Rainfall Generator for the Meuse Basin

3,000 year discharge simulations in the Meuse basin

P. Aalders, P.M.M. Warmerdam and P.J.J.F. Torfs

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Sub-department Water Resources
Nieuwe Kanaal 11
6709 PA Wageningen
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Wójcik, R. & T.A. Buishand, 2001. Rainfall Generator for the Meuse Basin: Simulation of 6-hourly rainfall and temperature for the Ourthe catchment.
KNMI-publication; 196-I.

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

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

Aalders, P. & M. de Wit, 2004. Rainfall Generator for the Meuse Basin: Case study Ourthe basin.
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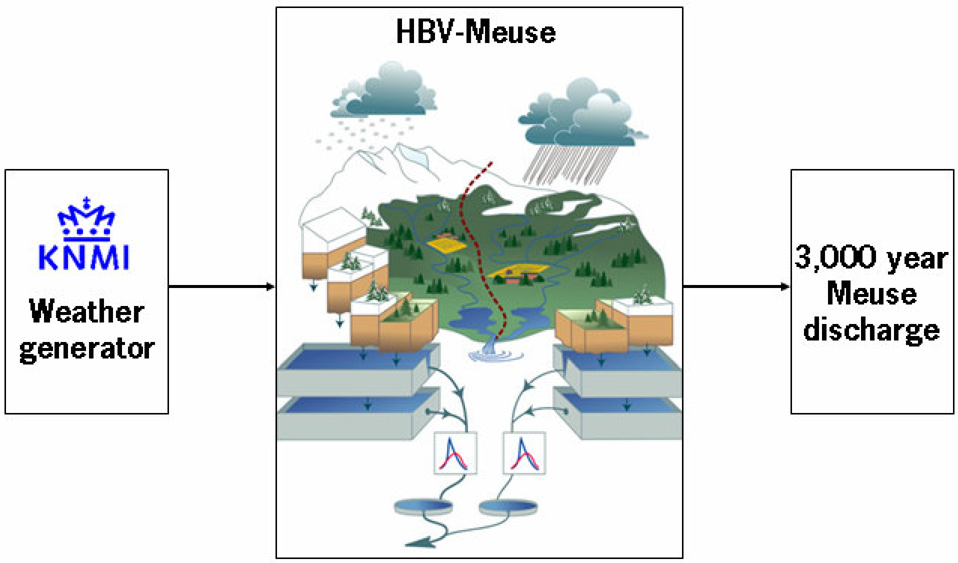
HBV-Meuse
KNMI
Weather generator
3,000 year Meuse discharge

Contents

Summary

A new methodology has been proposed to provide a better physical basis for the estimation of design discharges of the Dutch rivers. This new methodology is known as *rainfall generator*. The hydrological part of the rainfall generator, a rainfall-runoff simulation in the Meuse basin, is described in this report. Therefore, ten generated records containing 3,000 year of precipitation and temperature data have been used as input for the HBV-Meuse model. The main part of the actual work consists of the construction of a program which automatically executes the calculation sequence.
The general results of the 3,000 year simulations (average, standard deviation, temporal distribution) are satisfactorily. However, the simulations seem to underestimate annual maxima in the middle and highest range. Additionally, Gumbel and GEV distributions of extreme discharge events show unpredictable behavior in the highest range if compared to each other. This behavior is due to random effects during generation of the precipitation and temperature records. Furthermore, the results show that the use of a 'large window' during the generation of these records seems to have no significant improvement on the simulation of extreme discharge events. Additionally, the simulations prove that an extreme peak on the Meuse follows from a long period of moderate wet days instead of one or two extreme wet days.

Samenvatting

Om een betere fysische basis te verschaffen voor het schatten van maatgevende afvoeren in de Nederlandse rivieren, wordt een nieuwe methode ontwikkeld. Deze nieuwe methode staat bekend als *neerslaggenerator*. Het hydrologische deel van de neerslaggenerator, een neerslag-afvoer simulatie van de Maas, wordt in dit rapport beschreven. Tien gegenereerde reeksen van 3000 jaar aan neerslag en temperatuur gegevens zijn gebruikt als invoer voor het HBV-Maas model. Het grootste deel van het daadwerkelijke werk heeft bestaan uit de constructie van een computerprogramma dat de volledige berekening automatisch uitvoert.
De algemene resultaten van de 3000 jaar simulaties (gemiddelde, standaard deviatie, spreiding) zijn bevredigend. Daartegenover staat dat de simulaties de jaarlijkse maxima in het midden en hoogste bereik lijken te onderschatten. Tevens vertonen de verschillende simulaties onvoorspelbaar gedrag in het hoogste bereik van de Gumbel en GEV verdelingen wanneer deze onderling worden vergeleken. Dit gedrag komt voort uit 'random effecten' tijdens het genereren van de neerslag en temperatuur gegevens. Daarnaast volgt uit de resultaten dat het gebruik van een 'groter window' tijdens het genereren van deze gegevens geen zichtbare verbetering oplevert. Verder valt op dat een extreme afvoergolf op de Maas volgt uit een lange periode van gemiddeld natte dagen in plaats van als gevolg van één of twee extreem natte dagen.

1. Introduction

The most important rivers in the Netherlands are the Rhine and the Meuse. Flood protection along these rivers is based on design water levels with a given probability of exceeding. The estimation of the design discharges is currently based on the extrapolation of the measured discharges at Borgharen (Meuse) and Lobith (Rhine). However, the determination of design discharges from statistical analyses of the measured peak discharges faces various problems. First, it is unknown how representative the relatively short measured discharge records are. Secondly, the discharge record is potentially non-homogeneous because of changes in the upstream basin, the river geometry and climate. Third, the choice of frequency distributions is also a point of uncertainty. Therefore, RIZA and KNMI are working together on a new methodology to provide a better physical basis for the estimation of the design discharge of the Dutch rivers. This methodology is based on a stochastic weather generator which generates long-term rainfall and temperature records. These records are being used as input data for the discharge simulation with the hydrological model HBV. Altogether this new methodology is known as rainfall generator.
During a preceding study the rainfall generator has been tested in a Meuse tributary: the Ourthe (*Aalders & De Wit, 2004*). The aim of this study is to retain more and new insights according to extreme discharge events and the estimation of design discharges for the Meuse catchment upstream of Borgharen. This report describes the results of several simulations with 3,000 year records of daily discharge followed by an analysis of the statistical properties of these records. The main part of the actual work consists of the construction of an automatic procedure for the necessary computation sequence. A detailed description and a manual for this automatic procedure can be found in annex 1. Because the aim of the research is about the estimation of design discharges, this report contains several Gumbel plots of measured and simulated annual discharge maxima. These plots do not describe actual design discharges. During the estimation of a design discharge some more aspects have to be taken into account, see Parmet et. al. (*2001*).
Chapter 2 gives a short description of the HBV-Meuse model and some results of the calibration by Van Deursen (*2004*). Chapter 3 contains a summarized description about the KNMI rainfall generator and the linking procedure with the HBV-Meuse model. Chapters 4 and 5 contain the results of the 3,000 year simulations. The report will be completed with some conclusions and recommendations.

2. The HBV-Meuse model

2.1 General features of HBV-Meuse

The Meuse basin (21,000 km^2) upstream from Borgharen is divided in 15 separate subbasins (figure 2.1 and table 2.1).

Figure 2.1 Meuse catchment divided in 15 subbasins

Table 2.1 Subbasins Meuse catchment

Number	Name
1	Maas Source-St.Mihiel
2	Chiers
3	Maas St.Mihiel-Stenay
4	Maas Stenay-Chooz
5	Semois
6	Viroin
7	Maas Chooz-Namur
8	Lesse
9	Sambre
10	Ourthe
11	Amblève
12	Vesdre
13	Mehaigne
14	Maas Namur-Borgharen
15	Jeker

This subbasin division has been used for the schematization of the Meuse catchment in the hydrological model HBV. HBV is a rainfall-runoff model that has been developed by the Swedisch Meteorological and Hydrological Institute (*SMHI, 1999*). HBV is a semi-distributed, conceptual model containing a large number of parameters. These parameters are not physically based, so they have to be calibrated. A more extended description of the HBV model can be found to the website of the Swedish Meteorological and Hydrological Institute (http://www.smhi.se).
Booij (*2002*) and Van Deursen (*2004*) constructed and calibrated the HBV model for the Meuse schematization, in this report referred to as HBV-Meuse. The HBV-Meuse model calculates at a daily resolution, therefore all mentioned discharges in this report have been expressed as daily average values (in m^3/s) if not stated otherwise. Each of the 15 subbasins has a distinctive parameter set and input data record. Van Deursen (*2004*) gives a detailed description of the HBV-Meuse model.
The parameters have been calibrated with the historical data of the period 1968-1984. The general calibration results were satisfying. During the calibration the Nash-Sutcliffe R^2 for the model outlet equals 0.91. Validation of the parameters has been performed on the period 1985-1998 resulting in a Nash-Sutcliffe R^2 of 0.93. It is important to notice that the model has been calibrated with discharge data of Monsin instead of Borgharen (*Van Deursen, 2004*). The discharge of Monsin equals the discharge of Borgharen corrected for extraction by channels. This extraction has not been implemented in the HBV-Meuse model, so the outcome of the model at Borgharen corresponds with the corrected historical record of Monsin. Therefore, the comparisons between simulated and historical discharge have been performed with the corrected record of Monsin. In general, the discharge at Borgharen is somewhat lower than Monsin.

2.2 Additional calibration results

In this section some additional analyses have been performed to get a more complete understanding of the advantages and disadvantages of the HBV-Meuse model.
Table 2.2 contains the average, maximum and the standard deviation of the measured and modeled discharge (daily average values) during the period 1968-1998. Both the average and the standard deviation of the simulated discharge are somewhat higher than the measured discharge.

Table 2.2 Basic statistics of the measured and simulated discharges during the period 1968-1998

	Average (m^3/s)	Maximum (m^3/s)	Standard deviation (m^3/s)
Measured	266	3080	269
HBV-Meuse	274	2976	283

From table 2.2 it is clear that HBV-Meuse is in general capable of simulating Meuse discharges. However, this study concentrates on extreme discharge events so especially these events have been studied by analyzing annual maxima. All annual analyses have been performed for hydrological years. A hydrological year starts at the 1st of October and ends at the 30th of September. The use of hydrological years prevents that during one winter event more than one discharge maximum is selected. Figure 2.2a shows a Gumbel plot of the historical and the simulated annual discharge maxima (daily average values). In addition to the more custom Gumbel distribution, the measured and simulated maxima have also been fitted to the General Extreme Values (GEV) distribution (figure 2.2b). Gumbel is actually a special case of the GEV (*Chow et. al., 1988*). GEV fitting is performed with three parameters in contradiction to the Gumbel fit which uses only two parameters (shape parameter equals 0).

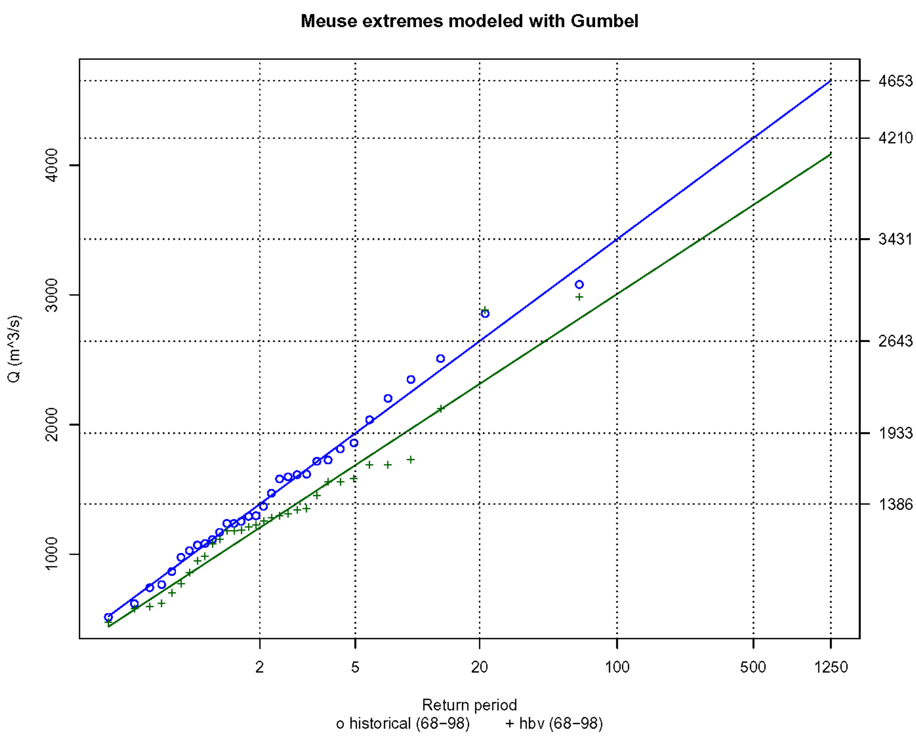

Figure 2.2a Gumbel distribution of measured (o) and simulated (+) annual discharge maxima

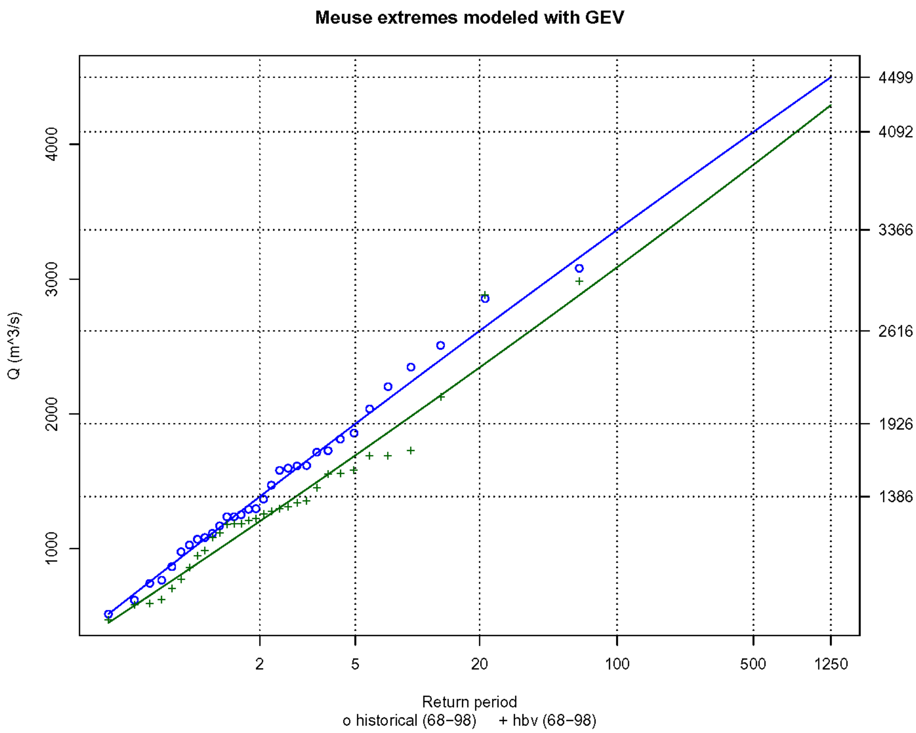

Figure 2.2b GEV distribution of measured (o) and simulated (+) annual discharge maxima

Both figures show some bias between the measured and modeled annual discharge maxima, especially in the middle range with return periods from 2 to 15 years. The two most extreme discharges, corresponding to the events in December 1993 and January 1995, seem to be simulated properly. Because of the underestimation of the HBV model in the middle range, the Gumbel fit of the modeled period is positioned lower than the measured fit. The discharges corresponding to a return period of 1250 years differ approximately 500 m^3/s. Again, it is stressed that the numerical values of Q_{1250} cannot be compared to actual design discharges because of some fundamental differences. These differences embrace different frequency distributions, data records and threshold values (*Parmet et.al.,2001*).

Fitting with a General Extreme Value distribution (GEV) gives a different result. Both measured and simulated distributions are more similar in comparison with the Gumbel fits. The GEV is relatively more sensitive for the two most extreme events. Therefore the entire fit is lying somewhat higher which seems to be more accurate according to the measured GEV fit.

Figures 2.3 and 2.4 show the Gumbel (a) and GEV (b) plots of the measured and simulated annual 4- and 10-day discharge maxima (in millimeters). From these figures it is clear that HBV-Meuse is capable of a good simulation of multi-day extreme values. Multi-day extreme values give an indication for the volume of water that has been passed at the outlet. The figures prove that HBV does not underestimate the volume of water during an extreme event but has some difficulty with the distribution of daily discharges surrounding the day a moderate extreme event occur.

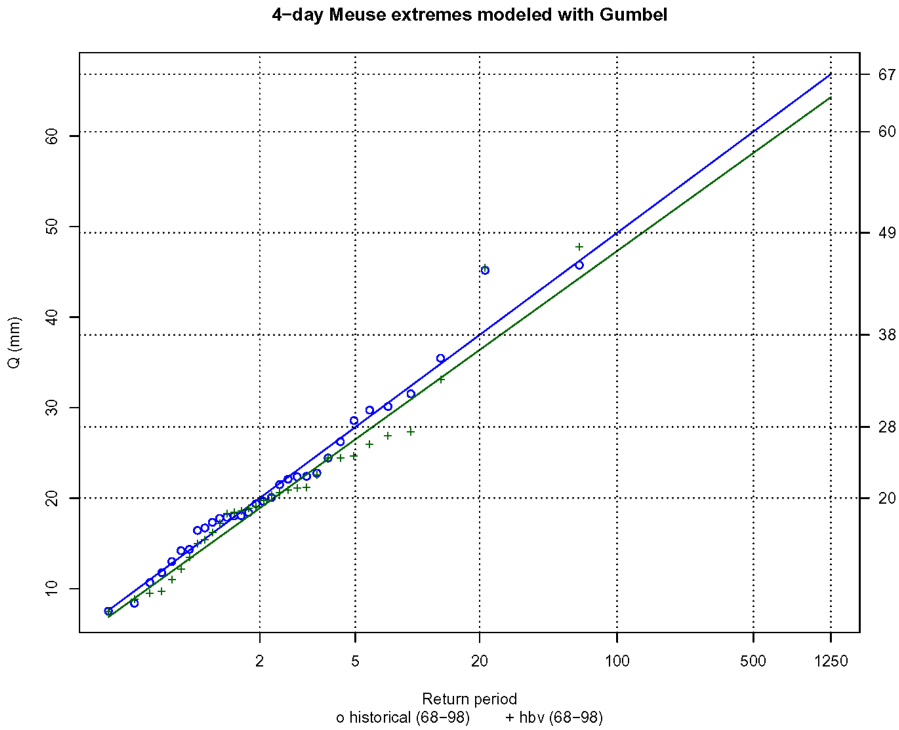

Figure 2.3a Gumbel plot of measured (o) and simulated (+) annual 4-day discharge maxima (mm)

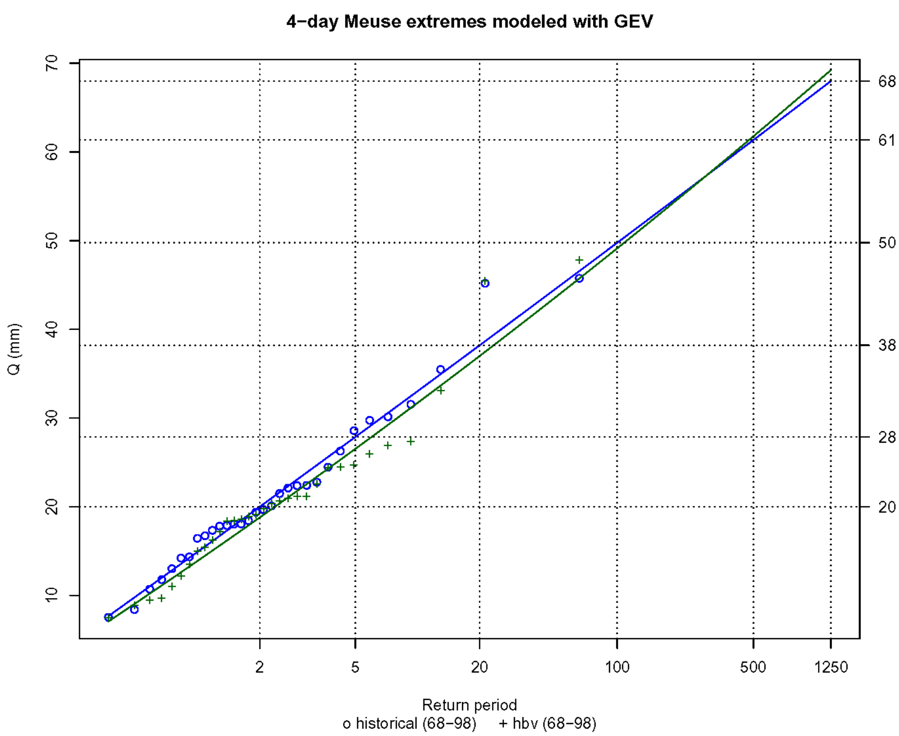

Figure 2.3b GEV plot of measured (o) and simulated (+) annual 4-day discharge maxima (mm)

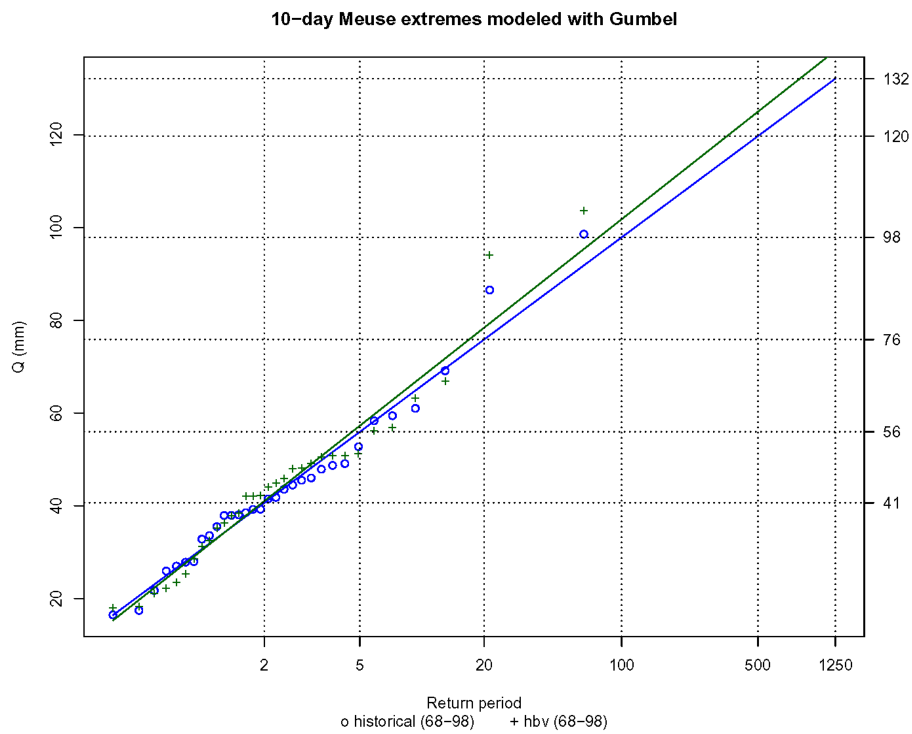

Figure 2.4a Gumbel plot of measured (o) and simulated (+) annual 10-day discharge maxima (mm)

