Rainfall generator for the Meuse basin

Extension of the base period with the years 1999-2008

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Summary

In KNMI publication 196-III a multi-site weather generator for the French and Belgian parts of the Meuse basin was developed. Daily precipitation and temperature are generated by resampling from the observed daily precipitation and temperature for the period 1930-1998 (or 1961-1998) using a nearest-neighbour technique. This weather generator forms part of a new methodology to estimate the design discharge for flood protection works in the Netherlands.

In this report the extension of the base period for resampling up to 2008 is discussed. The homogeneity of the long precipitation series that drive the resampling procedure was tested in the same way as for the old base periods. This resulted in a small number of inhomogeneities near the end of the old base periods.

A new 20 000-year simulation was conducted using the extended base period 1930-2008. The precipitation series driving this simulation were corrected for inhomogeneities. The resulting distributions of the 10-day winter precipitation maxima were compared with those of an earlier 20 000-year simulation, based on the 1930-1998 data (the reference ‘Ref’ simulation in KNMI publication 196-IV). The differences between the extreme-value distributions for both simulations turned out to be small.

The actions necessary to apply the weather generator on a routine basis for the estimation of the design discharge are outlined. Bottlenecks are the provision of climate data from foreign countries, handling of missing data and inhomogeneities, and the determination of area-average precipitation over the subbasins. A point of concern is the maintenance of knowledge on resampling procedures and climate data of the Meuse basin.

1 Introduction and motivation

Next to the river Rhine, the Meuse is the second largest river in the Netherlands. The river originates on the plateau of Langres in northeastern France. After passing through France and the Belgian Ardennes, it enters the Netherlands a few kilometers south of Maastricht. The catchment area upstream of Borgharen (the gauging site near Maastricht) is about 21 000 km^2, whereof about 10 000 km^2 in France and 11 000 km^2 in Belgium. Design discharges for flood protection works along the Dutch part of the river are based on the flow record of this site. For the dikes in the non-tidal part the estimated discharge that is exceeded on average once in 1250 years is used (Middelkoop and van Haselen, 1999). The Flood protection Act that was established in 1996 requires that this design discharge is re-estimated every 5 years. The latest evaluation dates from 2006 (Ministerie van Verkeer en Waterstaat, 2007). It was decided to maintain the value from the 2001 evaluation, which was based on a fit of three distributions (three-parameter lognormal, three-parameter gamma and Gumbel) to the annual maximum flows (Parmet *et al.*, 2001).

The determination of a 1250-year event from a record of about 100 years has been criticized for a long time. The method requires an uncertain extrapolation that does not take the physical properties of the river basin into account. It is therefore not surprising that already in the 1990s an alternative methodology has been proposed to determine the design discharges of the rivers Rhine and Meuse. The first component in this new methodology is a stochastic multi-site weather generator (often indicated as rainfall generator), which generates long (e.g., 10 000 years) synthetic sequences of daily precipitation and temperature over the river basin. The second component consists of a hydrological model (and for the river Rhine also a hydraulic model), which transforms the generated precipitation and temperature sequences into a long synthetic discharge series from which the design discharge is determined. Since recently the combination of these two components is referred to as GRADE: Generator of Rainfall And Discharge Extremes. Apart from a potentially more accurate determination of the design discharge, the GRADE methodology provides information on the shape and duration of floods and facilitates the assessment of the effects of climate change and future upstream interventions such as retention basins. An overview of the work on the GRADE instrument up to 2007 is given by de Wit and Buishand (2007).

A multi-site weather generator for the Meuse basin was developed by Leander and Buishand (2004c). This weather generator was based on the principle of nearest-neighbour resampling, a method which samples daily precipitation and temperature from a historical record with replacement while preserving the temporal and spatial dependence. Two historical periods were considered as base period for resampling: 1961-1998 and 1930-1998 (excluding the year 1940). The simulations based on these historical periods have been indicated as Sim61 and Sim30 respectively. Several sequences of 3000 years were generated. These sequences were used for discharge simulations using a semi-distributed HBV model of the Meuse basin and the resulting maximum flows were analyzed (Aalders *et al.*, 2004; Leander *et al.*, 2005). In order to study the sensitivity of the 1250-year discharge to the choice of the base period several 20 000-year simulations were conducted with various 33-year subsets of the 1930-1998 period as well as a 20 000-year simulation based on the entire 1930-1998 period, serving as the reference simulation (Leander and Buishand, 2008). These 20 000-year sequences were used with different calibrations of the HBV model (Kramer *et al.*, 2008; Kramer and Schroevers, 2008). It was concluded that the largest uncertainties in the GRADE instrument were due to the choice of the base period and the choice of the HBV parameters. For one of the 20 000-year sequences, the shapes and durations of the floods were compared with those of the observed floods (Barneveld and van den Berg, 2010). A reasonable agreement was found.

Because of the promising results obtained so far with the GRADE instrument, it was decided to give it a semi-operational status in the next evaluation of the design discharge of the river Meuse in 2011. This requires a detailed comparison with the traditional method. For this next phase of the GRADE instrument, it is necessary that the base periods for resampling are extended beyond 1998. The augmentation up to 2008 is discussed in this report. A comparison of a new 20 000-year simulation based on the extended base period 1930-2008, referred to as Sim30-08, with the earlier 20 000-year reference simulation Sim30-ref is also considered. With a view towards a future operational use of GRADE, the report concludes with an overview of the actions that are necessary to extend the base period and the potential difficulties in this process.

2 Precipitation data

The weather generator first generates long sequences of daily precipitation at 7 locations and the daily temperature at 2 (Sim30) or 4 (Sim61) locations. The data for these locations must span the entire base period. Daily sequences of area-average precipitation for 15 subbasins of the Meuse basin and daily temperature at 10 locations are generated in a second stage. A nearest-neighbour replacement step was added to the procedure in order to cope with incomplete sequences for the base period (Leander and Buishand, 2004c; Leander *et al.*, 2005). In this section the augmentation of the long-term station records of daily precipitation is addressed first, and then daily area-average precipitation is dealt with.

2.1 Long-term daily precipitation series

Table 2.1 presents an overview of the long-term station series used in the Sim30 and Sim61 simulations. An extensive homogeneity analysis (Leander and Buishand, 2004a) showed that these series were homogeneous over the periods 1930-1998 and 1946-1998, respectively. The location of the stations is shown in Fig. 2.1. For Sim30 all available homogeneous records in or close to the Meuse basin were used. For Sim61 the geographical position and mean annual precipitation of the rain gauge sites were also taken into consideration.

Data from Meix-devant-Virton and Han-sur-Lesse were used to fill gaps in the records of Lacuisine and Rochefort, respectively. Two gaps in the series of Le Chesne in 2007 were supplemented with data from Vouziers. As in Leander and Buishand (2004a), a correction factor (on an annual basis) was used to compensate for the difference between the stations. There were no missing data in the records of the other stations within the period 1999-2008.

The data from Chaumont for the period August 2002 to December 2008 were corrected for the transition from the Reclancourt site (52121002) to Parc DDE (52121007) by multiplying the daily values from Parc DDE by a factor of 1.24 (December-February), 1.12 (March-May), 1.13 (June-August) or 1.10 (September-November). These factors are based on a comparison of the data from both sites for the common years 1999-2001.

For each station in the set, the relative homogeneity of the annual precipitation amounts was tested in the same way as in Leander and Buishand (2004a). The adjective ‘relative’ refers here to the fact that homogeneity is tested with respect to a reference series, in this case consisting of the average of the remaining series in the set. Four statistical tests were applied to the deviations from the reference series: two cumulative sum tests (one based on the standardized range R and one based on the standardized absolute maximum Q), the Standard Normal Homogeneity Test (SNHT, test statistic T_0), and a test on the Von Neumann ratio N. The statistics R, Q and T_0 tend to be large for inhomogeneous data, whereas N should be about 2 in the case of homogeneity and tends to be smaller than 2 for inhomogeneous data. Critical values of R and N were obtained from Wijngaard et al. (2003). For Q and T_0, the critical values were taken from Buishand (1982) and Khaliq and Ouarda (2007), respectively. The tests based on Q and T_0 also provide an estimate of the year in which a systematic change occurs, respectively indicated as K_S and K_T. Further details on the used test-statistics can be found in Leander and Buishand (2004a).

