) and the period 1991-2016 (right)

When comparing 2019 with the 1991-2016 period, an increased number of stations with lower mean discharge is notable. However, 22% of the stations have negligible variations. These are mostly located in the Danube, Rhône, southern Rhine river basins and the Scandinavian Peninsula. 15% suffer moderate or extreme negative variations. Most of those stations are located in Elbe, Oder, Vistula and Dnieper river basins. A number of stations in the Danube, Rhine, Guadalquivir and Ebro river basins show a moderate drought as well. On the other hand, 11% of the stations present a severe or moderate surplus of mean discharge in 2019 compared with the period 1991-2016. They are mostly located in basins in Southern Norway and Sweden, and in the confluence of the Danube, Rhine and Rhône upper river basins, but can also be found in basins across Spain, Ireland and England and isolated stations of the Dnieper river basins in Ukraine.

As summary, as the *Figure 6 (left and right)* shows, we can say that 2019 was dryer compared to the historical data but also that both 2018 and 2019 were relatively dry years, which was also confirmed in the report for 2018.

Minimum and maximum value analysis

In 2019, 42% of the stations recorded minimum mean daily discharge values that were lower than the ones in 2018 (or the river flow was zero), as it's shown in *Figure 6 (left)*. We can see that these stations are found all across Europe but the concentration was higher in north-eastern Europe, from the Elbe to the Dnieper river basin, medium and lower Danube river basin and basins in Spain, the Scandinavian peninsula and southern England. On the other hand, around 23% of the stations recorded minimum mean daily values in 2019 that were considerably higher than the minimum values in 2018. This mainly occurred in stations located in the main course and in the higher parts of the Rhine river basin, in the Danube river basin and in basins of Norway, Sweden, Ireland, Scotland and England. High minimum values were also found in some stations in the Dnieper (Ukraine), Daugava (Latvia and Belarus), Elbe (Germany) river and locally for some Spanish river basins. Concerning the period 1991-2016 we found that only 15% of the stations recorded a lower minimum value than in the reference period (or the river flow was zero) *(Figure 6, right)*. Most of these stations are located in the Elbe, Oder, and Vistula basins. We also found a number of these stations in basins of Spain (Guadalquivir, Ebro, Llobregat, Douro and Minho) Sweden and Norway. Contrastingly, 16% of the stations had discharge minimum values considerably higher than the minima in the historical period. This mostly occurred in basins in the Scandinavian Peninsula, stations across the Danube river basin (more frequently in Bulgaria), Ebro river basin (Spain), higher Rhine river basin (Germany) and isolated stations in the Dnieper river basin, Ireland and Scotland. The minimum values of the rest of the stations are almost equally distributed according the different degrees of closeness to the minimum for the period 1991-2016. *Figure 7 (left)* shows a comparison of the maximum mean daily discharge for 2018 and 2019 and show that the maximum values were higher in 2019 for 50% of the stations across Europe. However, we must to consider as well that, for many stations, 2018 was the driest year in the historic records. Despite of this, around 14% of the stations recorded maximum mean daily values considerably below the maximum value in 2018. These stations are mainly located in the Dnieper (Ukraine), Neman (Belarus), Daugava (Latvia) and lower basin of Danube, Vistula, Oder, Elbe, Rhine and Ebro

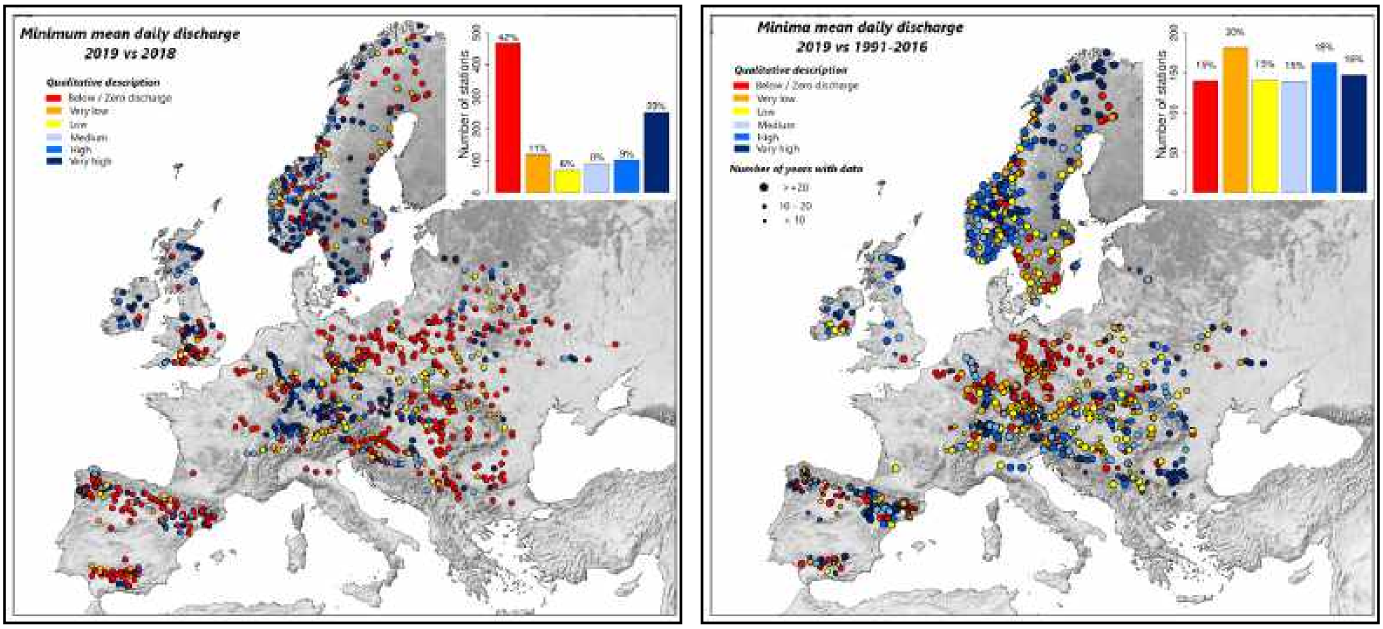


Figure 6. Spatial distribution of stations and the minimum values in 2019 with respect to 2018 (left) and the period 1991-2016 (right)

rivers. Considerably lower extremes also occurred more locally for some stations in southern Sweden, Finland, Ireland and Guadalquivir river basin in Spain. Between the high and low maximum values, we find 8% of the stations that which recorded lower maximum discharge in 2019 than in 2018. These are found in France, Sweden, Norway and southern Spain.

Figure 7 (right) shows that 52% of the stations across Europe recorded maximum values for 2019 that were just below their historic maxima from the period 1991-2016. Moreover, 11% of the stations exceeded in 2019 the maximum mean daily value of the period 1991-2016. These exceedances took place in stations of Minho-Sil, Ebro, Douro, LLobregat and Guadalquivir river basins in Spain and in the higher Danube river basin in Austria and Switzerland. There were also exceedances at stations located in Sweden, Norway and in the Po River in Italy as well as the Garonne River in France. On the other hand around 11% of the station recorded maximum mean daily values in 2019 considerably below the maximum historical values. These station are mainly located in the Elbe, Oder, Vistula, Dnieper river basins and isolated stations in Lower Danube, Ebro, Guadalquivir, Corrib (Ireland) , Kemijoki (Finland) and Morrumsam (Sweden) river basins.

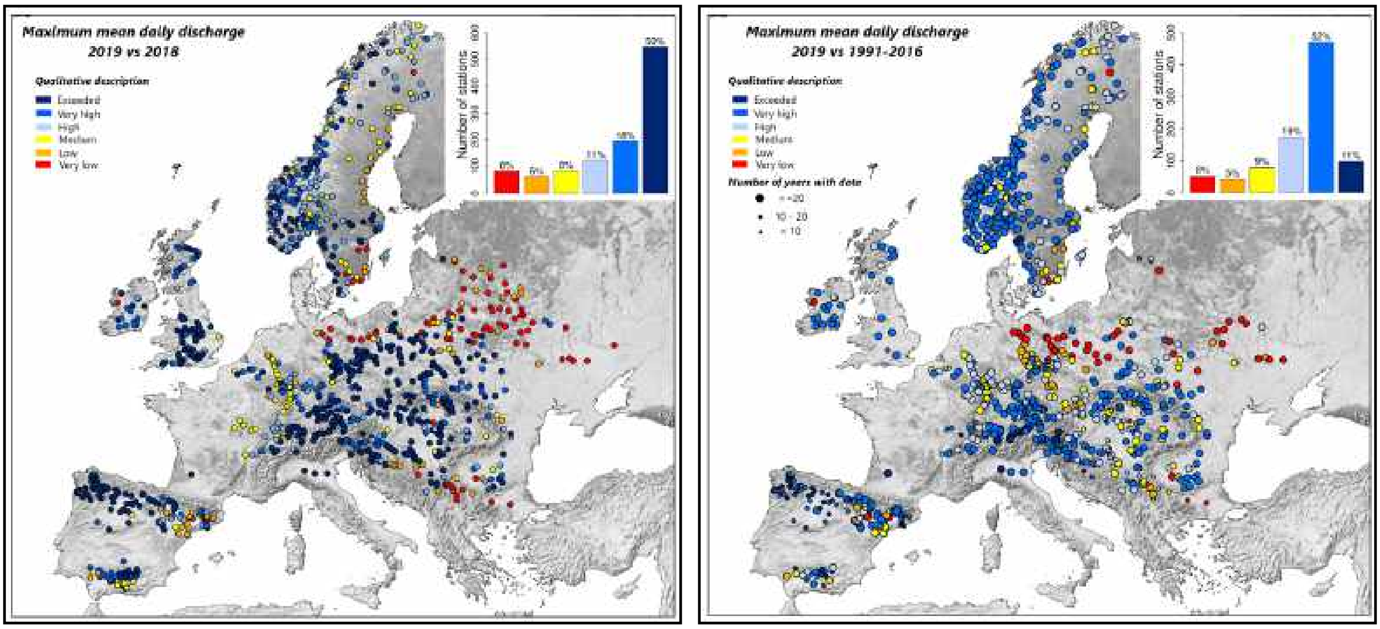


Figure 7. Spatial distribution of stations and the maximum values in 2019 compared with 2018 (left) and the historical period 1991-2016 (right)

2 Gaps Analysis on the CEMS hydrological data base

Initial considerations

This chapter analyses the gaps in the CEMS hydrological data collection for the year 2019, collected by the Hydrological Data Collection Centre (HDCC).

The CEMS hydrological data collection is continuously growing with hydrological data from 1,792 gauging stations across Europe. The data observation frequency among those vary from every minute to daily *(see Fig. 8)*. A gap occurs when either no data is received for a specific period of time or if the data received fails the quality control criteria and is considered as missing. The basic gap unit considered is a single missing value. A gap ends once the data delivery is resumed, and the missing values are not uploaded. The importance of a gap will depend on its length.

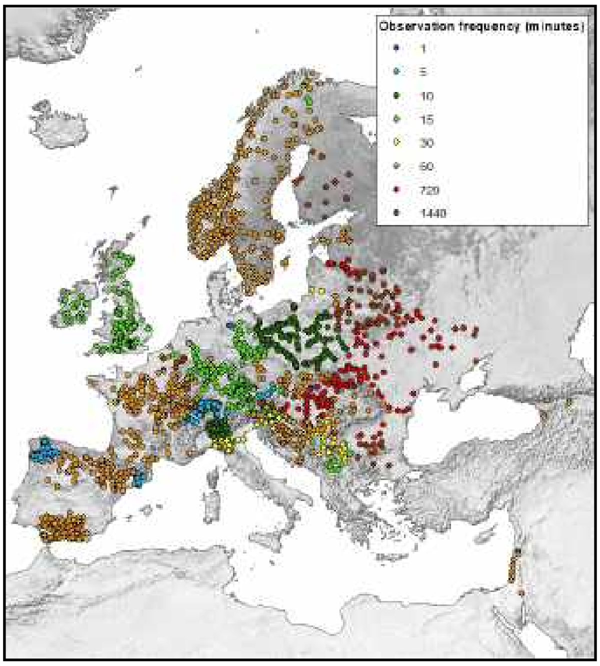


Figure 8 : Provision frecuency by station

Gap analysis

We analysed data from 1,558 stations providing water level and/or discharge values (see Introduction), from 40 data providers (DPs). 1,474 of these stations had problems with data transmission between January 1st 2019 and December 31st 2019 on at least one occasion.

In total 4.87% of all the data values expected for 2019 were not received. If we compare this value with 2018, it is slightly lower, but with an increment in the number of data received, as it can be seen in *Figure 9*. However, 99% of all the 605,961 gaps lasted less than 1 day and 80% lasted less than 1 hour. To select only gaps relevant for HDCC operations, gaps consisting of 10 consecutive missing values or less, and with observation frequencies higher than 1 hour are discarded. That means that maximum 5 hours gaps were discarded as those do not interfere with the data processing tasks of the HDCC.