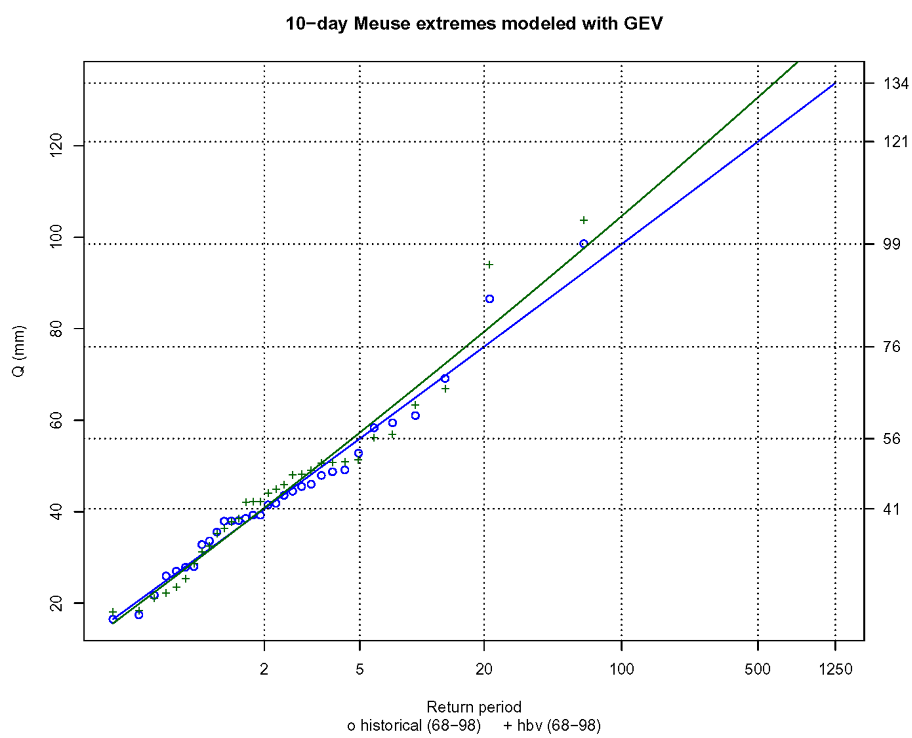

Figure 2.4b GEV plot of measured (o) and simulated (+) annual 10-day discharge maxima (mm)

Concluding, it is clear that the HBV-Meuse model correctly reproduce the general characteristics like the average and standard deviation of daily discharges. Also the high values of the Nash-Sutcliffe R^2 prove that HBV-Meuse should be capable of a good simulation of the Meuse discharge. However, the analysis of annual maxima shows two important aspects. The middle range of the annual daily extremes has been underestimated by the HBV model. On the other hand, for the most extreme values HBV is capable of a good simulation of the peak discharge. Furthermore, HBV simulates the volume of water during an extreme event well as was shown from the 4- and 10-day annual maxima distributions. Similar conclusions about HBV have already been found during a case study for the Ourthe (*Aalders & De Wit, 2004*).

3. Data and methods

3.1 Introduction

Chapter 2 described the HBV-Meuse model and some of its results during calibration. The input data for the HBV-Meuse model during this study have been generated by the KNMI weather generator which consists of 3,000 year precipitation and temperature records (*Leander & Buishand, 2004*). The first part of this chapter will summarize some features of this generator. The final paragraph gives a short description of the linking procedure between the KNMI weather generator and the HBV-Meuse model.

3.2 KNMI weather generator

KNMI constructed a stochastic weather generator to simulate long series of precipitation and temperature for the entire Meuse basin. The generator is based on the principle of nearest-neighbour resampling. Daily data from a historical record have been used to generate long series such that the temporal and spatial correlations are being preserved. KNMI provided RIZA with different series of 3,000 year containing precipitation and temperature records for each subbasin in the Meuse catchment. It is important to notice that KNMI uses the same subbasin division (figure 2.1), but a deviant subbasin numbering. The generation of the precipitation and temperature series is described in detail in Leander & Buishand (*2004*). The most important conclusions are listed below.

Precipitation records for 16 sub-catchments (Sambre basin is divided into a Belgian and a French part) are generated using historical data of 1961-1998. Temperature records for 11 stations have been generated from historical data of the period 1967-1998. No significant bias has been found in the 3,000 year precipitation and temperature records. Especially, there is a good agreement between the simulated and historical quintiles of the 4-, 10- and 30-day seasonal maxima of area-average precipitation. These multi-day events are important for peak discharge on the Meuse which was concluded during a case study in the Ourthe basin preceding to this study (*Aalders & De Wit, 2004*).
Another 3,000 year record has been generated, which was based on historical records for the period 1930-1998 (excluding the year 1940). The seasonal maxima of multi-day amounts corresponding to high return periods are lower in this simulation in comparison with the generated record based on the period 1961-1998.
Simulations using a window of 61 days contain the most extreme multi-day amounts by repetition of certain wet historical days. A broader window of 121 days reduces this repetition. The most extreme multi-days events are also lower when this window is applied.

KNMI provided four series which are based on the historical data of 1961-1998. These series with different random number seeds, will be referred to as 61sim1, 61sim2, 61sim3 and 61sim4. KNMI also provided four series which are based on the historical data of 1930-1998 referred to as 30sim1, 30sim2, 30sim3 and 30sim4. All series are generated using a small window. Additionally, KNMI generated two series using a larger window. Those records are based on the period 1930-1998 and will be referred to as 30sim8 and 30sim9. So, totally KNMI provided ten different 3,000 year records for the entire Meuse basin which have been used as input for the hydrological simulation with the HBV-Meuse model.

3.3 Linking weather generator to HBV-Meuse

This section describes how the output of the KNMI weather generator (paragraph 3.2) and the calibrated HBV-Meuse model (chapter 2) have been linked to calculate 3,000 year of Meuse discharges. A large part of the actual work during this study consisted of the construction of an automatic procedure for this calculation sequence. This procedure has been split into three parts, the Pre-processor, the Main-processor and the Post-processor (figure 3.1). A detailed description and manual will be found in annex 1. Only some main features are listed below.

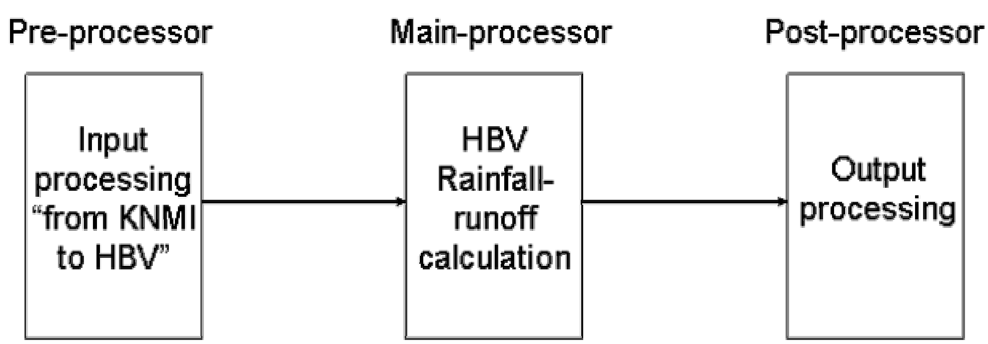

Figure 3.1 Schematized image of the calculation sequence

The Pre-processor is responsible for the conversion of the KNMI records to HBV input data. It contains operations for precipitation, temperature and evapotranspiration data and will cut the 3,000 year record into 75 pieces of 40 years. The latter is necessary because HBV has a limited calculation time. After the Pre-processor the input data is ready to be used in the HBV-Meuse model. The Main-processor will run the actual rainfall-runoff module of the HBV model. This discharge simulation is repeated 75 times for the 75 blocks of 40 years. Finally the Post-processor combine all 75 output blocks to one record of 3,000 years. Furthermore, the Post-processor execute some statistical analyses on the output data. The complete calculation sequence (Pre-processor, Main-processor and Post-processor) has been combined in a fully automatic computation procedure. As stated earlier, annex 1 contains a manual for this automation procedure and describes all separate computation steps in more detail.

4. Results of generated records based on 1961-1998

4.1 Introduction

The first part of this chapter gives the results of the simulation 61sim1. The final part summarizes the results of all simulations based on the period 1961-1998.

4.2 Simulation 61sim1

4.2.1 General results

Table 4.1 contains the average, maximum and standard deviation of the discharge (on daily basis) of 61sim1 and the historical record.

Table 4.1 Average, maximum and standard deviation of (daily average) discharge

	Average (m^3/s)	Maximum (m^3/s)	Standard deviation (m^3/s)
Measured (1961-1998)	271	3080	275
61sim1 (3,000 years)	256	3914	270

Compared to the historical values both average and standard deviation are somewhat underestimated. This is in contrast with the results in table 2.2 which show that HBV overestimated the average and standard deviation of the discharge during the calibration. The maximum daily discharge during a period of 3,000 years is logically exceeding the historical maximum discharge over a period of 38 years.

Figure 4.1 shows the rest term of the annual water balance during a period of 3,000 hydrological years. The used water balance only contains the terms precipitation, actual evapotranspiration and discharge (Equation 4-1).

$$P - ET_{act} - Q = R \qquad [4\text{-}1]$$

where:

P	: precipitation (mm)
ET_{act}	: actual evapotranspiration (mm)
Q	: discharge (mm)
R	: rest term (mm)

Precipitation has been generated by the weather generator. Discharge and actual evapotranspiration are output variables of the HBV model.

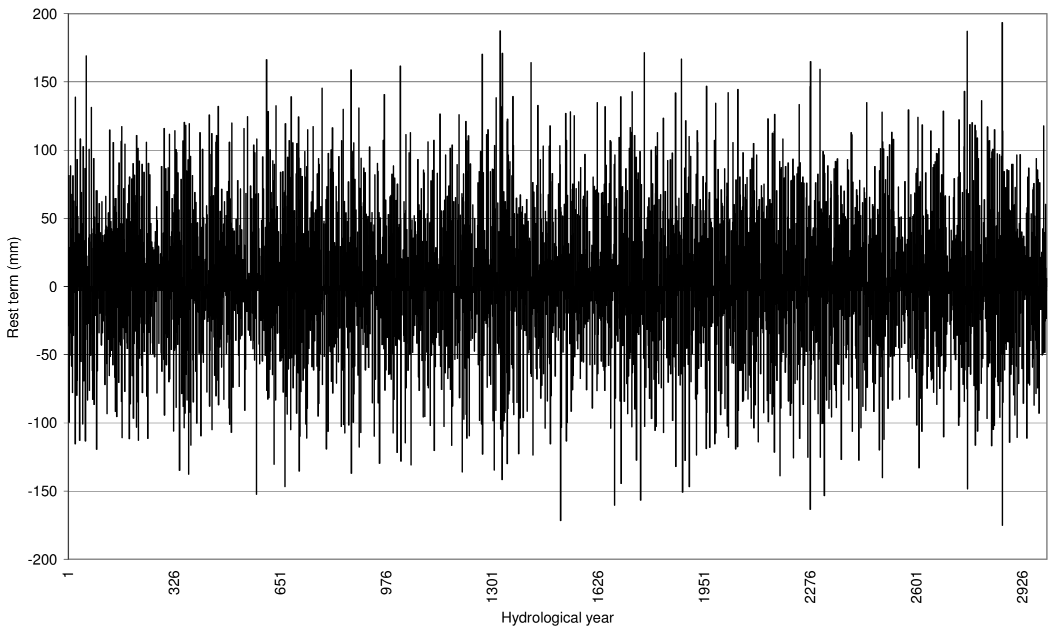

Figure 4.1 Rest term (R) of the water balance for 3,000 hydrological years

If R is positive, the catchment storage has increased during a year. If R has a negative value, the total catchment storage has decreased during the year. The positive and negative rest terms are equally distributed over the 3,000 year period and no trends have been found. This shows that the water that has been stored during a year comes to discharge during the following years.

The general results of the 3,000 year simulation of the Meuse discharges are reasonable. A same conclusion was drawn by Aalders & De Wit (*2004*) during the preceding study in the Ourthe basin.

4.2.2 Extreme discharge events

In this section extreme discharge events have been examined. Extreme events are important for the determination of design discharges. Figure 4.2 shows the annual discharge maxima for a period of 3,000 years represented with the dots. The figure also contains the minimum and maximum measured annual maxima (both lines). Because the temporal resolution of the HBV-Meuse model equals one day, all annual maxima have been expressed as daily average values.

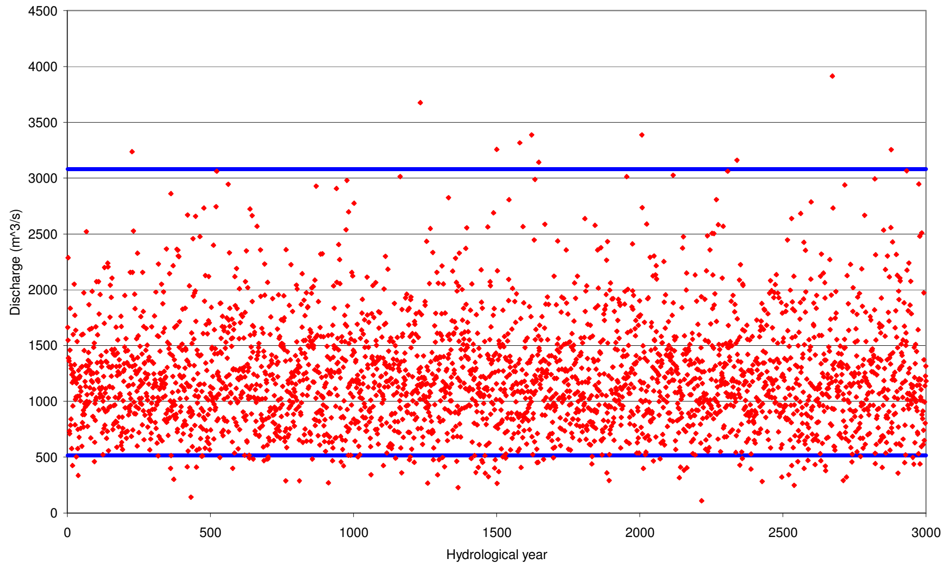

Figure 4.2 Simulated annual maxima (dots) and the minimum and maximum measured year maxima (both lines) expressed as daily averages

Ten out of 3,000 years exceed the maximum measured value of 3080 m^3/s. The dots show a random temporal distribution and again no trend was found in the simulated data record. Figure 4.3 shows the highest peak discharge of 3914 m^3/s in more detail with the corresponding area-average precipitation which has been generated by the KNMI weather generator.

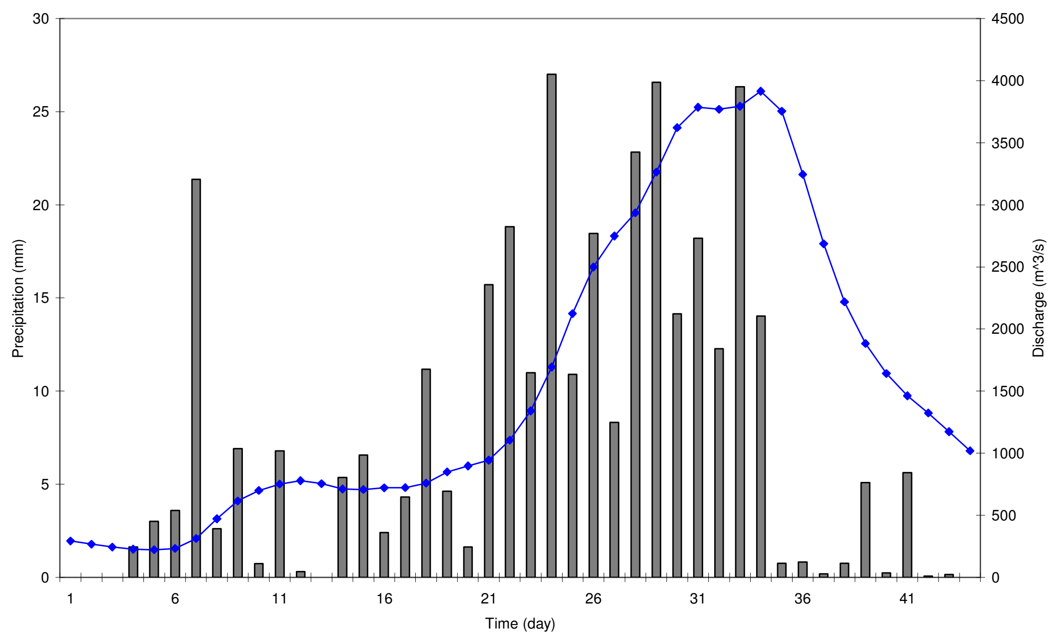

Figure 4.3 Simulated daily discharge with corresponding daily precipitation

From this figure it is clear that an extreme discharge event follows from a series of days with moderate high precipitation rather than one ore two extreme precipitation events. Totally an area-average precipitation amount of 245 mm fall on the catchment in only 14 days. Furthermore, it is important to notice that this event occurred during the months January and February. Such an amount of precipitation during the summer does not assure a similar discharge event. The season of occurrence and the wetness of the catchment are important factors for extreme peak discharges.

Figure 4.4 shows the Gumbel (a) and GEV (b) plots of the annual discharge maxima of the generated record and the HBV calibration result (see also figures 2.2a and b). Again, all maxima have been expressed as daily average values due to the temporal resolution of the HBV-Meuse model.
The generated annual maxima have been fitted well to the Gumbel distribution in the lowest and middle range and show a similar distribution as the HBV calibration results of 1968-1998. However, the generated dataset shows an underestimation in the highest range of the annual discharge maxima if compared to the fitted Gumbel function. In that particularly range, the GEV seems to fit the generated annual maxima much better than the more customary Gumbel distribution. It is important to notice that these most extreme annual maxima of the generated dataset embrace only 1% of the total record of 3000 annual maxima. 1% of the calibration (or measured) record correspond to only one point in the figure representing just a single annual maxima. This large difference in record length must be kept in mind when studying these plots.

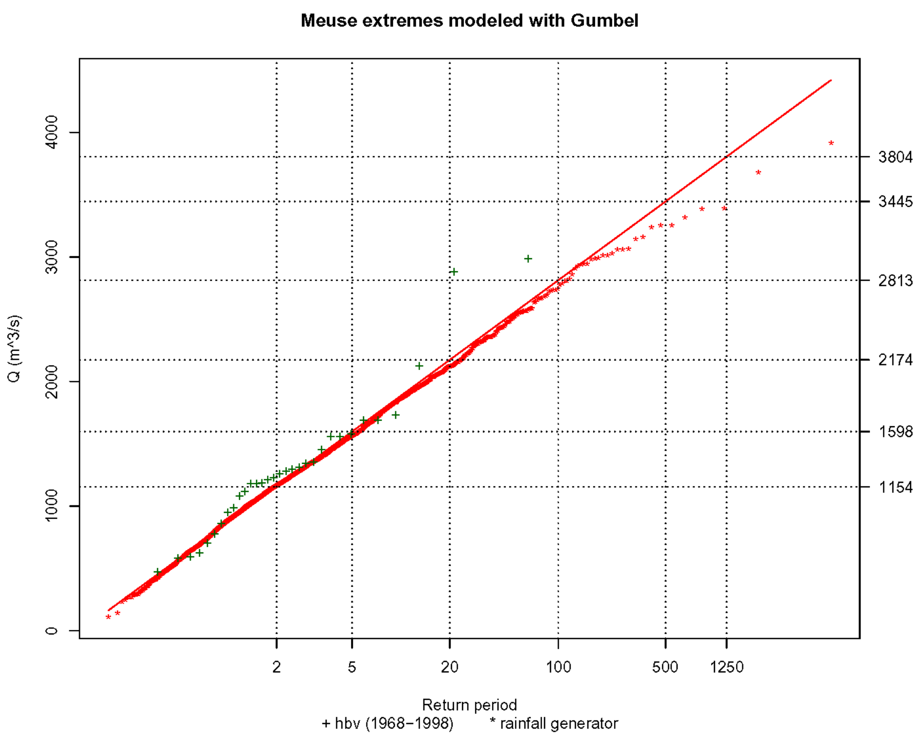

Figure 4.4a Gumbel plot of HBV 1968-1998 (+) and generated (*) annual discharge maxima (m^3/s)

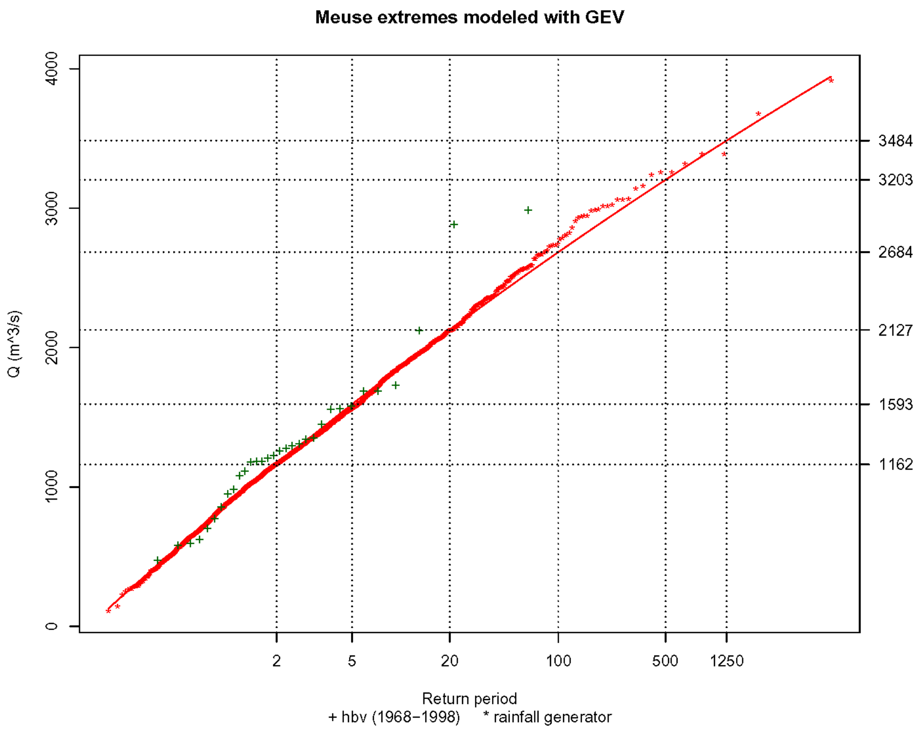

Figure 4.4b GEV plot of HBV 1968-1998 (+) and generated (*) annual discharge maxima (m^3/s)

It appears that the events in December 1993 and January 1995 of the HBV calibration period are out of the distribution. A similar bias has been found in the Ourthe basin (*Aalders & De Wit, 2004*). This bias seems to have no effect on the generated record.

