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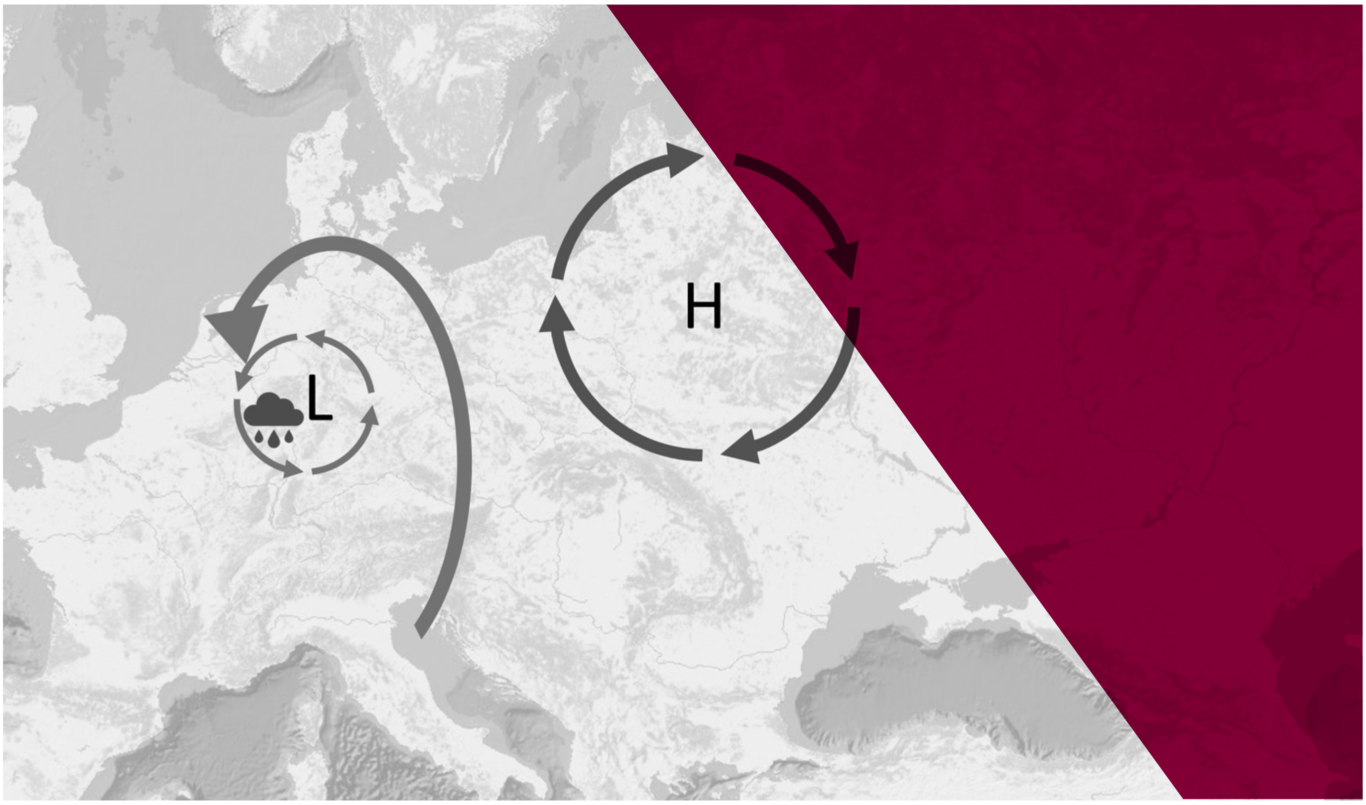

K.A.R.L.® INSIGHTS

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The July Flood 2021 in the West of Germany

Beyond imagination

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The July Flood 2021 in the West of Germany

Beyond imagination

„Photographing the situation on the ground would have been simply too inadequate. Houses and roads gone, people not knowing what to do next, and others stoically searching for the dead. Just everything broken ...“ (verbatim quote from a disaster relief worker in Kreuzberg/Ahr).

Therefore, instead of showing a teaser image related to the topic, we show a simplified schematic representation of the large-scale weather situation. In the days following the flooding, the media provided a great deal of disturbing footage. Helpers on the spot also report that the conditions in the destroyed villages along the Ahr, Erft, Swist and the other severely affected low mountain range rivers are orders of magnitude worse than photos are even able to express. Therefore, it is difficult to focus on the scientific aspects of what has happened in the face of such an apocalyptic catastrophe, for which we here in our supposedly safe western Germany were virtually unprepared.

Nevertheless, we would like to try to place this extraordinary natural disaster in a statistical context and to explore what such a real event means for the theoretical analysis of natural hazards. In this way, we may be able to make a small contribution to ensuring that future catastrophes claim fewer victims and cause fewer material losses. One thing is already certain, however: they cannot be prevented.