Table 2.2 shows the results of the homogeneity tests for the period 1930-2008 (with the exception of 1940). For Chaumont and Vouziers the statistics R,Q and T_0 are

Figure 2.1: Location of stations in and around the Meuse basin and the definition of the HBV subbasins.

Table 2.1: Long-term daily precipitation series used in the Sim30 and Sim61 simulations.

Country	Station name	Sim30	Sim61
France	St Quentin[1]	●	
	Nancy[2]	●	
	Vouziers	●	
	Chaumont	●	
	Langres		●
	Neufchâteau		●
	Le Chesne		●
Belgium	Uccle	●	●
	Chiny[3]	●	●
	Stavelot		●
	Rochefort		●
Germany	Aachen	●	

[1] Fontaine-les-Clercs (St Quentin airport 02320) from 1999 onwards.

[2] Combination of Nancy (54395) and Tomblaine (Nancy-Essey 54526).

[3] Chiny closed after January 1987. A nearby station, Lacuisine, was used to continue the series.

Table 2.2: Results of the homogeneity tests for the period 1930-2008. The criteria for a significant inhomogeneity at the 1% level are enclosed by parentheses in the heading of each column. Significant test results are shown in bold.

$R(\geq 1.82)$	$Q(\geq 1.54)$	$N(\leq 1.47)$	$T_0(\geq 11.90)$	K_S	K_T	
1.60	1.21	1.63	6.71	1966	1993	Aachen
1.80	**1.75**	1.86	**16.69**	1989	1989	Chaumont
1.65	**1.54**	2.08	11.31	1984	1990	Chiny
1.47	1.06	1.80	4.53	1966	1966	Nancy
1.39	0.71	1.99	3.90	1942	1942	St Quentin
1.00	0.81	1.77	3.28	1959	1941	Uccle
1.83	1.44	2.05	**14.00**	1994	1994	Vouziers

significant, or almost significant, at the 1%-level. The annual precipitation amounts of Vouziers show a significant increase of about 60 mm (relative to the other stations) around 1994. A correction for this inhomogeneity was made by increasing the series before 1994 by 3.1% (December-February), 8.7% (March-May), 13.6% (June-August) or 5.3% (September-November). These corrections were based on the ratio between the seasonal averages of Vouziers and Le Chesne, before and after 1994. For Chaumont, the deviations from the reference series are shown in Fig. 2.2. These deviations exhibit a clear change around 1989 (in agreement with the values of K_S and K_T in Table 2.2). This inhomogeneity can be reduced by replacing the data for the period 1999-2008 by the *uncorrected* data from Parc DDE and correcting the data from Reclancourt for the period 1990-1998 towards Parc DDE by applying the reciprocals of the aforementioned correction factors. The homogeneity tests were repeated after these adjustments (Table 2.3). The test criteria for homogeneity are no longer exceeded.

Table 2.3: Results of the homogeneity tests for the period 1930-2008 with the new Chaumont record and corrected Vouziers record for inhomogeneity. The criteria for a significant inhomogeneity at the 1% level are enclosed by parentheses in the heading of each column. These criteria are not violated.

$R(\geq 1.82)$	$Q(\geq 1.54)$	$N(\leq 1.47)$	$T_0(\geq 11.90)$	K_S	K_T	
1.33	0.76	1.76	3.61	1966	1931	Aachen
0.93	0.74	2.29	2.29	1960	1960	Chaumont[1]
1.38	1.24	2.26	7.16	1984	1984	Chiny
1.47	1.40	1.81	7.89	1966	1966	Nancy
1.65	1.11	1.96	4.93	1970	1970	St Quentin
0.89	0.79	1.92	3.14	1959	1990	Uccle
1.41	0.90	2.33	5.77	1986	1932	Vouziers[1]

[1] Series altered with respect to those in Table 2.2

The 7 long-term precipitation series used in the Sim61 simulations (Table 2.1) were selected from a set of 14 precipitation series that were homogeneous over the period 1946-1998. For this set of series, Table 2.4 displays the results of the homogeneity tests for the period 1961-2008. There is strong evidence that the Stavelot series is not homogeneous. For this station, the annual differences from the reference series are shown in Fig. 2.3. A jump in the mean of more than 100 mm is observed around 1995. For Le Chesne, the Von Neumann ratio points to some inhomogeneity, which is, however, not confirmed by the other test statistics.

2.2 Daily area-average precipitation of subbasins

For rainfall-runoff modeling, the Meuse basin is subdivided into 15 subbasins (the HBV subbasins). These subbasins are listed in Table 2.5 and their locations are given

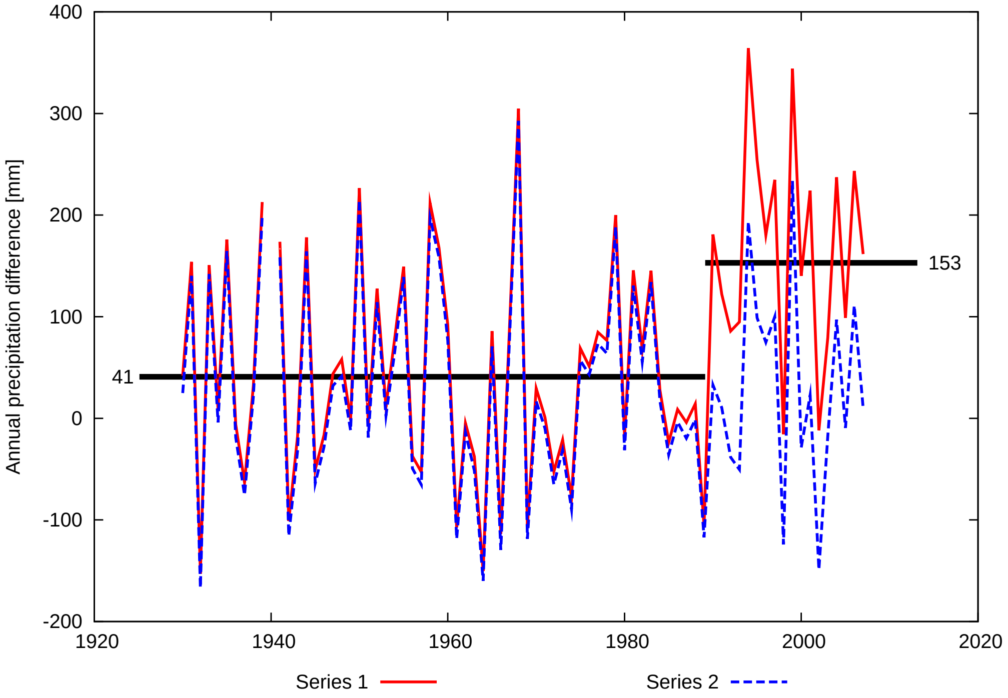


Figure 2.2: Deviation of the annual totals of two composed precipitation series of Chaumont from the references. In Series '1' the record of site 52121002 (Reclancourt) was continued with corrected data of site 52121007 (Parc DDE) from August 2002 onward. The detected jump in 1989 from 41 to 153 mm is indicated. For series '2' uncorrected data from Parc DDE were used from 1999 onward. The data from Reclancourt for the years 1990-1998 were then adjusted towards the data from Parc DDE.

Table 2.4: Results of the homogeneity tests for the period 1961-2008 (with the new Chaumont record and corrected Vouziers record). The criteria for a significant inhomogeneity at the 1% level are enclosed by parentheses in the heading of each column. Significant test results are shown in bold.

$R(\geq 1.77)$	$Q(\geq 1.52)$	$N(\leq 1.35)$	$T_0(\geq 11.12)$	K_S	K_T	
1.10	0.66	2.88	3.13	1978	1962	Reims
1.05	0.56	1.79	2.21	1996	1966	Châteauvillain
1.24	0.67	2.37	2.72	1970	1970	St Quentin
1.56	0.97	1.54	8.57	1966	1966	Nancy
0.90	0.77	2.27	5.86	1986	1962	Vouziers
0.97	0.69	2.17	4.66	1966	1964	Chaumont
1.28	1.28	1.76	9.33	1997	1997	Langres
1.17	1.17	2.17	6.19	1976	1976	Neufchâteau
1.70	1.35	**1.30**	7.28	1984	1984	Le Chesne
1.07	0.71	1.94	4.21	1976	1964	Uccle
1.36	1.36	2.15	7.41	1984	1984	Chiny
1.89	**1.59**	1.56	**13.48**	1996	1996	Stavelot
1.18	0.89	2.00	4.02	1973	1973	Rochefort
1.35	1.02	1.63	8.49	1974	1966	Aachen

Table 2.5: Overview of the subbasins of the river Meuse as defined in HBV. The rightmost column summarizes the origin of the data (interpolated station data or RMIB subbasin data).