Figures 4.5 and 4.6 show the Gumbel (a) and GEV (b) distributions of annual maxima of the 4- and 10-day running discharge sum (in millimeters). Again, the figures contain both the generated maxima as well as the maxima of the HBV calibration. The generated record appears to have a similar distribution as the HBV calibration record on 4- and 10-daily basis with exception of the events in December 1993 and January 1995. The most extreme maxima of the generated record have been underestimated if compared to the Gumbel fit. Again, the GEV distribution seems to yield in a better fit for the multi-day events rather than Gumbel.

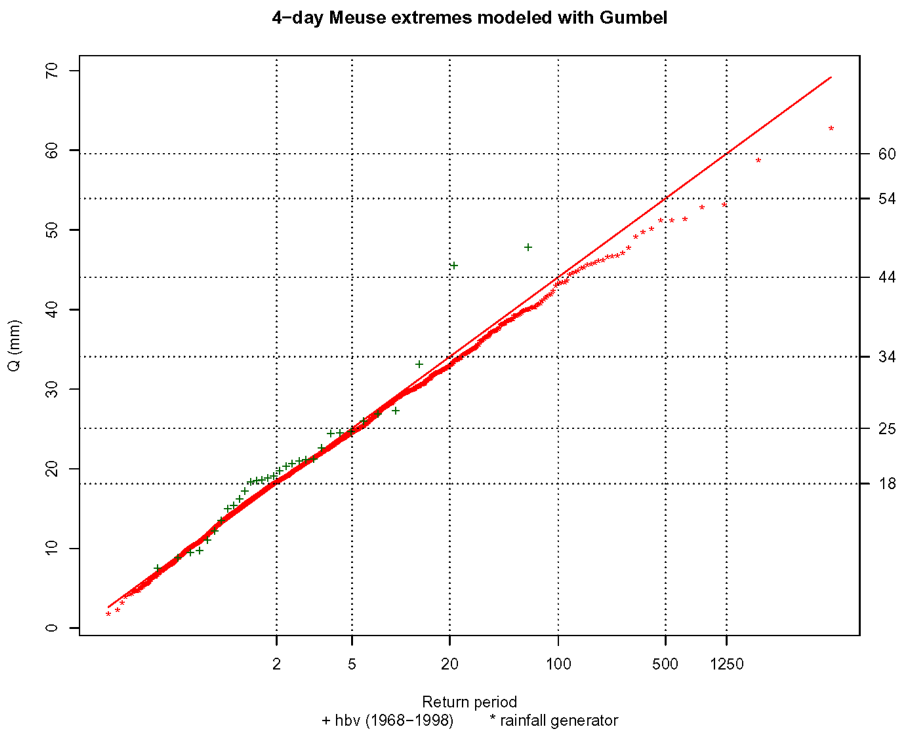

Figure 4.5a Gumbel plot of HBV 1968-1998 (+) and generated (*) annual 4-day discharge maxima (mm)

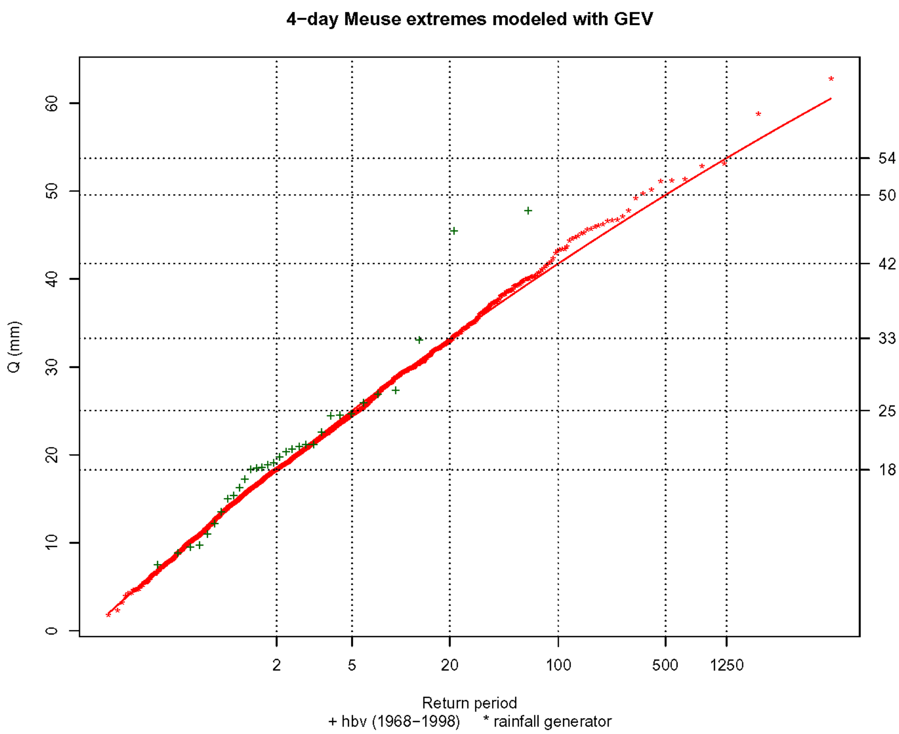

Figure 4.5b GEV plot of HBV 1968-1998 (+) and generated (*) annual 4-day discharge maxima (mm)

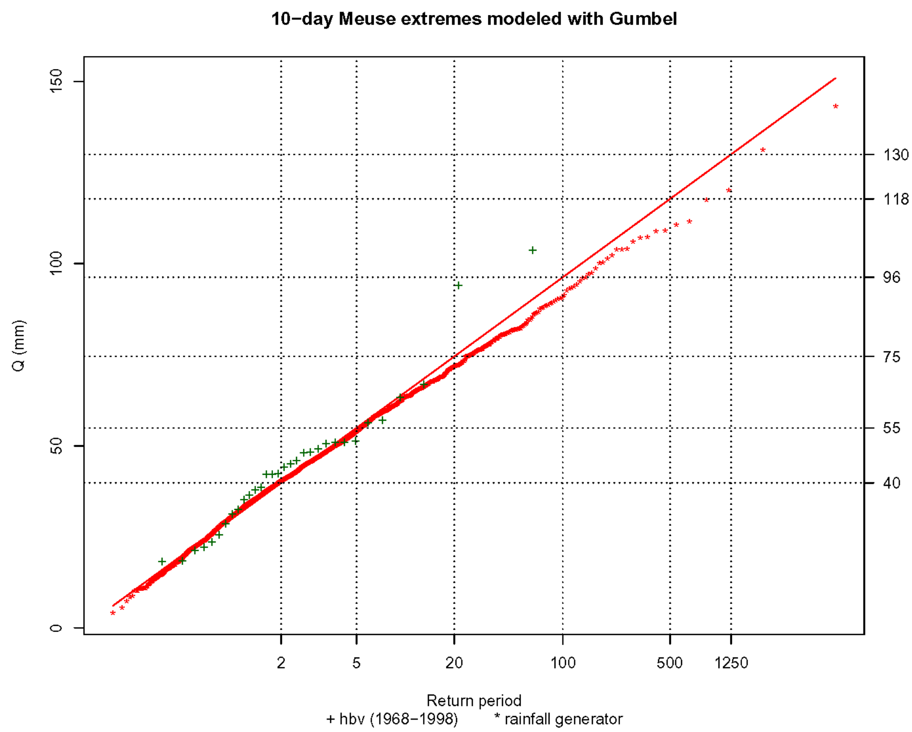

Figure 4.6a Gumbel plot of HBV 1968-1998 (+) and generated (*) annual 10-day discharge maxima (mm)

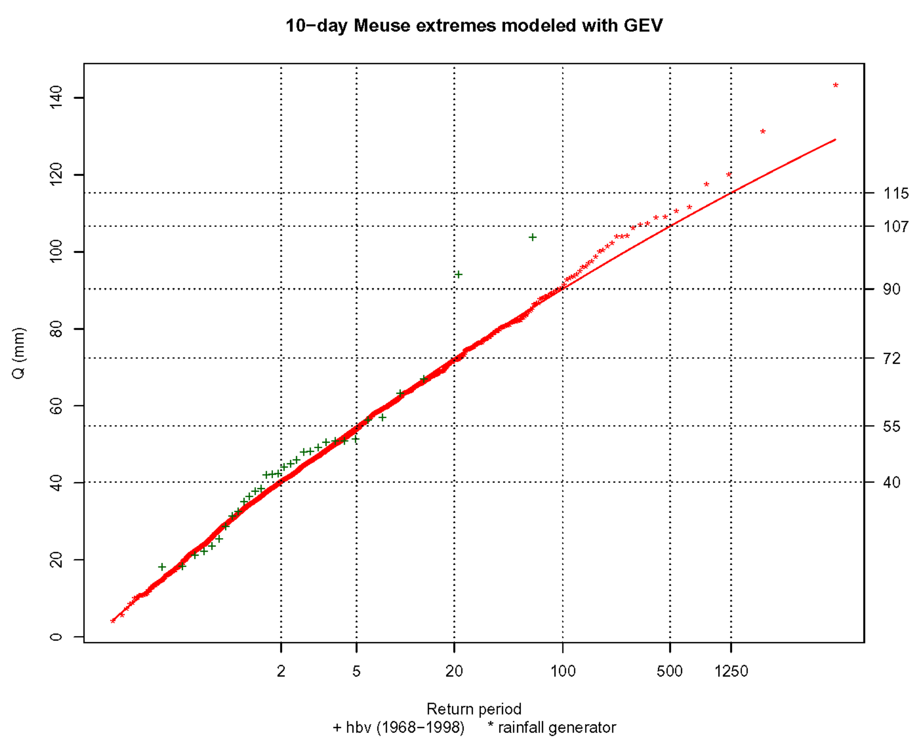

Figure 4.6b GEV plot of HBV 1968-1998 (+) and generated (*) annual 10-day discharge maxima (mm)

4.3 Other simulations based on 1961-1998

4.3.1 General results

Next to the earlier discussed 61sim1 some other simulations based on 1961-1998 have been performed. Table 4.1 has been elaborated with the other simulations which lead to table 4.2.

Table 4.2 Average, maximum and standard deviation of (daily average) discharge

	Average (m^3/s)	Maximum (m^3/s)	Standard deviation (m^3/s)
Measured (1961-1998)	271	3080	275
61sim1	256	3914	270
61sim2	257	3921	269
61sim3	255	4340	264
61sim4	254	4464	265

The averages and standard deviations of the simulated discharges seem to be equal for each record. The maximum daily discharges are different.

4.3.2 Extreme discharge events

The figures with annual discharge maxima distributed in time, like figure 4.2, are listed in annex 2. All figures show a different distribution of the most extreme annual maxima, so the series seem to be randomly generated. Every simulation contains between 10 and 15 maxima that exceed the measured maximum.

Table 4.3 contains the estimated peak discharges of the once every 1,250 year flood derived from the Gumbel distributions of all four 3,000 year simulations. The same has been done for the measured period and the HBV simulation of that historical period. See also figures 2.2a and 4.4a.

Table 4.3 Estimated peak discharge (daily average) of the once every 1,250 year flood (T_r = 1,250) derived from a Gumbel distribution of hydrological year maxima

	Discharge corresponding to T_r = 1,250 according to the Gumbel distribution
Measured (1968-1998)	4653
HBV (1968-1998)	4085
61sim1	3804
61sim2	3831
61sim3	3832
61sim4	3753

The difference of 600 m^3/s between the measured and the HBV (1968-1998) distribution is due to the underestimation of annual maxima in the middle range of the HBV model (see figure 2.2a). All simulated series of 3,000 year show an underestimation of almost 300 m^3/s if compared to the discharge corresponding to a Gumbel fit for the HBV calibration record. This could be due to uncertainties in the KNMI weather generator. The Gumbel fits of the generated records of 3,000 year show no mutual differences, all discharges are approximately 3800 m^3/s. In table 4.4 estimated discharges corresponding to a return period of 1,250 years according to a GEV distribution are listed. See also figures 2.2b and 4.4b.

Table 4.4 Estimated peak discharge (daily average) of the once every 1,250 year flood (T_r = 1,250) derived from a GEV distribution of hydrological year maxima

	Discharge corresponding to T_r = 1,250 according to the GEV distribution
Measured (1968-1998)	4499
HBV (1968-1998)	4291
61sim1	3484
61sim2	3565
61sim3	3497
61sim4	3475

The difference between the generated 3,000 year records and the HBV calibration period is about 800 m^3/s. This is relatively large in comparison with the Gumbel distributions. So, uncertainties in the weather generator seem to have a larger effect when the GEV distribution is used. The discharges corresponding to the generated records are about 400 m^3/s lower than the ones in table 4.3. This is due to the difference between the Gumbel and GEV distribution. Again, the mutual differences between all simulations of 3,000 year are negligible.
Figure 4.7 shows the Gumbel (a) and GEV (b) plots of simulation 61sim3. Gumbel and GEV plots of 61sim2 and 61sim4 can be found in annex 3.

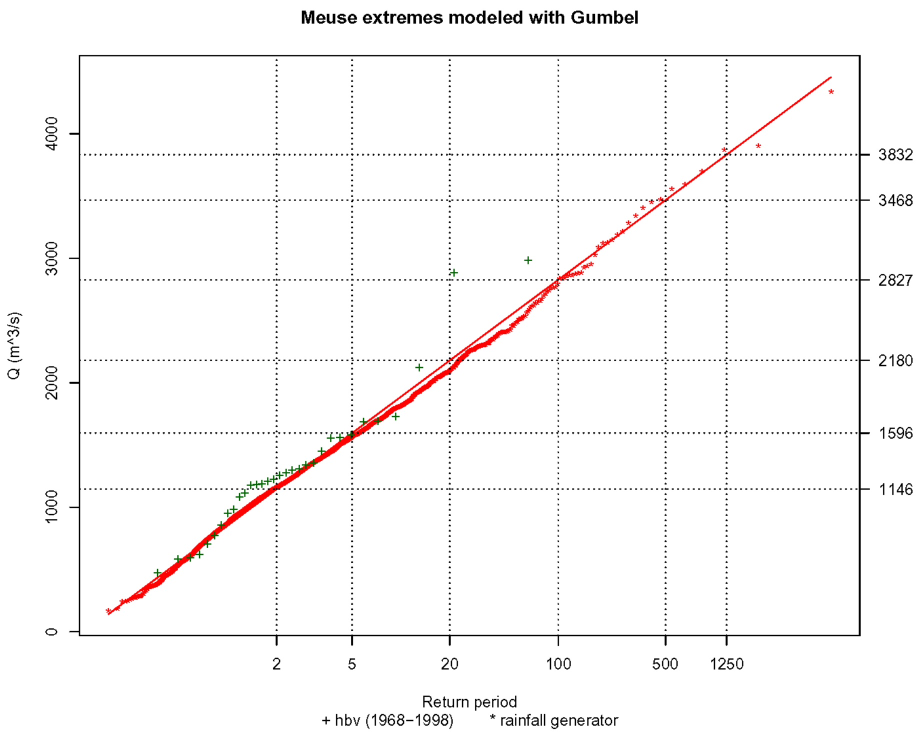

Figure 4.7a Gumbel plot of HBV 1968-1998 (+) and generated (*, 61sim3) annual discharge maxima (m^3/s)

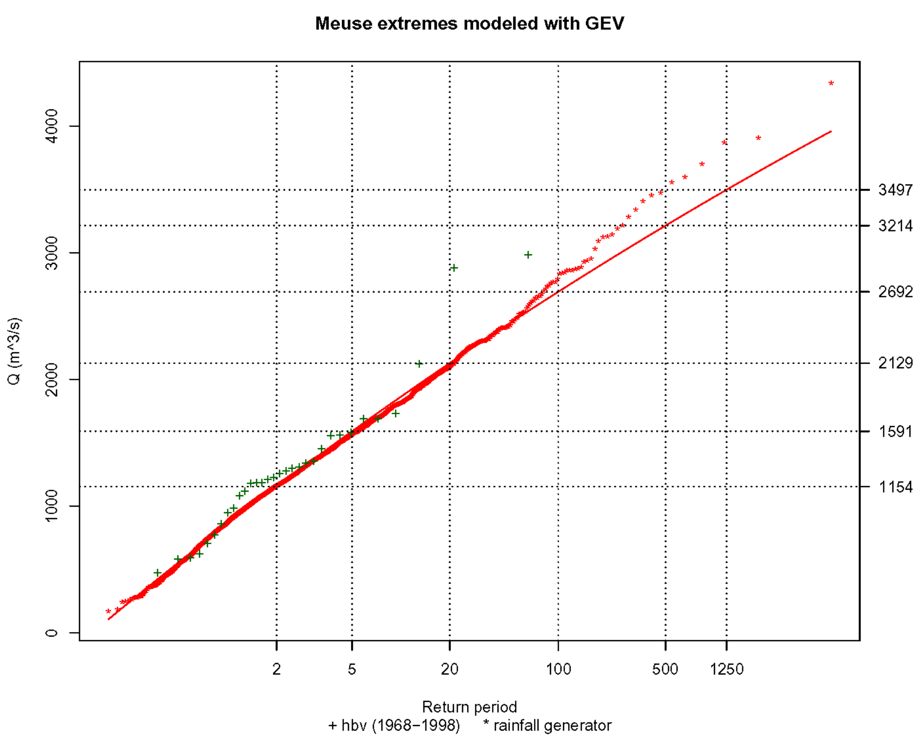

Figure 4.7b GEV plot of HBV 1968-1998 (+) and generated (*, 61sim3) annual discharge maxima (m^3/s)

The difference between 61sim1 (figure 4.4) and 61sim3 (figure 4.7) is striking. As shown before, the simulation of 61sim1 shows a clear bias with the fitted Gumbel distribution in the range of the highest peak events. Figure 4.7a shows that the simulation of 61sim3 fits perfectly with the Gumbel distribution. This difference can only be due to random effects during the generation of the precipitation and temperature series. Proportionally, the GEV distribution of 61sim1 (figure 4.4b) gives a good fit in the range with the highest annual maxima. This is in contrast with figure 4.7b which demonstrates that simulation 61sim3 fits inaccurate in the range of the highest annual maxima. So, the simulations 61sim1 and 61sim3 show a contradictive perspective. This can not be concluded from tables 4.3 and 4.4 because the fitted functions are similar. Gumbel and GEV fits are mostly based on the low and middle range of the annual maxima. These extreme events embrace approximately 1% of total record (30 years), so they have a relatively small influence on the fitted function. As stated before, 1% of the HBV calibration record corresponds to only one annual maxima.

Concluding from all plots, 61sim2 seems to be similar to 61sim1 and in contrast with 61sim4 which demonstrate to be more similar to 61sim3. These resemblances can also be found in the Gumbel and GEV plots of the multi-day events of 61sim2, 61sim3 and 61sim4 (annex 4) and 61sim1 (figures 4.5 and 4.6).

5. Results of generated records based on 1930-1998

5.1 Introduction

The chapter gives a short overview of the results of the generated records based on 1930-1998, referred to as 30sim1, 30sim2, 30sim3 and 30sim4. Additionally, two series generated with a large window have been used for a discharge simulation, 30sim8 and 30sim9. Due to divergent characteristics no comparisons between generated records and measured or HBV calibration results have been performed.

5.2 General results

In table 5.1 the average, maximum and standard deviation of the simulated records (daily values) are listed.

Table 5.1 Average, maximum and standard deviation of (daily average) discharge (LW = large window)

	Average (m^3/s)	Maximum (m^3/s)	Standard deviation (m^3/s)
30sim1	238	3599	250
30sim2	240	4113	252
30sim3	238	3543	249
30sim4	240	3352	253
30sim8 (LW)	247	3621	251
30sim9 (LW)	250	3306	253

The four averages and standard deviations of the regular runs are almost similar to each other, between 238-240 m^3/s and 249-253 m^3/s respectively. The “large window” simulations, 30sim8 and 30sim9, do have a somewhat higher average discharge in comparison to the regular ones. The use of a larger window seems to sort no effect on the standard deviation. No structural discrepancies have been found in the maximum discharges.
All discharges are lower than the results of the simulations based on the period 1961-1998 (chapter 4). This is because 1961-1998 is a relatively wet period.

5.3 Extreme discharge events

Figure 5.1 shows the temporal distribution of the annual discharge maxima (daily average values) of simulation 30sim1. The same figures of the other simulations can be found in annex 5.

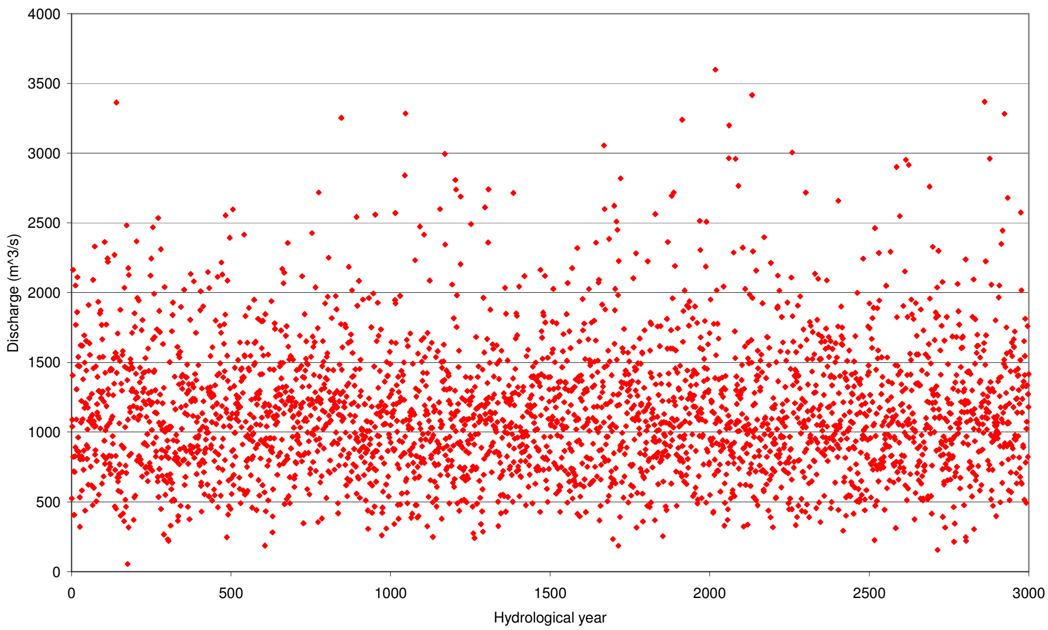

Figure 5.1 Simulated annual maxima (dots, 30sim1)

All runs seem to have a random temporal distribution of discharge maxima throughout a period of 3,000 years. The number of events exceeding the 3000 m^3/s varies from six to twenty. Using a larger window during the generation of the precipitation and temperature records seems to have no effect on the number of events exceeding the 3000 m^3/s.
Table 5.2 shows the estimated discharges according to a fitted Gumbel function corresponding to a return period of 1,250 year.