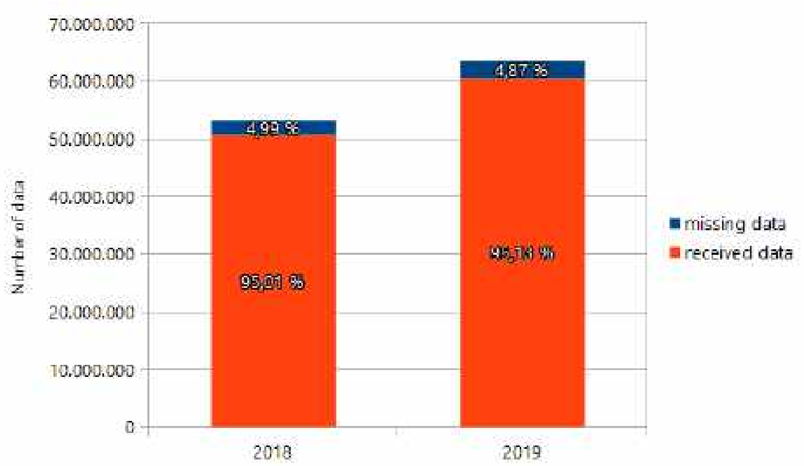


Figure 9 : Reception rate comparison between 2018 and 2019

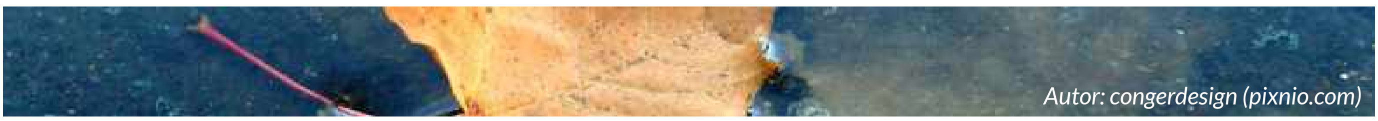
This filtering reduced the number of gaps to be analysed to 83,357, coming from 1,390 stations and for 2,170 variables. This number is higher than the number of stations, as each station can provide up to two variables (water level and/or discharge values).

Gap classification by duration

We define five classes of duration.

- More than 30 days
- From 10 to 30 days
- From 3 to 10 days
- From 1 to 3 days
- Less or equal than 1 day

Figure 10 (left panel) shows the number of gaps according to their duration. 91% of the gaps have a duration of 1 day, resulting mostly from changes in the data observation frequencies and/or delays in data transmissions. 7.8% last between 1 and 3 days, whereas 1.3% (1,071 gaps) lasted more than three days and required our intervention. *Figure 10* (right panel) shows the distribution of those gaps longer than three days.



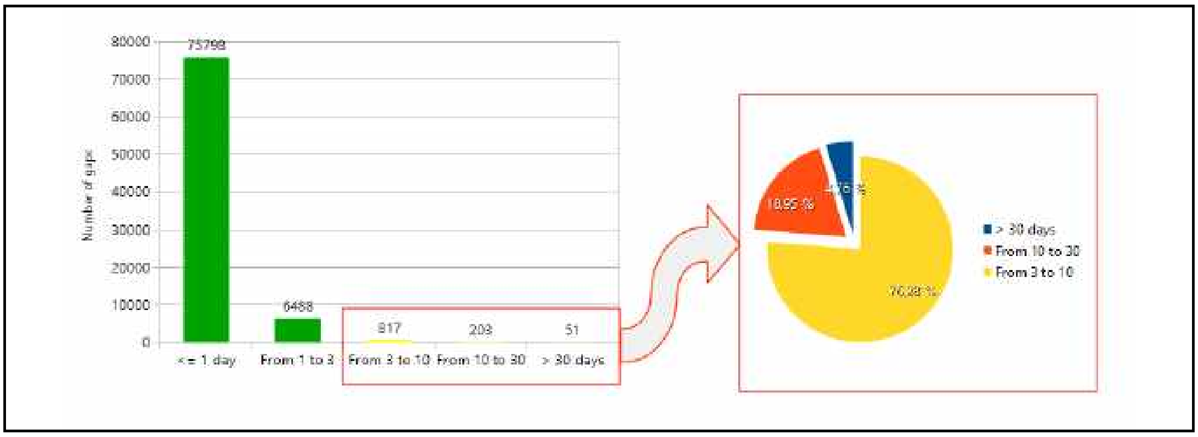


Figure 10. Number of gaps by duration (left panel) and distribution in percentage of those longer than three days (right panel).

Most gaps longer than 3 days last ≤ 10 days as the HDCC establishes contact with the respective data provider after three days of failed delivery. Usually the data providers can solve the issues within a couple of days. Gaps longer than 30 days are less frequent as all parties involved have been notified and in most cases had time to solve the issues.

Gap classification by status

Once a gap occurs, 4 scenarios may unfold.

FILLED: The gap is filled at a later stage, with the missing data sent by the data provider.

FILLED INTERPOLATED: The gap is filled by the HDCC data interpolation process. Gaps with a duration of less than 5 days, are filled by an automatic interpolation process.

PENDING: Pending action, this applies to gaps recently detected.

NOT FILLED: No interpolation or filling is carried out. It usually happens for gaps longer than 5 days. The gap remains.

In the case of interpolated data, if the missing data from the data provider is received at a later stage, the new data replaces the interpolated data.

Figure 11 shows the distribution of gaps status for each duration interval. Most gaps (of less than 3 days) are filled either through interpolation or data from the DPs. Roughly half of the gaps between 3 and 10 days are filled with data from the DP, a quarter is filled by interpolation and the last quarter remain not filled. Gaps longer than 10 days are not filled and will be permanent unless the data providers deliver the missing values.

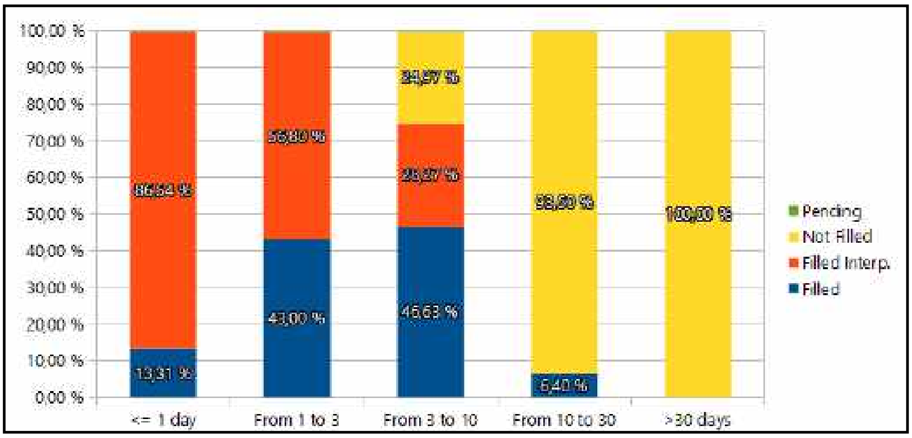


Figure 11.Percentage of gap status by gap length.

Other aspects to be considered

The 83,357 gaps analysed add up to 1,936,029 missing values covering a total of 37,113 accumulated days. The average length per gap is 0.4 days (10 hours), whereas the average number of gaps per station and variable is about 38.4; hence an average of 17 days of gaps for each data variable.

Figure 12 presents monthly boxplots with the percentage of received data against expected data for each data provider. The mean value ranges between 90.4 and 95.7 %, although some data providers provide lower ratios.

When comparing these values to 2018 the mean received data percentage for 2019 is lower (92.4 against 95.5 %). The main reason for this is that stations belonging to Narva, Parnu and Käsari basins in Ukraine interrupted the data delivery from January to September and stations from France had a very low reporting rate from January to April.

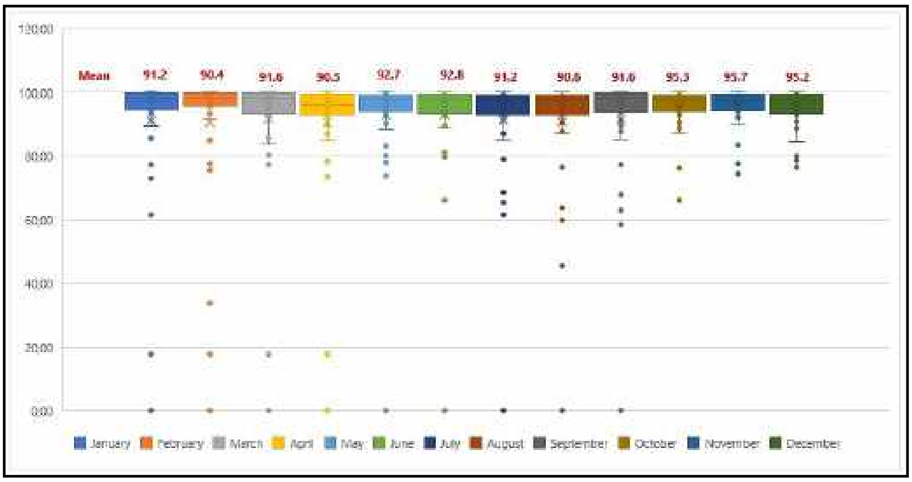


Figure 12. Box plot showing the monthly percentage of data received, out of the expected number of data records to be delivered from EFAS data providers.

The maps in *Figure 13* and *Figure 14* show the spatial distribution of gaps, with respect to the average gap duration (days) and maximum gap length (days), respectively.

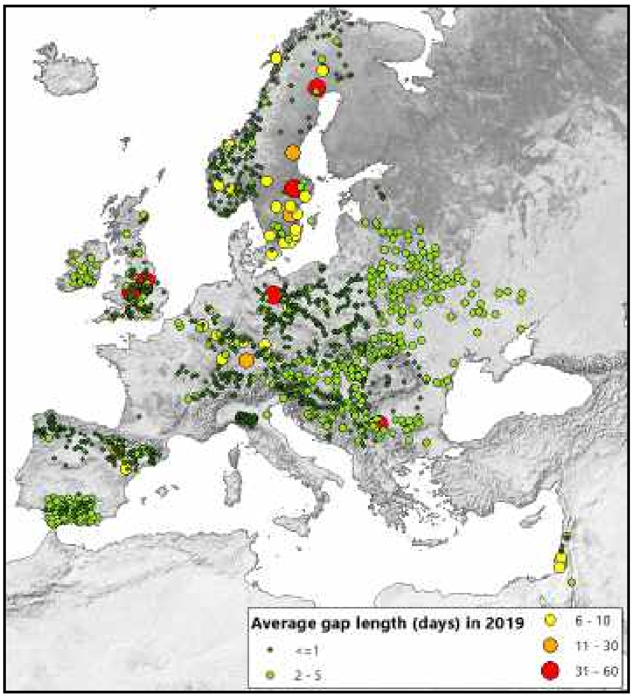


Figure 13. Average gap length in days per station.

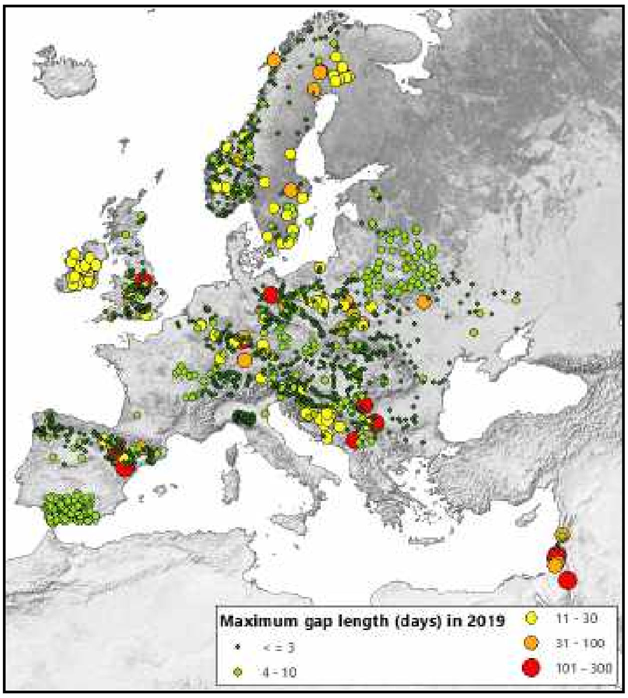


Figure 14. Maximum gap length in days per station

Gap typology and proposal for future data collection strategy

In only 1071 cases (1.3% of all gaps), gaps were longer than 3 days and required the HDCC to communicate with the data provider. Based on communication with the data providers and their replies, it was possible to establish a gap classification system based on gap causes *(see Table 5)*. This classification helps to develop and propose a series of measures to improve the data collection strategy both quantitatively and qualitatively.

Table 5: Gap classification with possible solutions

GAP TYPOLOGY	FURTHER INFO	% OF OCCURANCE	RECOMMENDATION / POSSIBLE SOLUTION
Technical issues between data provider and HDCC	Issues concerning the Data Collection service between data providers and the HDCC: Delays in data transfers from data provider to HDCC, changes in IP addresses, problems with the servers... etc.	26.24	Improving communication with data providers to achieve a more efficient and faster solution. (Prompt communication when missing data is detected or when IP addresses are changed)
Limited resources of data provider to attend data gap requests	Lack of technical personnel available to attend data gap requests on behalf of HDCC.	18.49	No easy solution exists as it does not depend on the HDCC. Some agreement between the HDCC and data providers might help minimize the effort needed (data services access, etc...). Otherwise this could result in the number of gaps to grow, issue should be discussed with EFAS.
To be determined.	No information on this type of gap	18.21	These are the cases of the smallest gaps (from 3 to 5 days). As it is not known which might be the cause of these gaps, it is difficult to propose a solution.
Lack of reply from data provider.	Data provider usually reply to HDCC communication, but on certain occasions we don´t receive replies.	13.72	These issues rely enterely on the data provider. A meeting between HDCC and data provider to analyse the situation is highly recommended.
Communication Failure between Sensor and data provider	Communication Failure between Sensor and the facilities responsible for the data collection and transmission.	7.94	This relies on the data provider (data collection and transmission personnel). Quick communication help minimize the impact of missing data.
Data Sensor Failure	Sensor malfunction that causes data transmission failures, or wrong/unexpected data to be sent (i.e -9999 values).	6.72	The solution is repairing the sensor, or replacing it with a new one. This solution depends directly on the data provider.
Gauging Station out of order	Usually caused by breakdown, maintenance, repairs, etc. as a consequence of lightning, floods, sensor replacement, long term breakdown...	5.41	If the station has any alternative sensor with identical characteristics, those data could be an alternative.
Readings taken only during specific hydrological conditions	Data values only obtainable under specific conditions (i.e. above a certain water level).	2.52	For this kind of issues our proposal, whenever possible, is to look for an alternative station. In case this is not possible, it would be advisable to find out if missing values can be calculated from the station rating curve in order to complete the data series.
Extreme Meteorological Conditions beyond sensor capacity.	Extreme Meteorological Conditions that obstructs the correct functioning of the sensor. Frozen rivers are the most common cases in this category.	0.56	We need to consider if the extreme meteorological conditions are odd and very rare situations or if they occur on a regular or frequent basis. If the events are regular and frequent, either an alternative station or a different placement would be advisable.
Delay due to stations requiring a manual intervention	Delay in the data collection of stations which require a manual intervention of personnel as well as lack of personnel to obtain the data.	0.19	HDCC always procures to maintain quick communication with data providers when no data is being received.

