## 2.8 Storm Precipitation Depths

A storm precipitation event is a natural or defined precipitation event with a high precipitation intensity in relation to its duration, making it a rare occurrence. The mean period in which an event either reaches a value once or exceeds it is referred to as the *return period* or recurrence interval. Using a regionalisation procedure, the local results from precipitation stations are applied to sites for which no measurements are available. Nonetheless, the results still only refer to specific locations. Knowledge of storm precipitation depths of prolonged precipitation events in accordance with the return period is important for many practical issues, including sizing of water management installations, e. g. emergency spillways and reservoirs. It would thus seem sensible to carry out extreme-value statistical examinations of high precipitation in Germany.

### Methodology

The time series of daily precipitation depths from January to December at around 2700 stations throughout Germany in the period 1961 to 1990 serve as the base data for calculating and regionalising storm precipitation depths with durations of D = 24 h and D = 72 h. These stations were checked for homogeneity and local characteristics beforehand on the basis of the annual precipitation depths. They proved suitable for a more detailed evaluation.

In order to calculate station-based storm precipitation depths, a precipitation phase of a specified duration is moved within the precipitation continuum by forming rolling intervals of the daily precipitation depths, until the maximum value is reached. This procedure is not dependent on the actual duration of the underlying precipitation events. The daily precipitation values are equidistant measurements. These values are usually smaller than the maximum precipitation depths sought, beginning and ending at any time, because a coherent precipitation event can be divided between two measurements. Therefore, measurements increased by certain percentages are used in the extreme-value statistical analysis of each duration. The empirically calculated increase factor depends on how often the basic measurement interval occurs in the duration. The precipitation depths of duration D = 24 h (the basic interval 1 d from the morning of the previous day to the morning of the measurement day) are the daily precipitation depths plus 14 %. The precipitation depths of duration D = 72 h (the basic interval 1 d multiplied by three) are the daily precipitation depths plus 4 %.

In order to assess the coincidental precipitation events during a sufficiently long measurement period and to extrapolate the results to very rare high storm precipitation events, an extreme-value statistical analysis must be carried out. There are numerous statistical methods for calculating storm precipitation depths, including selection of the random sample to be described and use of a statistical distribution function.

Essentially, there are two methods for providing the necessary random samples for an extreme-value statistical analysis of measured time series of precipitation levels, i. e.:

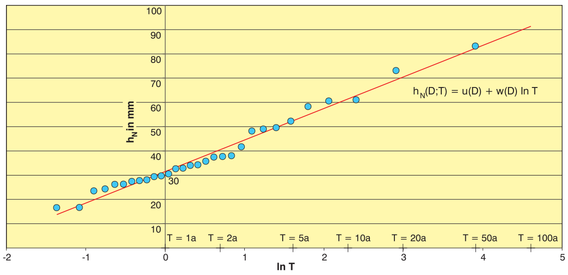
1. using the annual maximum values – the annual series method and
2. using the precipitation levels above a threshold value – the partial series method

The results in Map 2.8 are based on annual series. Exactly one measured precipitation event (precipitation depth per duration) per year measured is included in the annual series. Relatively low annual maximum values are taken into account even if the measurement is exceeded several times in another year.

The distribution function must be linked to the data material using an adjustment calculation. As a result of testing different procedures, the theoretical extremal I distribution (also known as Gumbel distribution) is adjusted to the annual series of precipitation depths for the durations D = 24 h and D = 72 h using a regression calculation. The distribution can be presented as an equation in the following form

$$h_N(T) = u + w \cdot \ln T \qquad (1)$$

per duration D in accordance with the return period T, where u and w are the parameters of the distribution function. Figure 1 shows how the u and w parameters are calculated using a graphical evaluation. The annual-series values, in order of size, are entered at their plotting positions in accordance with the recurrence intervals T(k) estimated in advance based on the size of the random sample (M) or the length of the series of observation data. The plotting position for the largest (first) value of the random sample size M = 30 is T(1) ≈ 50 a. In the coordinate system with the natural logarithm of the return period T on the X axis, the distribution function is represented by means of a straight regression line. The u parameter is the ordinate intercept for ln 1 = 0, the w parameter signifies the incline of the compensation line (Fig. 1).




return period T estimated in advance: T(k) = exp (-ln (ln ((M + 0,2) / (M - k + 0,6))))

**Fig. 1 Example of graph-based calculation of the u and w parameters on the basis of the annual series for precipitation levels for duration D = 24 h** (Plauen station, 1961–1990, M = 30 a, index k = 1, ..., M)

The station-based extreme-value statistical evaluations of annual series from measurement series of daily precipitation depths result in the parameters u(D) and w(D) for the durations D = 24 h and D = 72 h. These parameters are used to indicate the high precipitation depths $h_N$ for every station in accordance with the duration and the recurrence interval. The formula for calculating storm precipitation depths is:

$$h_N(D;T) = u(D) + w(D) \cdot \ln T \qquad (2)$$

For each duration D, the u(D) parameter equals the storm precipitation depth for the return period T = 1 a since ln 1 = 0. The w(D) parameter can be calculated using two storm precipitation depths for this duration; the most useful storm precipitation depths are those for T = 1 a and T = 100 a.

In order to determine the storm precipitation depths for sites without stations, too, the local results are transferred to a 1 km² grid for the whole of Germany. Instead of directly regionalising the u(D) and w(D) parameters, as would be possible, the high precipitation depths for the return periods T = 1 a and T = 100 a are regionalised for the respective durations D = 24 h and D = 72 h. This method is more manageable than direct regionalisation of the u(D) and w(D) parameters because it enables the effects of the various steps in the regionalisation procedure on the high-precipitation-depth fields (for T = 1 a and T = 100 a) to be better checked.