Table 5.2 Estimated peak discharge of the once in every 1,250 year flood (T_r = 1,250) derived from a Gumbel distribution of hydrological year maxima.

	Discharge corresponding to T_r = 1,250 according to the Gumbel distribution
30sim1	3655
30sim2	3639
30sim3	3594
30sim4	3708
30sim8 (LW)	3633
30sim9 (LW)	3660

All estimated simulated discharges show much similarity. Again, the use of a larger generation window seems to sort no effect on the extreme events. The discharges with a return period of 1,250 year fitted with a General Extreme Value distribution are listed in table 5.3. The mutual differences of the 3,000 year records seem to be relatively larger than noticed during the simulations described in chapter 4 (table 4.4).

Table 5.3 Estimated peak discharge of the once in every 1,250 year flood (T_r = 1,250) derived from a GEV distribution of hydrological year maxima.

	Discharge corresponding to T_r = 1,250 according to the GEV distribution
30sim1	3338
30sim2	3410
30sim3	3511
30sim4	3295
30sim8 (LW)	3646
30sim9 (LW)	3383

Figure 5.2 contains the Gumbel and GEV plots for simulation 30sim1. All other plots corresponding to the values in tables 5.2 and 5.3 are listed in annex 6. The simulated maxima during calibration and measured values have been left out of the plots. This is due to the deviant characteristics of the records. The fact that HBV-Meuse has been calibrated and validated with the period 1968-1998 (instead of 1930-1998) contributes to these deviances. Additionally, the potential evapotranspiration series have been estimated with equation 3 (annex 1) which contains E_{maand} and T_{norm} records based on the period 1967-1998.

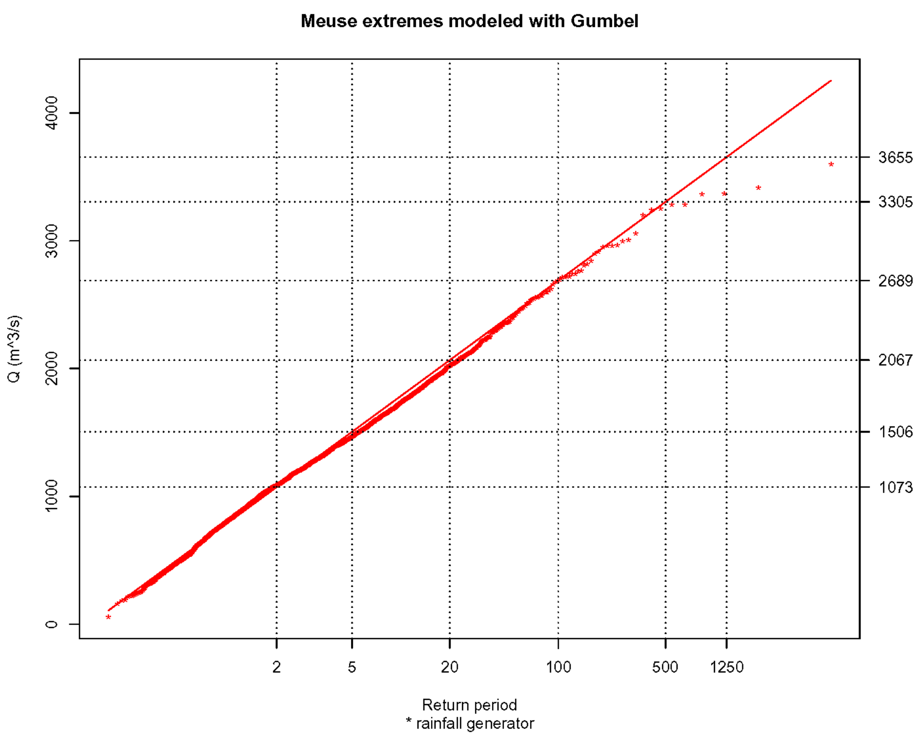

Figure 5.2a Gumbel plot of generated (*, 30sim1) annual discharge maxima (m^3/s)

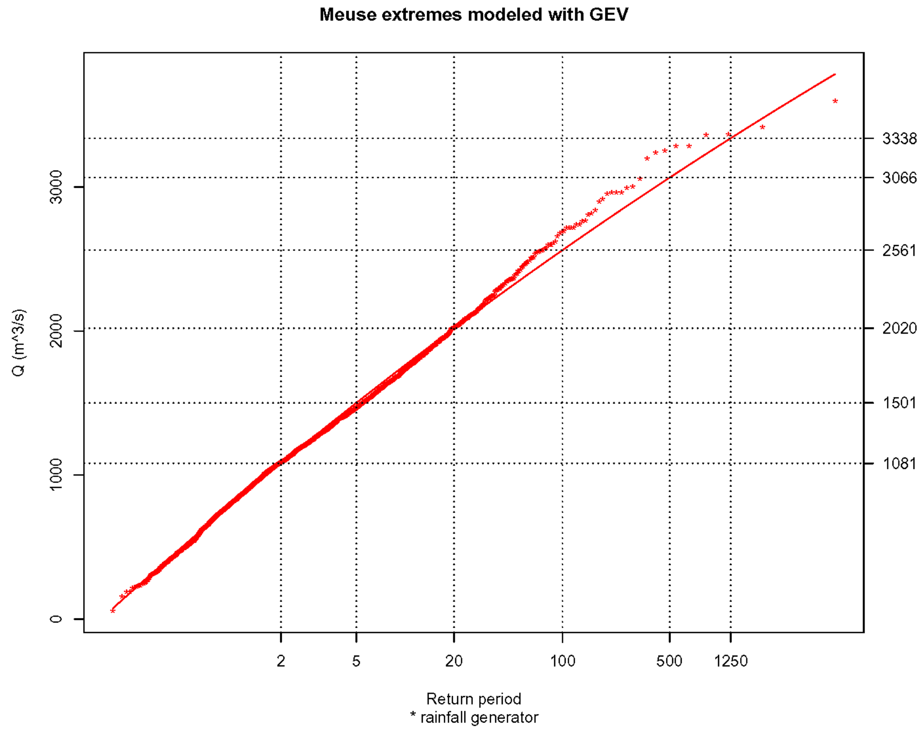

Figure 5.2b GEV plot of generated (*, 30sim1) annual discharge maxima (m^3/s)

Again, the annual maxima in the highest range seem to be unpredictable. Simulation 30sim1 fits best with the GEV distribution rather than Gumbel. However, 30sim2 show a better Gumbel fit in comparison with the GEV. The simulations 30sim3 and 30sim4 seem to have some difficulties with both the Gumbel and GEV distributions. The use of a larger window during generation of the precipitation and temperature records has no visible effect on the distribution and occurrence of peak discharges. This is shown in the Gumbel and GEV plots of simulations 30sim8 and 30sim9.

6. Conclusions and recommendations

6.1 Conclusions

The first and most important conclusion of this study is the fact that the program for the automatic calculation of a 3,000 year record with HBV-Meuse is finished and works satisfactorily. In fact the largest part of the study consisted of the construction of this program. Next to the technical part, the most important results from ten calculations of 3,000 years have been reported. From these calculations some conclusions are drawn and have been listed below. Additionally, some recommendations will complete this report.

The general results of the 3,000 year simulations (average, standard deviation, temporal distribution) are similar to the measured dataset. Additionally, this study reveals the following uncertainties of the rainfall generator with respect to the estimation of design discharges in the Meuse basin:

- The HBV-Meuse model shows an underestimation of the annual maxima in the middle range. On the other hand, the lowest and highest annual maxima are simulated satisfactorily, although the extreme events of December 1993 and January 1995 seems to be out of the distribution. Effect on Q_{1250} with Gumbel: 600 m^3/s, effect on Q_{1250} with GEV: 200 m^3/s.
- Some uncertainties are due to the weather generator. Effect on Q_{1250} with Gumbel: 300 m^3/s, effect on Q_{1250} with GEV: 800 m^3/s.
- Two different extreme value distributions (Gumbel and GEV) yield in two different discharges corresponding to the once in 1,250 year flood event. Neither could be pointed out as most reliable. All 3,000 year simulations show a different perspective if fitted to a Gumbel and GEV distribution.
- The series of records based on 1961-1998 result in general in somewhat higher discharges than the records based on 1930-1998. Additionally, the series based on the period 1930-1998 seems to have relatively more variety in terms of Gumbel and GEV distributions.

Furthermore, the use of a larger window during generation of the records seems to sort no significant effect on the results.
The research also reveals that the most extreme discharge peaks on the Meuse follow from a preceding period of moderate wet days instead of one or two extreme precipitation events. During the completion of this study a student of the Wageningen University started with a research that take a closer look at the model features during an extreme peak event on the Meuse (*Dortmans, in prep.*).

6.2 Recommendations

Overall it can be stated that the unpredictable behavior of the most extreme discharge events is difficult to interpret. Some differences are due to random effects which seem to have more influence than was expected on forehand. Therefore, some recommendations are listed below which may result in some improvement of the uncertainties.

The HBV-Meuse model has been calibrated for the period 1968-1984 and validated with the period 1985-1998. The model can also be calibrated for the entire period (1968-1998), so all available data will be embraced into the parameter set.

The fitted functions of the Gumbel and GEV distributions result in several fitting parameters which could be analyzed in more detail. This could provide more insight into the unpredictable behavior of the most extreme annual maxima.

The series based on the period 1930-1998 have been run with a HBV model that is calibrated and validated with data records of 1968-1998. Additionally, the used data for estimation of the potential evapotranspiration for T_{norm} and E_{maand} are also based on the same period. Therefore, caution is advised when drawing any conclusions from the results of these particularly runs.

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Annex 1 Linking procedure KNMI weather generator and HBV-Meuse

Introduction

This text gives a detailed description of the automatic procedure which realizes the linking between the KNMI weather generator and the HBV-Meuse model for an application of 3,000 years (daily values). The whole program will be referred to as "hbv_batch" and files and directories have been printed **bold** and *italic* respectively. In the first part the background and separate calculation steps will be described. The final part contains a manual and installation instructions.

Automatic linking procedure

General calculation

Figure 1 shows a schematic of the total calculation sequence. The calculation consists of three parts, referred to as Pre-processor, Main-processor and Post-processor. The Pre-processor (**pre_proc.bat**) is responsible for the operation which transforms the KNMI records into HBV input files. The Main-processor (**hbv_cal.bat**) executes the actual rainfall-runoff module of the HBV-Meuse model. Finally the Post-processor (**post_proc.bat**) transforms the rough HBV output data into usable results and graphs. All three parts contain several small sub-steps which will be described in detail in the next sections. The division into sub-steps provides an easy way to make changes or adaptations in the program. The entire calculation sequence can be started with executing the batch-file **start.bat**, however it is also possible to run one of the three main parts separately.

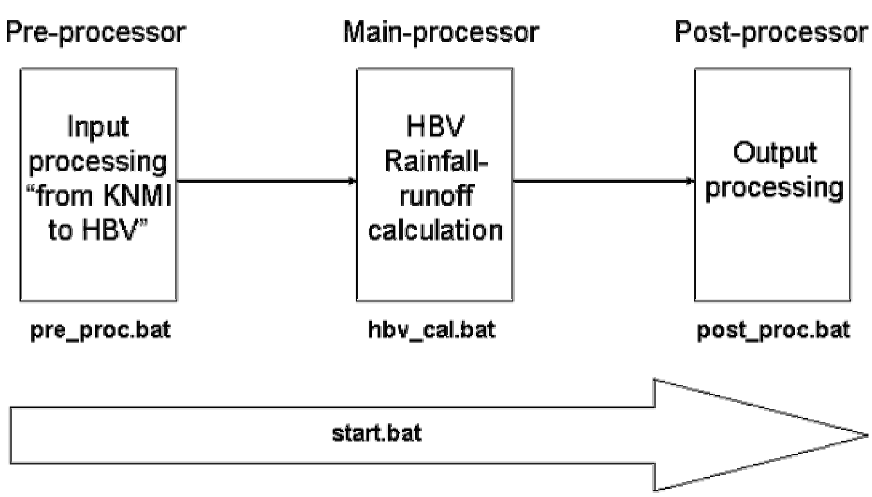


Figure 1 Schematic of the total calculation procedure

The calculation of 3,000 years has to be cut into 75 pieces of each 40 years, because HBV has a limited calculation time.

Pre-processor

Introduction

The Pre-processor transforms the 27 generated records provided by KNMI into 3375 HBV input files. This will be done in six different computation steps as shown in figure 2.

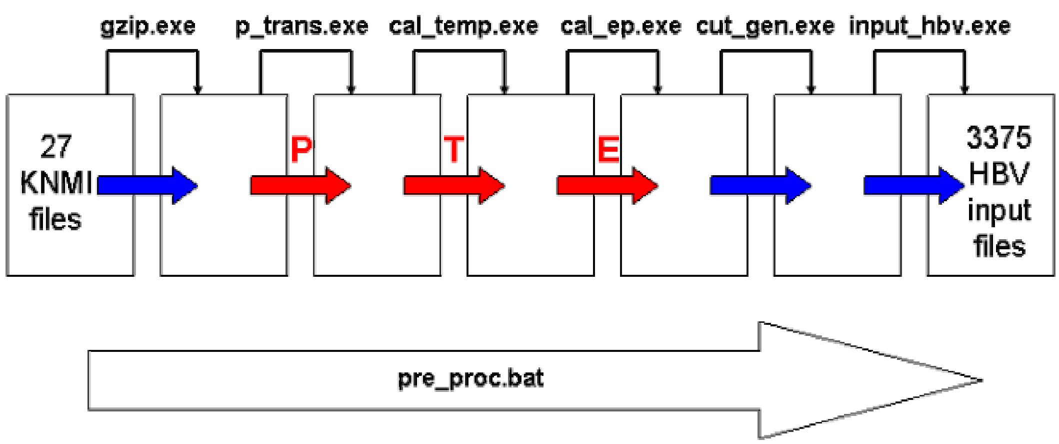


Figure 2 Schematic of the Pre-processor

Step1 - Unzipping

This first step contains the unzipping of the KNMI files with the program **gzip.exe**.

Step2 – Precipitation operation

KNMI generated 16 precipitation records for the Meuse basin, 14 directly for each corresponding subbasin. The only exception is the Sambre subbasin which contains two records, a French and a Belgium part. The precipitation operation (**p_trans.exe**) calculates from both records one Sambre subbasin record using equation 1.

$$P_{Sambre} = \frac{(2 * P_B + P_{Fr})}{3} \qquad [1]$$

where:

P_{Sambre} : total precipitation subbasin Sambre (mm)

P_B : precipitation Belgium part Sambre (mm)

P_{Fr} : precipitation French part Sambre (mm)

Equation 1 is based on the fact that the Belgium part contains 2/3 of the total subbasin area. The remaining 1/3 equals the French part. The precipitation operation is also responsible for the change from KNMI subbasin numbers to RIZA subbasin numbers.

Step3 – Temperature operation

The temperature operation (**cal_temp.exe**) calculates a subbasin temperature record. KNMI provided 11 station records which have to be used to calculate an area-average temperature for each subbasin according to equation 2.

$$T_{DG} = \frac{\sum_{i=1}^{4} \{T_i + [(H_{T_i} - H_{DG})/100] * f_h\}}{4} \qquad [2]$$

where:

T_{DG}	: temperature subbasin (°C)
T_i	: temperature of station *i* (°C)
H_{Ti}	: height of station *i* (m)
H_{DG}	: height of subbasin (m)
f_h	: temperature height correction factor (°C)

The difference in height between the station and the subbasin will be corrected with 0.6°C per 100m. This correction will be adapted on the temperature. Each subbasin will use four different geographically selected temperature stations for an area-average temperature. If the temperature operation has finished the 11 station temperature records have been changed into 15 subbasin temperature records.

Step4 – Evapotranspiration operation

The input of the HBV model consists of precipitation, potential evapotranspiration and temperature. Precipitation and temperature have been generated by the KNMI. Therefore the potential evapotranspiration have to be calculated by an evapotranspiration operation (**cal_ep.exe**). Potential evapotranspiration is estimated using equation 3.

$$E_{pot} = E_{month}[1 + \alpha(T - T_{norm})] \qquad [3]$$

where:

E_{pot}	: potential evapotranspiration (mm•d^{-1})
E_{month}	: monthly evapotranspiration (mm•d^{-1})
α	: parameter (°C^{-1})
T	: temperature (°C)
T_{norm}	: long term average temperature at calendar day (°C)

The monthly average evapotranspiration (E_{maand}) is calculated from the available data for the period 1967-1998, so every month has a specific potential evapotranspiration. The factor α has been calibrated with the HBV model and equals 0.17. The actual temperature (*T*) has been generated by the KNMI rainfall generator and the temperature operation described in step3. T_{norm} is the long term average of all measured temperatures on for example the 1st of January. T_{norm} has been calculated for each calendar day. After this calculation 15 subbasin potential evapotranspiration series have been generated.

Step5 – Cutting

As stated before HBV is not capable of a direct computation of 3,000 years. Therefore the simulation has to be cut into 75 blocks of each 40 years. The program **cut_gen.exe** cut the 45 records (15 precipitation, 15 potential evapotranspiration and 15 temperature) of 3,000 years into 3375 files of 40 years.

Step6 – Readable input for HBV

The final step of the Pre-processor is the program **input_hbv.exe**. This program add necessary information to each of the files to make it them possible for HBV to read the data properly. During this final step a fictive date (1st of January 1901 – 31st of December 1940) will also be added to the files.

Files Pre-processor

cal_ep.exe : FORTRAN program executing step4
cal_temp.exe : FORTRAN program executing step3
cut_gen.exe : FORTRAN program executing step5
date.txt : Date file necessary during step6
This file contains a fictive date record from 1st of January 1901 – 31st of December 1940. The format of this file is: year (8) // month (8) // day (8)
The numbers between brackets represent the column width of the record. Due to HBV limitations the calculation period is fixed on 1901-1940.
em_areaXX.txt : E_{maand} files necessary during step4
XX represent the subbasin number from 01 to 15. In these files E_{maand} values have been blurred out over a period of four successive years with a leap year finishing the record. The files contain only evapotranspiration data which have to be located in the first eight positions of each file.
gzip.exe : Program executing step1
input_hbv.exe : FORTRAN program executing step6
p_trans.exe : FORTRAN program executing step2
pre_proc.bat : Batch file executing entire Pre-processor calculation sequence
tn_areaXX.txt : T_{norm} files necessary during step4
XX represent the subbasin number from 01 to 15. In these files T_{norm} values have been blurred out over a period of four successive years with a leap year finishing the record. The files contain only temperature values which have to be located in the first eight positions of each file.

Main-processor

Introduction

The Main-processor executes the actual rainfall-runoff module of the HBV-Meuse model. As stated before, instead of 3,000 years at once HBV will calculate 75 separate loops of 40 years. The linking between two sequent blocks have been realized by transforming the ‘end-state’ of the preceding block into an ‘initial state’ of the following block. The exceptional character of the calculation makes it necessary to avoid the HBV model interface. Figure 3 contains a schematic of the Main-processor which consists of two major steps. In the next section, every step and sub-step will be described in detail.

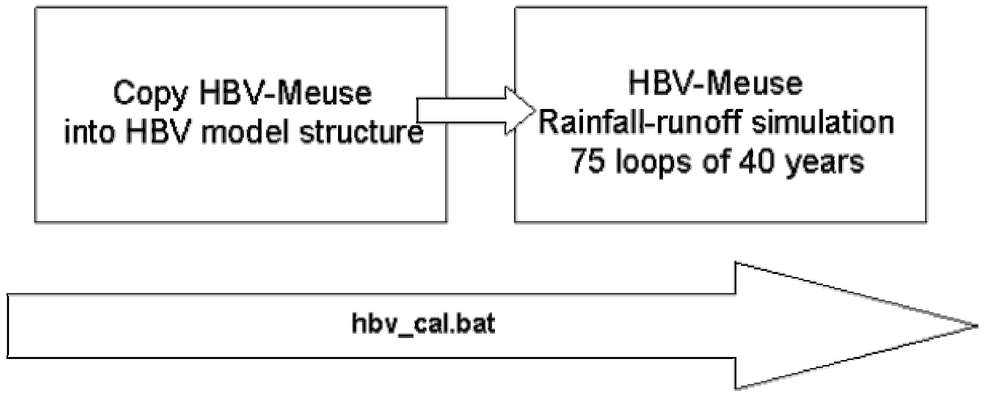


Figure 3 Schematic of Main-processor

<u>Step7 – Copy HBV-Meuse into HBV model structure</u>
The whole HBV-Meuse model will be copied in the HBV model structure during this step. Every file of the HBV-Meuse model is defined in such a way that the calculation of 3,000 years is possible. Furthermore, the executable files (**m_start.exe**, **d_addptq.exe**, **upd_inst.exe** and **err_check.exe**) will be copied to the designated destinations. The directory *c:\smhi\ihms\hbv_batch\output* is created for the output files for each subbasin.

<u>Step8 – Rainfall-runoff simulation</u>
Figure 4 shows the schematic of the rainfall runoff simulation. First 45 input files (precipitation, potential evapotranspiration and temperature of 15 subbasins) will be copied from the main input directory *c:\smhi\ihms\hbv_batch\input* to the HBV-input directory *c:\smhi\ihms\dat\meuse\input*. HBV will then read the input with the program **d_addptq.exe**. The initial state of the model has been defined during step7 when the HBV-Meuse model was copied. HBV-Meuse contains the first initial state condition, so the model is ready for the first simulation of 40 years. The rainfall-runoff module is executed with **m_start.exe**. After the computation two series of output files have been generated. First a **comp.txt** file for each subbasin is generated containing the most important output data like discharge and actual evapotranspiration. These files will be renamed to **output_gXX.txt** (XX describes the actual block number) and moved to the output directory *c:\smhi\ihms\hbv_batch\output\subbasinYY* (subbasinYY is the directory of the actual subbasin). The second series of output files consists of the end-state files for each subbasin. These files will be transformed to initial-state files with the program **upd_inst.exe**. After the replacement of the old initial-state files by the new ones, the procedure will be restarted. So totally, the sequence shown in figure 4 will be repeated 75 times. Additionally, an error checker have been constructed which will ultimately generate a log file (**hbv.log**) which describes if HBV had encountered any errors during reading input (**addptq.log**) and rainfall-runoff simulation (**mstart.log**). After the whole procedure it is advised to check the log file for eventual errors.

