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The European Flood Awareness System - A technical assessment of the EFAS performance during the Meuse and Rhine floods in July 2021

Prepared by the CEMS HYDROLOGICAL FORECAST CENTRE – Analytics and Dissemination, the CEMS HYDROLOGICAL FORECAST CENTRE – Computations, the CEMS METEOROLOGICAL DATA COLLECTION CENTRE, the CEMS HYDROLOGICAL DATA COLLECTION CENTRE, and the JOINT RESEARCH CENTRE.

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Abstract

The July 2021 floods across Belgium, Germany, Luxemburg and the Netherlands were unprecedented in the combination of timing and magnitude as well as in casualties and damages. This report presents an assessment of the performance and quality of the service provided by the European Flood Awareness System (EFAS) of the Copernicus Emergency Management Service (CEMS).

During the event, EFAS issued 25 notifications: 5 Formal Flood Notifications, 6 Informal Flood Notifications, and 14 Flash Flood Notifications. EFAS notifications for riverine flooding were issued for the rivers Rhine, Moselle, Rur (or Roer), Ourthe (more than two days before the EFAS predicted start of the event), Sauer and Meuse (less than two days before the EFAS predicted start of the event). EFAS notifications of flash floods were issued for small catchments of the Moselle, Saar, Ruhr, Meuse, Rhine basins. EFAS notifications could not be issued for the Sambre.

The analysis of the report highlighted an overall good performance of the system. Nevertheless, the in-depth investigation of each notification and of the EFAS forecasts and simulations allowed to streamline a number of actions to further improve the service. These actions include the continued update of the EFAS hydrological model set-up to improve simulation accuracy; a review of the criteria for the issue of EFAS notifications; improvements in the communication protocol.

Executive summary

The July 2021 floods across Belgium, Germany, Luxemburg and the Netherlands were unprecedented in the combination of timing and magnitude as well as in the casualties and damage that resulted. This report presents an assessment of the performance and quality of the service provided by the European Flood Awareness System (EFAS) of the Copernicus Emergency Management Service (CEMS). Such an assessment facilitates the identification of potential improvements to EFAS. The conclusions and recommendations of this report should not be used for any other purpose. Moreover, some of the analyses in the present report are based on information that was not available at the time of the event (namely: meteorological and hydrological observations). Therefore, the report cannot and should not be used to assess any flood event management decision taken at the time.

EFAS issued 25 notifications of upcoming riverine and flash floods events. EFAS notifications for riverine flooding were issued for the rivers Rhine, Moselle, Rur (or Roer), Ourthe, Sauer and Meuse. EFAS notifications of flash flood events were issued for small catchments of the Moselle, Saar, Ruhr, Meuse, Rhine basins. The first EFAS notification of riverine flooding was issued on Saturday, July 10. The first EFAS flash flood notifications were issued on Monday, July 12. The flash flood notifications for the hard-hit locations in both Germany and Belgium (e.g., the Vesdre and the Ahr basins) were issued just before midday on Tuesday, July 13. By Saturday, July 17, all EFAS flash flood notifications were deactivated and by Tuesday, July 20 all EFAS notifications for riverine flooding were deactivated. The a posteriori collection of the measured streamflow discharge data showed that in the majority of cases, exceptionally high streamflow values were recorded from Wednesday, July 14 to Friday, July 16.

There are two types of EFAS notifications for riverine flooding, namely Formal and Informal. Formal notifications are issued according to a strict set of criteria and at least 48 hours before the EFAS predicted start of the event. Formal notifications were issued for the Rhine, Ourthe, Rur (or Roer), and Moselle; however, formal notifications could not be issued (because the criteria were not met) for the Meuse, Sauer, Ruhr, and Sambre. EFAS Informal notifications have been designed to complement the Formal notifications: Informal notifications are issued for lead time shorter than 48 hours and with a degree of flexibility in the notifications criteria in order to leverage on the expertise of the Officers on Duty. Informal notifications were issued to raise awareness in two river stretches in which the Formal notifications criteria were not met, specifically the Meuse and the Sauer. A flash flood notification was issued for the Ruhr; no-notifications could be issued for the Sambre because the event was not detected by the EFAS forecasts. Finally, one Informal notification resulted in a false alarm (Nahe River).

This report therefore investigated the effectiveness of the protocol for the issue of Formal notifications in capturing the flood events. This analysis was performed by using the EFAS water balance simulation (the simulation produced by the EFAS operational set-up but forced with observed meteorological observations) as the 'verifying truth'. In 33 out of 46 instances the criteria for the issue of Formal flood notifications were in agreement with the water balance simulation. An in-depth analysis of the remaining 13 instances highlighted that Formal notifications criteria were not met due to the flashy nature of the events and due to inconsistencies in the forecasts. Therefore, the analysis of this report suggested a statistical study of the criteria for the issue of Formal flood notifications to further improve the service.

The accuracy of EFAS forecasts mainly depends on two factors, which are the accuracy of EFAS simulations (i.e. of the hydrological model set-up) and the accuracy of the meteorological forecasts. The accuracy of EFAS simulations for the event of this report was assessed by comparing the EFAS water balance simulation with the observations of streamflow discharge. This analysis showed that, for this specific event, EFAS simulated discharge peak were generally larger and earlier than the observations. The event-based analysis of this report showed that, despite the overall satisfactory results, further improvements are needed to reduce the bias in the simulation of peak magnitude and increase the accuracy of the simulation of peak timing. The EFAS operational set-up is routinely updated (with the last major release, EFAS v4.0, in October 2020 featuring the increase of computational time step from once a day to four times a day). The findings of this report advocate for the continued review and upgrade of the hydrological model set up.

The analysis of the accuracy of the meteorological forecasts was out of scope for this report, however, a brief literature review highlighted that the precipitation forecasts were highly uncertain and affected by underestimation error. A precipitation forecast verification study is therefore recommended to clarify the extent and nature of the uncertainty in precipitation forecasts.

The effectiveness of EFAS early warnings requires timely and accurate forecasts, but also an efficient and effective communication strategy. EFAS notifications are sent to EFAS partners, third party partners, and the Emergency Response Coordination Centre, which is the operational centre of the European Union civil protection mechanism. The communication protocol in place in July 2021 was correctly implemented during the event. However, the analysis of this report highlighted ways to further improve the effectiveness and clarity of the EFAS notifications to facilitate the uptake of the early warnings by the regional and national authorities.

1 Introduction

The July 2021 floods in Belgium, Germany, the Netherlands and Luxembourg were extraordinary. Both magnitude and intensity were unprecedented (Kreienkamp et al. 2021) and so were the high number of casualties and was the amount of economic damage. Furthermore, they took place in *summer* which, in this region, is unusual. The unexpectedness of flood magnitude and timing underlines the relevance of hydrometeorological forecasting systems that must create timely awareness of imminent flooding. The European Flood Awareness System (EFAS) is one such system.

1.1 The European Flood Awareness System

EFAS is one of the components of the Copernicus Emergency Management Service (CEMS) which supports the management of natural or man-made disasters by providing geospatial information (Copernicus Emergency Management Service). EFAS is the first operational system for the monitoring and forecasting of floods across Europe. The aim of EFAS is to support preparatory measures before major flood events strike, particularly in the large trans-national river basins and throughout Europe in general. For this purpose, EFAS provides complementary, added-value information (probabilistic, medium range flood forecasts, flash flood indicators or 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.

The European Commission's Joint Research Centre is entrusted with the technical and administrative management of EFAS. In addition, it is responsible for its further evolution and contributes to relevant tasks such as the development of the hydrological model. The operational EFAS is executed by four separate entities:

- The CEMS Hydrological Forecast Centre – Computation (COMP) executes forecasts and hosts the EFAS-Information System platform.
- The CEMS Hydrological Forecast Centre – Analytics and Dissemination (DISS) provides analysis of the system; it supports users with training and information as well as the management of communication tools.
- The CEMS Hydrological Data Collection Centre (HYDRO) collects historic and real-time river discharge and water level data across Europe.
- The CEMS Meteorological Data Collection Centre (METEO) collects historic and real-time meteorological data across Europe.

Specifically, from 2021 to 2027, these entities are implemented by the European Centre for Medium-Range Weather Forecasts (COMP); a consortium of the Swedish Meteorological and Hydrological Institute, Rijkswaterstaat (The Netherlands), and the Slovak Hydro-Meteorological Institute (DISS); Ghenova Digital (HYDRO); KISTERS AG and Deutscher Wetterdienst (METEO).

Detailed information about the generation of EFAS forecasts, including meteorological forcings, hydrological model set-up, and procedures, are available from the EFAS wiki pages EFAS models and procedures - Copernicus Emergency Management Service - CEMS - ECMWF Confluence Wiki.

1.2 Purpose, limitations, and structure of this report

The present report comprises an assessment of the performance and quality of the EFAS service and forecasts during the July 2021 flood event. Such an assessment facilitates the identification of potential improvements to EFAS. Its conclusions and recommendations should not be used for any other purpose.

The assessment will explore the quality of the EFAS service and the quality of the underlying forecasts. It contains various analyses, each of which analyses the quality of a different component of the wider EFAS system:

1. Quality of the Dissemination Centre decisions: An analysis of the notifications that were issued versus the forecasting procedure.
2. Quality of the procedure and the underlying forecasts: Did the combination of the forecasts and the notification procedure capture the floods in time, as measured by their 'verifying truth'?
3. Accuracy of the 'verifying truth' that is used in EFAS: The water balance simulation.

A thorough analysis of the quality of the inputs to EFAS (notably, meteorological observations and meteorological forecasts) is not within scope. However, the report will briefly discuss some analyses that have been done by third parties.

Some of the analyses in the present report are based on information that was not available at the time of the event (namely: Meteorological and hydrological observations). Consequently, the report cannot and should not be used to assess any flood event management decisions taken at the time.

The present assessment considers a single flood event only, which – in many respects – was unique. Any conclusions drawn from this event analysis therefore do not generally apply to EFAS at large. By construction, as this is an analysis of a known flood event, any tendency of any system to issue false alarms is underemphasized.

This report is structure as follows: Chapter 2 outlines the study area and describes the meteorological situation. Chapter 3 presents the analysis of the discharge measurements. The EFAS notifications are analysed in Chapter 4. The assessment of the EFAS forecasts and model simulations is given in Chapter 5. Chapter 6 lists the conclusions are drawn and recommendations stemming from the analysis of this report. Finally, the Annexes contain detailed technical information that supports the analysis presented in this report.

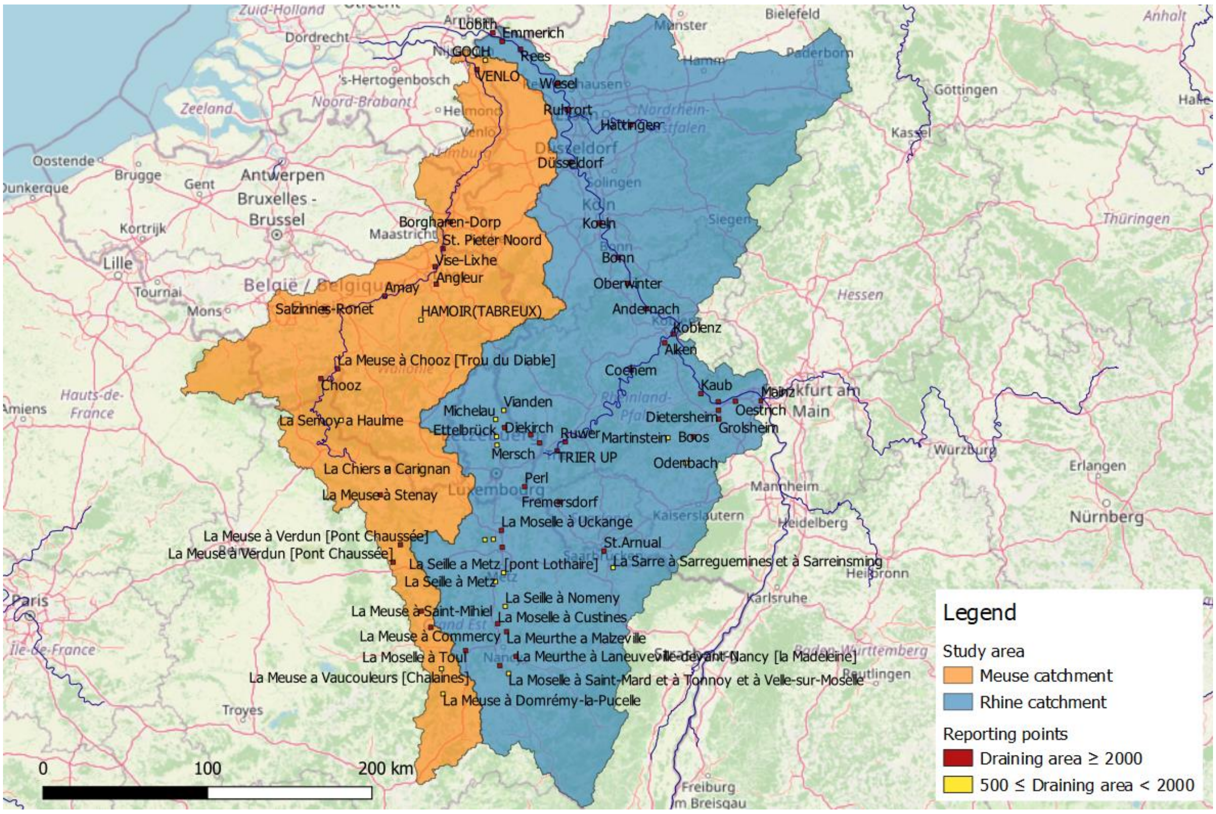
2 The July 2021 flood event

In July 2021, unusually high precipitation amounts resulted in severe flooding across the German federal states North Rhine-Westphalia and Rhineland-Palatinate, in the Belgian Ardennes, in the Dutch province of Limburg and in the Grand-Duchy of Luxemburg. Sadly, the floods caused over 200 casualties and a large amount of flood damage, which is currently estimated at several dozens of billions of Euros (Expertise Netwerk Waterveiligheid, 2021) (Kreienkamp, et al., 2021).

2.1 Study area

The present assessment focuses on floods that resulted from or were aggravated by the precipitation that occurred on Tuesday, July 13 through Thursday, July 15. The study area was defined based on the location of this precipitation; Annex 1 provides the detailed explanation of the methodology that led to the definition of the study area. **Figure 1** shows the study area encompassing the Meuse catchment and part of the Rhine catchment. Moreover, **Figure 1** shows the location of EFAS fixed reporting points. EFAS fixed reporting points are points where forecasts outputs are always available, these locations are selected according to the availability of metadata and data. **Figure 1** highlights the reporting points with draining area of at least 2000 km2. Previous analysis demonstrated that EFAS v4.2 (i.e. the EFAS version available at the time of the event) had highest performance for medium, large catchment areas (red points), nevertheless, the same analysis proved that EFAS v4.2 forecasts have value also for smaller catchments (yellow points).

Figure 1. Study area including EFAS reporting points.



2.2 Event meteorology

The flood event was preceded by above-average precipitation in the three weeks prior to the on-set of the event. During that period, in large parts of the study area precipitation depths exceeded 90mm; locally, precipitation depths exceeded 150mm (**Figure 2**). Consequently, a very limited amount of soil water storage space was available. For instance, in Rhineland-Palatinate and in South Westphalia, some areas had less than 10 mm free water storage available (Junghänel, et al., 2021).

Weather conditions on Monday, July 12 through Thursday, July 15 over Central Europe were characterised by a low-pressure area referred to as "Bernd"[1] . This attracted warm and very moist air from the Mediterranean area. Dynamic and orographic up-lifting and reduced freedom of movement due to the Sauerland, Westerwald and Eifel mountains resulted in recurring and continuing heavy precipitation: First locally, then over a large domain (Junghänel, et al., 2021). Most of the study region received over 80 mm of accumulated precipitation during these four days (**Figure 3**). Some areas received even larger precipitation depths: The Eifel, the Belgian Ardennes, Dutch Limburg and the Ruhr area received from 125 up to over 200 mm of precipitation (**Figure 3** and **Figure 4**).

The long-term, July averages of some example stations in the study area lie between 60 and 105mm, so in many areas more than the monthly average rainfall occurred in less than 4 days. Many stations in North Rhine-Westphalia and Rhineland-Palatinate exceeded a return period of more than 100 years (Junghänel, et al., 2021).

An analysis done by "World Weather Attribution" (Kreienkamp, et al., 2021) suggests that this event was made more likely by climate change. In the analysis, the event was broken up in two days. The probability of occurrence of both a 1-day and a 2-day event was assessed. It was concluded that "The likelihood of such an event to occur today compared to a 1.2 ºC cooler climate has increased by a factor between 1.2 and 9 for the 1-day event in the large region. The increase is again similar for the 2-day event."

Figure 2. Accumulated precipitation amounts during the three weeks from June 21 through July 11, 2021.

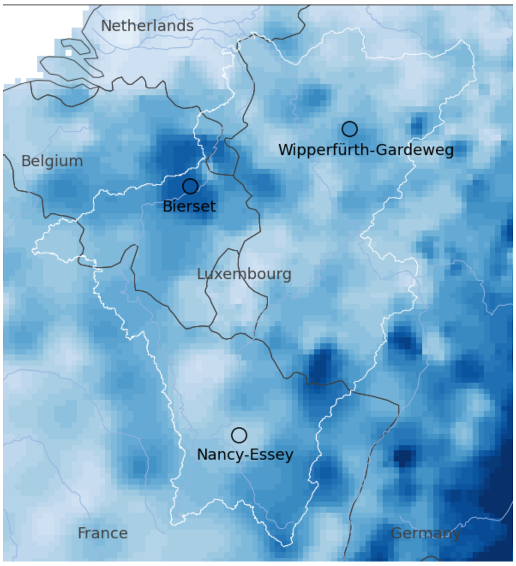


Figure 3. 96-hour accumulated precipitation amounts from Monday, July 12 through Thursday, July 15, 2021

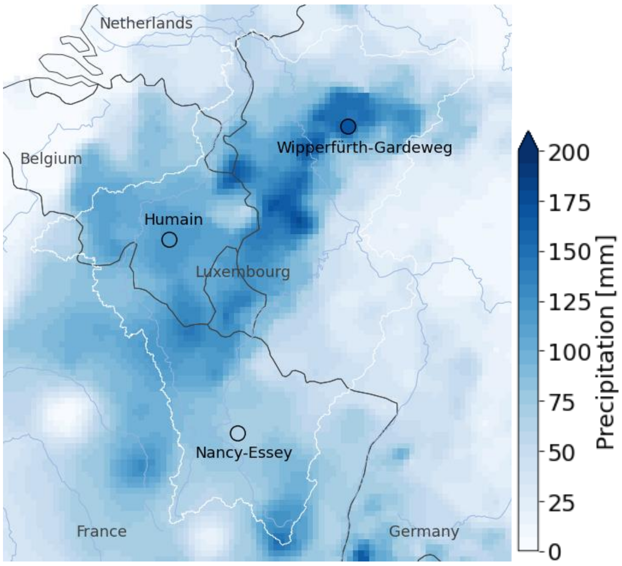
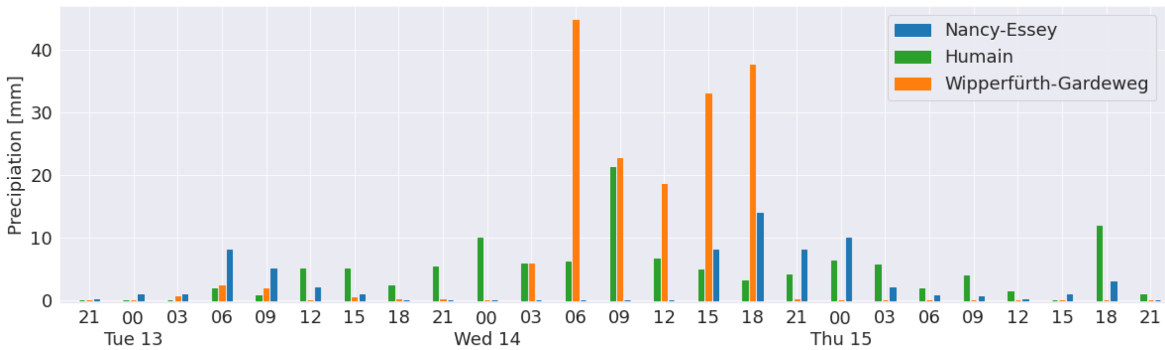


Figure 4. Timeline of 3-hourly measured precipitation by three example stations in the study region between Monday, July 12 and Thursday, July 15, 2021.



[1] Bernd was classified by the DWD (2021) as "Central Europe Trough" (as per the Hess & Brezowsky (1952) classification).

3 Hydrological observations

The present chapter describes the hydrological measurements taken during the event. The purpose is to give an indication of the location, timing and intensity of the event. The analysis used river discharge data available from the EFAS Hydrological Data Collection Centre's database. The available data was obtained from 41 gauging stations (**Figure 5**), these stations were operational during the event. The data were provided by:

— Service Public de Wallonie (SPW; Belgium),

— Service Central d'Hydrométéorologie et d'Appui à la Prévision des Inondations (SCHAPI; France),

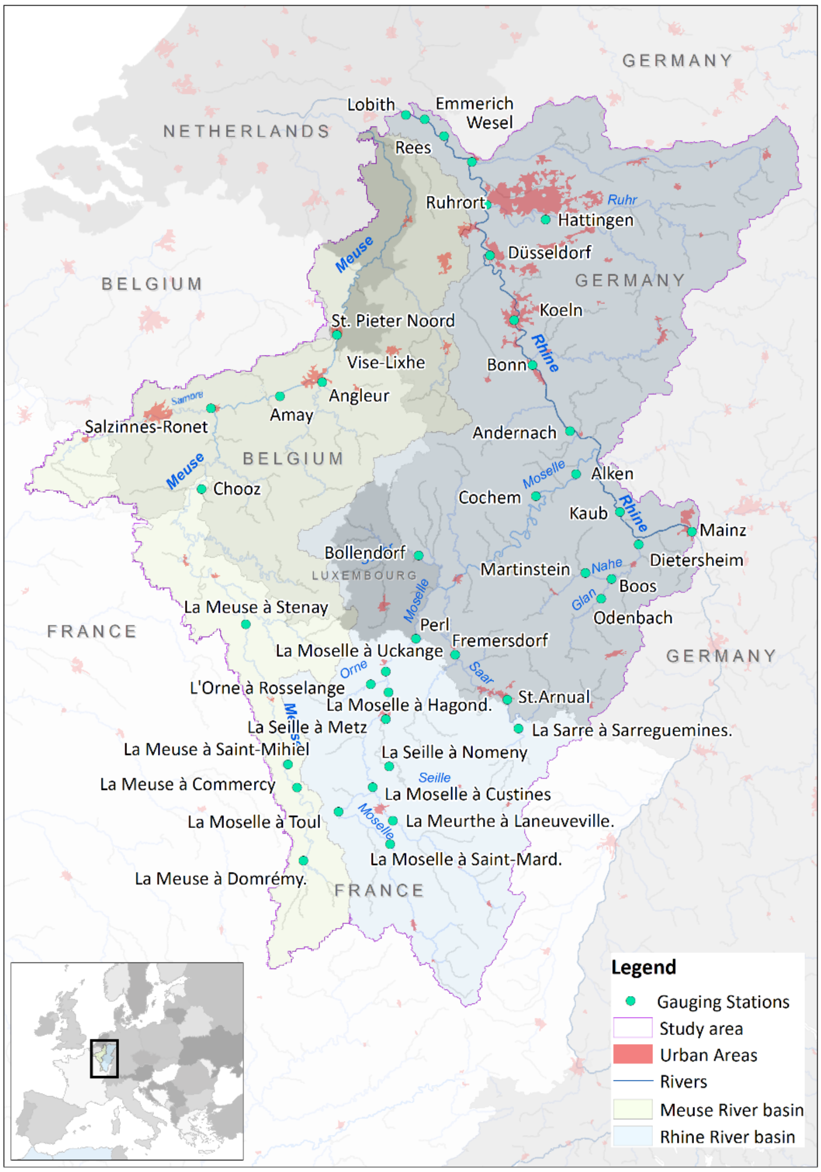
— Bundesanstalt für Gewaesserkunde (BfG, Germany),

— Landesamt für Umwelt Rheinland-Pfalz (LfU, Germany), and

— Rijkswaterstaat (RWS, the Netherlands).