Figure 15 shows the number of gaps for each category classified by gap duration.

The following considerations may be useful as well:

- If a specific station presents gaps repeatedly, an alternative station (located nearby) could be proposed as replacement or the station could be removed from the system.
- When transmission data often delays for a specific data provider or station, a possible solution to avoid the unnecessary communication between HDCC and DP could be to increase the response time for the data collection process, i.e., increase the time before considering the data as missing. This measure would reduce the need for HDCC to intervene when the missing data is likely to be automatically updated in the following data transfer.
- For gaps that are of less than 1 hour or apparent gaps in time series with irregular observation frequency, these could be avoided by normalizing the data series (i.e. aggregating data to 1-hour operational tables).

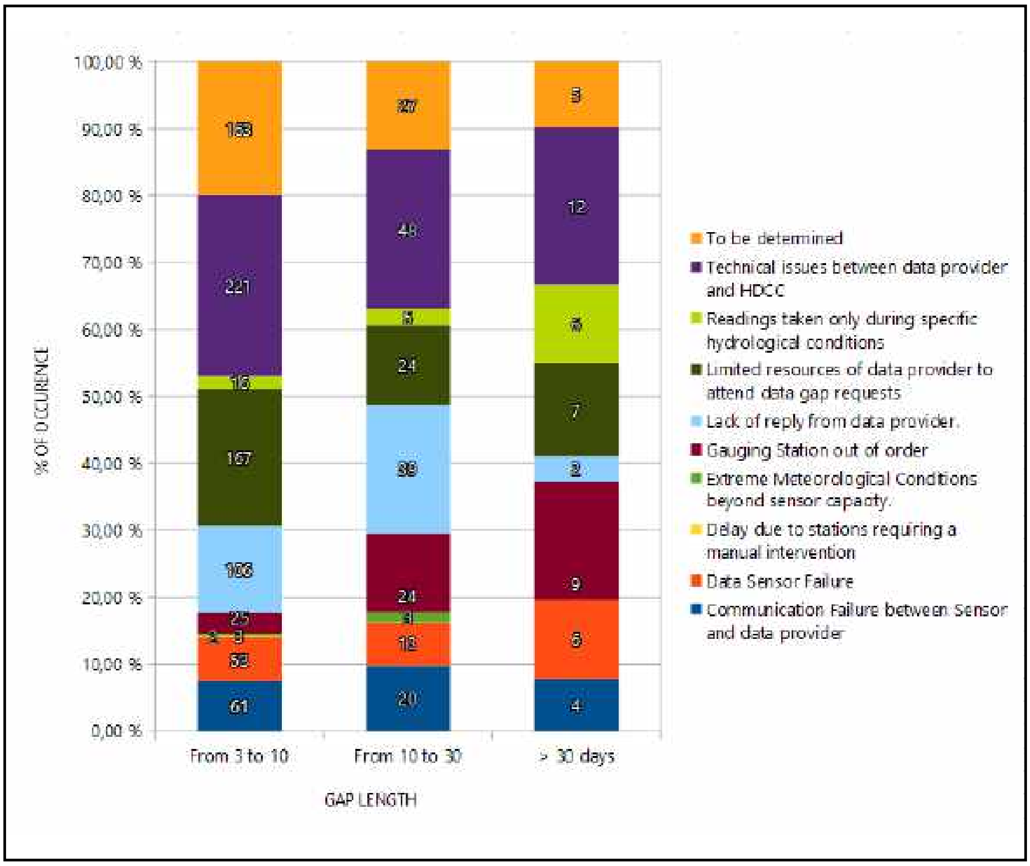


Figure 15. Number/percentage of gaps by/per duration and typology.

Outliers analysis

One of the data quality control procedures of the HDCC checks for outliers. Outliers are defined as values that are beyond their minimum or maximum threshold level. Those threshold levels usually correspond to the historical minimum and maximum value recorded by that station. Hence, they are station and variable specific and are usually provided by the respective DP.

Once a data value exceeds its threshold level it is marked in the database for further visual inspection. This is necessary step for deciding if this outlier is an actual erroneous value or merely the consequence of a natural event. If an outlier is confirmed to be an erroneous data value, then it is flagged as such. If several consecutive outliers are detected, these are defined as a set of erroneous data values.

A total of 163,672 outliers were detected in data from 434 stations out of the 1,558 stations studied in this report. Considering that the total number of values received is 60,554,250, the rate of outliers is approximately 0.27 %.

Figure 16 illustrates the different types of outliers according to their aggregation and frequency.

Most outliers detected are single values while large aggregations are the least frequent.

Figures 17, 18 and 19 show the stations that registered outliers in 2019, the total outlier's duration in days per station and the rate of outliers relative to received data for each station.

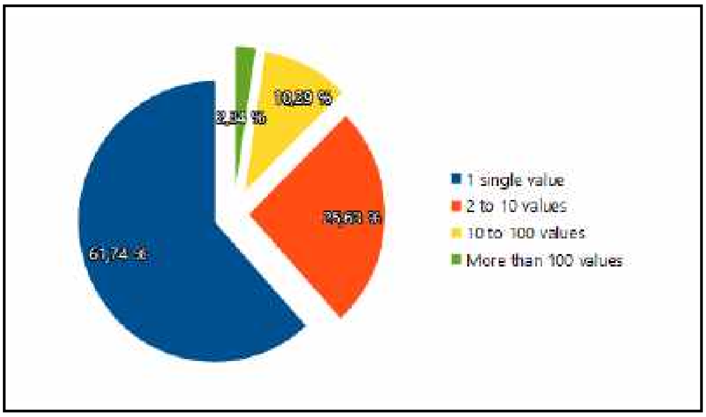


Figure 16 Sets of outliers and their frequencies

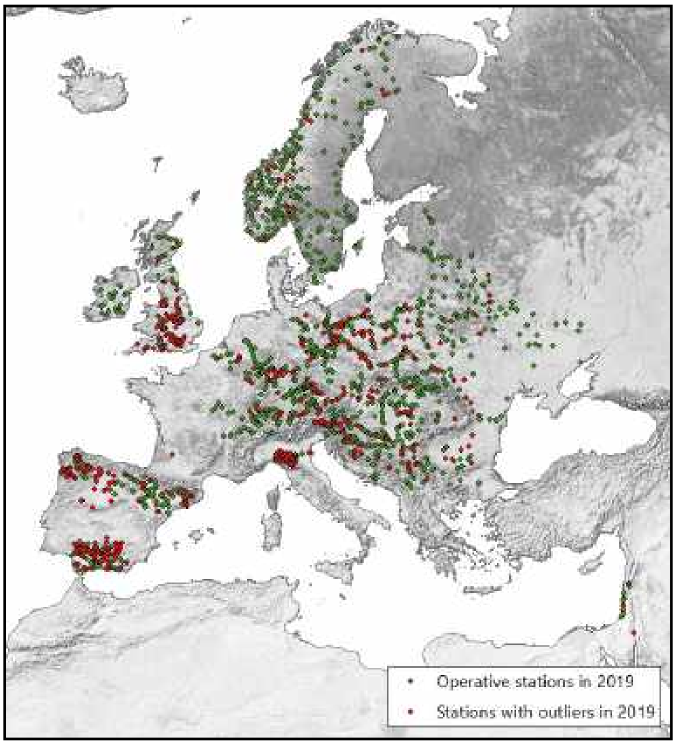


Figure 17. Stations that registered outliers in 2019

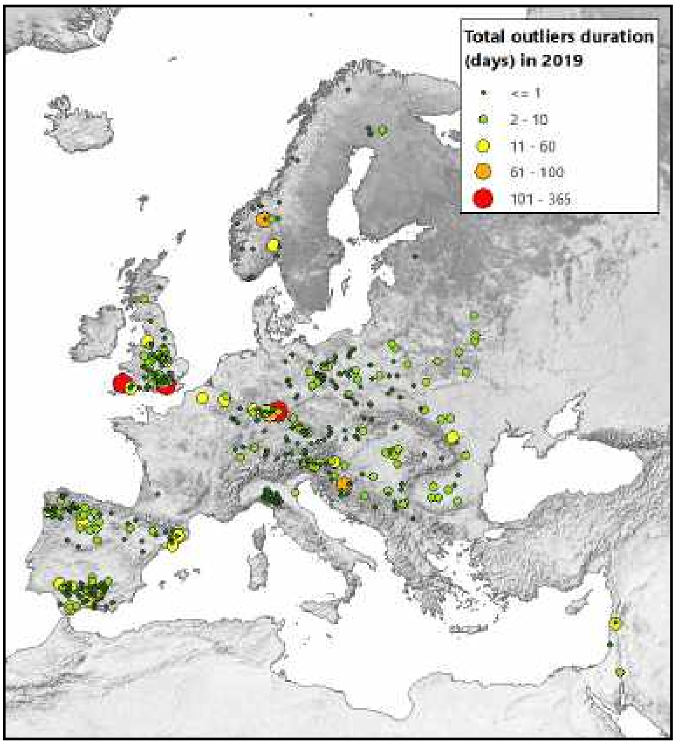


Figure 18. Total outliers duration in days in 2019.

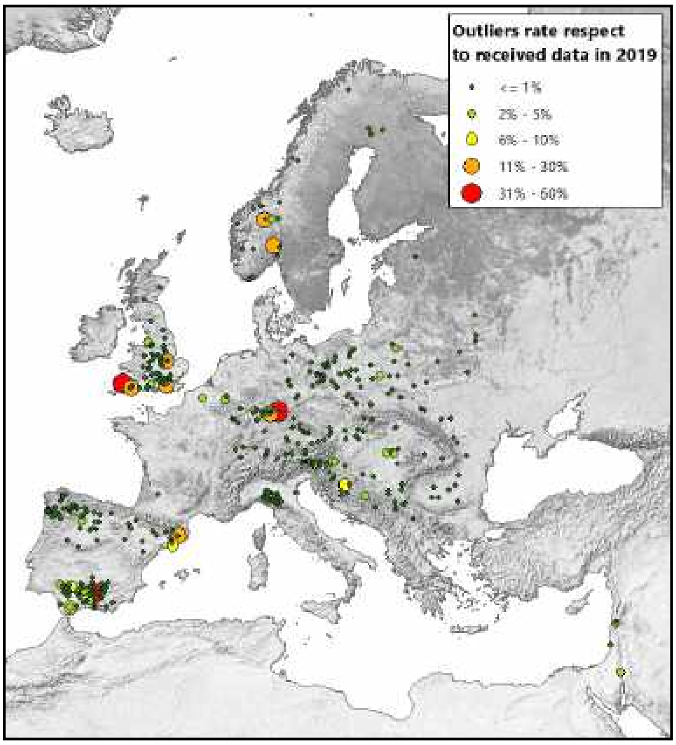


Figure 19: Percentage of outliers occurrence relative to the total amount of data received per station in 2019

3 Analysis of Exceedance Events

In this section the hydrological stations that exceeded their threshold level during 2019 are analysed. A threshold level is a gauging-station specific value, usually discharge or water level, provided by the national/regional authorities responsible for a gauging station network. The number of threshold levels varies from 0 to 4 for each station. These levels help the authorities in assessing the current hydrological situation, and in case of a threshold exceedance they can start to plan and implement mitigation measures.

The analysis focuses on the exceedance of threshold levels for high river flows. An event is defined as each time a measured discharge or water level value exceeds any of the station's threshold levels. The event duration is considered from the first level exceedance until the values again drop below the lowest threshold level.

All near real-time observations (water level and discharge) are displayed on the EFAS website in the "National flood monitoring" layer. Where available, also the national/regional threshold levels are shown and exceedances of those are highlighted by the HDCC.