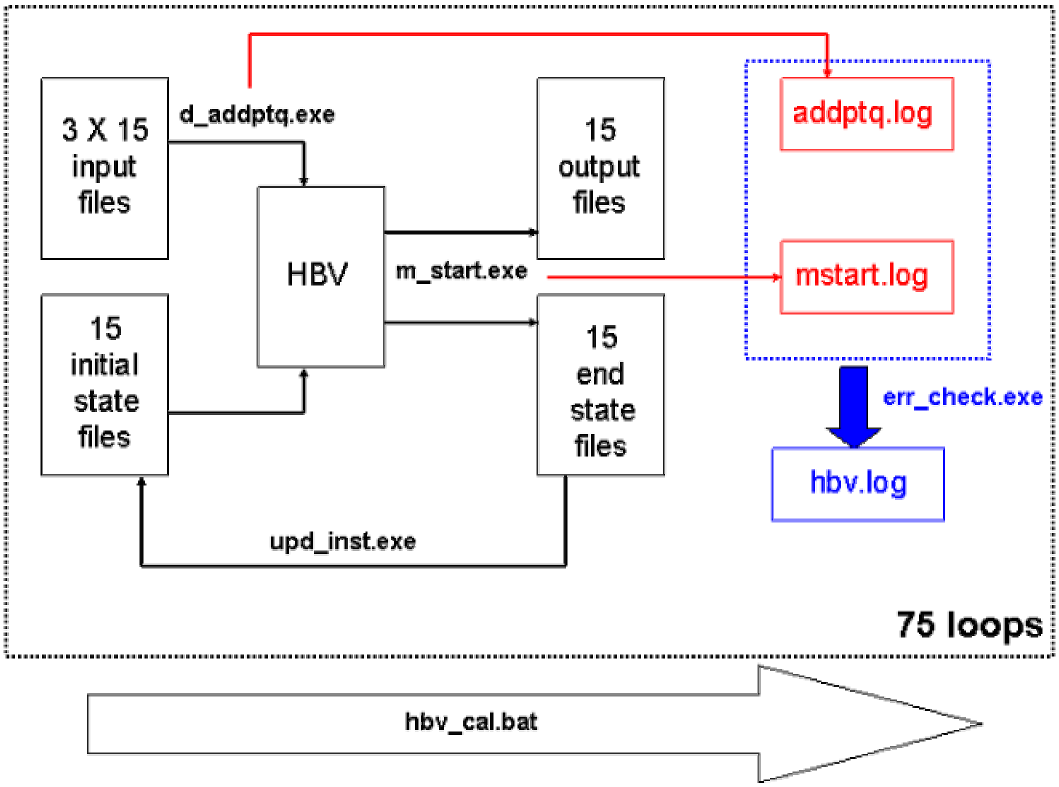


Figure 4 Schematic of HBV calculation of the Main-processor

Files and directories Main-processor

\meuse : HBV-Meuse model with all necessary model files
d_addptq.exe : HBV program which read the input files
This special version of the program prevents pop-up windows, so the input procedure will be terminated automatically.
district.par : HBV file
This file contains all information about district and directory structures.
err_check.exe : FORTRAN program executing error checker
The program scans the two log files (**mstart.log** and **addptq.log**) generated after every loop for words like 'error' and 'warning'.
hbv_cal.bat : Batch file executing Main-processor
m_start.exe : HBV program which execute rainfall-runoff simulation
This special version of the program prevents pop-up windows, so the rainfall-runoff simulation will be terminated automatically.
upd_inst.exe : FORTRAN program for transformation end-state files
Every subbasin has a similar program which transforms the end-state file to an initial state files. This procedure is linking all 75 calculation blocks together.

Detailed information about the HBV files in the */meuse* directory and **district.par** can be found in the HBV model manual (*SMHI, 1999*).

Post-processor

Introduction

The Post-processor is responsible for the output operation. Figure 5 gives the schematic of the procedure. It contains deleting needless information, combining the output to one file, output analysis tools and executing R-scripts. When the Post-processor and following the entire hbv_batch program is finished, the output will consist of 27 files. In the next section every step of the Post-processor will be described in more detail. More details about the output files can be found in the manual below.

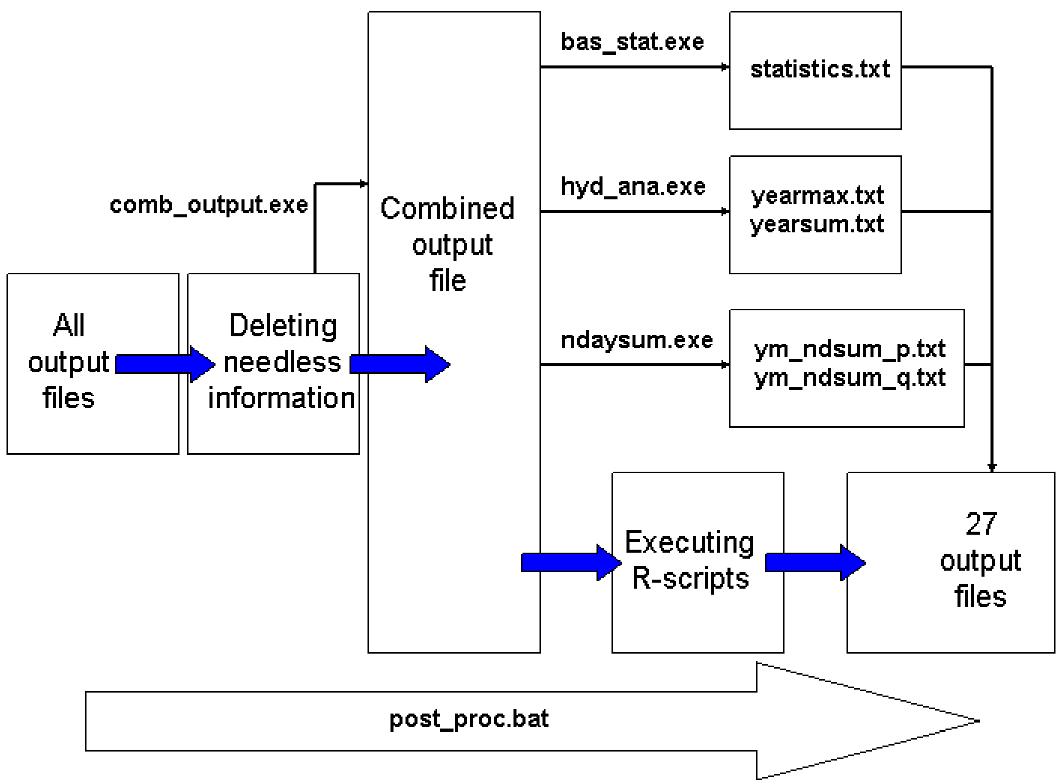


Figure 5 Schematic of Post-processor

Step9 – Deleting needless information

The first step of the Post-processor consists of the deleting of needless information. HBV generated a lot of output for each subbasin. During this step a division of important and needless output is executed. Actually, the deleting of files happens during the entire Post-processor procedure, but in favor of simplicity it is schematized in only one step. If some other data is required, it can be easily adapted by deleting some functions in the Post-processor.

Step10 – Combining output

During step10 the program **comb_output.exe** combines all 75 blocks containing 40 years to one file of 3,000 years. This file will be analyzed in the next steps.

Step11 – Basic statistics
The program **bas_stat.exe** will create a file (**statistics.txt**) with some basic statistics regarding daily precipitation, actual evapotranspiration and discharge.

Step12 – Hydrological yearmax and yearsum
Series of hydrological year maxima and year sums of precipitation, actual evapotranspiration and discharge are generated by the program **hyd_ana.exe**. Running this program yields into two files **yearmax.txt** and **yearsum.txt**.

Step13 – Ndaysum
The program **ndaysum.exe** calculate the annual maxima of 2-, 3-, 4- and 10-day sums for precipitation (**ym_ndsum_p.txt**) and discharge (**ym_ndsum_q.txt**).

Step14 – R-scripts
During step14 diverse statistical analyses will be executed regarding annual maxima of daily, 2-, 3-, 4- and 10-day data of precipitation and discharge. These analyses will be run with the program R (version 1.9.1, http://www.r-project.org). Before the hbv_batch program is able to function well, the R statistical program has to be installed on the hard disk.

Files Post-processor

bas_stat.exe	: FORTRAN program executing step11
comb_output.exe	: FORTRAN program executing step10
hyd_ana.exe	: FORTRAN program executing step12
ndaysum.exe	: FORTRAN program executing step13
post_proc.bat	: Batch file executing Post-processor
ym_2dsp_ana.R	: R-script step14 year maxima 2-day sum precipitation
ym_2dsq_ana.R	: R-script step14 year maxima 2-day sum discharge
ym_3dsp_ana.R	: R-script step14 year maxima 3-day sum precipitation
ym_3dsq_ana.R	: R-script step14 year maxima 3-day sum discharge
ym_4dsp_ana.R	: R-script step14 year maxima 4-day sum precipitation
ym_4dsq_ana.R	: R-script step14 year maxima 4-day sum discharge
ym_10dsp_ana.R	: R-script step14 year maxima 10-day sum precipitation
ym_10dsq_ana.R	: R-script step14 year maxima 10-day sum discharge
ym_p_ana.R	: R-script step14 year maxima daily precipitation
ym_q_ana.R	: R-script step14 year maxima daily discharge

Manual hbv_batch program

Installation

The entire program will be delivered as one zip-file, **RG_HBV-Meuse.zip**. The unzipping should be done in the *c:* root, because the necessary directory structure is already defined in the zip archive. After the files have been unzipped, a new directory (*c:\smhi\ihms\hbv_batch*) has been formed containing the automatic procedure. This new directory is divided into six subdirectories and three files.

/bl_ana : R-script for block analysis

This directory contains an R-script which can be used as an analysis tool for separate calculation loops of 40 years. The script is facultative and is not integrated in the automatic procedure.

/fortran : FORTRAN program codes

The codes of all FORTRAN programs, which are present in the automatic procedure, are listed in this directory. With the use of a Fortran-compiler is it possible to adapt and extend the programs. This directory is divided into the sub-directories for the Pre-, Main- and Post-processor.

/hbv_cal : Main-processor
/post_proc : Post-processor
/pre_proc : Pre-processor
/xtra_tools : Extra tools (FORTRAN & R-scripts)

Some extra tools for analyzing data and making graphs according to Gumbel and GEV plots are present in this directory.

KNMI-NG HBV-Maas 3000 : Shortcut to start the hbv_batch program
start.bat : Batch file executing the hbv_batch program
readme.doc : This manual text

Before the automatic procedure is able to run properly, the programs HBV and R (version 1.9.1, http://www.r-project.org) have to be installed in their default directories on the hard disk (*c:\smhi\ihms* respectively *c:\program files\r\rw1091*). The install program of R (**rw1091.exe**) will be delivered together with the **RG_HBV-Meuse.zip** file. Furthermore, it is important that the “evd” package has been installed in the R program. This can be done by starting R and use the “Install package(s)…” function from the “Packages” menu. Additionally, the user should make a directory *c:\smhi\ihms\hbv_batch\input* for the KNMI input files. Furthermore, the HBV model have to be manually run once on the computer.

Using the program

Input files
The KNMI input files have to be copied to the hbv_batch input directory (*c:\smhi\ihms\hbv_batch\input*). It is important that KNMI provide the same data files with the same structure and format for each separate calculation sequence. The KNMI input files (27) are:

- precipitation Maas Source-St.Mihiel (**area01.sim.gz**)
- precipitation Chiers (**area03.sim.gz**)
- precipitation Maas St.Mihiel-Stenay (**area02.sim.gz**)
- precipitation Maas Stenay-Chooz (**area04.sim.gz**)
- precipitation Semois (**area05.sim.gz**)
- precipitation Viroin (**area06.sim.gz**)
- precipitation Maas Chooz-Namur (**area07.sim.gz**)
- precipitation Lesse (**area08.sim.gz**)
- precipitation Sambre (Bel.) (**area9B.sim.gz**)
- precipitation Sambre (Fr.) (**area9F.sim.gz**)
- precipitation Ourthe (**area12.sim.gz**)
- precipitation Ambleve (**area13.sim.gz**)
- precipitation Vesdre (**area14.sim.gz**)
- precipitation Mehaigne (**area11.sim.gz**)
- precipitation Maas Namur-Borgharen (**area10.sim.gz**)
- precipitation Jeker (**area15.sim.gz**)
- temperature Aachen (**aachen.sim.gz**)
- temperature Beek (**beek.sim.gz**)
- temperature Chimay (**chimay.sim.gz**)
- temperature Dourbes (**dourbes.sim.gz**)
- temperature Ernage (**ernage.sim.gz**)
- temperature Forges (**forges.sim.gz**)
- temperature Lacuisine (**lacuis.sim.gz**)
- temperature Langres (**langes.sim.gz**)
- temperature Reims (**reims.sim.gz**)
- temperature St.Hubert (**sthubert.sim.gz**)
- temperature Uccle (**uccle.sim.gz**)

Starting
Before the program is started, it is important to realize that the program needs 5 GB of temporal hard disk space. The program can be cancelled during the run with CONTROL C, but this is not advisable because the program have to be installed all over again. Furthermore, due to file shifts it is necessary to start again with a fresh record of input files.
Starting the procedure is simple, run the **start.bat** file. The shortcut **KNMI-NG HBV-Maas 3000** is another way to start the hbv_batch program and can be copied to the desktop.

Output

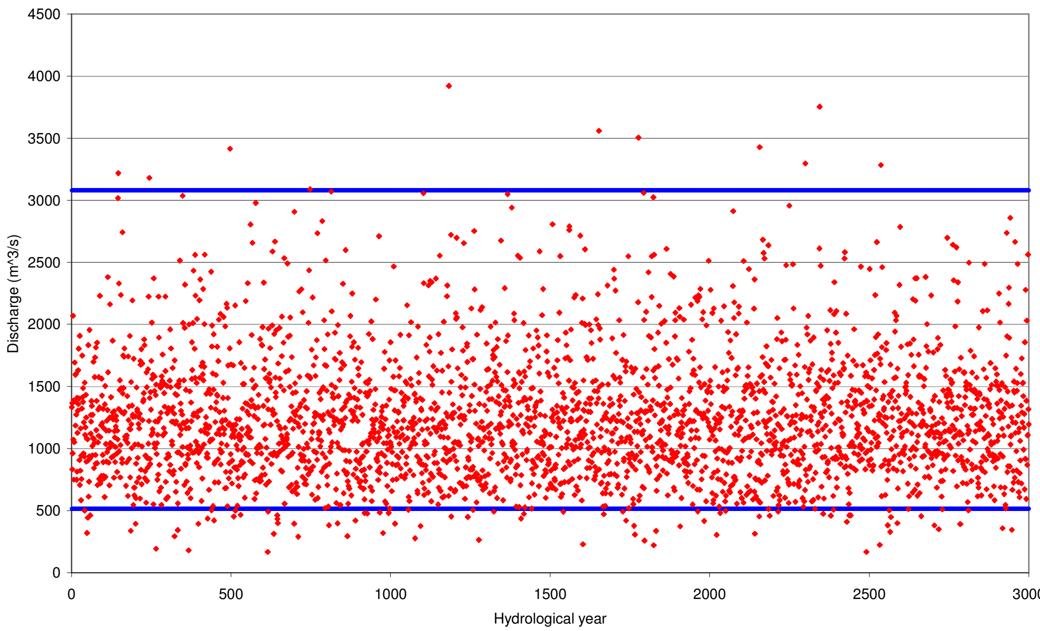
When the program is finished with the 3,000 year simulation, 27 output files have been generated in the directory *c:\smhi\ihms\hbv_batch\output*:

hbv.log : HBV log file (see also step8 & figure 4)
This file contains for 75 calculation blocks (Run01 till Run75) if the input reading and the HBV calculation encountered any errors. If an error did occur, the message is: “!!!ERROR!!!” instead of “Completed succesfully".
output_PEQ.txt : General output file
This is the most important file, because all other output files have been derived from this combined data file (figure 5). The format is:
Year (6) // Month (6) // Day (6) // Precipitation (10) // Act. ET (10) // Discharge (10)
The numbers between brackets represent the column width. The date is fictional and starts at 1st of January 0001.
statistics.txt : Basis statistics file (daily values)
This file contains daily average, minimum, maximum and standard deviation of precipitation, actual evapotranspiration and discharge over the entire period of 3,000 years.
yearmax.txt : Hydrological year maxima
This file contains the annual (hydrological year, starting at 1st October) year maxima of the precipitation, actual evapotranspiration and discharge. The format is:
Hydro. year (8) // Precip. (13) // Act. ET (13) // Discharge (17)
The #’s at the first position of the first two lines make the program R ignore that particularly lines.
yearsum.txt : Hydrological yearsum
In this file the hydrological year sums (mm) of precipitation, actual evapotranspiration and discharge are listed. Additionally, the rest term of the annual water balance ($R = P – ET_{act} - Q$) is added to the file. The format is:
Hydro. year (8) // Precip. (14) // Act. ET (13) // Discharge (13) // Rest term (11)
ym_2dsp_ana.ps : Statistical analysis year maxima 2-day running precipitation sum
Postscript file as result from an R-script which contains some statistical figures for the year maxima of the 2-day running precipitation sum. These analyses contain temporal distributions, histograms, cumulative distributions, Q-Q plots and diverse Gumbel and GEV analyses. Every postscript file (.ps) below contains a similar analysis.
ym_2dsp_ana.Rout : Basic statistics year maxima 2-day running precipitation sum
This text file contains the “screen-information” during the run of an R-script. It contains minima, 1st-quantiles, medians, means, 3rd-quantiles, maxima and standard deviations of the data in the **ym_ndsum_p.txt** file. The rest of the text can be ignored. The columns in **ym_ndsum_p.txt** correspond to the columns in the **ym_2dsp_ana.Rout** file. So, the latter file contains not only 2-day running sum data, but 3-, 4- and 10-day running sums as well. The data in for example **ym_4dsp_ana.Rout** will be the same. Every R output file (.Rout) below is described in a same matter.
ym_2dsq_ana.ps : Statistical analysis year maxima 2-day running discharge sum
ym_2dsq_ana.Rout : Basic statistics year maxima 2-day running discharge sum
ym_3dsp_ana.ps : Statistical analysis year maxima 3-day running precipitation sum
ym_3dsp_ana.Rout : Basic statistics year maxima 3-day running precipitation sum
ym_3dsq_ana.ps : Statistical analysis year maxima 3-day running discharge sum
ym_3dsq_ana.Rout : Basic statistics year maxima 3-day running discharge sum

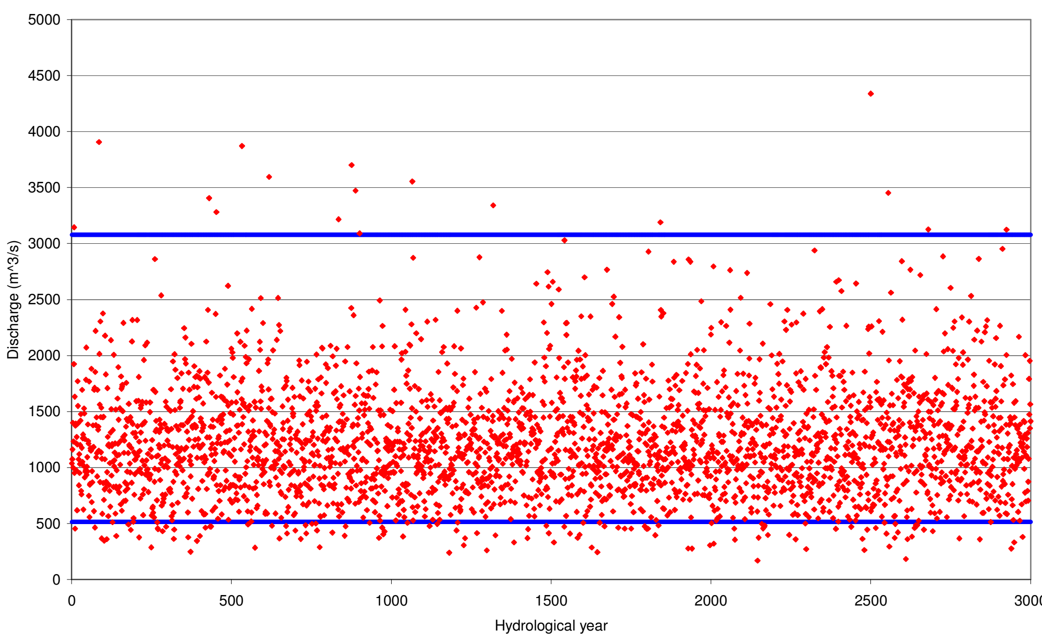
ym_4dsp_ana.ps : Statistical analysis year maxima 4-day running precipitation sum
ym_4dsp_ana.Rout : Basic statistics year maxima 4-day running precipitation sum
ym_4dsq_ana.ps : Statistical analysis year maxima 4-day running discharge sum
ym_4dsq_ana.Rout : Basic statistics year maxima 4-day running discharge sum
ym_10dsp_ana.ps : Statistical analysis year maxima 10-day running precipitation sum
ym_10dsp_ana.Rout : Basic statistics year maxima 10-day running precipitation sum
ym_10dsq_ana.ps : Statistical analysis year maxima 10-day running discharge sum
ym_10dsq_ana.Rout : Basic statistics year maxima 10-day running discharge sum
ym_ndsum_p.txt : Hydrological year maxima running precipitation sums
This file contains the annual (hydrologic) maxima of the 2-, 3-, 4- and 10-day running precipitation sums. All postscript (.ps) and R output (.Rout) files with precipitation ("p") and day-sum ("ds") in the filename have been derived from this general "precipitation n-day sum" file. The format of this file is:
Hydro. year (8) // 2-daysum (14) // 3-daysum (14) // 4-daysum (14) // 10-daysum (14)
ym_ndsum_q.txt : Hydrological year maxima running discharge sums
This file contains the annual (hydrologic) maxima of the 2-, 3-, 4- and 10-day running discharge sums. All postscript (.ps) and R output (.Rout) files with discharge ("q") and day-sum ("ds") in the filename have been derived from this general "discharge n-day sum" file. The format of this file is:
Hydro. year (8) // 2-daysum (14) // 3-daysum (14) // 4-daysum (14) // 10-daysum (14)
ym_p_ana.ps : Statistical analysis year maxima daily precipitation
ym_p_ana.Rout : Basic statistics year maxima daily precipitation
ym_q_ana.ps : Statistical analysis year maxima daily discharge
ym_q_ana.Rout : Basic statistics year maxima daily discharge

Annex 2 Simulated annual maxima (dots) and minimum and maximum measured year maxima (both lines)