The hydrological analysis is based on three different analyses that are set out below. To facilitate the interpretation of the results, a number of maps and calendar matrices have been developed that show the indicators and their evolution over time.

Figure 5. Study area and gauging stations that collected discharge data during the July floods



3.1 Flow percentiles

Percentiles are used to assess the severity of the flood event in a historical perspective. The objective is to compare the values during the event with the historical series available from the database. Percentiles have been computed using the longest available data records. Data at the sub-daily level (e.g., hourly data or 3-hourly data) are not sufficient to calculate maximum values per day for the entire period. Therefore, for this analysis, daily averaged data has been used instead of daily maxima. Stations for which there is less than 10 years of data available have been omitted from the analysis. Note also that longer data records may be available in the archives of the data providers but that are not included in the database of the EFAS Hydrological Data Collection Centre. Hence, statistical indicators derived from national or regional data providers may differ.

The indicators chosen are the 99th percentile (P99) and the 100th percentile (MAX). Thus, MAX rep-resents the daily average value that has never been exceeded in the period of time used for its calculation, and the P99 represents values that were exceeded on 1% of the days on record.

Once the percentiles have been calculated, a 'flood event diary' is generated by comparing the daily average discharge during the event with the P99 and MAX values. **Figure 6** shows the hydro-graph for St Pieter Noord station, comparing the daily average discharge with percentiles P99 and MAX. The horizontal calendar bar above the hydrograph indicates the days on which either the P99 or the MAX value was exceeded.

Figure 6. Comparison between daily average discharge and P99 and P100 (Max) values using the complete dataset for St. Pieter Noord station. Each cell in the top calendar bar covers an entire day and is coloured in red when the daily average discharge exceeds P99. The colour is purple for those days where daily average discharge exceeds the P100 (Max).

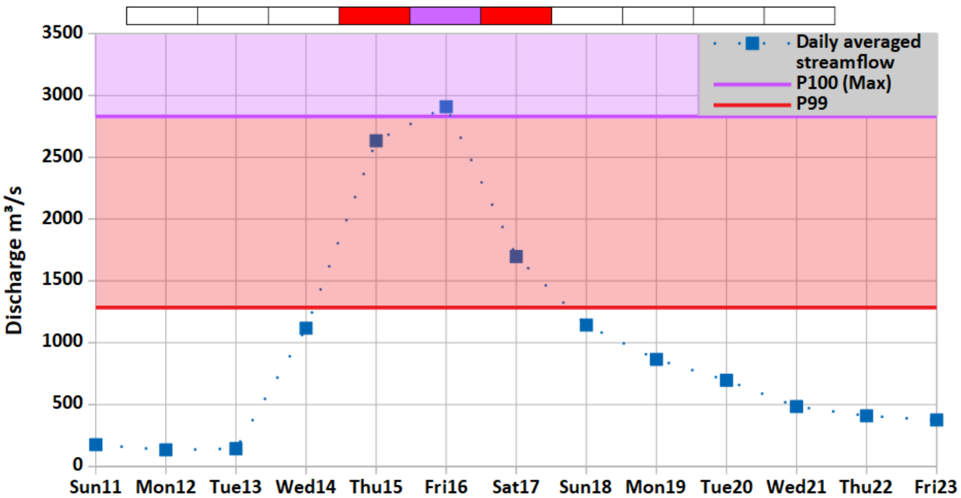


Table 1 and **Table 2** show the number of days where observed discharge exceeded MAX and/or P99 for 'full year' and 'summer only' (i.e. during months June, July and August) time series, respectively; these numbers are subsequently plotted on a map (**Figure 7** and **Figure 8**).

The analysis led to the following observations:

— In the majority of cases, the 'full series' P99 and MAX exceedances commenced on Thursday, July 15 or Friday, July 16. The 'summer only' P99 and MAX values were first exceeded on Wednesday, July 14 and Thursday, July 15.

— The fact that the averaged streamflow during the summer of 2021 exceed P99 and MAX in stations with more than 20 years of data demonstrates the magnitude of the July 2021 event.

— In the case of the comparison with summer values only, the exceedances are higher and last longer. The reason is that the P99 and MAX values for 'summer only' time series are lower than those computed using the 'full year' time series.

Table 1. Number of days with Q > P99 and Q > Max. The table is ordered according to basin (Rhine on top; Meuse below) and, within the basins, by decreasing catchment area.

Name	Basin	River	Catchment [km2]	Years [-]	P99 [m3/s]	Max [m3/s]	Mon July 12	Tue July 13	Wed July 14	Thu July 15	Fri July 16	Sat July 17	Sun July 18	Mon July 19	Tue July 20	Wed July 21	Thu July 22	Fri July 23	Days over P99 [-]	Days over Max [-]
Lobith	Rhine	Rhine	160,800	118	6,470	13,000													2	0
Rees	Rhine	Rhine	159,683	194	6,480	11,700													2	0
Emmerich	Rhine	Rhine	159,555	64	6,580	11,700													2	0
Wesel	Rhine	Rhine	154,528	68	6,509	11,800													2	0
Ruhrort	Rhine	Rhine	153,176	69	6,530	11,600													3	0
Düsseldorf	Rhine	Rhine	147,680	89	6,317	10,700													2	0
Koeln	Rhine	Rhine	144,232	203	6,030	10,900													2	0
Bonn	Rhine	Rhine	140,901	65	5,980	10,500													2	0
Andernach	Rhine	Rhine	139,549	89	6,010	10,400													2	0
Kaub	Rhine	Rhine	103,488	89	4,220	7,160													0	0
Mainz	Rhine	Rhine	98,206	89	4,050	6,920													2	0
Cochem	Rhine	Moselle	27,088	119	1,650	4,020													3	0
Perl	Rhine	Moselle	11,522	45	882	2,225													0	0
Fremersdorf	Rhine	Saar	6,983	67	450	1,170													0	0
La Moselle à Cust nes	Rhine	Moselle	6,830	42	568	1,915													2	0
Dietersheim	Rhine	Nahe	4,037	17	177	655													0	0
St.Arnual	Rhine	Saar	3,945	26	253	910													0	0
La Moselle à Toul	Rhine	Moselle	3,338	43	391	1,070													1	0
Bollendorf	Rhine	Sauer	3,222	61	254	826													3	0
Boos	Rhine	Nahe	2,832	58	179	717													0	0
La Meurthe à Laneuveville.	Rhine	Meurthe	2,780	34	187	685													4	0
Mart nstein	Rhine	Nahe	1,468	57	115	446													0	0
L'Orne à Rosselange	Rhine	Orne	1,226	52	90	231													1	0
Odenbach	Rhine	Glan	1,086	63	66	236													0	0
La Seille à Nomeny	Rhine	Seille	925	45	57	125													0	0
St Pieter Noord	Meuse	Meuse	21,100	25	1,285	2,829													3	1
Amay	Meuse	Meuse	16,416	20	960	1,793													3	1
Chooz	Meuse	Meuse	10,120	30	700	1,555													1	0
Angleur	Meuse	Ourthe	3,607	20	285	626													4	2
Salzinnes-Ronet	Meuse	Sambre	2,841	14	138	272													3	1
La Meuse à Saint-Mihiel	Meuse	Meuse	2,540	52	199	557													0	0
La Meuse à Commercy	Meuse	Meuse	2,290	22	136	473													0	0
La Meuse à Domrémy-la-Pucelle	Meuse	Meuse	1,031	41	115	322													2	0

Table 2. Number of days with Q > P99 and Q > Max as computed for summer months only (June, July and August).

Name	Basin	River	Catchment [km2]	Years [-]	P99 [m3/s]	Max [m3/s]	Sat July 10	Sun July 11	Mon July 12	Tue July 13	Wed July 14	Thu July 15	Fri July 16	Sat July 17	Sun July 18	Mon July 19	Tue July 20	Wed July 21	Thu July 22	Fri July 23	Days over P99 [-]	Days over Max [-]
Lobith	Rhine	Rhine	160,800	118	4,379	9,520															9	0
Rees	Rhine	Rhine	159,683	194	4,530	9,187															8	0
Emmerich	Rhine	Rhine	159,555	64	4,717	9,091															7	0
Wesel	Rhine	Rhine	154,528	68	4,617	8,487															8	0
Ruhrort	Rhine	Rhine	153,176	69	4,783	8,096															7	0
Düsseldorf	Rhine	Rhine	147,680	89	4,465	7,749															7	0
Koeln	Rhine	Rhine	144,232	203	4,160	7,168															8	0
Bonn	Rhine	Rhine	140,901	65	4,460	6,495															6	0
Andernach	Rhine	Rhine	139,549	89	4,289	6,250															7	1
Kaub	Rhine	Rhine	103,488	89	3,558	5,896															10	0
Mainz	Rhine	Rhine	98,206	89	3,460	5,684															12	0
Cochem	Rhine	Moselle	27,088	119	625	1,433															6	3
Perl	Rhine	Moselle	11,522	45	376	732															5	2
Fremersdorf	Rhine	Saar	6,983	67	157	418															4	0
La Moselle à Cust nes	Rhine	Moselle	6,830	42	298	501															4	2
Dietersheim	Rhine	Nahe	4,037	17	84	303															0	0
St.Arnual	Rhine	Saar	3,945	26	99	219															4	0
La Moselle à Toul	Rhine	Moselle	3,338	43	194	337															3	1
Bollendorf	Rhine	Sauer	3,222	61	78	238															6	3
Boos	Rhine	Nahe	2,832	58	68	244															1	0
La Meurthe à Laneuveville.	Rhine	Meurthe	2,780	34	121	223															6	3
Mart nstein	Rhine	Nahe	1,468	57	39	153															2	0
L'Orne à Rosselange	Rhine	Orne	1,226	52	40	191															4	0
Odenbach	Rhine	Glan	1,086	63	23	104															1	0
La Seille à Nomeny	Rhine	Seille	925	45	30	39															2	0
St Pieter Noord	Meuse	Meuse	21,100	25	504	861															7	6
Amay	Meuse	Meuse	16,416	20	462	695															7	4
Chooz	Meuse	Meuse	10,120	30	266	375															8	5
Angleur	Meuse	Ourthe	3,607	20	150	278															6	4
Salzinnes-Ronet	Meuse	Sambre	2,841	14	65	168															7	3
La Meuse à Saint-Mihiel	Meuse	Meuse	2,540	52	80	117															4	3
La Meuse à Commercy	Meuse	Meuse	2,290	22	68	97															4	0
La Meuse à Domrémy-la-Pucelle	Meuse	Meuse	1,031	41	58	84															3	3

Figure 7. Number of days with Q > P99 and Q > Max.

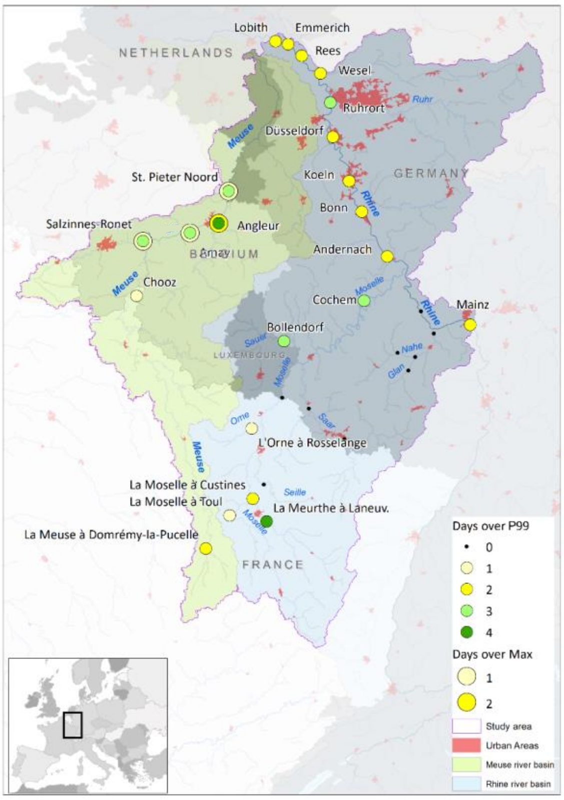
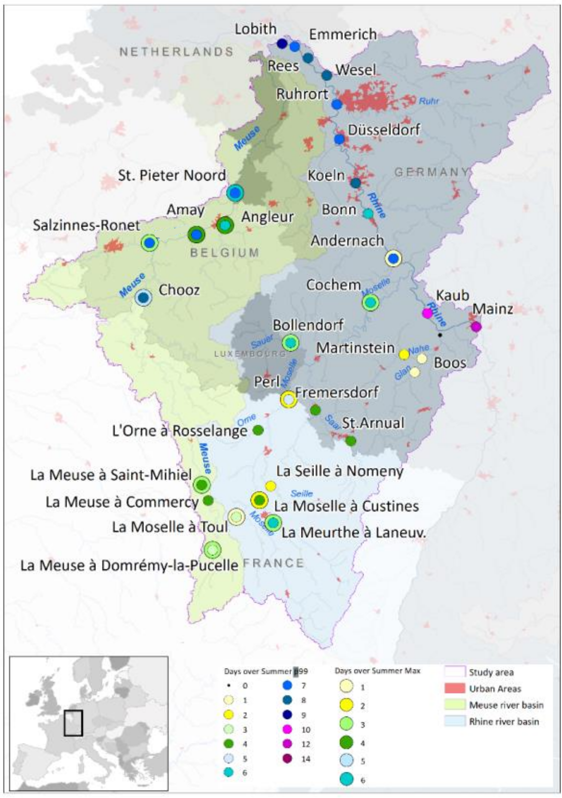


Figure 8. Number of days with Q > P99 and Q > Max as computed for summer months only (June, July, August)



3.2 Exceedance of the historical maximum values provided by each organization

For 32 gauging stations in the study area, the database contains historical maximum discharge data. These are instantaneous peak values, therefore they differ from the daily averaged streamflow which was used in the previous section 3.1. **Table 3** shows the days on which these values were exceeded.

Table 3. Days over the historical maximum discharge registered for those stations that were provided with this information in the EFAS System. Calendar matrix.

Station_Name	River	Basin	Catchment	Hist. Max. D	Date	12J	13J	14J	15J	16J	17J	18J	19J	20J	21J	22J	Days over Hist. Max D
Lobith	Rhine	Rhine	160,800	12,280	Not provided	3,319	3,565	3,951	5,080	6,319	6,680	6,697	6,458	5,952	5,469	5,012	0
Rees	Rhine	Rhine	159,683	12,200	Not provided	3,530	3,780	4,210	5,480	6,680	6,960	6,960	6,610	6,030	5,360	5,050	0
Düsseldorf	Rhine	Rhine	147,680	10,900	Not provided	3,800	3,880	4,700	6,030	6,580	6,710	6,510	5,860	5,390	4,840	4,590	0
Andernach	Rhine	Rhine	139,549	11,100	Not provided	3,780	3,840	4,170	5,850	6,520	6,440	5,800	5,330	4,960	4,490	4,270	0
Kaub	Rhine	Rhine	103,488	7,200	Not provided	3,580	3,580	3,560	3,700	3,970	4,090	4,160	4,180	4,080	3,870	3,770	0
Mainz	Rhine	Rhine	98,206	7,000	Not provided	3,570	3,570	3,520	3,700	3,930	4,040	4,140	4,140	3,970	3,800	3,670	0
Perl	Moselle	Rhine	11,522	2,290	Not provided	164	158	477	663	862	894	817	508	398	295	263	0
La Moselle à Uckange	Moselle	Rhine	10,770	2,360	Not provided	99	124	412	648	859	875	750	468	335	234	193	0
La Moselle à Hagondange et à Hauconcc	Moselle	Rhine	9,387	2,080	Not provided	101	135	346	547	697	741	610	409	315	239	204	0
Fremersdorf	Saar	Rhine	6,983	1,420	Not provided	63	166	333	358	251	184	151	119	99	83	65	0
La Moselle à Cust nes	Moselle	Rhine	6,830	2,000	Not provided	77	130	312	612	769	720	473	324	240	181	151	0
Hattingen	Ruhr	Rhine	4,118	907	Not provided	53	75	970	1,450	819							2
St.Arnual	Saar	Rhine	3,945	964	Not provided	44	125	197	199	159	132	109	79	57	45	39	0
La Moselle à Toul	Moselle	Rhine	3,338	1,190	Not provided	44	133	175	456	529	409	227	150	115	94	84	0
Bollendorf	Saar	Rhine	3,222	895	Not provided	20	46	517	913	801	385	187	112	79	55	51	1
Boos	Nahe	Rhine	2,832	835	Not provided	23	51	79	83	65	65	37	28	21	18	15	0
La Meurthe à Laneuveville	Meurthe	Rhine	2,780	779	Not provided	30	85	161	307	390	323	221	161	107	71	57	0
La Moselle à Saint-Mard	Moselle	Rhine	1,976	827	Not provided	43	150	156	344	350	280	176	127	99	82	69	0
Martinstein	Nahe	Rhine	1,468	582	Not provided	15	38	50	63	37	26	21	16	13	11	9	0
La Seille à Metz	Seille	Rhine	1,280	174	Not provided	4	4	15	30	30	27	23	19	19	20	21	0
L'Orne à Rosselange	Orne	Rhine	1,226	318	Not provided	2	5	35	92	131	113	53	33	19	12	10	0
Odenbach	Glan	Rhine	1,086	332	Not provided	8	29	30	22	38	36	16	10	7	6	5	0
La Seille à Nomeny	Seille	Rhine	925	125	Not provided	5	4	9	28	28	27	26	28	29	30	31	0
St. Pieter Noord	Meuse	Meuse	21,100	3,062	1993-12-22	299	283	1,767	3,263	3,254	2,155	1,372	980	795	661	578	2
Amay	Meuse	Meuse	16,416	1,867	2003-01-04	114	137	684	1,639	1,933	1,128	814	661	506	393	322	1
Chooz	Meuse	Meuse	10,120	1,560	1995-01-30	82	86	365	656	732	579	511	442	356	270	233	0
La Meuse à Stenay	Meuse	Meuse	3,904	533	Not provided	29	56	75	143	143	110	99	102	105	108	114	0
Angleur	Ourthe	Meuse	3,607	829	1993-12-02	33	35	505	1,396	739	429	254	174	132	106	87	1
Salzinnes-Ronet	Sambre	Meuse	2,841	314	2011-01-07	21	33	123	220	313	177	116	96	68	43	33	0
La Meuse à Saint-Mihiel	Meuse	Meuse	2,540	658	Not provided	13	12	15	43	66	73	79	89	215	213	176	0
La Meuse à Commercy	Meuse	Meuse	2,290	598	Not provided	18	72	91	97	89	83	72	46	34	26	21	0
La Meuse à Domrémy-la-Pucelle	Meuse	Meuse	1,031	562	Not provided	5	5	17	72	178	167	113	63	28	17	12	0

Figure 10 shows the locations where the observed discharge exceeded the historic maximum at any time during the July flood event. The table and the map highlight the severity of the event: At 5 of the 32 stations, the maximum discharge in the July event exceeded the historical records.

3.3 Exceedances of the threshold levels provided by each organisation

The CEMS Hydrological Data Collection Centre (HYDRO) collects information about '[local threshold levels](#)'. These are supplied by the EFAS partners. Four threshold levels are defined (TL1 through TL4, with TL1 being the lowest threshold), ranging from warning to critical values for flood events. Not all the stations have four levels defined, as some organizations use fewer thresholds. The system then orders them as follows according to the number of levels provided:

— One Level: TL1

— Two levels: TL1 and TL4

— Three levels: TL1, TL3, TL4

— Four levels: TL1, TL2, TL3, TL4

This analysis compares the measured discharge values during the event with the thresholds provided by the EFAS partners and it has the purpose of complementing the above analysis of the magnitude of the observed event. This analysis could be completed for 8 stations. See **Figure 9** as an example for St. Pieter Noord station.

Figure 9. Comparison between daily maximum discharge and the three threshold levels defined for St Pieter Noord station. Each cell of the top bar covers an entire day and is colour-coded according to the highest threshold that was exceeded.

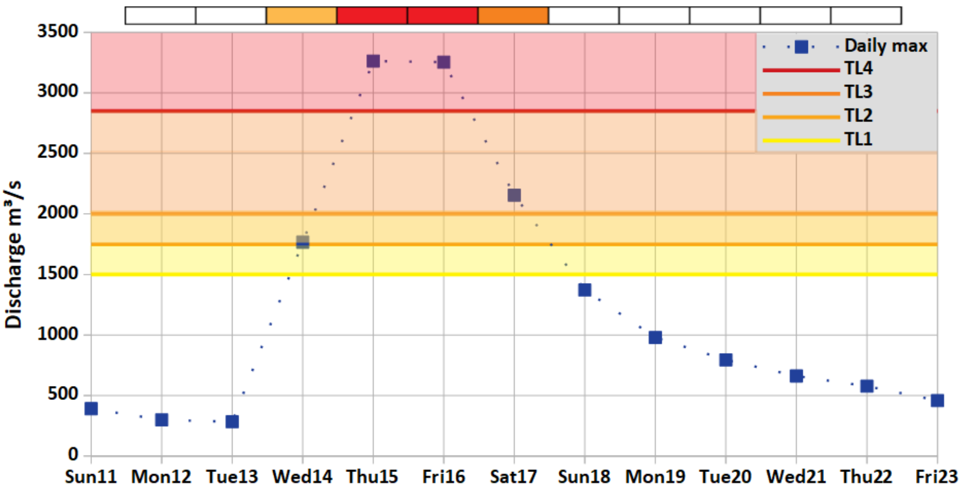


Figure 10and **Figure 11** show how observed discharge relates to these threshold levels. It can be observed that various stations exceeded at least one of the local thresholds and some exceeded the highest threshold.

Table 4. Calendar matrix showing the evolution of threshold level exceedance by station, including number of days above each threshold level.

