

**THE 1995 ALARMING RIVER DISCHARGES IN
THE NETHERLANDS**

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Abstract. The paper deals with hydrometeorological aspects of flood events occurred in the Meuse River in December 1993 and January-February 1995 and describes the critical situation along the dikes of the Rhine River in early 1995. These events originated mainly due to widespread intense rainfall and wet antecedent conditions. A number of research topics are considered. They include, the multisite daily rainfall generation and probability distribution of n -days totals, long term variations of seasonal rainfalls and their climatic implications, which are related to the Rhine and Meuse rivers, with emphasis on the design discharges for river dike construction and maintenance in the Netherlands.

1. INTRODUCTION

The Rhine and the Meuse are the most important rivers in the Netherlands. The Rhine rises in the Swiss Alps. With a length of 1,320 km it is the longest river in North-western Europe. The river enters the Netherlands near Lobith (Figure 1). The area upstream of this site is about 160,000 km², of which about 100,000 km² is in Germany (CHR,1978). The Meuse rises in North-eastern France (plateau of Langres) and flows through Lorraine and the Belgian Ardennes into the Netherlands. The Meuse crosses the Belgian-Dutch border a few kilometers to the south of Maastricht, which owes its name to the river (Meuse is Maas in Dutch). The area upstream of Maastricht is about 21,000 km².

The high river discharges around Christmas 1993 and during January-February 1995 made the Dutch people aware that these rivers could still be a real threat. In fact, large parts of the most southern province of Limburg suffered from both of those floods. About 250,000 people in the Rhine area were evacuated by early February 1995, due to the danger of impending overtopping of protecting dikes along the river. This paper deals with the hydrometeorological aspects of the exceptional discharges occurred in 1993 and 1995 and the actions taken after those events. In addition, a brief discussion on design discharges and recommended research are presented.

2. THE DECEMBER 1993 MEUSE FLOOD

December 1993 was an extremely wet month in Belgium, the Netherlands, and large parts of France and Germany. Figure 2 shows that a rapid increase in the river discharge at Borgharen (the

measurement site near Maastricht) occurred on December 19 and 20. This increase was due to two widespread rainfall events (Van Meijgaard, 1995), covering the entire upstream area, and to the wet antecedent conditions. Because the Meuse and its tributaries are rather steep in the Belgian Ardennes, the river quickly responds (discharge at Borgharen) to excess rainfall in this region. The maximum discharge ($3,120 \text{ m}^3/\text{s}$) was reached on December 22nd. A comparable peak discharge ($3,175 \text{ m}^3/\text{s}$, according to a homogenized record) only occurred once before during this century, in January 1926. For the December 1993 peak, a mean return period of 155 years has been estimated (Delft Hydraulics, 1994). The probability of two or more exceedances of the 150-year peak in one century is about 0.15 for a purely random sequence.

