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Scientific Assistance towards a Probabilistic Formulation of Hydraulic Boundary Conditions

Test case for the Yser basin

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Test case for the Yser basin

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Abstract

A methodology for the probabilistic formulation of hydraulic boundary conditions is tested within a test case for the Yser basin. This navigable waterway in the Flanders Region of Belgium has its origin in Northern France and mouths in the North Sea in Nieuwpoort. A hydrodynamic model in the Mike11 software is made available by Flanders Hydraulics Research. The model has a downstream boundary in Nieuwpoort and seven upstream boundaries, i.e. the Yser in Roesbrugge and six tributaries of the Yser. The boundaries coincide with gauging stations. The time series available from the stations range from 20 to 40 years. On the basis of the time series, synthetic boundaries are generated for each of the boundaries. The time series have been validated. To reduce the uncertainty of an extreme value analysis, the length of the long-term time series should be maximized while taking care of the homogeneity of the time series in order to reduce bias. Correlation analysis indicates that the occurrence of extreme discharge events at the upstream boundary of the Yser (Roesbrugge) and high as well as low water levels at Nieuwpoort are independent. On the other hand it indicates that the occurrence of extreme discharge events at the upstream boundary of the Yser (Roesbrugge) and at a representative tributary of the Yser, i.e. the Poperingevaart, is dependent. Hence two dependency tests are considered: partial and full dependency of discharge at the Yser and the tributaries. In the first test a bivariate extreme value Copula analysis is applied to determine joint probabilities. In the second test a univariate extreme value analysis is applied to determine probabilities. On the basis of the probabilities, sets of synthetic events with known frequencies have been dressed up of for both tests. This yields in a considerably larger number of events in case of the Copula analysis. The two sets of synthetic events have been simulated with the hydrodynamic model. On the other hand a long-term simulation of 18 years of gauged data is executed as part of a validation. The simulation results are analysed in return level-return period plots for 12 check points along the Yser. The water levels and discharges based on the synthetic boundary conditions accord well with the levels and discharges on the basis of historic events in the long-term simulation. The synthetic events from the two dependency tests produce corresponding water levels and discharges in the case of the Yser basin.

Contents

List of tables

List of figures

1 INTRODUCTION

1.1 Scope of contract

Flanders Hydraulic Research (FHR) has commissioned IMDC NV to adapt its standardized methodology for rendering composite hydrographs, developed at KU Leuven (Willems 2001 & 2002), to recent evolutions (e.g. climate change), updated data series (e.g. recent measurements) and diversifying applications (e.g. coastal zone, flood risk calculations,…).

The project team consists of Sarah Doorme (advisor), Gert Leyssen (Jr. Eng.), Lorens Coorevits (Jr. Eng.) and Joris Blanckaert (Sr. Eng. and project manager for IMDC). On behalf of FHR, Eng. Fernando Pereira is in charge of the general supervision of the project. Eng. Toon Verwaest of FHR ministers scientific support towards coastal zone applications.

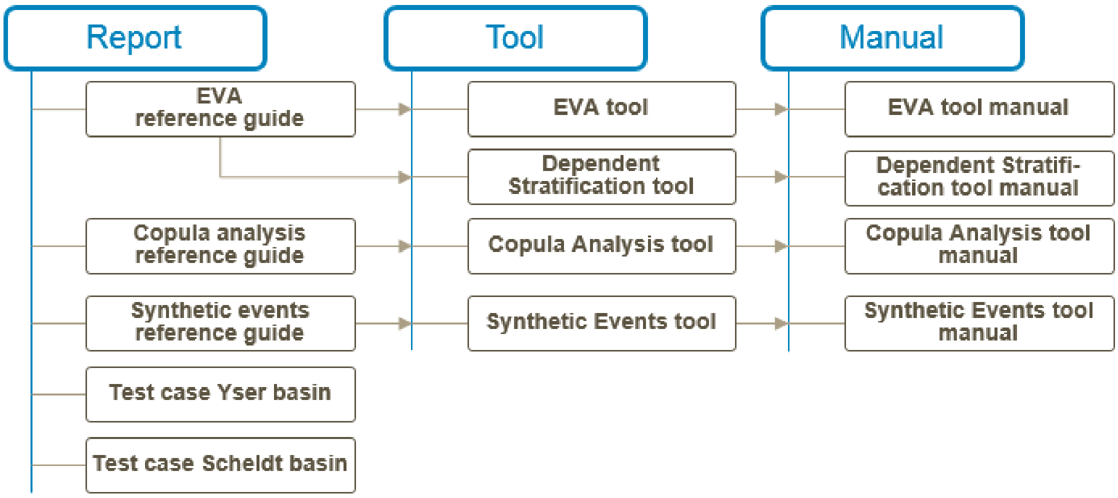
1.2 Overview

A new methodology is presented, which is based on extended literature review and expertise of the project team members. The methodology is described in a set of technical reports and is implemented in a suite of software tools for use in flood risk analysis and probabilistic design projects. The Graphical User Interfaces of the software tools are described in a set of manuals.

The new methodology is tested within two representative test cases, i.e. for the Yzer basin and the Scheldt basin (navigable waterways in Flanders). The test cases are described in two reports.

Figure 1-1 presents an overview of the reports, tools and manuals.

Figure 1-1: Overview of reports, tools and manuals



1.3 This report

This report describes the application of the methodology for the probabilistic formulation of hydraulic boundary conditions to the Belgian part of the Yser basin on the basis of a gauged dataset.

Chapter 2 gives a short description of the Yser basin and the modelled area. Chapter 3 situates the methodology in the framework of flood risk assessment. The gauged data available to generate the boundary conditions is presented and validated in Chapter 4.

In Chapter 5 correlation analysis between the downstream water level and upstream discharge boundaries and between the discharge of the Yser and its tributaries are treated. An extreme value analysis for discharges is performed in Chapter 6 in order to obtain extreme value distributions. On the basis of the correlations analysis in Chapter 5 joint probabilities are established for the boundaries of the Yser basin in Chapter 7. On the basis of the joint probabilities the extreme value distributions are stratified to obtain a set of extreme quantiles with a known frequency for each boundary. The time shift between the event peaks of the boundaries is determined in Chapter 8. In Chapter 9 a set of unit profiles is established for each boundary. In Chapter 10 the unit profiles are combined with the extreme quantiles and the time shift to obtain a set of synthetic events for each boundary. Furthermore boundaries are established for the ungauged catchments of the Yser basin.

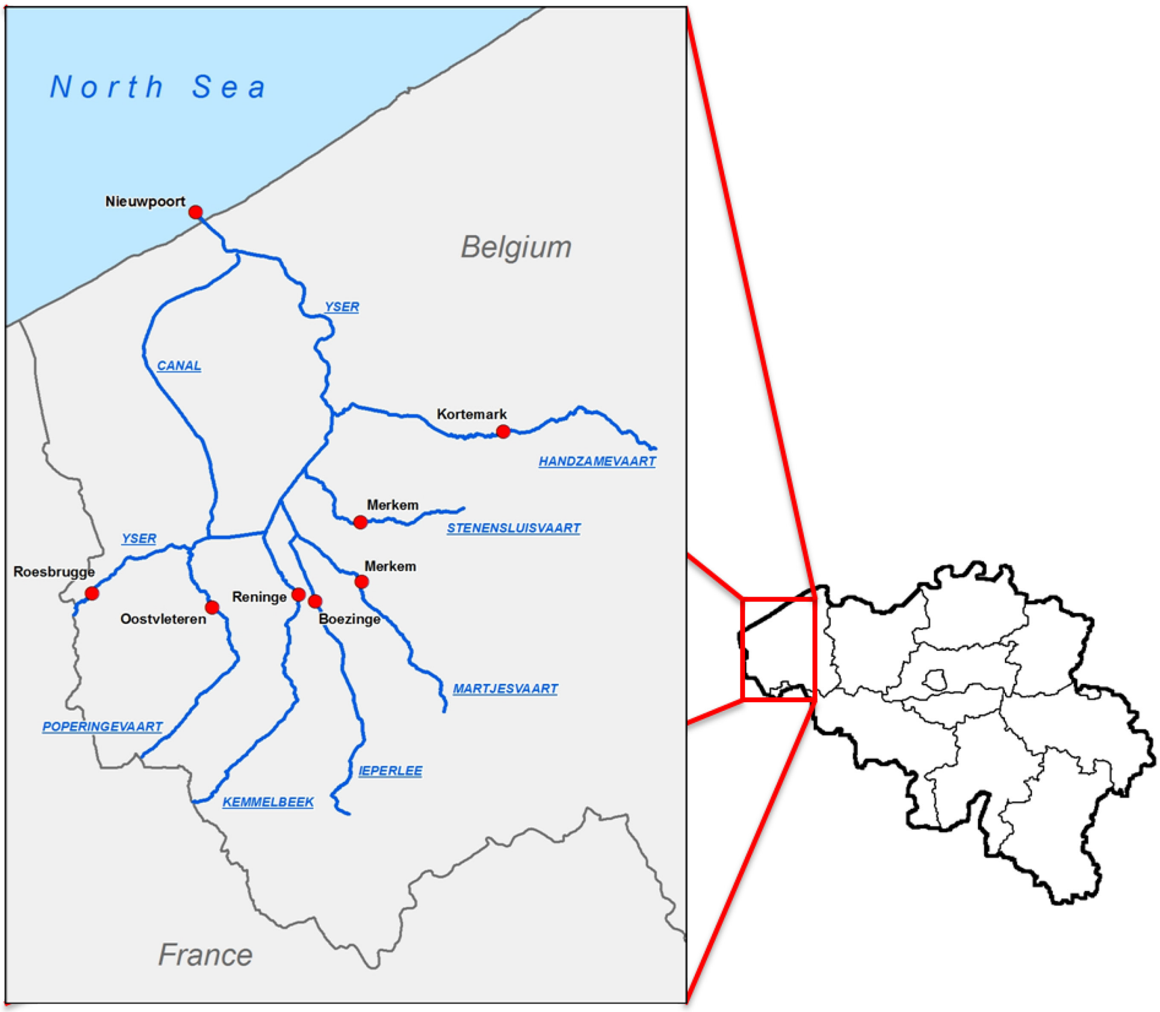
Chapter 11 gives an overview of the executed simulations of the synthetic events and of historical events. The results of the latter simulations are used to validate the results of the synthetic events simulations in Chapter 12. For the purpose of future scenario analysis a subset of normative events is selected on the basis of the results of the synthetic events simulations in Chapter 13. Chapter 14 presents the conclusions of the test case.

2 Yser Basin and model

The Yser is a river that has its origin in Northern France, has a total length of 78 km of which 45 km in Belgium and mouths in the North Sea through a control structure in Nieuwpoort. The total Yser basin has an area of 1101 km2, of which 730 km² in Belgium. The Belgian part consists of the Yser and six tributaries presented in Figure 2-1. Furthermore there is the Lo Canal through which part of the Yser flow can be diverted during high discharge events. During this events vast floods of mainly agricultural area occur along the Yser and its tributaries.

A hydrodynamic model made up in the Release 2011 version of the Mike11 software (DHI, 2011) of the Yser basin is made available by Flanders Hydraulics Research. The boundaries of the model are visualized in Figure 2-1 by means of red dots. They coincide with gauging station managed by Flanders Hydraulics Research and the Flemish Environment Agency (VMM). In this test case, for each of the boundaries a set of synthetic events is dressed up by applying the methodology for the probabilistic formulation of hydraulic boundary conditions.

Figure 2-1: The Yser Basin and the gauging stations (red dots) at the boundaries of the hydrodynamic Yser model



3 Overview of the Methodology

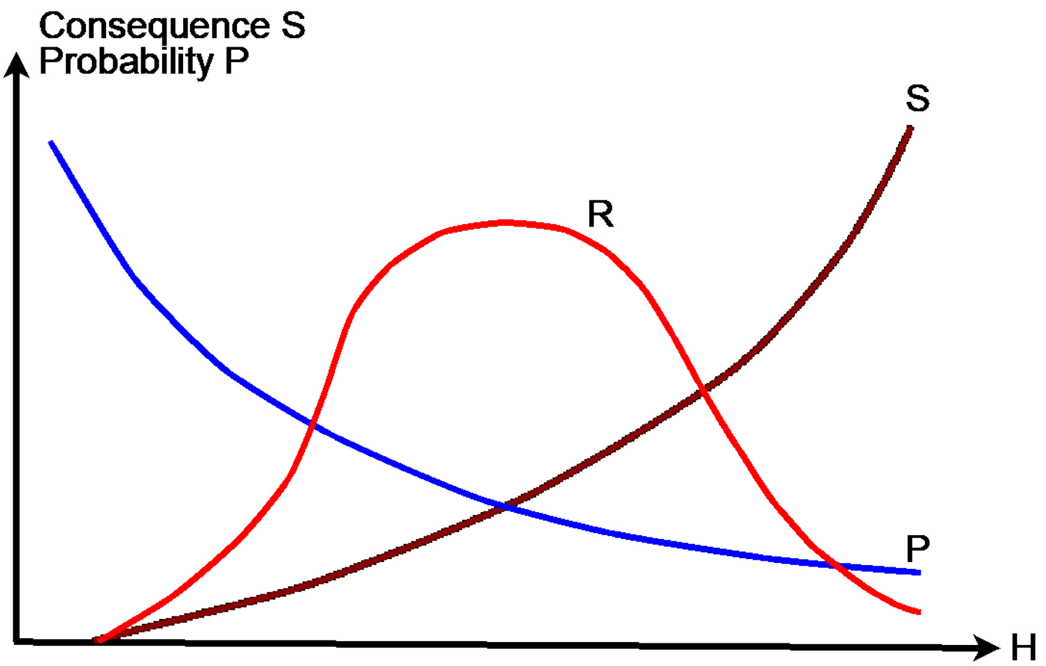
The proposed methodology of synthetic event allows the determination of return level, and therefore there risk, of the consequences with very high return period without the need to extrapolate historical consequences. The extrapolation of this historical consequences has the limit that the behaviour under more extreme events is not known. As example, a certain flood plain does not flood during the historical event but it will flood during the more extreme synthetic events. The extrapolation of historical inundation depths is not possible because of the simple fact that there are no historical inundations.

Risk by definition is being calculated by integrating consequences with their probabilities. A graphical explanation of the risk-concept is shown in Figure 3-1. In this graphic, total risk is represented by the surface beneath the R-curve, or integrating the consequences over the entire probabilistic domain as well as the flood area.

$$R = \int_{prob.dom.} \int_{flood\ area} Prob. \times Consequence$$

One can interpret the formula above as considering the probabilities of all possible events (likely as well as extremely unlikely) that might have a significant consequence. R usually converges asymptotically to a maximum, since flood risk consequences usually don't increase significantly for the extremely low probabilities.

Figure 3-1: Risk concept



Discretizing the integral yields

$$R = \sum_{prob.dom.} \sum_{flood\ area} Prob. \times Consequence$$

with a summation over the probability domain and the considered flood area. In Flanders different methodologies are being applied to evaluate the above expression, according to the discretization technique of the probability domain.

The proposed method strictly sticks to the above expression by a stratification of the probability domain in k classes or (hyper)cubes Δp, k being large enough to ensure convergence :

$$R = \sum_{i=1}^{k} \sum_{flood\ area} Consequence_i \times \Delta p_i$$

Hence a synthetic event will be designed for each single hypercube or class Δp.

The probability or frequency of each class is determined by taking into account the multivariate frequency of each of the boundary conditions, upstream Yser discharge, the discharge of the tributaries and the downstream water level in the North Sea.

4 Data Validation

An overview of the available time series at the boundaries of the Yser basin model is in Table 4-1. In the test case, for each of the boundaries a set of synthetic events is dressed up by applying the methodology for the probabilistic formulation of hydraulic boundary conditions. Below the data validation of the upstream and downstream boundary data is described.

Table 4-1: Overview of the gauging stations at the boundaries of the hydrodynamic Yser model and the period of available data

Boundary	Location	Code	Variable	Start	End
North Sea	Nieuwpoort	NPT-1069	WL	1971/01/01	2012/06/13
Yser	Roesbrugge	ijz06a-1066	Q	1987/01/01	2012/07/10
Poperingevaart	Oostvleteren	L01_491	Q, H	1972/02/16	2012-06-15
Kemmelbeek	Reninge	L01_492	Q, H	1986/05/14	2012-06-15
Ieperlee	Boezinge	L01_495	Q, H	1978/06/01	2012-06-15
Martjesvaart	Merkem	L01_496	Q, H	1986/05/05	2012-06-13
Stenensluisvaart /Steenbeek	Merkem	L01_499 L01_49A	Q, H	1990/09/05 2005/12/02	2009/12/02 2012/06/16
Handzamevaart	Kortemark	L01_488	Q, H	1994/04/13	2012-06-15

4.1 Upstream boundary data

The discharge and water level time series of the navigable waterways were provided by the HIC (“Hydrologisch Informatiecentrum”) and those of the tributaries or unnavigable waterways by the VMM (Vlaamse Milieumaatschappij, http://www.waterinfo.be).

The discharge values are derived from gauged water levels in combination with a rating curve (QH relation). The data is validated by making scatterplots of the simultaneous water level and discharge data and checking for inconstancies. Changes to QH relations are not considered as inconsistencies.

The figures of the discharge and the water levels validation with full explanation can be found in Appendix A. A summary is given in Table 4-2. The data of 2000 at the Ieperlee and the Martjesvaart show a strange relationship between the water level and the discharge starting from 2000/02/29. Because 2000 is a leap year, a possible error in the Q or H data is assumed to lead to this time shift. At the end of 2000 this shift stops. These dates are corrected. Some small obvious errors are also corrected in the various datasets.

The available data periods at the upstream boundaries range from 18 to 40 years.

Table 4-2: Overview of the data validation of the upstream boundary data

Boundary	Location	Validation
Yser	Roesbrugge	No modifications applied. No inconsistencies
Poperingevaart	Oostvleteren	No modifications applied. No inconsistencies. Two QH rating curves used to derive discharge.
Kemmelbeek	Reninge	No modifications applied. Linear trend in water level time series, multiple QH rating curves used.
Ieperlee	Boezinge	Time shift applied in 2000
Martjesvaart	Merkem	Time shift applied in 2000, discarded 2 events, very steep QH curve above 2.5 m TAW
Stenensluisvaart/Steenbeek	Merkem	Combination of station 499 and 49A, Discarded some suspicious events
Handzamevaart	Kortemark	New QH rating curve applied for high water levels, discarded suspicious data

4.2 Downstream boundary data

A water level time series with a frequency of 10 minutes starting from 2001 is available in the harbor of Nieuwpoort. The high and low water levels of this dataset are determined. In a previous project (IMDC, 2004) a long-term low water and high water time series in Nieuwpoort is determined based on the low and high waters in Ostend (Figure 4-1). This set is combined with the recent data to obtain a long-term high and low water dataset. This long dataset is necessary to estimate the linear trend together with the influence of the nodal tide. The nodal tide has a period of 18.61 years. So it is important that the time series is longer than this period to make a fit possible. The trend fitting is performed on the yearly averaged high and low waters (Figure 4-2 and Figure 4-3). By applying the linear form on the low and high waters a detrended time series (H2010) for the year 2010 is calculated out of the original water level (H):

$$HW_{2010} = HW + (2010 - Time_{HW}) * 0.20$$

$$LW_{2010} = LW + (2010 - Time_{LW}) * 0.27$$

This dataset will be used in the further extreme value analysis (Figure 4-4).

Figure 4-1: High and low water time series in Nieuwpoort before detrending

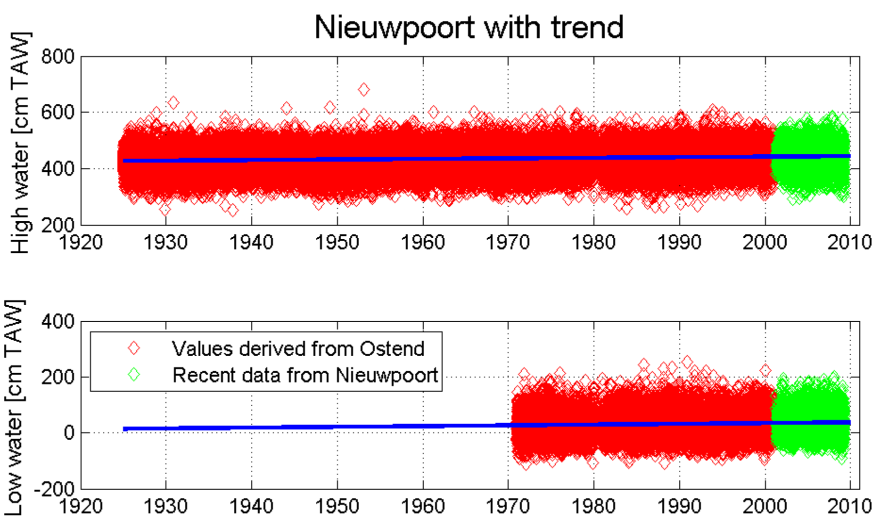


Figure 4-2: Yearly average high water and trend (x=year)

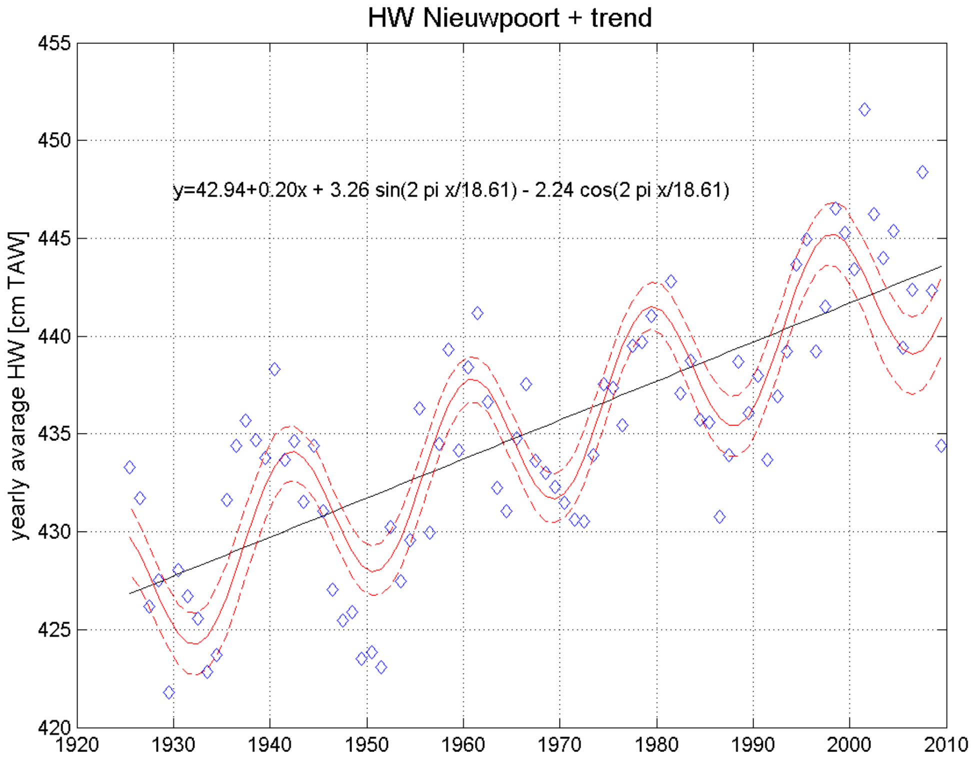


Figure 4-3: Yearly average low water and trend (x=year)

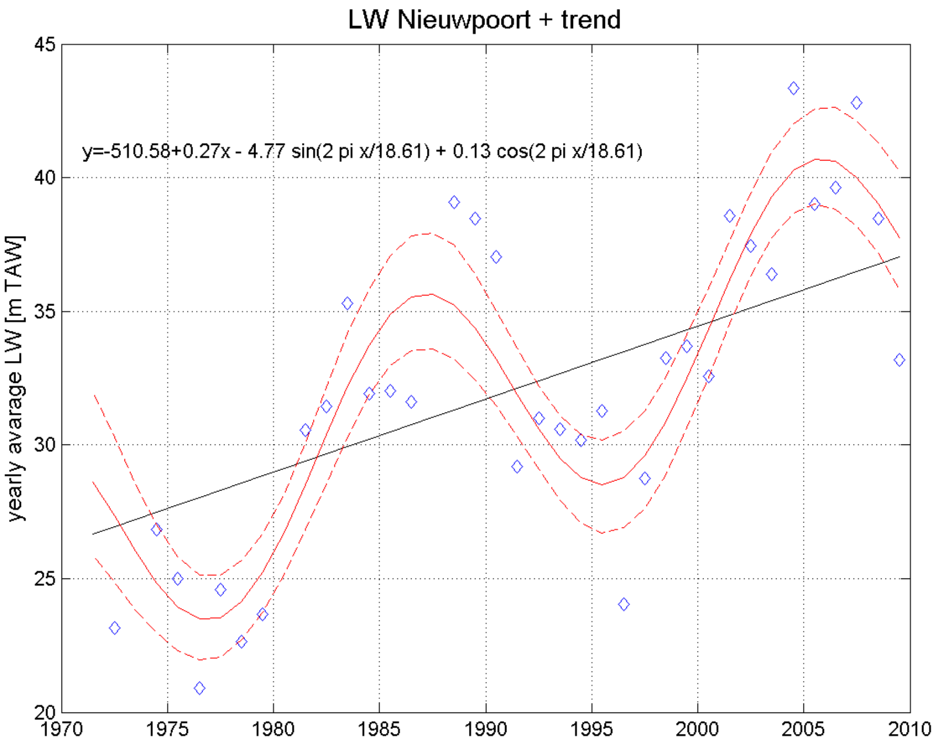
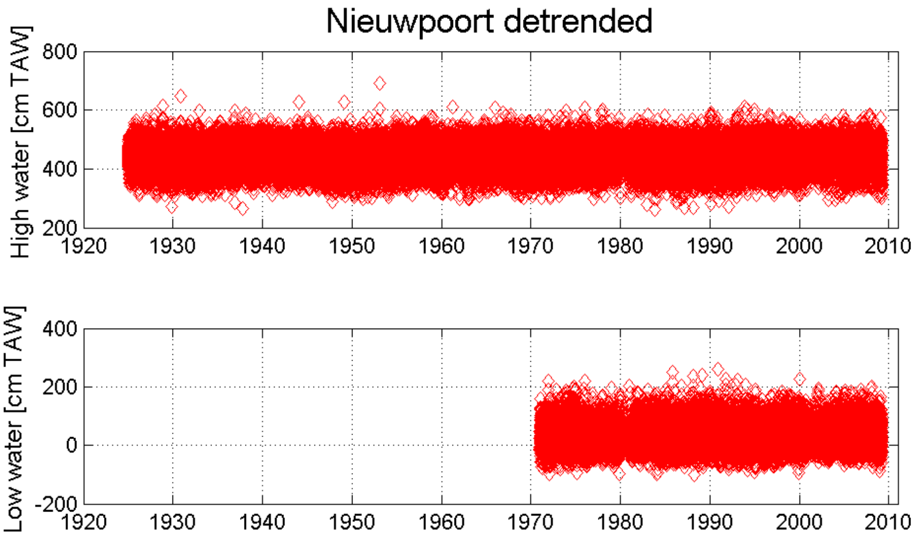
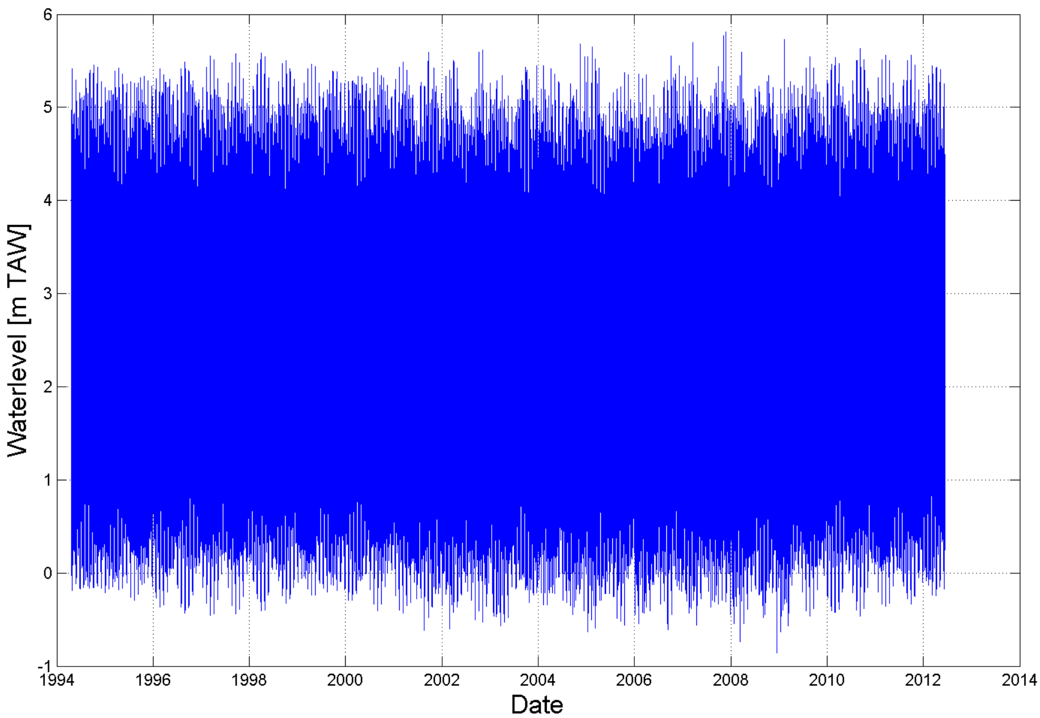


Figure 4-4: Detrended high and low water level time series in Nieuwpoort (reference year 2010)



The available measured water level time series of Nieuwpoort is combined with harmonical predictions of the tide to obtain a time series from 1994/03/19 till 2012/06/13 (Figure 4-5). The harmonical components are obtained from the last complete year of data (2007). These time series is used in the validation by means of the historical run (see chapter 12).

Figure 4-5: The water level time series of Nieuwpoort combined with harmonical predictions of the tide



5 Correlation analysis

The correlation between the extremes of the different variables is tested by the p-test of the Pearson, Spearman and Kendall correlation values (see Appendix B). The extremes are obtained by a peak over threshold (POT) analysis of simultaneous time series. A time shift of 48 hours is allowed between linked POT values. If the p value is higher than a predefined confidence level, in this case 0.05, the zero hypothesis of dependence can be rejected. The extremes are determined with the EVA tool and coupled with the Copula Analysis tool (see Figure 1-1).

5.1 LW Nieuwpoort - Q Roesbrugge

The dependency between the extreme discharge events at the upstream boundary of the Belgian part of the Yser (Roesbrugge) and high low water levels at Nieuwpoort is investigated. Because higher low water level impede the discharge of the Yser.