	Subbasin	Source of daily area-average precipitation
1	Meuse (St Mihiel)	interpolated station data
2	Meuse (St Mihiel-Stenay)	interpolated station data
3	Chiers	interpolated station data (French part) and Ton (Harnoncourt)
4	Meuse (Stenay-Chooz)	interpolated station data
5	Semois	Semois (Membre)
6	Viroin	Viroin (Vierves)
7	Meuse (Chooz-Namur)	Meuse (Namur, ex. Sambre), excluding Lesse (Gendron), Viroin (Vierves), Semois (Membre) and Ton (Harnoncourt)
8	Lesse	Lesse (Gendron)
9	Sambre	interpolated station data (French part) and Sambre (Namur, Belgian part)
10	Meuse (Namur-Liège)	Meuse (Namur-Huy), Meuse (Huy-Liège), Berwinne (Dalhem) and Hoyoux (Marchin)
11	Mehaigne	Mehaigne (Moha)
12	Ourthe	Ourthe (Hamoir/Tabreux)
13	Amblève	Amblève (Martinrive)
14	Vesdre	Vesdre (Chaudfontaine)
15	Jeker	Jeker (Kanne)

in Fig. 2.1. In the Sim30 and Sim61 simulations historical daily precipitation amounts for each of the HBV subbasins for the period 1961-1998 were used. For the French part of the Meuse basin, these historical values were derived from the daily data of 63 stations (Chiny/Lacuisine and Chimay Forges in Belgium, and 61 stations in France), using inverse squared distance interpolation on a regular 2.5 km × 2.5 km grid (Leander and Buishand, 2004b). Only stations within a radius of 50 km from the grid point of interest were considered in the interpolation procedure. For the Belgian part of the Meuse basin, the area-average precipitation amounts were derived from

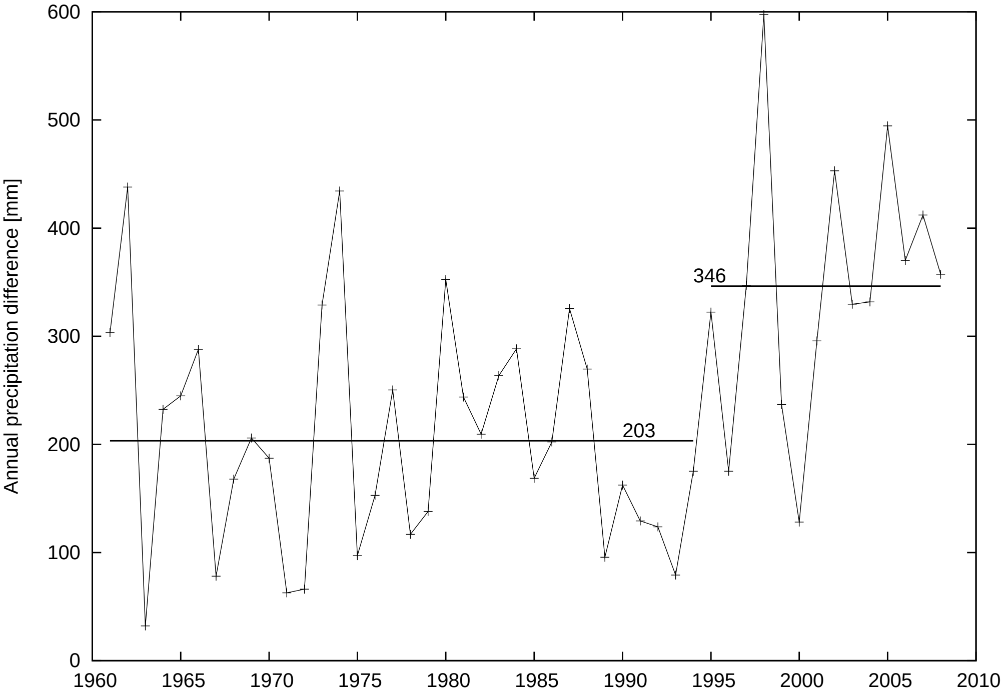


Figure 2.3: Deviation of the annual totals of the precipitation series of Stavelot from the reference.

the daily values for 31 subbasins that were routinely calculated by the Royal Meteorological Institute of Belgium (RMIB). These RMIB subbasins are listed in Appendix A.1. Table 2.5 summarizes the RMIB subbasins associated with the HBV subbasins. For instance, HBV subbasin 10 of the Meuse between Namur and Liège encompasses four RMIB subbasins. A notable subbasin is that of the river Chiers in France (HBV subbasin 3), which has a small tributary, Ton, in Belgium. In earlier applications, the daily average precipitation for the Ton at Harnoncourt was erroneously not considered in the calculation of daily average precipitation of HBV subbasin 3 (Chiers), but included in the daily area-average precipitation of HBV subbasin 7 (Meuse from Chooz to Namur).

The routine calculation of daily average precipitation for the RMIB subbasins was terminated on 31 December 2007. The daily area-average precipitation series for the HBV subbasins were therefore only augmented to 2007. It further turned out that some of the original 61 French stations used for the calculation of area-average precipitation were discontinued between 1999 and 2007. Therefore, the data from 11 additional stations were also used to derive the area-average precipitation amounts for this period. An overview of all stations used for the calculation of area-average precipitation amounts in the French part of the Meuse basin is given in Appendix A.2.

Figure 2.4 presents an overview of terminated and substituted precipitation stations. In particular around subbasins 2 and 3 the number of changes is large. This may lead to inhomogeneities in the estimated area-average precipitation in these areas. The homogeneity of the subbasin precipitation therefore had to be investigated. The precipitation series for subbasin 2 was tested relatively against the average of the stations Bras-sur-Meuse, Damvillers, Loxeville (Erneville-aux-Bois), Varennes-en-Argonne and Vigneulles, of which the complete series were retrieved. For subbasin 3 the stations Bras-sur-Meuse, Damvillers, Charleville-Mézières, Le