The cause - the weather situation

From 12 to 15 July this year, the weather was dominated by a pronounced low-pressure complex over Central Europe. The low-pressure area near the ground, called „Bernd“, had developed in connection with a low pressure system at high altitude, which slowly approached from France across the Atlantic. Due to a stable, pronounced high-pressure cell over western Russia, which had already led to above-average temperatures up to Arctic latitudes there over a longer period of time, the low-pressure system was initially unable to move further east.

Thus, the low pressure system „Bernd“ rotated for several days with its centre over Germany, allowing extremely moist air masses from the Mediterranean region and south-eastern Europe to flow across eastern and northern Germany into the affected areas (see Fig. 1). The air masses had accumulated a lot of water vapour both on their way in the Mediterranean region and the Baltic Sea, the letter having experienced above-average temperatures this year.

In the vicinity of the western low mountain ranges (e.g. Eifel, Sauerland), special regional meteorological effects (e.g. forced elevation and damming effects) then occurred, triggering the large-scale, long-lasting heavy precipitation.

From 13 July onwards, thunderstorms with heavy rainfall initially occurred over parts of northern Bavaria and Saxony in connection with depression „Bernd“. In the course of the day and in the night of 14 July, immense amounts of rain were then dumped over the northern Sauerland region. The region around the town of Hagen was particularly affected. There, almost 100 l/m² of precipitation were measured within 3 hours during the night.

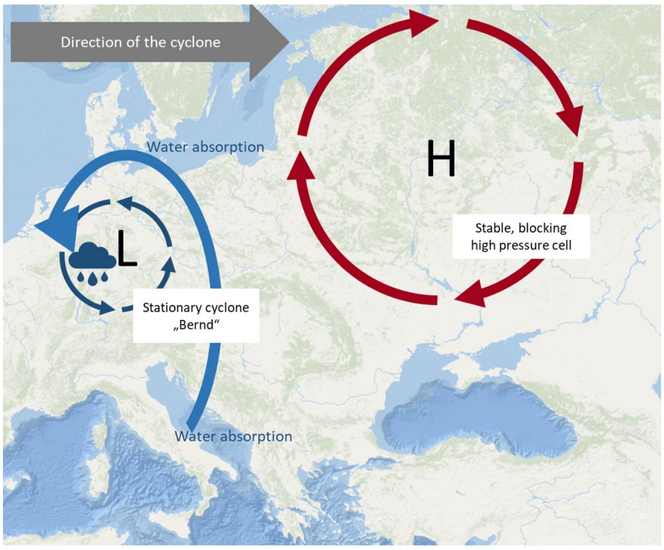

Fig. 1: Highly simplified schematic representation of the air pressure conditions (large-scale weather situation over Europe) for the period July 12-15, 2021.

On 14 July, the rain clouds, which rotated counterclockwise around the centre of the low-pressure system, which at that time was located approximately over southern Germany, had reached the low mountain region of the Eifel. Here, over the catchment areas of the rivers Ahr, Erft, Swist, Nette, Nitzbach, Rur, Inde, Merzbach, Vichtbach, Kyll and Wurm, precipitation amounts were unleashed that had never been observed in this region since the beginning of weather records.

At this time, the soils were already heavily soaked due to the wet weather in the weeks before the extreme event. The weather in many regions of Germany in this year's spring and early summer is thus in contrast to recent years, which have tended to be characterised by above-average dryness. Soils that are both too wet and too dry have difficulty absorbing precipitation, resulting in rapid runoff of rainwater at the surface in regions with slopes. Countless drainage channels, gutters and streams collected it and fed it - almost simultaneously - to the rivers mentioned above, which thus burst their banks within hours and carried away everything in their path. In a large river system such as the Rhine, on the other hand, there was only a moderate flood, with only a few riverside promenades and car parks flooded. The high-water mark at which navigation must be suspended was exceeded only briefly.

Summary: Cause - the large-scale weather situation

Enormous amounts of precipitation due to special meteorological conditions such as

- constant large-scale weather situation
- high moisture content in the atmosphere

Flood event resulting from increased surface runoff due to

- intensively structured terrain
- saturated soils due to persistent wet weather prior to the event

The precipitation amounts

However, what would have been „normal" rainfall amounts? How is „normal" actually to be defined in this context? A statistical frequency analysis can be used to determine whether a certain amount of precipitation matches the experience gathered over decades in a region. The example of the Dahlem weather station near the source of the River Ahr in Blankenheim illustrates the methodology of such an analysis:

The Dahlem station has been in operation since 1931 and thus covers an observation period of just over 90 years. The daily precipitation totals are recorded for almost every day of this period. These values are sorted in descending order of magnitude in a first evaluation step. Table 1 lists the highest 9 values of these.