Station_Name	River	Basin	Catchment	TL1(D)	TL2(D)	TL3(D)	TL4(D)	12J	13J	14J	15J	16J	17J	18J	19J	20J	21J	22J	Days>TL1	Days>TL2	Days>TL3	Days>TL4
Lobith	Rhine	Rhine	160,800	7,960	10,464	12,676	15,000	3,319	3,565	3,951	5,080	6,319	6,680	6,697	6,458	5,952	5,469	5,012	0	0	0	0
Ruhrort	Rhine	Rhine	153,176	5,580				3,810	3,970	4,940	6,850	7,100	7,130	6,980	6,320	5,800	5,150	4,880	5	0	0	0
Mainz	Rhine	Rhine	98,206	4,110				3,570	3,570	3,520	3,700	3,930	4,040	4,140	4,140	3,970	3,800	3,670	2	0	0	0
Bollendorf	Sauer	Rhine	3,222	437	569	750	869	20	46	517	913	801	385	187	112	79	55	51	1	0	1	1
Boos	Nahe	Rhine	2,832	392	522	697	804	23	51	79	83	65	65	37	28	21	18	15	0	0	0	0
Martinstein	Nahe	Rhine	1,468	267	360	497	589	15	38	50	63	37	26	21	16	13	11	9	0	0	0	0
Odenbach	Glan	Rhine	1,086	134	182	249	292	8	29	30	22	38	36	16	10	7	6	5	0	0	0	0
St. Pieter Noord	Meuse	Meuse	21,100	1,500	1,750	2,000	2,850	299	283	1,767	3,263	3,254	2,155	1,372	980	795	661	578	0	1	1	2

Figure 10. Exceedance of Historical Maximum Discharge

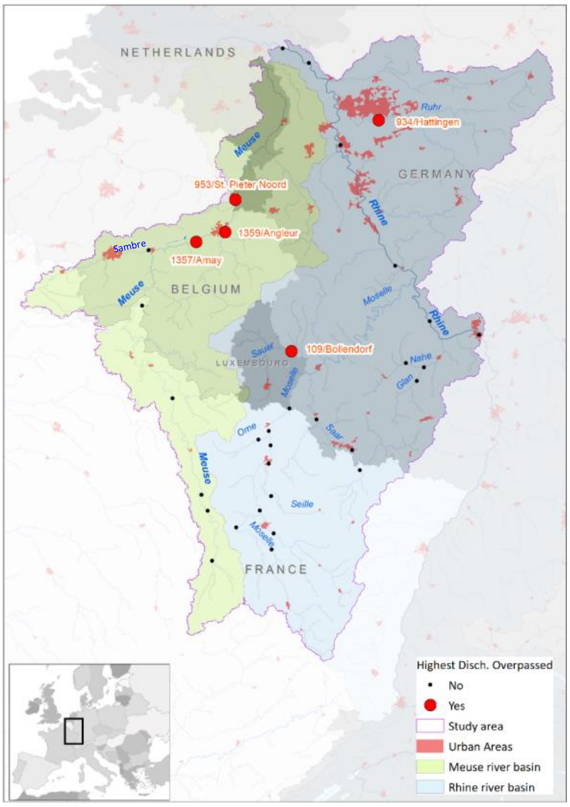
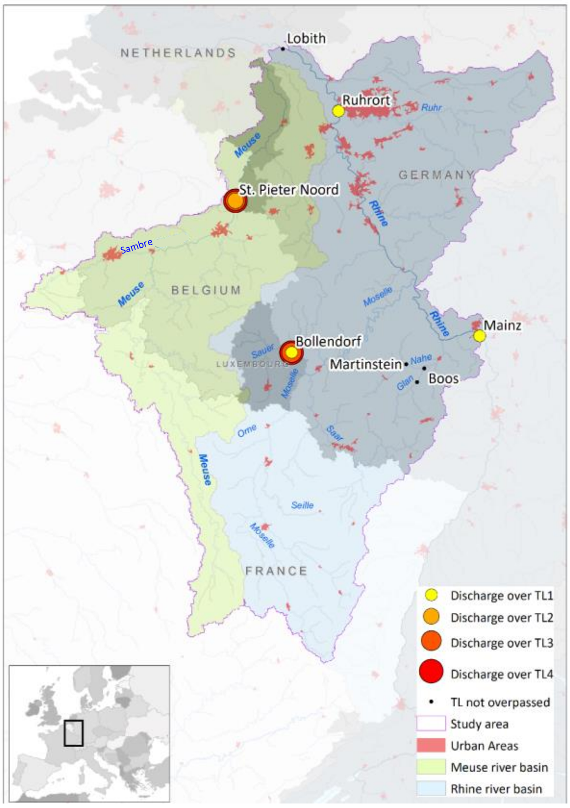


Figure 11. Highest exceeded 'local threshold' level



4 Assessment of notifications

EFAS provides an overview of flood probability over the coming 10 days (medium range flood forecasts). EFAS forecasts are available twice a day, based on the 00 UTC and 12 UTC meteorological forecasts. These become available at approx. 9 UTC and 21 UTC (**Table 5**). The EFAS forecasts are made available in real time to all EFAS registered users (EFAS partners, third party partners, and the ERCC) through the EFAS website (www.efas.eu , also referred to as EFAS-IS, where IS refers to "Information System") where all EFAS products are visualized. EFAS registered users can also request dedicated data transfer protocols to receive the EFAS forecast data in real time. Non-registered users can visualize the EFAS forecasts through the EFAS website and download the EFAS forecast data from the Copernicus Data Store but with a 30-days delay.

EFAS notifications are based on the analysis of EFAS medium-range flood forecasts, these are created by comparing the EFAS forecast simulations with EFAS flood threshold levels (T=1.5yrs / 2yrs / 5yrs / 20yrs). Detailed information about the generation of EFAS forecast simulations, including meteorological forcings, hydrological model set-up and procedures, are publicly available from EFAS models and procedures - Copernicus Emergency Management Service - CEMS - ECMWF Confluence Wiki. EFAS flood threshold levels are calculated for each grid cell of the EFAS domain, based on a historical discharge time series simulated by the operational hydrological model forced by observed meteorological data.

EFAS notifications are sent by the Officers on Duty of the CEMS Hydrological Forecast Centre – Analytics and Dissemination (DISS) to the EFAS partner or third party partner of the area affected by the event, and to the ERCC. Becoming EFAS partner or EFAS third party partner is voluntary and there is no obligation to use the information provided by EFAS. Information about how to become an EFAS partner/third party partner and the list of EFAS partners and third party partners is accessible on the EFAS webpage (Become EFAS Partner | Copernicus EMS - European Flood Awareness System).

Section 4.1 provides an overview of the notification process, and it explains the criteria for the issue of EFAS notifications. Section 4.2 provides an in-depth, point-scale analysis of the protocol for the issue of Formal notifications. Specifically, the analysis of Section 4.2 is completed for each reporting point, and it has the purpose to evaluate the effectiveness of the criteria for the issue of the Formal notifications for the specific event of this report. However, it is of paramount importance to remember that EFAS notifications apply to a river reach and not to a single reporting point. In order to introduce the assessment of the corrected and accuracy of EFAS notifications issued during the July 2021 floods, section 4.3 provides the details of the 25 notifications that were issued by the Officers on Duty, and the recipients of those notifications. Consequently, section 4.4 accounts for the area of validity of the notifications to provide an assessment of the pragmatic value of the Formal notifications issued during the event. Section 4.5 then investigates the role of Informal notifications, while Flash Floods notifications are analysed in section 4.6. Finally, section 4.7 gathers the feedbacks provided by the EFAS partners and third-party partners.

4.1 Overview of the EFAS notifications criteria and protocol

EFAS notifications are classified into three categories: Formal, Informal, Flash floods.

EFAS Formal and Informal notifications are based on the comparison between EFAS medium-range discharge forecasts and pre-computed returning period discharge thresholds. Similarly, EFAS flash flood notifications are based on the comparison between the forecasted surface runoff accumulated over the upstream catchment with a reference threshold. Discharge and runoff return period thresholds are based on a simulation of approximately 30 years. Specifically, observed meteorological forcings for the past ~30 years are used as input to the operational set-up of the hydrological model to simulate the historical discharge and runoff time series (model climatology). The return period discharge thresholds are then derived by the statistical analysis of the historical discharge and runoff time series. The comparison between forecasts with model-derived threshold exceedances allows to provide an early view of a potential flood situation.

The criteria for the issue of each type of notification are explained in this open page of the EFAS website: EFAS Notifications | Copernicus EMS - European Flood Awareness System. The Officers on Duty of the CEMS Hydrological Forecast Centre – Analytics and Dissemination (DISS) use the information provided by the EFAS Map Viewer of the EFAS IS to verify whether the criteria for Formal, Informal, Flash Floods notifications are met. More specifically, Formal and Informal notifications are based on the Reporting Points layer (under the "Flood summary" tab): Fixed reporting points (section 2.1) and dynamic reporting points. The former are always available, while the latter are displayed only in case of a flood signal. Flash Floods notifications are based on ERIC reporting points (under the Flash Flood tab). For convenience, the criteria are reported below.

4.1.1 Criteria for Formal Flood Notifications

An EFAS Formal Flood Notification is issued when the probability of exceeding critical flood thresholds is forecasted more than 48 hours ahead in a river basin with a minimum upstream area of 2000 km2 where there is an EFAS partner. The forecast also must be persistent (see below) and at least one deterministic forecast must exceed the EFAS 5-year return period. Formal flood notifications are automatically added to the ERCC overview (restricted information) and disseminated to the respective EFAS partner(s).

1. Catchment part of Conditions of Access.
2. Catchment area is >= 2,000 km^2.
3. Event >= 48 hours in advance with respect to forecast date.
4. Forecasts are persistent (3 consecutive forecasts with >= 30 % exceeding EFAS 5-year return period threshold according to ECMWF-ENS or to COSMO-LEPS).
5. At least one of the deterministic forecasts (ECMWF or DWD) exceeds also the EFAS 5-year return period threshold.

4.1.2 Criteria for Informal Flood Notifications

The EFAS Informal Flood Notification is issued when a probability of exceeding critical flood thresholds are forecasted in a river basin where there is an EFAS partner but the forecasted event does not satisfy the rules of an EFAS Formal Flood Notification, e.g. warning lead time, size of river basin, or location of event. An EFAS Informal Flood Notification can also be issued if EFAS results are not conclusive but one of the multiple forecasts indicates risk of severe flooding. Informal flood notifications are sent to the respective EFAS partner(s) and the ERCC.

1. Catchment part of Conditions of Access.
2. Any of the above criteria for a formal notification is not met (catchment size, lead time, forecast persistence, deterministic forecast exceedance) but the forecasters think the authorities should be informed.
3. Catchment >= 1000 km2. The minimum catchment size where EFAS provides skilful results is approx. 1000 km^2. For catchment areas significantly smaller than 1000 km^2 no Informal Flood Notification should be sent.
4. Any other doubt.

The reasoning of the Officer On Duty is briefly explained in the “comments” section of the notification email which is sent to the EFAS partners and EFAS third party partners.

4.1.3 Criteria for Flash Flood Notifications

An EFAS Flash Flood Notification is issued when the probability of exceeding a 5 year return period magnitude of the surface runoff index is forecasted to be equal or greater than 30% and the earliest lead time to the occurrence of the threshold probability exceedance is <= 48 hours, in a region where there is an EFAS partner. Flash flood notifications are sent to the respective EFAS partner(s) and the ERCC.

EFAS Flash flood notifications are issued for administrative regions.

1. Catchment part of Conditions of Access.
2. Probability of exceeding the 5-year ERIC return period is >= 30%
3. Lead time to the event is <= 48 hours ahead
4. Catchment <=2000 km2.
5. The start of the event is defined as the point where 30% of the probabilistic forecasts exceed the 5-year return period threshold.

6. Actual lead time to the earliest predicted peak is > 0 hours. Here, 'actual lead time' is defined as the time difference between the current time when the forecaster analyses the forecast and the timing of the predicted peak of the event.

4.1.4 Additional rules for both formal and informal notifications

In addition to above criteria, the following rules are in place – for both Formal and Informal notifications. These rules are technical guidelines to support the work of the Officers On Duty (and for this reason, they have not been published). Nevertheless, these technical guidelines are reported here for completeness as they can help the readers to understand the spatial and temporal distribution of the notifications.

- If an EFAS Flood Notification has been sent already for a tributary there is no need to send another one if a new reporting point appears further downstream in the same tributary (i.e. the flood wave is travelling downstream).
- If an EFAS Flood Notification has been sent for a tributary and a new reporting point appears further downstream located in the main stream a notification should be sent.
- If an EFAS Flood Notification has been sent for major river and a new reporting point appears further downstream a notification should be sent if the new reporting point is located in another country.
- If an EFAS Flood Notification has been sent for a specific reporting point and the forecasted discharge falls below the EFAS high threshold and then rises again above the EFAS high threshold this can be considered a new event and a new notification should be sent.

The first three points detail the spatial location of the notifications and are intended to (1) avoid sending several notifications within the same river reach (tributary); (2) ensure that a notification is issued when the conditions arise in a new river reach; (3) ensure that all the EFAS partners (from different countries) area aware of the event. Finally, the last point clarifies the temporal distribution of the notifications, and it has the scope to raise awareness in case of subsequent flood events.

4.1.5 Operational protocol

The Officers on Duty of the CEMS Hydrological Forecast Centre – Analytics and Dissemination analyse the EFAS forecasts twice daily, in the morning by 08:30 CET/CEST (in working days) and in the afternoon by 14:00 CET/CEST (**Table 5**). Officers on Duty discuss the situation and which notifications will be sent via the communication platform. The notifications are distributed by email including the name of the responsible Officer on Duty who can then be contacted by the email recipients in case of follow-up questions. Moreover, the notifications are logged into the EFAS IS and they can be visualised using the EFAS Map Viewer by EFAS partners and EFAS third party partners (and by the ERCC officers).

Table 5. Timelines of EFAS forecast production and dissemination.

Forecast time	Available in EFAS-IS	Dissemination time	Dissemination time minus forecast time
00 UTC	09 UTC	14 CET = 13 UTC 14 CEST = 12 UTC	13 hours (in winter) 12 hours (in summer)
12 UTC	21 UTC	08:30 CET = 07:30 UTC working days 09:30 CET = 08:30 UTC weekends and bank holidays 08:30 CEST = 06:30 UTC working days 09:30 CEST = 07:30 UTC weekends and bank holidays	19.5 hours (in winter, working days) 20.5 hours (in winter, weekends and bank holidays) 18.5 hours (in summer, working days) 19.5 hours (in summer, weekends and bank holidays)

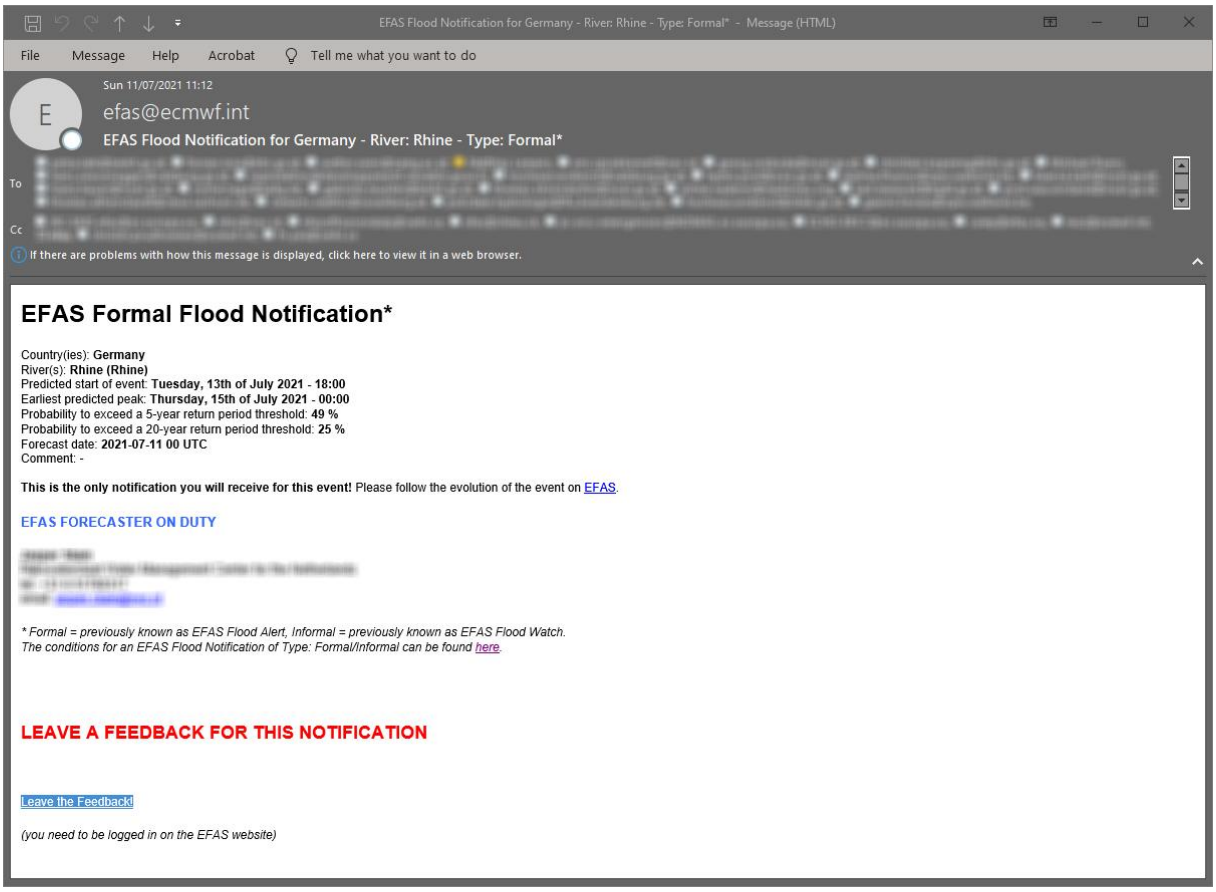
As an example, **Figure 12** shows the screenshot of a notification email. The notification contains information about the location (although the level of detail is limited to stating the name of the river) and about the forecast it was based on. It further includes a note saying "This is the only notification you will receive for this event!

Please follow the evolution of the event on EFAS", where the word EFAS comprises a hyperlink to www.efas.eu. The notification also includes a note saying "The conditions for an EFAS Flood Notification of Type: Formal/Informal can be found here" where the word 'here' comprises a hyperlink to the online documentation.

Moreover, the CEMS Hydrological Forecast Centre – Analytics and Dissemination sends a daily overview to the Emergency Response Coordination Centre (ERCC) of the European Commission. This daily overview contains information on ongoing floods in Europe as reported by the national services and by EFAS.

Once a flood event has passed, the notification is deactivated. This deactivation is done in the EFAS-IS by the Officer on Duty. Once deactivated, the notification is no longer visible in the EFAS Map Viewer and it is removed from the ERCC overview. No email messages are sent for the deactivation.

Figure 12. Sample EFAS notification. Here, a Formal Flood Notification that was issued in the 2021 July flood event is shown.



4.2 Point scale analysis of the criteria for the issue of a Formal notification

The point scale analysis of this section allows an in-depth assessment of the effectiveness of the Formal notifications criteria for this specific flood event. Specifically, this analysis focuses on each reporting point, and it aims to define whether the Formal notifications criteria allowed to timely and effectively flag the event. Such a point scale analysis has scientific value, but it does not reflect the pragmatic value of the EFAS notifications which were issued by the Officers on Duty during the event. The latter assessment must account for the area of validity of each notification: While this section provides a detailed, point scale analysis, the sections 4.3 and 4.4 include a discussion on the area of validity of the notifications in order to assess the correctness and accuracy of the notifications that were issued during the event.

The analysis is based on the comparison between the EFAS forecasts with the water balance simulation. The water balance simulation is therefore used as 'verifying truth'. This simulation is the EFAS simulation forced using meteorological observations (the EFAS water balance simulation are available from the Climate Data Store). Comparing the EFAS forecasts with the water balance simulation allows eliminating the impact of hydrological model bias and thus quantifying the exceedance of predicted river flows in terms of the model climatology. This approach is consistent with the mandate of EFAS, which is to create early awareness. More specifically, this section checks whether the criteria for the issue of a Formal notification were met and whether the water balance simulation exceeded the 5 years return period threshold. This analysis was repeated for all the reporting points with the purpose of analysing the impact of the notification criteria on the issue of the notifications and on their timing. Therefore, this point-scale analysis has the scope to highlight needs for improvements in the notifications criteria and protocols.

The exercise of this section focuses on 46 reporting points in the study area where the upstream area exceeds 2,000 km^2 (**Table 7**; note that 45 of these are fixed reporting points and 1 is a dynamic reporting point). These points are visualized in **Figure 13**.

The agreement between the conditions to issue a Formal notification and the exceedance of the 5 years return period of the water balance simulation is summarised using **Table 6**.

Table 6. Agreement between the criteria for Formal flood notifications and the water balance at point scale: Q_{WB} is the discharge value of the water balance simulation; Q_{T5} is the discharge threshold value with 5 years return period.

	Formal Notification criteria met	Formal Notification criteria NOT met
$Q_{WB} > Q_{T5}$	Agreement	Disagreement – miss
$Q_{WB} < Q_{T5}$	Disagreement – false	Agreement

Forecast quality at the reporting points is not statistically independent and for this reason the evaluation metrics can only be used to infer conclusions on the protocol for the issue of Formal notifications (it cannot be used to quantify “Agreements/Hits” and “false alarms”). Furthermore, it must be underlined that while such an approach has the clear advantage of providing a straightforward evaluation of the notifications criteria at the point scale, it also has the large limitation of not accounting for the probabilistic value of EFAS forecasts.

Figure 13. EFAS reporting points included in the study area with catchment drainage area >= 2,000 km2

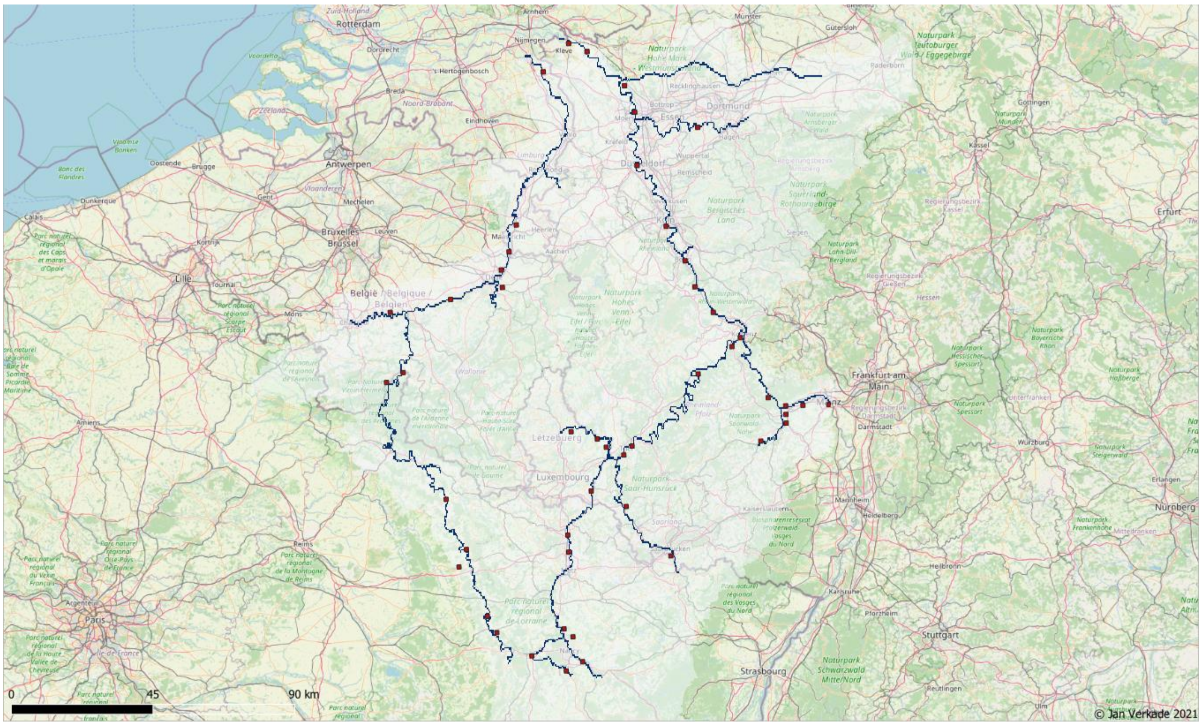


Table 7 provides the results of the point scale analysis for Formal notifications for the 46 reporting points in the study area that have an upstream area of at least 2,000 km^2.

Table 7. Results of the point scale analysis for Formal notifications for the 46 reporting points in the study area that have an upstream area of at least 2,000 km^2. For the interpretation of the superscript INF the reader is invited to complement the information of this table with the analysis of the Informal flood notifications provided by section 4.5.