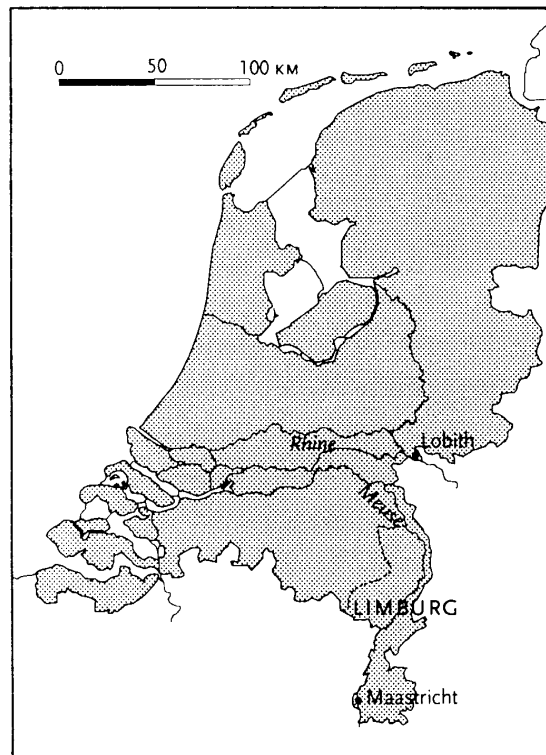


Figure 1. The Rhine and the Meuse rivers in the Netherlands

A further insight into the exceptionality of the December 1993 event was obtained from an analysis of the precipitation amounts over the Belgian Ardennes (Demarée et al., 1994). Daily rainfall amounts from 8 historic stations over the period 1880-1994 were considered. From these data, representative values of the daily areal average amounts over the entire Belgian Meuse basin upstream of Visé near the Belgian-Dutch border (about $12,000 \text{ km}^2$) were derived, using a slightly modified Thiessen procedure. Especially, the largest n -day amounts in the winter half-year (October-March) were examined, because high river discharges at Borgharen are mainly restricted to this period. Table 1 presents the largest n -day amounts for various values of n . The December 1993 amounts are the largest in the 114-year record for $n = 3, 4$ and ≥ 7 days. These maxima cannot be considered as

outliers, however. The second largest values differ always less than 10% from the December 1993 maxima.

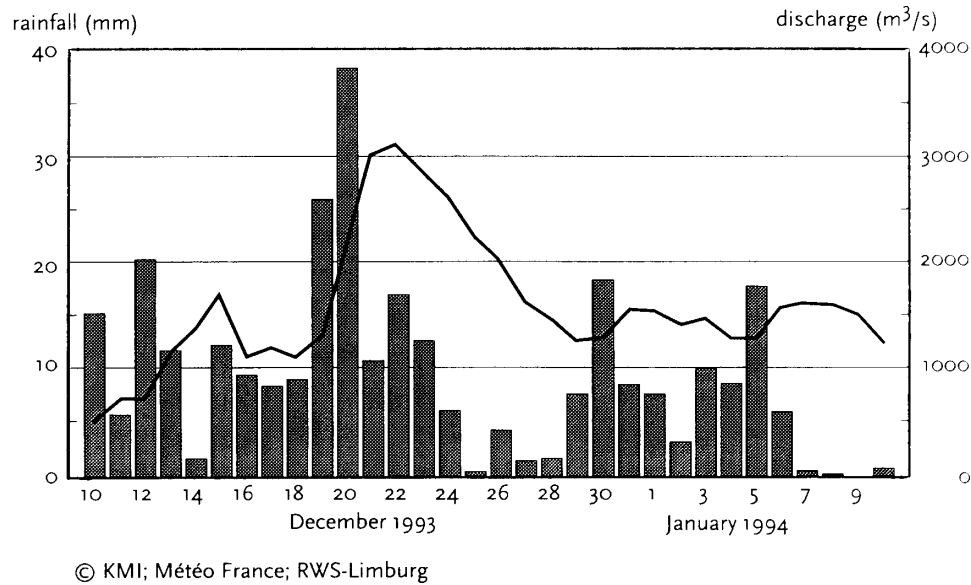


Figure 2: Discharge of the Meuse River at Borgharen (near Maastricht) during the period December 10, 1993 - January 10, 1994 and mean daily precipitation amounts over the entire upstream area. The precipitation amount for a particular day refers to the 24-hour interval running from 0700 GMT of that day to 0700 GMT of the next day.

General Extreme Value distributions were fitted to the n -day maxima in the winter half-year, resulting in estimated return periods of 100 to 500 years for the longer durations ($n \geq 10$). There is, however, considerable uncertainty about the shape of the upper tail for these durations. The consistency of the fitted distributions needs further investigation. Due to the rather short upper tail of the fitted distributions, a small change in the amount of precipitation leads to a substantial change in the estimated return period.

Table 1. Largest n -day amounts over the Belgian Meuse basin for the winter half years (October - March) 1880/81,...,1993/94.

n	Winter	Amount (mm)
1	1960/61	50.7
2	1947/48	67.6
3	1993/94	76.4
4	1993/94	90.5
5	1925/26	105.1
7	1993/94	122.0
10	1993/94	151.6
20	1993/94	234.7
30	1993/94	303.2

Nearly 10% of the area of Limburg was flooded. Unlike the lower parts further downstream, there are no dikes in this region. Shortly after the floods, the Boertien-II Committee was installed to give advice about measures to reduce the danger of flooding in the upper part of the Meuse basin in the Netherlands. The Committee completed its work in December 1994. The main advice was to deepen and widen the riverbed and to construct additional embankments where necessary. Besides reducing the flood risk, widening of the cross section is also attractive for landscape and nature development.