RP	Precipitation (mm)	Date
?	129,2	14.07.2021
45,0	70,8	04.08.1982
30,0	64,5	06.10.1988
22,5	64,4	04.11.1940
18,0	64,1	04.07.1937
15,0	63,7	27.09.2007
12,9	63	01.07.1942
11,3	60	24.07.1947
10,0	56,5	29.05.1956

Tab. 1: Listing of maximum daily sums of precipitation at the station Dahlem (incl. corresponding return period and observation date (data DWD)). Note: All dates are given in german date format (dd.mm.yyyy)

The maximum precipitation value in this list is 129.2 mm (equivalent to 129 l/m^2) and was recorded in connection with this year's extreme event in July. Using the extreme value statistical method chosen here, this value would be attributed a return period (RP) of 90 years, as it was reached once in 90 years. For example, using the same approach, the third precipitation value in the list (64.5 mm on October 6, 1988) would be attributed a return period of 30 years because this value was reached or exceeded three times during the observation period. The ninth value (56.5 mm on 29.5.1956) should therefore be a 10-year event. In this way, the statistical return period (RP in years) can be calculated for each daily precipitation value. In this way, the statistical return period (RP in years) can be calculated for each daily precipitation value.

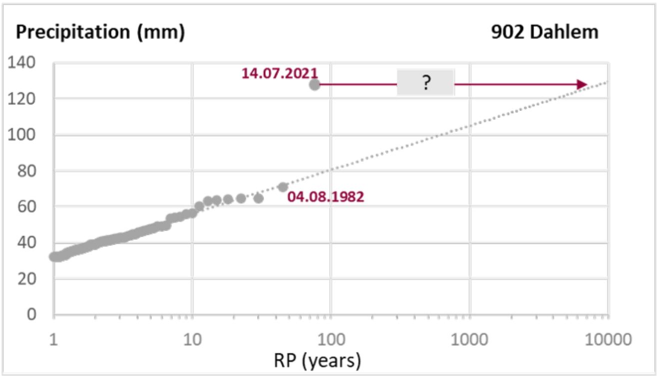

Fig. 2: Frequency analysis of daily precipitation at Dahlem station (DWD data).

If the return periods calculated in this way are compared with the corresponding precipitation values in a diagram with a logarithmically divided abscissa (X axis), these are normally grouped around a logarithmic compensation line (see Fig. 2). Common procedures, for example to clarify design issues, extrapolate this compensation line to estimate the magnitude and annuality of rare heavy precipitation events. With this procedure and without taking into account this year's July event, the 100-year precipitation event for the Dahlem station should actually only be 80 mm and a „millennium rainfall" just over 100 mm.

However, the precipitation event on 14 July 2021, with 129.2 mm, not only exceeded the previous record value by a factor of 1.82, but also lies far above the compensation line calculated in connection with the previous observations (see Fig. 2). If it were assumed that the relationship between return period and daily precipitation calculated from concrete measured values of past decades could also be extrapolated into the range of higher return periods, then the precipitation in Dahlem on 14 July 2021 would be a - roughly - 10,000-year event. For this, the respective daily value would have to be shifted to the right to the compensation line (red arrow in Fig. 2). This, however, is rather unlikely, because the probability of a 10,000-year event occurring during the 90-year observation period of the Dahlem monitoring station is less than 1 percent. But still, it is not inconceivable.

In this case, however, such extrapolation need not lead to the desired result. One possible reason is that the compensation line only reflects the „usual" weather conditions during the observation time available to us. In Central Europe, this would include so-called westerly weather conditions, in which Atlantic frontal systems bring precipitation areas in from a westerly or southwesterly direction. The „statistical outliers" would then be seen as the result of completely different - extreme - weather conditions. At least on 14 July 2021, this was exactly the case: the rain clouds did not reach North Rhine-Westphalia and Rhineland-Palatinate from the west, but from the north-east, because they had been guided in a wide arc around the eastern edge of the almost stationary low pressure vortex. Their path led from the Mediterranean via Eastern Europe, the Baltic Sea and Northern Germany to Western Germany (Center for Disaster Management and Risk Reduction Technology (CEDIM)). Over this long distance, the air was able to become saturated with water vapour to almost the limit of its capacity, which then fell over western Germany as heavy rain.

The fact that such extreme events, which do not fit into the long-term statistics, are by no means rare, is demonstrated e.g. by the weather stations Köln-Stammheim