ID	Station name	River	Area [km2]	Formal Notification criteria met	Water balance > 5 year RP	Assessment
110	Boos	Nahe	2850	NO	NO	Agreement
112	Grolsheim	Nahe	4000	NO	NO	Agreement
111	Dietersheim	Nahe	4025	NO	NO	Agreement
3101	Laneuville-devant-Nancy [la Madeleine]	Meurthe	2800	NO	NO	Agreement
3108	La Sarre à Sarregueimes et à Sarreinsming	Saar	3700	NO	NO	Agreement
51	St. Arnual	Saar	3900	NO	NO	Agreement
60	Fremersdorf	Saar	7025	NO	NO	Agreement
4358	Diekirch	Sauer	2125	NO	YES	**DISagreement (miss)** ^{INF}
109	Bollendorf	Sauer	3250	NO	YES	**DISagreement (miss)** ^{INF}
4388	Rosport	Sauer	4200	NO	YES	**DISagreement (miss)** ^{INF}
NA	Not a station	Sauer	16175	NO	YES	**DISagreement (miss)** ^{INF}
2956	Tonnoy	Moselle	2050	NO	NO	Agreement
3100	Toul	Moselle	3325	NO	NO	Agreement
3102	Custines	Moselle	6950	NO	NO	Agreement
3105	Hagondange et a Hàunconcour	Moselle	9400	NO	NO	Agreement
3107	Uckange (France)	Moselle	10700	NO	NO	Agreement
32	Perl (Germany)	Moselle	11525	NO	NO	Agreement
1970	Trier	Moselle	23650	YES	YES	Agreement
38	Cochem	Moselle	27025	YES	YES	Agreement
930	Alken	Moselle	27925	YES	YES	Agreement
934	Hattingen	Ruhr	4225	NO	YES	**DISagreement (miss)**
49	Mainz	Rhine	98300	YES	YES	Agreement
36	Kaub	Rhine	103525	YES	YES	Agreement
50	Koblenz	Rhine	109850	YES	YES	Agreement
57	Andernach	Rhine	139549	YES	YES	Agreement
62	Bonn	Rhine	140901	YES	YES	Agreement
40	Koeln	Rhine	144150	YES	YES	Agreement
58	Dusseldorf	Rhine	147750	YES	YES	Agreement
47	Ruhrort	Rhine	152875	YES	YES	Agreement

54	Wesel	Rhine	154150	YES	YES	Agreement
48	Rees	Rhine	159400	YES	YES	Agreement
46	Emmerich	Rhine	159550	YES	YES	Agreement
153	Lobith	Rhine	159675	YES	YES	Agreement
1360	Salzinnes-Ronet	Sambre	2900	NO	YES	**DISagreement (miss)**
1359	Angleur	Ourthe	3725	YES	YES	Agreement
NA	Roemond (point ID: DH001146)	Rur (or Roer)	2475	YES	YES	Agreement
3110	Commercy	Meuse	2400	NO	NO	Agreement
3111	Saint-Mihiel	Meuse	2675	NO	NO	Agreement
2766	Verdun (Meuse)	Meuse	3400	NO	YES	**DISagreement (miss)** INF
1356	Chooz	Meuse	10225	NO	YES	**DISagreement (miss)** INF
2768	Chooz (Trou du Diable)	Meuse	10500	NO	YES	**DISagreement(miss)** INF
1357	Amay	Meuse	16750	NO	YES	**DISagreement (miss)** INF
1358	Vise-Lixhe	Meuse	20825	NO	YES	**DISagreement(miss)** INF
953	St Pieter Noord	Meuse	21075	NO	YES	**DISagreement (miss)** INF
154	Borgaren Dorp	Meuse	22050	NO	YES	**DISagreement(miss)** INF
2201	Venlo	Meuse	27025	YES	YES	Agreement

Table 7.

Table 8 shows the summary of the metrics for the 46 reporting points listed in **Table 7**.

Table 8. Agreement between the formal notification criteria and the water balance at point scale: Q_{WB} is the discharge value of the water balance simulation; Q_{T5} is the discharge threshold value with 5 years return period Individual station behaviour is shown in Table 16

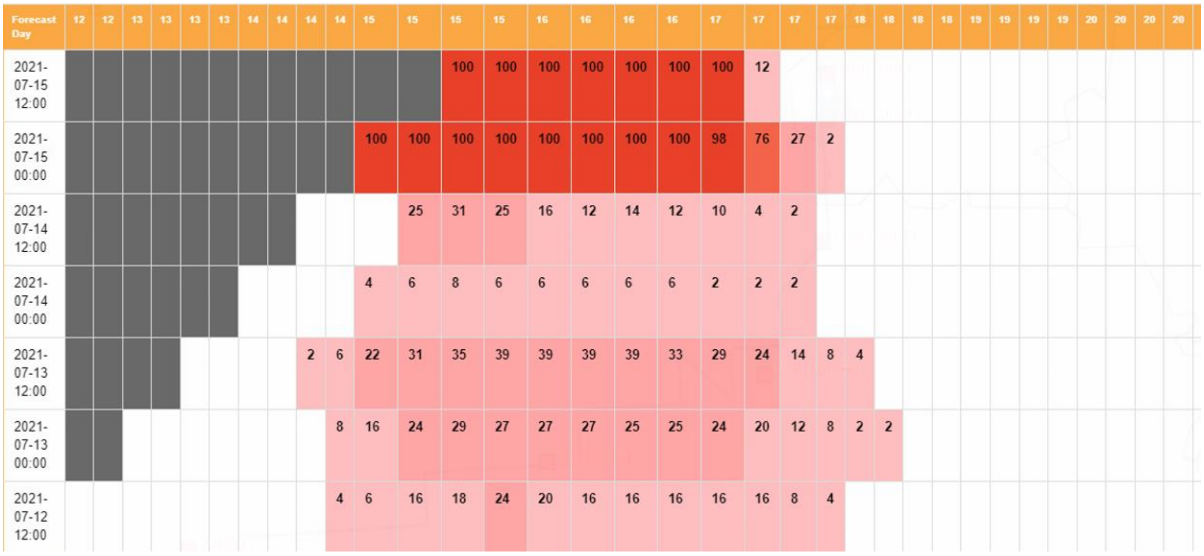
	Formal Notification criteria met	**Formal Notification criteria not met**
$Q_{WB} > Q_{T5}$	18 (agreement)	13 (disagreement – miss)
$Q_{WB} < Q_{T5}$	0 (disagreement – false)	15 (agreement)

The number of reporting points for which the criteria for formal notifications agreed with the exceedance of the 5 years return period threshold was 33 out of 46. Vice versa, for 13 reporting points the criteria for formal notifications were in disagreement with the exceedance of the water balance 5 years return period threshold. More specifically, in 13 instances the water balance simulation exceeded the 5 years return period, but the criteria for the issue of a Formal notification were not met. These 13 instances were found in the Sauer, Ruhr, Sambre, and Meuse. Albeit the forecasts at the various locations are not statistically independent and albeit the analysis did not account for the probabilistic value of EFAS forecasts, the result above clearly required an in-depth investigation.

In quite a few cases (e.g. Sauer, Ruhr), the reason for which criteria for sending a Formal Notification were not met is in the '48 hour rule'. The 'flashy' nature of the July floods meant that floods weren't forecasted until very close to their occurrence – often within 48 hours of their occurrence. As a result, Formal Notification criteria were not met. The forecast signal for the Sambre was elusive, an early but highly inconsistent hint for an event could be seen in the July 13th 00 forecast, however, the flood signal disappeared in all the following forecasts, and the exceedance of the 5 years return period threshold was not forecasted.

Another instance of a 'miss' was found in the Meuse basin. For instance, at St Pieter Noord, the July flood constituted what is now the highest flood on record. Yet no Formal Notification was required to be sent. When scrutinizing the record of forecasts, it was found that the *persistence criterion* was the reason why notification criteria were not met. Various forecast runs indicated probabilities of exceedance of the T5 level of 30% or higher. Note, however, the Wednesday, July 14, 00 UTC forecast; this forecast indicated that the probability of exceedance of the T5 level would not exceed 8% (**Figure 14**). Similarly, the *persistence criterion* was the reason for which Formal notification criteria were not met at Vise-Lixhe and Borgaren Dorp.

Figure 14. St. Pieter Noord (Meuse river, station ID 953): ECMWF-ENS forecast scenario showing the probability of exceedance of the T5 level. Note the middle row, showing the probabilities as estimated in the Wednesday, July 14 00 UTC forecast (https://www.efas.eu/efas_frontend/#/home)



Forecast Day	12	12	13	13	13	13	14	14	14	14	15	15	15	15	16	16	16	16	17	17	17	17	18	18	18	18	19	19	19	19	20	20	20	20
2021-07-15 12:00													100	100	100	100	100	100	100	12														
2021-07-15 00:00											100	100	100	100	100	100	100	100	98	76	27	2												
2021-07-14 12:00												25	31	25	16	12	14	12	10	4	2													
2021-07-14 00:00											4	6	8	6	6	6	6	6	2	2	2													
2021-07-13 12:00									2	6	22	31	35	39	39	39	39	33	29	24	14	8	4											
2021-07-13 00:00										8	16	24	29	27	27	27	25	25	24	20	12	8	2	2										
2021-07-12 12:00										4	6	16	18	24	20	16	16	16	16	16	8	4												

4.3 Notifications issued during the July 2021 flood event

During the event, 5 formal flood notifications, 6 informal flood notifications, and 14 flash flood notifications were sent (**Table 9** and **Table 10**).

The first informal flood notification was issued on Saturday, July 10. The first flash flood notifications were issued on Monday, July 12 – for various regions in France. The flash flood notifications for the hard-hit locations in both Germany and Belgium were issued just before midday on Tuesday, July 13.

By Saturday, July 17, all flash flood notifications were deactivated and by Tuesday, July 20 the same was true for all formal and informal flood notifications.

Table 9. Flood notifications issued during the July flood event – formal and informal. The list of Formal and Informal Flood notifications is available to EFAS registered users at https://www.efas.eu/en/efas-formal-flood-notification, https://www.efas.eu/en/efas-informal-flood-notification (updates in near real time)

Type	Location	forecast time[2] [UTC]	issue time [CEST]	deactivation time [CEST]
Informal	Rhine at Kaub (DE; 103,488 km^2)	Sat, Jul 10, 00:00	Sat, Jul 10, 11:35	Sun, Jul 11, 11:11
Formal	Rhine at Kaub (DE; 103,488 km^2)	Sun, Jul 11, 00:00	Sun, Jul 11, 11:12	Mon, Jul 19, 07:30
Informal	Ourthe at Angleur (BE; 3,607 km^2)	Mon, Jul 12, 00:00	Mon, Jul 12, 11:28	Tue, Jul 13, 07:53
Informal	Rur (or Roer) near Roermond (NL; 2,475 km^2)	Mon, Jul 12, 00:00	Mon, Jul 12, 11:31	Tue, Jul 13, 07:53
Formal	Rhine at Lobith (NL; 160,800 km^2)	Mon, Jul 12, 12:00	Tue, Jul 13, 07:48	Mon, Jul 19, 07:31
Formal	Ourthe at Angleur (BE; 3,607 km^2)	Mon, Jul 12, 12:00	Tue, Jul 13, 07:49	Mon, Jul 19, 07:30
Formal	Rur (or Roer) near Roermond (NL; 2,475 km^2)	Mon, Jul 12, 12:00	Tue, Jul 13, 07:50	Tue, Jul 20, 12:56
Informal	Meuse at Borgharen (NL; 22,050 km^2)	Tue, Jul 13, 00:00	Tue, Jul 13, 11:23	Sun, Jul 18, 11:39
Informal	Nahe at Martinstein (DE; 1,468 km^2)	Tue, Jul 13, 00:00	Tue, Jul 13, 11:24	Fri, Jul 16, 07:27
Formal	Moselle at Alken (DE; 27,960 km^2)	Tue, Jul 13, 12:00	Wed, Jul 14, 07:43	Mon, Jul 19, 07:30
Informal	Sauer at Rosport (LU; 4,200 km^2)	Wed, Jul 14, 00:00	Wed, Jul 14, 11:31	Sun, Jul 18, 08:38

[2] This is the initialization time of meteorological forecasts on which the hydrological forecasts are based.

Table 10. Flash flood notifications issued during the July flood event. The list of Flash Flood notifications is available to EFAS registered users at https://www.efas.eu/en/efas-formal-flood-notification, https://www.efas.eu/en/efas-flash-flood-notification (updates in near real time)

type	country	region	river	forecast time [UTC]	issue time [CEST]	deactivation time [CEST]
Flash	FR	Vosges	Mosel (or Moselle)	Sun, Jul 11, 12:00	Mon, Jul 12, 07:49	Sat, Jul 17, 07:15
Flash	FR	Meurthe-et-Moselle	Mosel (or Moselle)	Sun, Jul 11, 12:00	Mon, Jul 12, 07:49	Sat, Jul 17, 07:15
Flash	FR	Moselle	Saar	Mon, Jul 12, 00:00	Mon, Jul 12, 11:33	Thu, Jul 15, 12:59
Flash	DE	Trier	Mosel (or Moselle)	Tue, Jul 13, 00:00	Tue, Jul 13, 11:25	Fri, Jul 16, 12:55
Flash	DE	Koblenz	Rhine	Tue, Jul 13, 00:00	Tue, Jul 13, 11:25	Fri, Jul 16, 12:55
Flash	DE	Koln	Rhine	Tue, Jul 13, 00:00	Tue, Jul 13, 11:25	Fri, Jul 16, 12:55
Flash	DE	Dusseldorf	Rhine	Tue, Jul 13, 00:00	Tue, Jul 13, 11:25	Fri, Jul 16, 12:55
Flash	NL	Limburg	Maas (or Meuse)	Tue, Jul 13, 00:00	Tue, Jul 13, 11:25	Fri, Jul 16, 12:55
Flash	BE	Prov. Liege	Maas (or Meuse)	Tue, Jul 13, 00:00	Tue, Jul 13, 11:26	Fri, Jul 16, 12:55
Flash	BE	Prov. Luxembourg	Maas (or Meuse)	Tue, Jul 13, 00:00	Tue, Jul 13, 11:26	Fri, Jul 16, 12:55
Flash	DE	Arnsberg	Ruhr	Tue, Jul 13, 12:00	Wed, Jul 14, 07:44	Fri, Jul 16, 07:27
Flash	DE	Saarland	Sarre	Tue, Jul 13, 12:00	Wed, Jul 14, 07:44	Fri, Jul 16, 07:27
Flash	DE	Rheinhessen-Pfalz	Rhine	Tue, Jul 13, 12:00	Wed, Jul 14, 05:45	Thu, Jul 15, 12:59
Flash	BE	Prov. Namur	Meuse	Wed, Jul 14, 00:00	Wed, Jul 14, 14:45	Fri, Jul 16, 07:26

EFAS notifications are sent to EFAS partners, EFAS third party partners (see EFAS webpage: Become EFAS Partner | Copernicus EMS - European Flood Awareness System) and to the ERCC. In the context of the present report, it should be noted that the authority from the German state of North Rhine-Westphalia did not receive any EFAS notifications as they became an EFAS partner after the July 2021 flood event.

EFAS Formal and informal (fluvial) flood notifications are issued to a list of recipients that are related to the main river: a notification for a reporting point in a Rhine tributary basin (e.g., Moselle) is sent to the same set of recipients as a notification for a forecasting point on the main channel and the list is identical regardless of the location of the reporting point (i.e., upstream or downstream). The reason for this is to raise an early awareness about a possible upcoming flood with all relevant authorities sharing the river basin, not only for emergency preparedness of the potentially affected authorities but also for authorities not directly affected (e.g. those located in the upstream part of the river basin) to possibly start organizing support in case the flood would overwhelm the capacities of the affected authorities. For instance, a flood notification for Lobith (in the Netherlands, just downstream of the German/Dutch border) is sent to many recipients including Austrian and Italian authorities although only very small upstream parts of the Rhine river basin are located in Austria or Italy.

During the event under investigation, the various EFAS flash flood notifications were sent to the following organizations depending on the affected region:

- State Environmental Agency Rhineland-Palatinate, Germany
- SPW: Service public de Wallonie, Belgium
- RWS: Rijkswaterstaat, the Netherlands
- SCHAPI: Service central d'hydrométéorologie et d'appui à la prévision des inondations, France
- BfG: Bundesanstalt für Gewässerkunde, Germany
- DWD: Deutscher Wetterdienst, Germany.

Most of the above organizations are mandated to produce and disseminate operational flood forecasts. The exceptions here are the BfG, whose mandate is primarily in the field of water level forecasting for shipping and navigation purposes and the DWD who does not have flood forecasting or flood warning responsibilities (Bundesministerium der Justiz und für Verbrauchersc, 1998). The French and Dutch organizations operate at the national[3] (country) level. The German and Belgian organizations operate at a sub-national level namely that of states and communities, respectively.

Within the Netherlands, EFAS notifications are sent to Rijkswaterstaat. This organization has a mandate to, and responsibility for producing and disseminating fluvial flood forecasts for the 'primary waterways'. These include the Dutch stretches of the main channel of the river Meuse but not its tributaries. In similar vein, RWS has no mandate to forecast pluvial flooding. Fluvial flood forecasting for non-primary waterways and pluvial flood forecasting is the responsibility of a separate layer of government: the water boards. These water boards are not recipients of EFAS flash flood forecasts. It is also noted that flash flood forecasts are issued on a region-by-region basis. In the Netherlands, these regions take the shape of the Dutch provinces. This has been a pragmatic choice, however, as the provincial authorities have no role in flood event management and indeed, as they are not EFAS partners they did not receive EFAS notifications during the July floods. Arguably, the water boards would be a more suitable level for grouping EFAS flash flood notifications or indeed becoming EFAS partners. This would still be a rather pragmatic choice, informed by warning considerations and not by hydrometeorological considerations. Indeed, since the July floods, Rijkswaterstaat procedures have been modified to ensure that EFAS flash flood notifications are forwarded to the water boards. Conversations are taking place between Rijkswaterstaat and the water boards to further discuss this issue (Sprokkereef, 2021).

[3] By 'national' we mean: at the level of the nation-state.

4.4 Analysis of Formal notifications issued during the event

EFAS notifications have value for an extended river reach and not for a single reporting point. This section has two objectives: (1) to verify whether the Formal notifications issued during the event correctly followed the protocol; (2) to verify whether the Formal notifications issued during the event allowed to raise awareness in the river stretches in which the water balance simulation (i.e. the 'verifying truth') exceeded the 5 years return period. As mentioned above, the notification message states the name of the river and encourages the recipients to seek more detailed information from the EFAS Map Viewer. The notification symbol on the EFAS Map Viewer is located at a specific reporting point, this location is selected by the Officer on Duty, and it helps to visualize the river reach which is interested by the warning. The area of validity of each notification can then be identified using the information provided by other layers of the EFAS Map Viewer.

The preparation of this report highlighted doubts on the methodology to identify the area of validity of a notification: Albeit the use of additional layers of the EFAS Map Viewer is advised during trainings, an explicit step-by-step protocol has not yet been included in the guidelines. A clear understanding of the area of validity of a notification is crucial for the correct use of EFAS forecasts and the actions planned to improve the communication of the area of validity of an EFAS notification are presented in chapter 6.

Upon receipt of a notification, users are encouraged to explore the EFAS interface (as explicitly stated by each notification email). This section shows the information that a user was able to view during the event under investigation. For this purpose, **Figure 15** and **Figure 16** present a series of screenshots of the layers available in EFAS version 4.2 (EFAS operational version in July 2021). The first objective of this section requires verifying whether the Formal notifications issued during the event encompassed all the reporting points at which the criteria were met. In other words, the (strongly recommended) complementary analysis of the layers available from the EFAS Map Viewer allows to infer the area of validity of a notification and therefore to establish whether the issued notifications encompassed the relevant river stretches (such an evaluation is not possible when looking at the single reporting points). EFAS version 4.2 provided the following layers: two layers under the "Flood summary" tab, namely "Flood probability < 48h" and "Flood probability > 48h"; four layers under the "Hydrological" tab, namely "COSMO > 5-years RP", "ECMWF-ENS > 5-years RP", "Det. DWD", "Det. ECMWF". The layers "Flood probability > 48h" and "Flood probability < 48h" show for each pixel the probability of ECMWF-ENS forecasts to exceed the EFAS 5-year return period threshold in the forecasting range 2-10 days and 0-48 hours, respectively. The layer "Flood probability > 48h" can help to identify the area of validity of an EFAS Formal notification: A threshold of 30% can be used for consistency with the notifications criteria. The layers under the "Hydrological" tab can then be used to complement this information because they provide for each pixel the percentage of the probabilistic forecasts (ECMWF and COSMO) exceeding the EFAS 5-year return period threshold and the highest return period exceedance of the deterministic forecasts (DWD and ECMWF-Det) within the entire forecast range (from 5.5 to 10 days).

The verification was performed for each one of the 5 Formal notifications issued during the event: 1 for the Ourthe, 1 for the Moselle, 2 for the Rhine, 1 for the Rur (or Roer); the details are shown in **Table 9**.

Figure 15 shows the Formal notification issued for the Ourthe and the layers providing spatially distributed information of the forecast timestamp used to send the notification.

Figure 16 shows the Formal notification issued for the river Moselle and the layers providing spatially distributed information for the forecast timestamp used to send the notification.