The p values of Pearson, Kendal and Spearman coefficients all indicate that the H_0 hypothesis of independency could not be rejected at α=0.05 (Table 5-1). This conclusion can be explained by substantially different meteorological events that generate extreme discharge in the Yser and extreme low waters at Nieuwpoort. Hence, joint occurrences of extreme values are unlikely, and the upstream extreme synthetic discharge events will be coupled with a neap, average and spring tide.

Table 5-1: Correlation analysis of LW Nieuwpoort and Q-Roesbrugge

	Rho/tau	p-test
Pearson	0.25073	0.27295
Kendall	0.26253	0.10281
Spearman	0.34881	0.12121

5.2 HW Nieuwpoort - Q Roesbrugge

The dependency between the extreme discharge events at the upstream boundary of the Belgian part of the Yser (Roesbrugge) and high water levels at Nieuwpoort is also investigated.

The p values of Pearson, Kendal and Spearman coefficients all indicate that the H0 hypothesis of independency could not be rejected at α=0.05 (Table 5-2). This conclusion can be explained by substantially different meteorological events that generate extreme discharge in the Yser and extreme low waters at Nieuwpoort. Hence, joint occurrences of extreme values are unlikely, and the upstream extreme synthetic discharge events will be coupled with a neap, average and spring tide.

Table 5-2: Correlation analysis of HW Nieuwpoort en Q-Roesbrugge

	Rho/tau	p-test
Pearson	-0.075104	0.79022
Kendall	-0.047619	0.84584
Spearman	-0.067857	0.81244

5.3 Q Roesbrugge – Q Tributaries

The Poperingevaart is selected as a representative subcatchment for all tributaries to calculate the joint probabilities of the upstream discharge at Roesbrugge and the discharge from the subcatchments.

Now, the null hypothesis of independency between the discharge events of the Yser (Roesbrugge) and the Poperingevaart can be discarded at α=0.05 (Table 5-3). The underlying meteorological events, extreme rainfall events above the Yser catchment, are clearly linked.

Table 5-3: Correlation analysis of Q-Roesbrugge and Q-Poperingevaart

	Rho/tau	p-test
Pearson	0.42289	0.00017428
Kendall	0.30826	0.00010905
Spearman	0.44372	7.5045^{e}-05

6 Extreme value analysis

The extreme value analysis is performed with the EVA tool (see Figure 1-1).

6.1 Analysis overview

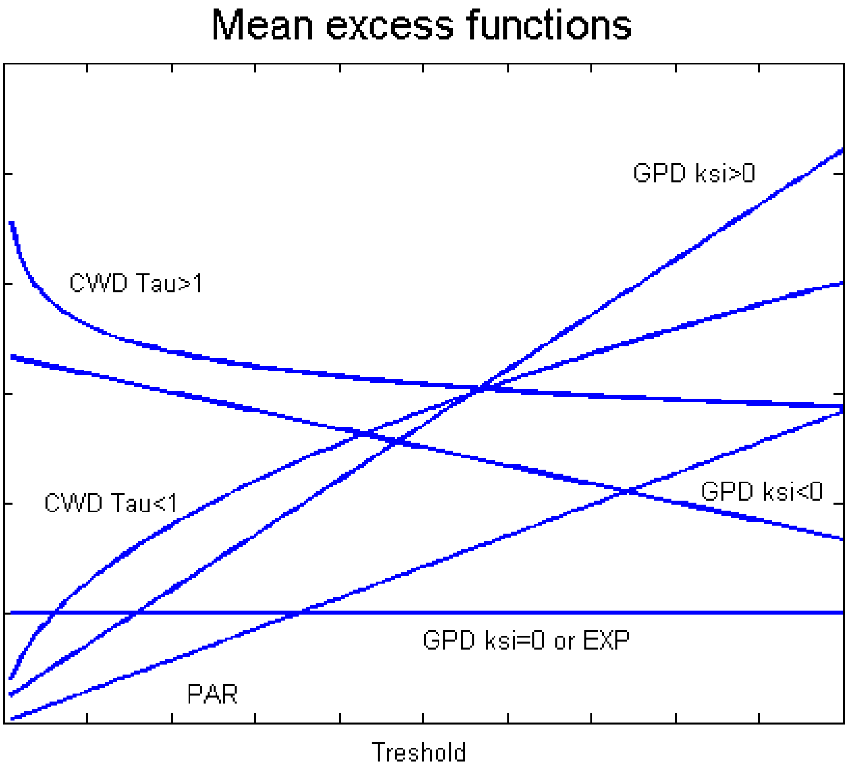
Conditional distributions are selected to extrapolate the extreme behavior of the selected variables. By selecting all the extreme events the maximum amount of information can be used to determine the parameters of the appropriate distribution. The fit of a conditional distribution is based on peak over threshold (POT) values. POT values are all independent values that exceed a set threshold. The independency is guaranteed by two additional selection criteria: the inter event level and the time interval (delta T). The inter event level is the maximum value the minimum between two POT values may have. It is determined by a factor that has to be multiplied with the minimum of the two POT values. The time interval is the minimum time lag between two successive POT values. The initial threshold has to be kept sufficiently low to select enough extreme events. In a second step the optimal threshold will be determined, i.e. the threshold above which the values are extreme and follow the considered extreme value distribution.

The correct distribution and optimal threshold is selected by the mean excess function, the shape parameter of the Generalized Pareto Distribution (GPD) and the root mean square error (RMSE). The empirical mean excess function is compared with the theoretical mean excess function of all the available distributions (Figure 6-1). All conditional extreme value distributions are a member of the GPD family. So a shape parameter of the GPD distribution around zero leads to the use of the Conditional Weibull or the Exponential distribution and a shape parameter higher than zero to the Pareto distribution. The RMSE error is used to determine the optimal threshold and the RMSE of the selected threshold to choose between the distributions. At last there is also a visual control in a combined plot of the obtained distribution and the empirical POT values.

A check of the Poisson process (a condition to fit the distribution) is also performed. By assigning an empirical probability of i/(1+n) to the POT values, an implicit assumption of a stationary Poisson process is made. This means that the occurrence of extreme values follow a Poisson distribution and are not clustered. A check of this assumption is the dispersion coefficient (Vitolo, 2009). This is the ratio of the variance and the mean of the number of POT values per year. A dispersion smaller than 1 indicates a more regularly process and larger than 1 indicates clustering.

The distributions are fitted by a maximum likelihood fit with a 95 % confidence interval calculated by a bootstrap method.

Figure 6-1: Theoretical mean excess functions



GPD= generalised Pareto Distribution, CWD= Conditional Weibull Distribution,
Par= Pareto distribution, EXP= Exponential Distribution

6.2 Discharge time series

The POT's of all the discharge time series are selected with an inter event level factor of 0.37 and a delta T of 48 hours. The resulting figures are in Appendix C and the main values are in Table 6-1.

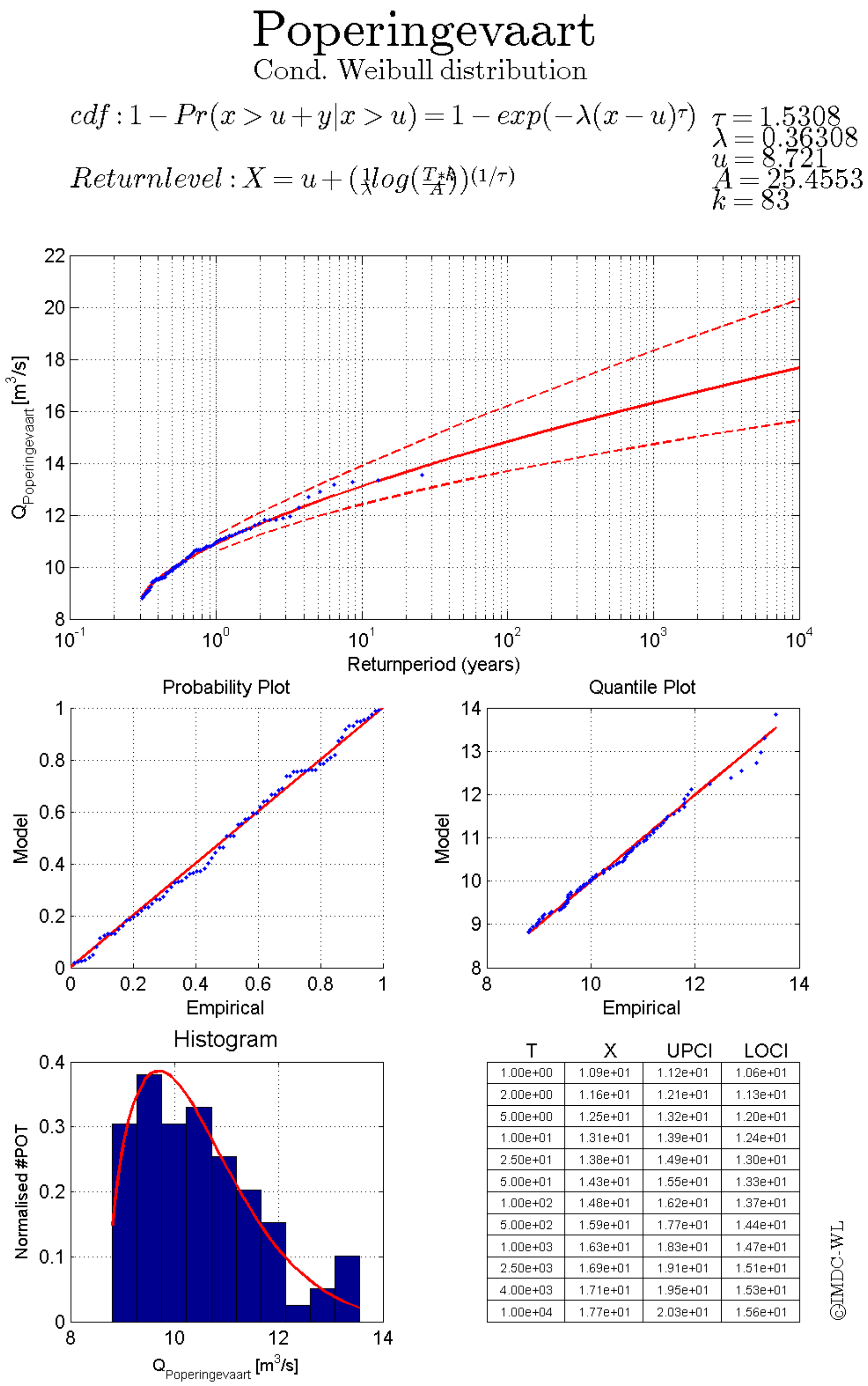
Based on the visual check of the return level-return period figure the distributions fit the empirical distribution based on the POT values. As an example the resulting plot of the Poperingevaart is visualized in Figure 6-2.

The most extreme POT value of the Martjesvaart deviates from the other POT values. Therefor only the frequency but not the value is taken into account for the maximal likelihood fit.

Table 6-1: Overview of the extreme value distributions of the discharge time series

Location	Distribution	Threshold [m³/s]	#POT
Yser Roesbrugge	Exponential	13.700	121
Poperingevaart	CWD	8.721	83
Kemmelbeek	CWD	4.486	108
Ieperlee	CWD	1.863	86
Martjesvaart	CWD	5.667	109
Steenbeek	CWD	1.249	118
Handzamevaart	CWD	8.364	53

Figure 6-2: Extreme value distribution of the Poperingevaart



T	X	UPCI	LOCI
1.00e+00	1.09e+01	1.12e+01	1.06e+01
2.00e+00	1.16e+01	1.21e+01	1.13e+01
5.00e+00	1.25e+01	1.32e+01	1.20e+01
1.00e+01	1.31e+01	1.39e+01	1.24e+01
2.50e+01	1.38e+01	1.49e+01	1.30e+01
5.00e+01	1.43e+01	1.55e+01	1.33e+01
1.00e+02	1.48e+01	1.62e+01	1.37e+01
5.00e+02	1.59e+01	1.77e+01	1.44e+01
1.00e+03	1.63e+01	1.83e+01	1.47e+01
2.50e+03	1.69e+01	1.91e+01	1.51e+01
4.00e+03	1.71e+01	1.95e+01	1.53e+01
1.00e+04	1.77e+01	2.03e+01	1.56e+01

7 Joint probability

Correlation analysis (see chapter 5) revealed that discharge of the Yser in Roesbrugge and of the tributaries is not independent. In order to determine the joint probabilities of both variables two cases dependency of discharges for the Yser in Roesbrugge and the tributaries are considered:

- partial dependency;
- full dependency.

7.1 Partial dependency Q Roesbrugge – Q Tributaries

The joint probabilities of the discharge at the tributaries and the Yser are modeled with a Copula. Furthermore the tributaries are considered fully dependent and stratified together. This results in 120 classes with each 3 frequencies of occurrence (mean, upper confidence interval, lower confidence interval).

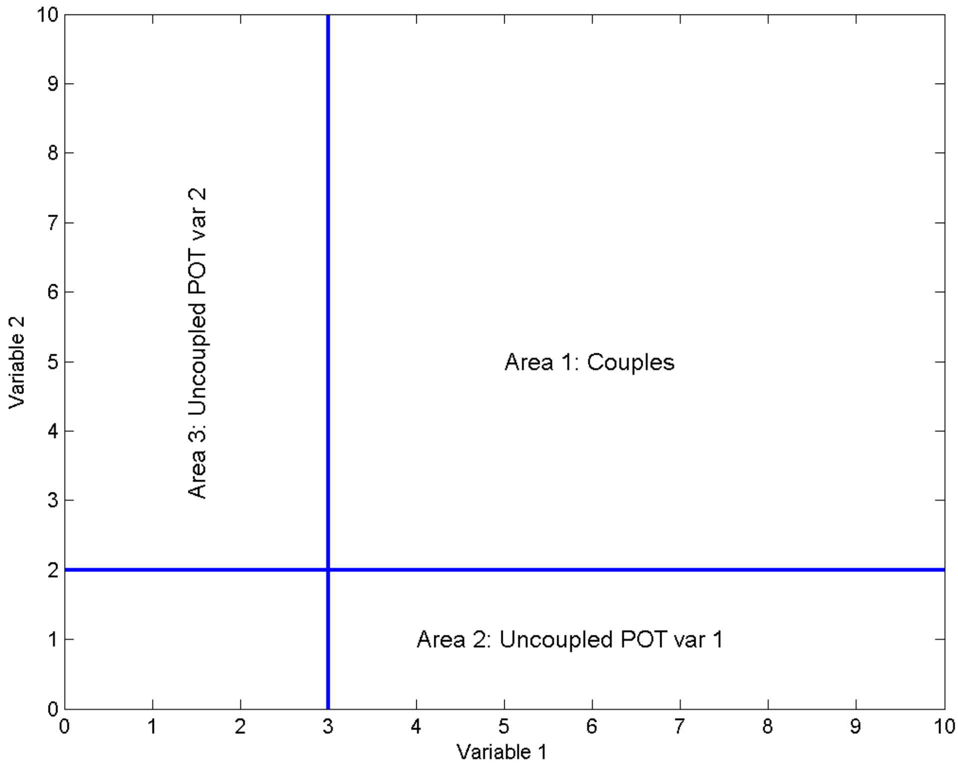
7.1.1 Copula

The joint probabilities of the extreme Yser discharge in Roesbrugge and the extreme discharge of the Poperingevaart are modeled by a Gumbel Copula with the Copula Analysis tool (see Figure 1-1). A copula is a function that joins or couples a multivariate distribution to their univariate marginal distribution functions or a distribution function whose univariate margins are uniform (Li 2000, Nelsen 2006). The Gumbel Copula of copulas was first discussed by Gumbel (1960b) and is given by:

$$C(u,v) = exp\left(-[(-\ln(u)^{\alpha} + (-\ln(v)^{\alpha}]^{1/\alpha}\right)$$

To estimate the dependence couples of simultaneous events are needed. Because univariate conditional distributions are only valid above their threshold, only the simultaneous extremes that exceed there corresponding threshold can be used as couples. This will evidentially leave some extremes without a corresponding extreme of the other variable. The greater the dependence between the two investigated variables, the smaller this number of uncoupled POT. Figure 7-1 gives the areas in which the couples and the uncoupled POT's of variable 1 and 2 occur.

Figure 7-1: Area of occurrence of couples and uncoupled POT



The exceedance probability of the joint occurrences in a certain point of area 1 can be calculated by the Copula. If we stratify variable 1 and variable 2 both into 10 parts we will get 100 cells and 120 Copula values. The yearly frequency of occurrence of every cell can be calculated by:

$$Frq(i,j) = \frac{k_1}{A_1}(C(i+1,j+1) - C(i,j+1) - C(i+1,j) + C(i,j))$$

Where C is the exceedance probability given by the Copula, k is the number of couples and A is the amount of year. The value of variable 1 and 2 in the middle of each class will be assigned to that class (red dots in Figure 7-2).

The yearly frequencies of occurrence of area 2 and 3 can be calculated by their univariate distributions.

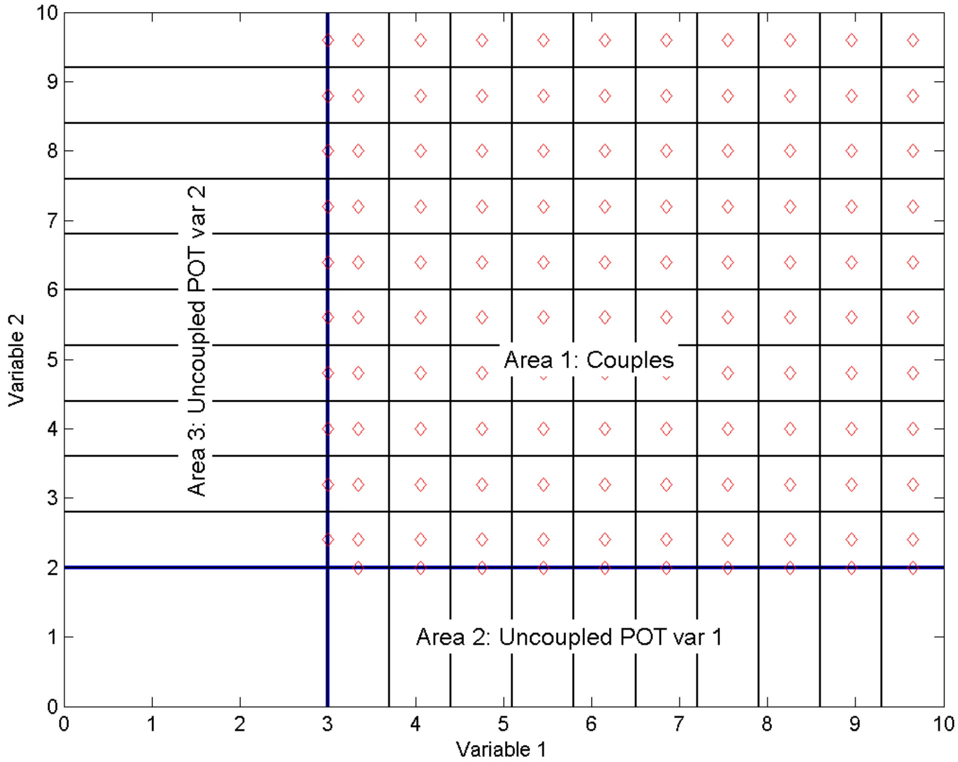
$$Frq_{area2}(i) = \frac{k_2}{A_2}\left(CDF(i+1) - CDF(i)\right)$$

$$Frq_{area3}(j) = \frac{k_3}{A_3}\left(CDF(j+1) - CDF(j)\right)$$

Where k_2, k_3 and A_2, A_3 are the number of POT and years of data in the corresponding areas. By definition there is no corresponding value of variable 2 available for the uncoupled POT of variable 1 but we know it has to be a value lower than the threshold of variable 2.

So it will be a secure assumption to assign the threshold value of variable 2 to the cells in area 1 together with the value of variable 1 in the middle of the class (red dots on the lowest horizontal blue line in Figure 7-2). The reasoning is similar for the uncoupled POT of variable 2 (red dots on the leftmost vertical blue line in Figure 7-2).

Figure 7-2 Stratified Area of occurrence of couples and uncoupled POT



The selected couples are visualised in figure 7-3. The validity of the univariate extreme value distributions is controlled by making an empirical return level-return period plot of all the POT values and the coupled POT values Figure 7-4. The maximal likelihood fit gives a Gumbel Copula with α= 1.4633. In order to ensure taking into account all potential events that could contribute to the risk value, the discharge domain was subdivided in 10*10 equidistant discharge classes between the thresholds of the extreme value distributions and the upper limit of the 95% confidence interval at the frequency of 10-3 per year. Lower frequencies do not contribute to the total risk value and can be neglected. So the Copula is stratified into 120 cells with outer boundaries of 13.7 m3/s to 230.0 m3/s for the Yser at Roesbrugge and 10 m3/s to 20.0 m3/s for the Poperingevaart. The frequency of occurrence of each cell is calculated with 95% confidence intervals (Figure 7-5). These confidence intervals are calculated with a bootstrap procedure. This yields a stratified two dimensional (QYser and QPoperingevaart) space with known frequencies.

As a check the return level-return period plot can be made by sorting the discharges in descending order and accumulating the corresponding probabilities Psynth,i,k. This plot is compared with the original univariate distribution (Figure 7-6) to give a measure of the errors as a result of the discretisation.

Figure 7-3: Time series with POT values and couples for the Yser in Roesbrugge and the Poperingevaart

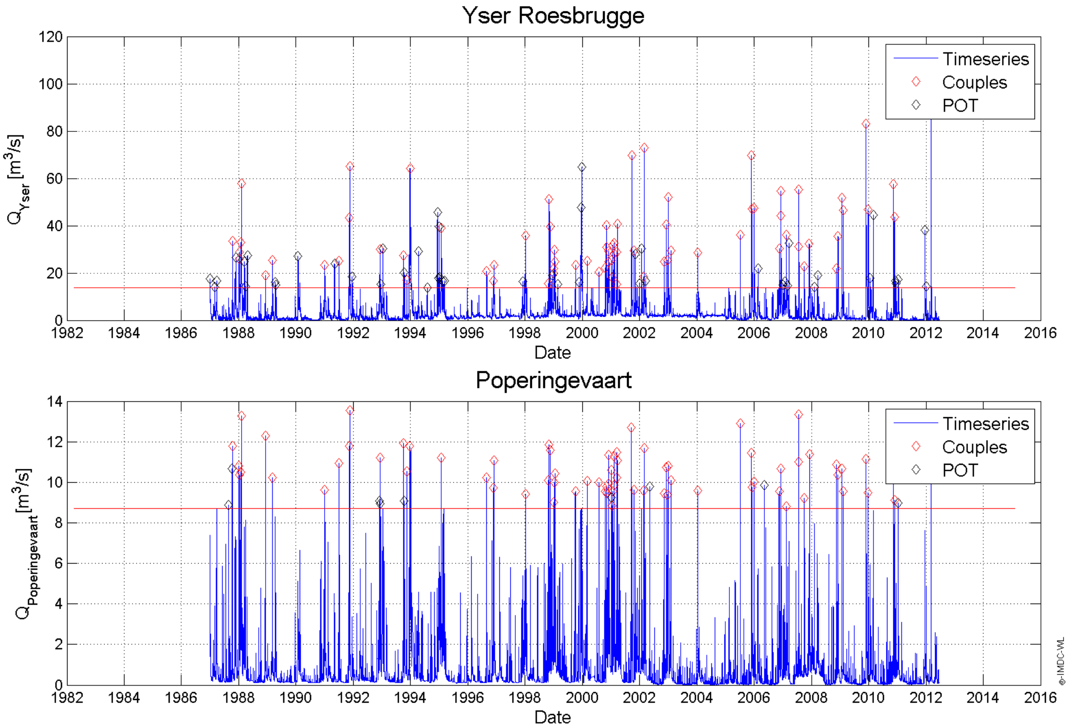


Figure 7-4: Empirical return periods of all POT and Coupled POT, Couples domain

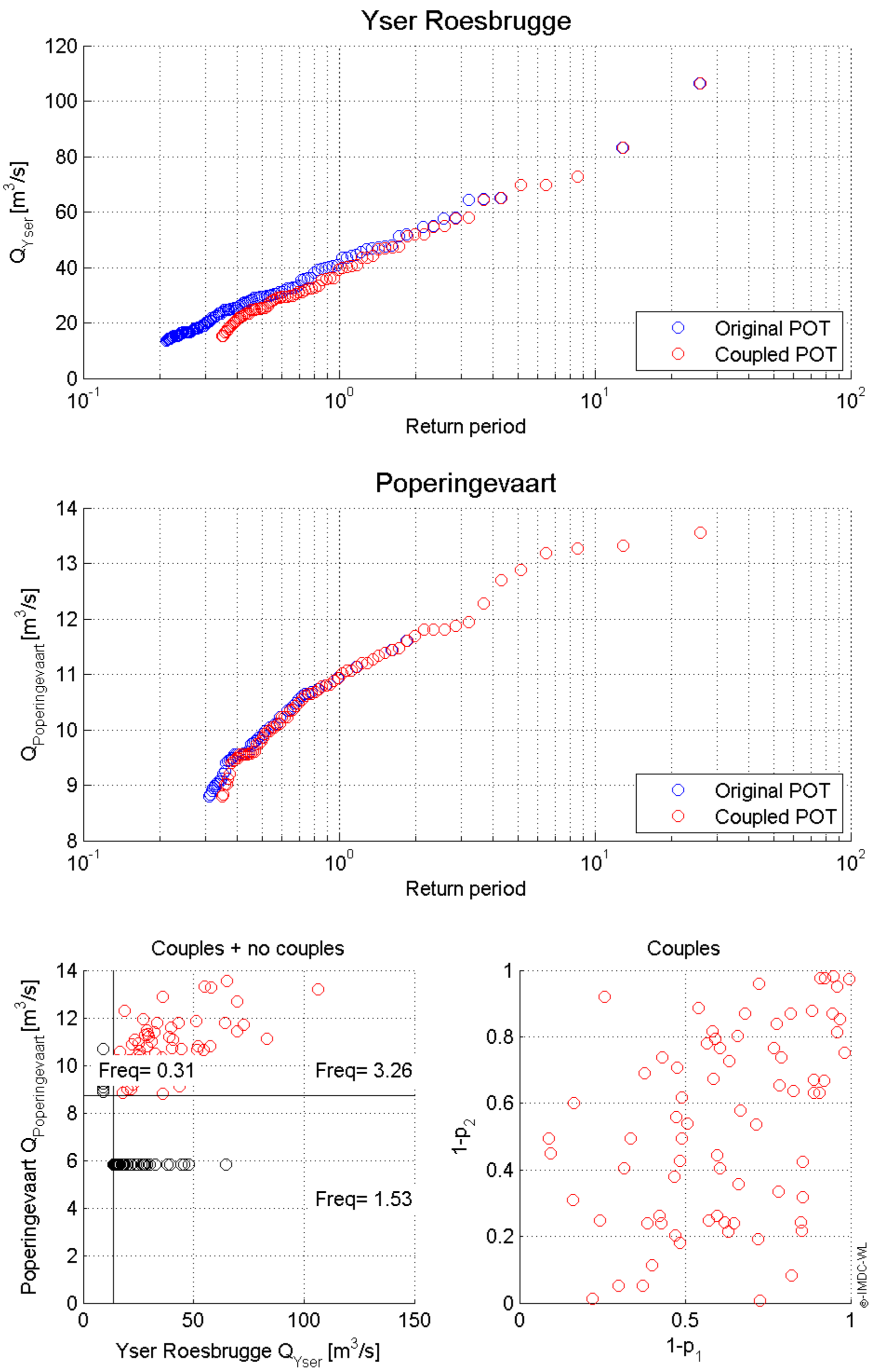


Figure 7-5: Frequency of cells

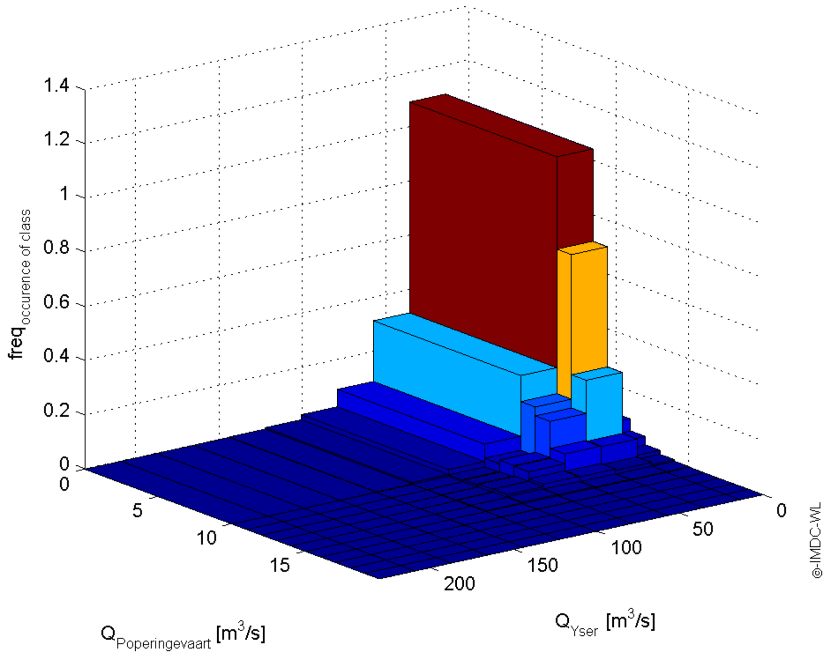
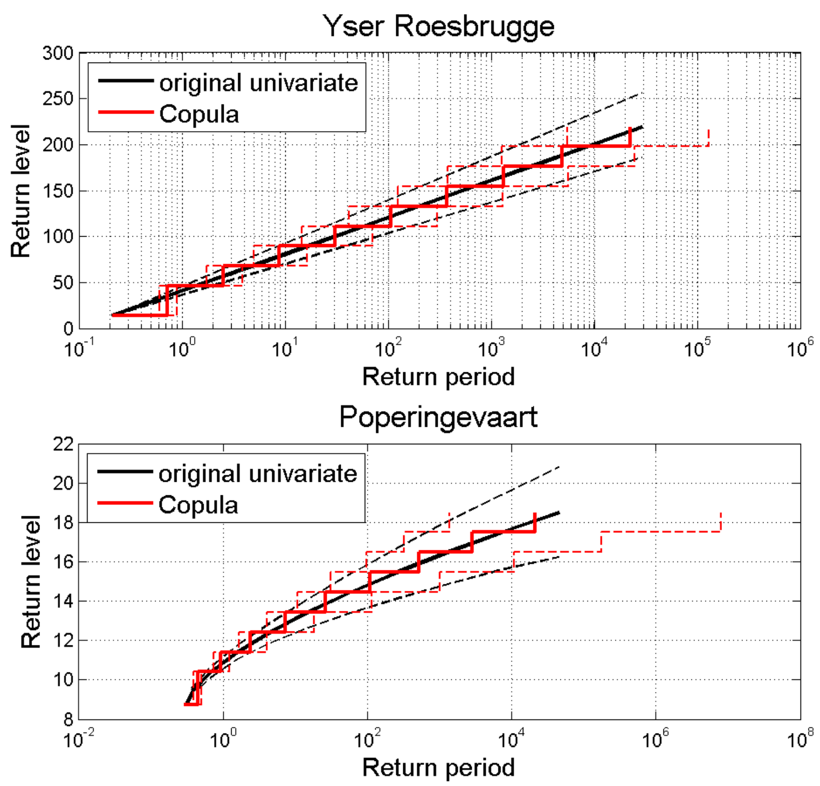


Figure 7-6: Stratification check by means of the univariate distributions of the Yser in Roesbrugge and the Poperingevaart



7.1.2 Combined stratified sampling

The univariate extreme value distributions of the tributaries are considered to be fully dependent and there distributions are stratified together with the Dependent Stratification tool (see Figure 1-1). This means that the return period boundaries of every class is equal, while the return level values are calculated through the cumulative density function of the selected distribution. The return periods of the Poperingevaart obtained in the Copula stratification are used as the fixed boundaries of the classes. Figure 7-7 displays the stratification process of the threshold model for peak flows of one distribution. Each synthetic event i, representing a discharge class Q_i, has a probability of occurrence, expressed as the expected number of occurrences per year of a peak flow in the considered class. The probability of occurrence per year of a random event within class i is:

$$P_{\Delta Qi} = f_{i1} - f_{i2} = \frac{1}{T_{i1}} - \frac{1}{T_{i2}}$$

With f_{i1} and f_{i2} the exceedance frequency, and T_{i1} and T_{i2} the return periods, of lower limit Q_{i1} and upper limit Q_{i2} of stratum i or discharge class ΔQ_i. This way each distribution is stratified in 10 classes with a known frequency of occurrence. All the univariate distributions are visualized with the stratified Poperingevaart in Figure 7-8.