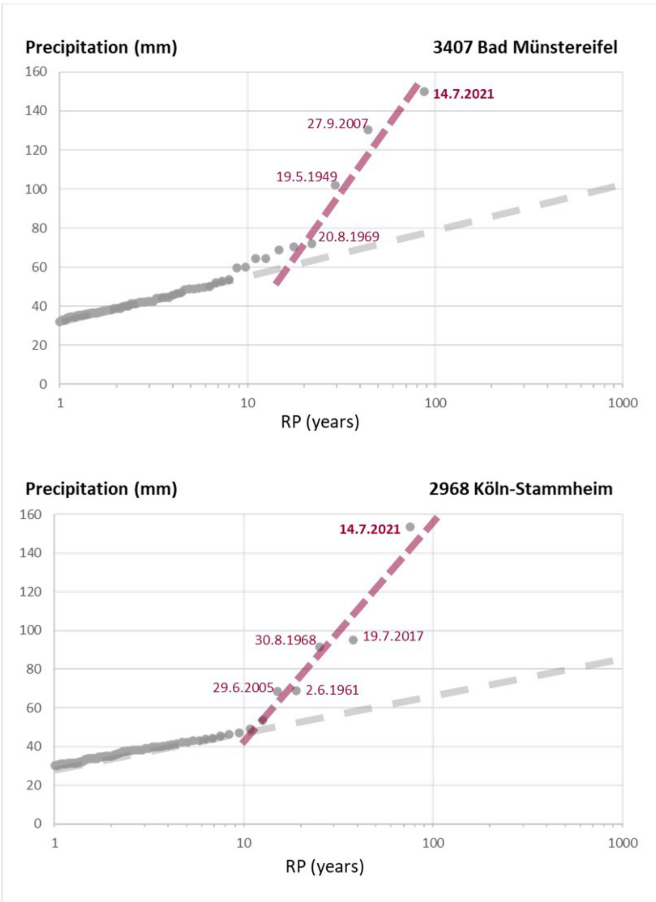

Fig. 3: Frequency analyses of daily precipitation at the stations Bad Münstereifel and Köln-Stammheim (DWD data).

and Bad Münstereifel (see Fig. 3). For Bad Münstereifel, the daily value of 14.7.2021 was estimated from data taken from the surrounding areas to be about 150 mm, since the station has not been operated since 2020. It can be clearly seen in Fig. 3 from the data of the Bad Münstereifel station that there have been at least 3 precipitation events in the 72 years since 1949 which differ significantly from the long-term statistics. Thus, such a conspicuous heavy rainfall event would be repeated here - roughly calculated - about every 24 years. An extreme event like the one in July 2021 would be expected about every 90 to 100 years. The situation is similar at the Köln-Stammheim station (see Fig. 3, below), where 5 „conspicuous“ heavy rainfall events (with daily totals of more than 60 mm) are distributed over the 60 years since 1961. Extreme values would therefore be expected here approximately every 12 years, whereby the return period of this year‘s extreme event at this station is also in the order of 100 years.

At the stations Rodder, Blankenheim, Kall-Sistig and Lommersum the precipitation value of 14.7.2021 either appears as a singular extreme value or it is accompanied by only one or two subordinate values (see Tab. 2). A statistical classification, even if only rough, is therefore hardly possible at these stations. However, as this was probably at least a centennial event, these stations are marked with „RP >> 100“ in Figure 4. At the stations Simmerath, Kaltenborn and Pulheim, which are located outside or at the edge of the heavy rainfall area, the