General description

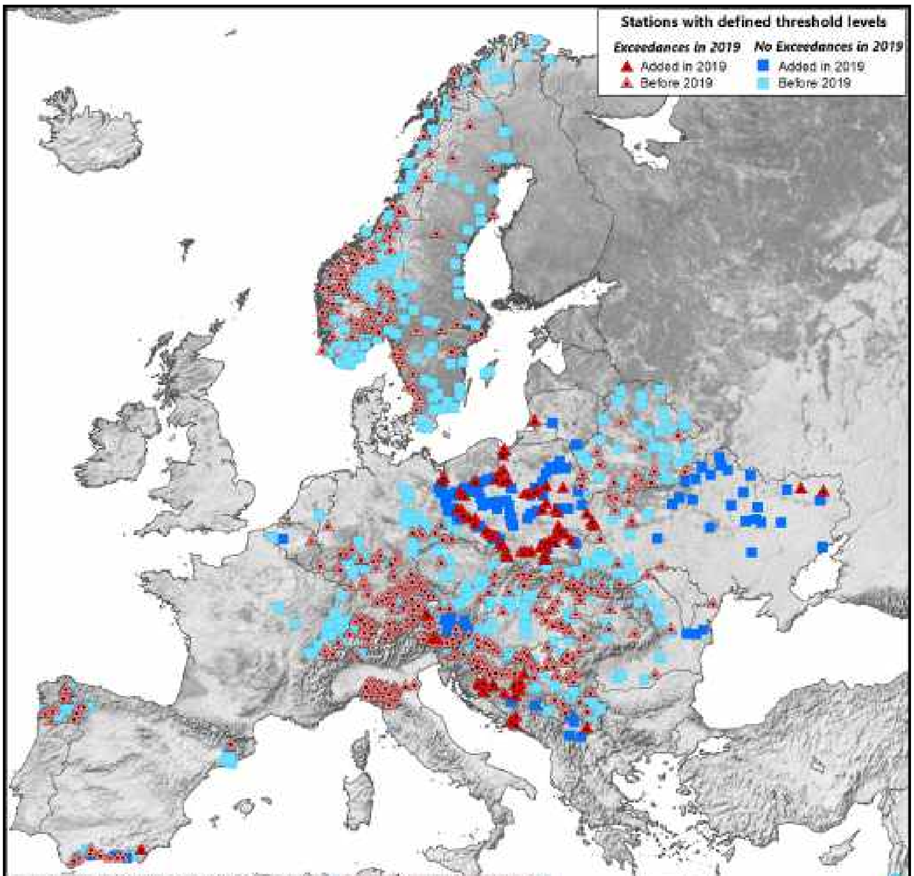
Out of the 1,558 active stations initially selected for this report, threshold levels are available for 1,092 stations (70%) *(light and dark blue stations in Figure 20)*. Compared to 2018, the number of stations with at least one threshold level has increased by 206 and these stations now cover a total of 559 rivers, 171 basins and 24 countries *(see table in Figure 20)*, rising the number of rivers, basins and countries by 55, 8 and 4 respectively, in 2019.

The new countries that have been included in 2019 into the EFAS stations threshold level monitoring system are:

- Kosovo, with stations located in the Drin-Bojana, Ibar, Lepenac and Danube basins.
- Bosnia and Herzegovina, where three new rivers in the Neretva basin have been incorporated and more stations have been added over different rivers in the Danube basin.
- Lithuania, where the number of stations on the Neman river has been increased and a new station has been added on the Atmata river.
- Poland, where new stations have been added to the Oder and Vistula basins, covering 9 and 13 new rivers, respectively.

In addition, four new basins were incorporated: one in Spain (the Almanzora basin) and three in Ukraine (the Don, Kalmius and Southern Bug basins). Lastly, the following basins have increased their number of stations in 2019: Danube, Dnieper, Guadalfeo, Guadalhorce, Oder, Vistula and Scheldt.

Red tones triangles in *Figure 20* represent stations that had threshold levels exceedances; 552 stations (51%) had at least one of their threshold levels exceeded in 2019. This covers 55% of European rivers and 54% of European basins. Out of 24 countries that share data, only 2 (Belgium and France) did not register any threshold exceedances. However, these two countries have very few stations with threshold levels (2 and 3, respectively).



Threshold level	Station available in the HDCC data base	Stations	Rivers	Basins	Countries
Not exceeded	<2019	886	504	163	20
	2019	[illegible]	[illegible]	[illegible]	[illegible]
	Total	1,092	559	171	24
Exceeded in 2019	<2019	458	277	88	18
	2019	[illegible]	[illegible]	[illegible]	[illegible]
	Total	552	307	92	22

Figure 20: Stations with no exceeded threshold levels in 2019 (in blue tones), differentiating between stations already existed in 2018 and stations added in 2019. Stations with threshold levels exceeded in 2019 in red tones (stations existed in 2018 and stations added in 2019). The table shows a summary of threshold levels (exceeded and no exceeded) in 2019 by spatial aggregation levels (station, river, basin and country), providing the total number of stations, rivers, basins and countries in 2019 (all).

Duration of exceedances

Duration per station

Figure 21 shows the number of events and their total duration per station. A total of 2,747 exceedances were recorded during 2019 at 552 stations, nearly twice as many events compared to 2018 (1,443 exceedances at 458 stations).

In 2019 most stations recorded between 1 and 8 events. The average number of events per station has increased from 3 in 2018 to 5 in 2019, while the average accumulated duration of the events per station has decreased from 14 days in 2018 to 7.6 days in 2019.

For 80% of the stations, the accumulated duration of all events lasted less than 10 days. Longer accumulated durations (between 10 and 108 days) were found among stations in the Danube, Po, Dnieper, Rhine, Minho, Vistula, Neretva, Neman, Don and Fyris basins *(see Figure 21)*.

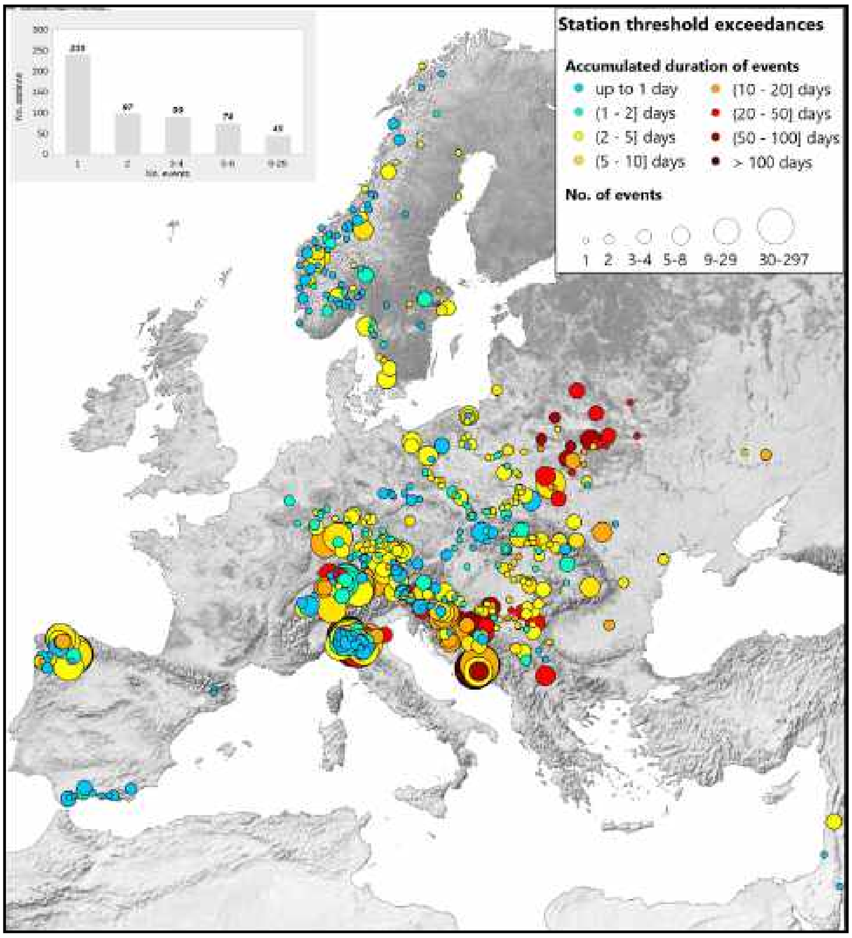


Figure 21. Station classification according to number of events (symbol size) and total accumulated duration of exceedance events (colour coding). Bar chart on the upper left corner shows the number of stations per event frequency.

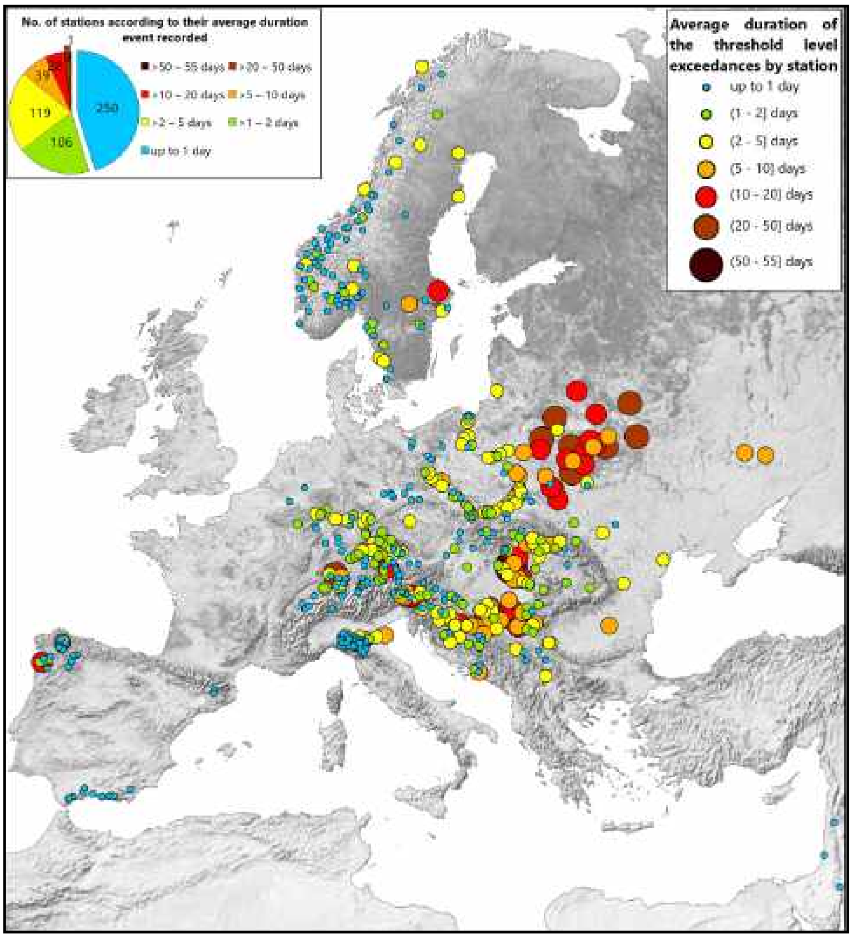


Figure 22. Average duration of events for EFAS stations in 2019 and number of stations according to the average duration event recorded in each station (pie chart).

Figure 22 shows the average event duration per station, which has decreased from 7.5 days in 2018 to 3 days in 2019. For 64% of the stations the average duration is less than 2 days. These stations are mainly located across rivers in Germany, Norway, Italy, Austria, Spain, Poland, Sweden, Switzerland, Romania, Slovakia and Bosnia and Herzegovina.

On the other side, the longest average durations (22 to 54 days) were recorded at stations across:

- The Danube basin, on the Tisza River through Hungary (54 days) and Serbia (21.7 days)
- The Dnieper basin, on the Styr river through Belarus (34.5 days) and Ukraine (23 days) and on the Dnieper (29), Sozh (22 days) and Ubort (22 days) rivers in Belarus
- The Vistula basin, on the Narev river (28 days)
- The Neman basin on the Neman river (25.5 days)
- The Rhine basin, on the Untersee river in Switzerland (24 days)

Duration of events

As mentioned above, there have been more exceedance events in 2019 than in 2018, but with a shorter duration. Considering all the events, the average duration in 2019 is 1.5 days, one third of the average duration in 2018. Also, 75% of the exceedance events in 2019 lasted less than 1.1 days, compared with 2.7 days in the previous year. The remaining 25% is distributed as follows: 15% of the events lasted between 1.1 days and 4 days, 5% lasted from 4 to 7 days and 5% lasted from 7 to 54 days. Stations with short events often have more frequent events, which explains the difference between the average of all events here and the average length for each station above.

Events lasting less than 1.1 days were the most common and occurred across 75% of the rivers. Out of the 307 rivers with exceedances, the ones with the largest number of short events are located on the Stirone, Torrente Chero, Secchia, Cedra, Taro and Panaro rivers, in the Po basin (Italy), on the Inn river, in the Danube Basin (Austria), on the Burbia river in the Minho basin (Spain) and in the Neretva basin (Bosnia and Herzegovina), on the Neretva and Trebizat rivers. Most events took place during the spring (May and June) and the autumn months (November and December). In the months leading up to both seasons (March-April and October), the fewest events were registered.

The longest 12 events (over 30 days) started between the months of January and May and in November. They were located across:

- Ukraine (on the Stokhid and Western Bug rivers)
- Belarus (on the Narev, Neman, Pripyat and Styr rivers)
- Croatia (on the Danube and Sava rivers)
- Bosnia and Herzegovina (on the Krupa river).
- Hungary (on the Tisza river, in the Danube basin, with a threshold exceedance event that lasted 54 days (207 days in 2018), from 8 April 2019 to 1 June 2019.

Single case analysis showed that not all threshold level exceedance events correspond to actual flood events, but rather with relatively low first national threshold levels. This seems to be the case for Tisza River in the Danube basin. The long threshold exceedance events (above 30 days) that happened in Belarus rivers do correspond to a real flood event, a result of the recession of spring waters lasting more than 30 days.

High threshold level exceedances

This section identifies the most severe events. As mentioned above the number of threshold levels per station varies across Europe between 0 and 4. In this subsection we will treat the following cases as high level events:

1) stations with more than 1 threshold level, and the highest threshold has been exceeded

2) stations that have only 1 threshold level, and the level (discharge or water level) has been exceeded by at least 50%.

Figure 23 shows the spatial distribution and duration of the high level events for 2019. 62 stations exceeded 1) or 2).