Figure 7-7: Stratification procedure example

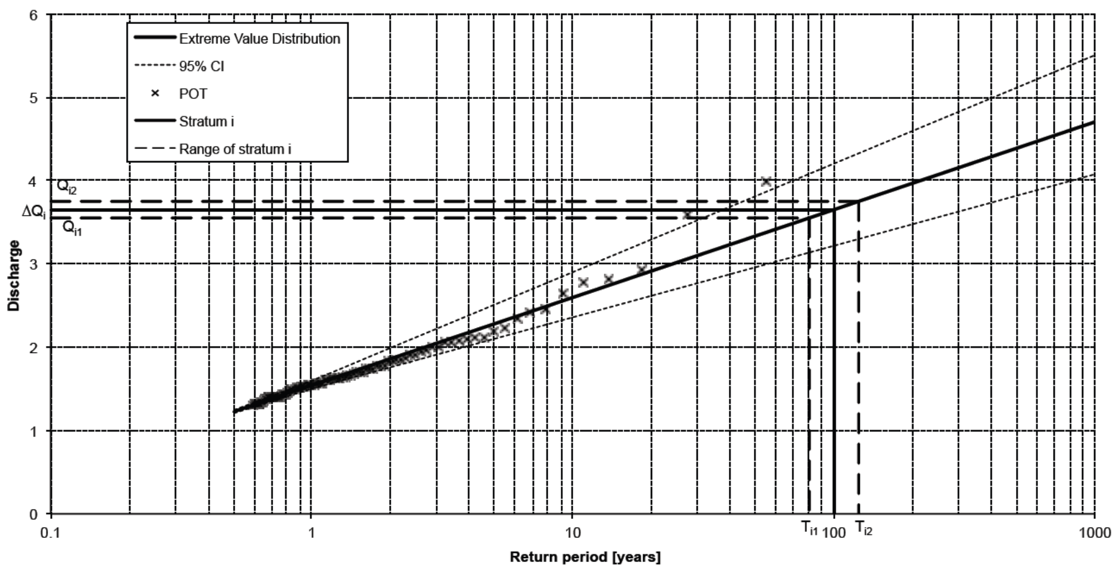
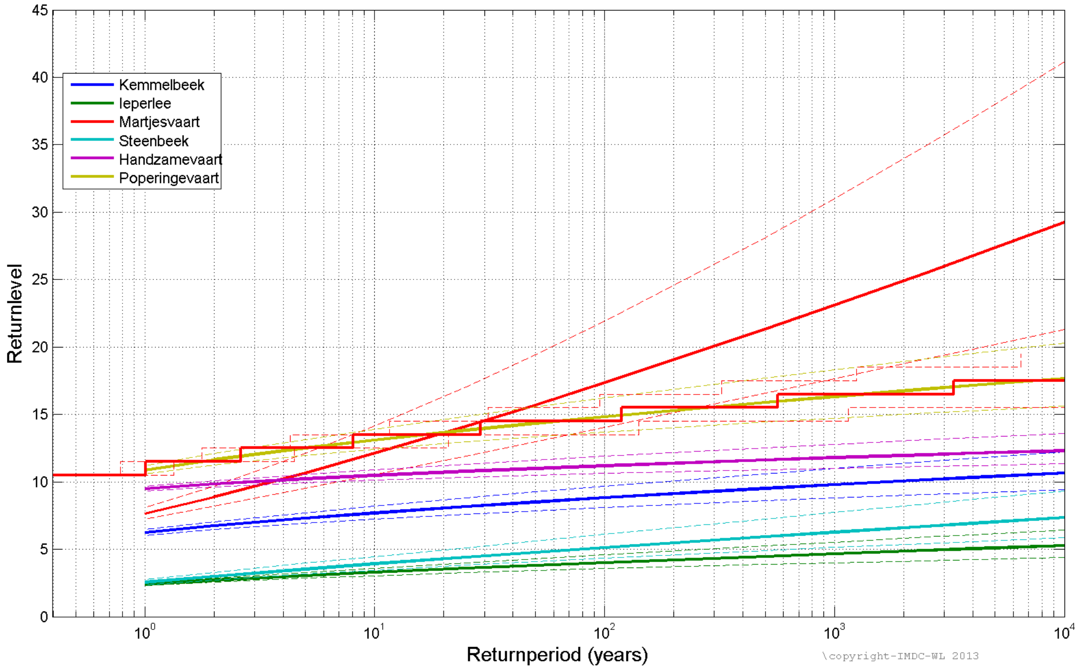


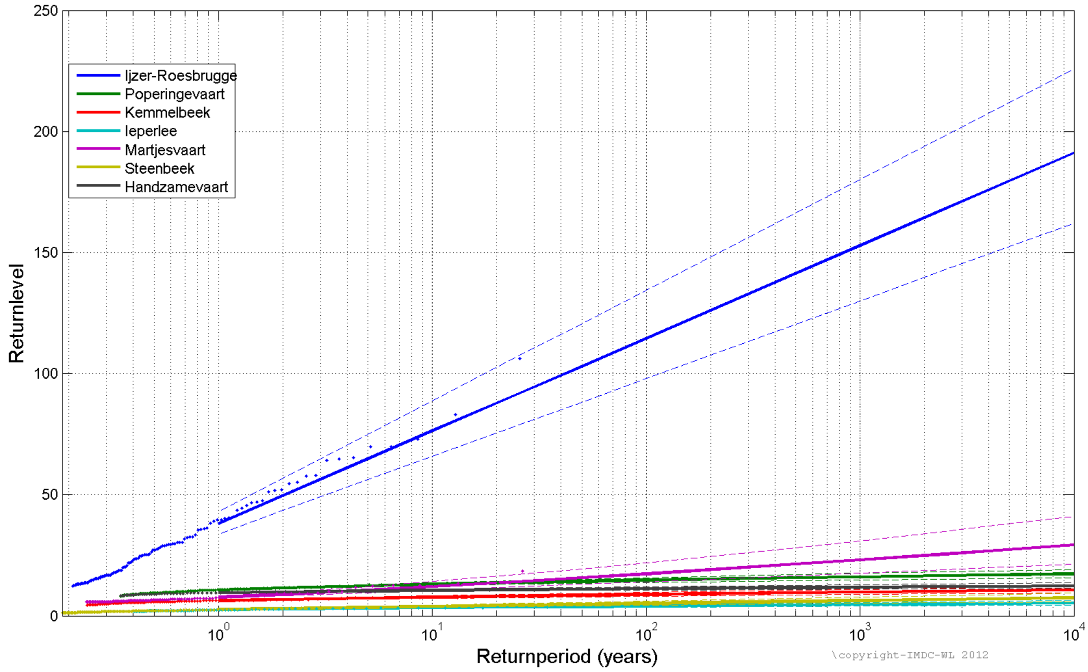
Figure 7-8: Combined stratification of univariate distributions of the tributaries in case of partial dependency of discharges for the Yser in Roesbrugge and the tributaries



7.2 Full dependency Q Roesbrugge – Q Tributaries

The advantage of the assumption of full dependency is that it allows to omit the Copula fit and reduce the number of simulations. The seven univariate discharge distributions are stratified together as explained in chapter 0 by means of the Dependent Stratification tool (see Figure 1-1). Twenty classes are selected from the Yser distribution form 25 m³/s to 200 m³/s. These values yield the boundary return level values used in the stratification of the other distributions. This results in 20 classes with each 3 frequencies of occurrence (mean, upper confidence interval, lower confidence interval).

Figure 7-9: Combined stratification of univariate distributions in case of full dependency of discharges for the Yser in Roesbrugge and the tributaries



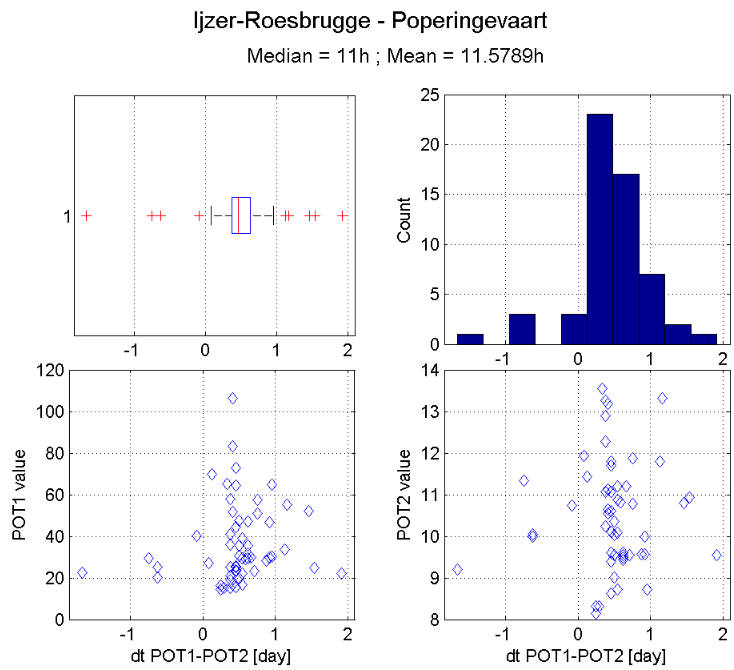
8 Time shift

The median time difference between the occurrence of the peak at the tributaries and at the Yser in Roesbrugge is calculated based on simultaneous events (Table 8-1; Figure 8-1). The peak discharges occurs between 7 and 15 hours before the peak discharge of the Yser at Roesbrugge. The rainfall runoff in the tributary catchments enters there tributary faster than the time the rainfall runoff peak from the France catchments needs to arrive at Roesbrugge. No clear relation between the peak value and the time shift is found in the plots (Figure 8-1, 2 figures in the bottom). So a constant time shift is applied per tributary to couple every synthetic event with the corresponding synthetic event of the Yser.

Table 8-1: Time difference with Yser Roesbrugge [positive values means the peak of the tributary occurs before the peak of the Yser]

River	Location	Delta t [hours]
Poperingevaart	Oostvleteren	11
Kemmelbeek	Reninge	9
Ieperlee	Boezinge	7
Martjesvaart	Merkem	12
Steenbeek	Merkem	15
Handzamevaart	Kortemark	13

Figure 8-1: Time shift between the occurrence of a peak at the Poperingevaart and at the Yser in Roesbrugge



positive means the peak of the Poperingevaart occurs before the peak of the Yser

9 Variation in time

9.1 Unit profile of Discharge

9.1.1 Tributaries

The classes with peak discharge, calculated in chapter 7, are combined with typical discharge profiles to obtain realistic synthetic event. In case of flood risk assessment, the time profile of the event has a major influence on the location and the extent of the flood area. Short high peak flows affect upstream areas, while large volumes mostly affect downstream areas.

For each location the 25 highest POT values with corresponding events are selected. The number of extreme events is a compromise between a focus on extreme behavior, by decreasing the number of extreme events, and reducing the influence of random behavior of a single event, thus increasing the number of extreme events.

This time frame around the POT values is dependent on the variable and the duration of the event and is determined by manual inspection. A wide time frame can contain multiple events where only the event corresponding to the extreme value is desirable.

The events are normalised by dividing every value by the maximal value of the event. Hence normalized events with a peak value of 1 at time zero are obtained. The mean value for each time steps yields the unit profile. To take the natural variation around this mean unit profile (Y_{m_u}) into account the standard deviation is calculated for every time step:

$$Y_{m\_u} = \frac{\sum_{i=1}^{n} Y}{n}$$

$$std\_Y = \sqrt{\frac{\sum_{i=1}^{n} \left(Y - Y_{m\_u}\right)^2}{n-1}}$$

This results in five unit events with a known probability under the assumption of a normal distribution (Figure 9-1):

- μ-2σ: the mean unit event minus twice the standard deviation
- μ- σ: the mean unit event minus the standard deviation
- μ: the mean unit event
- μ+ σ: the mean unit event plus the standard deviation
- μ+2 σ: the mean unit event plus twice the standard deviation

The total width of the unit profiles are 8 days before the peak and 13 day after the peak value. The unit profiles are multiplied with the class values obtained by the stratification, to get synthetic event with a known frequency of occurrence (Appendix E). Because the two considered dependency tests of discharges for the Yser in Roesbrugge and the tributaries (see chapter 7) have different classes, separate synthetic event are created. As an example the synthetic events of the Poperingevaart are visualized in Figure 9-2.

Figure 9-1: Probability of the five unit profiles under the normal distribution assumption

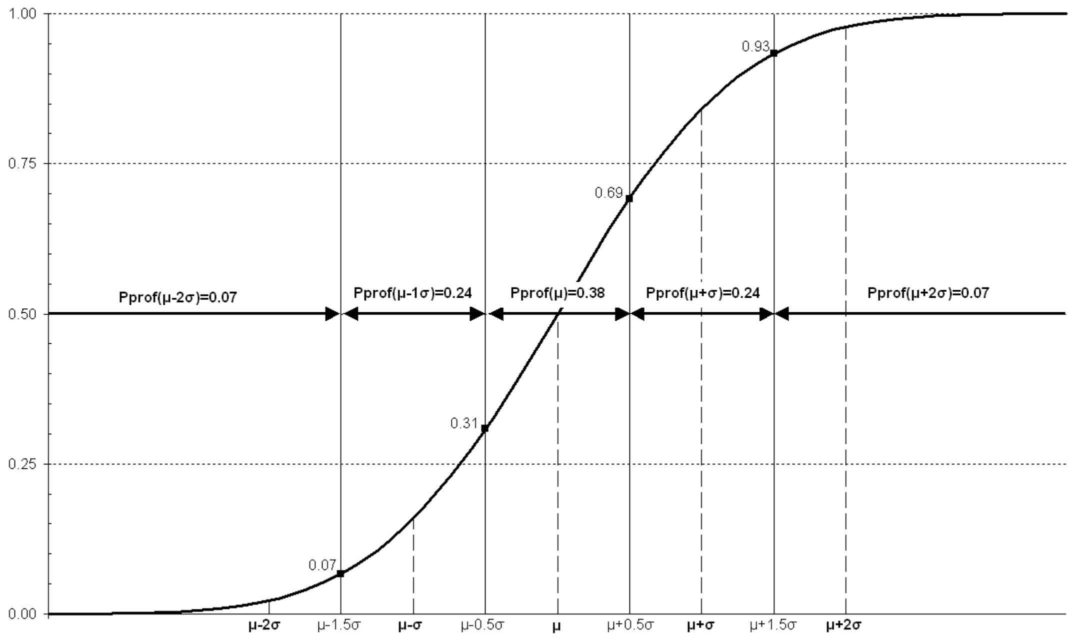
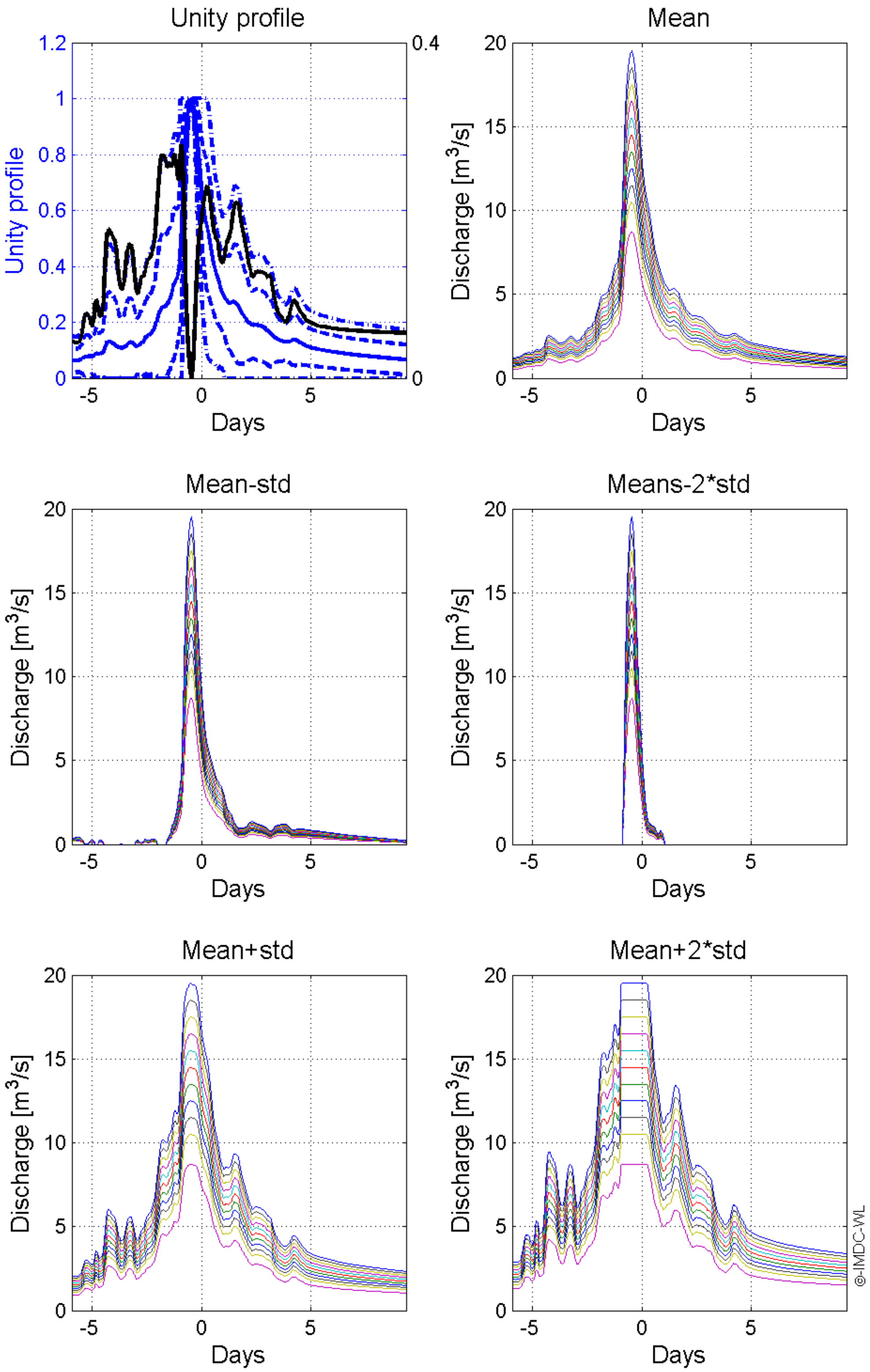


Figure 9-2: Synthetic events for the Poperingevaart in a test considering partial dependency of discharges for the Yser in Roesbrugge and the tributaries



9.1.2 Yser

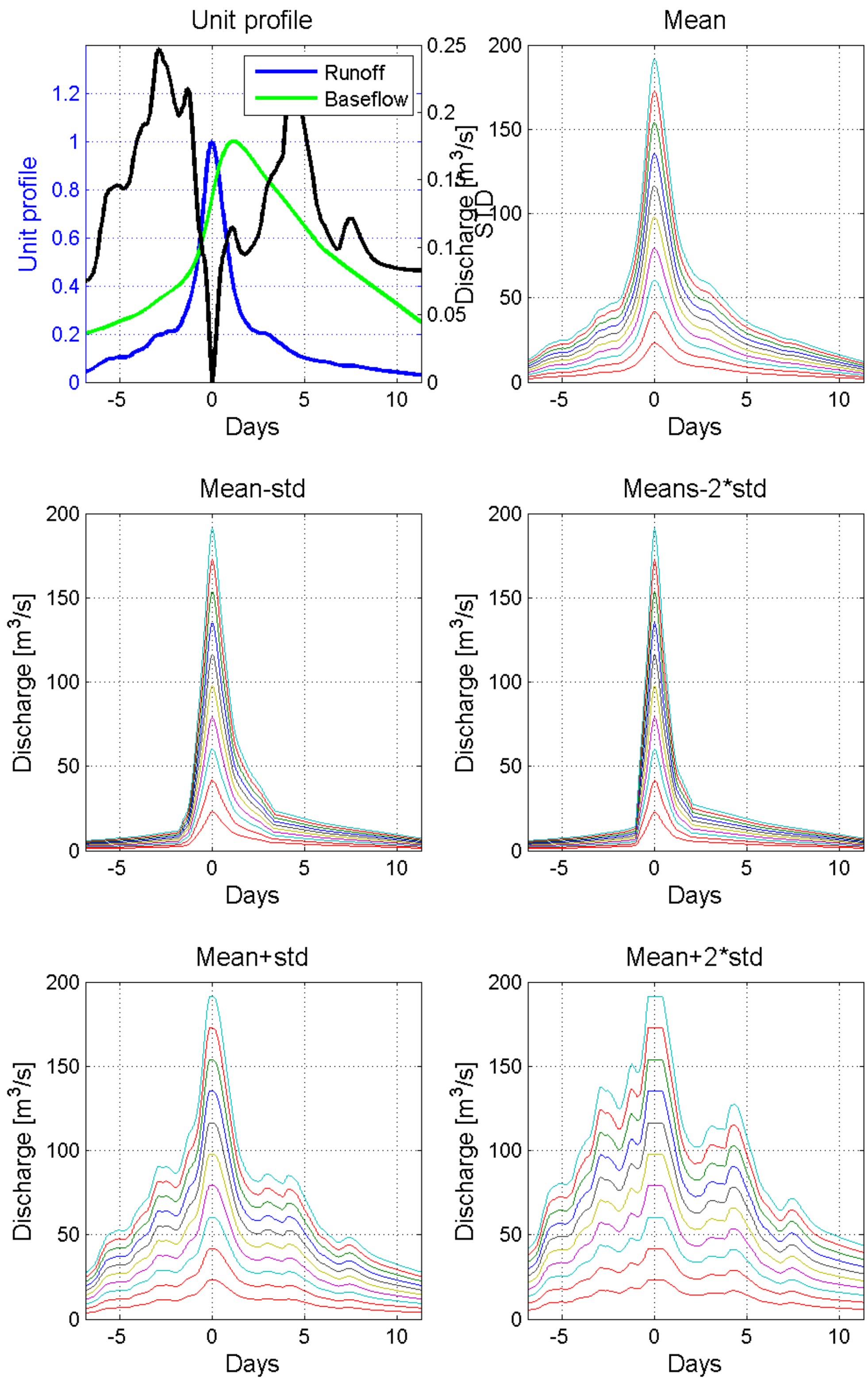
While the tributaries have a very fast response to rainfall events, the Yser has a longer response time which necessitates the splitting of the total discharge into base flow and runoff. This gives a more accurate unit profile. The total discharge is the sum of the runoff and the base flow. This base flow can be calculated by the procedure described in Eckhardt (2005)

$$Q_b(t) = \frac{(1 - BFI) * \alpha * Q_b(t-1) + (1-\alpha) * BFI * Q(t)}{1 - \alpha * BFI}$$

with α the recession constant and BFI or baseflow index with default values of respectively 0,99 and 0,35.

Both the runoff as the base flow are normalized and a unit profile is calculated for both flows. The runoff and base flow are recombined into a total discharge by a regression curve where the maximal base flow and runoff are a function of the total discharge (Figure 9-3). A more extensive description of this procedure can be found in the Synthetic Events reference guide (see Figure 1-1).

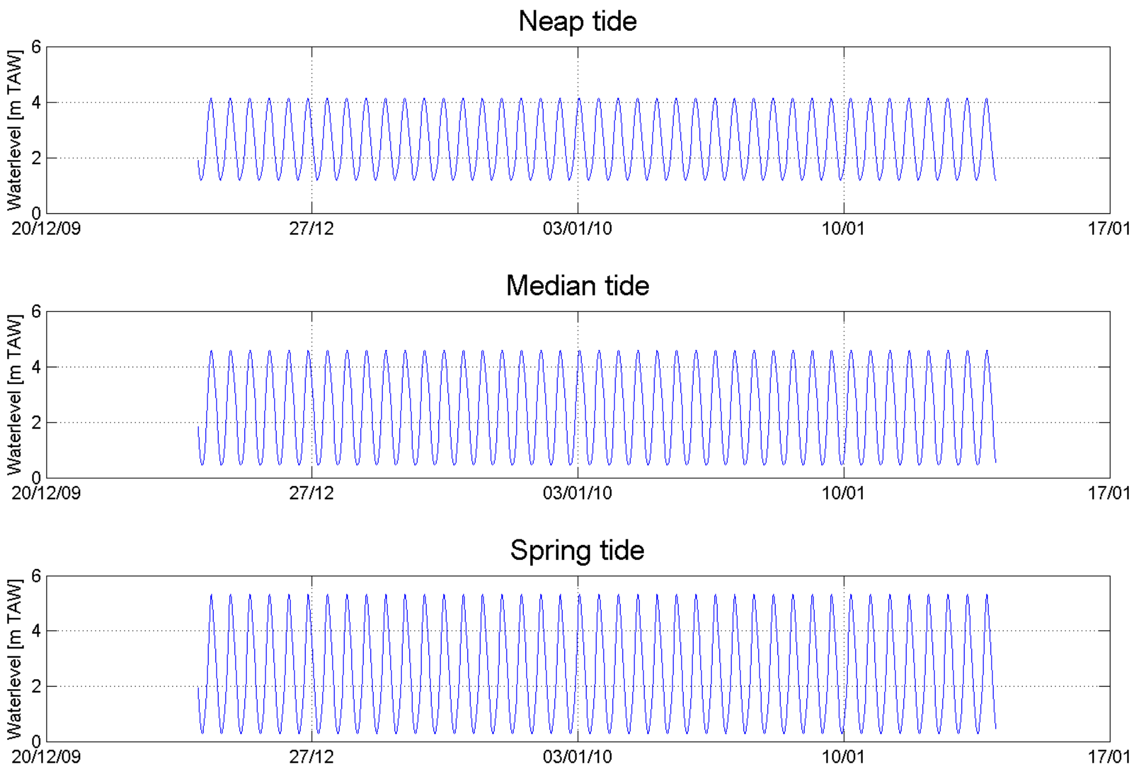
Figure 9-3: Synthetic events for the Yser in Roesbrugge in a test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries



9.2 Water level

Three water level time series are created for the downstream boundary in Nieuwpoort based on a spring, neap and median tide. The astronomical tide time series is divided in spring, neap and median tides based on the tidal amplitude and the mean tide of each category is selected. The selected tides are repeated for the entire simulation (Figure 9-1).

Figure 9-4: The water level time series for the downstream boundary of the Yser basin



10 Rescaling Synthtic events

The hydrodynamic Mike11 model of the Yser basin also includes upstream boundaries at ungauged locations. These boundary conditions are generated by rescaling the previous generated synthetic events for the gauged locations. The factors used in this rescaling are given in Table 10-1 and are based on the area of the subcatchments they represent.

Table 10-1: Rescaling factors for the ungauged upstream boundaries

Main Boundary	Secondary Boundary	Factor
Yser	’01IJZ1'	0,12039
Poperingevaart	’05POV1'	0,333430
	’06POV1'	0,666569
	’07POV2'	0,200000
Kemmelbeek	’08KBK1'	0,1532514
	’09KBK2'	0,0249896
Ieperlee	’10IEP1'	0,0569221
	’11IEP1'	0,0142305
	’12IEP2'	0,3789025
	’13IEP3'	0,1053295
Steenbeek	’14STB1'	0,5832298
	’15STB2'	1,127
	’16STB3'	0,9683229
	’17STB4'	0,8347826
	’18STB5'	0,4689440
	’19STB6'	0,8118012
Handzamevaart	’02HZV1'	0,225890
	’03HZV1'	0,774109
	’04HZV2'	0,142820

11 Simulations

11.1 Partial dependency Q Roesbrugge – Q Tributaries

For the test with partial dependency 120 classes are created with a known frequency of occurrence by the stratification of the Copula (see chapter 7.1). The value of each class is combined with the corresponding unit profiles (5). This gives 600 synthetic upstream boundary conditions. Each of these upstream boundary conditions is combined with the three downstream tidal time series (see chapter 9.2). This results in 1800 simulations. The model runs for around 50 minutes per simulation which means 62.5 days of calculation time.

11.2 Full dependency Q Roesbrugge – Q Tributaries

For the test with full dependency, 20 classes are created with a known frequency of occurrence by the stratification of the univariate distributions (see chapter 7.2). The value of each class is combined with the corresponding unit profiles (5). This gives 100 synthetic upstream boundary conditions. Each of these upstream boundary conditions is combined with the three downstream tidal time series (see chapter 9.2). This results in 300 simulations and 10.4 days of calculation time.