Figure 15. Ourthe at Angleur, Formal notification issued on Tue, Jul 13 at 7:49 AM UTC (please note that in the figure the symbol of the Formal notification is hidden by the symbol of the Informal notification – the latter was deactivated on Jul 13 at 5:53 AM UTC). Forecast on Jul 12 at 12 UTC: Flood probability > 48h (top left), COSMO > 5 year RP (top right), ECMWF Det (bottom left), DWD Det (bottom right) (https://www.efas.eu/efas_frontend/#/home)

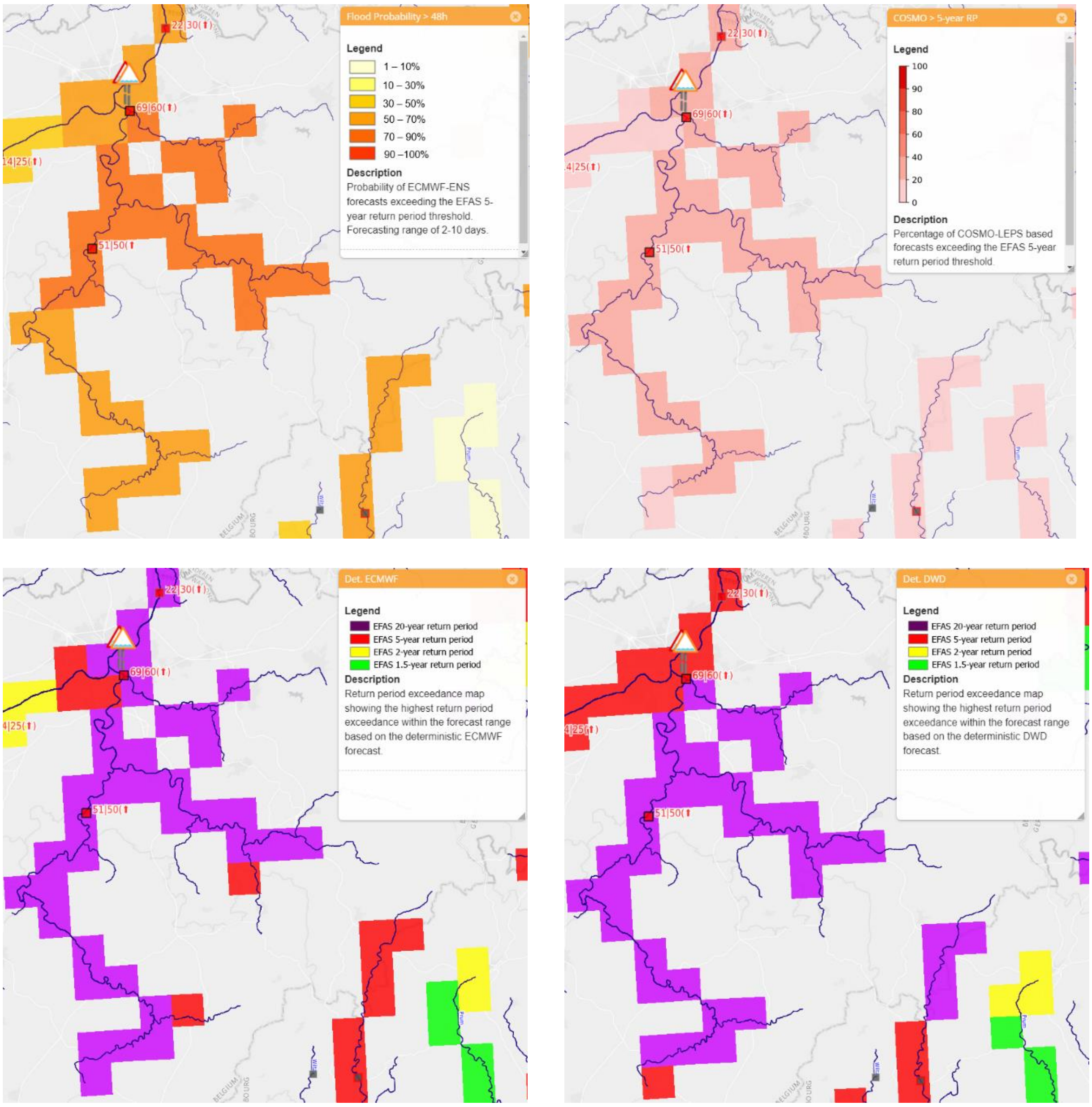
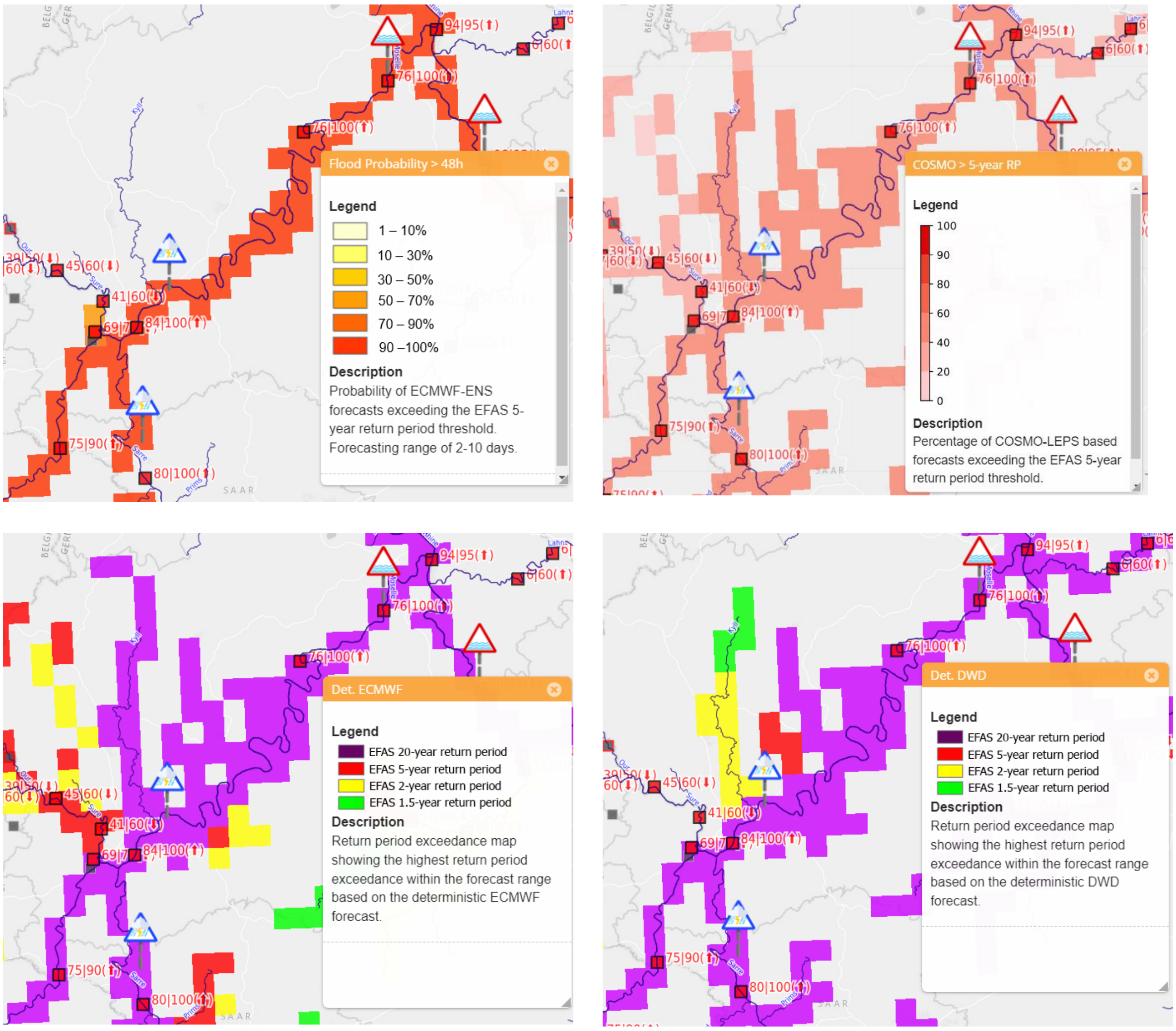


Figure 16. Moselle at Alken, Formal notification issued on Wed, Jul 14 at 7:43 AM UTC. Forecast on Jul 13 at 12 UTC: Flood probability > 48h (top left), COSMO > 5 year RP (top right), ECMWF Det (bottom left), DWD Det (bottom right) (https://www.efas.eu/efas_frontend/#/home)



Regarding the two formal notifications issued along the Rhine, the spatially distributed layers (figures not shown in this report) showed that the notification issued at Kaub on Sun, Jul 11 at 11:12 AM UTC aimed at raising awareness for the Rhine river reach from Mainz to Emmerich (i.e. the most downstream reporting point in Germany). The notification issued at Lobith (i.e. the most upstream reporting point in The Netherlands) on Jul 13 at 5:48 UTC could be used to raise awareness in the Rhine river reach from the German border to the river mouth.

The Formal notification issued near Roermond on the river Rur (or Roer) on Jul 13th at 7:50 AM UTC could be used to raise awareness for the Rur (or Roer) from Niddegen to its confluence with the Meuse.

The above analysis of the spatially distributed layers allowed to verify whether the Formal notifications issued during the event followed the protocol. According to this analysis, all the Formal notifications issued during the event were consistent with point scale analysis of the EFAS forecasts: The five Formal flood notifications issue during the event encompassed all the adequate reporting points along the same river reach. The reporting point ID2201 (Venlo, Meuse) could not be considered when sending out the notifications because the point was wrongly located on the EFAS Map Viewer. As stated above, the second objective of this section is to verify whether the Formal notifications issued during the event allowed to raise awareness in the river stretches in which the water balance simulation (i.e. the 'verifying truth') exceeded the 5 years return period. The answer to this question can be directly inferred by combining the point scale analysis and the list of issued notifications. Despite the water balance exceeded the 5 years return period for the Meuse, Sambre, Ruhr, and Sauer, the Formal notifications criteria were not met and Formal notifications could not be issued (in other words, the Officers on Duty did not commit an error). Informal notifications have the objective to complement Formal notifications and the following section verifies whether the issue of Informal notifications allowed to raise awareness in the above mentioned river stretches.

4.5 Analysis of Informal notifications issued during the event

Informal notifications were designed to complement Formal notifications. More specifically, Informal notifications are expected to raise awareness of incoming events in several circumstances. Examples are: The forecast signal is inconsistent (for instance, there are discrepancies between the deterministic and the probabilistic forecasts), the probabilistic forecast signal is not persistent, the lead time is smaller than 48 hours (this is the case of flashy events), the upstream area is smaller than 2000 km^2 (but larger than 1000 km^2).

While the criteria for the issue of Formal notifications have a sharp definition, the criteria for the issue of Informal notifications allow some flexibility; this flexibility is stated by the sentence: “Any of the criteria for a Formal notification is not met but the forecasters think the authorities should be informed”. The use of Informal notifications then allows leveraging on the experience and expertise of the Officers on Duty.

In order to acknowledge this degree of subjectivity, this report does not present a point scale analysis of the Informal notifications. Conversely, this report analyses whether the Informal notifications sent by the Officers on Duty contributed to raise awareness on upcoming events. More specifically, section 4.2 highlighted several reporting points in which the criteria for Formal notifications were not met, yet the water balance exceeded the 5 years return period threshold (**Table 7**). The purpose of this section is to verify whether the more flexible criteria for Informal notifications enabled to issue a warning at those specific river reaches.

This section presents the analysis of the 6 Informal notifications that were sent during the event (the complete list in presented in **Table 9**). The comments provided in the notification email allow to better understand the reasoning of the Officer on Duty.

Three Informal notifications preceded in time Formal notifications, namely, the Informal notifications for the Rhine (Kaub), for the Ourthe (Angleur), and for the Rur (Roermond) anticipated of 24 hours, 12 hours, and 12 hours, respectively, the Formal notifications. The common comment provided to explain the Informal notification was “model inconsistency”.

Two Informal notifications, for the Meuse (Borgharen) and for the Sauer (Rosport), were issued due to the inconsistency in the models and short lead time (Meuse), short lead time (Sauer). These notifications allowed raising awareness for the flashy events in the Meuse and in the Sauer (as highlighted by the superscript “INF” in **Table 7**). In these circumstances, the expertise and experience of the Officer on Duty allowed to adequately complement the criteria for Formal notifications.

One Informal notification was issued in the Nahe River (Martinstein), however, the water balance did not exceed the 5 years return period threshold. This notification was flagged as Informal because of the short lead time.

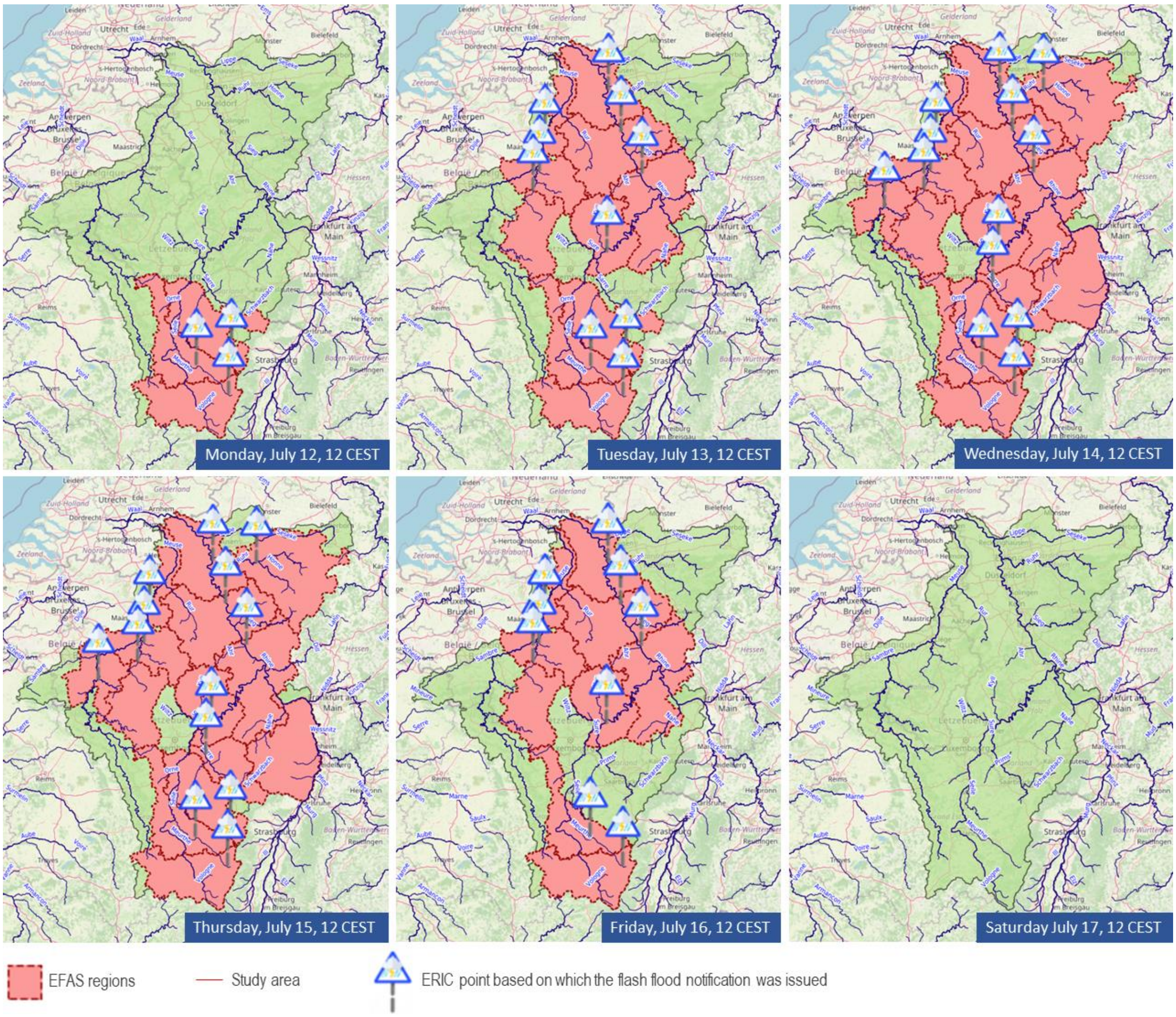
In summary, the Informal notifications aimed to raise awareness in two river reaches for which the Formal notification criteria were not met, nevertheless, one Informal notification led to a false alarm in one river reach.

4.6 Analysis of Flash flood notifications issued during the event

EFAS Flash flood notifications are issued for administrative regions, **Figure 17** shows the 14 Flash Floods notifications issued during the event and their area of validity.

Flash floods notifications have the purpose to raise awareness for events effecting small areas (< 2000 km^2) and with short lead time. The water balance simulation of the current implementation (with 5km resolution) of the EFAS hydrological model (LISFLOOD-OS) cannot be used as ‘verifying truth’ for events in such small areas, consequently, a quantitative evaluation of the flash floods notifications is not possible. Currently, feedbacks from EFAS partners and EFAS third party partners on the received notifications are the most adequate tool to achieve a qualitative evaluation of the Flash Floods notifications.

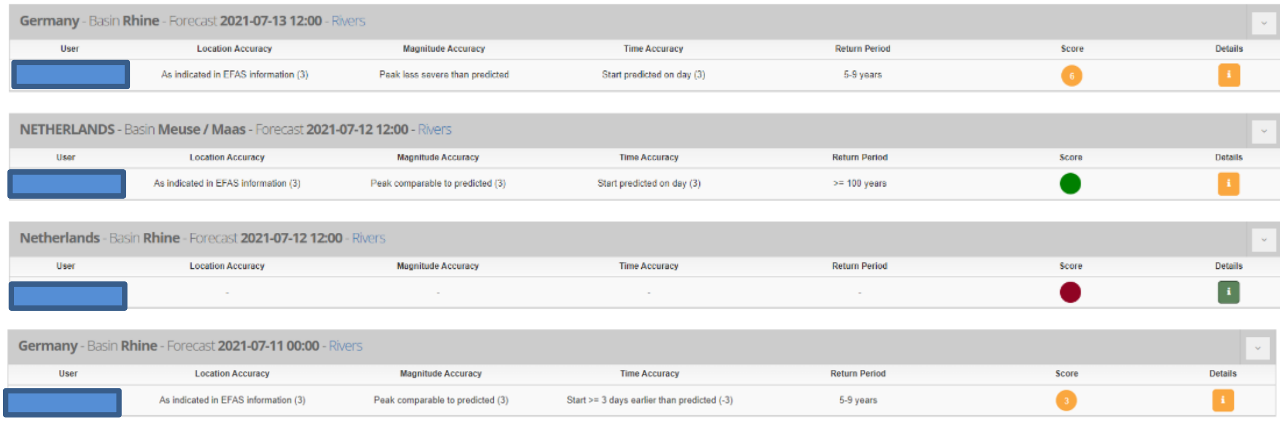
Figure 17. Flash Flood notifications and the “regions” for which they are valid, at various times during the event.



4.7 Feedback received through EFAS-IS

EFAS-IS allows for EFAS users to give feedback to notifications that they received. Out of the 25 notifications that were active during the July floods, 7 eventually had feedback against them: 4 relate to Formal Notifications (**Figure 18**) and 3 relate to Flash Flood Notifications (**Figure 19**). The full feedback content is included in **Annex 2**. The low number of received feedbacks hindered the performance of any quantitative analysis and only general remarks are provided in this section. There was an overall agreement between the EFAS notifications and the in-situ observations of the EFAS partners. Nevertheless, it can be noted that a false alarm was reported in the river reach of the Rhine in The Netherlands (albeit the water balance simulation exceeded the 5 years return period).

Figure 18. Feedback received to Formal Notifications issued during the July flood event. All the feedbacks can be visualized by EFAS registered users at https://www.efas.eu/efas_frontend/#/feedback)



Germany - Basin **Rhine** - Forecast **2021-07-13 12:00** - Rivers

User	Location Accuracy	Magnitude Accuracy	Time Accuracy	Return Period	Score	Details
[redacted]	As indicated in EFAS information (3)	Peak less severe than predicted	Start predicted on day (3)	5-9 years	6	i

NETHERLANDS - Basin **Meuse / Maas** - Forecast **2021-07-12 12:00** - Rivers

User	Location Accuracy	Magnitude Accuracy	Time Accuracy	Return Period	Score	Details
[redacted]	As indicated in EFAS information (3)	Peak comparable to predicted (3)	Start predicted on day (3)	>= 100 years		i

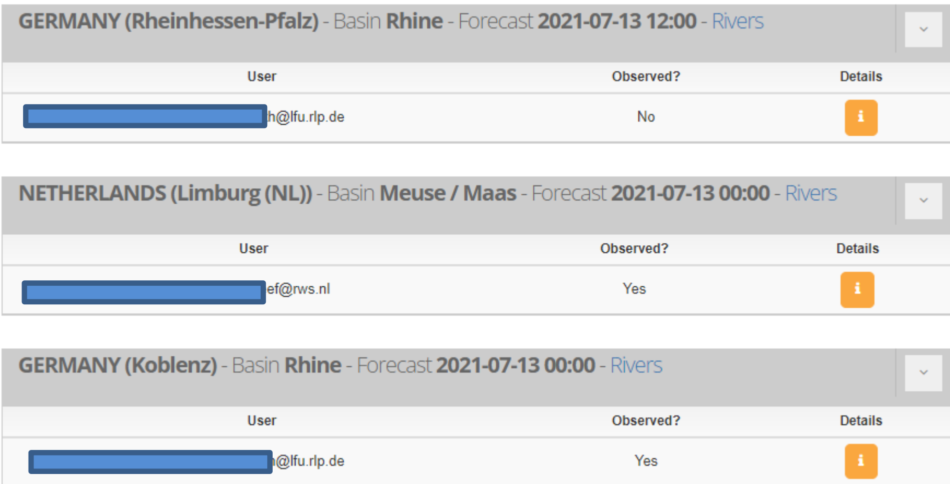
Netherlands - Basin **Rhine** - Forecast **2021-07-12 12:00** - Rivers

User	Location Accuracy	Magnitude Accuracy	Time Accuracy	Return Period	Score	Details
[redacted]	-	-	-	-		i

Germany - Basin **Rhine** - Forecast **2021-07-11 00:00** - Rivers

User	Location Accuracy	Magnitude Accuracy	Time Accuracy	Return Period	Score	Details
[redacted]	As indicated in EFAS information (3)	Peak comparable to predicted (3)	Start >= 3 days earlier than predicted (-3)	5-9 years	3	i

Figure 19. Feedback received to Flash Flood Notifications issued during the July flood event. All the feedbacks can be visualized by EFAS registered users at https://www.efas.eu/efas_frontend/#/feedback)



GERMANY (Rheinhessen-Pfalz) - Basin **Rhine** - Forecast **2021-07-13 12:00** - Rivers

User	Observed?	Details
[redacted]h@lfu.rlp.de	No	i

NETHERLANDS (Limburg (NL)) - Basin **Meuse / Maas** - Forecast **2021-07-13 00:00** - Rivers

User	Observed?	Details
[redacted]ef@rws.nl	Yes	i

GERMANY (Koblenz) - Basin **Rhine** - Forecast **2021-07-13 00:00** - Rivers

User	Observed?	Details
[redacted]@lfu.rlp.de	Yes	i

5 Verification of EFAS model simulation

EFAS notification criteria compare EFAS forecasts against the EFAS thresholds, the latter are based on historical time series of model simulations. The accuracy of the flood forecast for a specific event mainly depends on two factors: (1) The accuracy of the EFAS hydrological river discharge simulations, and (2) The accuracy of the weather forecasting products that are used as input to the hydrological model. Section 5.1 evaluates the accuracy of the EFAS hydrological water balance river discharge simulations, that is the capability of EFAS hydrological simulations to predict river discharge in situ observations for the July 2021 events when the model is forced using observed meteorological variables. Section 5.2 subsequently gives some insight on the quality of the weather forecasting products that were used as inputs to the July 2021 EFAS forecasts.

This section includes the findings of an event verification exercise only. This event was limited in space and in time, consequently,the findings do not pertain to all EFAS forecasts made anywhere, at any time. For that reason, the verification exercise will not include metrics that are typically computed for longer timeseries and a larger number of forecast locations, such as the modified Klinge-Gupta Efficiency, Continuous Ranked Probability Skill Score (CRPSS), etc. Rather, this section shows the original data (simulations and observations in single hydrographs) and a summary of how the simulations related to observations.

Interested readers can find complementary information under the tab "Evaluation" of the EFAS Map Viewer. Differently from the analysis presented in this section, the analysis provided by the "Evaluation" layers of the EFAS Map Viewer is based on the complete time series of available historical data. Specifically, the layer "Model Performance – Points" and "Model Performance – Catchments" provide the values of the modified Klinge-Gupta Efficiency and of its components (correlation, bias ratio, variability ratio), as well as a visual comparison between simulations and observations for historical time series for all the calibration stations. The layer "Medium-range forecast skill" provides the maximum lead time (in days) when EFAS medium-range river discharge forecast skill (CRPSS) is greater than 0.5, evaluated against a persistence benchmark forecast (6hr river discharge value persisted from previous time step).

5.1 Accuracy of water balance simulations for the event

This section aims to present an interesting insight of the capability of the water balance simulation to reproduce the timing and the magnitude of observed river discharge peaks. Nevertheless, when reading the outcomes of the analysis, it must be remembered that EFAS does not have the mandate to accurately predict the local discharge magnitude, but it aims to raise awareness for upcoming flood events. Coherently with the EFAS mandate, EFAS notifications are based on the comparison between the EFAS forecast and the EFAS thresholds and the latter are computed using historical simulations and not observed time series.

Observed flood peaks were identified for the 34 reporting points in the study domain for which sub-daily observations are available. The metrics used within the analysis are:

— The difference in timing between simulated and observed peak discharge: $T_{\text{peak,wb}} - T_{\text{peak,obs}}$

— The difference in magnitude between simulated and observed peak discharge, both in absolute and in relative terms: $Q_{\text{peak,wb}} - Q_{\text{peak,obs}}$ and $\frac{(Q_{\text{peak,wb}} - Q_{\text{peak,obs}})}{Q_{\text{peak,obs}}} \times 100\%$, respectively.

Figure 20 shows an example of simulated (water balance) and observed discharge hydrograph for a sample location in the study domain. The simulated hydrograph peak is indicated by a black point; the observed hydrograph peak by a blue one. Both have a timing associated with them (where the vertical dashed lines cross the horizontal time axis) and a magnitude (where the horizontal dashed lines cross the vertical discharge axis). The difference between these vertical and between the horizontal lines is then computed: the results for this example are shown in **Table 11**.

Figure 20. Simulated and observed discharge rates for a sample location in the study domain: St. Pieter Noord (Meuse).