75% of these stations are located across the following basins: Po (23%), Danube (21%), Vistula (21%) and Minho (10%). The remaining 25% are found in the basins: Aker, Anråsa, Dnieper, Glomma, Guadalhorce, Neman, Oder, Rhine, Stjørdal and Storelvi.

In 2019, just over 3% of the events can be defined as high level events. Although the total number of exceedance events in 2019 was almost the double of the number in 2018, the number of high level events was very similar for both years. 75% of the high threshold level events were located in the Po (15 events), Danube (24 events), Minho (7 events), Vistula (4 events) and Rhine (3 events) basins.

The longest events (over 5 days) occurred across Belarus (on the Neman in the Neman basin and Goryn rivers in the Dnieper basin), Austria (on the Lake Millstatt in the Danube basin) and Italy (on the Po river). Events lasting between 2 and 5 days occurred on the Po river in Italy, Vistula river in Poland, Lake Faak (Danube basin) in Austria, Krasna river (Danube basin) in Ukraine and Minho river (Minho basin) in Spain.

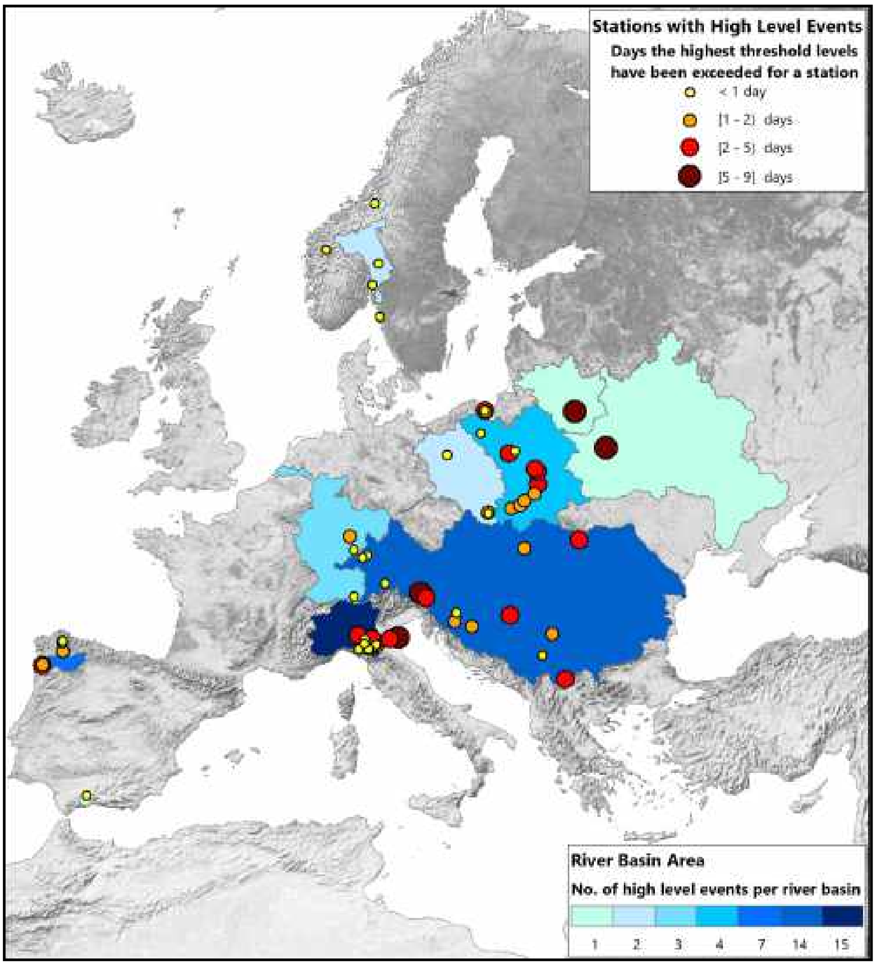


Figure 23. Duration of the high level events and river basins where the stations are located.

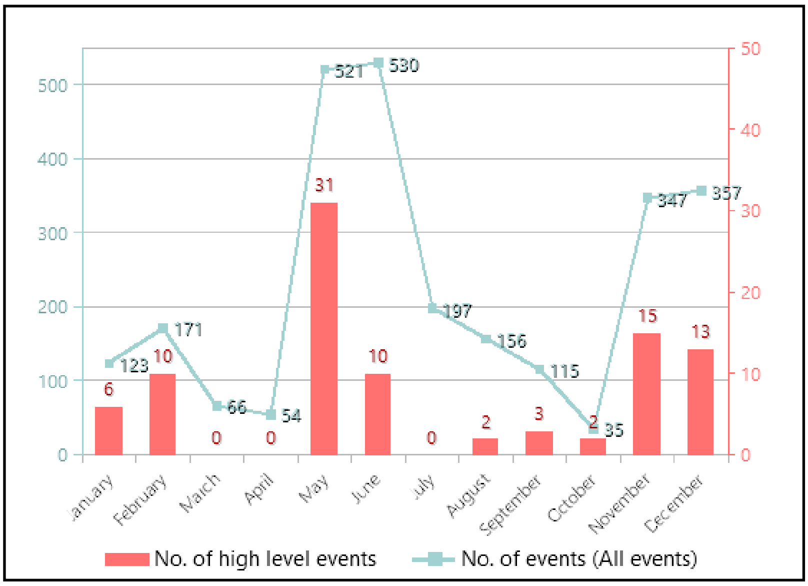


Figure 24. Number of high level events vs total events per month in 2019.

Figure 24 illustrates the total number of events (in blue) and the number of high level events (red bars) by month. May was the month with the largest number of events. Most high level events were registered in May, November and December, whereas no high level events occurred in the early spring (March, April) and hardly any during the summer months (July even none).

Lastly, the most severe events in terms of duration and magnitude were recorded on:

- Danube, Inn, Korana, Sava and Una rivers and Faak and Millstatt lakes (Danube basin)
- Goryn river (Dnieper basin)
- Labrada, Ladra and Minho (Minho basin)
- Neman, (Neman basin)
- Cedra, Po, Secchia and Taro rivers (Po basin)

4 Hydrological analysis

Introduction

In December 2019 intense weather events in South-Western Europe caused severe floods and consequently damages. The European Flood Awareness System produces an annual detailed assessment report that this year is focused on this event in four river basins in the northern area of Spain, where three chained meteorological events occurred: storm Daniel, that reached the Peninsula on 16th of December and affected the western side of Spain; storm Elsa, that started to have effects in Spain on the 18th of December and had impact until the 20th of December over almost all the country; and thirdly storm Fabien, whose life cycle ended the 22nd of December, when it dissipated between the Netherlands and Denmark.

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 (see the full detailed assessment document at: https://www.efas.eu/report/assessment-report-flood-events-northern-spain-december-2019). 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 25)*.

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 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.

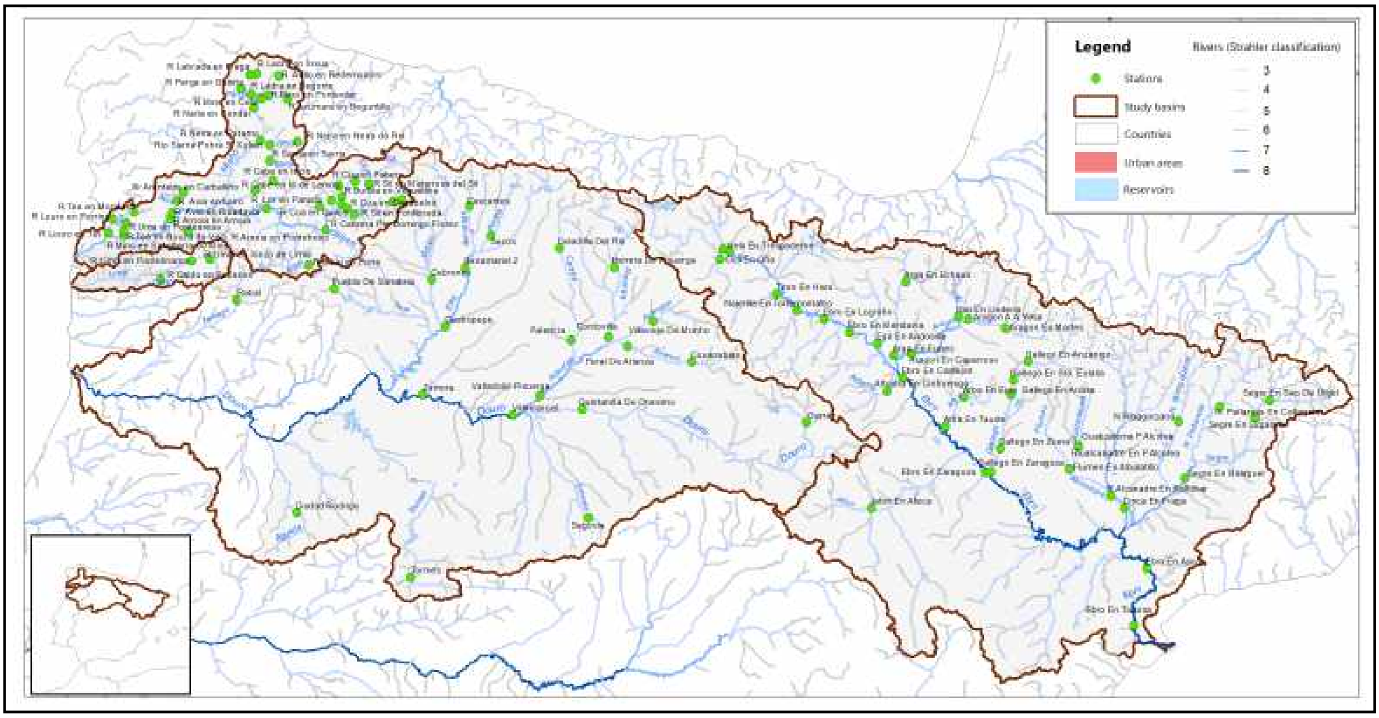


Figure 25. Spatial distribution of Efas station along Ebro, Douro, Minho and Limia basins.

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^f_{max}) and the maximum discharge on the day before the event starts (D^i_{max}), divided by their sum:

$$NVI = \frac{D^f_{max} - D^i_{max}}{D^f_{max} + D^i_{max}}$$

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 2 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 26).*

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, 99thand 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 27 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 31).*

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 28* as an example, where the comparison is an event from 2016).

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 29 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).*

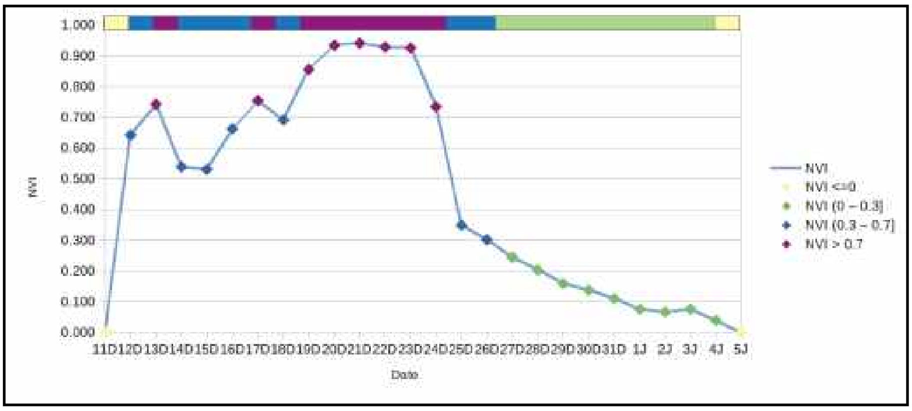


Figure 26. Example of NVI analysis. "Rio Louro en Tui" gauge station.

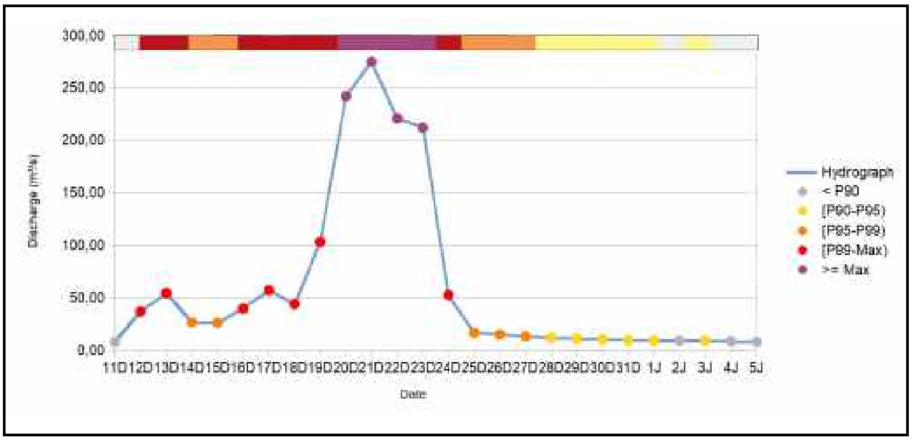


Figure 27. Example of percentile analysis. "Rio Louro en Tui" gauge station.