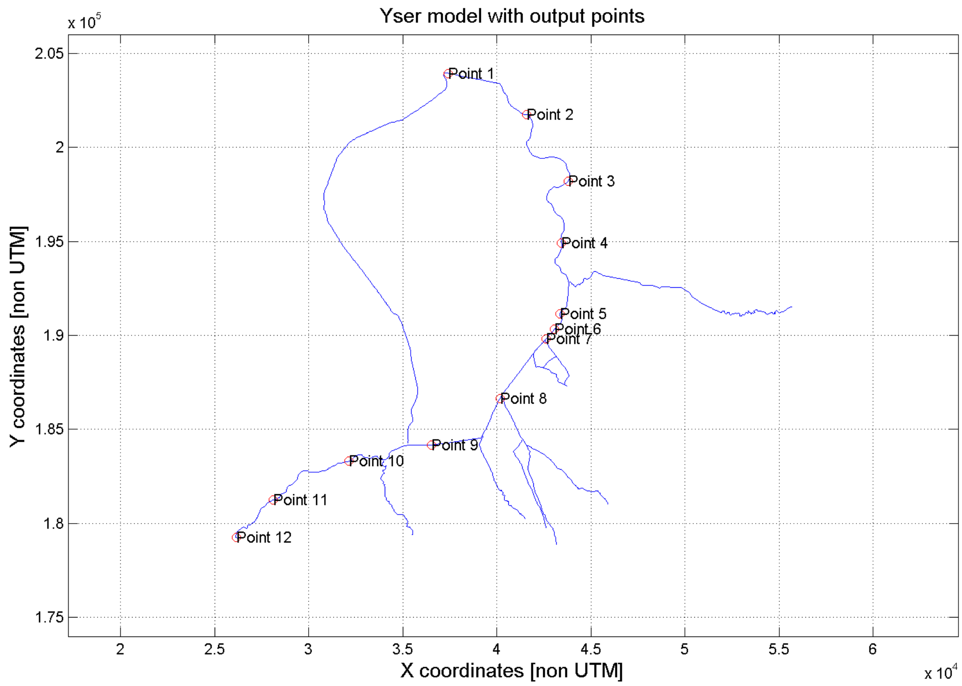
11.3 Historical run

The historical run is a simulation of the entire time frame of the available boundary conditions, so from 1994/03/19 to 2012/06/13, and is part of the validation of the synthetic events (see chapter 12). The simulated period comprises 6661 days and 11 days of calculation time. The time series used in this run are described in chapter 4.

12 Validation

The validation of the synthetic boundary conditions for the considered dependency tests is made by a comparison with the historical run at 12 locations along the Yser River. In order to make this analysis, an extreme value analysis is made of the historical run results at these 12 points (Figure 12-1). This analysis is made for both the discharge and the water level. The results of this extreme value analysis are displayed in Appendix F. No extreme value distribution is derived for Point 1 because the influence of the discharge steering mechanism of the outflow control structure of the Yser in Nieuwpoort does impede the selection of independent extremes.

Figure 12-1: Checkpoints in the Yser model for the validation of the synthetic events



The simulation results of the two dependency tests are processed and the maximum of each simulation is selected. These maxima are sorted in a descending order and there corresponding frequencies are accumulated. Point 12 is a good control point to check for errors in the followed procedure to dress up the upstream synthetic boundary conditions, because it is very close to the upstream boundary and the nonlinear response of the river system has only limited impact. At this location the results of the tests and the historical run are very similar, both in the extrapolation area and in the area with empirical results (Figure 12-2, Figure 12-3). The stepwise results of the tests are caused by the discretisation in the stratification procedure. The results at the other points are in Annex 0.

The return level-return period line of the tests are close to the historical extremes for all the check points. In the extrapolation domain there are mayor differences from point 2 till point 8. The simple extrapolation of the historical results underestimates the discharge and water level values (example Figure 12-4). These deviations can be explained by a different response of the higher return levels to the discharge steering mechanism of the outflow control structure at Nieuwpoort.
A simple extrapolation of the lower values does not contain this changed behaviour. This hypothesis is confirmed by the observation that the deviation reduces and disappears where the influence of the downstream boundary reduces.

Figure 12-2: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the upstream Yser checkpoint 12,
the red line is the distribution fitted through the historical POT values

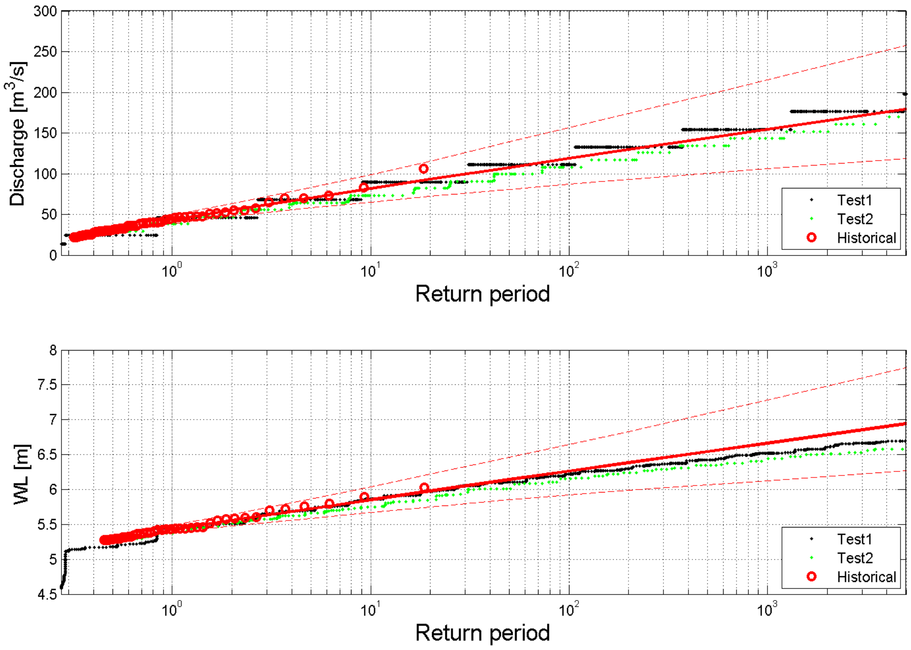


Figure 12-3: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the upstream Yser checkpoint 12 (Zoom),
the red line is the distribution fitted through the historical POT values

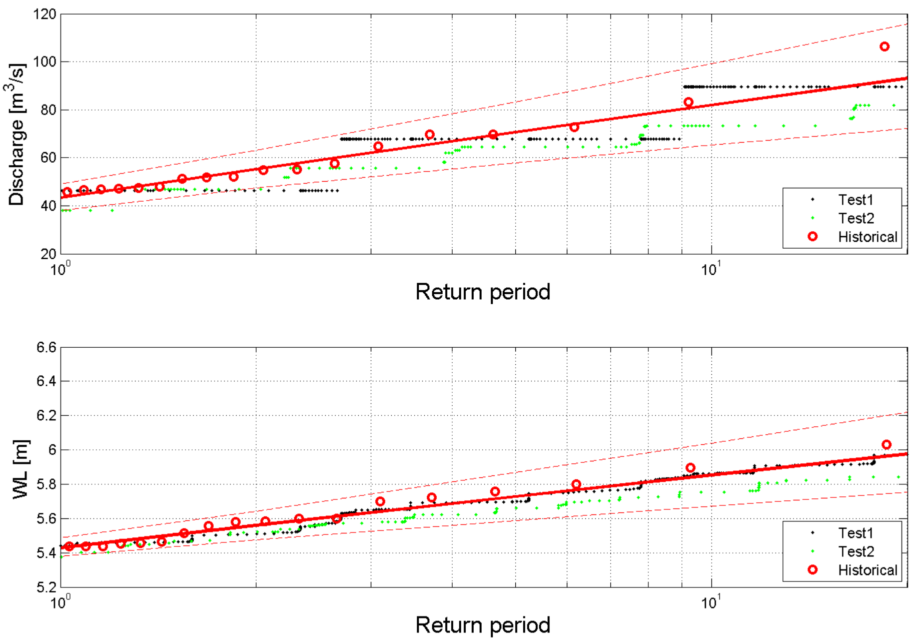


Figure 12-4: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the downstream Yser checkpoint 4,
the red line is the distribution fitted through the historical POT values

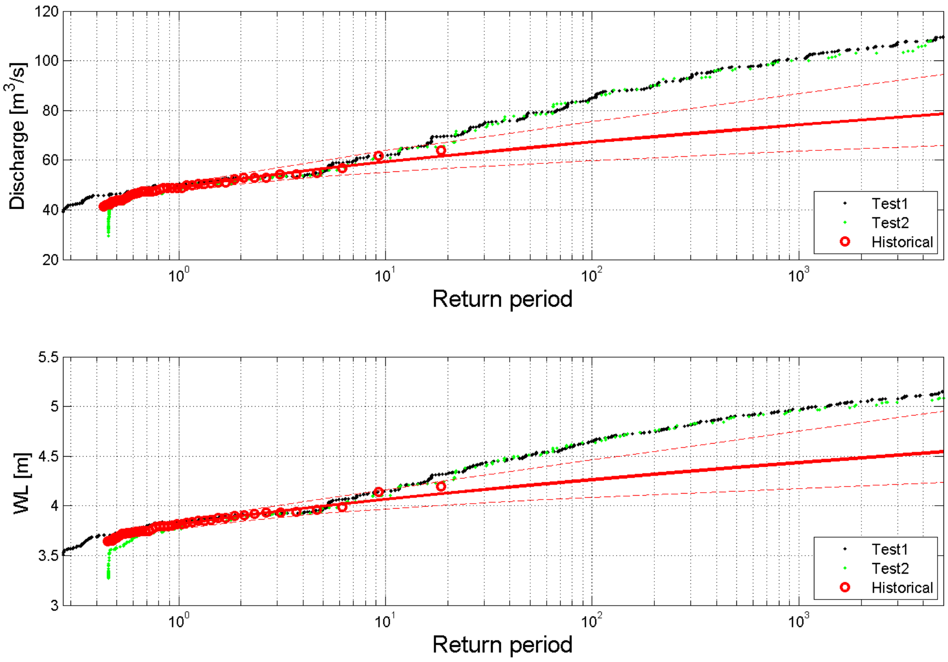
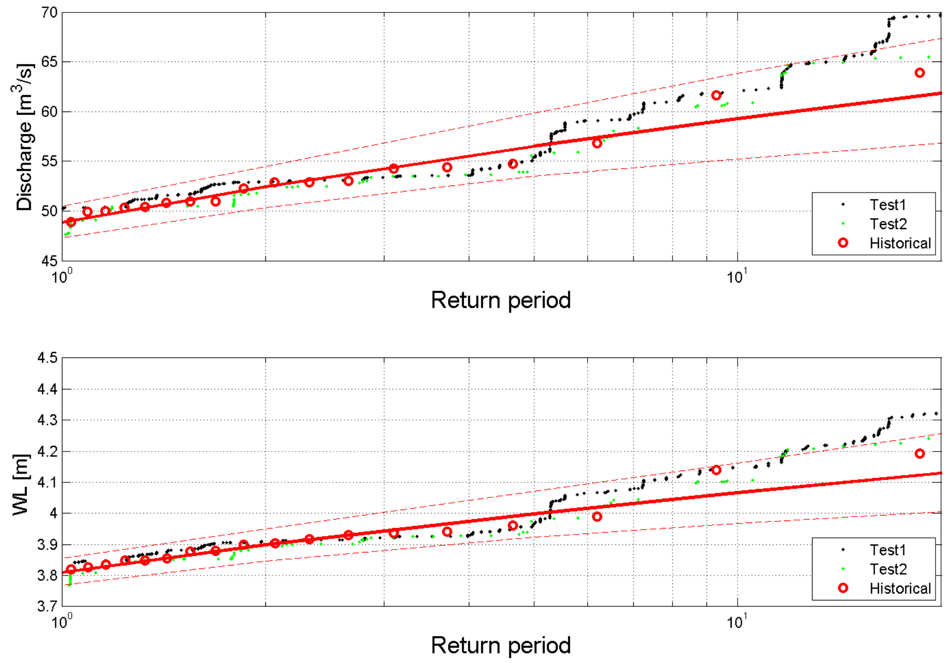


Figure 12-5: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the downstream Yser checkpoint 4 (zoom),
the red line is the distribution fitted through the historical POT values



A rather sudden increase in the return level-return period plot of both tests is visible between T4 and T6 (Figure 12-5). This shift is visible from point 2 till point 8. This sharp increase can also be seen in the empirical historical points but due to the limited resolution and the scatter on the POT values, it is not very clear. The line of the fitted distribution is not able to reproduce this kind behaviour. A sudden shift can be caused by a different behaviour to the downstream steering mechanisms. If the discharge to the North Sea is impeded from a certain return period the flow more upstream can be diminished and the water level increased for a short period of time.

This generates a higher discharge at a later time step. To investigate this hypotheses, the time of the peak flow and peak water level is determined for the events with 2<T<4, 4<T<6 and 6<T<10 (Annex G.2).

For the test with partial dependency it is very clear that the maximal discharge and water level occur at a later time for 4<T<6 and 6<T<10 (Figure 12-6). This confirms the stated hypotheses. The time shift is less clear for the second test with full dependency (Figure 12-7) but also the shift in return level was less clear in this case.

Figure 12-6: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 4 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

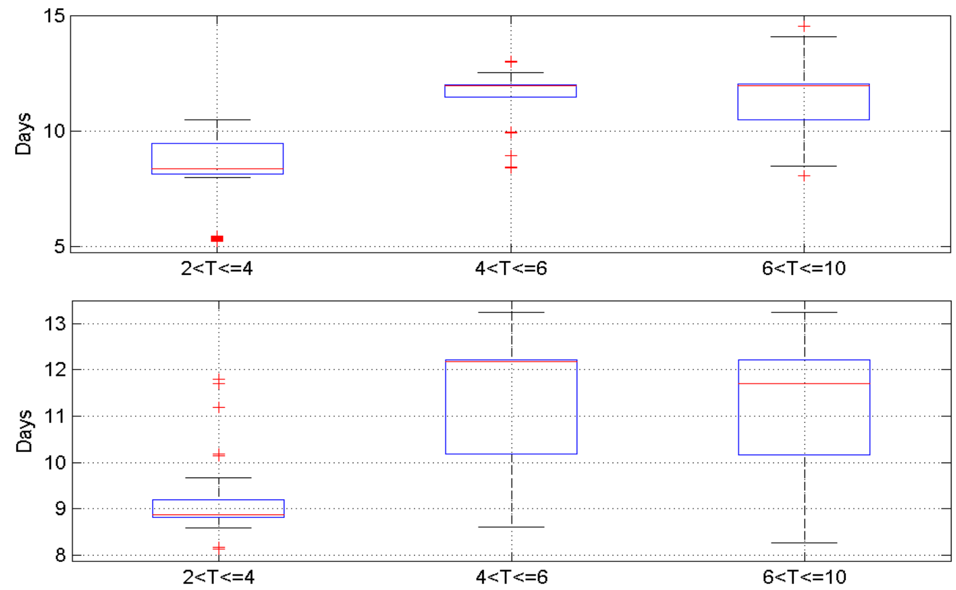
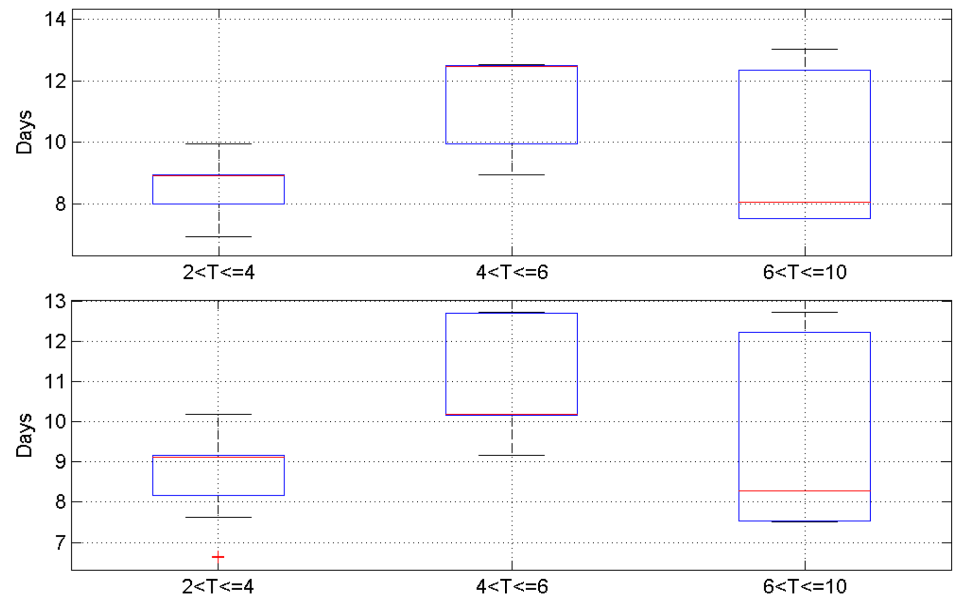


Figure 12-7: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 4 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries



13 Normative events

For the purpose of future scenario analysis a subset of normative events is selected on the basis of the results of the synthetic events simulations. On the basis of the time saving simulation of normative for a set of return periods, scenarios can be analysed quickly in contrast to repeating the time consuming simulation of the complete set of synthetic events for each scenario.

An event is selected as being normative for a considered return period on the basis of the difference in state variable between the events simulation result and the quantile for that return period at different locations in the model area. An event with a minimal difference in state variable throughout the model area is selected as the normative event for the considered return period.

The selection is based on the water levels simulated with the synthetic events for the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries in the 12 validation checkpoints (see chapter 12). These water levels result from the most accurate approach of the upstream boundary conditions. Table 13-1 gives a selection of normative events for 12 return periods identified by their rank in the synthetic events generation procedure.

Table 13-1: Normative events for a set of return periods

Return period [years]	Event Id
1	275
2	1525
5	398
10	342
25	491
50	535
100	671
500	866
1000	1002
2500	1046
4000	959
10000	1095

14 Conclusions

In the test case the methodology for the probabilistic formulation of hydraulic boundary conditions is successfully applied to the boundaries of the Yser basin model on the basis of gauged time series.

Correlation analysis indicates that peak discharges of the Yser are not independent of peak discharges on the tributaries of the Yser. Therefore the methodology is tested in two dependency cases, i.e. partial dependency and full dependency. In the test with partial dependency a set of 1800 synthetic events is generated by means of a Copula analysis, while in the test of full dependency a set of 300 events is generated by means of combined stratification.

The sets of synthetic events for the both dependency tests are simulated with the hydrodynamic model of the Yser basin. The results of the simulations are validated with the results of a historical long-term hydrodynamic simulation covering 18 years from 1994 to 2012.

In return level – return period plots, the water level and discharge results of the synthetic events for the two dependency tests are similar to the results of the historical long-term simulation up to a return period of 20 years. Return level with return periods above 20 years on the basis of the synthetic events overestimate the return levels as a result of a distribution function fit through the historical POT values in the downstream part of the Yser. These deviations are related to a different response of the higher return levels to the discharge steering mechanism of the outflow control structure at Nieuwpoort. A simple extrapolation of the lower values does not contain this changed behavior.

Though the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries provides a more accurate approach of the boundary conditions than the test with full dependency, the results of the tests are not significantly different in case of the Yser basin. On the other hand, the full dependency test allows for a significant reduction of the simulation time.

The test case for the Yser as well as for the Scheldt basin (see Figure 1-1 in chapter 1.2) proofs that the methodology for the probabilistic formulation of hydraulic boundary conditions is flexible and allows for a tailored, case dependent approach.

15 References

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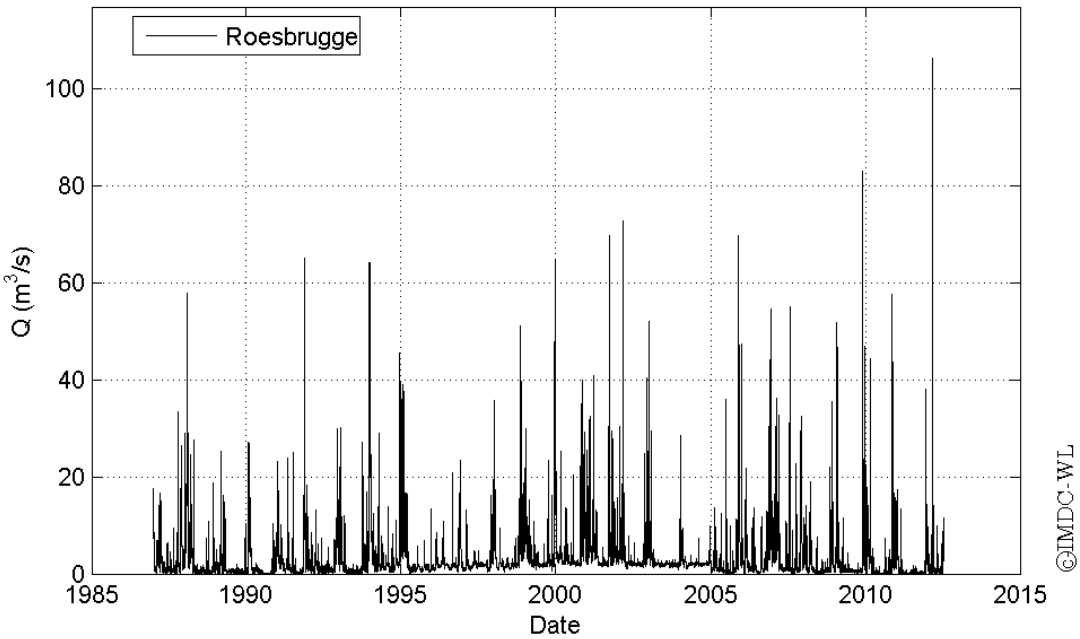
Appendix A: Discharge Data

Yser Roesbrugge

The validated discharge values of the Yser in Roesbrugge are delivered by HIC and a visual check does not reveal any inconsistencies. So the data is used in the following analysis without any modification.

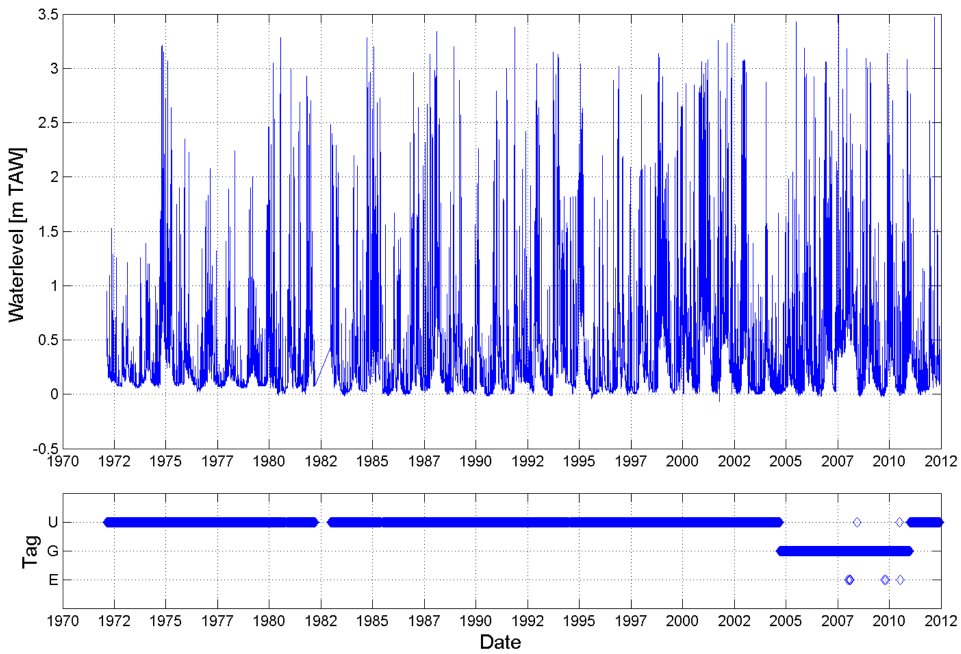
Figure A-1: Discharge time series of the Yser in Roesbrugge



Poperingevaart

The Poperingevaart discharge time series is derived from the water level time series with 2 different QH rating curves. There were no inconsistencies found.

Figure A-2:Water level (above) and discharge (below) time series of the Poperingevaart in Oostvleteren



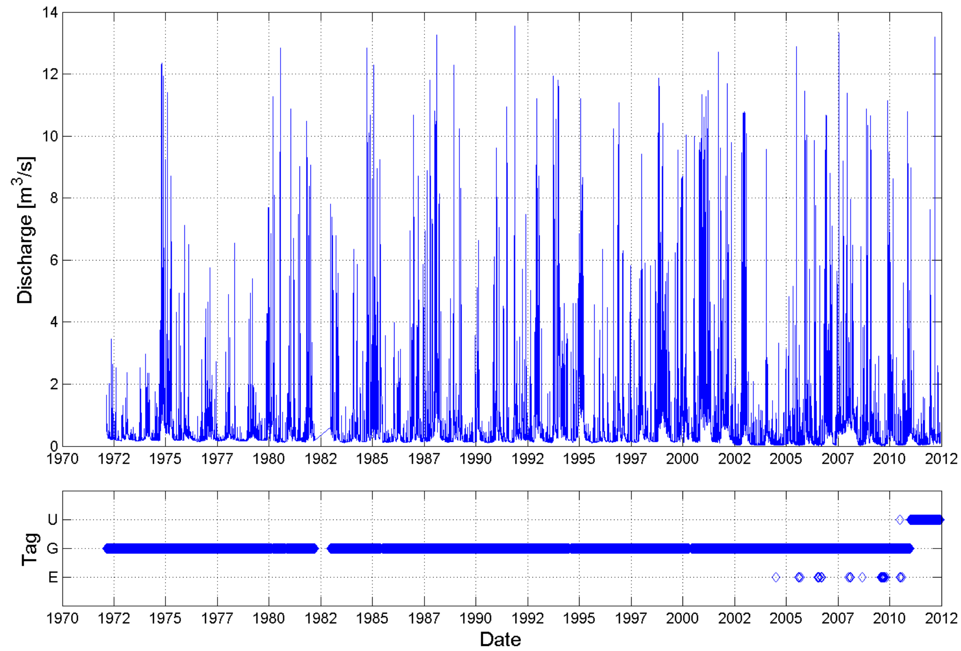
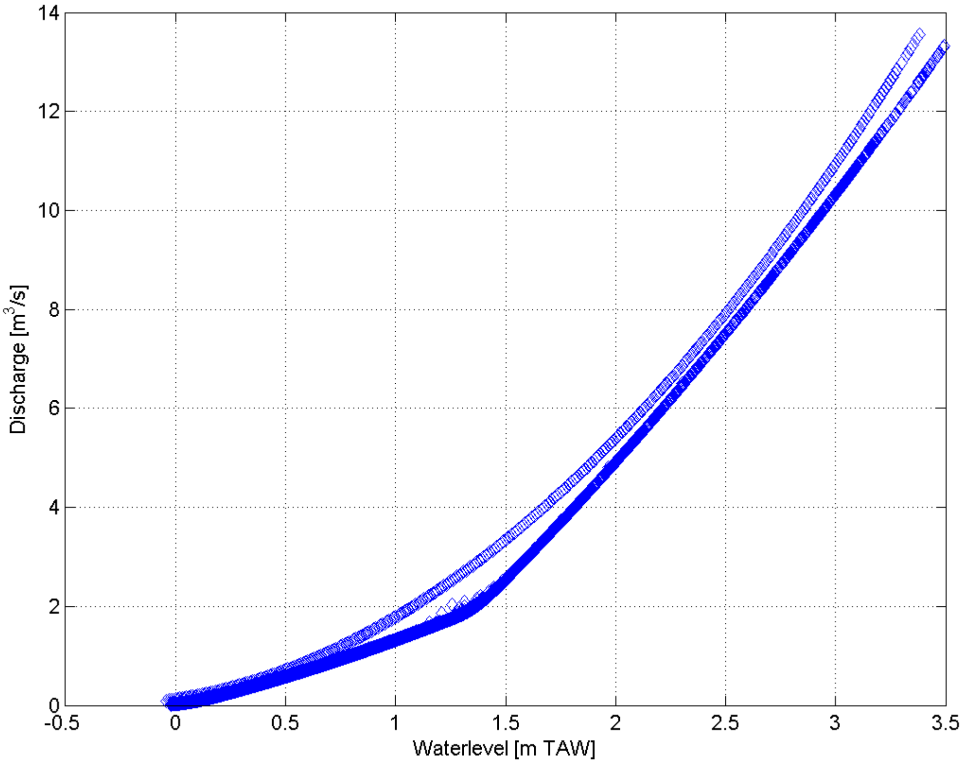


Figure A-3: QH points of the Poperingevaart in Oostvleteren generated with QH curve till 2001 (highest) and starting from 2002 (lowest)



Kemmelbeek

The water level time series of the Kemmelbeek appears to have a linear rising trend of the lower water levels but this is not visible in the discharge time series. It seems the linear trend is corrected in 2011. Because only the discharge will be used in the following analysis no modifications are applied on the data. The discharge data is derived with multiple QH rating curves.