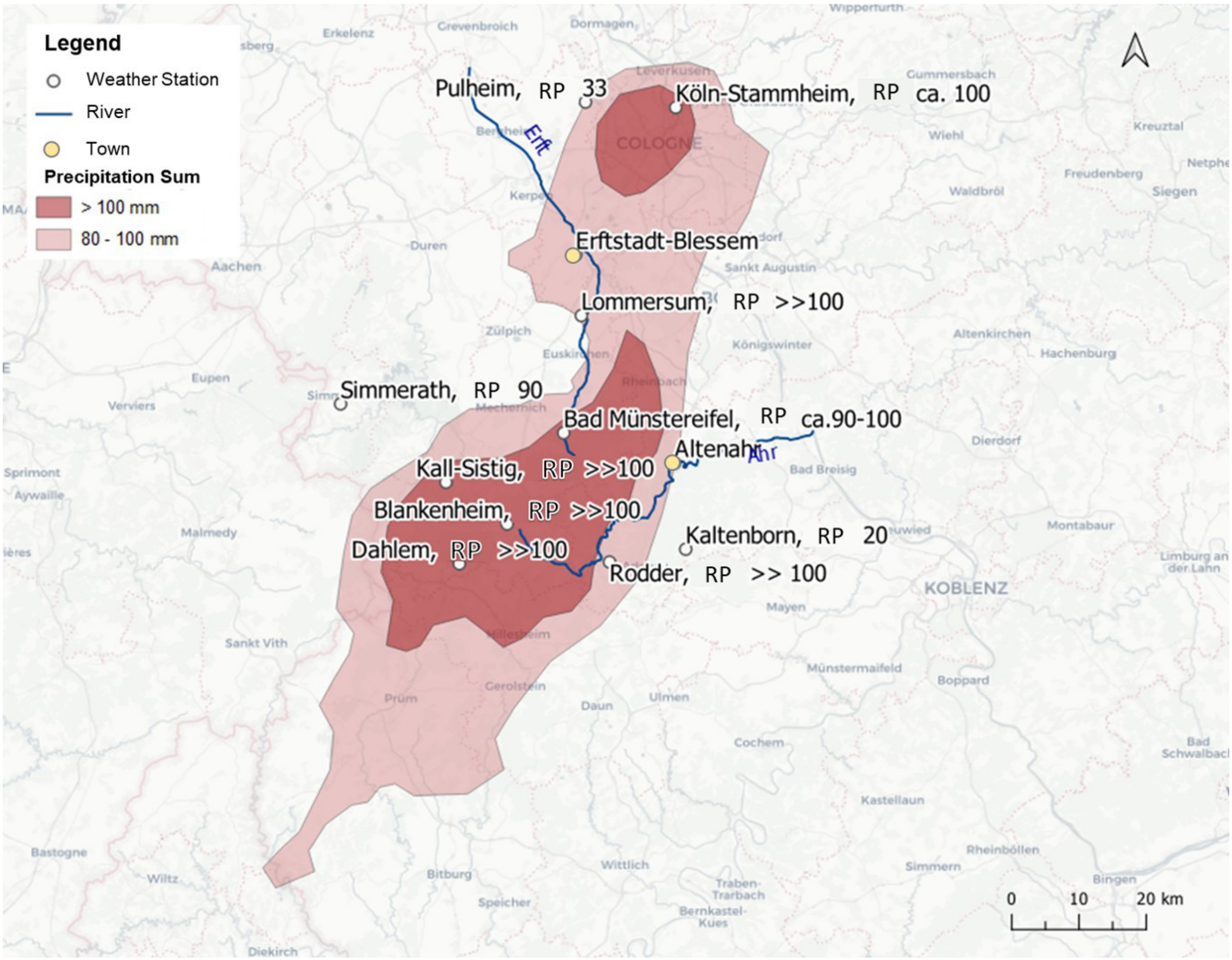

Fig. 4: Investigated precipitation area on 14.7.2021 over the Eifel and Cologne area. Regions with precipitation exceeding 80 mm are marked in color. Also shown are the investigated measuring stations and their estimated RP of the precipitation event on 14.07.2021.

Station	Begin of Record	Maximum values of daily precipitation sums (mm)			
		Maximum value	Date	Second highest value	Date
Bad Münstereifel	1931	ca. 150	**14.07.2021**	130,5	27.09.2007
Kall-Sistig	1947	144,8	**14.07.2021**	82,7	27.09.2007
Köln-Stammheim	1945	153,5	**14.07.2021**	95	19.07.2017
Rodder	1931	150	**14.07.2021**	71,6	04.08.2006
Dahlem	1931	129,2	**14.07.2021**	70,8	04.08.1982
Blankenheim	1961	111,2	**14.07.2021**	64	18.06.1966
W.-Lommersum	1905	113,9	**14.07.2021**	78,2	19.05.1949
Simmerath	1941	98	07.10.1982	93,5	**14.07.2021**
Pulheim	1951	94,3	30.08.1968	78,8	**14.07.2021**
Kaltenborn	1961	100,6	04.07.1975	82,2*	**14.07.2021**

*Third highest value

Tab. 2: Peak values of observed daily precipitation for different weather stations from the analyzed region (see also Fig. 4). Shown here are the maximum and second highest values since records began until and including July 2021.

event of 14.7.2021 fits into the long-term statistics, but also remains in the top group of the heaviest daily precipitation (see also Table 2).

It is also striking in Table 2 that the peak precipitation recorded before 2021 is distributed over different years at almost all the weather stations studied. They were therefore locally limited rainfall events. Only the stations Bad Münstereifel and Kall-Sistig, which are about 20 km apart, were recorded by the same heavy rainfall area in 2007. But this was also different in July 2021: At almost all stations on the 75 km long stretch between Köln-Stammheim in the northeast and Dahlem in the southwest, the previous record values were broken or, in most cases, even significantly exceeded. Even at the stations Simmerath, Kaltenborn and Pulheim, which are located away from the main precipitation area (see Fig. 4), the precipitation of 14.7.2021 can still be found in the top group on places 2 and 3.

Thus, this event must be classified as exceptional both in terms of its intensity and its areal extent. However, its supraregional probability of occurrence cannot be determined exactly on the basis of the individual station evaluations. For this purpose, it is necessary to consider its effects, the water levels and discharges of the surface waters concerned.

The focus of our evaluation here refers to a region from the Eifel to Cologne (Köln), which roughly comprises the rivers Ahr and Erft and their catchment areas. However, the actual precipitation area on 14 July 2021 had a much larger scale and includes a number of other regions in Germany (e.g. northern Sauerland) and adjacent countries where similar precipitation records were observed.

Summary: Precipitation amounts

- Observed precipitation amounts on 14 July 2021 at almost all stations studied were far above previously observed record values since records began (about 100 years ago).
- The areal extent of the heavy precipitation area was unusually large.
- Determination of return periods difficult due to data situation

The flood on the Ahr

As a representative of the many rivers which have their source in the Eifel and which have caused horrible devastation during this flood event, the discharge conditions of the Ahr shall be dealt with in more detail at this point.