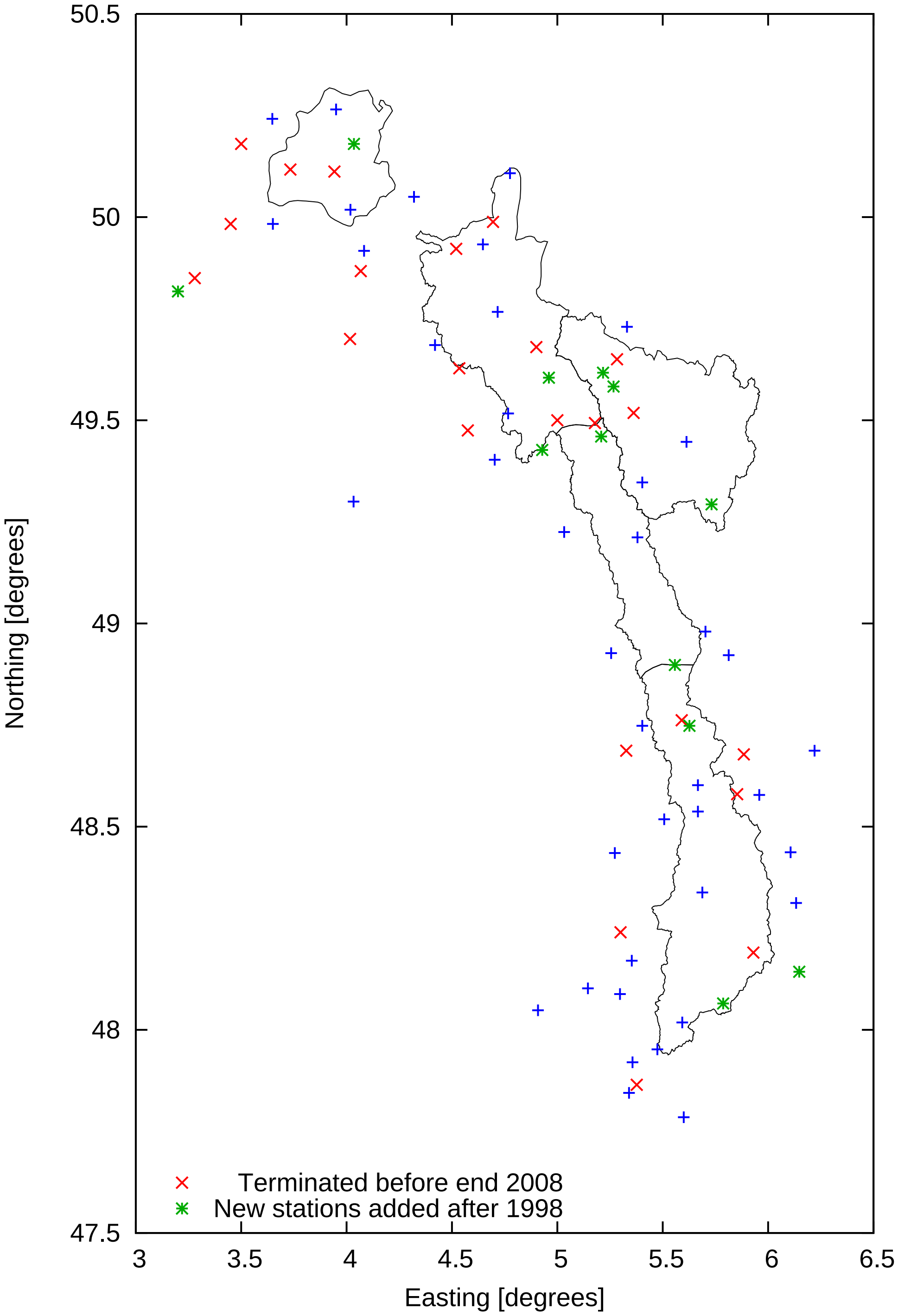


Figure 2.4: Stations used for the interpolation of area-average precipitation for the French subbasins (including the Belgian stations Chiny/Lacuisine and Chimay Forges). Red crosses signify stations, originally used but terminated before the end of 2008. Green stars denote newly selected stations after 1998.

Chesne and Chiny/Lacuisine were used. Table 2.6 shows that, except for a slightly critical Von Neumann ratio found for subbasin 2, no significant inhomogeneity emerges from these tests.

Table 2.6: Results of the homogeneity tests of the estimated areal precipitation of subbasins 2 and 3, each relative to a set of nearby stations.

$R(\geq 1.77)$	$Q(\geq 1.52)$	$N(\leq 1.35)$	$T_0(\geq 11.12)$	K_S	K_T	
1.19	0.69	1.44	2.72	1976	2004	subbasin 2
1.50	1.50	1.75	9.20	1987	1987	subbasin 3

3 Temperature data

Table 3.1 gives an overview of the daily temperature series used in the Sim30 and Sim61 simulations and those used in the new Sim30-08 simulation.

The temperature data from Uccle and Aachen for the period 1930-1998 were selected to drive the Sim30 simulations. For the Sim61 simulations the daily temperatures for the period 1961-1998 from Langres, Reims, Uccle and Aachen were used for that purpose. For these stations the daily average temperature (for Uccle up to 1998) and the daily maximum and minimum temperatures were available. The daily average temperatures for Uccle for the period 1999-2008 were derived from 3-hourly average temperatures (1999-2005) and hourly temperatures (2006-2008). The average of the daily maximum and minimum temperature was used in the case that no daily average value was available.

To obtain the daily temperatures at more locations, a nearest-neighbour replacement step (Leander and Buishand, 2004c, section 5.3) was applied to simulate daily temperature of ten stations, including the four aforementioned stations. Only the data for the period 1967-1998, the longest common period for these ten stations, were used. The simulated station temperatures were subsequently converted to subbasin average temperatures using four station values for each of the 15 subbasins (Aalders *et al.*, 2004). This procedure has also been applied to obtain historical subbasin average temperatures for the 30-year period 1969-1998.

In Leander *et al.* (2005) the station temperatures for the period 1968-1998 were considered in the nearest neighbour replacement step, because the HBV simulations were done with observed data for that period. The historical subbasin averages for the period 1969-1998 were taken in climate-change applications (Leander and Buishand, 2007; Leander *et al.*, 2008) and these data were also used by Beersma (2011). In the calibration of the HBV model (van Deursen, 2004) also the French station Loxeville was used (whereas the daily temperature series from Uccle was not considered). However, this station was erroneously left out in the earlier Sim30 and Sim61 simulations.

Since the new Sim30-08 simulation is a successor of Sim30, the temperatures from Uccle and Aachen for the period 1930-2008 were used to drive the resampling algorithm. The ten series of daily temperature used in Sim30 and Sim68 were extended up to 2008 and the French station Loxeville was added to the set. The daily average temperatures for this station in the period 1968-1974 were derived from the daily maximum and minimum temperatures. For the Belgian stations Ernage, Dourbes, Chimay Forges, Lacuisine and St Hubert, the daily temperatures were derived from 3-hourly averages up to November 1999 (Ernage), 2001 (Dourbes) or 2005 (Chimay Forges, Lacuisine and St Hubert). For Chimay Forges and Lacuisine only the daily maximum and minimum temperatures were available after 2005, while hourly temperatures were available for Ernage (from March 2002), Dourbes (from 2002) and St Hubert (from 2006).

In contrast to the Sim30 and Sim61 simulations, estimated subbasin average temperatures rather than station temperatures were used in the nearest-neighbour replacement step of the new Sim30-08 simulation. Prior to this simulation, sequences of area-average temperature for the 15 subbasins for the period 1967-2008 were derived from the augmented station temperature data. The same

Table 3.1: Used daily temperature series in the Sim30, Sim61 and new Sim30-08 simulations. The columns labled "A" lists the periods for which the respective temperature series is used to drive the simulation, whereas "B" refers to the use of data in a second nearest-neighbour replacement step.

Country	Station name	Sim30		Sim61		Sim30-08	
		A	B	A	B	A	B
France	Loxeville						67-08
	Langres		67-98	61-98	67-98		67-08
	Reims		67-98	61-98	67-98		67-08
Belgium	Uccle	30-98	67-98	61-98	67-98	30-08	67-08
	Dourbes		67-98		67-98		67-08
	Ernage		67-98		67-98		67-08
	Chimay Forges[1]		67-98		67-98		67-08
	Lacuisine		67-98		67-98		67-08
	St Hubert		67-98		67-98		67-08
Netherlands	Beek (M'tricht)		67-98		67-98		67-08
Germany	Aachen	30-98	67-98	61-98	67-98	30-08	67-08

[1] The daily maximum and minimum temperatures for the period 1967-1998 were both available under the name Chimay and under the name Forges, and were erroneously considered as two separate series in the earlier Sim30 and Sim60 simulations.

procedure was followed as for subbasin precipitation, except that the maximum distance of the considered stations was enlarged to 75 km.

4 Simulations

The long daily precipitation records listed in Table 2.3 and the temperature records of the stations Uccle and Aachen were used to drive the new Sim30-08 simulation. Nearest-neighbour replacement steps (Leander and Buishand, 2004c; Leander *et al.*, 2005) were applied to deal with the incompleteness of the area-average precipitation and temperature for the river basins. The simulated daily precipitation series of Uccle, the Ourthe basin upstream of Hamoir/Tabreux and the entire Meuse basin upstream of Borgharen are compared to those from the Sim30-ref simulation.

Fig. 4.1 compares the Gumbel plots of the simulated 10-day winter maxima for the station Uccle with those observed for the base periods 1930-1998 and 1930-2008. It can be seen that the distribution of the simulated maxima hardly changes due to the extension of the base period. The same can be said about the historical maxima. The highest extremes for the extended base period slightly shift to longer return periods, because there were no exceptional 10-day events in the Uccle record within the period 1999-2008.