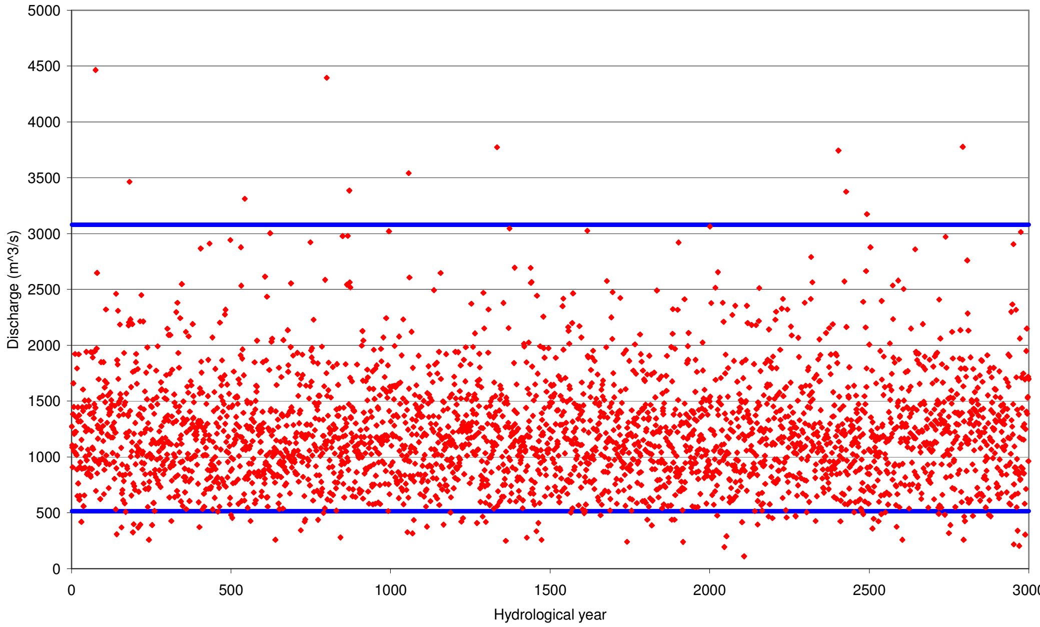
61sim2



61sim3



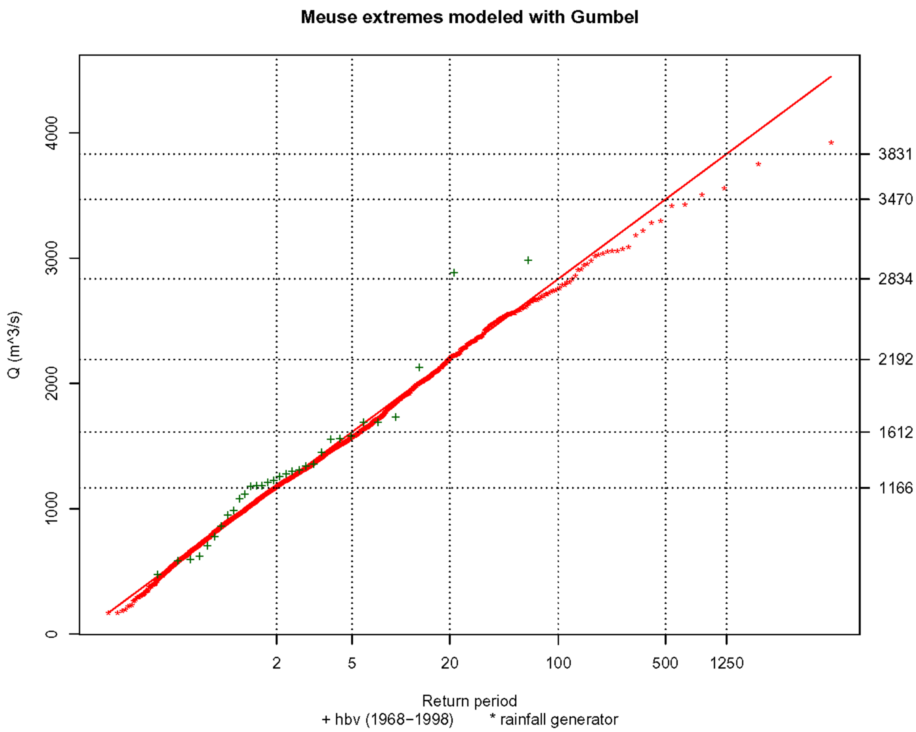
61sim4



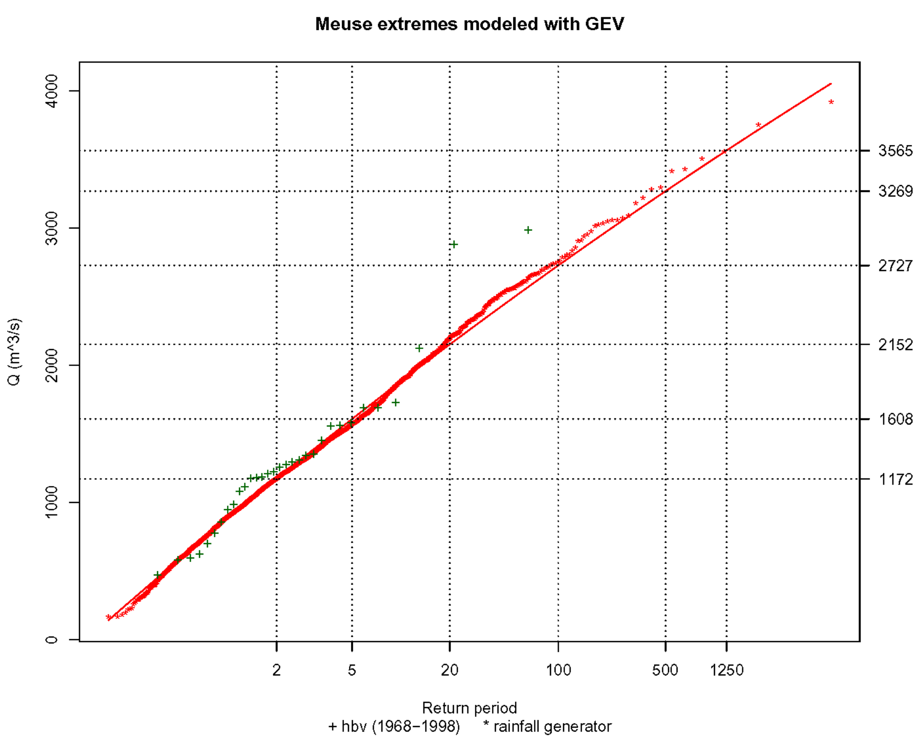
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Discharge (m^3/s)
0
500
1000
1500
2000
2500
3000
Hydrological year

Annex 3 Gumbel and GEV plots of measured, HBV 1968-1998 and generated annual discharge maxima

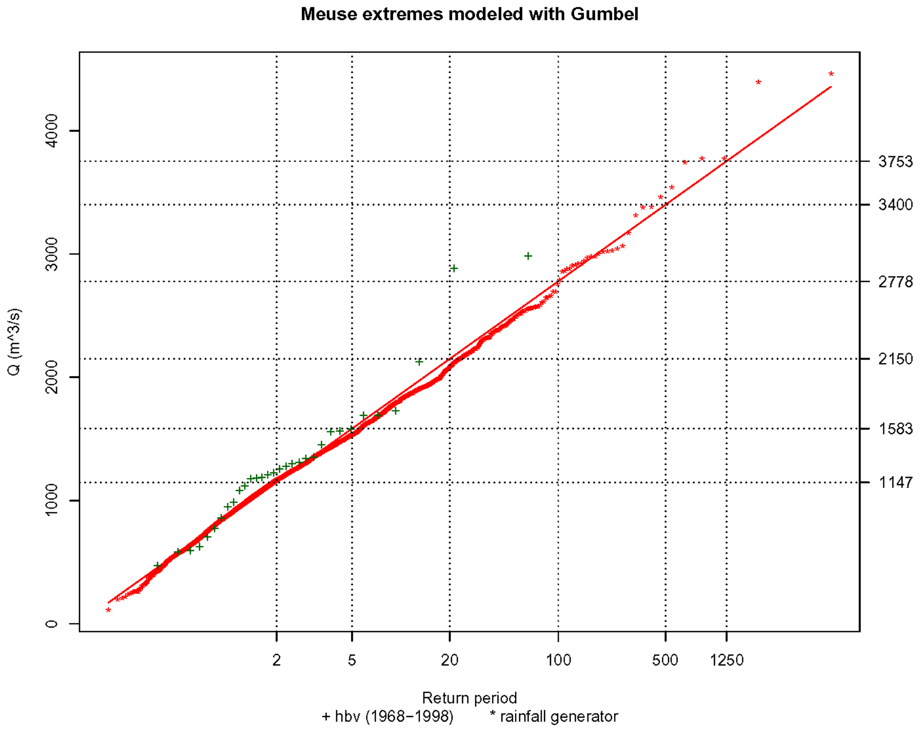
61sim2 - Gumbel



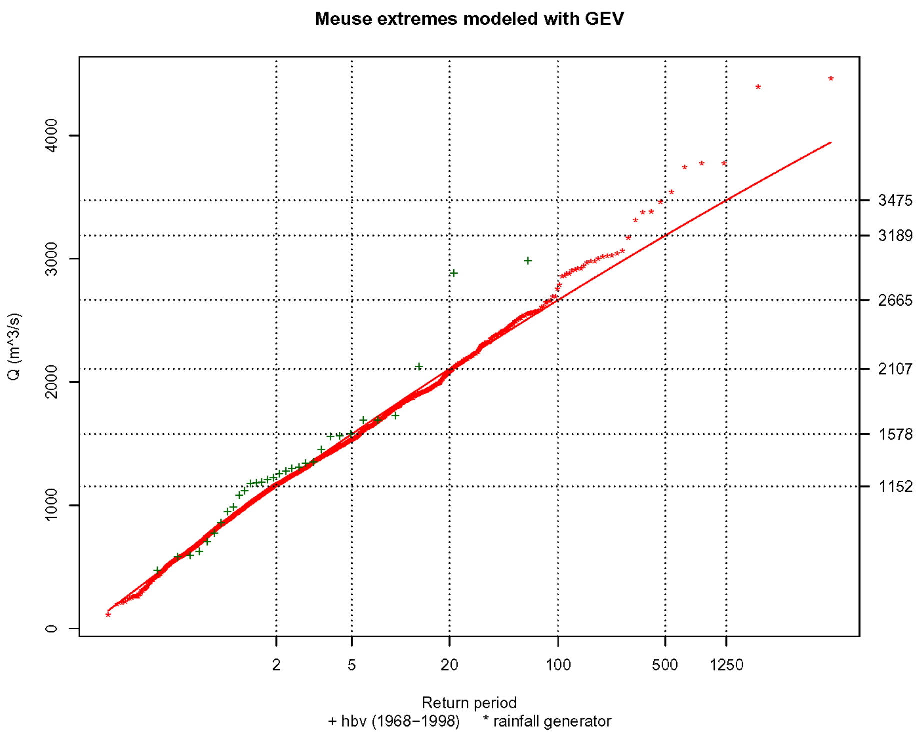
61sim2 – GEV



61sim4 - Gumbel

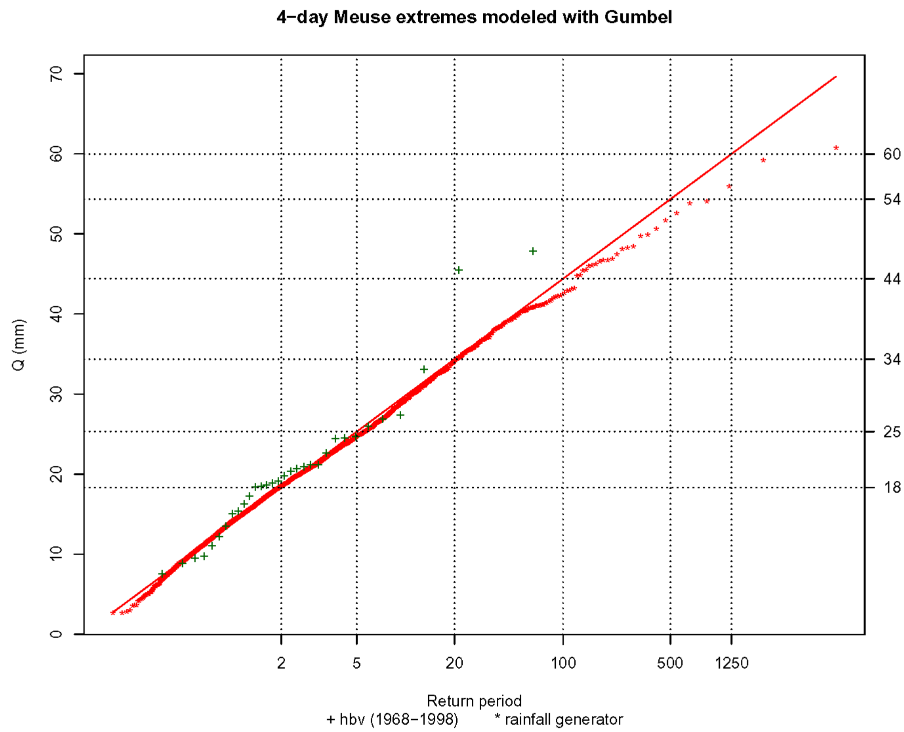


61sim4 – GEV

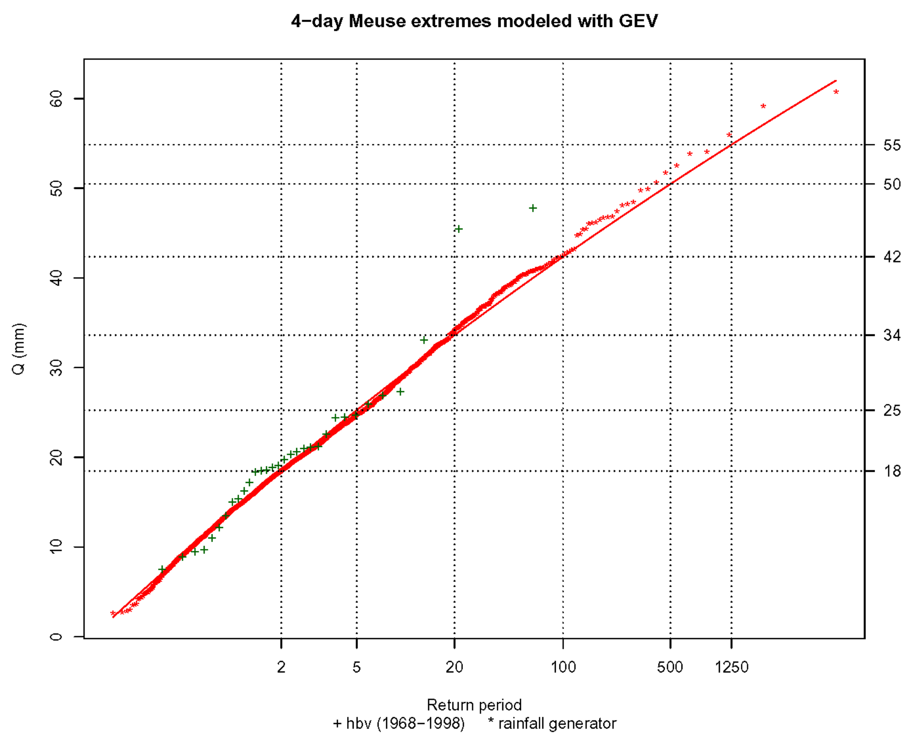


Annex 4 Gumbel and GEV plots of measured, HBV 1968-1998 and generated 4- and 10-day running discharge maxima