Since 1945, the gauging station on the Ahr in the village of Altenahr has reliably recorded the water level of the river. Due to the extremely high water levels, the recording was even interrupted on 14.7.2021, at least for about 10 days, as the measuring point was only set up for a maximum water level of 5.75 m. The water level of the Ahr was not recorded. In an evaluation by CEDIM (Flood Central Europe, July 2021 - Report No. 1) it is estimated that on this day the Ahr reached a water level of up to 7m. From the main values to the Altenahr gauge (Landesamt für Umwelt, Rheinland-Pfalz), a presumed discharge of 520 m^3/s could be extrapolated from this. Values in a similar order of magnitude (400 to 700 m^3/s) are also assumed in the CEDIM report. However, it is unlikely that the exact discharge associated with this exorbitant level can be determined.

This year's extreme event was not the first devastating flood on the Ahr. Scientists at the University of Bonn reconstructed the water levels of the Ahr for several extreme flood events of the nineteenth and twentieth centuries and estimated the corresponding discharge amounts for the town of Altenahr (ROGGENKAMP & HERGET 2015). Table 3 shows the highest discharge levels of the last 200 years, which are used as a basis for statistical evaluations in this report. Based on these data, it can be seen, for example, that there must have been a catastrophic flood event in 1804 - with about twice the discharge compared to the flood in July 2021 (in CEDIM, 2021). It is unimaginable what damage such a flood would have caused today.

Event	Discharge (m^3/s)	Source
1920*	170*	ROGGENKAMP & HERGET, 2015*
1918	236	ROGGENKAMP & HERGET, 2015
1888	280	ROGGENKAMP & HERGET, 2015
1910	496	ROGGENKAMP & HERGET, 2015
2021	520	KA, extrapolated from main values of the gauge Altenahr
1804	1091	KA, extrapolated on the basis of ROGGENKAMP & HERGET, 2015

* not included in the evaluation

Tab. 3: Peak values of runoff volumes for Altenahr. Data sources are Roggenkamp & Herget (2015) and Landesamt für Umwelt, Rheinland-Pfalz.

The period over which flood events above 200 m^3/s have occurred is at least 218 years if the year 1804, with the oldest reconstructed flood, marks the beginning of the observation period. However, there is also evidence of a comparable flood event in 1601 (CEDIM - Flood Central Europe, July 2021 - Report No. 1), but its discharge can no longer be reconstructed. If this event is included in the considerations, the available observation period increases to 420 years. In terms of magnitude, it can be assumed against this background that the five conspicuous flood catastrophes listed in Table 3 are distributed over a period of 200 to a maximum of 400 years.

Taking into account an average observation period of 300 years, this results in statistical return periods of 60 to 125 years for the events of 1888 and 1918, which are still within the range of the official return periods. The extreme catastrophe of 1804 is likely to have been a 300- to 500-year event, although an uncertainty range of up to a return period of 1,000 years must be applied here. According to our evaluation, the flood of July 2021 can thus be classified as a 100- to 250-year event, just like the flood of 1910 (see Fig.5).

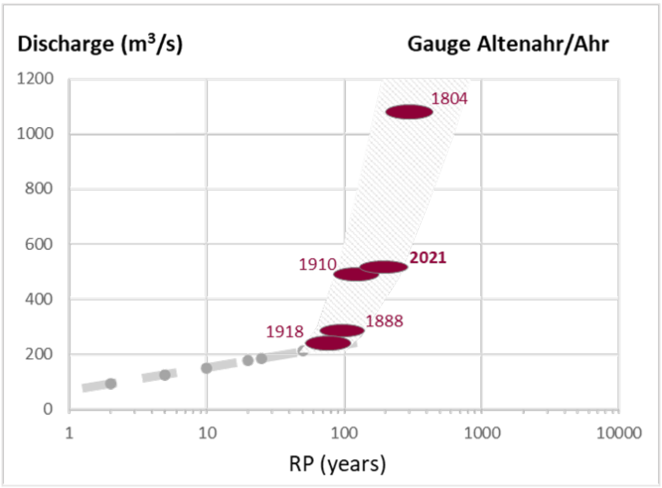

Fig. 5: Frequency analysis of the discharges of the river Ahr at the gauge Altenahr (data: Landesamt für Umwelt Rheinland-Pfalz, HERGET & ROGGENKAMP 2015).

Combining these results with the annualities issued by the Rhineland-Palatinate State Office for the Environment for the Altenahr gauge results in the diagram shown in Fig. 5. The distorted circles and the grey shaded area are intended to express the uncertainties in the calculations.

Summary: Flood on the Ahr

- Statistical classification based on gauge data in Altenahr shows that this was an exceptionally strong extreme event.
- However, historical records show other catastrophes in 1910 and 1804 of at least the magnitude of the July event.
- An event of at least the magnitude of the July event must be expected every 100 - 250 years.

The influence of climate change

Whether an individual event, such as the flood disaster discussed here, was specifically caused by climate change is almost impossible to prove. However, there are various arguments and indications that clearly point to the influence of climate change.