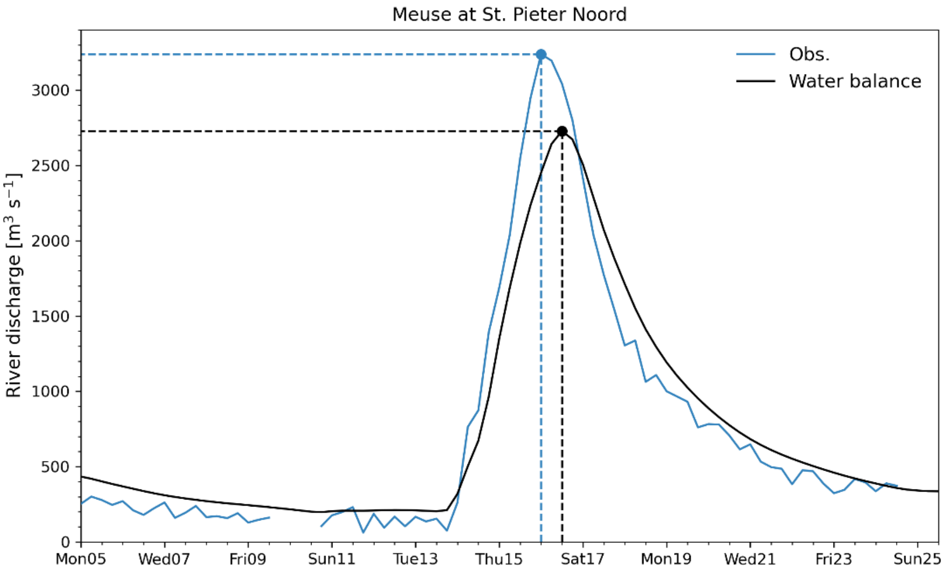


Table 11. Sample metric computation for St. Pieter Noord station

	Simulation ('water balance')	**Observation**	**Difference**	
Timing	Fri, July 16, 12 UTC	Fri, July 16, 00 UTC	12h (modelled peak later than observed peak)	
Magnitude	2,729 m^3/s	3,239 m^3/s	-510 m^3/s (modelled peak was lower than observed peak)	-15.7%

The metrics above were computed for each of the 34 available observed time series. The results are not summarized across the 34 points because the data are not independent. In quite a few cases, reporting points are located near other points on the same river and the simulations for the downstream reporting point are computed by nearly the same information as the upstream point.

Figure 21 and **Figure 22** show the results and enable general conclusions. The difference in timing between simulated (EFAS water balance) and observed peak discharge is shown as a function of the catchment area in Figure 21 (left) and according to the geographic location of the reporting point in Figure 22 (left). The EFAS water balance simulation predicted peak time was generally earlier than the observed peak time. This may have had an impact on the number of Formal Flood Notifications issued: Sometimes the '48-hour' criterion was not met and this discrepancy could have been caused by the fact that the model simulations predicted an earlier peak. The results of the analysis of the discrepancy between the simulated and observed peak discharge magnitude are shown as a function of the catchment area in Figure 21 (right) and according to the geographic location of the reporting point in Figure 22 (right). In general, the magnitude of the flood peak predicted by the water balance was higher than the observed magnitude.

Figure 21. Difference between the EFAS water balance and observed timing (left) and magnitude (right) of the flood peak as a function of the catchment area of the gauging stations.

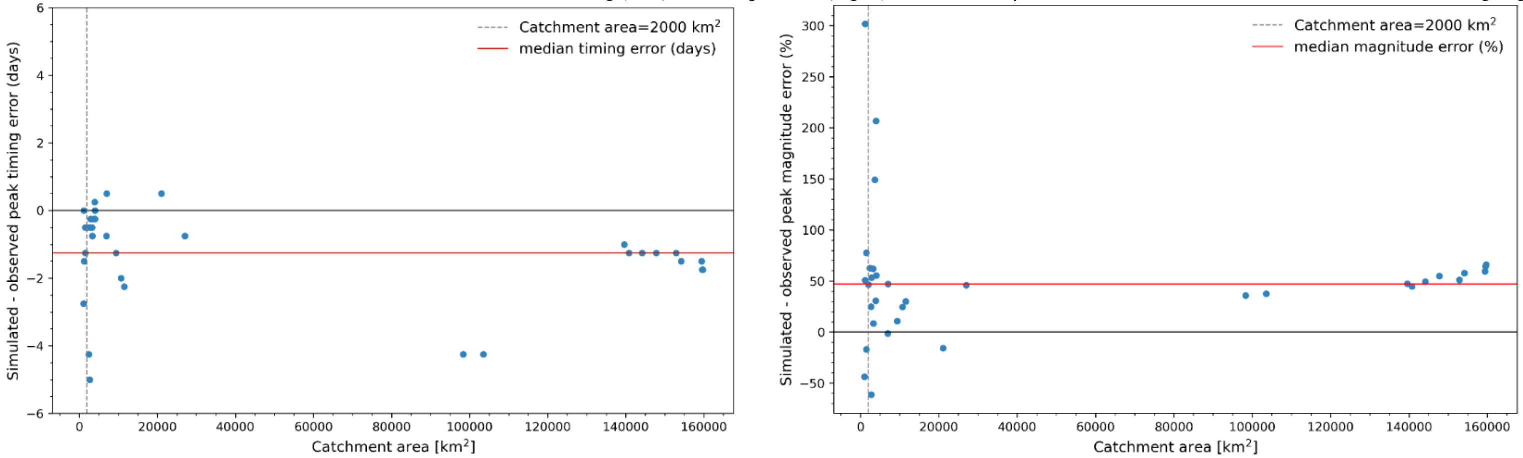
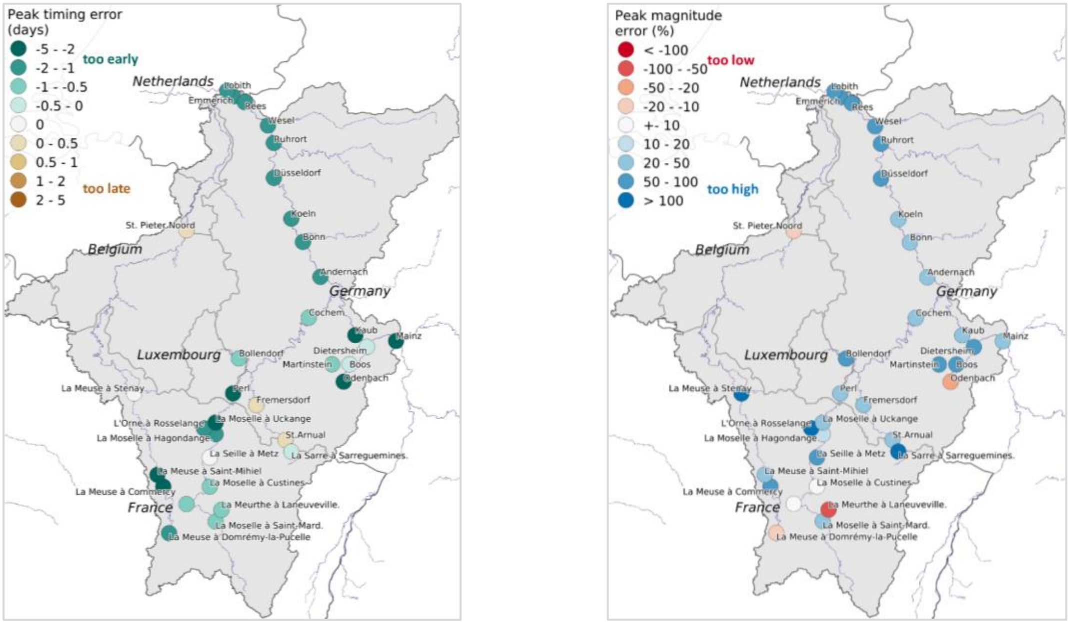


Figure 22. Difference between simulated (EFAS water balance) and observed timing (left) magnitude (right) of the flood peak.



5.1.1 A note on uncertainty in streamflow observations

Streamflow rates are not directly measured. Instead, they are estimated from water level (or other) measurements through a modelled relationship (e.g., through a *rating curve* or *stage-discharge relation*). These relationships are less certain at more extreme water levels. In the July flood event, some of the peak values were, compared to historical records, very high. It can therefore be assumed that the streamflow 'observations' are subject to considerable levels of uncertainty. The above section 5.1 should be interpreted as such.

5.2 Verification of precipitation forecasts

A thorough quantitative assessment of the quality of the precipitation forecasts that are used as inputs to EFAS is not within scope of the present assessment report. However, some observations may be made based on readily available publications and estimates. It should be taken into account, however, that these studies each focus on a specific geographic area.

5.2.1 ICON-EU forecasts over the Meuse basin

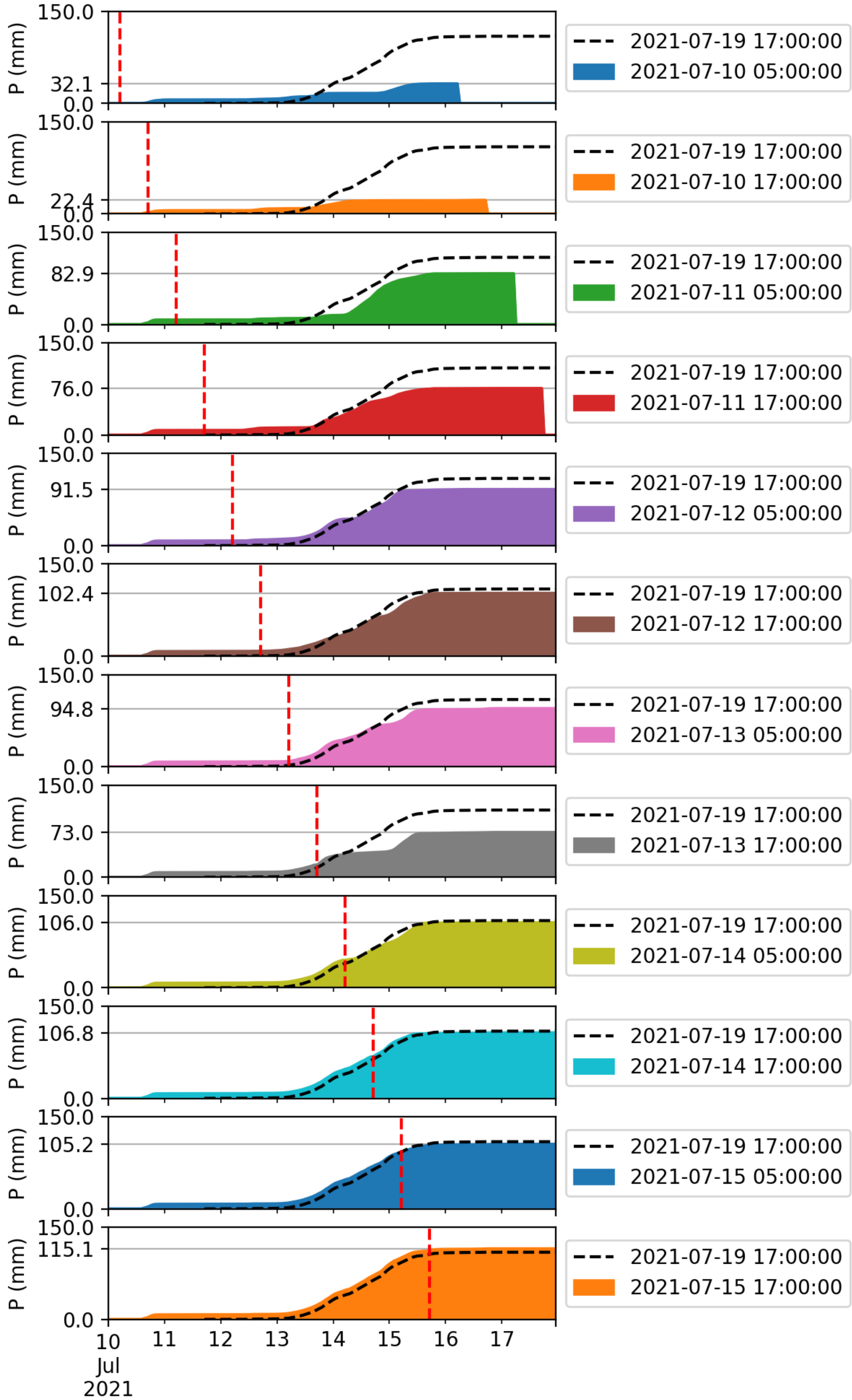
The ENW report of the July floods in the Netherlands (Expertise Netwerk Waterveiligheid, 2021) includes some notes about the quality of the ICON-EU precipitation forecasts over the Meuse basin. The forecasts are taken from the Rijkswaterstaat operational flood forecasting system *RWsOS Rivers*. Within the system, these estimates are available at the original ICON-EU model grid but also at the level of various river basin. In the report, the ICON-EU precipitation estimates are averaged over the Meuse basin upstream from Borgharen. Effectively this is the Meuse basin upstream from the Netherlands.

It should be taken into account that the DWD-DET product which is used in EFAS is not identical to the ICON-EU estimates used in RWsOS Rivers. The latter is a blend of ICON-EU (up until 120 hours into the future) and ICON-global (which, by the DWD, is simply referred to as ICON) which, at the 00 UTC and 12 UTC cycles, goes out 180 hours into the future. Within EFAS, DWD-DET is a blend, too, but here the regional model is used for the first 3 days and the global models for days 4 through 7. While not identical, the two ICON-blends are likely quite similar.

Figure 23 shows, from top to bottom, ICON-EU based cumulative precipitation forecasts averaged over the entire Meuse basin, from Saturday, July 10, 12 UTC through Thursday, July 15, 12 UTC. Note that the times in the legend are not precipitation forecast issue times, but the times at which these were used in a hydrological model run - in CEST. The dashed line should be interpreted as 'observation'. These observations are computed by spatial interpolation of the precipitation gauge measurements available to the flood forecasting system. Any estimate left of the vertical dashed red line is based on observations also.

The graph shows that ICON-EU precipitation estimates were initially much underestimated. From Sunday, July 11, 00 UTC onwards, the orders of magnitude of the forecasts and the posterior observations are somewhat in line with one another. As of Monday, July 12, 12 UTC the forecasts are near identical to the observations. The Tuesday, July 13 12 UTC forecast is an exception: Its estimates are considerably lower than the forecasts before and after it as well as the posterior observations. At no point did ICON-EU *over*estimate precipitation. Unfortunately, the spatial level of analysis doesn't allow for the identification of spatial uncertainty at various Meuse tributary scales.

Figure 23. Cumulative precipitation from July 10, 00 UTC onwards as estimated by 00 UTC and 12 UTC ICON-EU forecasts from July 10, 12 UTC through July 15, 12 UTC. The black dotted line is the observation. The red vertical lines denote forecast issue times. To the left of these, both the lines and the areas constitute cumulative observed precipitation.

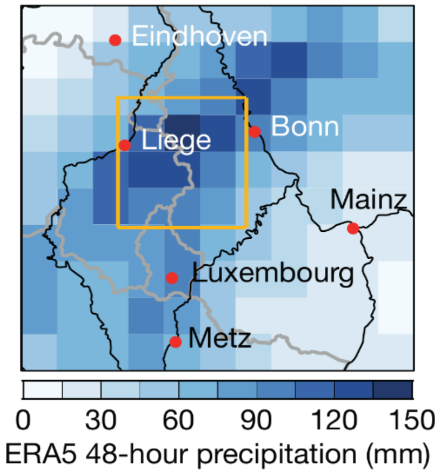


Source: Image slightly modified from Expertise Netwerk Waterveiligheid (2021) .

5.2.2 ECMWF-ENS and ECMWF-HRES forecasts

ECMWF reported on the quality of its forecast (Magnusson, Simmons, Harringan, & Pappenberger, 2021) . The analysis focuses on precipitation in the 48h window between Tuesday, July 13, 06 UTC and Thursday, July 15, 06 UTC over the area bounded by 50–51°N and 5.5–7°E as highlighted in **Figure 24**.

Figure 24. ERA5-estimated precipitation estimates in the 48h period between Tuesday, July 13 06 UTC and Thursday, July 15, 06 UTC.

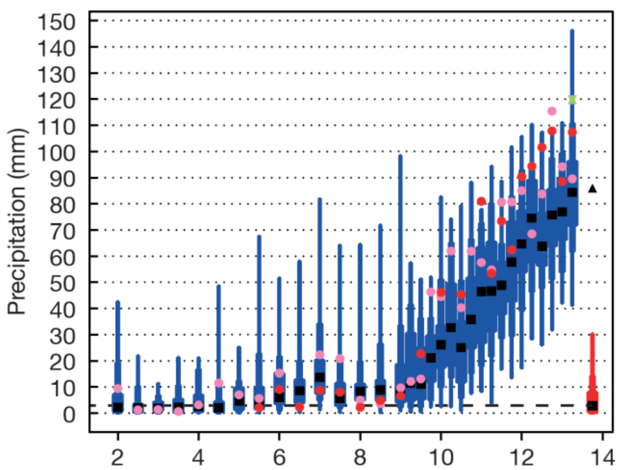


Source: Magnusson (2021).

Figure 25 shows box plots for the various ECMWF forecast products: The HRES deterministic forecast, the ensemble forecast (ENS) and the latter's control forecast (CF) for the 48-hour 'valid time' window and the posterior SYNOP precipitation observations over that same window. The plot shows that the various ECMWF forecast products all underestimated the observed precipitation amount. Only the latest forecast shown (that of July 13, 06 UTC) captures the observed precipitation – but only at a low probability of occurrence. However, the 3- day Extreme Forecast Index (EFI; not shown here) of ECMWF, which compares model predictions against a model climatology, indicated already a strong signal from 11 July onwards with the ensemble median above the 99th percentile of the model climate (Magnusson et al. 2021).

The article explains that the SYNOP observed precipitation may be an underestimate of *true* precipitation given gaps in the monitoring network. This leads the authors to conclude that "*... looking at the observation map, with a gap in available observations for the worst-affected region in Belgium, it is likely the real area-average precipitation was higher, and it is therefore plausible that the ECMWF forecasts underestimated the quantity.*"

Figure 25. Evolution of forecasts for 48-hour precipitation 13 - 15 July 06 UTC in a box over the worst affected region Legend: HRES (red dot), ENS CF (pink dot), ENS distribution (blue), model climate distribution based on reforecasts (red) with maximum in the sample of 1200 reforecasts (black triangle). The SYNOP precipitation observation is indicated by a green hourglass.



Source: Magnusson (2021).

6 Conclusions and recommendations

6.1 Summary of the findings

The July 2021 floods were extreme in magnitude. In many cases, the 99th percentile of the historical streamflow record was exceeded; moreover, for various locations, the July 2021 floods now constitute the highest flood on record in many of the affected regions. When considering the *summer* historical record only, the relative magnitude of the floods was even more extreme.

For the event, 25 EFAS notifications were issued (5 Formal Flood Notifications, 6 Informal Flood Notifications and 14 Flash Flood Notifications). The first EFAS (Informal) notification was issued on Saturday, July 10 and by Monday, July 19, all the Formal and Informal notifications had been deactivated. The first EFAS flash flood notifications, meant to give warnings against floods in smaller river basins such as the Vesdre and Ahr, were issued as of Tuesday, July 13, 24h to 36h prior to the flooding.

First, a point scale analysis allowed to investigate the effectiveness of the protocol for the issue of Formal notifications in capturing the flood events. This analysis was performed by evaluating whether for each point the criteria for the issue of Formal notifications were met and the water balance simulation exceeded the 5 years return period. The water balance simulation is the simulation produced by the operational set-up of the EFAS hydrological model (OS LISFLOOD) when forced with observed meteorological forcings. This simulation was used as the 'verifying truth'. In 33 out of 46 instances the criteria for the issue of Formal flood notifications were in agreement with the water balance simulation. However, in the remainder 13 instances the criteria for the issue of a Formal notification were not met but the water balance simulation exceeded the 5 years return period. An in-depth analysis of the latter 13 instances highlighted that Formal notifications criteria were not met due to the flashy nature of the events and due to inconsistencies in the forecasts.

The point scale analysis had the merit to allow a thorough analysis of the protocol for the issue of Formal notifications. However, EFAS notifications always refer to a river stretch. The assessment of the correctness and of the accuracy of the notifications issued during the event should account for the area of validity of each notification. The preparation of this report highlighted a problem in the communication of the definition of the area of validity of a notification. Albeit recommended during trainings and presentations, the use of complementary information from the EFAS Map Viewer has not been formalized in a set of concrete guidelines. This report made use of the layers with spatially distributed information which are available from the EFAS Map Viewer to visualize the area connected to the notifications issued during the event. Such an exercise allowed to confirm the general correctness of the Formal notifications issued during the event: The information provided by the spatially distributed layers in connection to the Formal notifications issued during the event encompassed the reporting points highlighted by the point scale analysis.

Albeit 5 Formal notifications were issued during the event for the Rhine, Ourthe, Rur (or Roer), and Moselle; Formal notifications could not be issued (because the criteria were not met) for river reaches of the Meuse, Sauer, Ruhr, and Sambre. EFAS Informal notifications are designed to complement the Formal notifications: Informal notifications allow a degree of flexibility in the notifications criteria in order to make use of the expertise of the Officers on Duty. The Informal notifications sent out during the event aimed to raise awareness in 2 river stretches for which the Formal notifications criteria were not met, specifically the Meuse and the Sauer. However, in one instance, the Informal notification resulted in a false alarm (Nahe river).

The verification of EFAS Flash Floods notifications requires timely feedbacks and the collection of soft information. Albeit the feedback received via the EFAS IS showed a general agreement between the issued notifications and the in-situ observations, the low number of the feedbacks hindered a quantitative analysis.

EFAS notifications are sent to all EFAS partners and third party partners in the river that the notification pertains to. The accurate analysis of the recipients of the notifications issued during the event highlighted the need for a review of the recipients list.

EFAS notifications rely on the comparison between EFAS forecasts and EFAS thresholds, the latter are derived from historical simulations. The accuracy of EFAS notifications thus depends on both the accuracy of the EFAS simulations and on the accuracy of the meteorological forecasts. The accuracy of the EFAS simulations for the event under investigation was assessed through a comparison of EFAS water balance simulations with observed streamflow values at 34 gauge stations. Such a comparison showed that the simulated peak magnitude and time were in general larger and earlier than the observations. While thorough verification of precipitation forecasts was not in scope, two external studies suggest that the forecasted precipitation underestimates the actual precipitation. Albeit initially the extent of this underestimation was large, the underestimation reduced as time progressed. As of Monday afternoon, July 12, the DWD ICON-EU forecasts for the Meuse basin captured the precipitation event well, although some individual forecasts continued to underestimate it. It must be noted that the uncertainty about the *location* of precipitation areas has not been accounted for in this brief analysis.

6.2 Recommendations

The present section outlines the recommendations stemming from the analysis presented in this report:

- Continuous improvements to the EFAS hydrological model set up to improve simulation accuracy (e.g. reduce biases in peak magnitude and errors in the predictions of peaks timing).
- A review of the criteria for the issue of Formal notifications. The operational EFAS is being regularly updated. For instance, in 2020 the temporal resolution of the computations increased from once a day to four times a day. It is recommended to conduct a thorough statistical analysis making use of the most updated operational set-up to investigate the notifications criteria that allow to maximize the number of instances in which the criteria for the issue of a Formal notification are met and the water balance exceeds the 5 year return period, while the number of false and missed Formal notifications is minimised.
- Improved definition of the area of validity of a notification either through more information contained in the notifications itself or through a more detailed documentation in the publicly available pages (pragmatic, step by step examples should be provided).
- A discussion on the criteria for the issue of Informal notifications. The criteria for Informal Flood Notification allow to leverage on the expertise of the Officers on Duty. The introduction of more restrictive guidelines can facilitate the understanding of the Informal notification message but can also limit the benefits of the expert opinion of the Officer on Duty. This trade-off should be discussed with the EFAS partners.
- A review of the list of recipients of EFAS notifications: This task will require concerted actions with the EFAS partners and third-party partners.
- Further optimization of the internal protocols of the CEMS Hydrological Forecast Centre-Analytics and Dissemination to streamline the communication of the criteria, to maximize information sharing, and to intensify the internal checks.
- A precipitation forecast verification study is required to clarify the extent and nature of the uncertainty in precipitation forecasts and its impact on the flood forecasts.