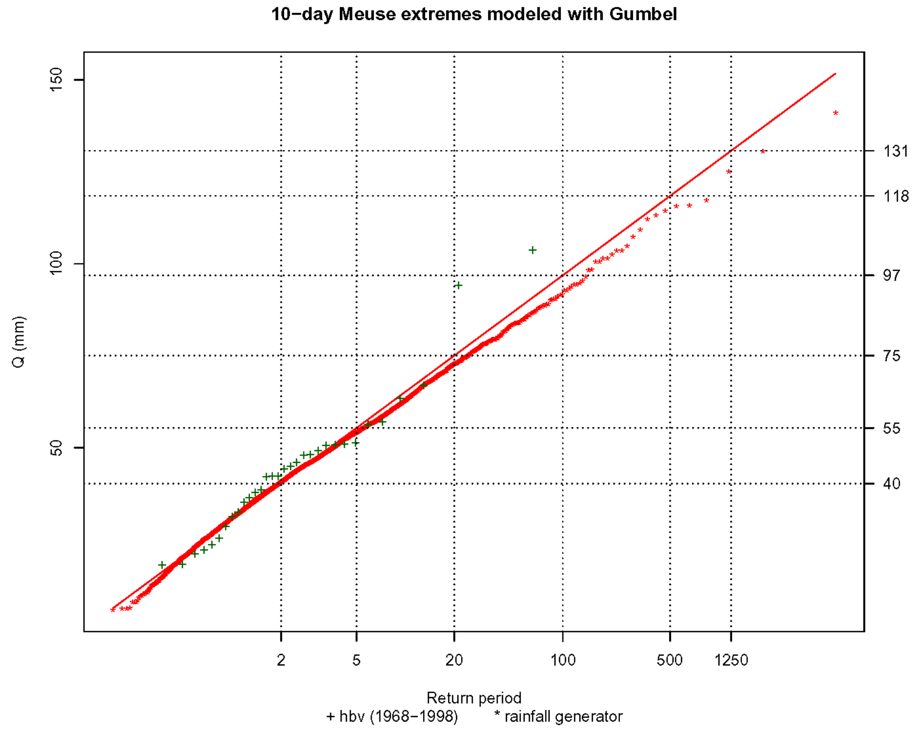
61sim2 – 4-day - Gumbel



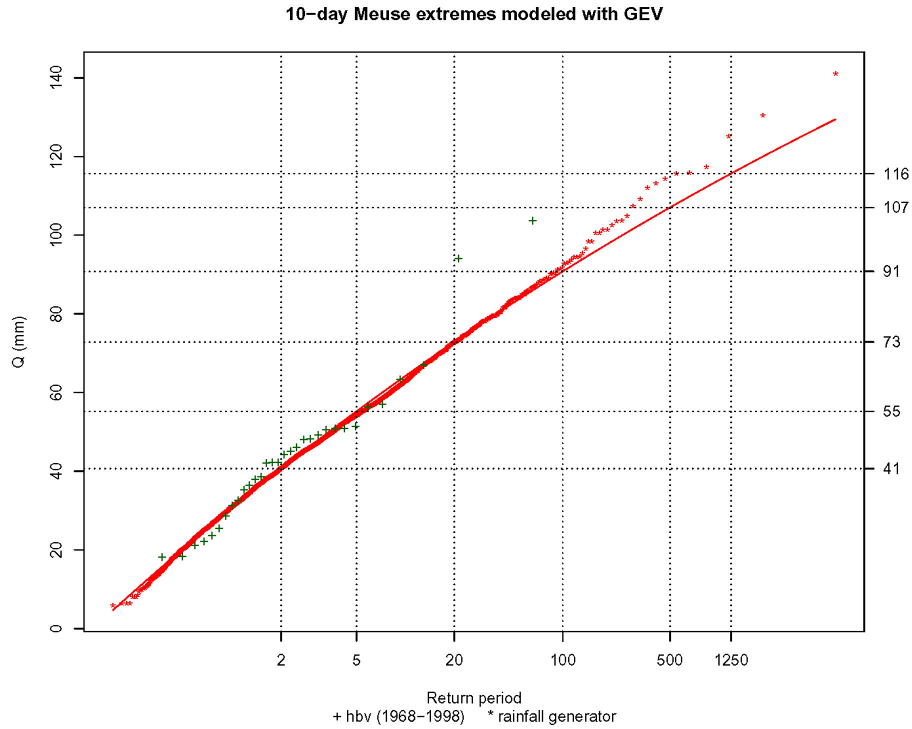
61sim2 – 4-day - GEV



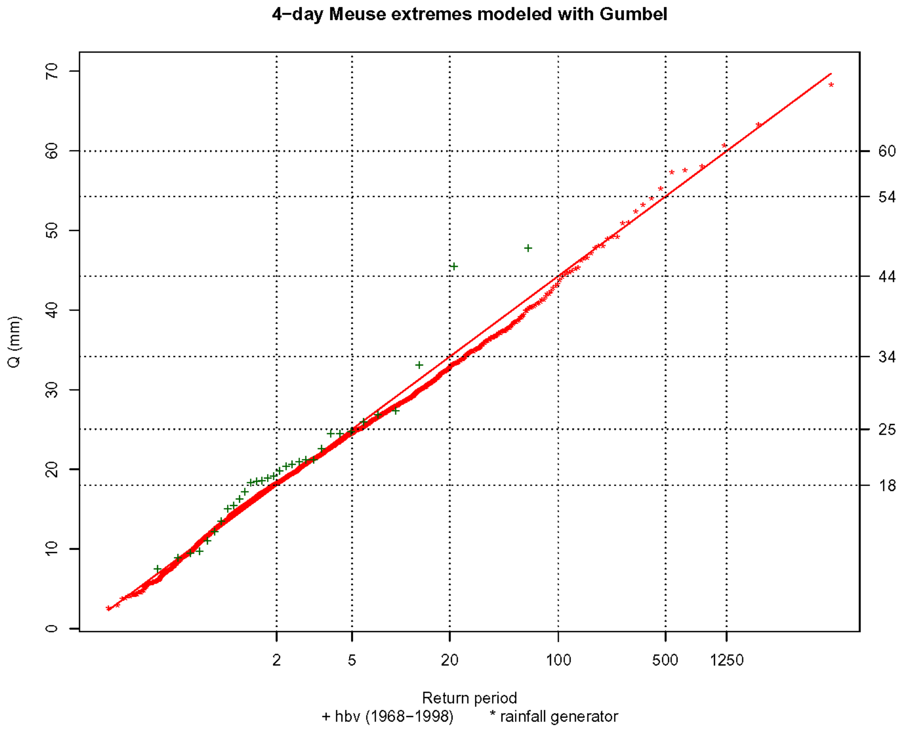
61sim2 – 10-day - Gumbel



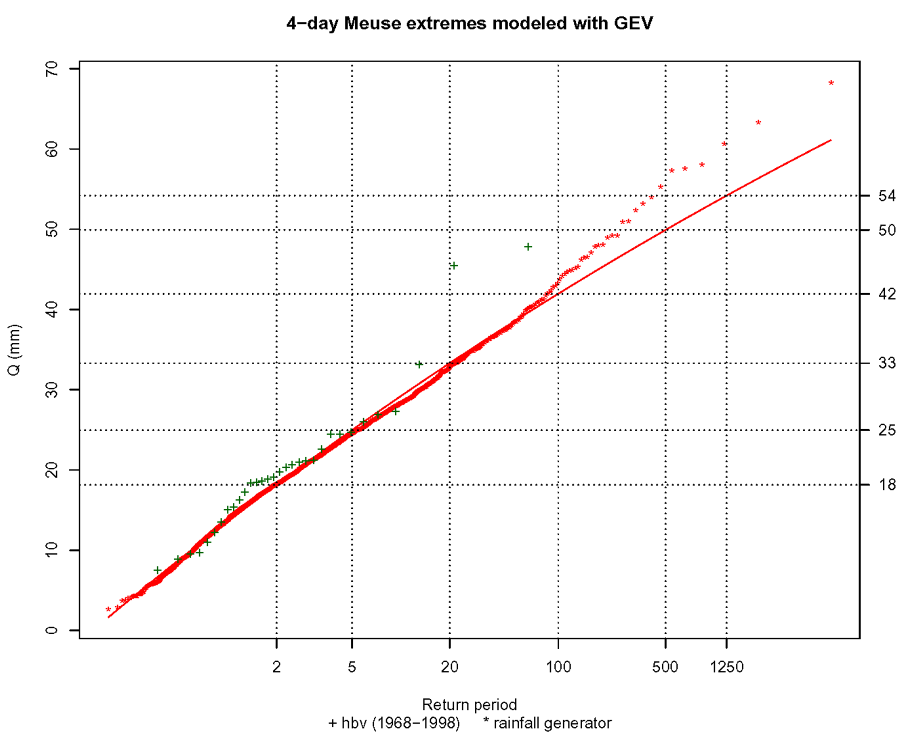
61sim2 – 10-day - GEV



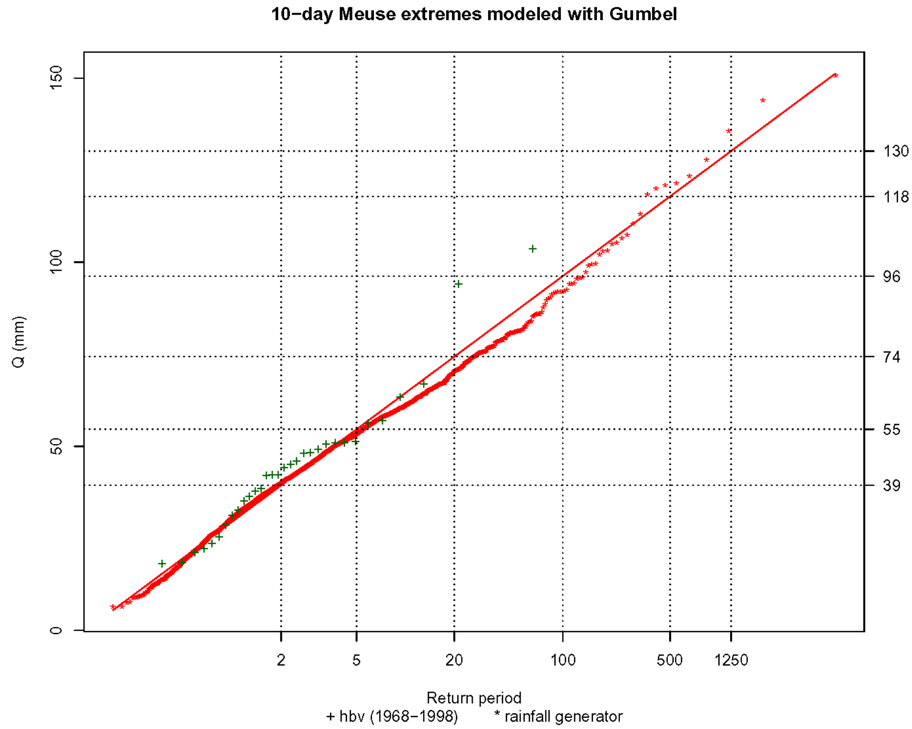
61sim3 – 4-day - Gumbel



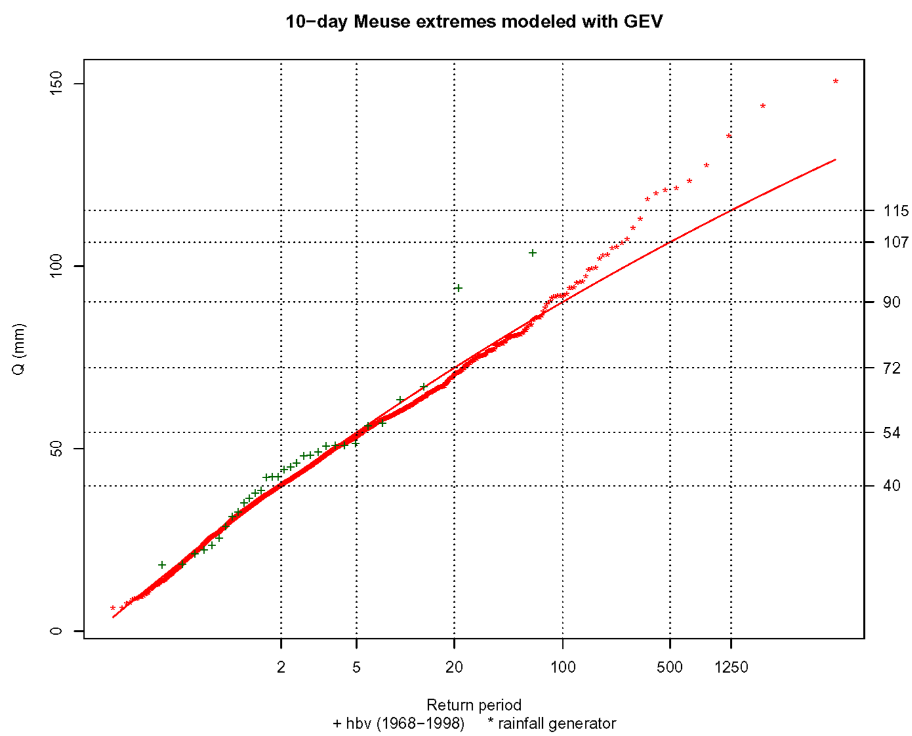
61sim3 – 4-day - GEV



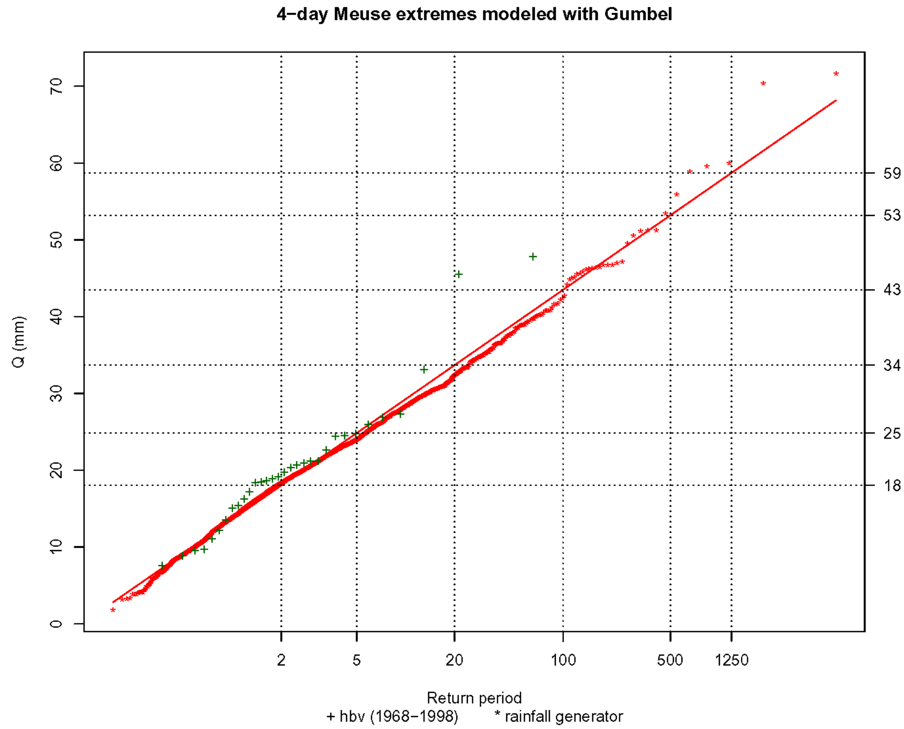
61sim3 – 10-day - Gumbel



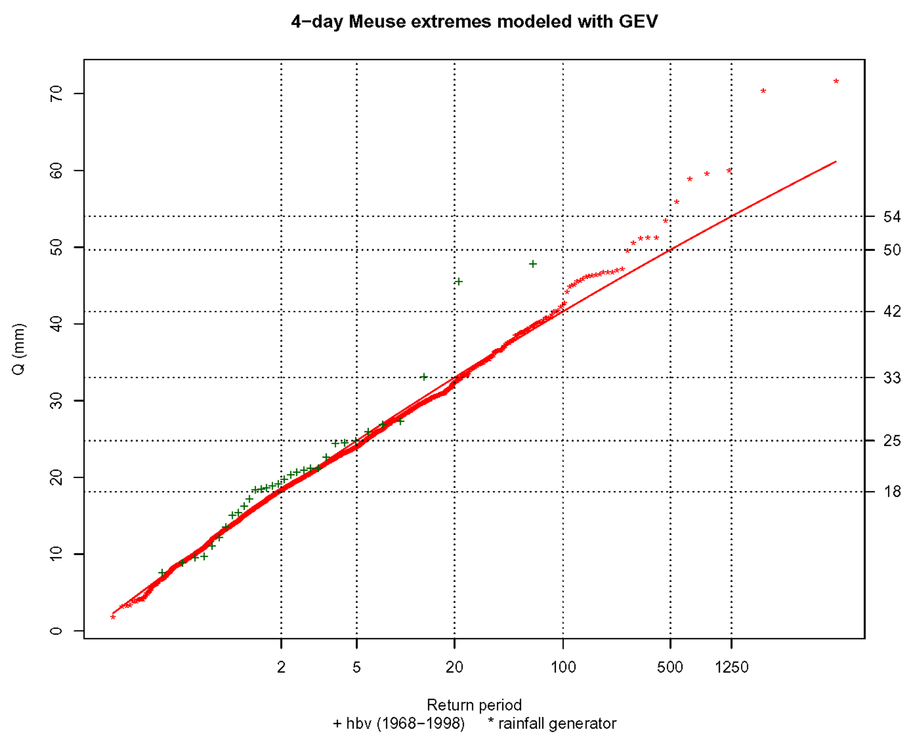
61sim3 – 10-day - GEV



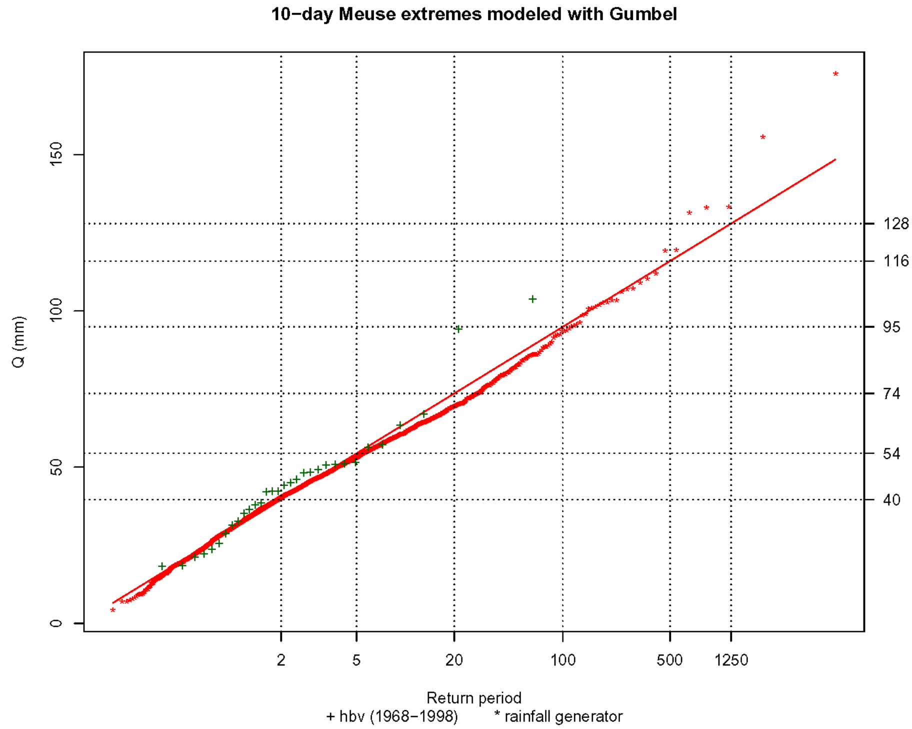
61sim4 – 4-day - Gumbel



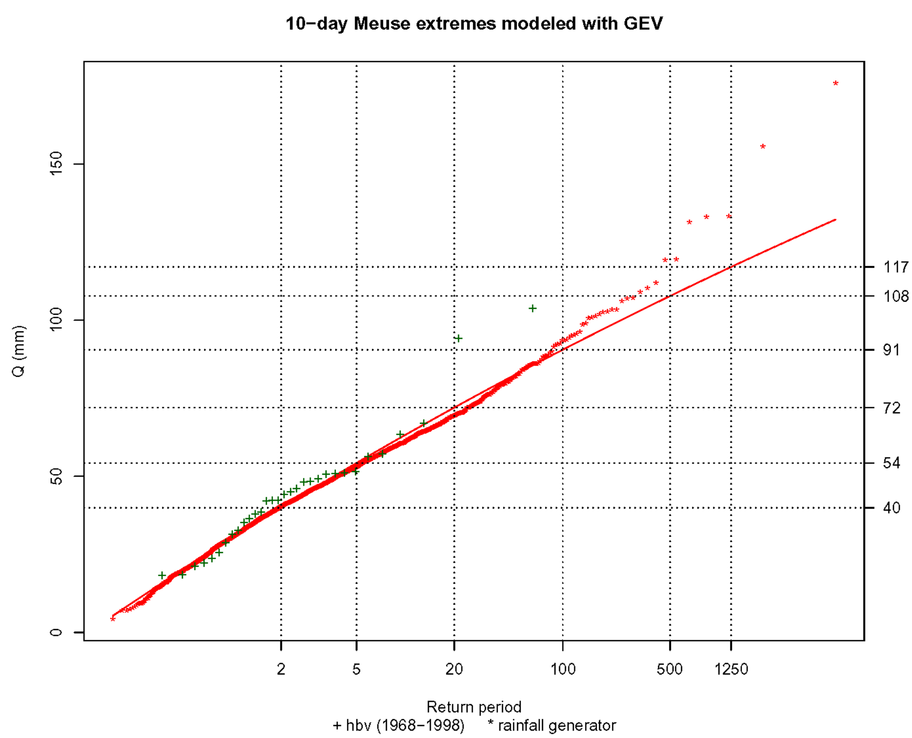
61sim4 – 4-day - GEV



61sim4 – 10-day - Gumbel

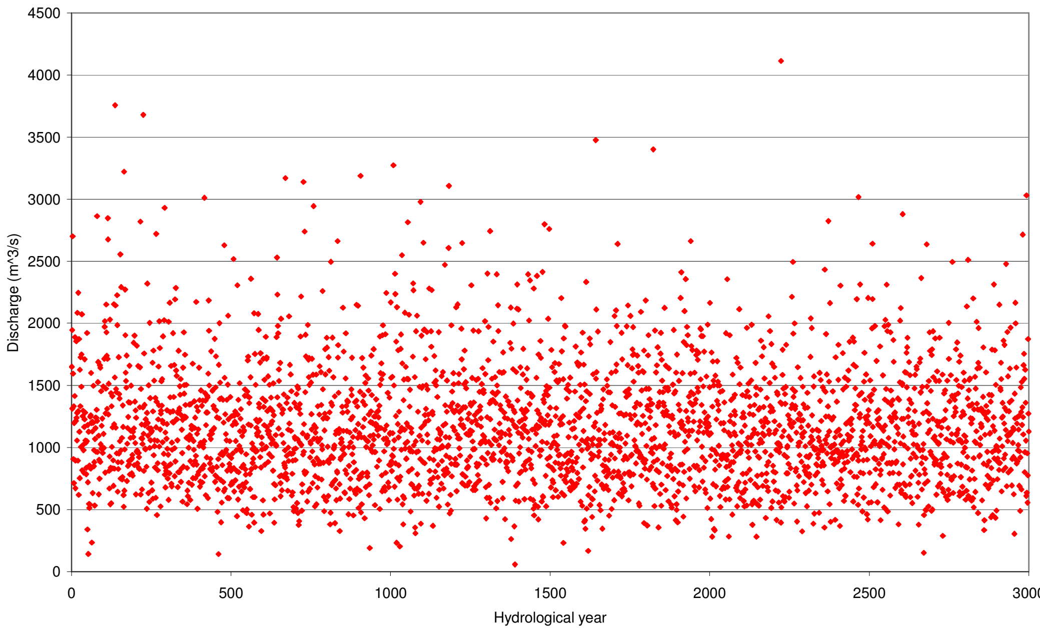


61sim4 – 10-day – GEV

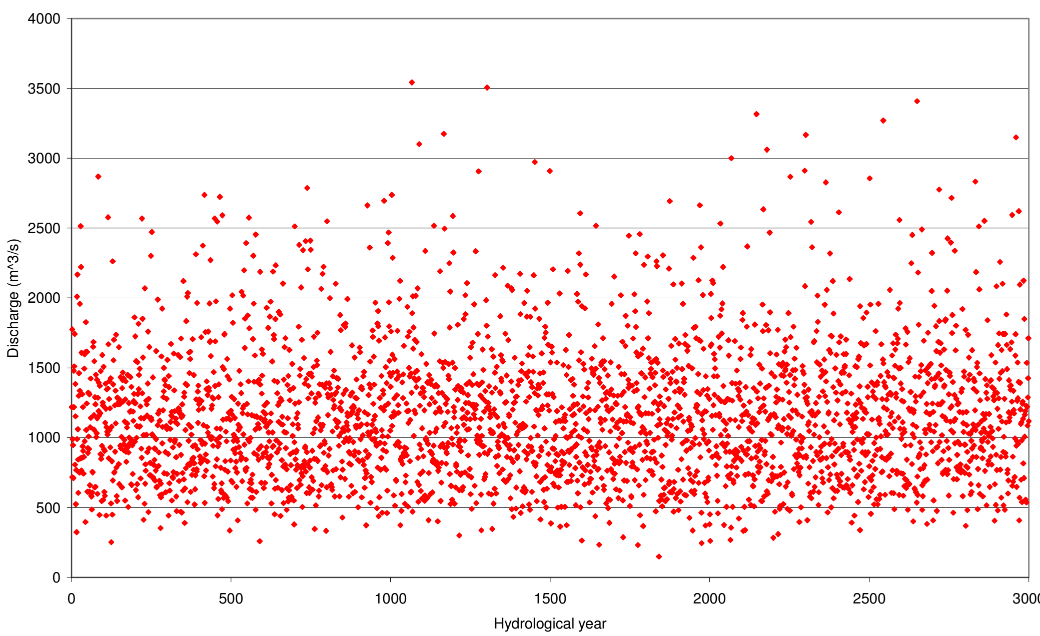


Annex 5 Simulated annual maxima (dots) and minimum and maximum measured year maxima (both lines)

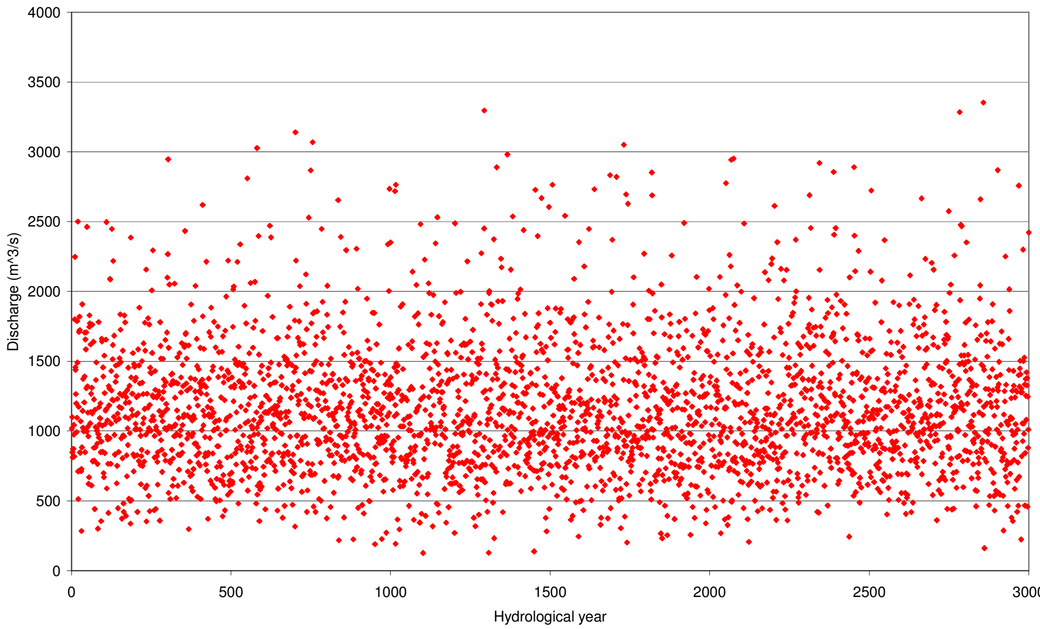
30sim2



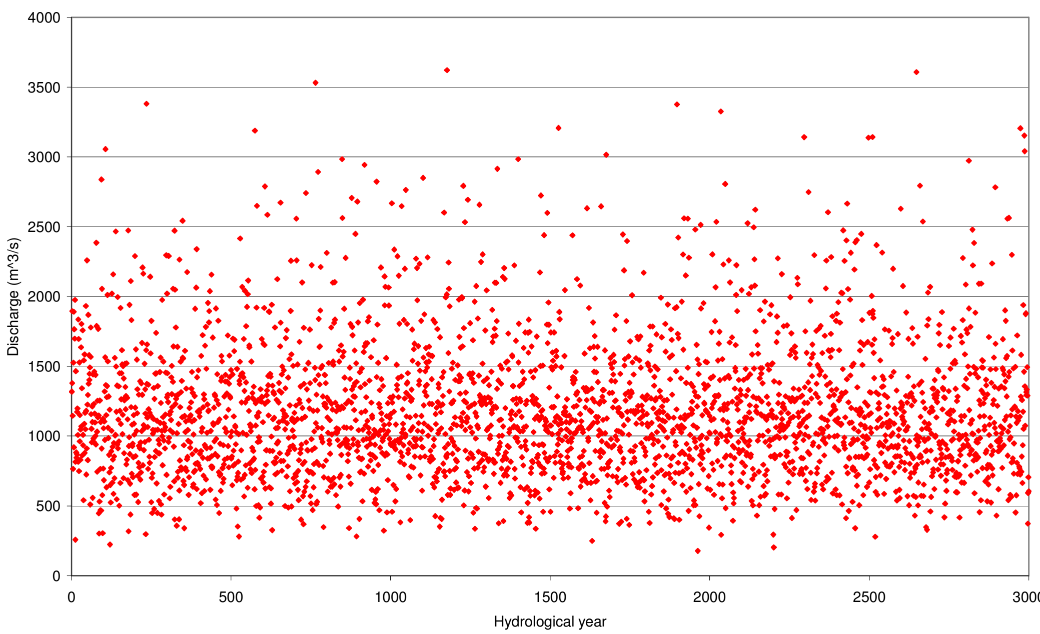
30sim3



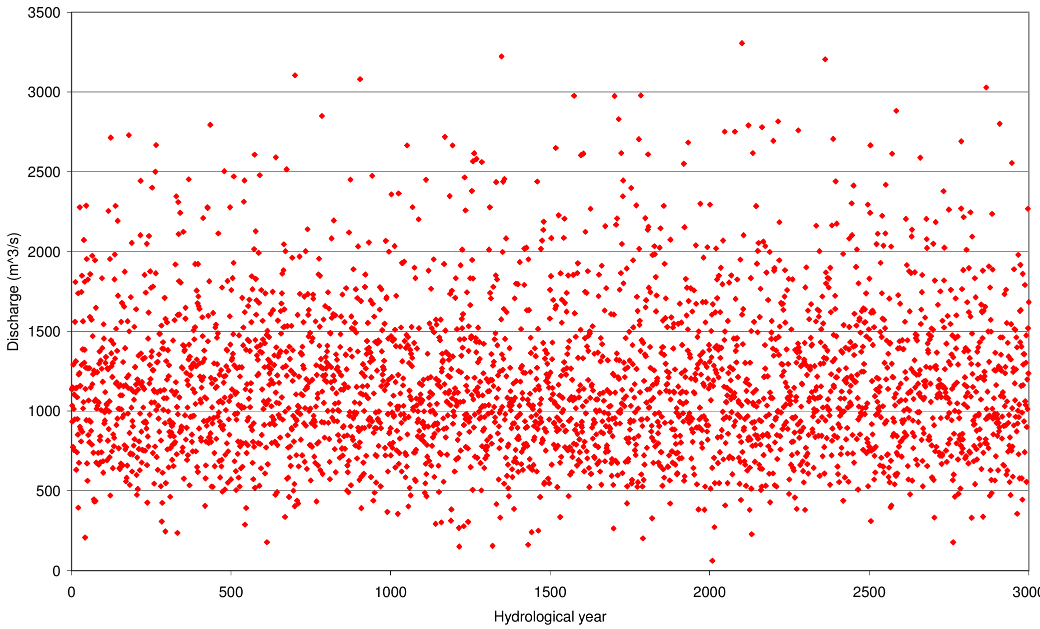
30sim4



30sim8 (LW)