Due to the increased thawing of the polar ice, less solar energy is reflected back into space, especially in the summer months, causing the polar latitudes to warm up more than the rest of the earth's atmosphere. Thus, the exchange of air between the pole and the equator, driven by the temperature difference between the Arctic and the tropics, slackens. Climate scientists assume that this causes high-pressure cells and low-pressure vortices to move forward more slowly, or even to remain stable in place for longer periods of time. The persistent dry spells in Central Europe in 2018, 2019 and 2020 may also be a consequence of these changes. The stationary low-pressure vortex that resulted in the precipitation discussed here is probably also due to this effect.

Since about the year 2000, global heating has become not only measurable, but also noticeable. In Germany, the warmest years since weather records began in 1881 all gather in the period between 1995 and 2020. A physical law (Clausius-Clapeyron equation) states that the warmer the air, the more water vapour it can absorb. Consequently, precipitation becomes heavier as the air releases this moisture. Therefore, it is not surprising that e.g. at the weather stations Bad Münstereifel and Köln-Stammheim the heaviest daily precipitation falls in the period after the year 2000 (2007, 2017 and 2021).

In earlier KA publications, it was already calculated on the basis of climate modelling that the intensity of heavy rainfall events could increase by an average of 10 to 20 percent by the middle of this century, depending on the region. In July 2021, it became clear that this could also be accompanied by a doubling of the maximum daily precipitation known to date.

Equally worrying, however, is that the mathematical relationship between return periods and the corresponding precipitation amounts means that return periods can be halved as a result: 200-year events become 100-year events and 100-year events become 50-year events. Based on current knowledge, this means nothing other than that the risks of heavy precipitation and the resulting flash floods could also double as a result of climate change, even if rainfall amounts „only“ increase by 10 to 20 percent. The above publications are available on the KA website (K.A.R.L.® Insights: Heavy Rainfall, Issue 01/2018, K.A.R.L.® Release: Heavy Rainfall - Hail Model - Climate Data, Issue 01/2019).

Outlook

The extreme precipitation event in July 2021 in western Germany and adjacent regions resulted in a devastating catastrophe with a high death toll and enormous damage to buildings and infrastructure.

Do not neglect extreme events

The statistical classification of this extreme event has shown that both the extreme precipitation and the resulting flood in July 2021 are record events that far exceed the observations of the last hundred years in terms of intensity and spatial extent. Due to this strong deviation from "normal" statistics, concrete statements about the occurrence probabilities of such events are difficult to make using standard statistical methods.

Thus, the results also point to difficulties of common procedures used to estimate hydrological extreme events with high return periods (> 100 years). Indeed, these methods often assume that the observed statistical relationship between intensity and return period (determined from observations of the last 50 to 100 years) can be extrapolated to the range of higher return periods by extending the regression line. However, the present report indicates that this assumption must be questioned.

In any case, it is certain that in principle all observed extreme events should be taken into account in planning and insurance issues, even if they deviate strongly from the "normal" statistics. This is because, as this brief study shows, exceptional extreme precipitation and flood events occur far more frequently than would be expected on the basis of previous statistics. When assessing or forecasting extreme events, therefore, historical data should also be used, if possible, in addition to the observation data of recent decades that have now been automatically recorded.

Focus on hazards on smaller tributaries

Up to now, the focus of interest has been on flood hazards on major rivers such as the Rhine, Danube or Elbe. The danger posed by their smaller tributaries and their tributary streams, on the other hand, has been underestimated. However, this was to change dramatically after the catastrophe on the Ahr and Erft rivers. The main point here is that flash floods on small rivers occur minutes, or at best hours, after the precipitation event that triggers them, whereas on the large rivers warning times of days or even weeks are possible. By contrast, the advance warning times on rivers such as the Ahr, Erft or Swist are extremely short.

Interpret signals in good time and react to them

It is therefore all the more important in future to correctly interpret the signals that precede such a disaster and to react to them accordingly. As early as the day before the disaster, weather forecasts for the affected regions were predicting rainfall of up to 150 l/m^2 , which actually occurred on 14 July 2021. Decision-makers on the ground must be put in a position to be able to correctly classify forecasts by weather services, i.e. they must know the comparative values at which it becomes dangerous in their area of responsibility and appropriate steps - urgent warnings to the population, evacuations, etc. - must be initiated. Then a warning period of at least 24 hours would have been available.

Simple methods of advance warning

There are also simpler methods of advance warning, which were already put into practice after the Elbe floods in 2002: When the level of the river - in this case the Müglitz near the village of Dohna near Dresden - reaches a critical value, above which, according to all experience, a devastating flood could be imminent, immediate measures must be taken, such as closing flood gates, shutting off drainage channels, switching off the power supply and immediately evacuating the population. On the Müglitz, a marker at a suitable location, visible to everyone, indicates when this is the case (see Fig. 6, red line below the bridge). For Altenahr, for example, this would be the water level of the Ahr, which, according to Figure 5, corresponds to a discharge of about 240 m^3/s, because above this level, catastrophic flooding has occurred in 3 out of 5 cases in the past. This corresponds to a probability of occurrence of 60 percent.