6.3 Actions implemented and planned at the time of publication of this report

At the time of the finalization of this report (Dec. 2022), the following actions were implemented and planned consistently with the main recommendations of this report.

Specifically, a number of actions were implemented in order to:

- Provide the EFAS partners with more detailed information and additional resources to learn how to read and use EFAS notifications and forecasts. Specifically, two new webinars were hold in December 2021: "What to do once you receive a flood notification", and "What to do if you do not receive a flood notification" and recordings are available from Webinars | Copernicus EMS - European Flood Awareness System (efas.eu)). Moreover, the EFAS User Guide was published in September 2022 and it includes a hands-on guide for EFAS partners as well as clear indications on where to find detailed technical additional information.
- Facilitate the definition of the area of validity of a notification. The layer "Flood probability persistence" has been added to the EFAS Map Viewer ("Flood summary" tab) with EFAS release version 4.4 in June 2022. A webinar was also organised in September 2022 and the recording is now available here.

Finally, the following actions have been planned:

- A statistical assessment to review the criteria for the issue of Formal notifications in order to maximize the agreement between the forecasts and the verifying truth.
- The review of the notifications email sent to the EFAS partner and EFAS third party partners.
- The provision of guidelines for the definition of the area of validity of a notification. These guidelines will also make use of the recently introduced "Flood probability persistence" layer. The detailed guidelines will

be added to the protocol used by the Officers On Duty and also clearly communicated to the EFAS partner and EFAS third party partners.

- The review of the recipients of the EFAS notifications.
- A new major EFAS upgrade to further improve hydrological model skill is foreseen for 2023. This major upgrade includes an increase in the spatial resolution, a completely revised model implementation set up with more accurate representation of catchments physical properties, and a new calibration.

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List of abbreviations and definitions

BfG	Bundesanstalt für Gewässerkunde
CEMS	Copernicus Emergency Management Service
CoA	Condition of Access
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium-Range Weather Forecasts
EFAS	European Flood Awareness System
EFAS-IS	EFAS Information System
NWP	Numerical Weather Predictions
RWS	Rijkswaterstaat
SCHAPI	Service Central d'Hydrométéorologie et d'Appui à la Prévision des Inondations
SPW	Service Public de Wallonie
T5	Streamflow threshold that is expected to be, on average, exceeded once every 5 years. Sometimes this is simply referred to as 'the five-year return period'

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Table 7. Results of the point scale analysis for Formal notifications for the 46 reporting points in the study area that have an upstream area of at least 2,000 km^2. For the interpretation of the superscript INF the reader is invited to complement the information of this table with the analysis of the Informal flood notifications provided by section 4.5. 19

Table 9. Flood notifications issued during the July flood event – formal and informal. The list of Formal and Informal Flood notifications is available to EFAS registered users at https://www.efas.eu/en/efas-formal-flood-notification, https://www.efas.eu/en/efas-informal-flood-notification (updates in near real time)...................22

Table 10. Flash flood notifications issued during the July flood event. The list of Flash Flood notifications is available to EFAS registered users at https://www.efas.eu/en/efas-formal-flood-notification, https://www.efas.eu/en/efas-flash-flood-notification (updates in near real time) 23

Table 11. Sample metric computation for St. Pieter Noord station 32

Annexes

Annex 1. Study area definition

The study area was determined as follows:

1. 'Consolidated' ERA5 precipitation data was accumulated over Monday, July 12 through Thursday, July 15. While ERA5 is a reanalysis product and may not prove to be the best possible estimate of actual conditions, it is deemed to have sufficient quality to be used for this purpose (study area definition). Moreover, ERA5 was available at the time of study area definition whereas other products were not. Note that, in the present report, ERA5 was only used for the purpose of study area definition.
2. Iteratively, various precipitation levels were assessed. It was found that the area within the 80 mm contour (i.e., where precipitation depths exceeded 80 mm over the 96 hour period) showed a reasonable coincidence with the location of reported floods and damage, noting that the study area was defined prior to completing the more detailed analyses.
3. The thus found area of high precipitation was combined with (i) the scope of present study (larger Ardennes/Eifel area) and (ii) polygons of Meuse and Rhine basins. Some areas outside of these river basins were omitted from the study area. Conversely, the areas downstream of the 80mm precipitation contours were included.
4. The thus defined study area includes the Meuse basin (until approx. Nijmegen in the Netherlands) and various Rhine tributary basins including those of the rivers Moselle, Erft, Ruhr, Wupper, Sieg, Ahr and Lippe.

Figure A- 1. General area of interest

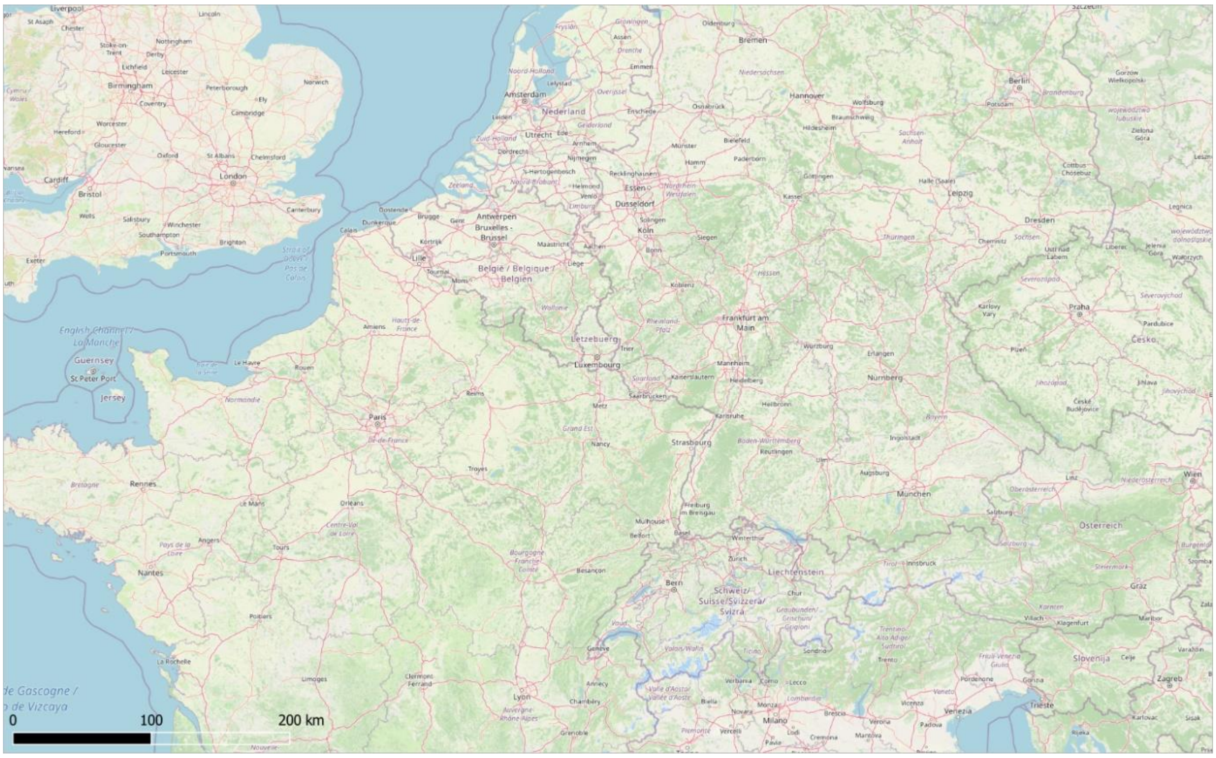


Figure A- 2. ERA5 estimated, 96h accumulated precipitation up until Friday, July 16, 00 UTC

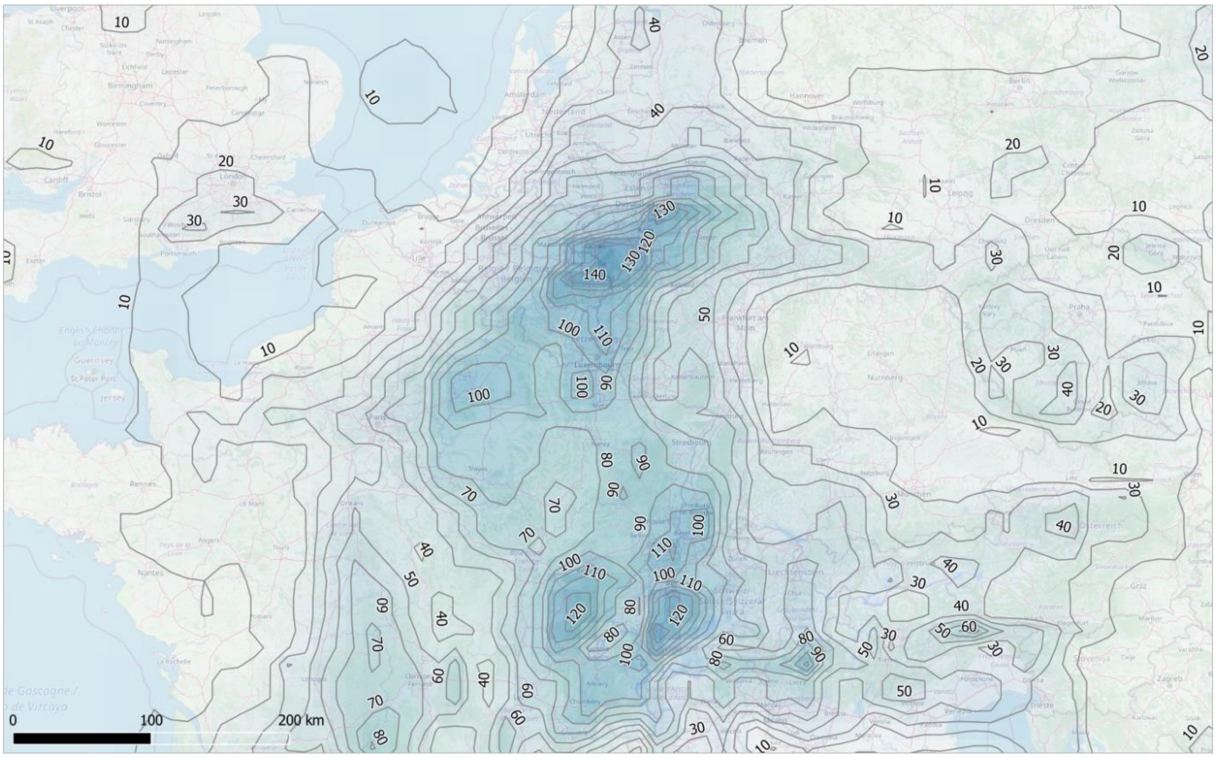


Figure A- 3. ERA5 estimated, 96h accumulated precipitation up until Friday, July 16, 00 UTC– 80mm contour line

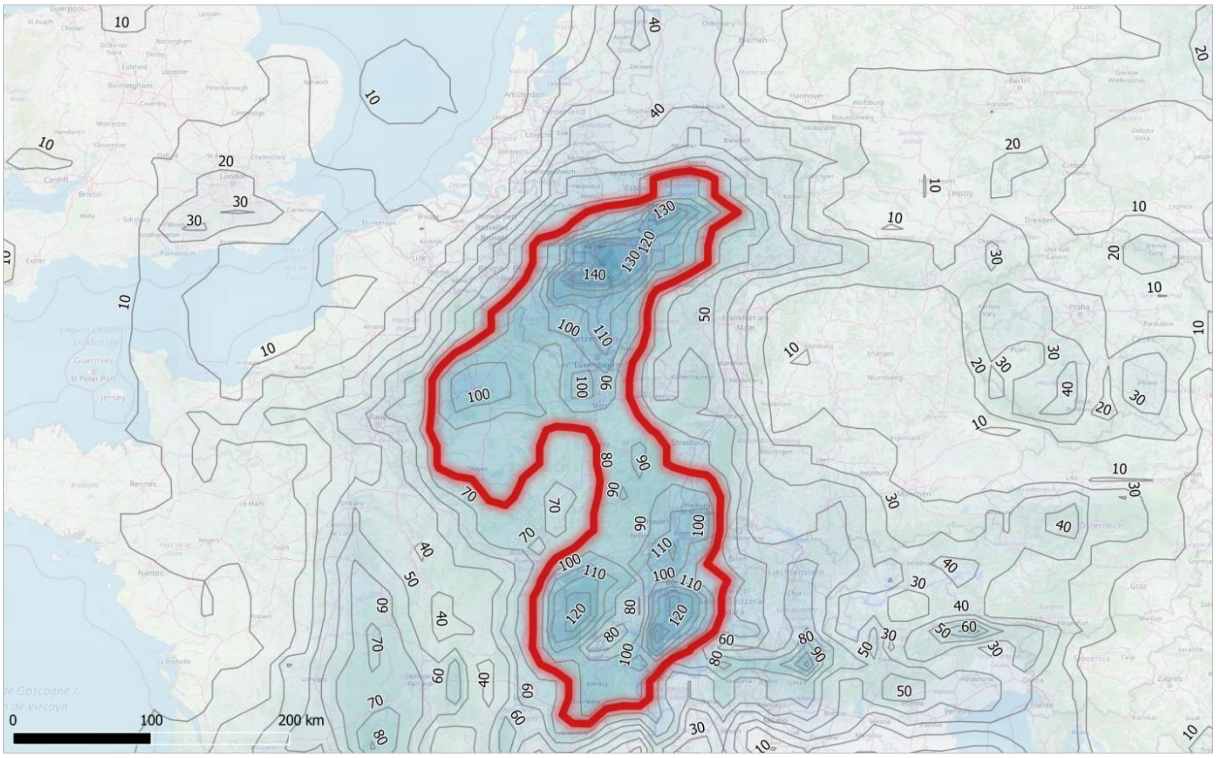


Figure A- 4. As before, with Meuse and Rhine basins included

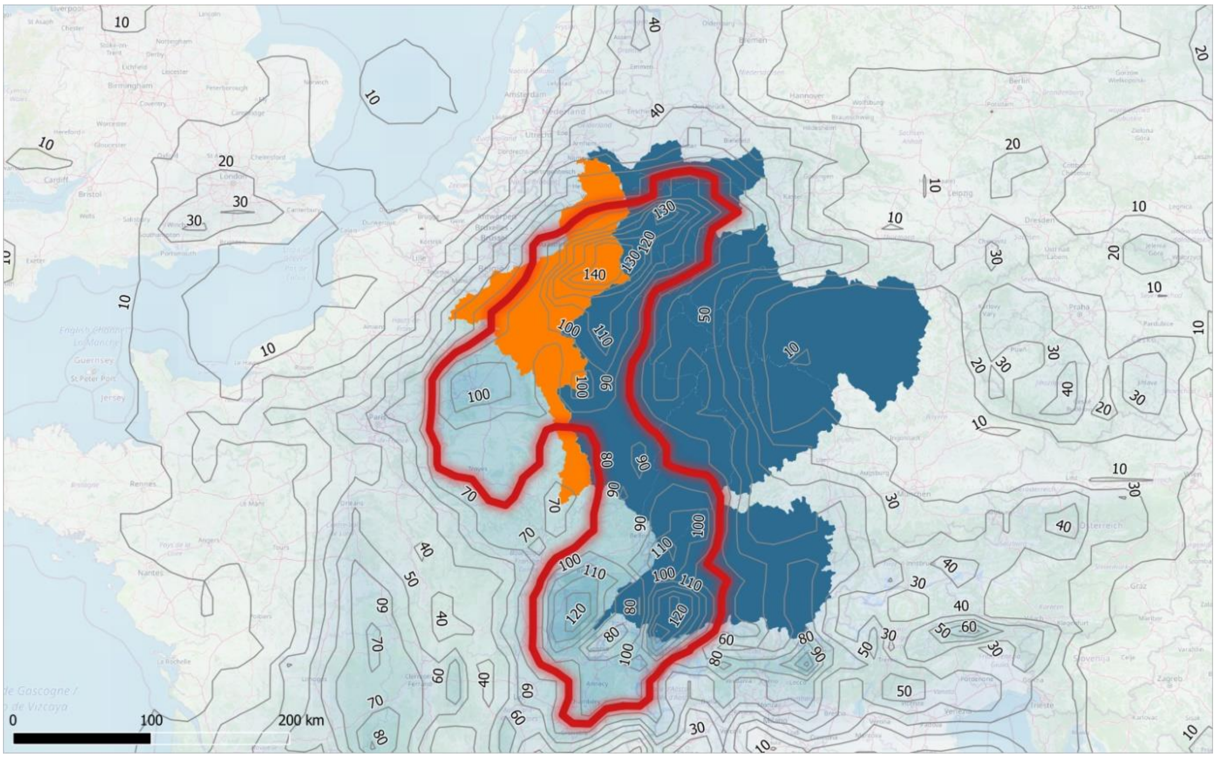


Figure A- 5. Inclusion and exclusion of various areas outside and within the 80mm precipitation contour line

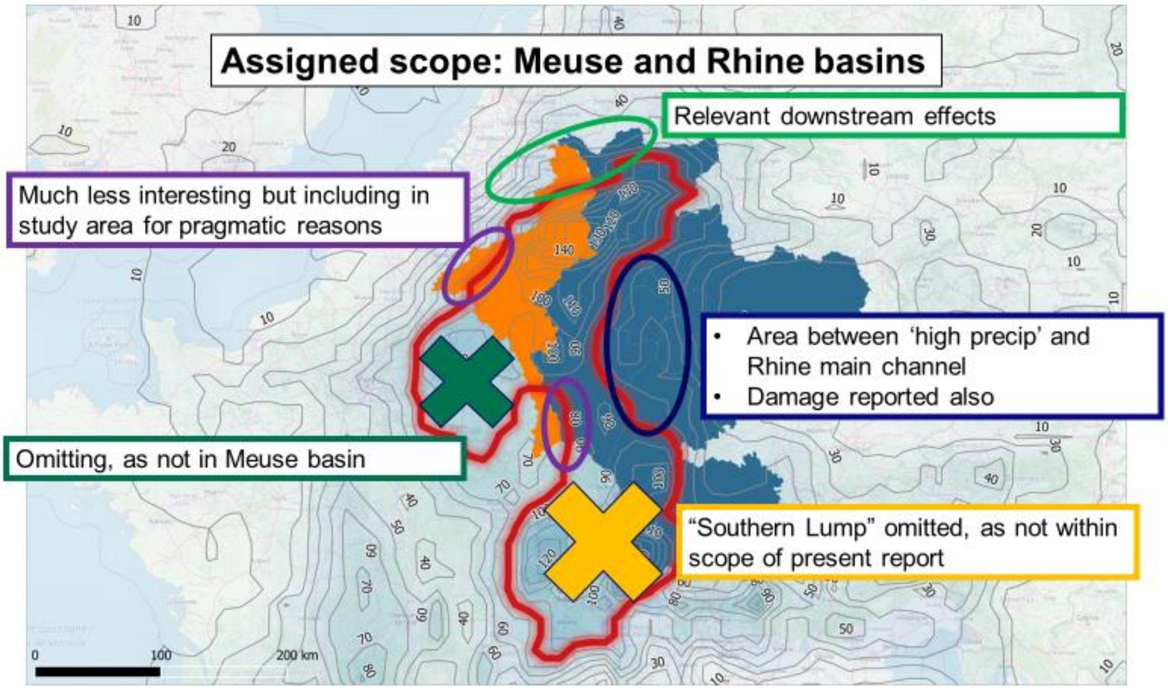
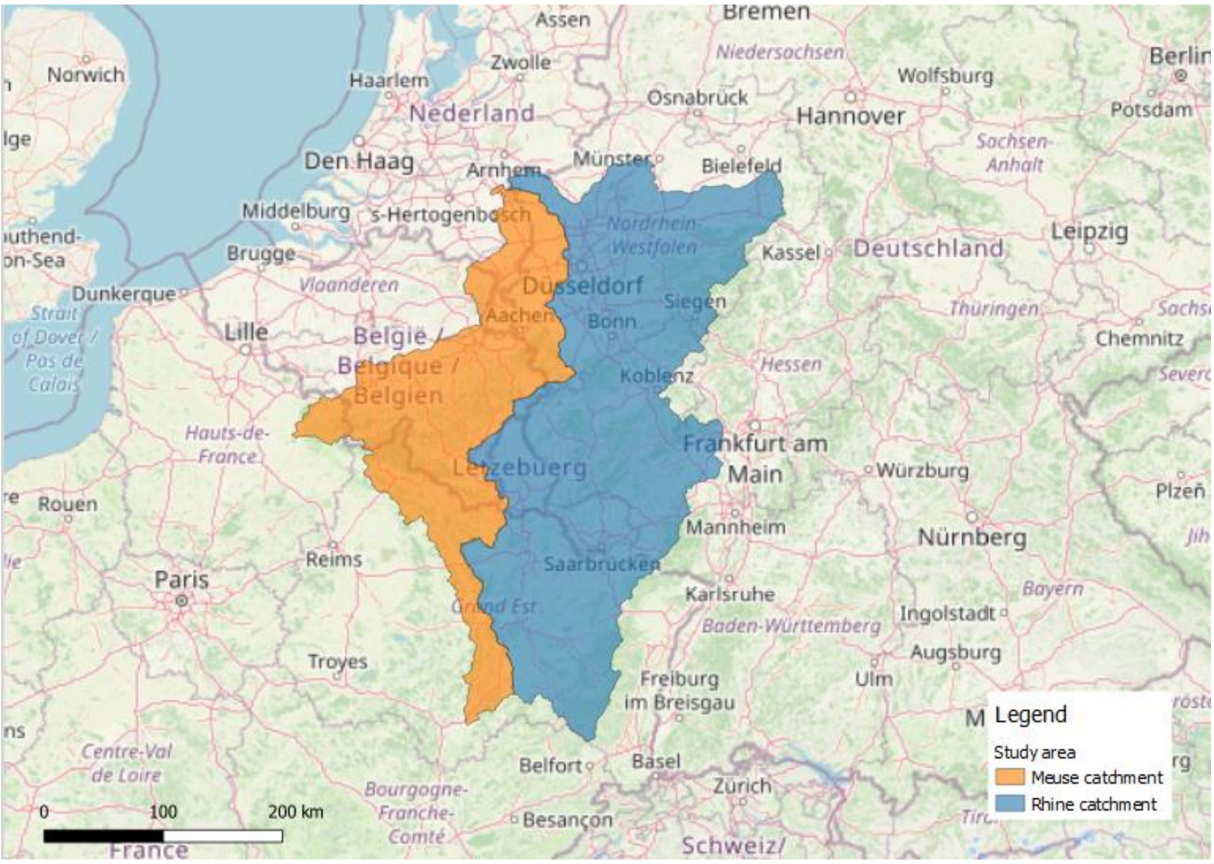


Figure A- 6. Resulting study area



Annex 2. Feedback received through EFAS-IS

Figure A- 7. Feedback received, for the Formal Notification that was sent on Sunday, July 11, 11:12am

Overview

Event Info

Date: 11/07/2021 - 11:12

Country: Germany

Basin: Rhine

River: Rhine

Flood Observed: **Yes**
How severe was the event? **5-9 years**
severity of the event: **Station Maxau Peak at Thursday, 15th of July 2021 03:00, water level 842 cm**
What caused the event? **Extreme rainfall, Soil saturation, Snow melt,**
How much lead time gave the notification? **0 Day(s)**
Location accuracy? **As indicated in EFAS information**

Timing of onset accuracy? **Start >= 3 days earlier than predicted**
Timing of peak accuracy? **Start >= 3 days earlier than predicted**
Peak magnitude accuracy? **Peak comparable to predicted**
Added value of the forecast? **2**
Other comments: **a second higher peak was observed 17h of July 2021 17:00, water level 865 cm (return period 10-19)**