Figure A-4: Water level (above) and discharge (below) time series of the Kemmelbeek in Reninge

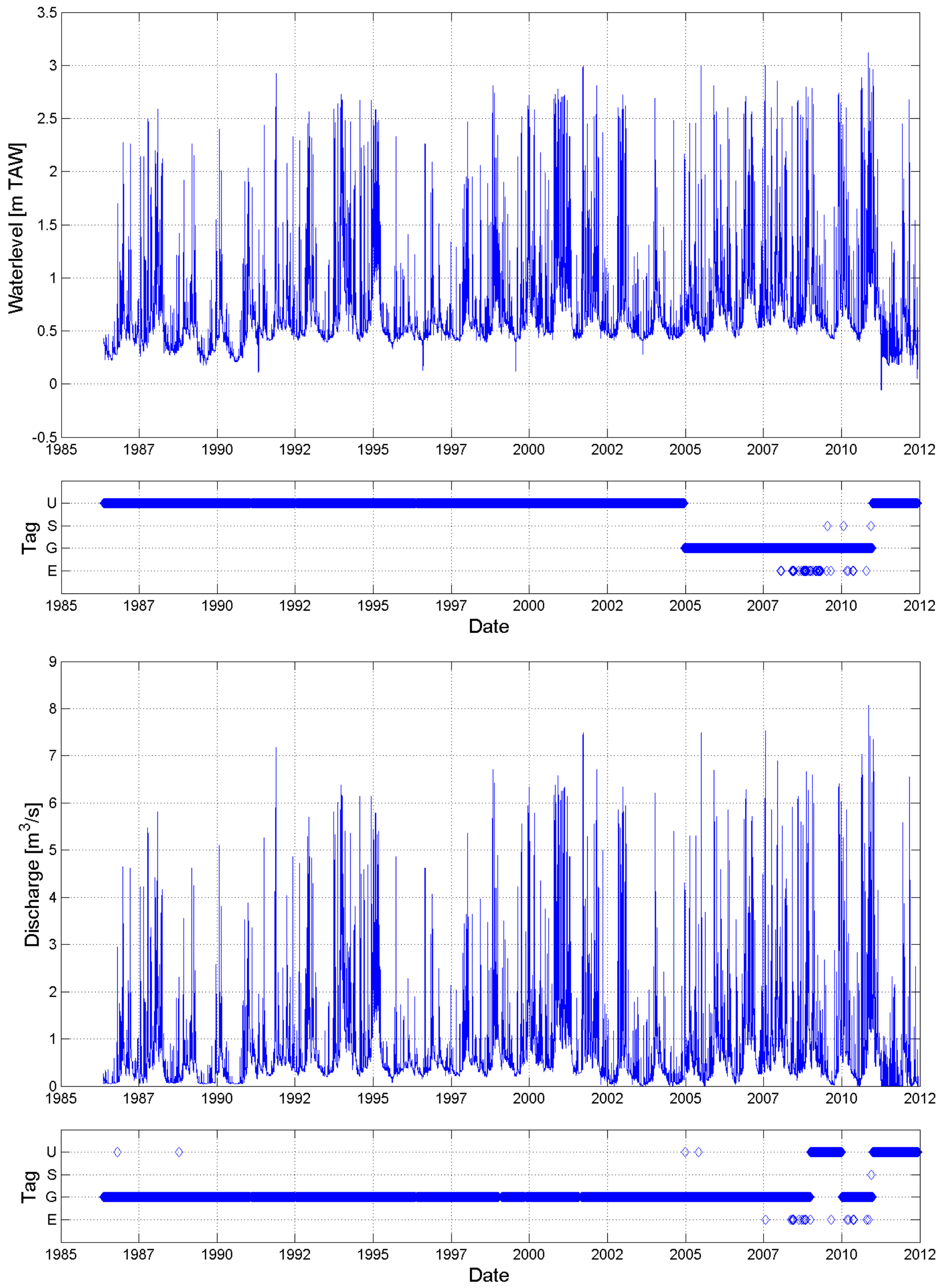
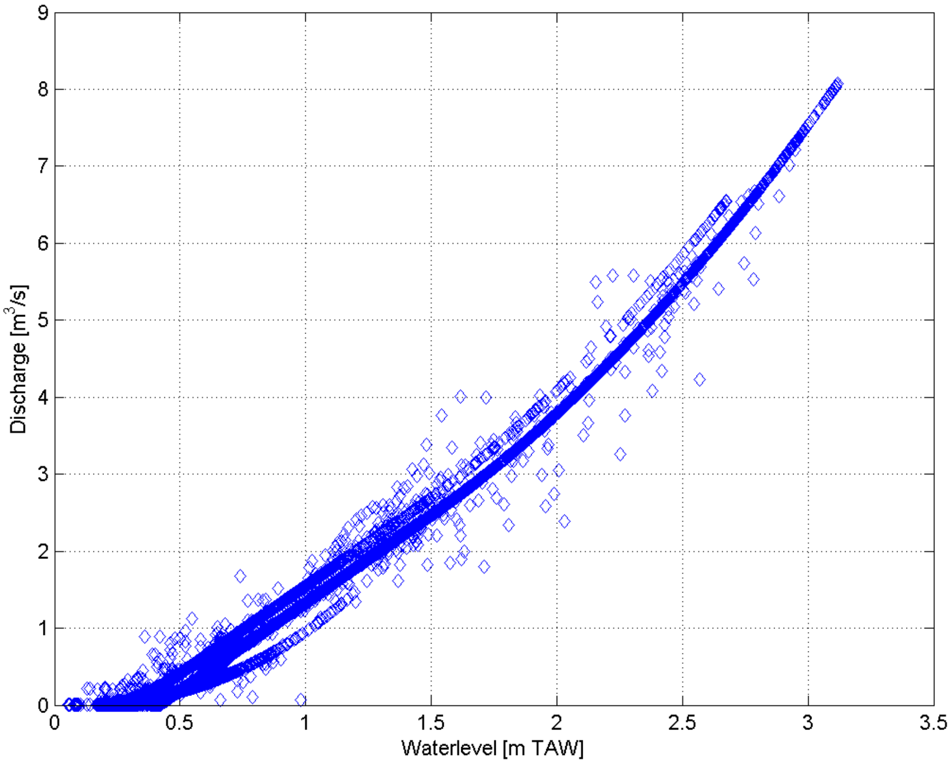


Figure A-5: QH points of the Kemmelbeek in Reninge



Ieperlee

The data of 2000 shows a strange relationship between the water level and the discharge starting from 29/02/2000 (Figure A-7). Because 2000 is a leap year a possible error in the Q or H data assumed which lead to this time shift. At the end of 2000 this shift stops. To check if the Q or the H data is correct the data is compared with the data from the Kemmelbeek (Figure A-8). The discharge time series of the Ieperlee seems to shift 1 day at 29/02/2000. A correction of 24h is applied to the dates of the discharge dataset (Figure A-9). The discharge data is derived from two different rating curves.

Figure A-6: Water level (above) and discharge (below) time series of the Ieperlee in Boezinge

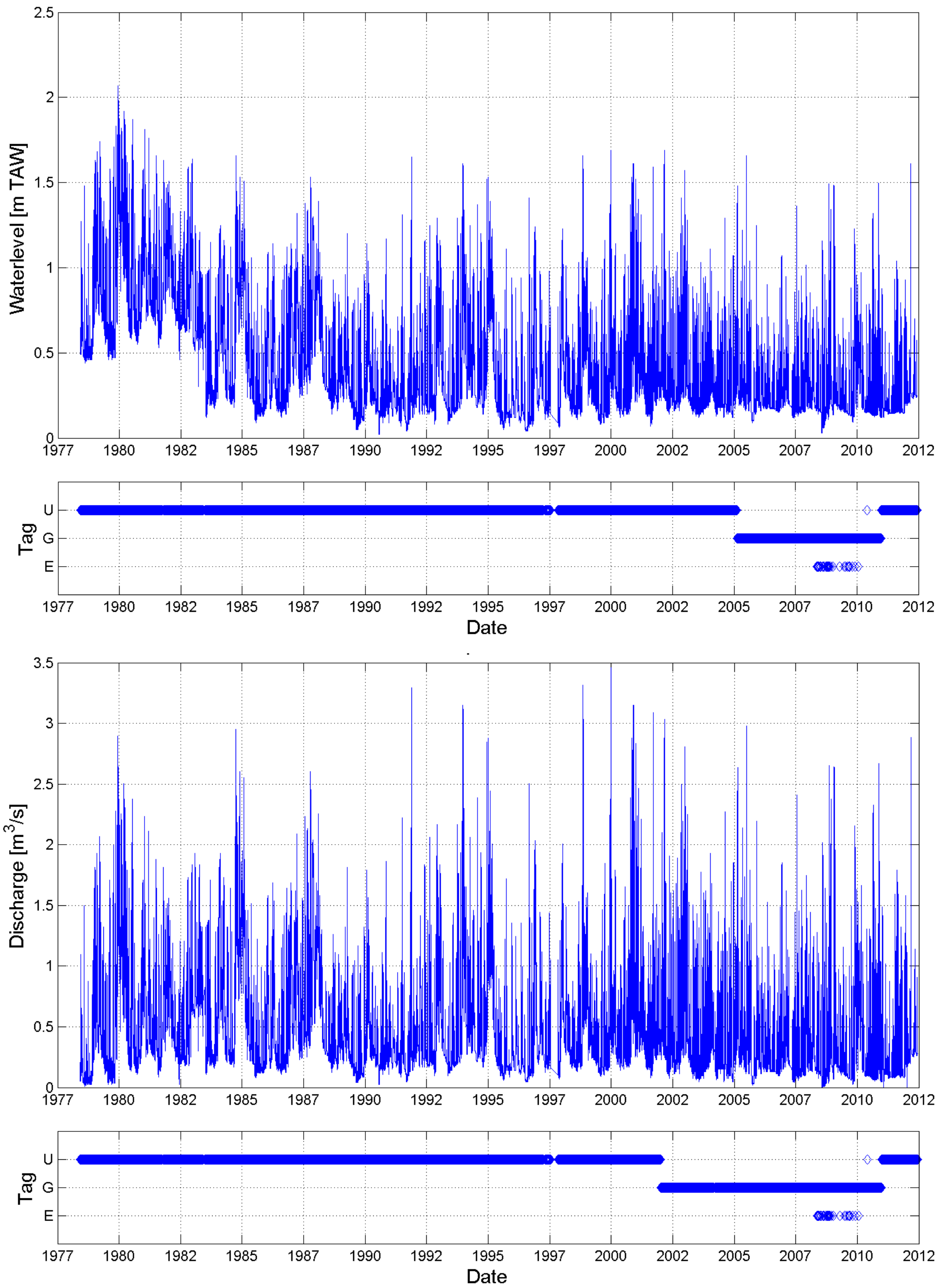


Figure A-7: Water level and discharge of the Ieperlee in Boezinge, February 2000

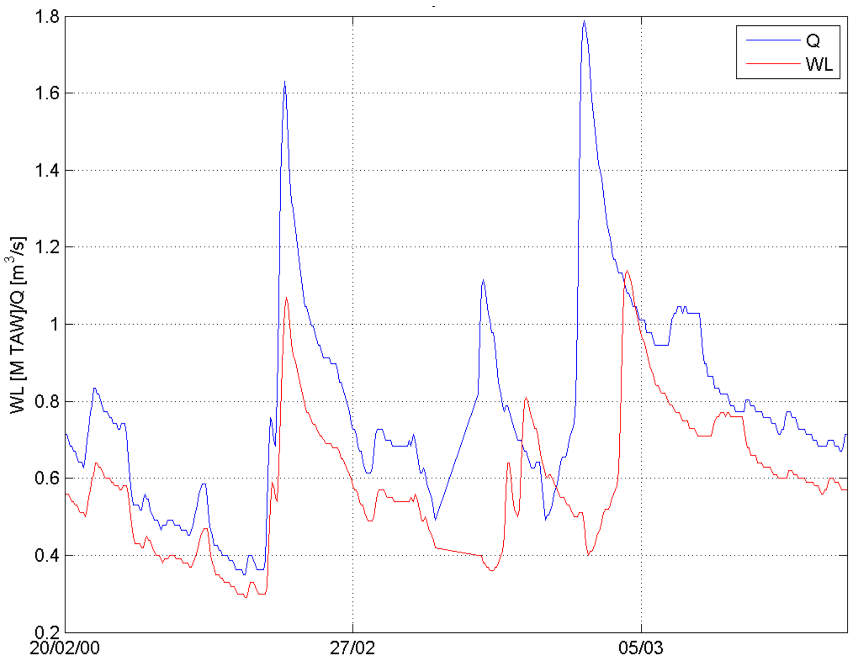


Figure A-8: Water level and discharge of the Ieperlee and the Kemmelbeek, February 2000

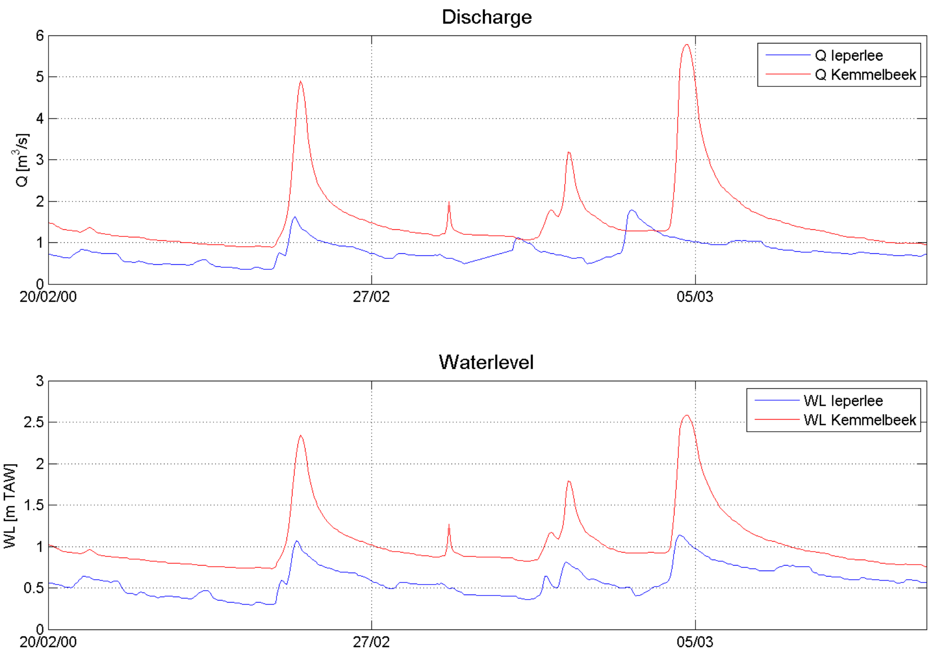


Figure A-9: Water level and discharge Ieperlee in Boezinge
after correction, February 2000

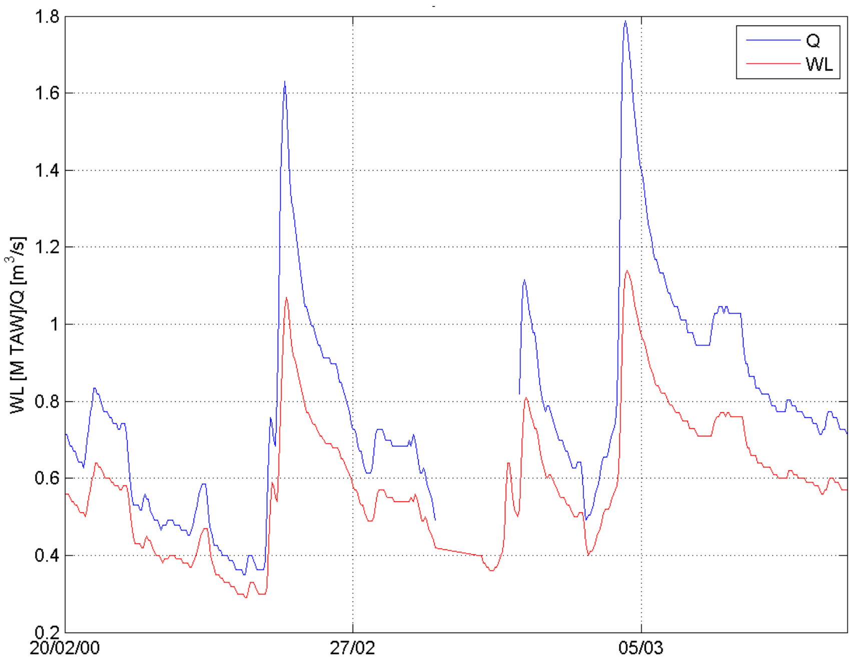
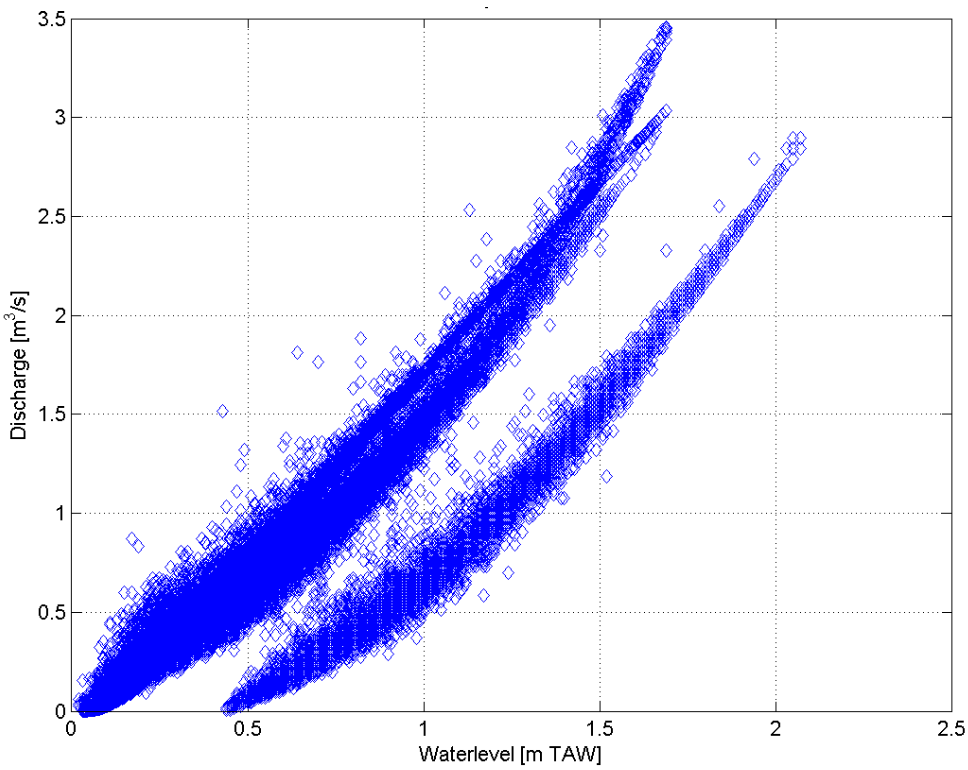


Figure A-10: QH points of the Ieperlee in Boezinge on the basis of two rating curves



Martjesvaart

The data of 2000 shows a strange relationship between the water level and the discharge starting from 29/02/2000 (Figure A-12). Because 2000 is a leap year a possible error in the Q or H data assumed which lead to this time shift. At the end of 2000 this shift stops. To check if the Q or the H data is correct the data is compared with the data from the Kemmelbeek (Figure A-15). The discharge time series of the Martjesvaart seems to shift 1 day at 2000/02/29. A correction of 24h will be applied on the discharge of this dataset (Figure A-14).

The QH rating curve is very steep above 2.5 m which indicates an overestimation of the discharge values. The evaluation of QH rating curves is however no part of this study. Because the possible error will be used in both the proposed methodology as in the historical run, its effect should be minimal in the comparison.

There is a strange QH relation at approximately 0.6m TAW. A set of constant water level points with variable discharge are visible. These points correspond to one event in 1989 (Figure A-16) that won't be used in the further analysis. There are also some points with a rather high water level but almost zero discharge. These event corresponds with a strange set of peaks in 1995 (Figure A-17). When these two event are discarded the QH relation looks like Figure A-18.

Figure A-11: Water level (above) and discharge (below) time series of the Martjesvaart in Merkem

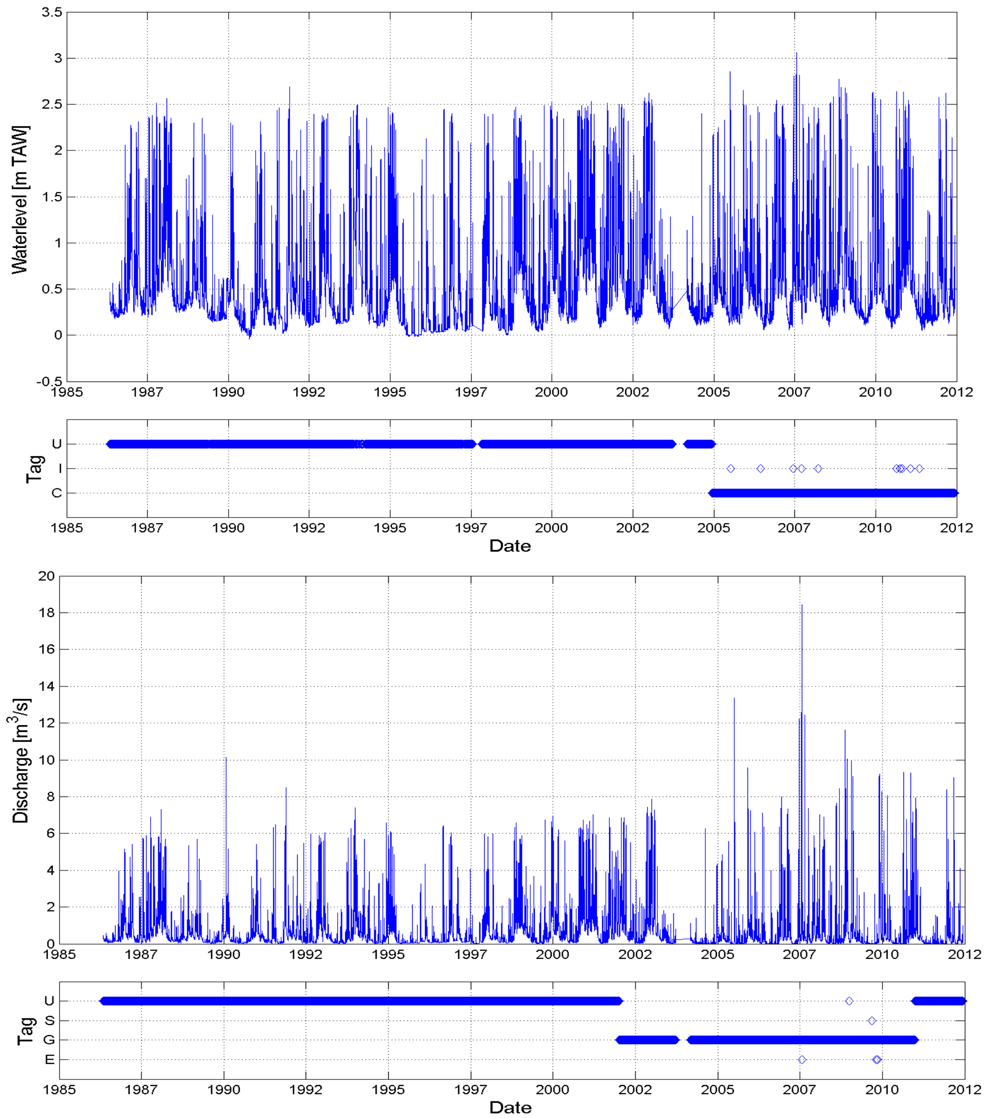


Figure A-12: Water level and discharge of the Martjesvaart in Merkem, February 2000

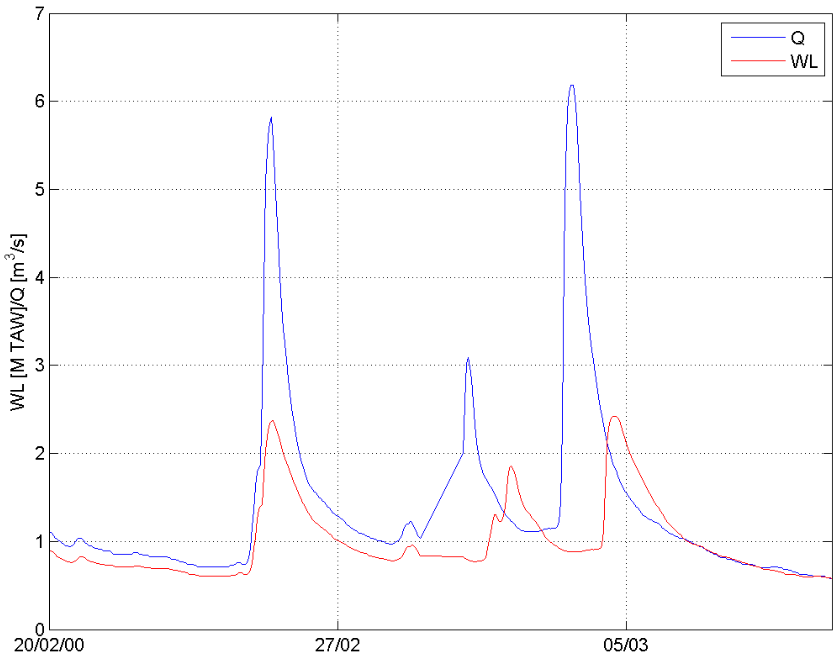


Figure A-13: Water level and discharge of the Martjesvaart and the Kemmelbeek, February 2000

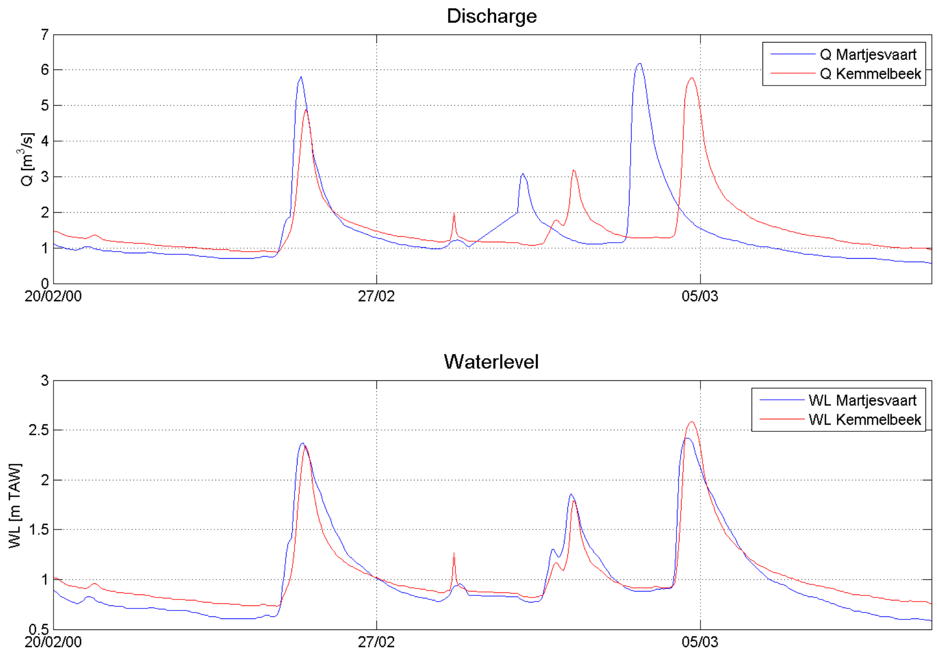


Figure A-14: Water level and discharge of the Martjesvaart in Merkem after correction, February 2000

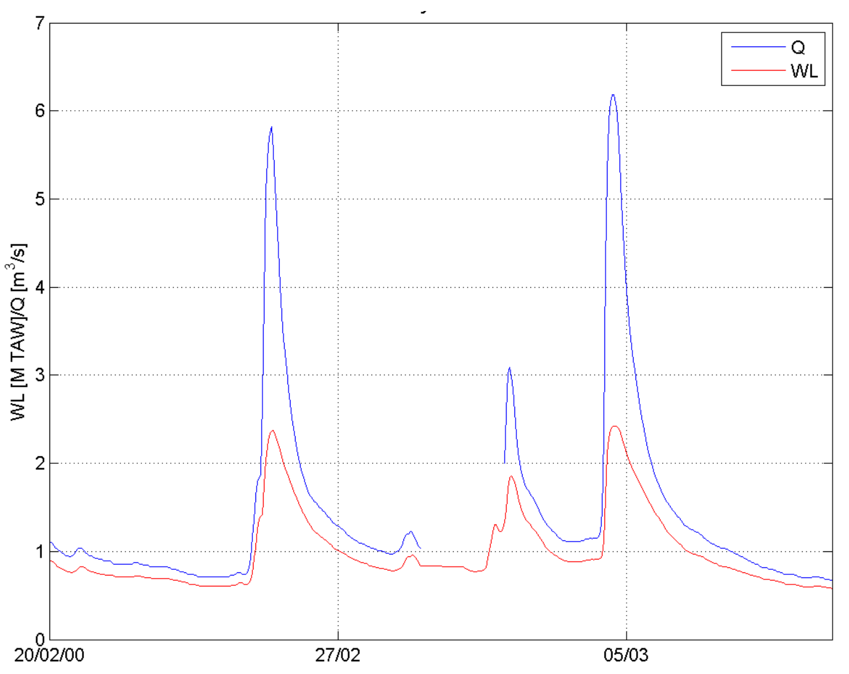


Figure A-15: QH points of the Martjesvaart in Merkem

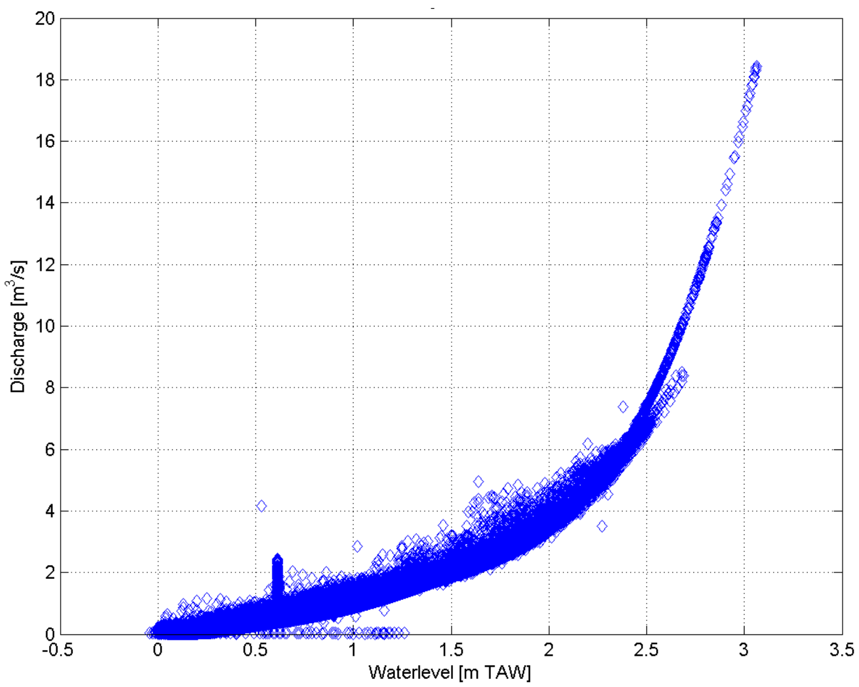


Figure A-16: Discharge (above) and water level (below) of the Martjesvaart in Merkem, error in the water level data of the year 1989