The Gumbel plots of the simulated 10-day winter maxima for the Ourthe basin and the entire Meuse basin are displayed in Fig. 4.2. Here also little change is seen with respect to the different base periods, though especially for the Meuse basin the upper tail of the distribution is somewhat shorter for the extended base period.

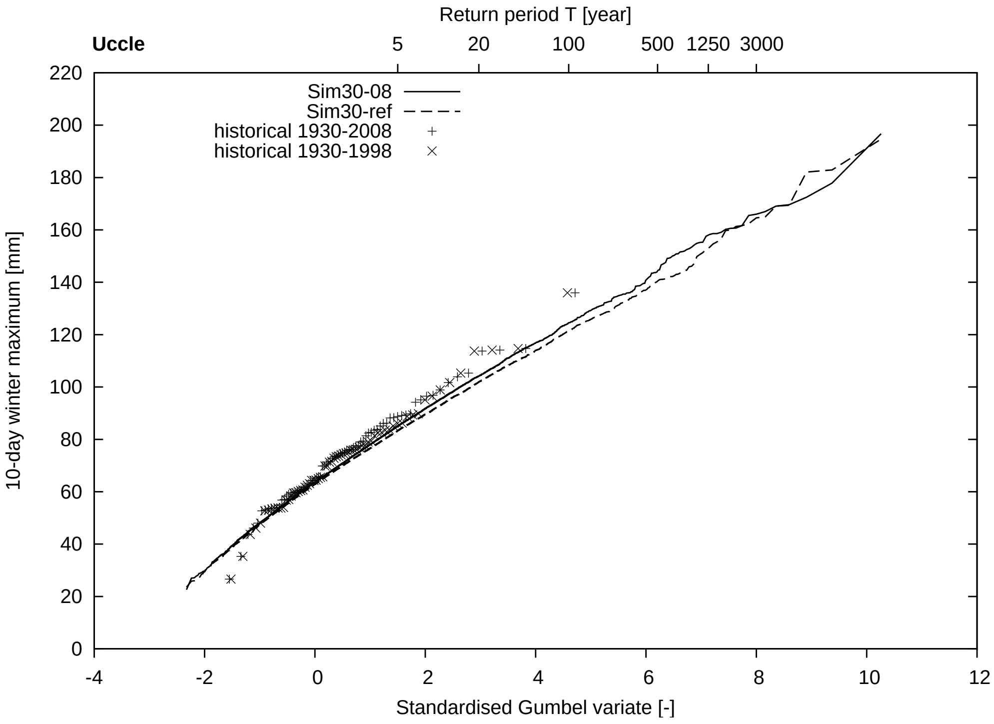
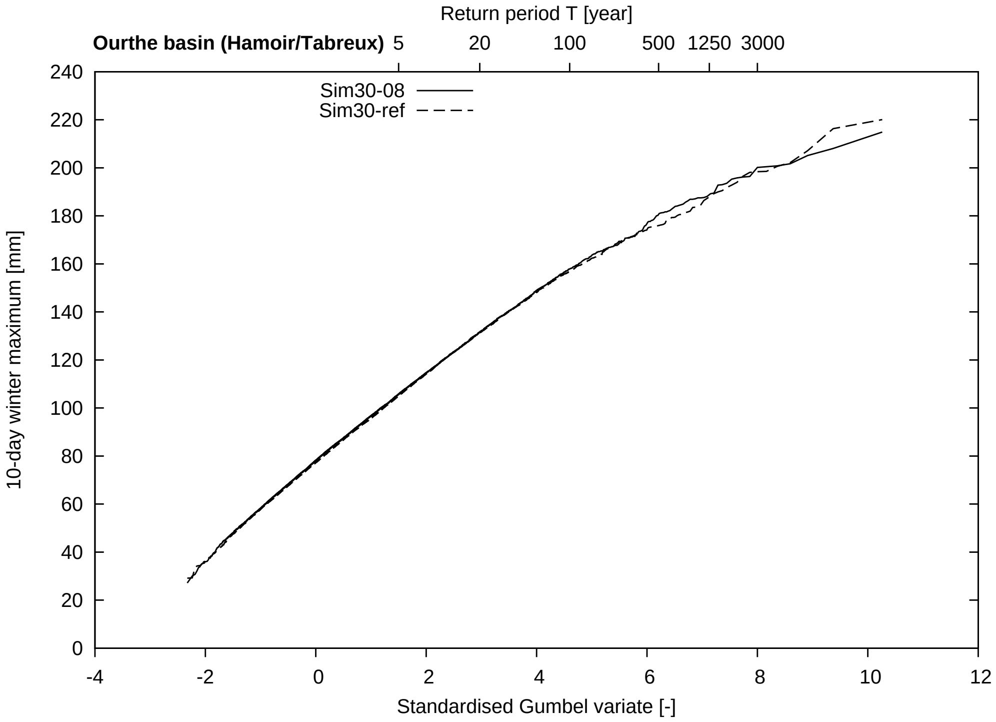


Figure 4.1: Simulated winter maxima of 10-day precipitation based on the period 1930-1998 (Sim30-ref, dashed) versus those based on the period 1930-2008 (Sim30-08, solid) for the Belgian station Uccle. The maxima of the historical data are also shown (crosses for the period 1930-1998 and plusses for the period 1930-2008).



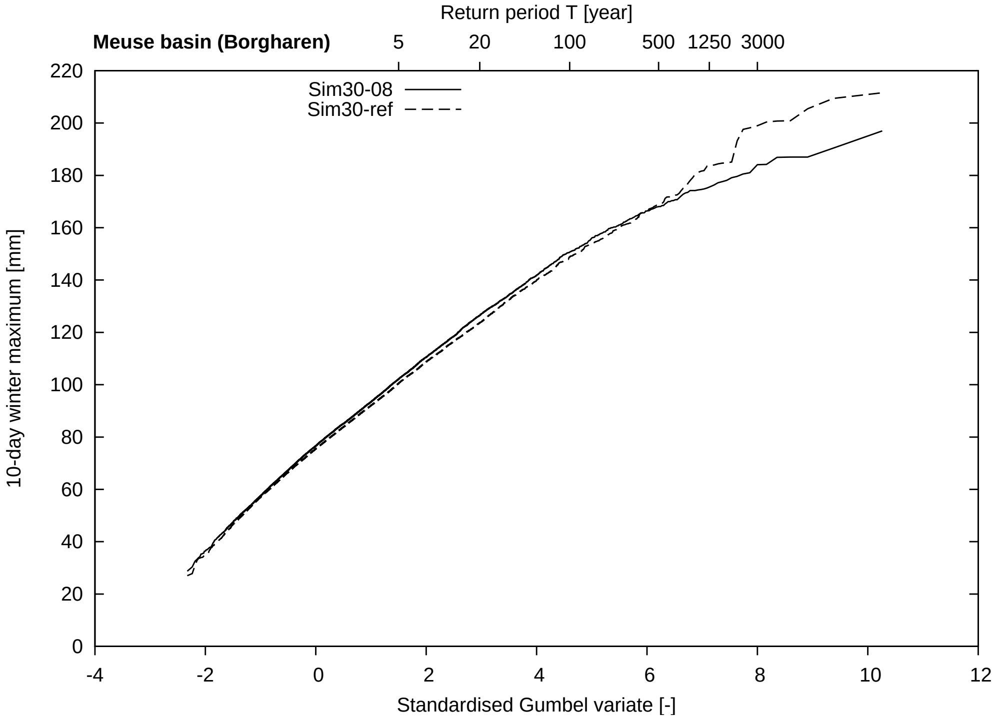


Figure 4.2: Simulated winter maxima of 10-day precipitation based on the period 1930-1998 (Sim30-ref, dashed) versus those based on the period 1930-2008 (Sim30-08, solid) for the Ourthe basin (top) and for the entire Meuse basin (bottom).

5 Outline of the augmentation process of GRADE

For GRADE to become a key component in the periodic re-evaluation of the design discharge of the Meuse, it is essential to identify all steps involved in the augmentation of the meteorological data. Furthermore, it is desirable that these steps require as less manual labour as possible and that arbitrary choices that could influence the outcomes are either reduced to a minimum or based on a prescribed procedure. The process of updating (precipitation and temperature) simulations in GRADE with new meteorological data can be outlined as follows.