3. THE JANUARY-FEBRUARY 1995 FLOOD

Just one year after the December 1993 floods, Limburg suffered anew from high discharges of the Meuse River. Again about 10% of the area were flooded. A number of intensive widespread rainfall events in the period 21-30 of January 1995 caused the high river discharges (Figure 3). The soil was already quite wet at the beginning of these rainfall events because of excessive rainfall in December 1994 and a short rainy period around January 10, 1995. In addition, there was also snowfall during these two periods in the higher parts of the Ardennes. Snow accumulation over the whole catchment occurred during the first days of January 1995. However, on January 21, 1995 practically all snow was melted. More details about the meteorological situation can be found in Jilderda et al.(1995) and Van Meijgaard and Jilderda (1996).

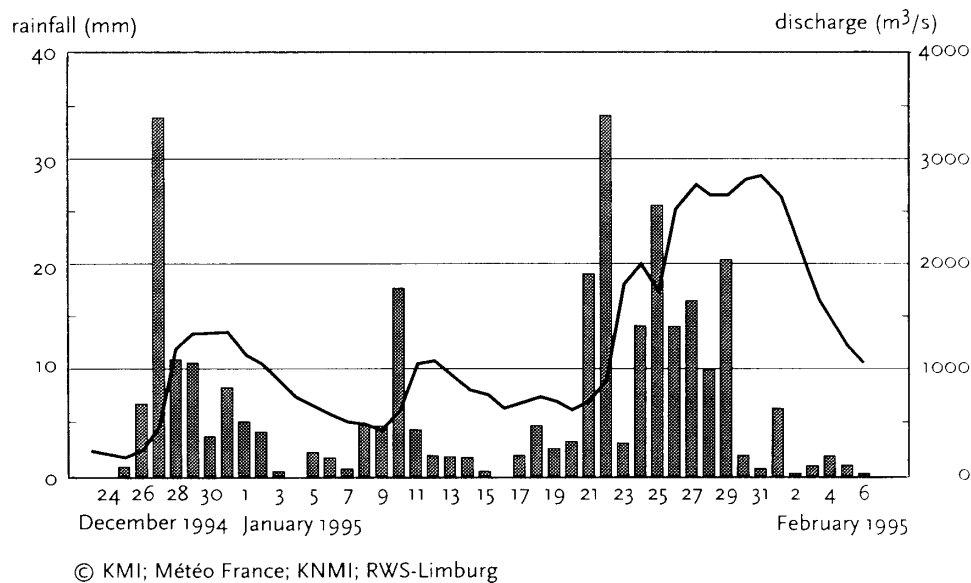


Figure 3: Discharge of the Meuse River at Borgharen (near Maastricht) during the period December 23, 1994 - February 6, 1995 and mean daily precipitation amounts over the entire upstream area. The precipitation amount for a particular day refers to the 24-hour interval running from 0700 GMT of that day to 0700 GMT of the next day.

The river discharge at Borgharen did not reach the 3,000 m³/s threshold as occurred in December 1993. The peak of 2,870 m³/s on January 31, 1995 was the third largest in the period

1911-1995. However, the duration of the high river discharges was longer than that of December 1993. This led to higher water tables downstream of Borgharen than in the year before (Parmet, 1995). The maximum 7-day (127.1 mm) and 10-day (161.3 mm) precipitation amounts over the Belgian Meuse basin exceeded those of December 1993 and are the highest since 1880. The January 1995 rainfall was less exceptional for other durations.

The frontal systems during January 21-30, 1995 were not restricted to the Meuse basin since large parts of the German Rhine basin were also extremely wet in the same period. The relatively high temperatures caused snowmelt in the upper parts of the Rhine basin. The antecedent conditions of the basins were also wet, partially because of snowmelt in the period January 10-20, 1995 (Parmet, 1995; Fink et al., 1996). The discharge at Lobith reached its maximum of 12,000 m³/s on February 1st, 1995. This peak value has only been exceeded once by the January 1926 record value of 12,600 m³/s.

After the flood event, a special law was issued to complete the most urgent dike reconstructions in 1995 and 1996. The Boertien-II Committee also gave priority to the embankments.