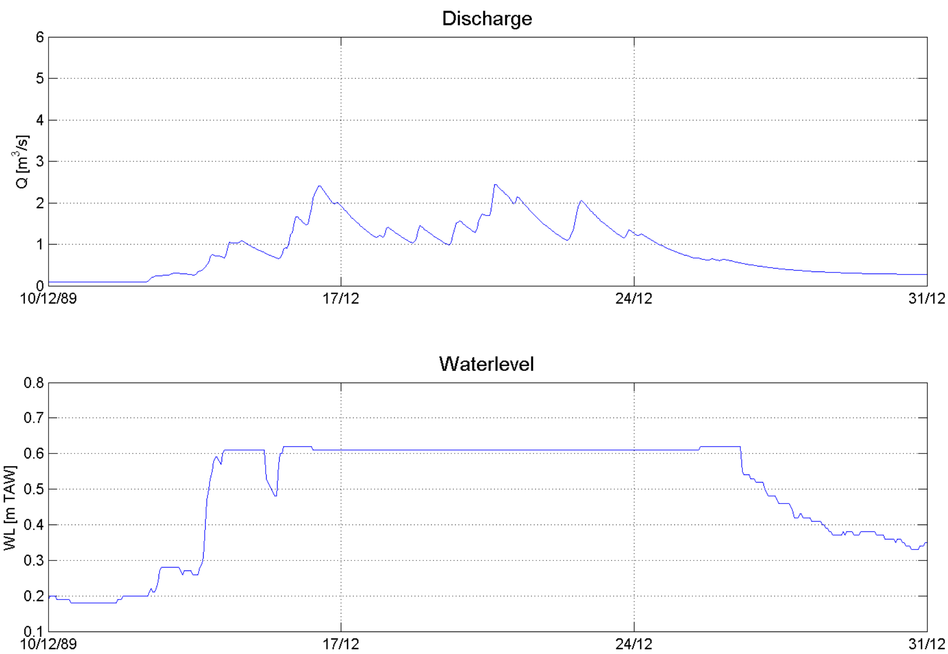


Figure A-17: Discharge (above) and water level (below) of the Martjesvaart in Merkem, error in the water level data of the year 1995

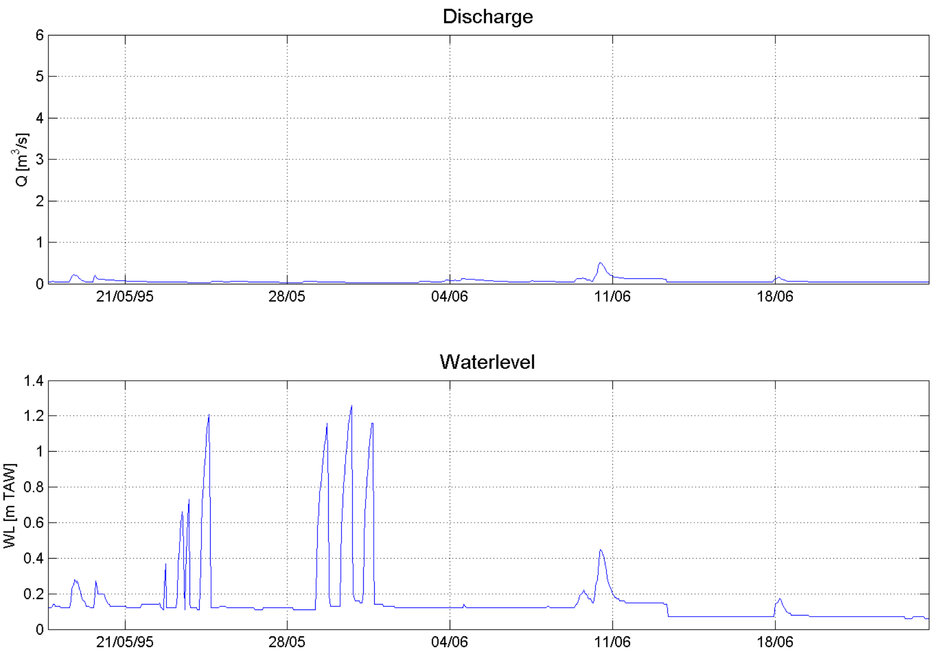
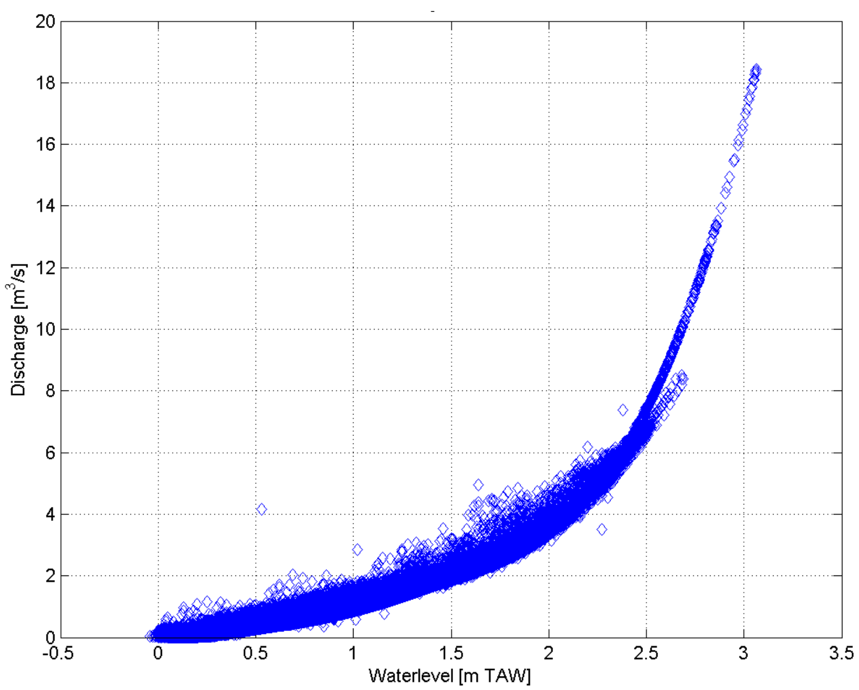


Figure A-18: Modified QH points of the Martjesvaart in Merkem



Steenbeek

There are two stations available at the Steenbeek in Merkem (L01_499 and L01_49A). A combined dataset is used in the following analysis to obtain an as long as possible time series. When the time series of station L01_499 ends the data of L01_49A is used.

Station L01_499

The discharge is derived from 2 different QH rating curves. Some suspicious events in 2008 are discarded and not used in further analysis.

Figure A-19: Water level (above) and discharge (below) time series of the Steenbeek at station L01_499 in Merkem

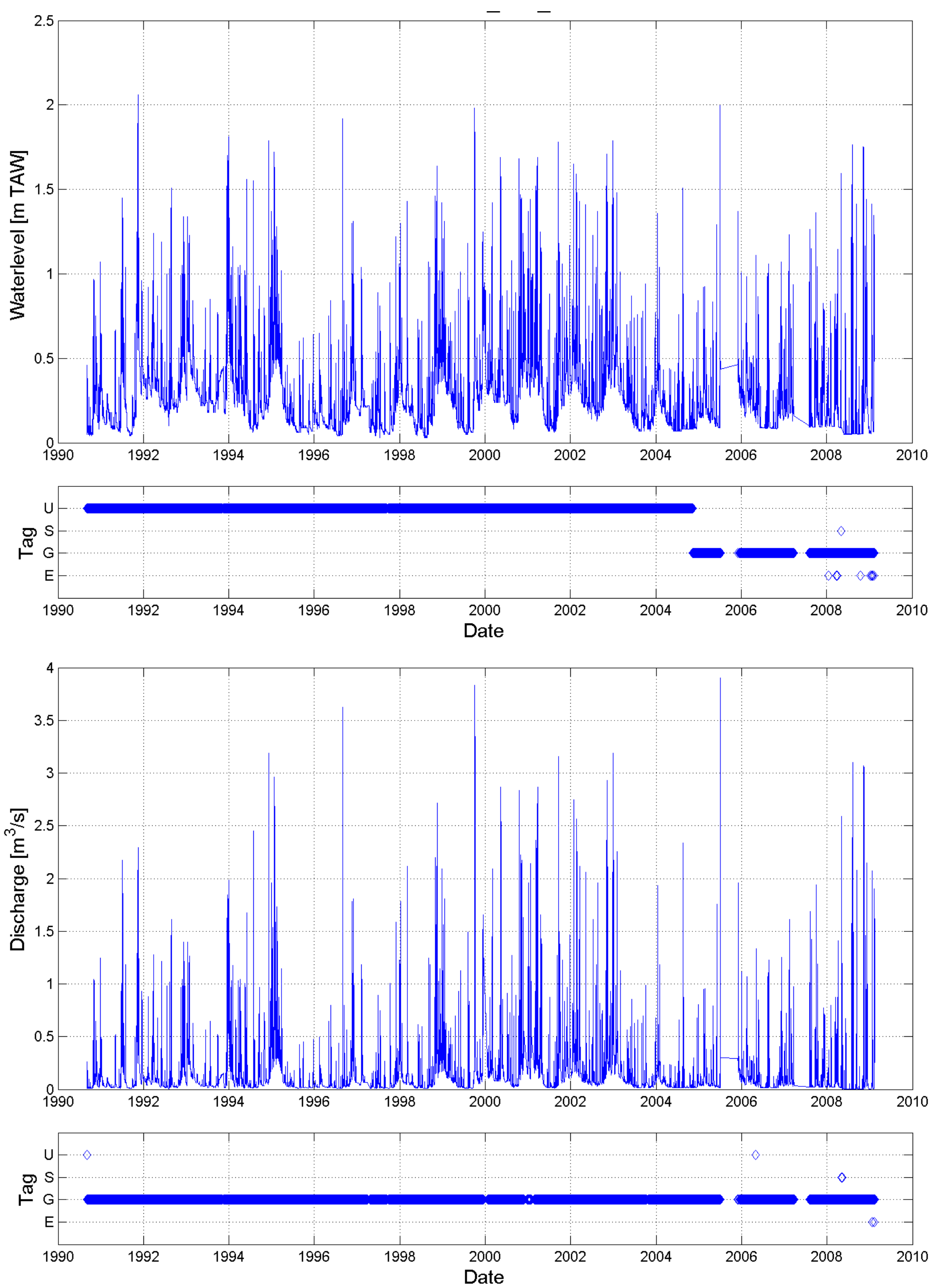


Figure A-20: QH points of the Steenbeek at station L01_499 in Merkem on the basis of two rating curves

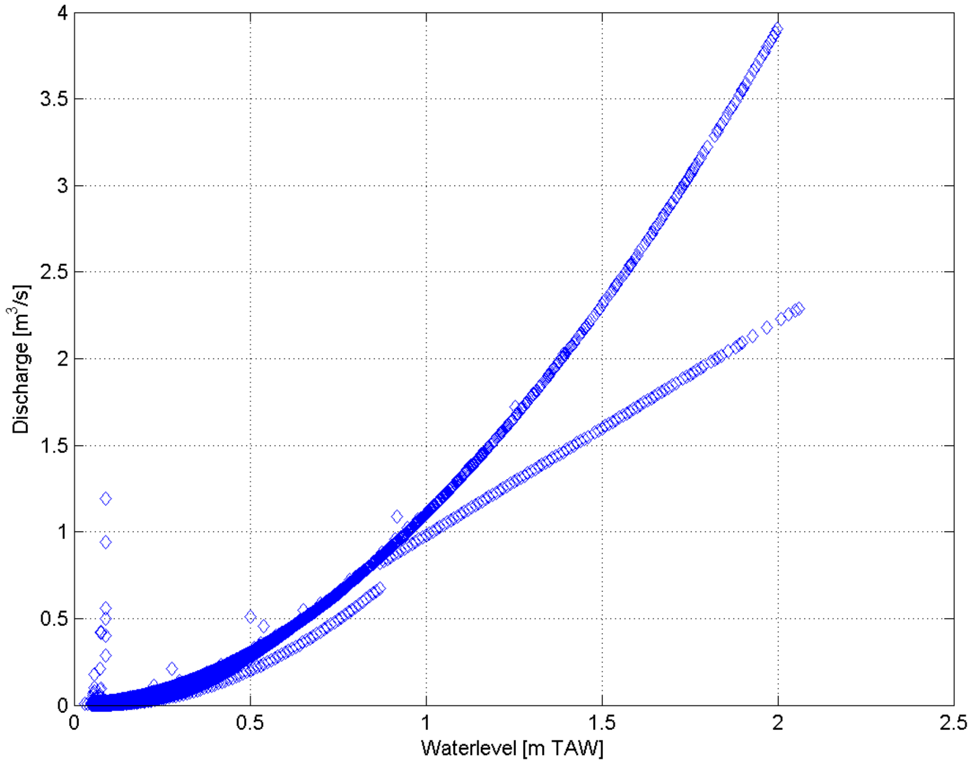


Figure A-21: Discharge (above) and water level (below) of the Steenbeek at station L01_499 in Merkem, suspicious event in 2008

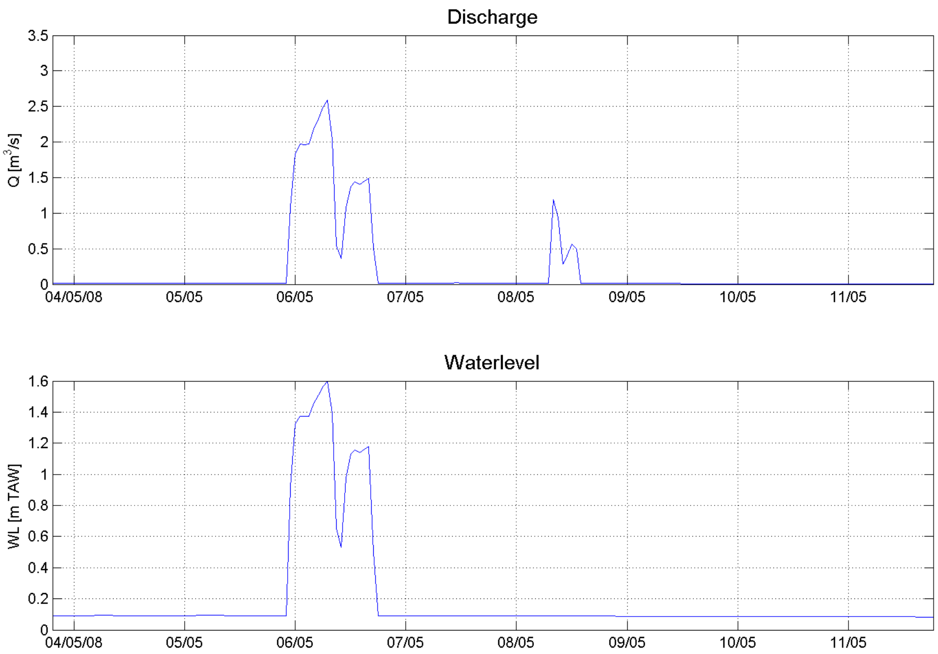
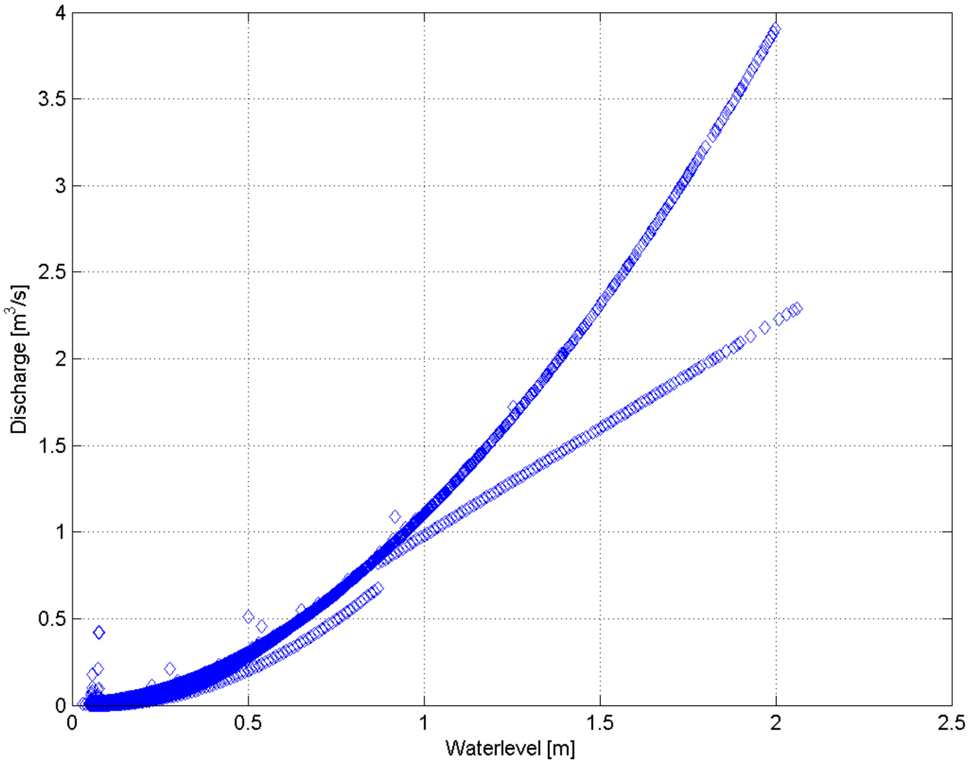


Figure A-22: Modified QH points of the Steenbeek at station L01_499 in Merkem on the basis of two rating curves



Station L01_49A

The QH rating curve (Figure A-24) of the 49A station of the Steenbeek has some suspicious data points of approximately 0.2 and 0.3 m above the reference plane. These points correspond with a set of discharge peaks in 2001, 2009 and 2011 without an increase in water level and are discarded (Figure A-25, Figure A-26, Figure A-27). The QH-rating curve of the modified data is visualised in Figure A-28.

Figure A-23: Water level (above) and discharge (below) time series of the Steenbeek at station L01_49A in Merkem

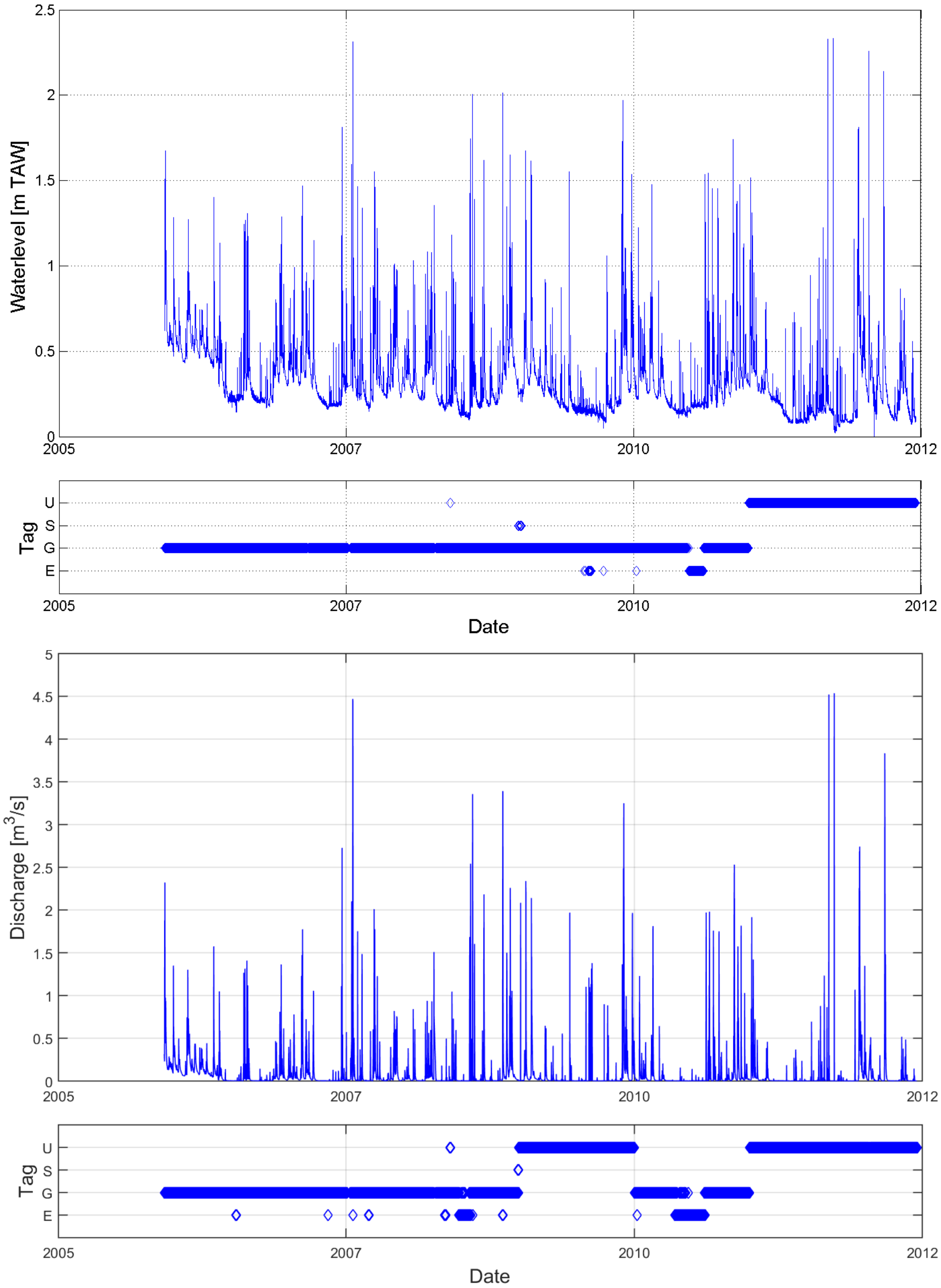


Figure A-24: QH points of the Steenbeek at station L01_49A in Merkem

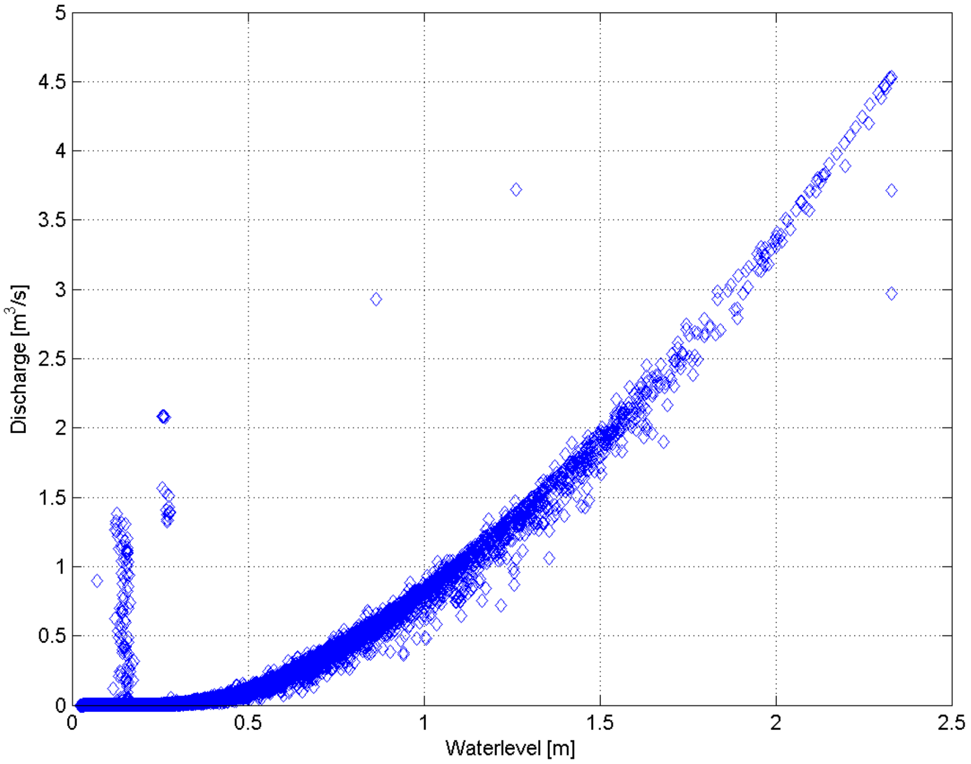


Figure A-25: Discharge (above) and water level (below) of the Steenbeek at station L01_49A in Merkem, suspicious event in 2001

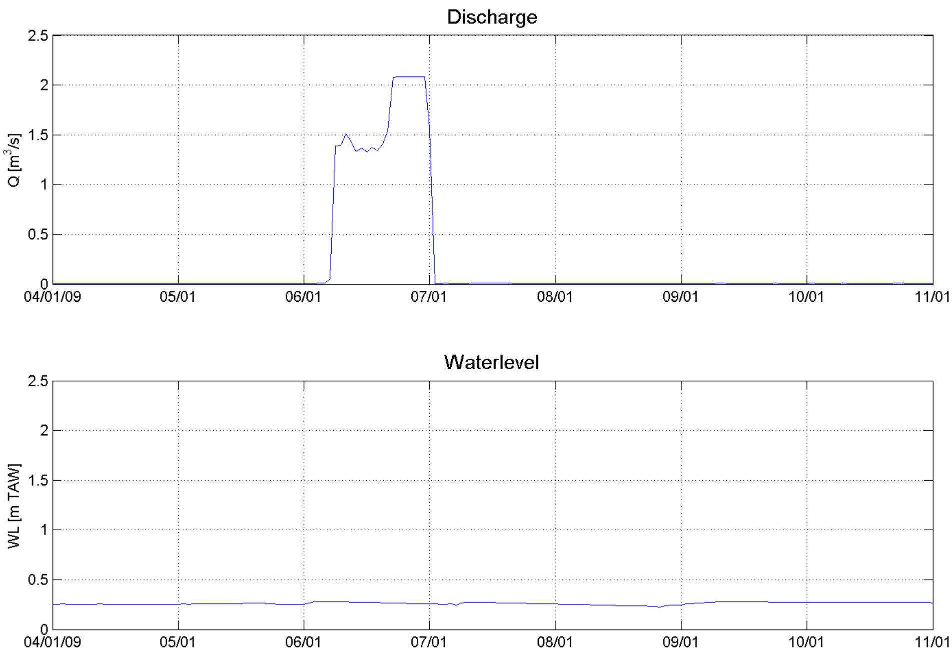


Figure A-26: Discharge (above) and water level (below) of the Steenbeek at station L01_49A in Merkem, suspicious event in 2009

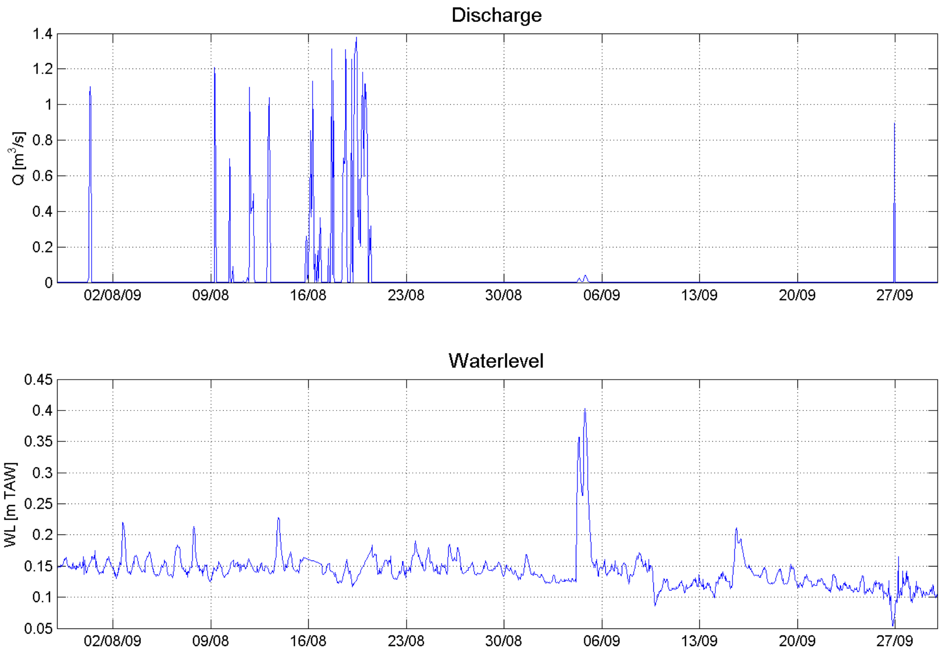


Figure A-27: Discharge (above) and water level (below) of the Steenbeek at station L01_49A in Merkem, suspicious event in 2011

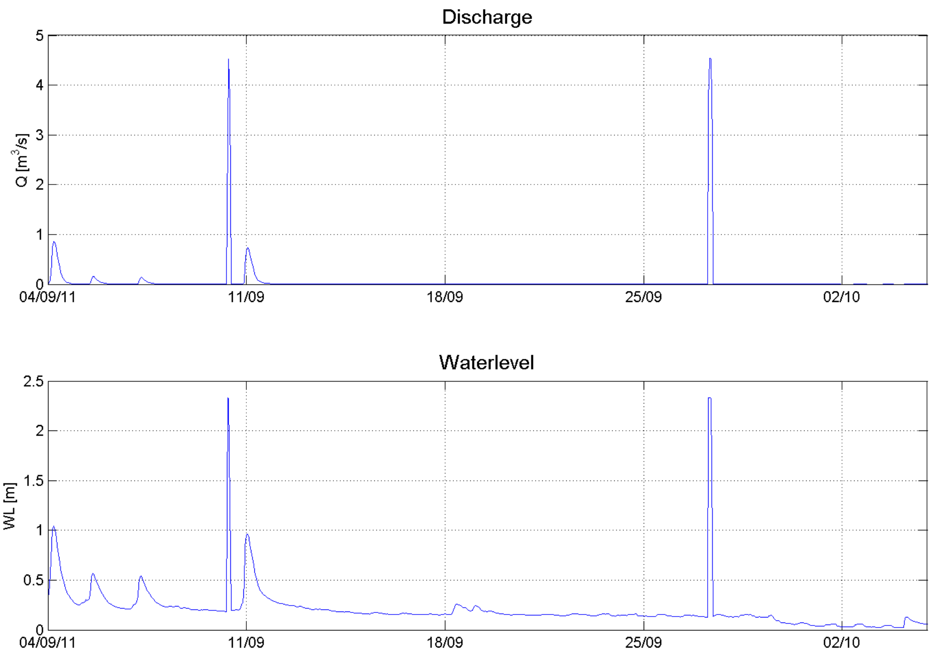
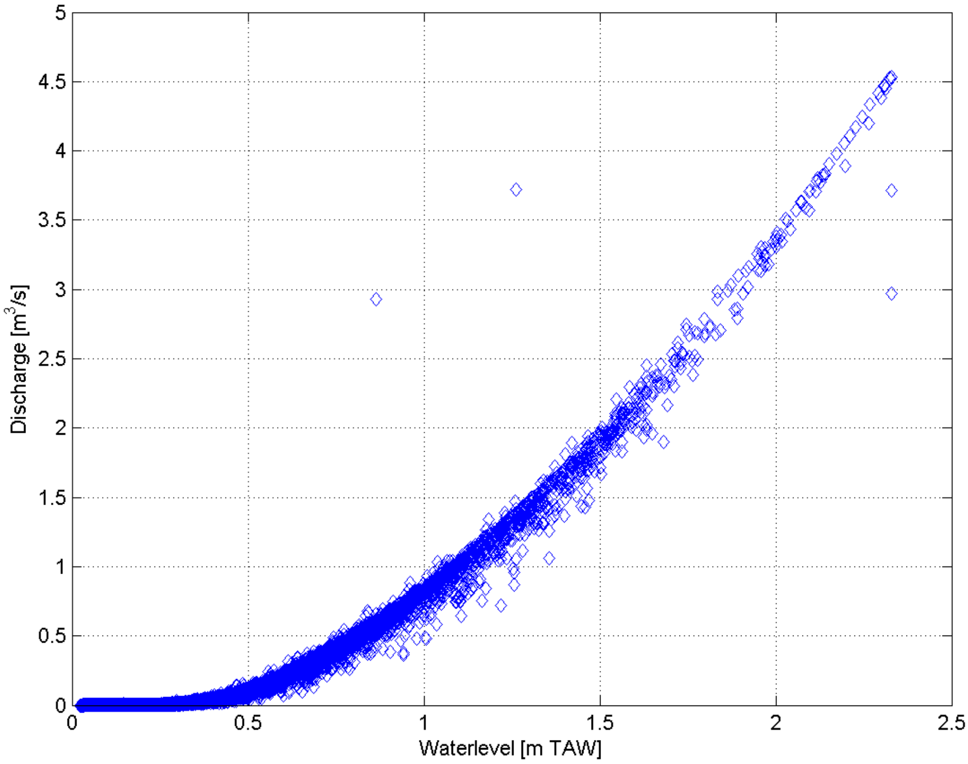


Figure A-28: Modified QH points of the Steenbeek at station L01_49A in Merkem



Handzamevaart

The QH rating curve (Figure A-29) of the Handzamevaart has a maximum discharge of 9.8 m^3/s. This would mean that the QH-rating curve is limited to this discharge and no extrapolation is made. A new fit is made based on a stacked power law to make to allow for this extrapolation. The formula of this power low is:

$$H \leq 1.73 \quad Q^{(1)} = 2.177 * (H - 0.22)^{1.29}$$
$$1.73 \leq H \quad Q^{(2)}(H) = Q^{(1)} + 1.8574 * (H - 1.73)^{1.50}$$

The QH rating curve contains has some suspicious data points at approximately 0.6 m above the reference plane. These points correspond with a set constant water level periods in 2012 (Figure A-30) and are discarded. The QH-rating curve of the resulting data is visualised in (Figure A-31).