1. **Acquisition of historical meteorological data**
   The process of acquiring data from the Belgian and French meteorological services (RMIB and Météo France) turned out to be tedious and awkward. This is related to the data policy of those services. Agreements about data transfer on a regular basis (e.g. yearly) are desirable. In the case of closed stations, alternatives need to be sought. This requires expert judgement and cannot be automated. Within GRADE the data (all daily precipitation and temperature series) are used in different ways:
   - Daily precipitation and temperature series driving the resampling
   - Daily precipitation and temperature series resampled in a second stage
     - Area-average precipitation of the French subbasins. The precipitation station data used for estimating these area averages need not be completed, as long as the set of stations is dense enough.
     - Area-average precipitation of Belgian subbasins. These series are complete, except that calculation of these series ceases after 2007.
     - Area-average temperature of all subbasins. These are estimated from station data similarly to the area-average precipitation of the French subbasins.

2. **Analysis and preparation of historical data**
   - Inspecting the completeness
     The driving data should be inspected for gaps. In the case of gaps there are three options:
     - Leave out the series of a station. Coverage of the basin by the remaining stations needs to be reconsidered.
     - Complete the series with data from nearby stations (back to step **1** if needed). This has been the standard procedure hitherto.
     - Remove data from remaining series, so that within each series the data are available for exactly the same historical days.

     Dealing with gaps in series requires expert judgement and cannot be automated.
   - Testing and adjusting for inhomogeneities
     The driving precipitation data should, after completion, be tested for inhomogeneities. In particular when measurements are resumed at a different location or when series have been completed, there is a reason to suspect a abrupt change in a series. Series with substantial inhomogeneities can either be
     - omitted. In this case a substitute series might be sought (back to step **1**). This, however, may take considerable effort and time, if at all possible.
     - corrected. Correction can be done either backward in time, i.e. the data before the change are adjusted, or forward in time, i.e. the data after the change are adjusted. A disadvantage of the latter is that every subsequent update has to be adjusted as well.

  Dealing with inhomogeneities in series requires expert judgement and cannot be automated.
- Estimation and composition of historical subbasin data
  - Estimation of area-average precipitation for the 5 French subbasins from station data using inverse squared distance interpolation.
  - Composition of area-average precipitation for the Belgian (HBV) subbasins. RMIB uses a more detailed definition of subbasins, which fit into the HBV subbasins. A major point of concern here, is that the automatical interpolation of subbasin precipitation by RMIB has stopped after 2007. In the future it might become necessary to perform this interpolation elsewhere. This would require the acquisition of a large amount of daily station data from RMIB, which may be tedious.
  - Interpolation of subbasin temperature from station data.

3. **Running the resampling simulation**
   No obstacles encountered or anticipated. The software should be robust or easily adaptable to an extension of the historical data. Long sequences may also be generated based on different subsets of the historical series to account for the uncertainty due to the finite base period, as was done in Leander and Buishand (2008). The necessity to repeat the uncertainty analysis with every update of the historical data should, however, be questioned.
4. **Post-processing the resampled series**
   - Potential evapotranspiration (PET) is derived from its climatology, the resampled temperature series and the temperature climatology.
   - The resampled precipitation and temperature and the derived PET need to be reformatted for use in HBV.

Dealing with gaps and inhomogeneities in time series of meteorological data and the estimation of area-average precipitation turn the augmentation procedure into a rather labour-intensive task. It may further take considerable time to obtain the precipitation and temperature data from Belgium and France (it took more than six months for the 1999-2008 data). The augmentation procedure requires insight into the available data in these countries. Knowledge of resampling procedures should also be maintained. To ensure continuity, a strong involvement of permanent staff is necessary.

A database of gridded daily precipitation and temperature for the entire Meuse basin, using all available station data, with a regular update would be of great benefit for GRADE. Recently the Deutsche Wetterdienst has started the construction of such a gridded dataset for the Rhine basin and other large German river basins for the period 1951-2006 (HYRAS-project). This dataset is, however, not regularly updated and its use is restricted. The construction of a similar dataset for the Meuse basin is highly desirable.

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References

Aalders, P., P. M. M. Warmerdam and P. J. J. F. Torfs, 2004. Rainfall Generator for the Meuse Basin: 3000 year discharge simulations in the Meuse basin. Report No. 124, Sub-department Water Resources, Wageningen University, Wageningen.

Barneveld, H. J. and T. van den Berg, 2010. GRADE 2009 Effect herijking HBV op de golfvorm van de Maas te Borgharen. PR134720, HKV lijn in water, Lelystad.

Beersma, J. J., 2011. Rainfall Generator for the Rhine Basin: Sensitivity to the composition of the feature vector and passive simulations. KNMI-publication 186-VI, Royal Netherlands Meteorological Institute (KNMI), De Bilt.

Buishand, T. A. (1982). Some methods for testing the homogeneity of rainfall records. *Journal of Hydrology*, 58:11–27.

van Deursen, W., 2004. Afregelen HBV model Maasstroomgebied. Rapportage aan RIZA, *Carthago Consultancy*, Rotterdam.

Khaliq, M. N. and Ouarda, T. B. M. J., 2007. On the critical values of the standard normal homogeneity test (SNHT). *International Journal of Climatology*, 27:681–687.

Kramer, N., J. Beckers and A. Weerts, 2008. Generator of rainfall and discharge extremes (GRADE) - part D & E. Deltares report Q4424, Deltares, Delft.

Kramer, N. and R. Schroevers, 2008. Generator of rainfall and discharge extremes (GRADE) - part F. Deltares report Q4424, Deltares, Delft.

Leander, R. and T. A. Buishand, 2004a. Rainfall Generator for the Meuse Basin: Inventory and homogeneity analysis of long daily precipitation records KNMI-publication 196-II, KNMI, De Bilt.

Leander, R. and T. A. Buishand, 2004b. Estimation of areal precipitation from station records Memorandum KA-04-11, KNMI, De Bilt.

Leander, R. and T. A. Buishand, 2004c. Rainfall Generator for the Meuse Basin: Development of a multi-site extension for the entire drainage area. KNMI-publication 196-III, KNMI, De Bilt.

Leander, R., T. A. Buishand, P. Aalders and M.J.M. de Wit, 2005. Estimation of extreme floods of the river Meuse using a stochastic weather generator and a rainfall-runoff model. *Hydrological Sciences Journal* 50(6), 1089–1103.

Leander, R. and T. A. Buishand, 2007. Resampling of regional climate model output for the simulation of extreme river flows. *Journal of Hydrology* 332, 487–496.

Leander, R. and T. A. Buishand, 2008. Rainfall Generator for the Meuse Basin: Description of 20 000-year simulations. KNMI-publication 196-IV, Royal Netherlands Meteorological Institute (KNMI), De Bilt.

Leander, R., T. A. Buishand, B. J. J. M. van den Hurk and M. J. M. de Wit, 2008. Estimated changes in flood quantiles of the river Meuse from resampling of regional climate model output. *Journal of Hydrology* 351, 331–343.

Middelkoop, H. and C. O. G. van Haselen, 1999. Twice a river. Rhine and Meuse in theNetherlands. RIZA report no. 99003, RIZA, Arnhem.

Ministerie van Verkeer en Waterstaat, 2007. Hydraulische randvoorwaarden primaire waterkeringen voor de derde toetsronde 2006-2011 (HR 2006). Den Haag.

Parmet, B.W.A.H., W. van de Langemheen, E.H. Chbab, J.C.J. Kwadijk, N.N. Lorenz, and D. Klopstra, 2001. Analyse van de maatgevende afvoer van de Maas te Borgharen. RIZA Report 2002.013, RIZA, Arnhem.

Wijngaard, J. B., Klein Tank, A. M. G., and Können, G. P., 2003. Homogeneity of 20th century European daily temperature and precipitation series. *International Journal of Climatology*, 23:679–692.

de Wit, M.J.M. and T.A. Buishand, 2007. Generator of Rainfall And Discharge Extremes (GRADE) for the Rhine and Meuse basins. Rijkswaterstaat RIZA report 2007.027/KNMI publication 218, Lelystad, The Netherlands.