4. DESIGN DISCHARGE

The design of river dikes in the Netherlands is based on a theoretical discharge with an average exceedance frequency of once in 1,250 years. This design discharge may be obtained by fitting various probability distributions to the maximum discharges at Borgharen (data are available since 1911) and Lobith (data are available since 1901). The design discharge is taken as the average 1,250-year event from the fitted distributions. A recent re-evaluation by the Boertien-I Committee resulted in a value of 15,000 m³/s for the Rhine River and 3,650 m³/s for the Meuse River (Delft Hydraulics and EAC-RAND, 1993). However, the Committee also felt that the method of extrapolation needed a more physical basis. In particular, it was suggested to develop a hydrological/hydraulic model for the entire Rhine catchment to study the runoff characteristics under extreme conditions. With such a model, it would also be possible to quantify the effects of changes in the catchment and to predict the potential impacts of climate change.

A further idea is to use multisite generated daily rainfall sequences as input to the intended hydrological/hydraulic model. The Royal Netherlands Meteorological Institute (KNMI), at the request of the Institute for Inland Water Management and Waste Water Treatment (RIZA), carried out a study on the feasibility of this idea (Buishand and Brandsma, 1996). The catchment size is much larger than the conventional sizes considered in multisite daily rainfall generation. It is important that the model can reproduce the joint distributional properties of extreme rainfall over periods of 4 to 10 days during the winter half-year. Extreme winter precipitation is usually associated with large intensive frontal systems. Thus there is a strong spatial association in the upper tail of the joint distribution of the daily amounts. Buishand (1984) showed that for daily maxima in the winter half-year in the Netherlands, the degree of association increases with event magnitude for distances greater than 50 km. This feature is not preserved by the spatial patterns generated from a (transformed) multivariate normal distribution. Multisite generation by resampling from the historic records has recently been considered by Hughes et al.(1993) and Zorita et al.(1995). The non-parametric technique assures that the spatial relationships between the various stations are preserved. The reproduction of temporal dependence may, however, cause serious problems.

5. RESEARCH NEEDS

- **MULTISITE DAILY RAINFALL GENERATION.** Routing generated precipitation data through a hydrological/hydraulic model of the catchment may lead to improved estimates of the magnitude of floods of high recurrence intervals. It is, however, necessary that the stochastic rainfall generator can reproduce the features of extreme rainfall events. For the Rhine and the Meuse Rivers in the Netherlands the upper tail of the joint distribution of multi-day amounts for the winter half-year is important. It might also be necessary to generate temperatures to account for snow accumulation and snowmelt.
- **DISTRIBUTION OF n -DAY RAINFALL AMOUNTS.** Accurate and consistent estimates of large quantiles of area-averages are required. It is also desirable to quantify the uncertainties of estimated quantiles and exceedance probabilities. Such information is important to get a first estimate of the exceptionality of catastrophic events. It can also be extremely useful for the validation of stochastic rainfall generators. The estimation of the upper quantiles of n -day amounts is in fact a problem of multivariate extremes because of the dependence between the maxima at different durations (Buishand, 1993). The analysis of multivariate extremes has rapidly been developed in the statistical literature (Coles and Tawn, 1994).
- **LONG-TERM VARIATION of WINTER RAINFALL.** There are indications that for the Rhine and Meuse catchments, the occurrence of extreme winter rainfall is not purely random. Caspary and Bárdossy (1995) observed a strong increase in the annual peak discharges of the Enz River in Germany since the mid- 1970s, which was related to an increase in the number of days with a west-cyclonic circulation during the months December, January, and February. Rapp and Schönwiese (1996) found significant upward trends in winter rainfall over large parts of Germany. The long records for the Belgian Ardennes showed a significant increase in mean winter rainfall around 1910. The nature of long-term variations needs to be investigated further. The possible impacts of natural climate change on the risk of failure should be quantified.
- **CLIMATE CHANGE IMPACT ASSESMENT.** GCM predictions suggest a 10 to 30 % increase in the mean precipitation amounts during December, January, and February around the middle of next century in the Rhine and Meuse catchments. Preliminary studies indicate that such a change would have a strong effect on the design discharges (Delft Hydraulics and EAC-RAND, 1993; Delft Hydraulics, 1994). The scenarios for potential future climate conditions need a better scientific basis. In the past years KNMI has modelled the relation between daily precipitation and temperature using non-linear regression techniques. These two variables are related because the capacity of the atmosphere to hold water vapour increases with temperature (the Clausius-Clapeyron relation). However, the relation between precipitation and temperature is often obscured by other effects such as orographic enhancement and cyclogenesis. Careful selection of explanatory variables is needed to take such effects into account.

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