It has proven useful to carry out the regionalisation area by area. The first-level river catchment areas are used as the basis (Map 3.2). The storm precipitation depths for the durations D = 24 h and D = 72 h are then regionalised in the following steps:

1. distance-based interpolation of the station-based storm precipitation depths for the return periods T = 1 a and T = 100 a onto the base grid (1 km² grid cells)
2. calculation of the storm precipitation depths in the base grid using a regression method comprising the following grid-based variables:
   · ground elevation,
   · mean precipitation depth in the period 1961 to 1990,
   · variance of the precipitation depths in the period 1961 to 1990,
   · ground exposure direction and
   · geographical situation of the grid cells
3. calculation of mean of the grid cells based on steps 1 and 2
4. distance-based interpolation of the residues at the station sites onto the surrounding grid cells
5. compensation of the contradictions in the cells which occur when examining individual seasons or durations
6. smoothing of the cells for recurrence interval T = 100 a
7. optical balancing of the extreme-value cells and correction of unrepresentative individual values

### Map Structures

The four maps (scale 1 : 4 000 000) show the regionalised storm precipitation depths for the durations D = 24 h and D = 72 h with return periods of T = 1 a and T = 100 a for Germany. The precipitation depths are divided into categories, whose ranges can be seen in the key. The lowest storm precipitation depths are brown, and the higher values are yellow and green. The dark-blue areas signify storm precipitation depths of $h_N$ (72 h, 100 a) which occur to that extent only in places.

The four maps show the good regional connection between the storm precipitation depths and the mean annual precipitation depths (Map 2.2). Irrespective of the durations, the four maps' structures display certain similarities. Some special features shall be examined in more detail in the following. The geographical distributions show the Alps, the foothills of the Alps and the Schwarzwald (Black Forest) to be the regions with by far the highest values. Very high precipitation depths occur in the upland regions – in accordance with the altitude. However, with a return period of T = 100 a, there are significant storm precipitation depths in valleys or leeward of the uplands, too. This is caused by extraordinary weather situations (e. g. change of wind direction due to extreme radiation) combined with local topographical effects.

The considerably high precipitation depths with a small recurrence interval at the eastern edge of Germany, particularly in Lausitz and east of the Berlin area, require a special explanation. They are the result of the occasional so-called Vb weather conditions whereby an extensive field of precipitation is created due to a low-pressure area stretching from Poland to Northern Italy and the field is continuously regenerated over a long period due to colliding air masses of different temperatures.

Low values of storm precipitation depths with T = 1 a are especially characteristic of the area between Lake Müritz and Greifswalder Bodden, in the Havelland area, the Magdeburg and Querfurt Börde, for small parts of the Emsland district and in the area between Hunsrück and Odenwald.

### Practical Information

When using the storm precipitation depths, a tolerance range is necessary because of the considerable temporal variability of precipitation. Furthermore, unavoidable inaccuracies in the measuring and evaluating methods and the limits of the extreme-value statistical method result in the storm precipitation depths being slightly unreliable. This unreliability increases the less the value is exceeded. Where the return period is T = 1 a the tolerance range should be ± 10 % and where it is T = 100 a the tolerance range should be ± 20 %.

The systematic error in the precipitation measurement (Map 2.5), primarily caused by wind blowing around the measuring device, results in the measured precipitation depths being too low. This error decreases as the precipitation intensity increases. Since the data material concerned here relates to storm precipitation events, this error is not corrected.

With regard to the precipitation duration, the duration D = 24 h does not necessarily mean that the precipitation lasts 24 hours. Precipitation-free intervals are possible during the 24 hours. The same applies to duration D = 72 h.

If the area values of the storm precipitation depth are to be determined using the local values estimated on the basis of Map 2.8, it must be borne in mind that precipitation intensity as calculated for a region decreases as the region increases. For this reason, the local values must be multiplied by reduction factors between 0.9 and 1 depending on the size of the hydrologic catchment areas.

Storm precipitation depths for a return period of T < 100 a must be calculated as shown in the following example.

### Example

The aim is to determine the storm precipitation depth for a return period of 20 years for a duration of 24 hours for a site west of Plauen (longitude 12° east and latitude 50.5° north). Storm precipitation depths $h_N$(24 h; 1 a) = u(24 h) = 35 mm and $h_N$(24 h; 100 a) = 95 mm are taken from the maps for the selected site and used in equation (2). In the first step, the w(24 h) parameter is calculated as follows:

$$w(24\ h) = (h_N(24\ h;\ 100\ a) - h_N(24\ h;\ 1\ a)) / \ln 100 \qquad (3)$$
$$w(24\ h) = (95 - 35) / 4.605 = 13.0$$

In the second step, the high precipitation depth sought $h_N$(72 h; 20 a) is derived as follows:

$$h_N(24\ h;\ 20\ a) = u(24\ h) + w(24\ h) \cdot \ln 20 \qquad (4)$$
$$h_N(24\ h;\ 20\ a) = 35 + 13.0 \cdot 2.996 = 73.9$$

On average, a storm precipitation depth of 74 mm in 24 hours (including interruptions) is reached or exceeded at the chosen site once every 20 years.

For further information and maps, please consult the KOSTRA-Atlas "Starkniederschlagshöhen für Deutschland" (Storm precipitation depths in Germany) (DWD 1997).