Figure A-29: Water level (above) and discharge (below) time series of the Handzamevaart in Kortemark

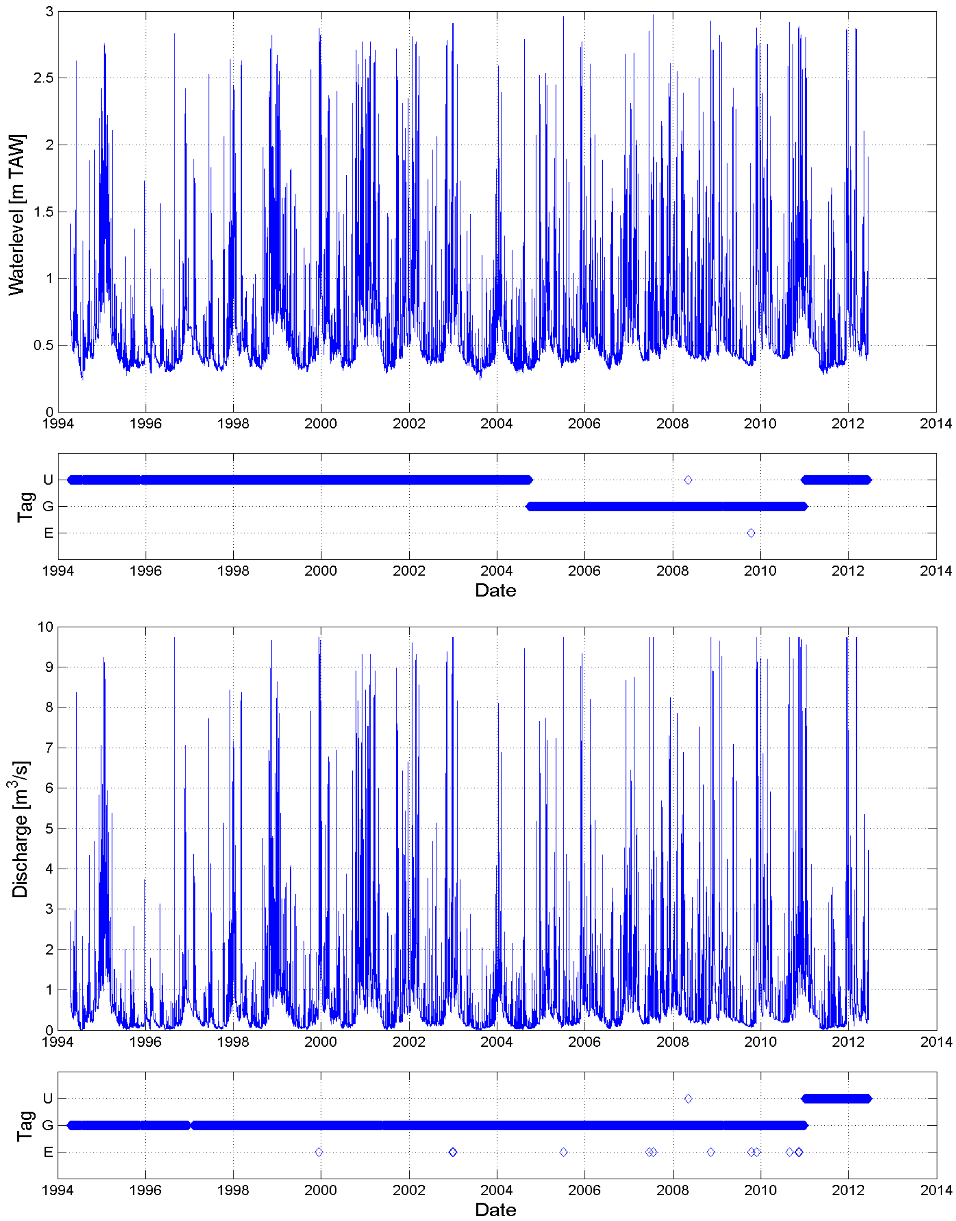


Figure A-30: QH points of the Handzamevaart in Kortemark

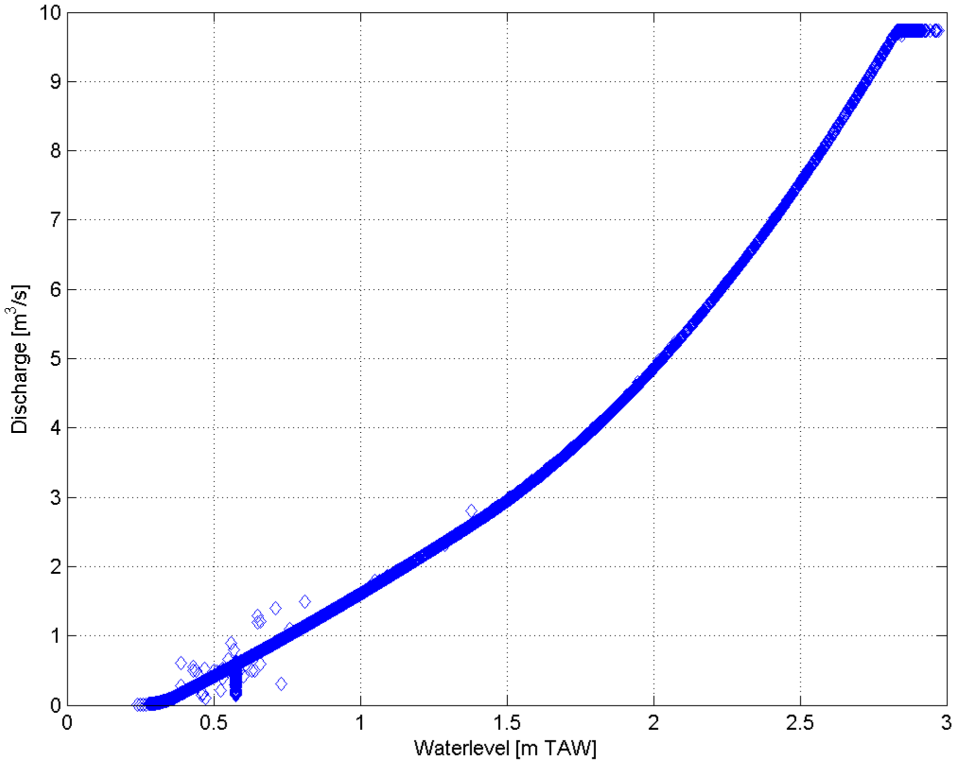


Figure A-31: Discharge (above) and water level (below) of the Handzamevaart in Kortemark, constant water level in 2012

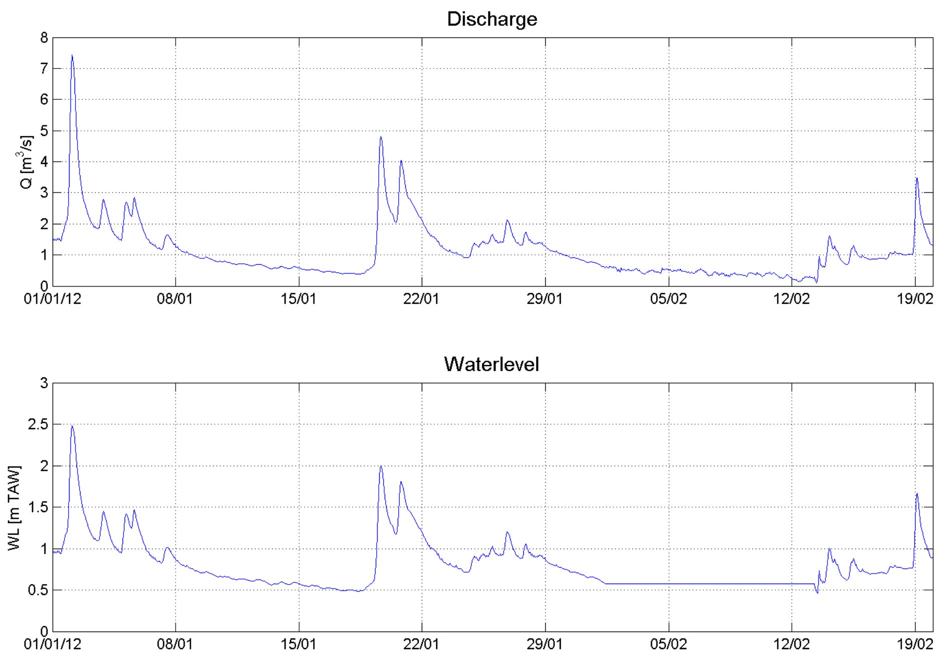
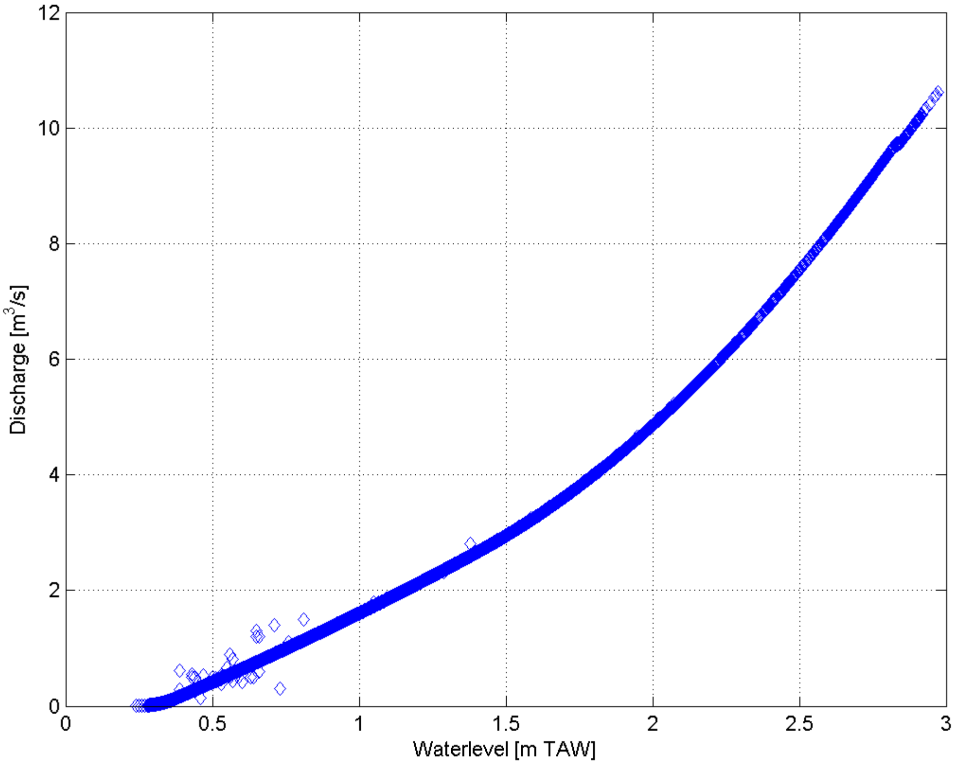


Figure A-32: Modified QH points of the Handzamevaart in Kortemark



Appendix B: Correlation analysis

There are two well-known nonparametric rank based measures available to quantify the dependence, i.e. the Spearman's rho and the Kendall tau. Because these measures are rank based they have some advantages over the well-known Pearson correlation coefficient. The Spearman ρ is given by:

$$\rho_n = \frac{\sum_{i=1}^{n}(R_i - \bar{R})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(R_i - \bar{R})^2 \sum_{i=1}^{n}(S_i - \bar{S})^2}}$$

Where

$$\bar{R} = \frac{1}{n}\sum_{i}^{n} R_i = \frac{n+1}{2} = \frac{1}{n}\sum_{i}^{n} S_i = \bar{S}$$

The Spearman's ρ has the property that its expectation vanishes when the variables are independent, like the classical Pearson r. However the Spearman's ρ has some advantages over the Pearsonn's r. E(ρ)=±1 occurs if and only if X and Y are functionally dependent, i.e., whenever their underlying copula is one of the two Fréchet–Hoeffding bounds, M or W. In contrast, E(r)= ±1 if and only if X and Y are linear functions of one another, which is much more restrictive. Moreover ρ estimates a population parameter that is always well defined, whereas there are heavy-tailed distributions such as the Cauchy, for example for which a theoretical value of Pearson's correlation does not exist (Embrechts 2002).

The Spearman ρ can be used to check the null hypothesis H_0 of independence between X and X. The distribution of ρ is close to normal with zero mean and variance (1/(n-1) so one may reject H_0 at the confidence level α=5% if $\sqrt{n-1}|\rho| > z_{a/2} = 1.96$. A standard p-test will give the minimal confidence level at which one may reject H_0.

The second, well-known measure of dependence based on ranks is Kendall's tau, whose empirical version is given by

$$\tau = \frac{4}{n(n-1)}P_n - 1$$

where P_n is the number of concordant . Here, two pairs (X_i, Y_i), $(X_j\ Y_j)$ are said to be concordant when $(X_i-X_i)(Y_j-Y_j)>0$. It is obvious that τ is a function of the ranks of the observations only, since $(X_i-X_j)(Y_i-Y_j)>0$ if and only if $(R_i-R_j)(S_i-S_j)>0$.

The Kendall τ can also be used to check the null hypothesis H_0 of independence between X and X. The distribution of τ under H_0 is close to normal with zero mean and variance 2(2n+5)/(9n(n-1)) so one may reject H_0 at the confidence level α=5% if

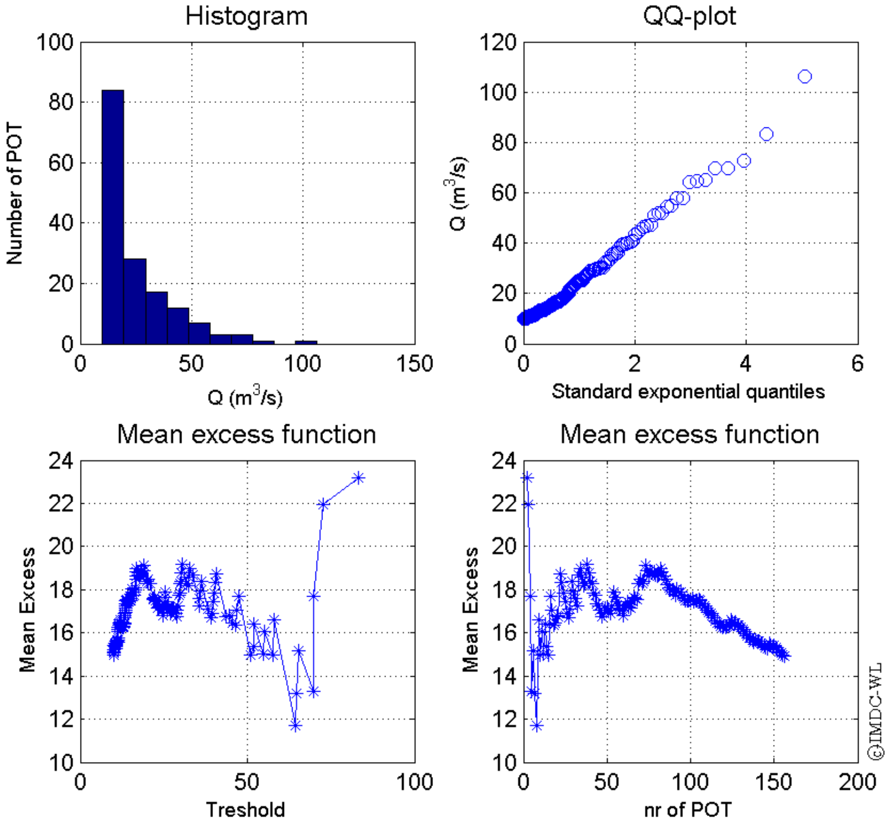
$$\sqrt{\frac{9n(n-1)}{2(2n+5)}}|\tau| > 1.96$$

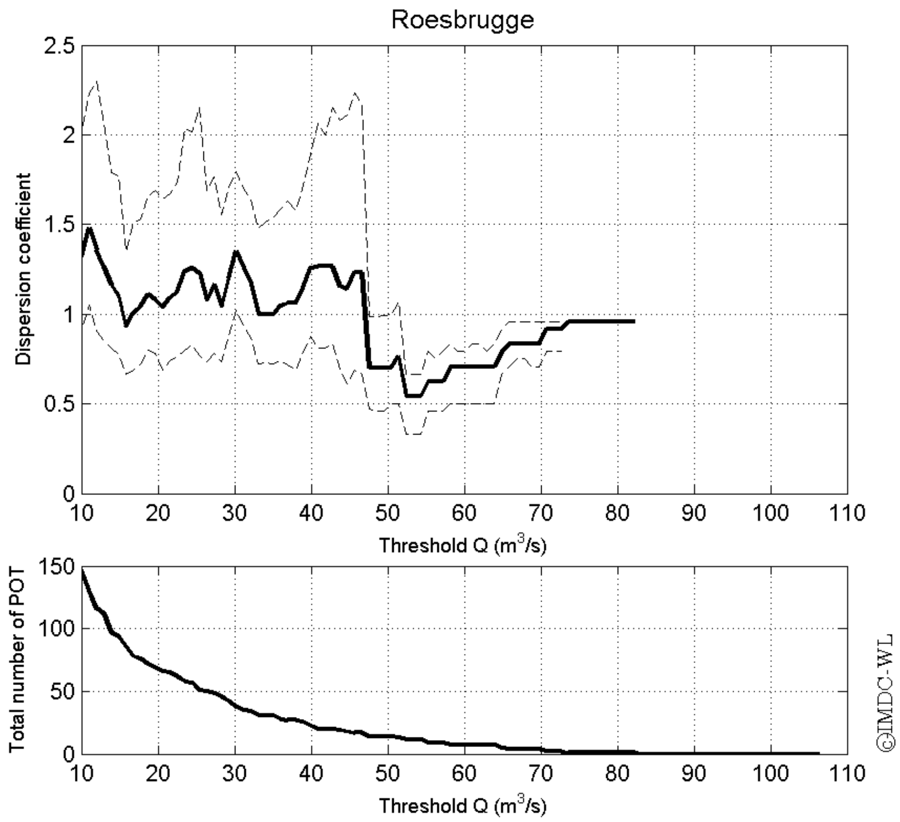
A standard p-test will give the minimal confidence level at which one may reject H_0.

Kendall τ and Spearman ρ can be used as an estimator of the Archimedean Copula parameter.

Appendix C: EVA

Yser Roesbrugge





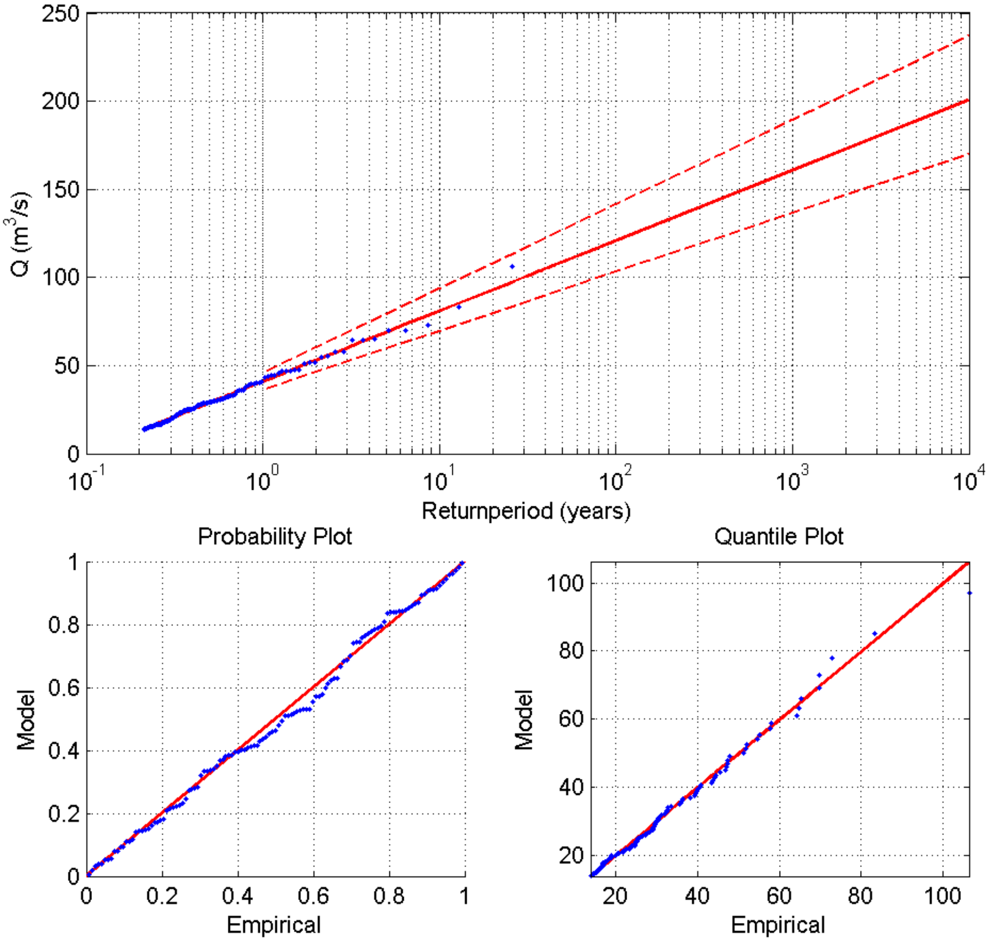
Roesbrugge

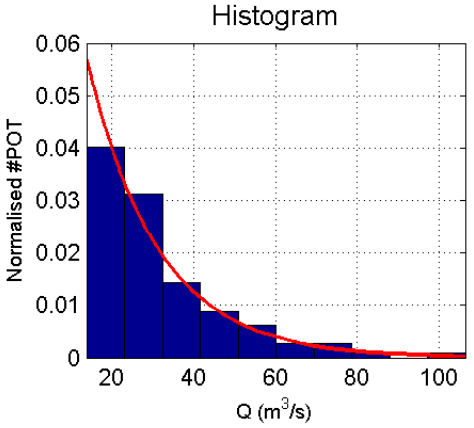
Exponential distribution

$$cdf: 1 - Pr(x > u + y|x > u) = 1 - exp(-\lambda(x-u))$$

$$Returnlevel: X = u + \frac{1}{\lambda}log(\frac{Tk}{A})$$

$\lambda = 0.057597$
$u = 13.7$
$A = 25.5254$
$k = 121$





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5.00e+00	6.87e+01	7.94e+01	5.97e+01
1.00e+01	8.07e+01	9.38e+01	6.98e+01
2.50e+01	9.66e+01	1.13e+02	8.31e+01
5.00e+01	1.09e+02	1.27e+02	9.31e+01
1.00e+02	1.21e+02	1.42e+02	1.03e+02
5.00e+02	1.49e+02	1.75e+02	1.27e+02
1.00e+03	1.61e+02	1.89e+02	1.37e+02
2.50e+03	1.77e+02	2.08e+02	1.50e+02
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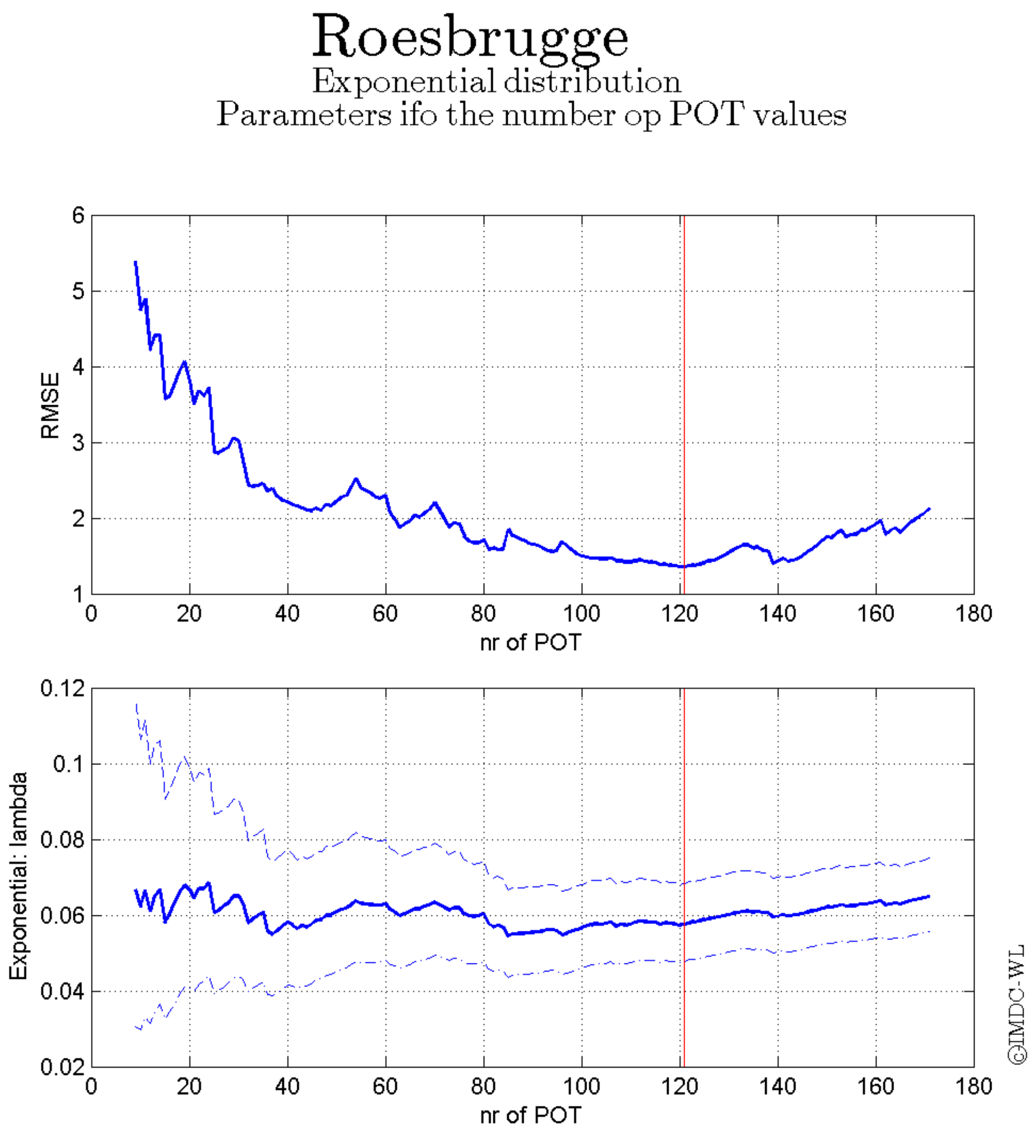
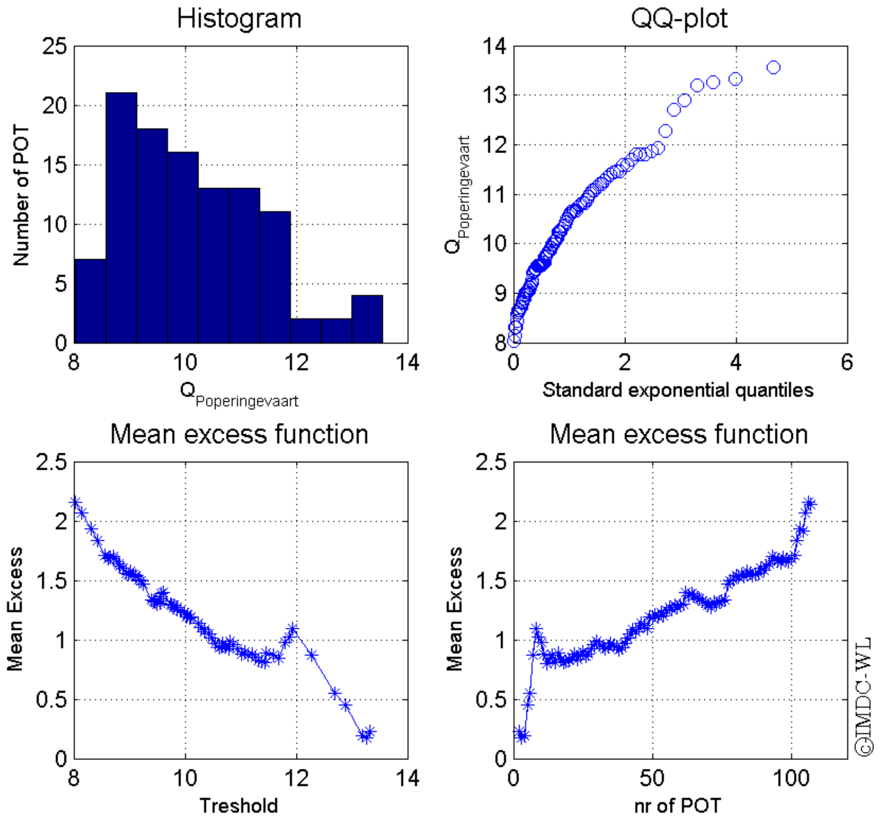
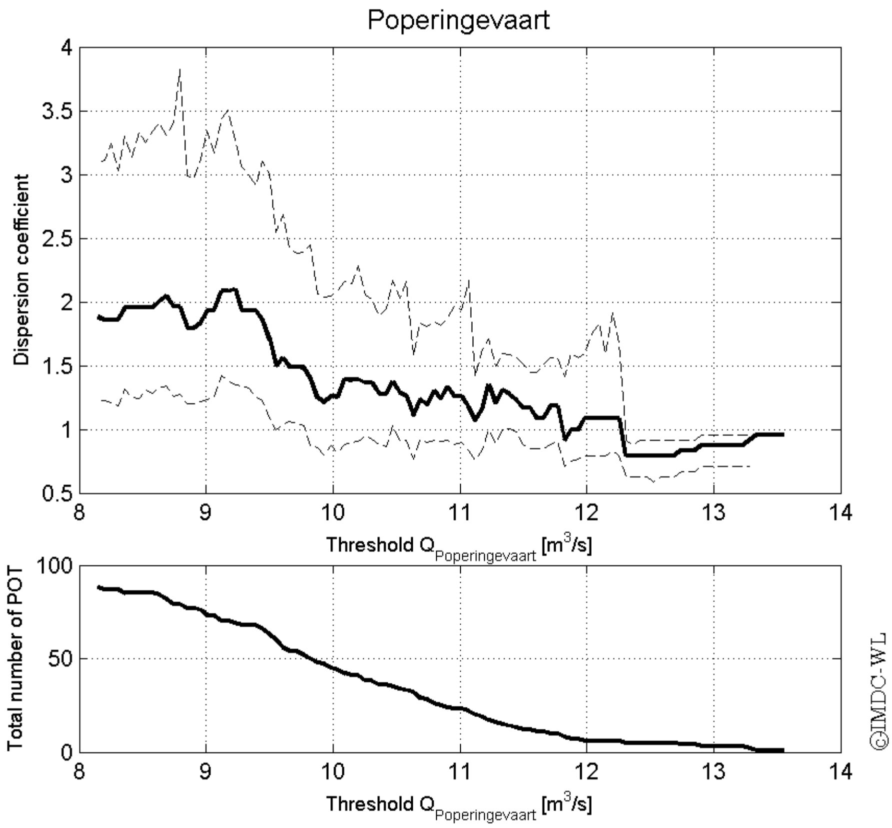