Current total Score

3

Figure A- 8. Feedback received, for the Formal Notification that was sent on Tuesday, July 13, 07:48am

Overview

Event Info

Date: 13/07/2021 - 07:48

Country: Netherlands

Basin: Rhine

River: Rhine

Flood Observed: **No**
Why the event did not occur? **A discharge occured of about 6800 m3/s. On an anual basis this is not verry special. Discharges of about 7000 m3/s occur in average every 2 years. What makes this event special, is that it happened in summer time. The discharge peak whas the highest summer peak since 1980.**
Added value of the forecast? **2**
Other comments:

Current total Score

Figure A- 9. Feedback received, for the Formal Notification that was sent on Tuesday, July 13, 07:50am

Overview

Event Info

Date: 13/07/2021 - 07:50

Country: NETHERLANDS

Basin: Meuse / Maas

River: Rur

Flood Observed: **Yes**
How severe was the event? **>= 100 years**
severity of the event: **Return period was about 300 years. For summer period even higher. The event caused massive economic damage.**
What caused the event? **Extreme rainfall, Long-lasting rainfall,**
How much lead time gave the notification? **1** Day(s)
Location accuracy? **As indicated in EFAS information**

Timing of onset accuracy? **Start predicted on day**
Timing of peak accuracy? **Start predicted on day**
Peak magnitude accuracy? **Peak comparable to predicted**
Added value of the forecast? **4**
Other comments:

Current total Score

Figure A- 10. Feedback received, for the Flash Flood Notification that was sent on Tuesday, July 13, 11:25am

Overview

Event Info

Date: 13/07/2021 - 11:25

Country: GERMANY

Region: Koblenz

Basin: Rhine

River: Rhine, section Mosel - Ruhr

*Was a flood observed in or around the area? ** Yes No

Drop some lines:

ERIC Reporting point for Koblenz region with upstream area 898 km2 (=Ahr catchment): P(T > 2) = 66 %, P(T<5) = T 48 %, P(T >20) = 31 %, LEPS 75 % = T ~ 75 - observed peak at station Altenahr T ~ 500 years ERIC Reporting point for Trier region with upstream area = 885 km2 (= Prüm catchment) P(T > 2) = 29 %, P(T<5) = T 17 %, P(T >17) = 8,3%, LEPS 75 % = T ~ 3 - observed peak at station Prümzurlay T >> 100 years ERIC Reporting point for Trier region with upstream area = 237 km2 (= Ruwer catchment) P(T > 2) = 44 %, P(T<5) = T 31 %, P(T >17) = 20 %, LEPS 75 % = T ~10 - false alarm ERIC Reporting point for Trier region with upstream area = 843 km2 (= Kyll catchment) P(T > 2) = 27 %, P(T<5) = T 16 %, P(T >17) = 8 %, LEPS 75 % = T ~3 - fobserved peak at station Kordel T >> 100 years

Figure A- 11. Feedback received, for the Flash Flood Notification that was sent on Tuesday, July 13, 11:25am

Overview

Event Info

Date: 13/07/2021 - 11:25

Country: NETHERLANDS

Region: Limburg (NL)

Basin: Meuse / Maas

River: Maas

*Was a flood observed in or around the area? ** Yes No

Drop some lines:

no input provided

Figure A- 12. Feedback received, for the Flash Flood Notification that was sent on Wednesday, July 14, 07:45am

Overview

Event Info

Date: 14/07/2021 - 07:45

Country: GERMANY

Region: Rheinhessen-Pfalz

Basin: Rhine

River: Rhine, section Ill - Neckar

*Was a flood observed in or around the area? ** Yes No

Drop some lines:

No floods south of the Moselle (with the exception of the Rhine).

Figure A- 13. Feedback received, for the Flood Notification that was sent on Wednesday, July 14, 07:42am

Overview

Event Info

Date: 14/07/2021 - 07:42

Country: Germany

Basin: Rhine

River: Moselle

Flood Observed: **Yes**
How severe was the event? **5-9 years**
severity of the event: **Station Trier, peak at Thursday, 15th of July 2021 - 16:45, water level 934 cm**
What caused the event? **Extreme rainfall, Soil saturation,**
How much lead time gave the notification? 0 Day(s)
Location accuracy? **As indicated in EFAS information**

Timing of onset accuracy? **Start predicted on day**
Timing of peak accuracy? **Start predicted on day**
Peak magnitude accuracy? **Peak less severe than predicted**
Added value of the forecast? **2**
Other comments: **the notification gave no additioal lead time, we published already at Monday 12 of July 2021 at first flood information for the Moselle basin**

Current total Score

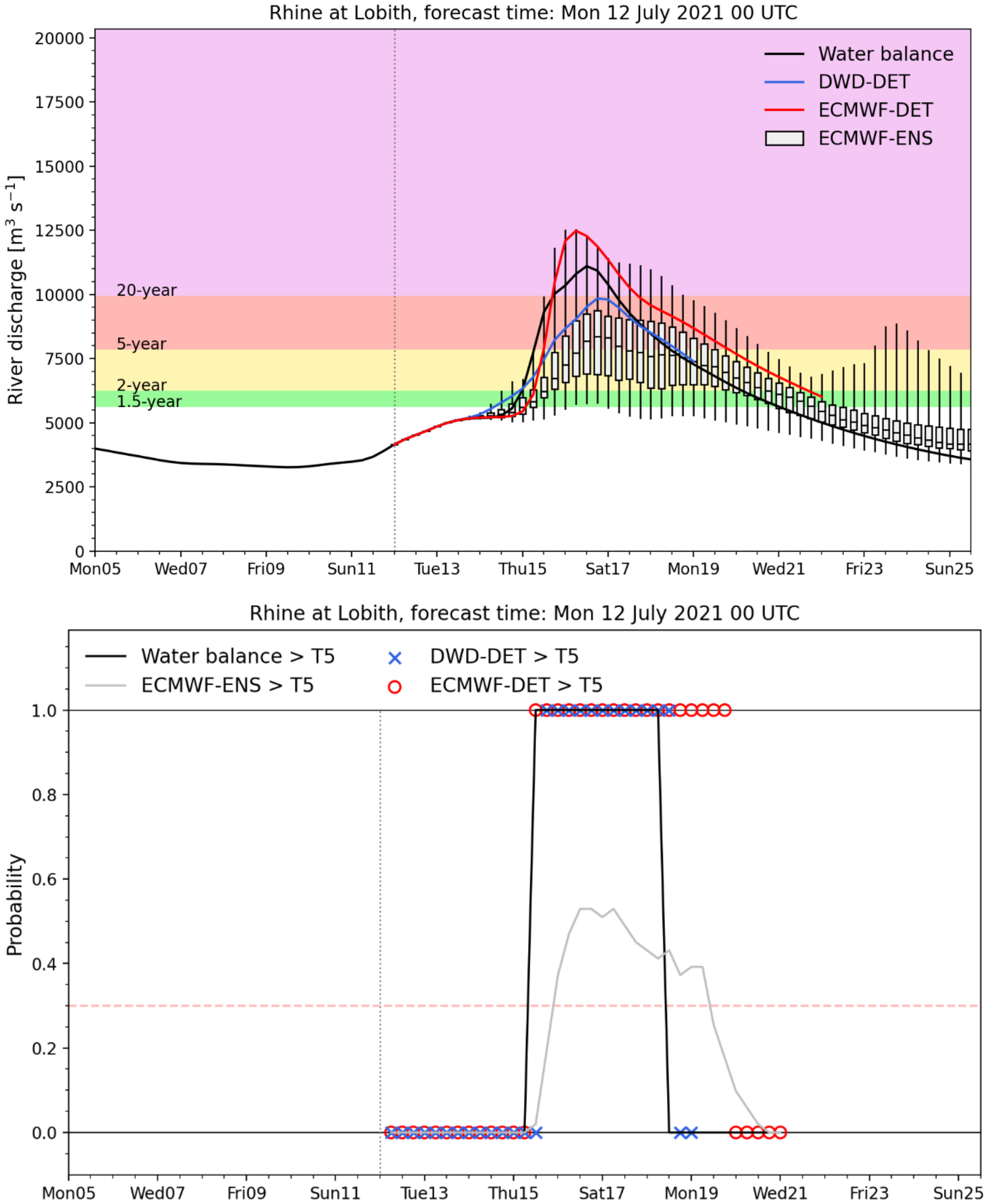
6

Annex 3: July 12, 00 UTC forecasts

The figures below shows a subset of he EFAS forecasts issued on July 12th 00 UTC for a number of selected stations. The forecasts shown in the figures are the ECMWF Ensemble forecast, the ECMWF deterministic forecast, the DWD deterministic forecast. Note that COSMO-LEPS forecasts are not shown here but are available to EFAS users in the map viewer and were COSMO-LEPS forecasts were also used during the event. These forecasts are compared to the water balance simulation and to the EFAS thresholds. This comparison is shown using traditional flood hydrographs (i.e. time series of discharge values as a function of time) and also by highlighting the exceedance of the 5 years return period threshold as a function of time (the water balance and the deterministic forecasts either exceed or not exceed threshold, a percentage of the ensemble forecast can exceed the threshold).

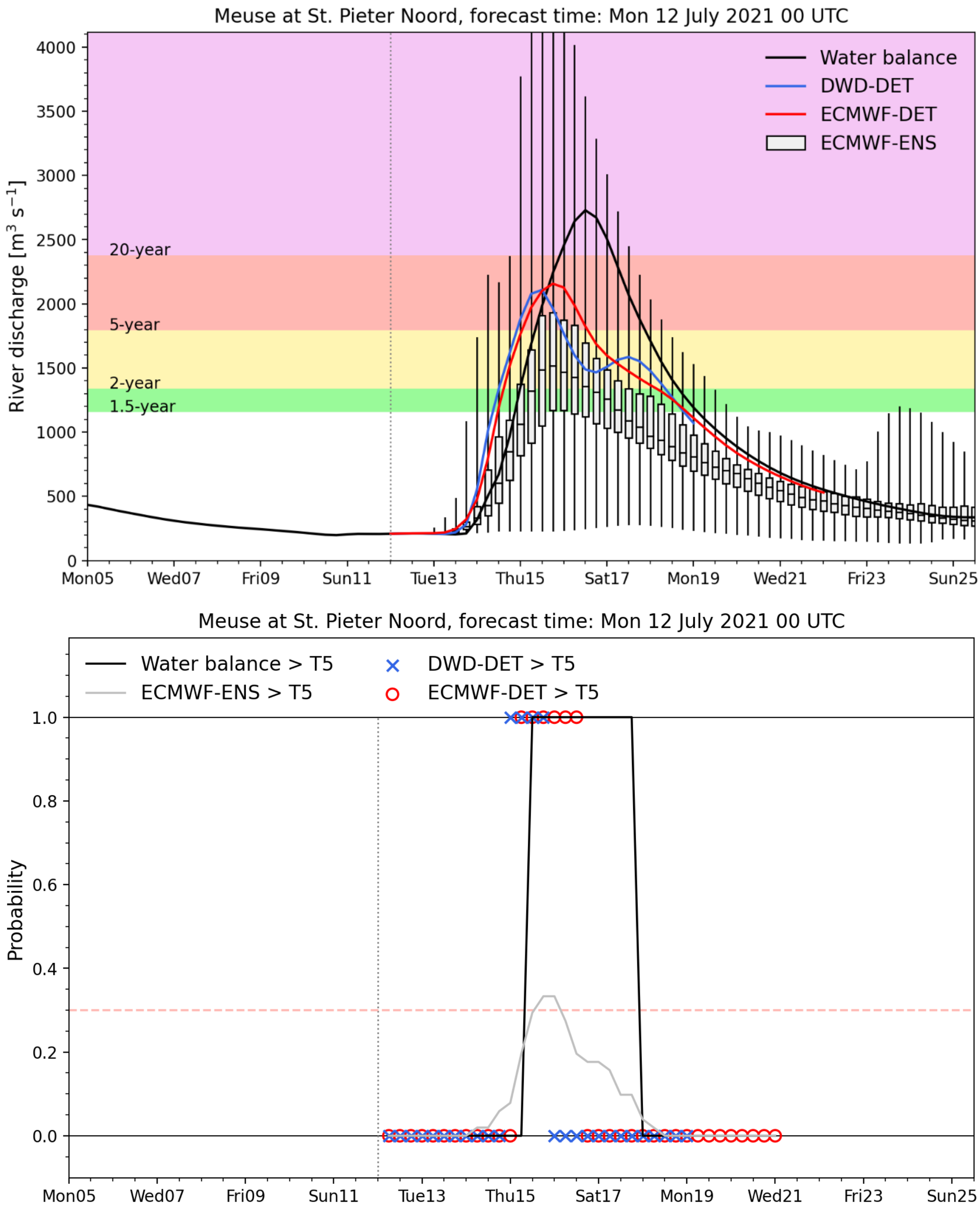
Rhine at Lobith

Figure A- 14. July 12, 00 : comparison of the forecasted magnitude and of the water balance simulation with the EFAS thresholds (top); exceedance of the 5 years return period EFAS threshold (bottom) for River Rhine at Lobith



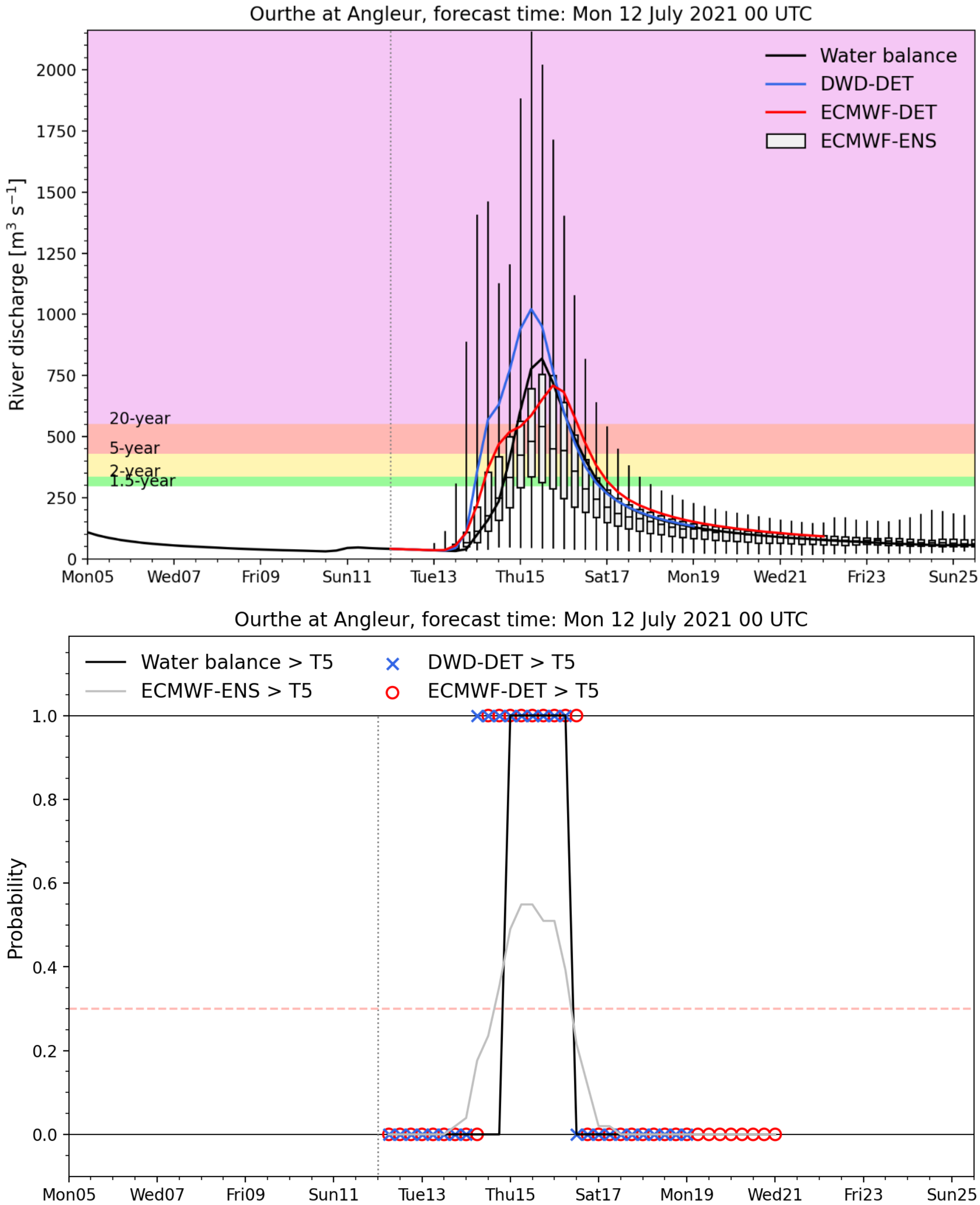
Meuse at St Pieter

Figure A- 15. July 12, 00 : comparison of the forecasted magnitude and of the water balance simulation with the EFAS thresholds (top); exceedance of the 5 years return period EFAS threshold (bottom) for River Meuse at St Pieter



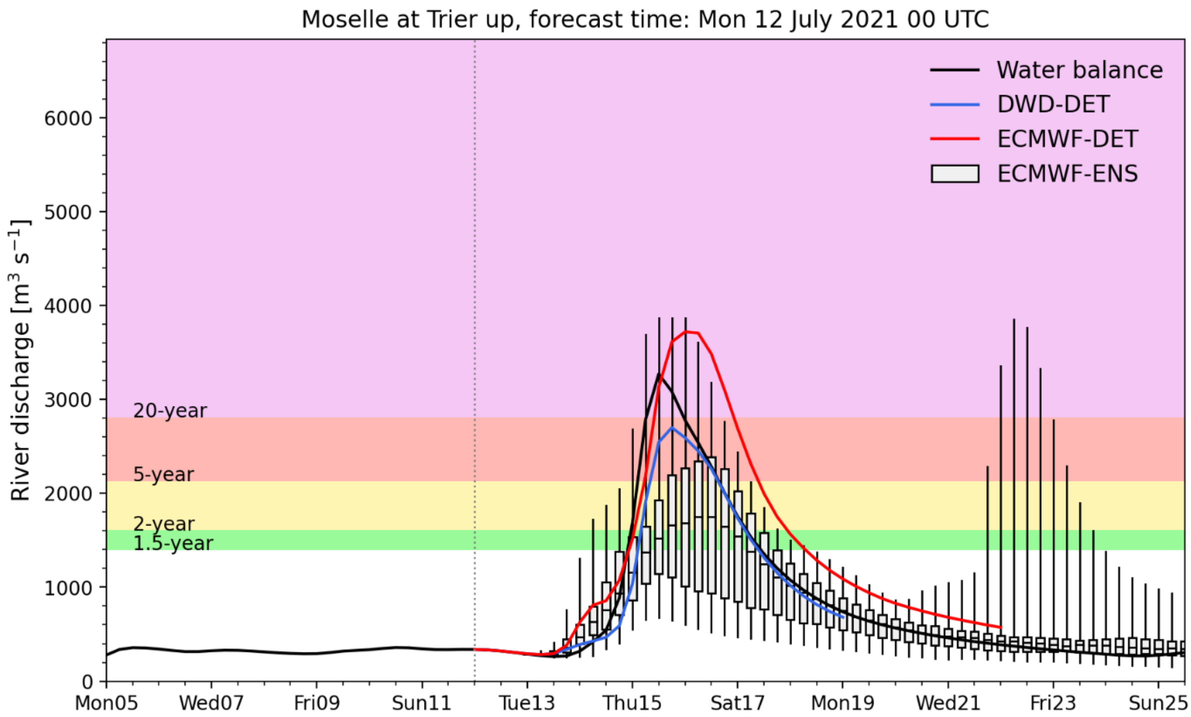
Ourthe at Angleur

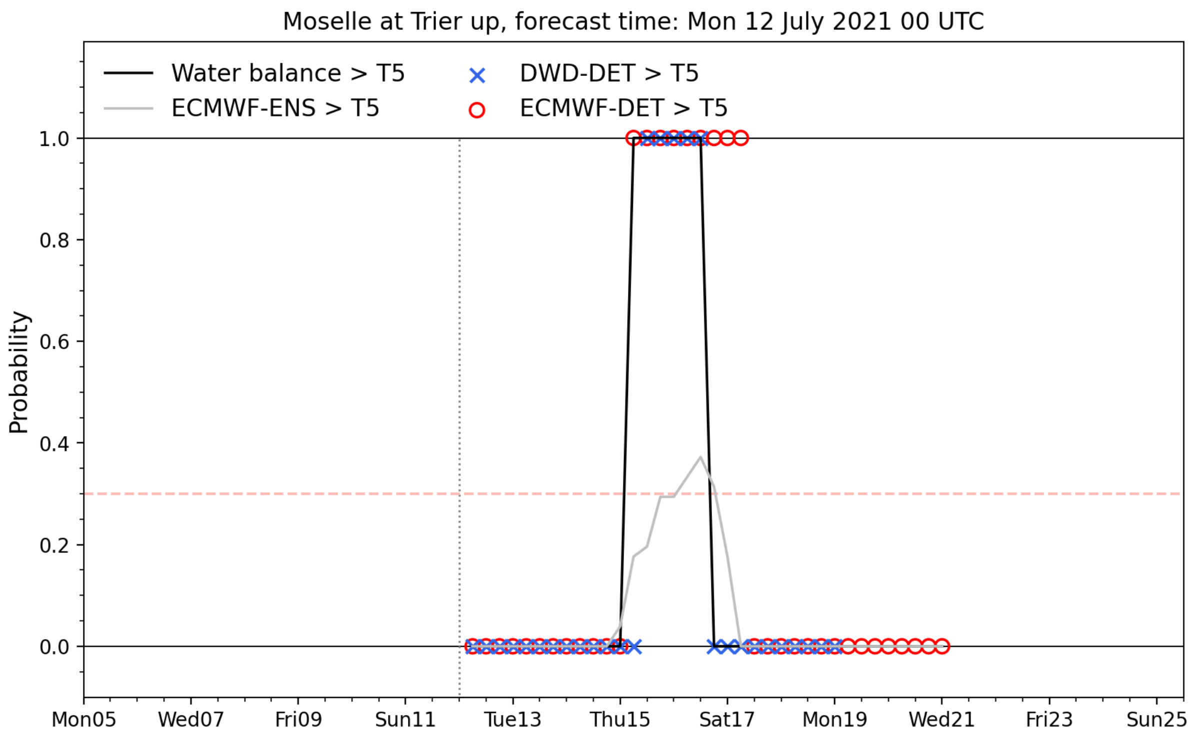
Figure A- 16. July 12, 00 : comparison of the forecasted magnitude and of the water balance simulation with the EFAS thresholds (top); exceedance of the 5 years return period EFAS threshold (bottom) for River Ourthe at Angleur



Moselle at Trier

Figure A- 17. July 12, 00 : comparison of the forecasted magnitude and of the water balance simulation with the EFAS thresholds (top); exceedance of the 5 years return period EFAS threshold (bottom) for River Moselle at Trier





Annex 4: data sources

Description	Source
EFAS formal flood notifications	https://www.efas.eu/en/efas-formal-flood-notification (This page is restricted to authenticated users only.)
EFAS informal flood notifications	https://www.efas.eu/en/efas-informal-flood-notification(This page is restricted to authenticated users only.)
EFAS flash flood notifications	https://www.efas.eu/en/efas-flash-flood-notification (This page is restricted to authenticated users only.)
EFAS forecasts	https://cds.climate.copernicus.eu/cdsapp#!/dataset/efas-forecast
EFAS 'water balance' simulations	https://cds.climate.copernicus.eu/cdsapp#!/dataset/efas-historical
Hydrological observations	In-situ data as received by the relevant data providers and collected and quality checked by the EFAS Hydrological Data Collection Centre.

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