Fig. 6 Flood warning marker on the Müglitz (Picture: Paus)

Who would still get into a car if the probability of an accident was just as high? Although the warning time is shorter with this method than if one refers to meteorological forecasts, it is still sufficient to save human lives, to bring the most valuable protected assets to safety and to get vehicles out of the garages and move them to a higher location.

Take sensible measures

In fact, it should be almost redundant, but needs to be recalled in light of the July 2021 flood: If you live within sight of a watercourse - no matter how small - and the height difference to this watercourse is not at least 10 metres, valuable assets such as computer systems, archives, expensive technical or medical equipment etc. do not belong in basements. Heating and air-conditioning systems, distribution cabinets or storage rooms should also be located above ground, if at all possible, i.e. at least on the ground floor. However, it is also clear that in the event of an event such as the floods of 14 July 2021, such safety precautions would not have helped everywhere, but they would have prevented people from seeking out basement rooms when the floods were approaching and thus putting their lives in danger.

Climate change influences extreme weather events

Who is prepared for a flood that statistically occurs less than 1 time per century? The answer: hardly anyone. But this is precisely what has to change, because climate change could mean that the return periods of flood events calculated on the basis of measured values from past decades are now already obsolete. We may have experienced an extreme event, but it is not as rare as we would like to believe. It is therefore quite possible that younger people in particular will have to survive a flood on the Ahr, Erft and Swist rivers like the one that occurred in July 2021 for a second time in their lives. A rethink in land use (less sealing of areas, more naturally grown forest areas) as well as flood-adapted construction are certainly of central importance here; not only in Germany, but on almost all middle and high mountain rivers around the globe. In this case in particular, however, the rainfall was so heavy that that whether the surfaces had been sealed or not it would have made little or no difference to the running off of the water.

Findings for K.A.R.L.

Narrow valleys with steep slopes can cause difficulties for digital elevation models. Since the elevation model is an important component of analysis in K.A.R.L., this can lead to inaccuracies when calculating flood risks in highly structured terrain. Digital elevation models usually describe the surface in terms of a regularly spaced grid of points, with the individual points representing elevation values. The limiting factor here is the resolution of the elevation model. Distinctive terrain elements cannot be depicted in detail at low resolution. Our task is to make our analysis system fit for such special locations. We are currently working hard to further improve K.A.R.L. in this area in order to be able to offer even more reliable risk analyses for complex terrain situations such as the Ahr valley. More information on this topic will be available in a K.A.R.L. Express to be published in the coming weeks.

Furthermore, the finding from this short report that extreme events occur more frequently than expected on the basis of the „normal“ distribution curve of observed values should also be taken into account in K.A.R.L. when estimating the RPs and intensities of extreme events. However, a number of further considerations are also required for the concrete implementation of this finding in K.A.R.L..

Literature & Sources

T. Junghänel, P. Bissolli, J. Daßler, R. Fleckenstein, F. Imbery, W. Janssen, F. Kaspar, K. Lengfeld, T. Leppelt, M. Rauthe, A. Rauthe-Schöch, M. Rocek, E. Walawender u. E. Weigl (2021): Hydro-klimatologische Einordnung der Stark- und Dauerniederschläge in Teilen Deutschlands im Zusammenhang mit dem Tiefdruckgebiet „Bernd" vom 12. bis 19. Juli 2021, Deutscher Wetterdienst 2021

A. Schäfer, B. Mühr, J. Daniell, U. Ehret, F. Ehmele, K. Küpfer, J. Brand, C. Wisotzky, J. Skapski, L. Rentz, S. u. Mohr, M. Kunz (2021): Hochwasser Mitteleuropa, Juli 2021 (Deutschland) – Bericht Nr. 1, Nordrhein-Westfalen & Rheinland-Pfalz, CEDIM Center for Disaster Management and Risk Reduction Technology 2021

T. Roggenkamp u. J. Herget (2015): Historische Hochwasser der Ahr - Die Rekonstruktion von Scheitelabflüssen ausgewählter Ahr-Hochwasser, Heimatjahrbuch Kreis Ahrweiler, hjb2015.47.pdf (kreis-ahrweiler.de)

Precipitation data: Daten extrahiert vom DWD Climate Data Center (CDC): Tägliche Stationsmessungen Niederschlagshöhe in mm, Version 2.1-v2107, 202107291811 (https://cdc.dwd.de/portal/202107291811/mapview)

Gauge data: Landesamt für Umwelt Rheinland-Pfalz, Messdaten Pegel Altenahr (http://213.139.159.46/prj-wwvauskunft/projects/messstellen/wasserstand/register3.jsp?intern=false&msn=2718040300&pegelname=Altenahr++&gewaesser=Ahr&dfue=1)

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