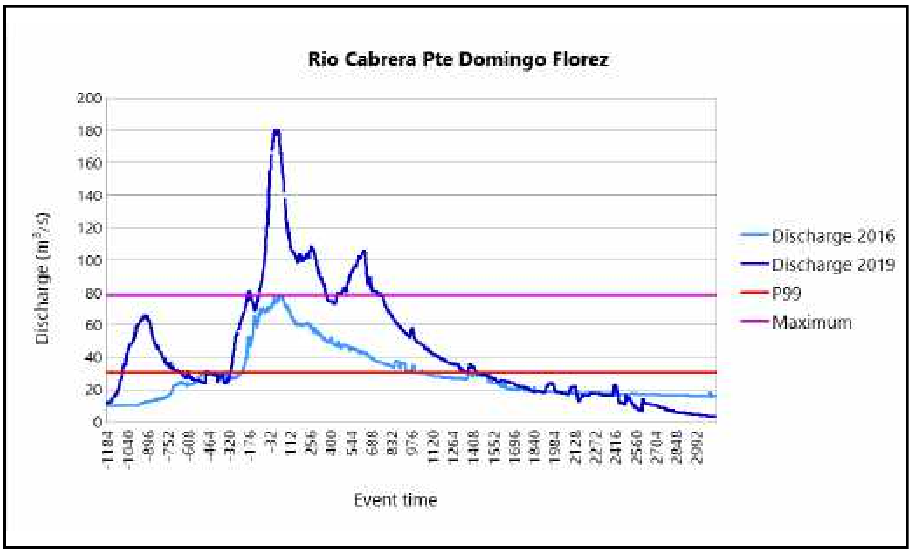


Figure 28. Example of an event comparison at hydrograph-level.

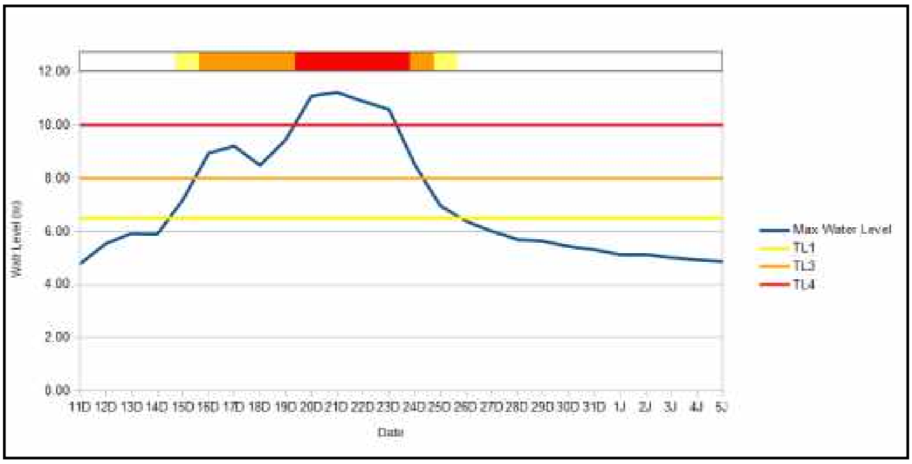


Figure 29. Example of a threshold exceedance evaluation. "Río Miño en Salvaterra do Miño" gauge station.

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.

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 30)*.

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 Limia basin exceed the NVI of 0.7 for 9 days. Two of those stations remain with an NVI of 0.3-0.7 till the end of the analysed period (5 January 2020).

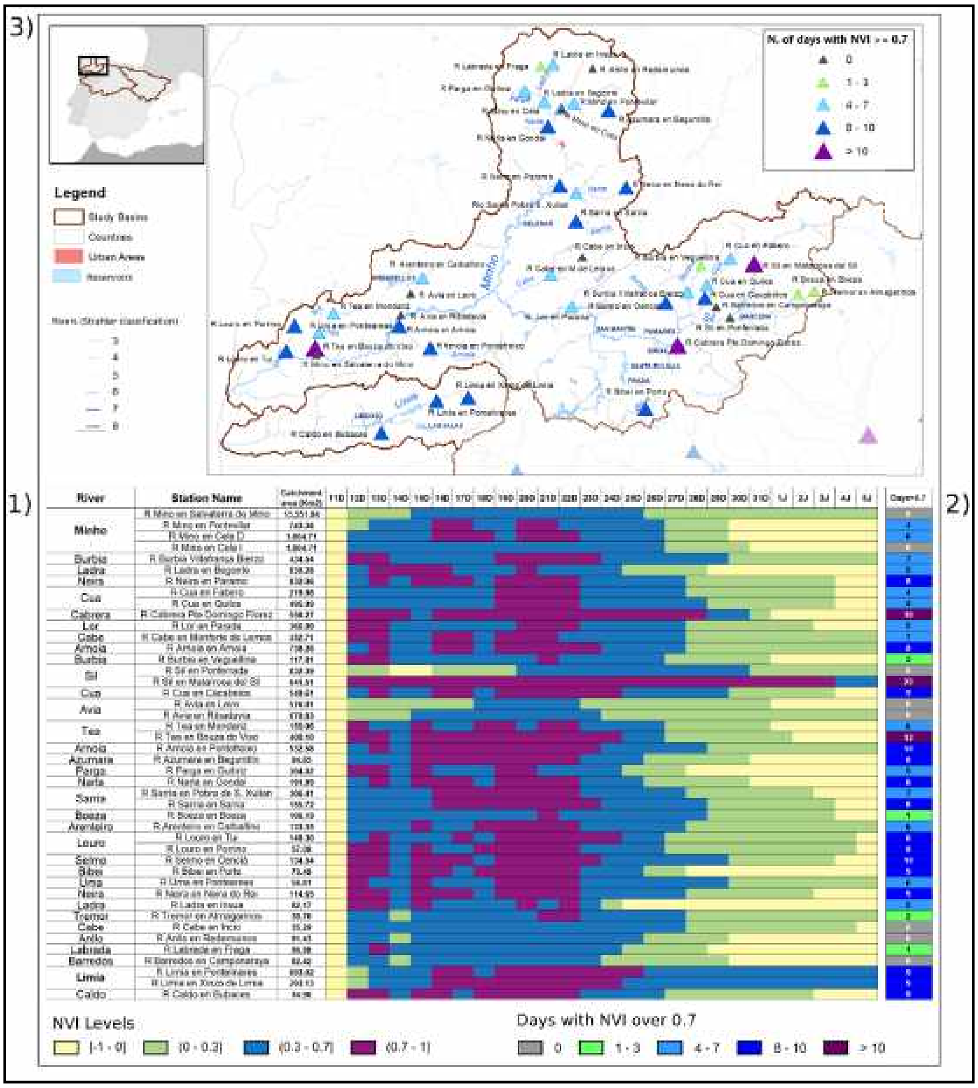


Figure 30. NVI analysis for the Minio and Limia basins. 1) Calendar matrix showing the evolution of NVI levels. 2) The number of days with NVI > 0.7 by river and station. 3) Map of stations representing the number of days with NVI > 0.7 grouped in 5 classes.

Figure 31 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 5 years. An even stronger indication is that the stations with the largest catchment area in both basins exceed the maximum, for 4 days in Minho (R. Miño en Salvaterra do Miño) and for 3 days in Limia (R. Limia en Pontelinares, see Figure 8). 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 (actually 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 7 days above the 99th percentile.

The previously most extreme event in the Minho-Limia since 2014 occurred from 9 to 23 February 2016. *Figure 32* 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 5 minutes.

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 33)* 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 located in the northern part of the basin, in the upstream tributaries of the Minho river and the Belesar reservoir.

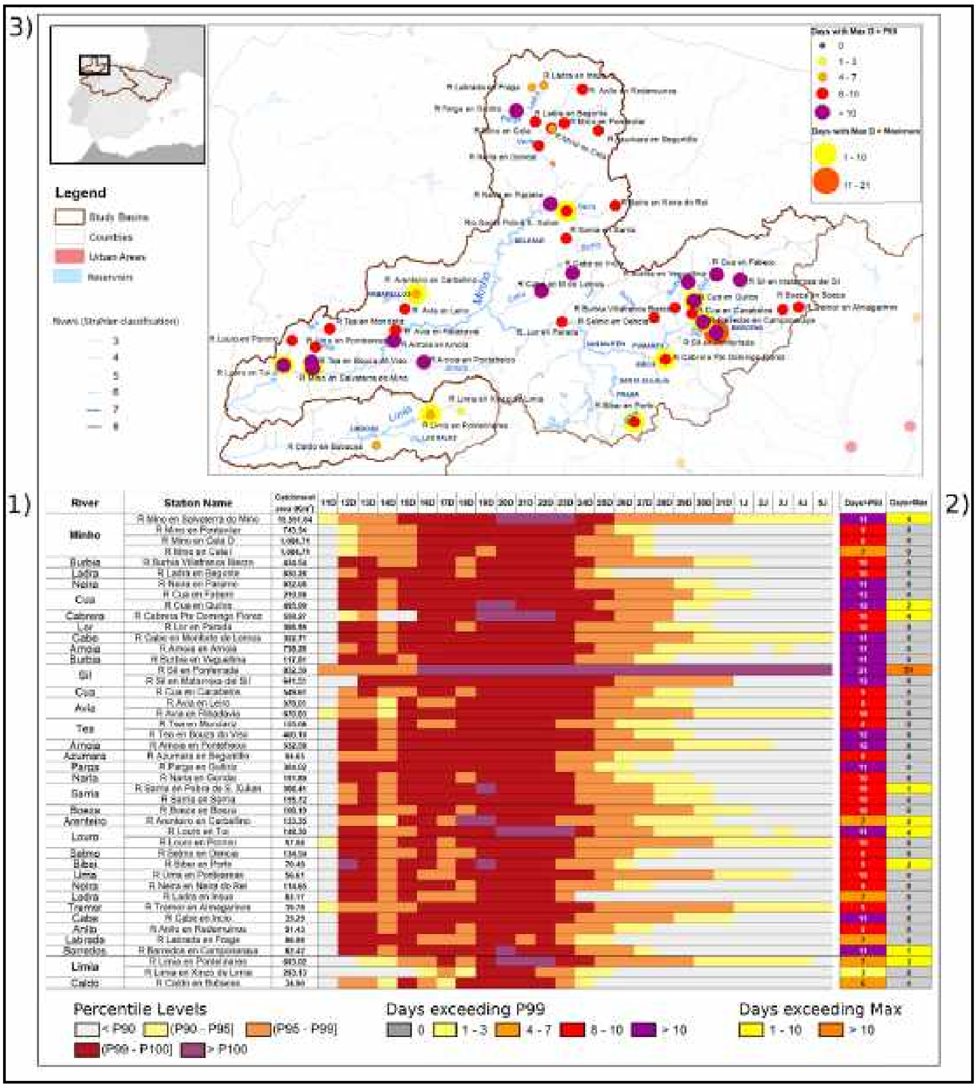


Figure 31. Percentiles analysis for the Minho and Limia basins. 1) Calendar matrix showing the evolution of Percentile levels. 2) The number of days with Maximum Daily Discharge (MaxD) > P99 and MaxD > Max by river and station. 3) Map of stations representing the number of days with MaxD > P99 grouped in 5 classes and MaxD > Max grouped in 2 classes.

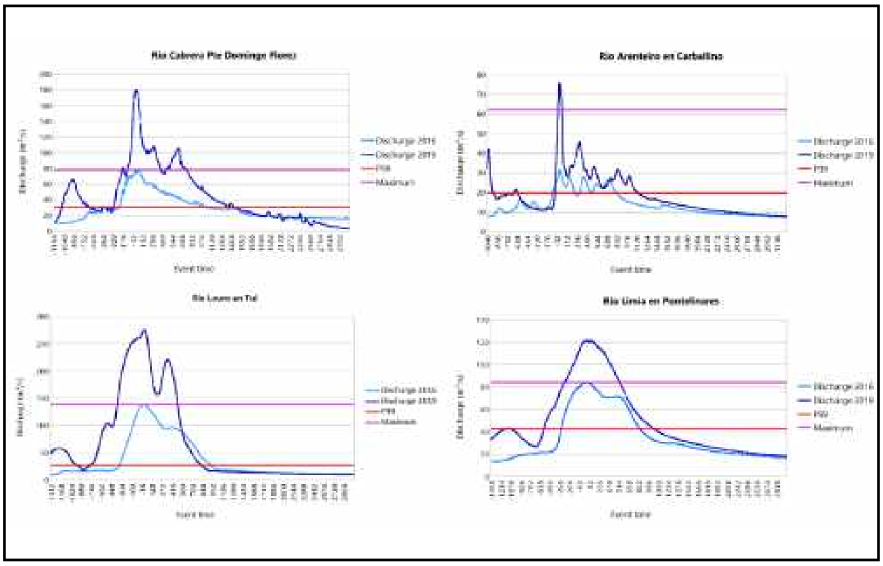


Figure 32. Comparison of the two largest events since 2014.

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 33)* 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 located in the northern part of the basin, in the upstream tributaries of the Minho river and the Belesar reservoir.