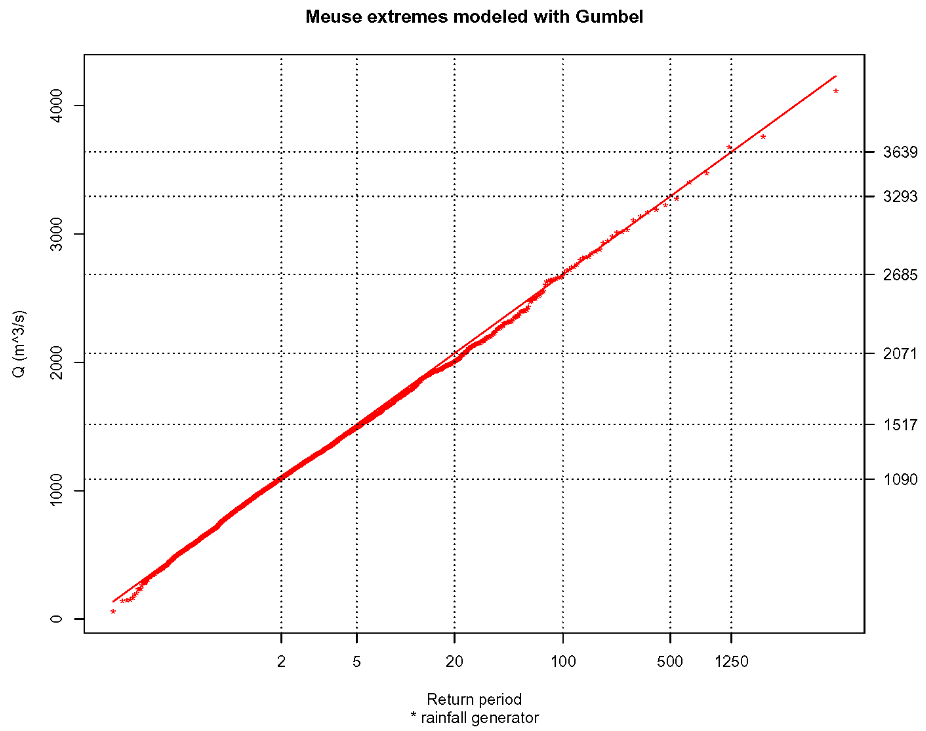
30sim9 (LW)



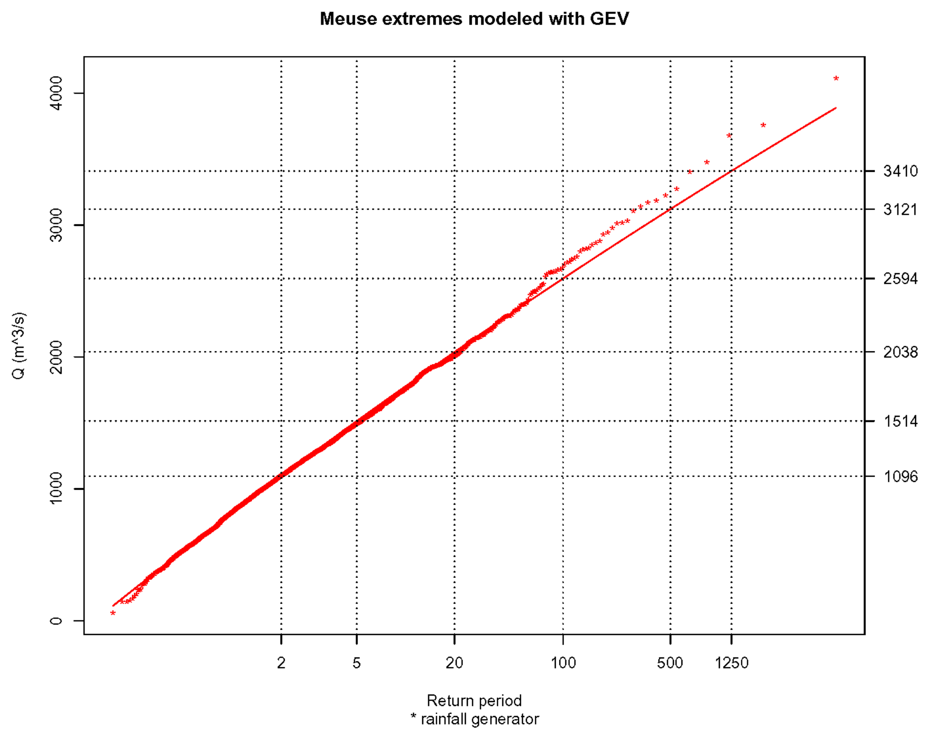
3500
3000
2500
2000
1500
1000
500
0
Discharge (m^3/s)
0
500
1000
1500
2000
2500
3000
Hydrological year

Annex 6 Gumbel and GEV plots of measured, HBV 1968-1998 and generated annual discharge maxima

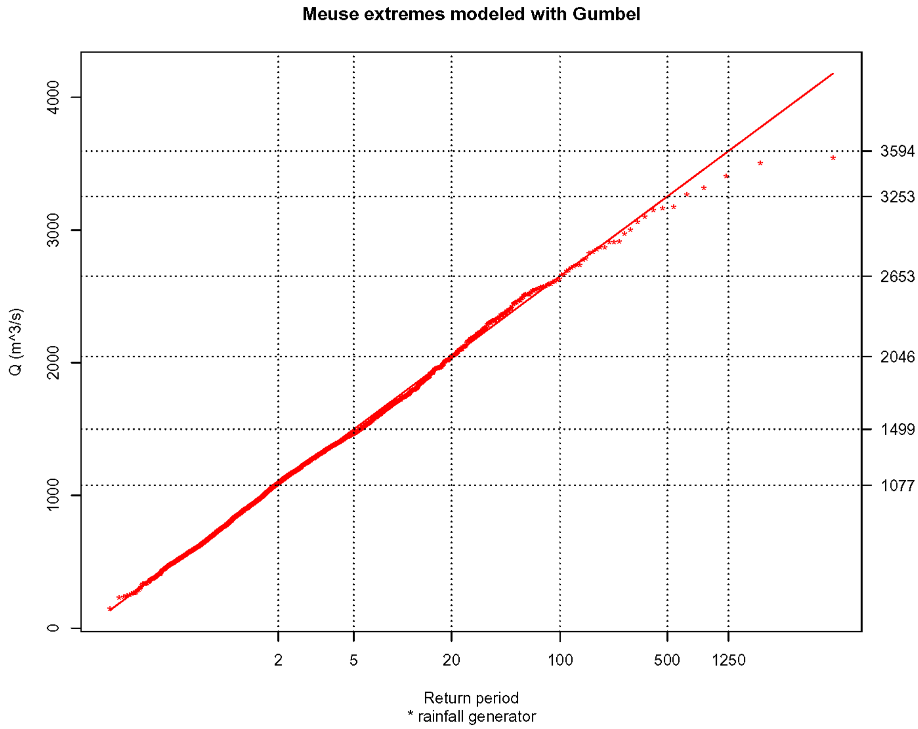
30sim2 - Gumbel



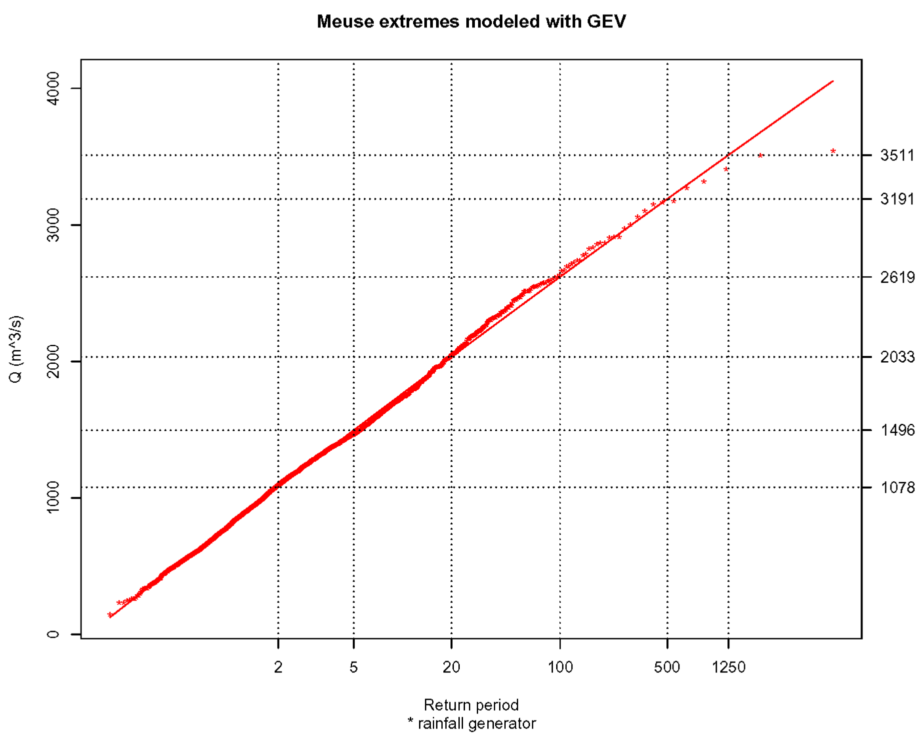
30sim2 – GEV



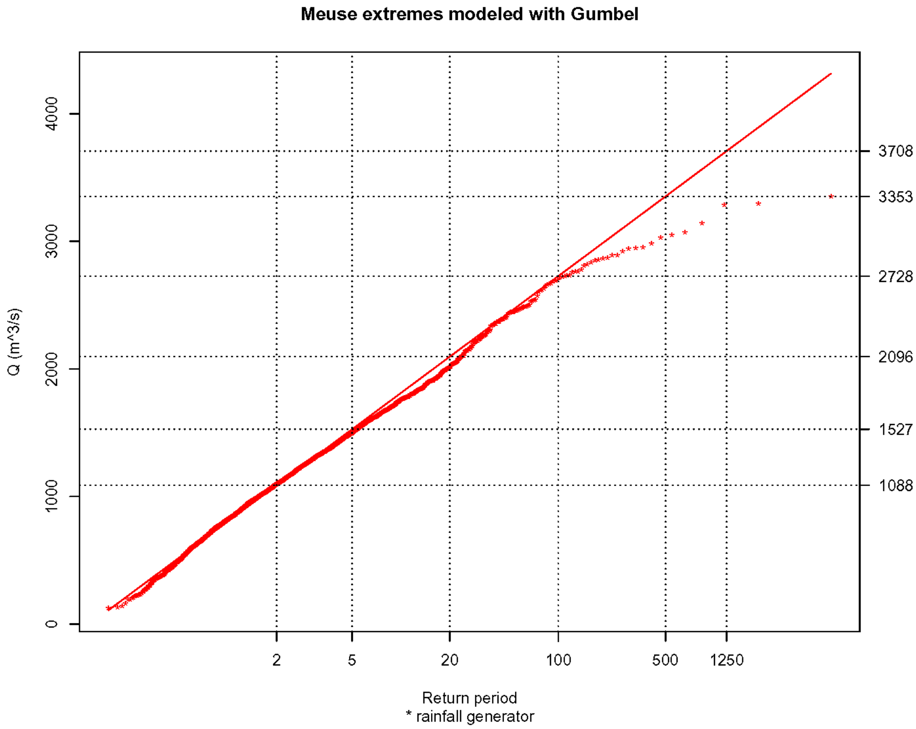
30sim3 - Gumbel



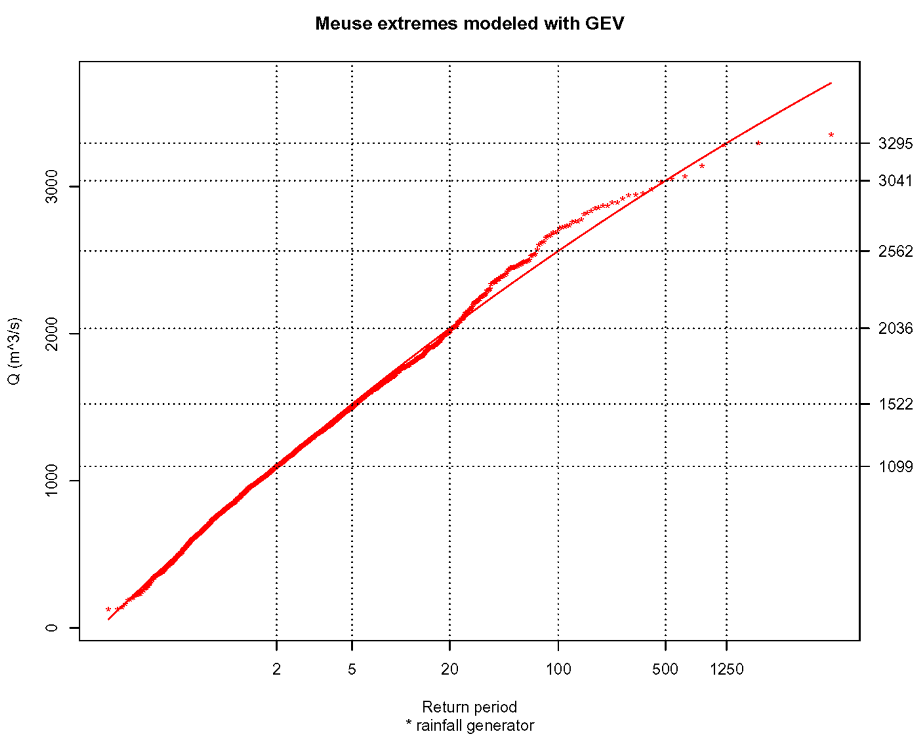
30sim3 – GEV



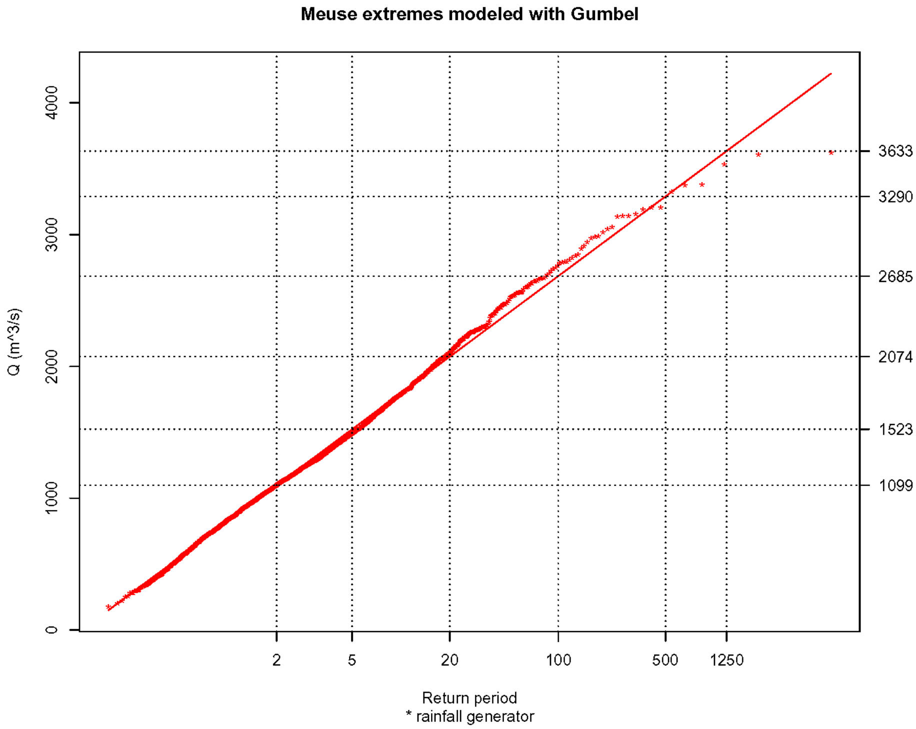
30sim4 - Gumbel



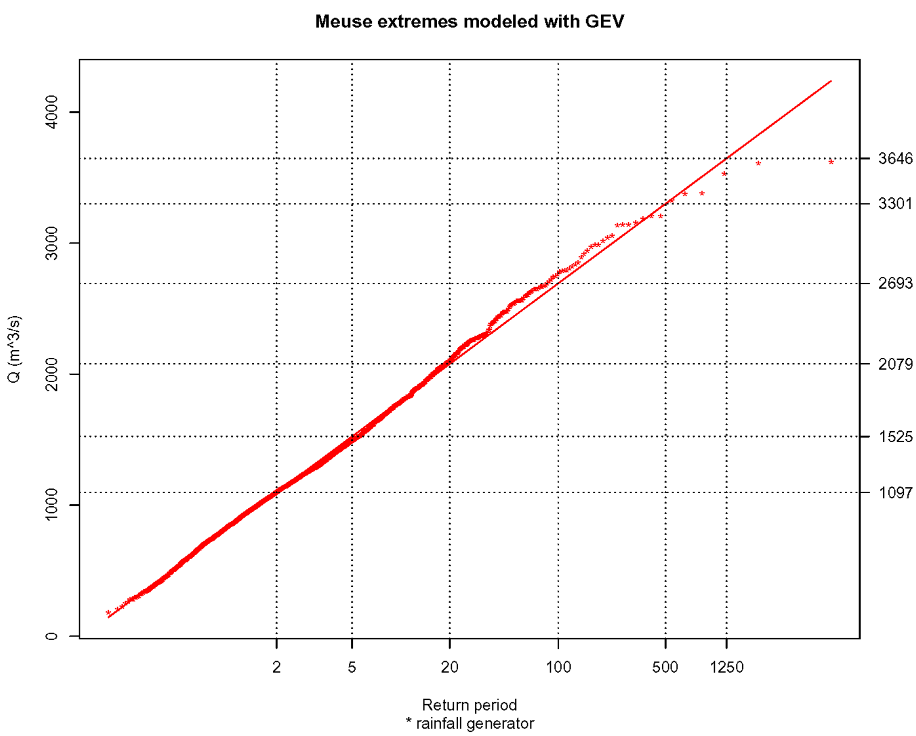
30sim4 – GEV



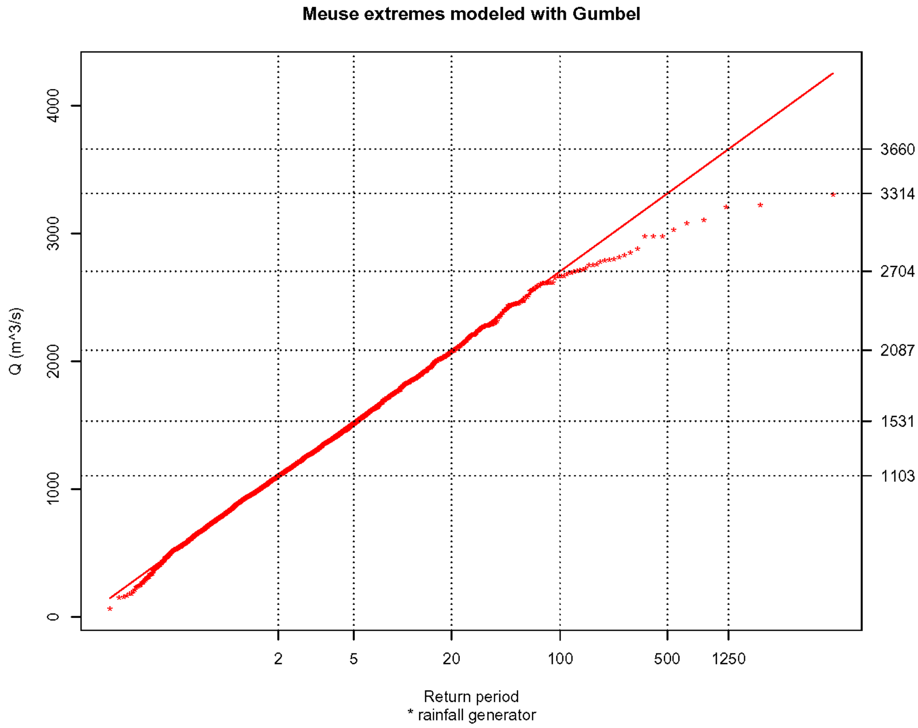
30sim8 (LW) - Gumbel



30sim8 (LW) – GEV



30sim9 (LW) - Gumbel



30sim9 (LW) – GEV