A Details of French and Belgian precipitation data

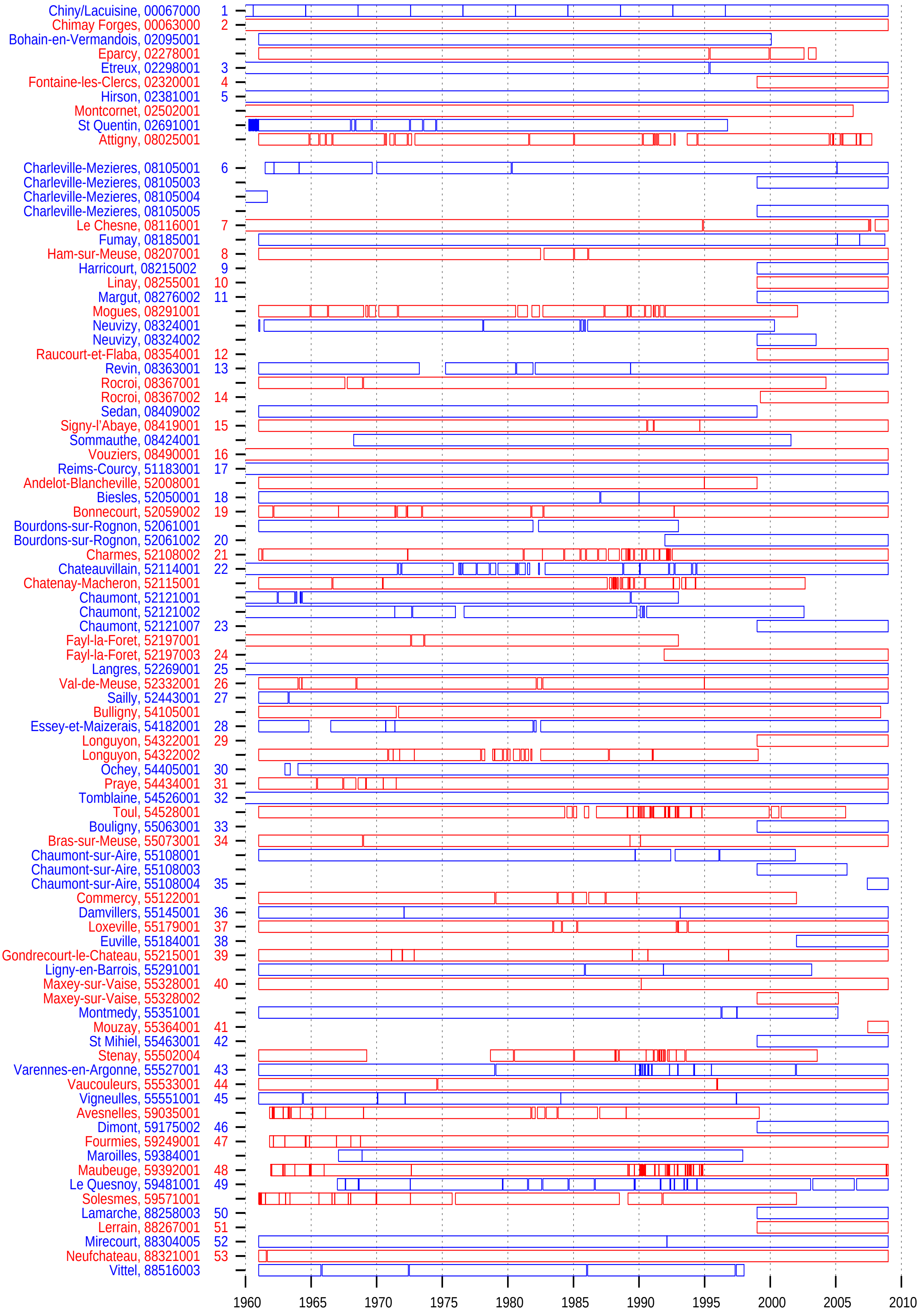
A.1 Belgian data

Belgian subbasins of the Meuse for which daily average precipitation was provided by RMIB for the period 1951-2007.

	Subbasin	Downstream point	Number	Area (km^2)
1	Meuse (ex. Ourthe)	Liège	5300	7941
2	Meuse	Visé (Wezet)	5310	11704
3	Meuse (Huy-Liège)	Liège	5320	271
4	Jeker	Kanne	5400	430
5	Berwinne	Dalhem	5520	118
6	Vesdre (Wese)	Chaudfontaine	5630	677
7	Hoegne	Theux	5710	190
8	Amblève	Martinrive	5920	1044
9	Ourthe	Angleur	6200	3626
10	Ourthe	Hamoir/Tabreux	6230	1597
11	Ourthe	Houffalize	6580	327
12	Mehaigne	Moha	6610	345
13	Hoyoux	Marchin	6710	246
14	Meuse (Namur-Huy)	Huy	6810	302
15	Meuse & Sambre	Namur	6880	6777
16	Meuse (ex. Sambre)	Namur	6890	5093
17	Sambre	Namur	6900	1621
18	Orneau	Jemeppe	7020	203
19	Eau d’Heure	Walcourt	7260	187
20	Bocq	Yvoir	7400	240
21	Molignée	Warnant	7530	127
22	Lesse	Gendron	7630	1314
23	Lesse	Eprave	7700	419
24	Lomme	Eprave	7810	474
25	Lesse	Daverdisse	8070	301
26	Hermeton	Hastière	8200	161
27	Houille	Felenne	8400	114
28	Viroin	Vierves	8520	529
29	Semois	Membre	8810	1235
30	Semois	Lacuisine	9100	748
31	Ton	Harnoncourt	9200	291

A.2 French data

Overview of the daily precipitation records available for the estimation of the area-average precipitation for the French subbasins (next page). The two-digit numbers, which are shown for the stations still operational, correspond to those in Fig. A.1 on the subsequent page.


Chiny/Lacuisine, 00067000 1
Chimay Forges, 00063000 2
Bohain-en-Vermandois, 02095001
Eparcy, 02278001
Etreux, 02298001 3
Fontaine-les-Clercs, 02320001 4
Hirson, 02381001 5
Montcornet, 02502001
St Quentin, 02691001
Attigny, 08025001
Charleville-Mezieres, 08105001 6
Charleville-Mezieres, 08105003
Charleville-Mezieres, 08105004
Charleville-Mezieres, 08105005
Le Chesne, 08116001 7
Fumay, 08185001
Ham-sur-Meuse, 08207001 8
Harricourt, 08215002 9
Linay, 08255001 10
Margut, 08276002 11
Mogues, 08291001
Neuvizy, 08324001
Neuvizy, 08324002
Raucourt-et-Flaba, 08354001 12
Revin, 08363001 13
Rocroi, 08367001
Rocroi, 08367002 14
Sedan, 08409002
Signy-l'Abaye, 08419001 15
Sommauthe, 08424001
Vouziers, 08490001 16
Reims-Courcy, 51183001 17
Andelot-Blancheville, 52008001
Biesles, 52050001 18
Bonnecourt, 52059002 19
Bourdons-sur-Rognon, 52061001
Bourdons-sur-Rognon, 52061002 20
Charmes, 52108002 21
Chateauvillain, 52114001 22
Chatenay-Macheron, 52115001
Chaumont, 52121001
Chaumont, 52121002
Chaumont, 52121007 23
Fayl-la-Foret, 52197001
Fayl-la-Foret, 52197003 24
Langres, 52269001 25
Val-de-Meuse, 52332001 26
Sailly, 52443001 27
Bulligny, 54105001
Essey-et-Maizerais, 54182001 28
Longuyon, 54322001 29
Longuyon, 54322002
Ochey, 54405001 30
Praye, 54434001 31
Tomblaine, 54526001 32
Toul, 54528001
Bouligny, 55063001 33
Bras-sur-Meuse, 55073001 34
Chaumont-sur-Aire, 55108001
Chaumont-sur-Aire, 55108003
Chaumont-sur-Aire, 55108004 35
Commercy, 55122001
Damvillers, 55145001 36
Loxeville, 55179001 37
Euville, 55184001 38
Gondrecourt-le-Chateau, 55215001 39
Ligny-en-Barrois, 55291001
Maxey-sur-Vaise, 55328001 40
Maxey-sur-Vaise, 55328002
Montmedy, 55351001
Mouzay, 55364001 41
St Mihiel, 55463001 42
Stenay, 55502004
Varennes-en-Argonne, 55527001 43
Vaucouleurs, 55533001 44
Vigneulles, 55551001 45
Avesnelles, 59035001
Dimont, 59175002 46
Fourmies, 59249001 47
Maroilles, 59384001
Maubeuge, 59392001 48
Le Quesnoy, 59481001 49
Solesmes, 59571001
Lamarche, 88258003 50
Lerrain, 88267001 51
Mirecourt, 88304005 52
Neufchateau, 88321001 53
Vittel, 88516003
1960
1965
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2010