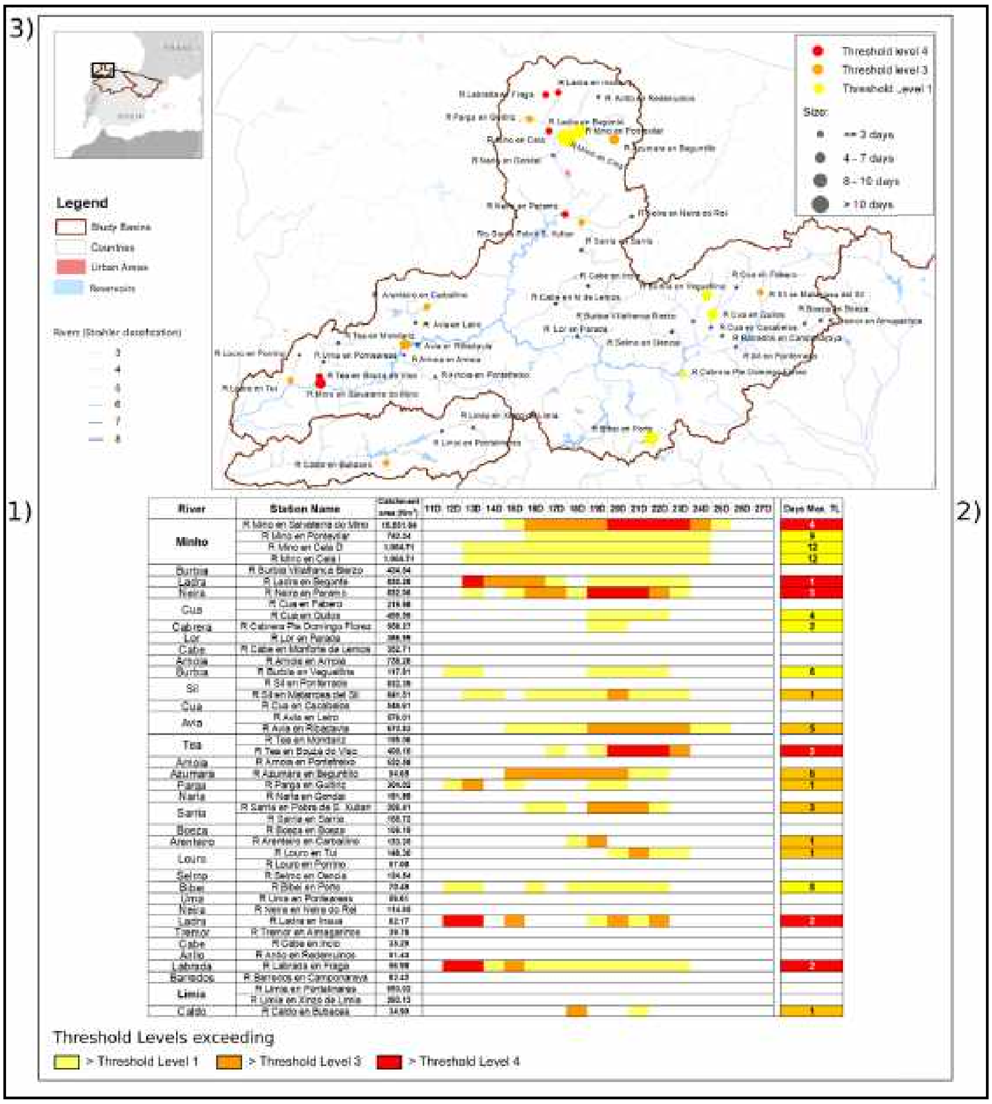


Figure 33. Threshold exceedance analysis for the Minho and Limia basins. 1) Calendar matrix showing the evolution of thresholds exceedance. 2) The number of days overpassing the maximum threshold by river and station. 3) Map of stations showing the number of days exceeding the maximum threshold level.

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 34)* 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).

A comparison of this event with the data from the past 7 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 3 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 5 days of exceedance, *see Figure 35*), Cascantes (for 4 days), Benamariel2 (for 3 days, *see Figure 35*) and Castropepe (for 4 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, as a consequence 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 2 days (December 23 and 24), Villamarciel and Valladolid-Pisuerga for 3 days (from December 22 to 24) and Quintanilla de Onesimo for 3 days (from December 23 to 25).

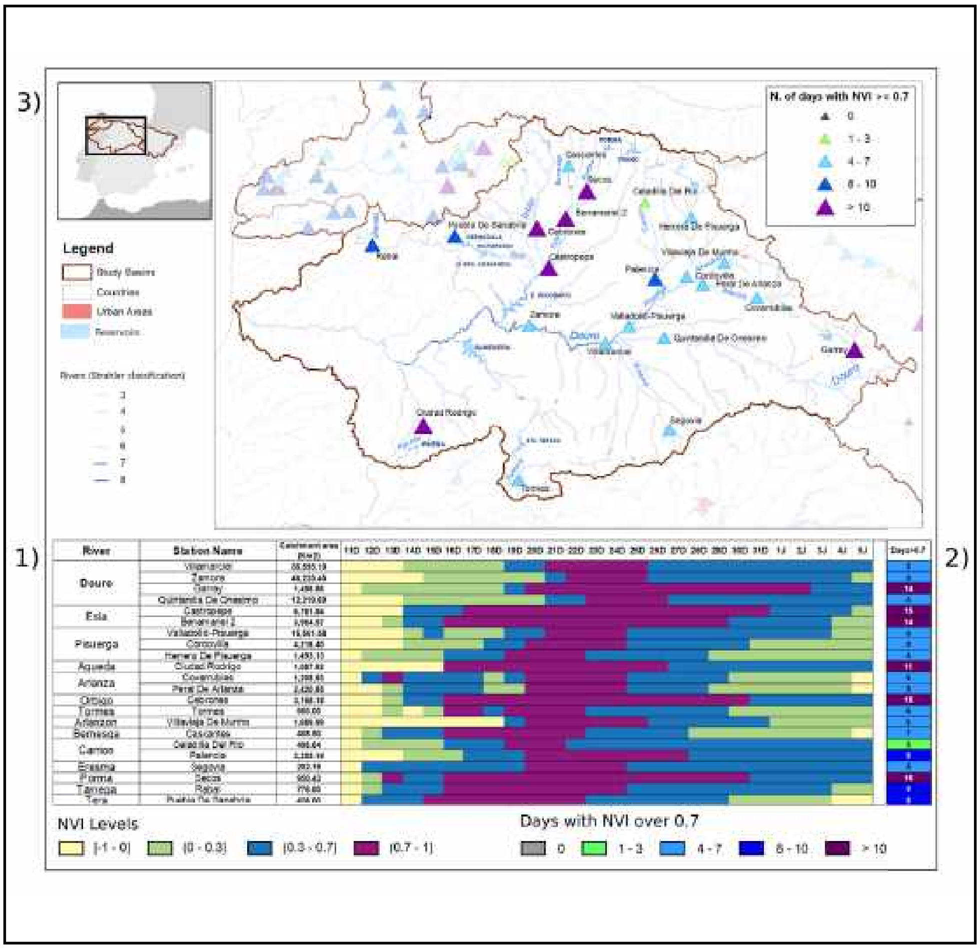


Figure 34. NVI analysis for the Douro basin. 1) Calendar matrix showing the evolution of NVI levels. 2) The number of days with NVI > 0.7 by river and station. 3) Map of stations representing the number of days with NVI > 0.7 grouped in 5 classes.

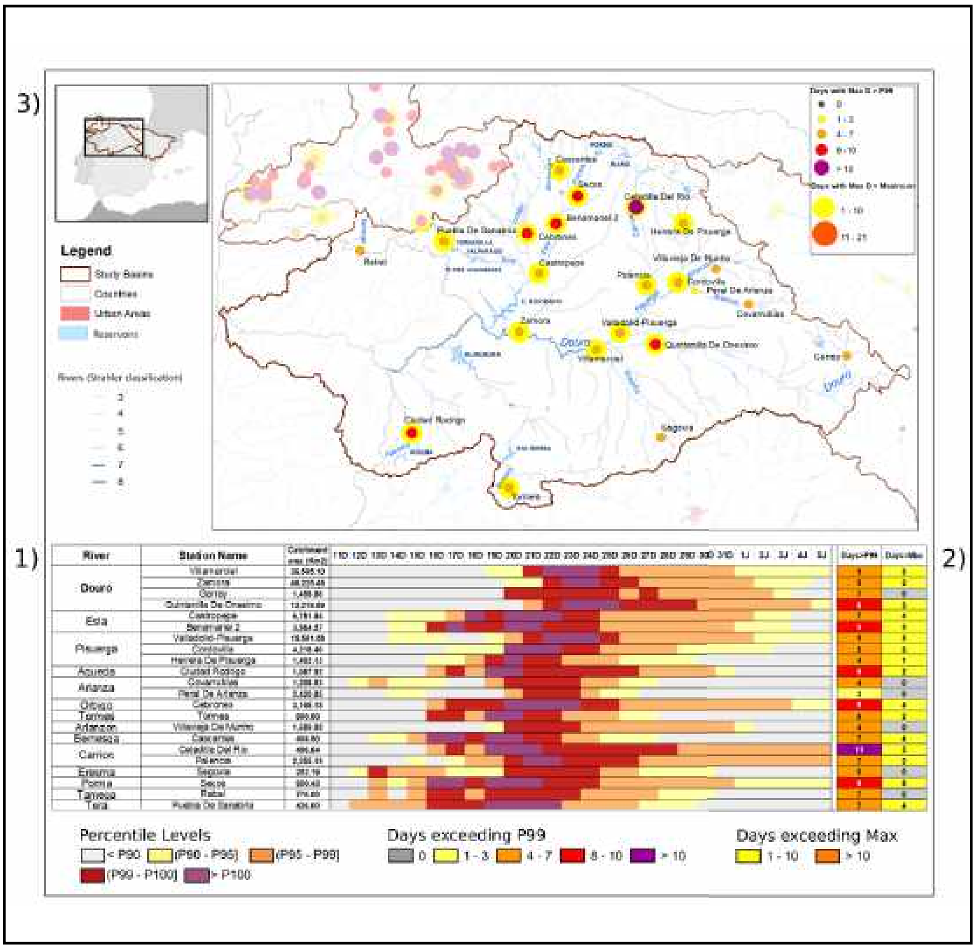


Figure 35. Percentiles analysis for the Douro basin. 1) Calendar matrix showing the evolution of Percentile levels. 2) The number of days with Maximum Daily Discharge (MaxD) > P99 and MaxD > Max by river and station. 3) Map of stations representing the number of days with MaxD > P99 grouped in 5 classes and MaxD > Max grouped in 2 classes.

Figure 36 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).

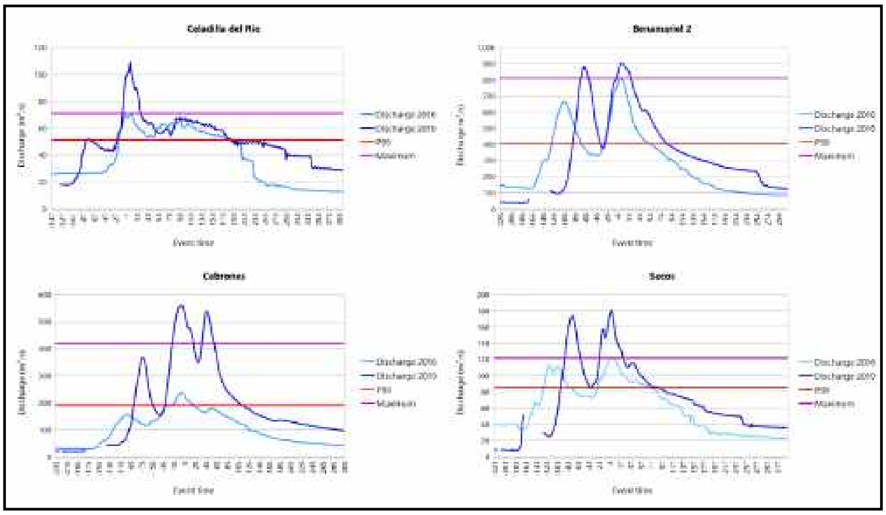


Figure 36. Comparison of the two largest events since 2014.

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 37)*. 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 3 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.

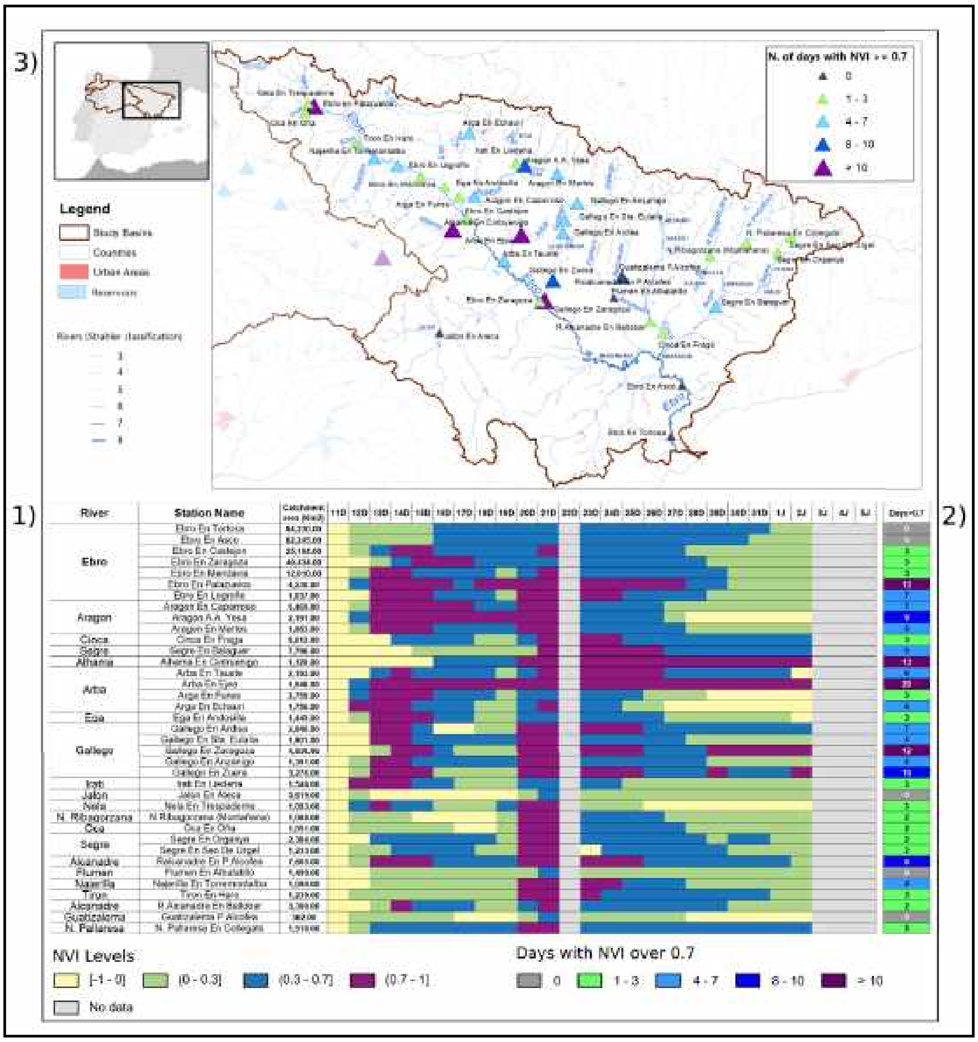


Figure 37. NVI analysis for the Ebro basin. 1) Calendar matrix showing the evolution of NVI levels. 2) The number of days with NVI > 0.7 by river and station. 3) Map of stations representing the number of days with NVI > 0.7 grouped in 5 classes.

A comparison of this event with the observations from the past 5 years (since 2014) shows that 75% of all stations exceeded the P99 threshold. The duration of those exceedances are, with a maximum of 6 days, mostly shorter than the ones observed in the other basins. Only four stations exceed the Maximum values: Aragon A. A. Yesa for 3 days, and Gallego en Anzanigo, Irati en Liedena and N Pallaresa for 1 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 subcatchments.

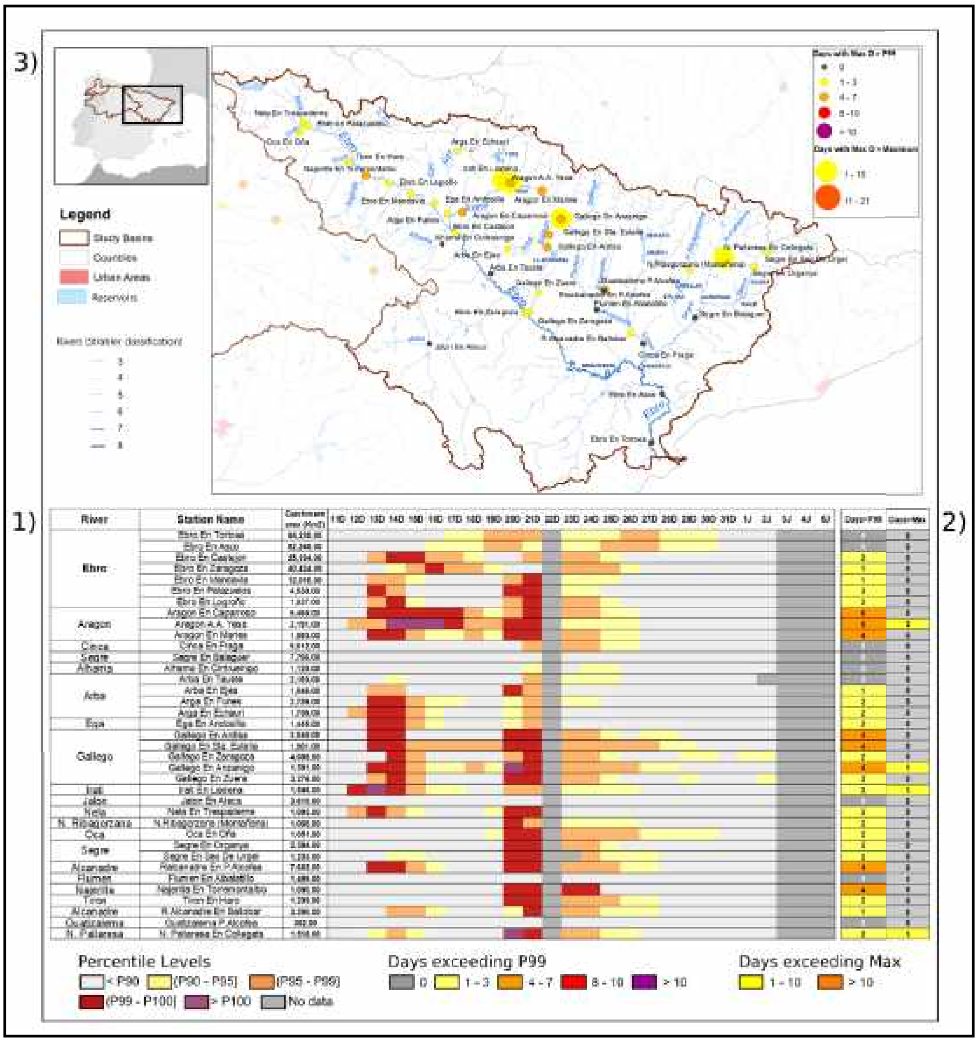


Figure 38. Percentiles analysis for the Ebro basin. 1) Calendar matrix showing the evolution of Percentile levels. 2) The number of days with Maximum Daily Discharge (MaxD) > P99 and MaxD > Max by river and station. 3) Map of stations representing the number of days with MaxD > P99 grouped in 5 classes and MaxD > Max grouped in 2 classes.

For the Ebro basin the largest event since 2012 (excluding the December 2019 event) occurred between 6 April and 8 May 2018. *Figure 39* 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 38*, which shows that the maximum discharge is only exceeded at 4 stations in total suggests that the 2018 event was of higher magnitude.

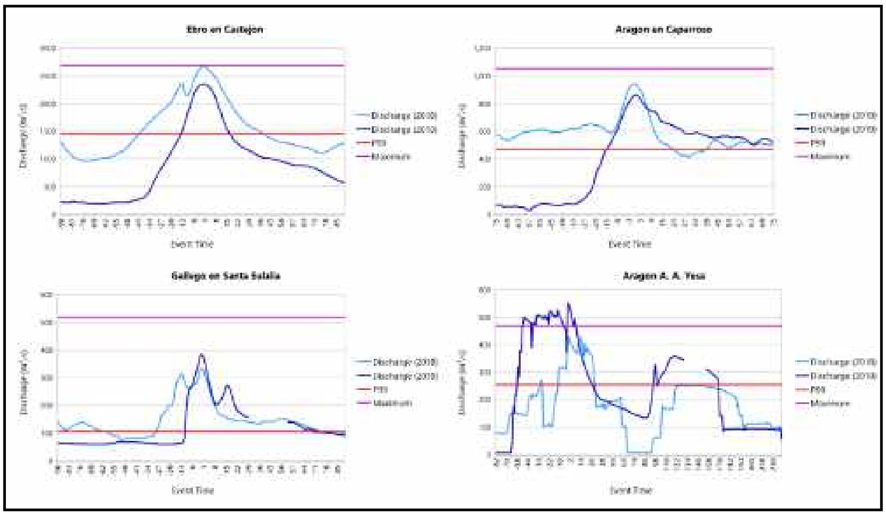


Figure 39. Comparison of the two largest events since 2012.

5 Conclusions

Hydrological Conditions

According to the data collected, the hydrological conditions of the stations in 2019 present some particularities that are worth mentioning:

- The water contribution in 2019 did not differ much from 2018, although it was clearly lower than it was in the historical period 1991-2016. Especially in Elbe, Oder, Vistula and Dnieper river basins the drier conditions were very pronounced, when comparing to historical period.
- The maximum and minimum mean daily values of discharge in 2019 followed a more extreme regime than 2018 in most of the stations, excluding the Rhine, almost all the Danube river basin and stations in Sweden and Norway.
- When comparing the maxima in 2019 to the period 1991-2016 a number of stations in basins of northern Spain (Minho, Douro, Ebro and Llobregat) exceeded the maximum mean daily discharge, together with other stations in higher Danube basin in Austria.
- The hydrological conditions in Elbe, Oder, Vistula and Dnieper river basins, where the lost of discharge in the gauge stations it's very pronounced, when comparing to historical period.

Gaps

Regarding to data gaps, the majority of them had a duration < 1 hour and were due to time interval variations (irregular data observation frequencies). Gaps that have a duration less than 5 days are filled by the HDCC data interpolation process. Gaps of longer durations are only filled if the data is provided by the authorities responsible of the hydrological data provision upon request from the HDCC.

Comparing 2019 with 2018, we see that the rate of received data vs expected data has slightly increased in 2019 (95,13%) with respect to 2018 (95,01%). The number of gaps has increased in 2019 with respect to the previous year (605,961 vs 526,201) but it has to be taken into consideration that total number of received data has increased by 20%. The cause of data gaps was identified in 82% of the cases and solutions have been proposed accordingly. However, for the remaining 18% of the cases the causes remain unknown.

The analysis reveals that the percentage of outliers in 2019 is really low compared to the annual amount of data received (0.27%). Most outliers are isolated data values, a small number are present in sets of erroneous data values.

Exceedances Events

Threshold levels were available for 1,092 stations and 24 countries. Since the beginning of 2019 the HDCC incorporated 206 new stations with threshold levels, covering 4 new countries (Kosovo, Bosnia and Herzegovina, Lithuania and Poland), 55 new rivers and 8 basins. 51% of all stations had at least one of their threshold levels exceeded during 2019 and registered a total of 2,747 exceedance events, twice as much if compared with 2018. The average number of events per station increased from 3 events in 2018 to 5 events in 2019; whereas the average accumulated duration per station decreased from an average of 14 days in 2018 to 7.6 days in 2019. The longest events were located across Ukraine, Belarus, Croatia, Bosnia Herzegovina and Hungary. Although the total exceedance events in 2019 almost doubled compared to the year before, the number of “high level" events has been very similar for both years. 3% of all the events observed in 2019 were "high level", and they were registered at 62 stations mainly located in the Po, Danube, Vistula and Minho basins. The most severe events took place in the Danube, Dnieper, Minho, Neman and Po basins.

Flood Event

The analysis of this year's extreme event focuses on the major floods that occurred in northern Spain in December 2019 as a consequence of the occurrence of three great storms chained in time, starting before December 16, with storm Daniel and ending after December 22, when the influence of the storm Fabien ends. The complete detailed assesment report has been executed jointly with the DISS Center, being the hydrological point of view carried out from the HYDRO Center, focusing on 4 basins in northern Spain: Minho, Limia, Douro and Ebro. The Minho, Limia and Douro basins have suffered severe increases in discharge in a generalized way for many days, however, in the Ebro the surpasses have been more localized. From the hydrological point of view it is also important to note that since 2014 in the EFAS System, no extreme event has been registered that seriously affected the four basins at the same time.

As a final consideration we would like to highlight the usefulness of historical and real time hydrological information provided by EFAS partners, which has allowed the analysis of this extreme case. The applied methodology can be replicated in other events in regions where historical and real time data were provided to the EFAS System.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Annex 1: Data provider list

Austria
Federal Ministry of Agriculture, Forestry, Environment and Water Management

Belgium
Hydrological Information Centre

Service public de Wallonie

Belarus
Republican Emergency Management and Response Center of the Ministry of Emergency Situations of the Republic of Belarus

Bosnia and Herzegovina
Federal Hydrometeorological Institute

Bulgaria
National Institute of Meteorology and Hydrology

Croatia
Meteorological and Hydrological Service of Croatia

Czech Republic
Czech Hydro-Meteorological Institute

Estonia
Estonian Environmental Agency

Finland
Finnish Environment Institute

France
Ministère de l'Ecologie et du Développement Durable Service Central d'Hydrométéorologie et d'Appui à la Prévision des Inondations

Georgia

Germany
Bundesanstalt fuer Gewaesserkunde

Saxon State Agency for Environment and Geology

Hessisches Landesamt für Umwelt und Geologie

Landesamt für Umwelt, Wasserwirtschaft und Gewerbeaufsicht Rheinland - Pfalz

Landesamt für Umwelt, Gesundheit und Verbraucherschutz

Bayerisches Landesamt für Umwelt

Hellenic Republic
Hellenic National Meteorological service

Hungary
Hungarian Hydrological Forecasting Service (OVSZ), General Directorate of Water Management (OVF)

Iceland
Icelandic Metereological Office

Ireland
Office of Public Works of Ireland

Italy
Servizio Idro Meteo Clima

Agenzia Regionale per la Protezione dell'Ambiente Regione Lombardia

Agenzia Regionale per la Protezione dell'Ambiente Regione Piamonte

Presidenza del Consiglio dei Ministri Dipartimento della Protezione Civile

Protezione Civile - Regione Lazio

Latvia
Latvian Environment, Geology and Meteorology Centre

Lithuania
Lithuania Hydrometereological Service

Luxembourg
Administration de la gestion de l'eau

Montenegro
Administration de la gestion de l'eau

Netherlands
Rijkswaterstaat Institute for Inland Water Management and Waste Water Treatment

Norway
Norwegian Water Resources and Energy Directorate, Hydrology Department

Poland
Institute of Meteorology and Water Management Wroclaw Branch

Republic of Kosovo
Kosovo Enviromental Protection Agency

Russian Federation
Hydrometcenter of Russia

Romania
Institutul National de Hidrologie Si Gospodarire A Apelor

Serbia
Republic Hydrometeorological Service of Serbia

Slovakia
Slovak Hydrometeorological Institute

Slovenia
Environmental Agency of the Republic of Slovenia

Spain
Automatic System of Hydrological Information for the Ebro River Basin

Spain

Confederación Hidrográfica del Miño - Sil

Confederación Hidrográfica del Duero

Confederación Hidrográfica del Guadalquivir

Government of Andalusia - Regional Ministry of Agriculture, Livestock, Fisheries and Sustainable Development

Confederación Hidrográfica del Segura

Catalan Water Agency

Sweden

Swedish Meteorological and Hydrological Institute, core services department

Switzerland

Federal Office for the Environment

Ukraine

State Emergency Service of Ukraine
Ukrainian Hydrometeorological Center

United Kingdom

UK Met Office - Flood Forecasting Centre

Scottish Environment Protection Agency

Departament of Infrastructure