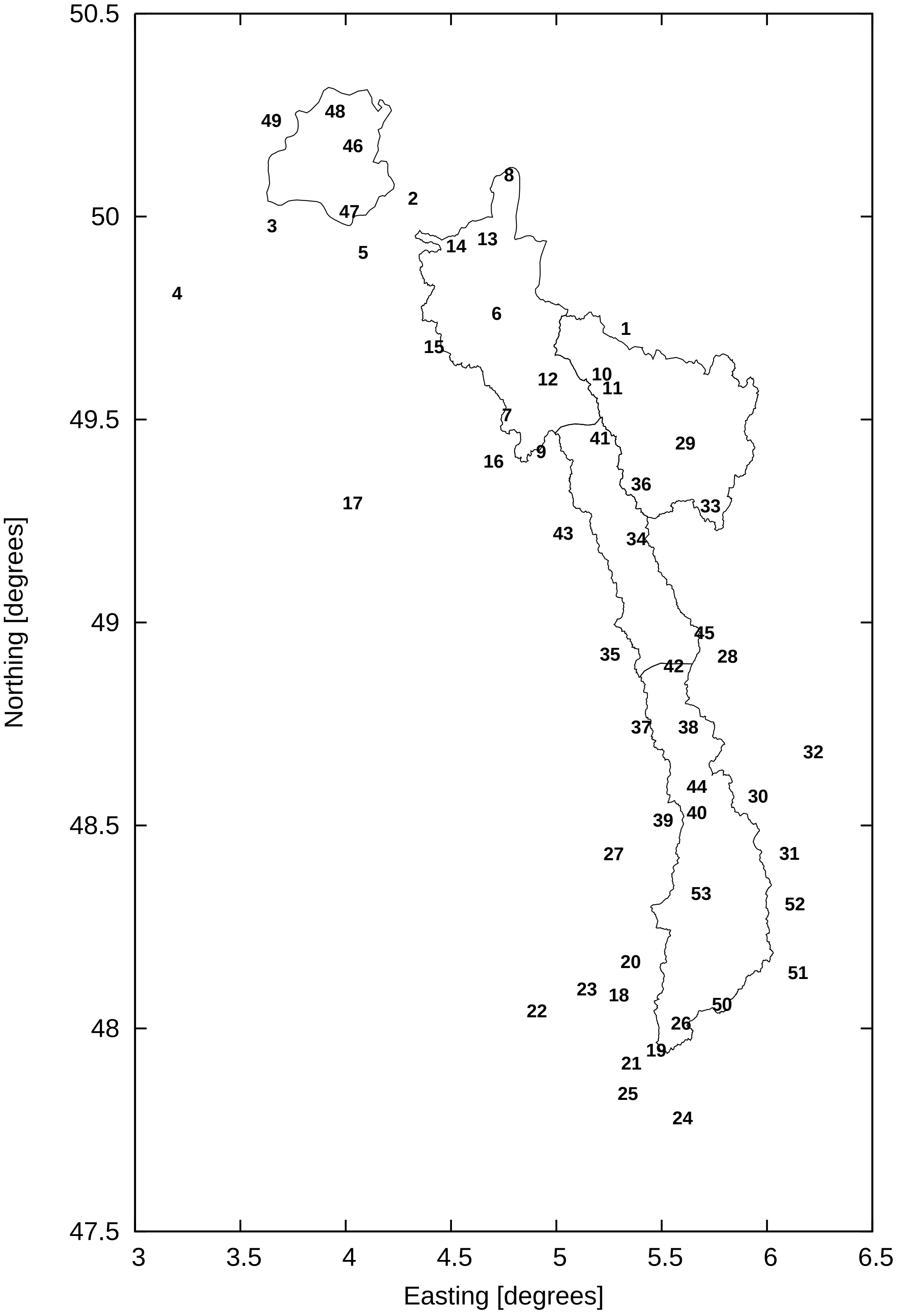

Figure A.1: Location of of the rainfall stations in Fig. 2.4 still operational by the end of 2008. The names and station numbers corresponding to the numbers on this map can be found in the overview on the previous page.

For the period 1999-2008 the data from all measurement sites in a municipality were made available. Only one of these sites was used for the estimation of area-average precipitation for a particular day. These sites are listed below.

Station	Number	Period
Chareleville-Mézières	08105001	whole period 1997-2008
Neuvizy	08324001	to 30 April 2000
	08324002	from 1 May 2000 to 30 June 2003
Rocroi	08367001	to 31 March 2004
	08367002	from 1 April 2004
Chaumont	52121002	to 31 July 2002
	52121007	from 1 August 2002
Longuyon	54322001	whole period 1997-2008
Chaumont-sur-Aire	55108001	to 30 November 2001
	55108003	from 1 December 2001 to 9 November 2005
	55108004	from 28 May 2007
Maxey-sur-Vaise	55328001	whole period 1997-2008

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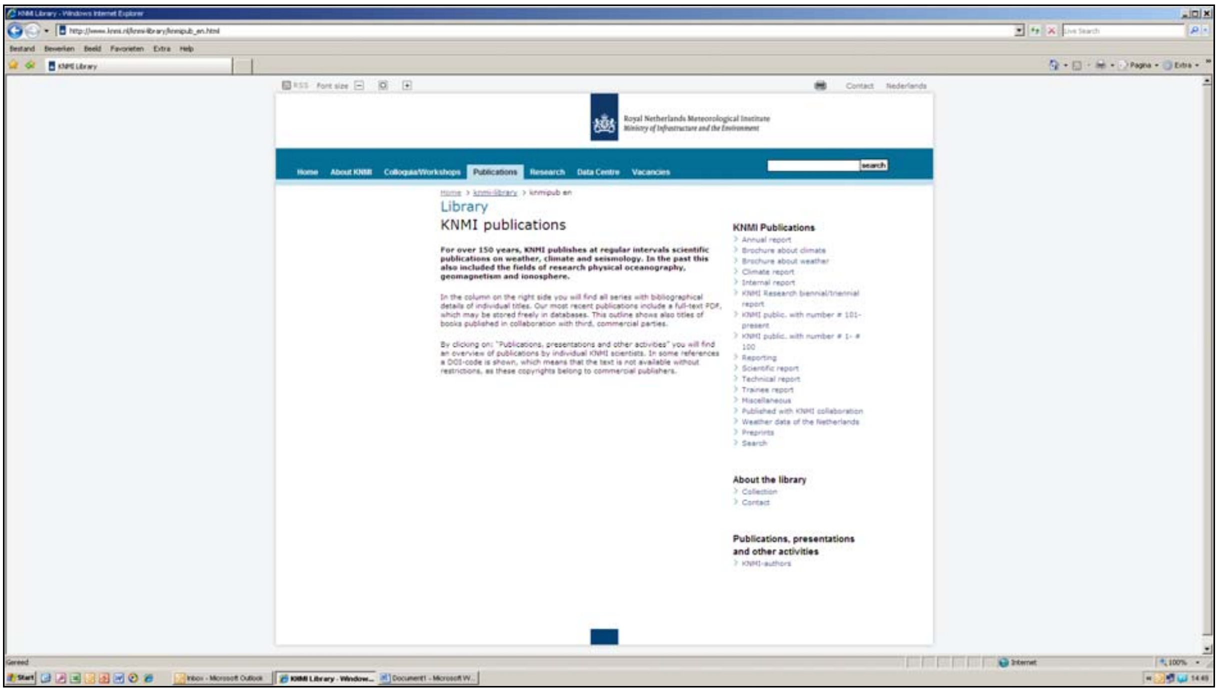

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