Roesbrugge
Exponential distribution
Parameters ifo the number op POT values
RMSE
nr of POT
Exponential: lambda
nr of POT
©IMDC-WL

Poperingevaart





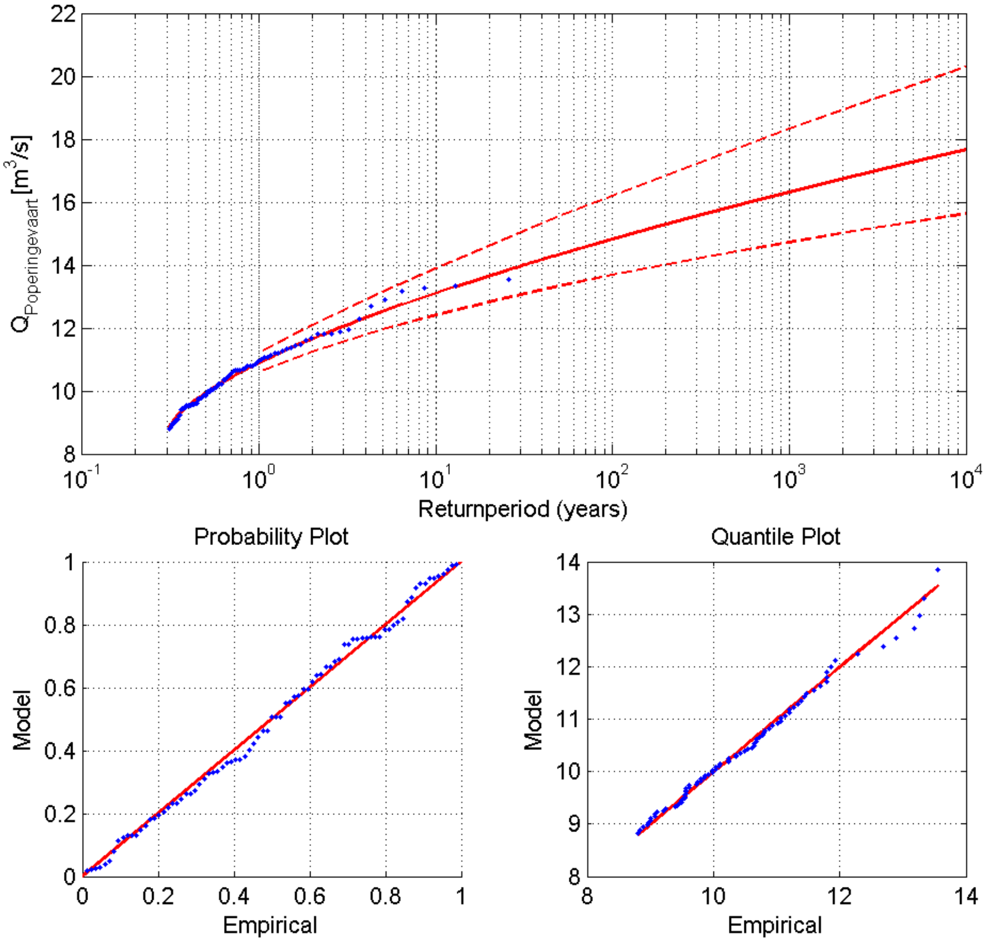
Poperingevaart

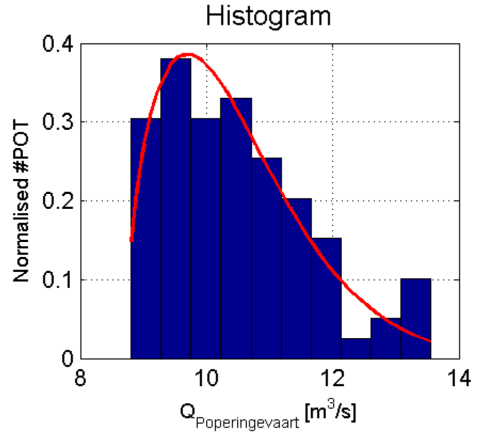
Cond. Weibull distribution

$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda (x-u)^{\tau})$$

$$Returnlevel: X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.5308$
$\lambda = 0.36308$
$u = 8.721$
$A = 25.4553$
$k = 83$





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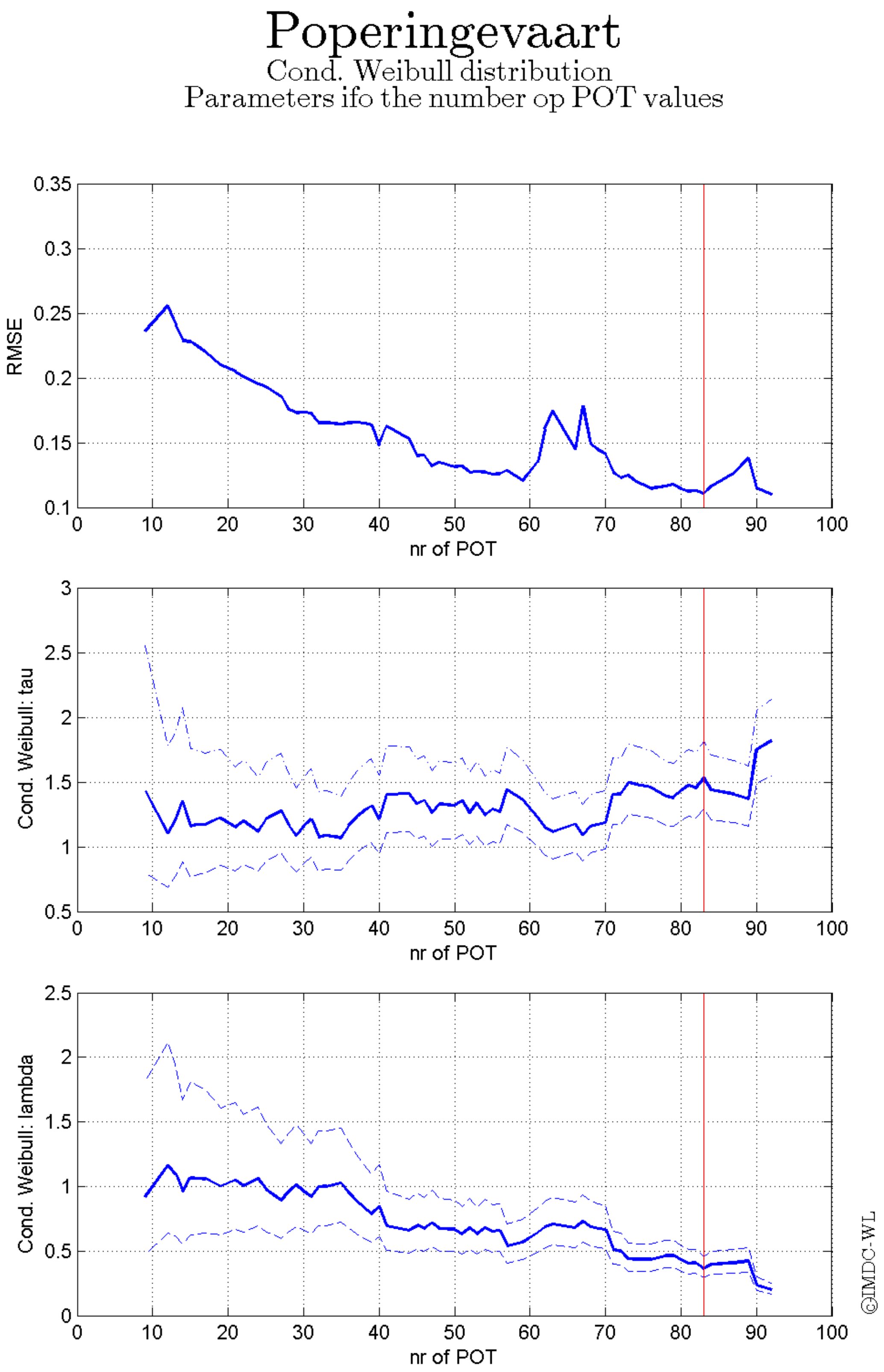
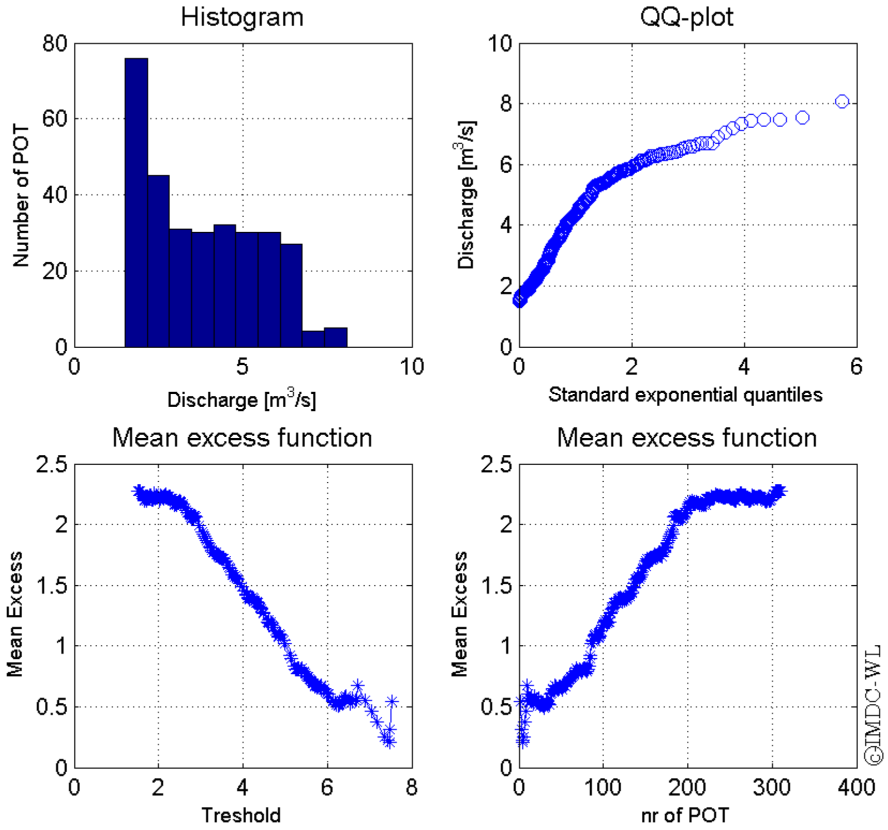
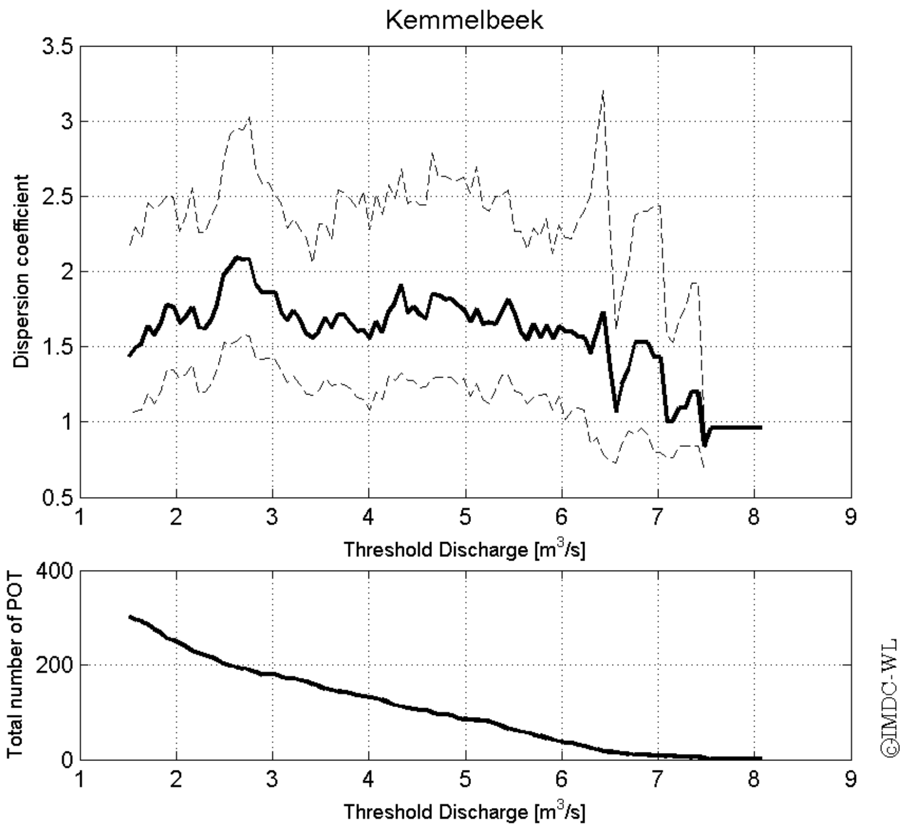
5.00e+00	1.25e+01	1.32e+01	1.20e+01
1.00e+01	1.31e+01	1.39e+01	1.24e+01
2.50e+01	1.38e+01	1.49e+01	1.30e+01
5.00e+01	1.43e+01	1.55e+01	1.33e+01
1.00e+02	1.48e+01	1.62e+01	1.37e+01
5.00e+02	1.59e+01	1.77e+01	1.44e+01
1.00e+03	1.63e+01	1.83e+01	1.47e+01
2.50e+03	1.69e+01	1.91e+01	1.51e+01
4.00e+03	1.71e+01	1.95e+01	1.53e+01
1.00e+04	1.77e+01	2.03e+01	1.56e+01


Poperingevaart
Cond. Weibull distribution
Parameters ifo the number op POT values
RMSE
0.35
0.3
0.25
0.2
0.15
0.1
0
10
20
30
40
50
60
70
80
90
100
nr of POT
Cond. Weibull: tau
3
2.5
2
1.5
1
0.5
Cond. Weibull: lambda
©IMDC-WL

Kemmelbeek


Histogram
Number of POT
Discharge [m^3/s]
QQ-plot
Discharge [m^3/s]
Standard exponential quantiles
Mean excess function
Mean Excess
Treshold
Mean excess function
Mean Excess
nr of POT
©IMDC-WL


Kemmelbeek
Dispersion coefficient
Threshold Discharge [m^3/s]
Total number of POT
Threshold Discharge [m^3/s]
©IMDC-WL

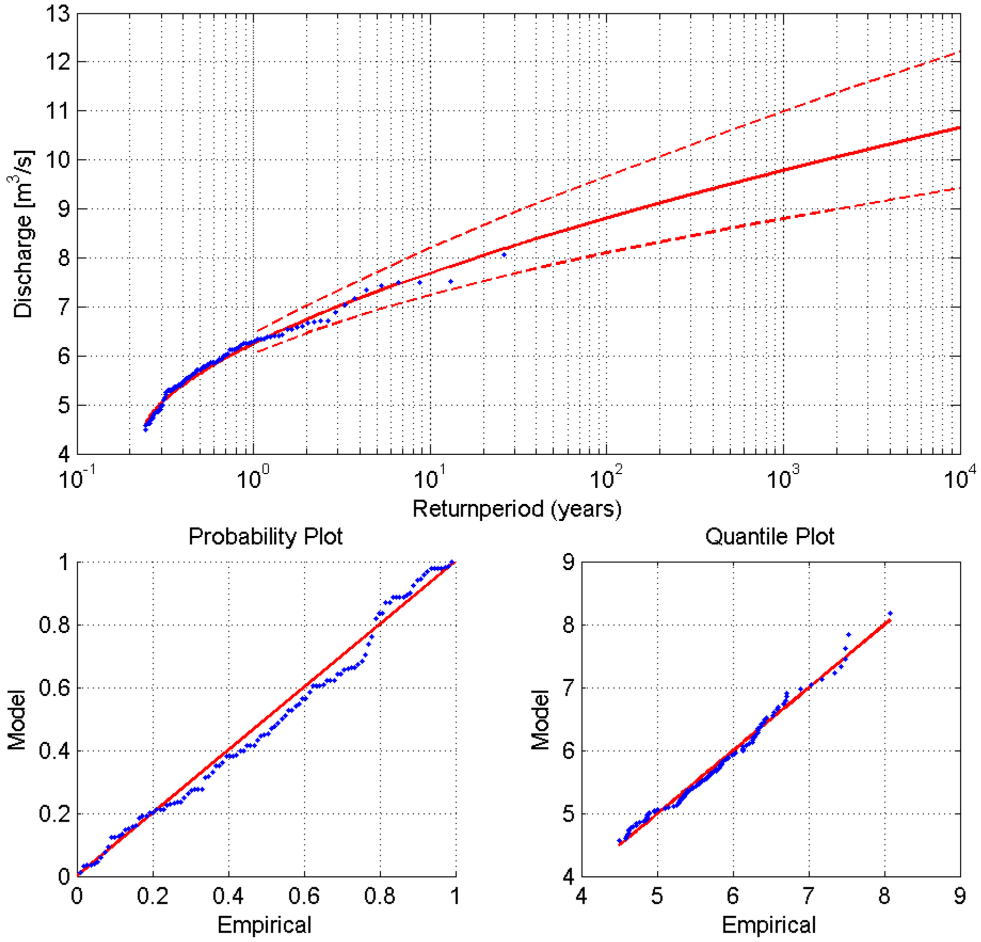
Kemmelbeek

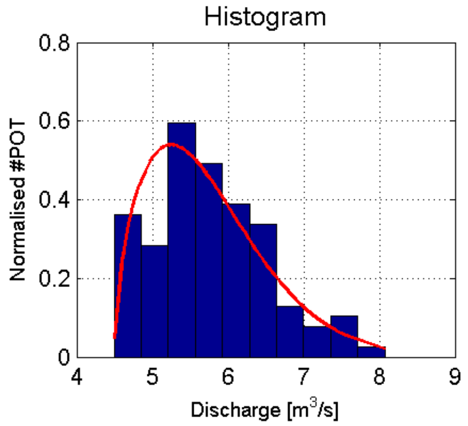
Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

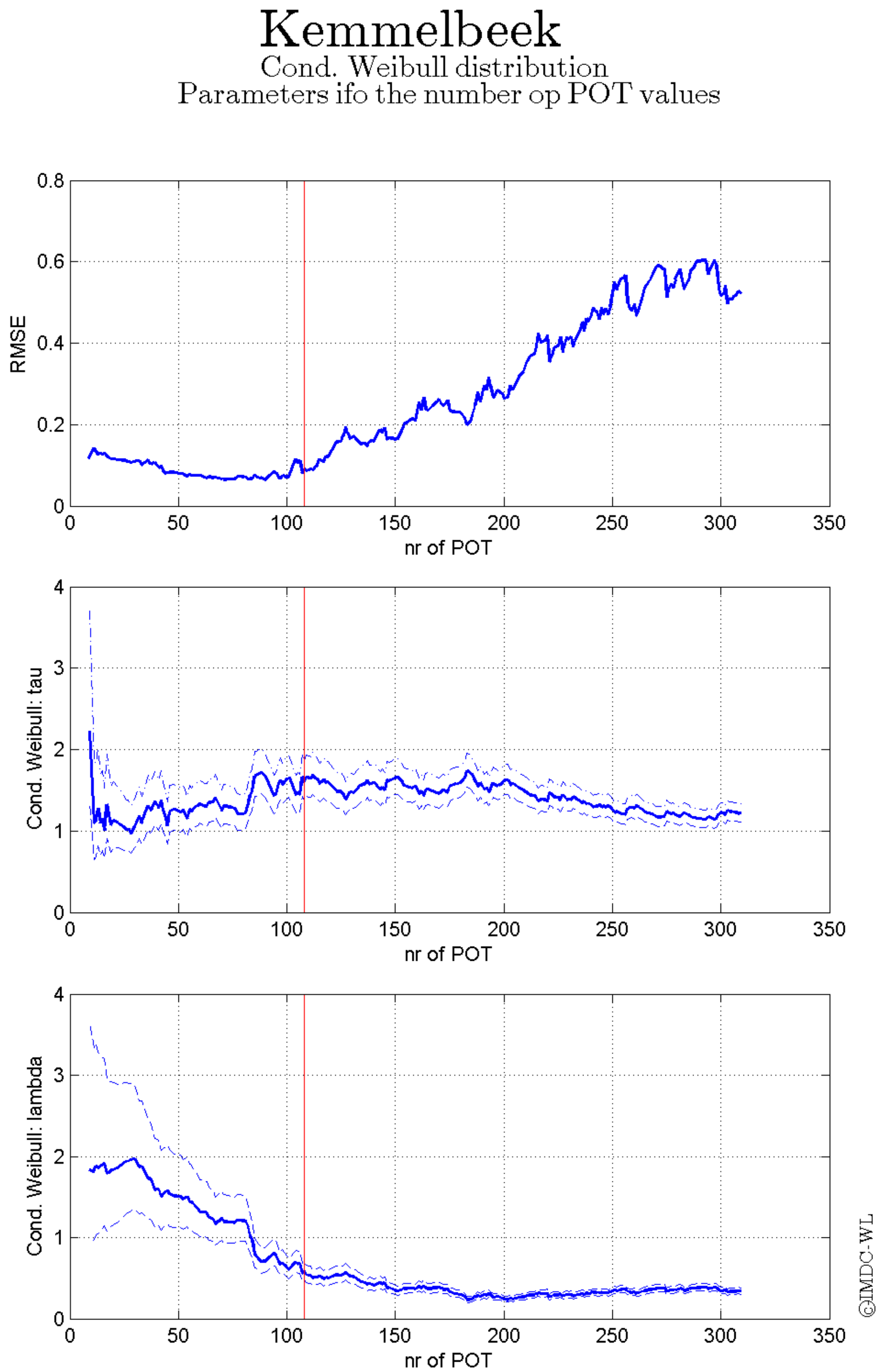
$$Returnlevel : X = u + (\tfrac{1}{\lambda} log(\tfrac{T k}{A}))^{(1/\tau)}$$

$\tau = 1.5979$
$\lambda = 0.58009$
$u = 4.486$
$A = 26.0898$
$k = 108$

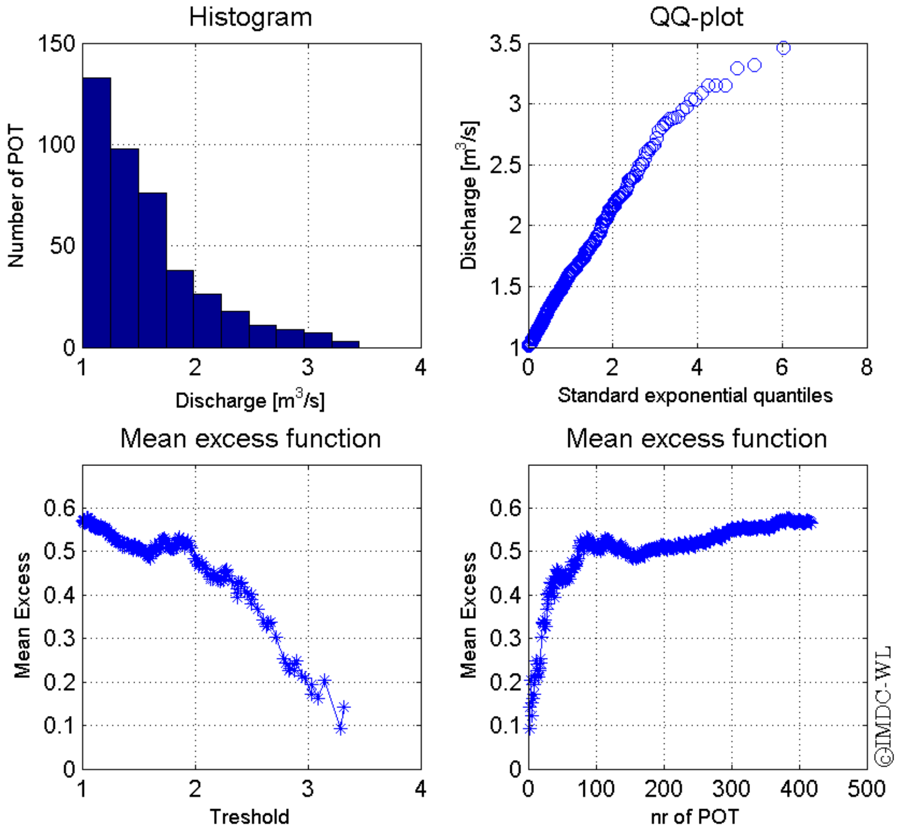


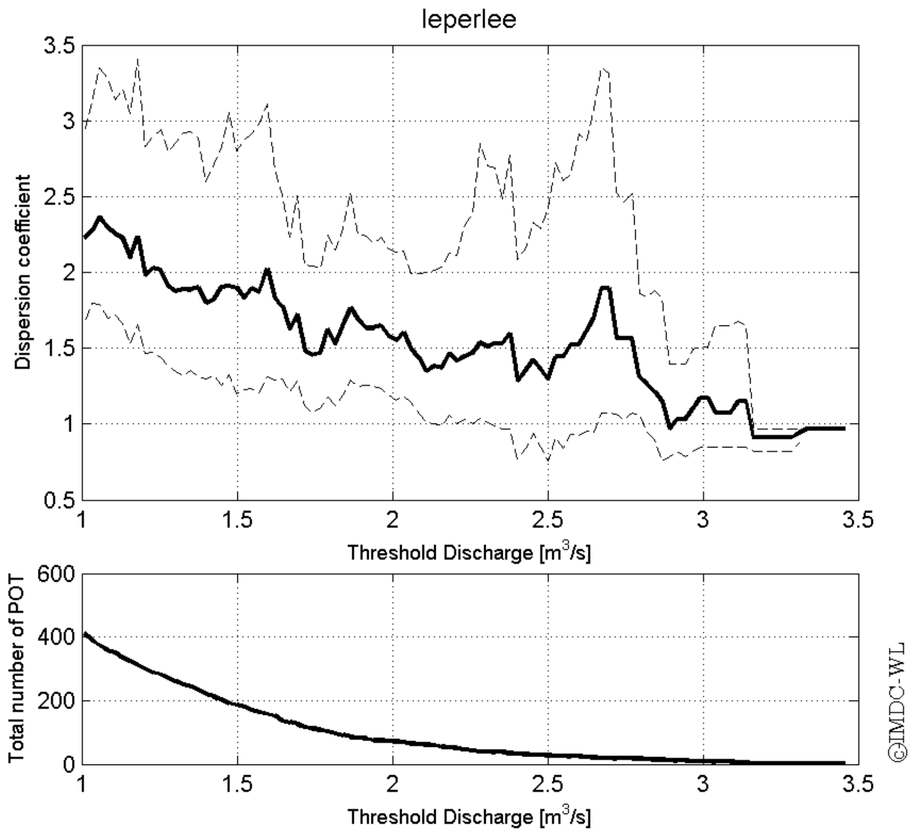


T	X	UPCI	LOCI
1.00e+00	6.24e+00	6.46e+00	6.04e+00
2.00e+00	6.73e+00	7.03e+00	6.47e+00
5.00e+00	7.30e+00	7.71e+00	6.94e+00
1.00e+01	7.69e+00	8.20e+00	7.25e+00
2.50e+01	8.16e+00	8.81e+00	7.61e+00
5.00e+01	8.49e+00	9.24e+00	7.86e+00
1.00e+02	8.81e+00	9.67e+00	8.10e+00
5.00e+02	9.50e+00	1.06e+01	8.60e+00
1.00e+03	9.78e+00	1.10e+01	8.80e+00
2.50e+03	1.01e+01	1.15e+01	9.06e+00
4.00e+03	1.03e+01	1.17e+01	9.18e+00
1.00e+04	1.07e+01	1.22e+01	9.42e+00


Kemmelbeek
Cond. Weibull distribution
Parameters ifo the number op POT values
RMSE
nr of POT
Cond. Weibull: tau
nr of POT
Cond. Weibull: lambda
nr of POT
©IMDC-WL

Ieperlee


Histogram
Number of POT
Discharge [m^3/s]
QQ-plot
Discharge [m^3/s]
Standard exponential quantiles
Mean excess function
Mean Excess
Treshold
Mean excess function
Mean Excess
nr of POT
©IMDC-WL


Ieperlee
Dispersion coefficient
Threshold Discharge [m^3/s]
Total number of POT
Threshold Discharge [m^3/s]
©IMDC-WL

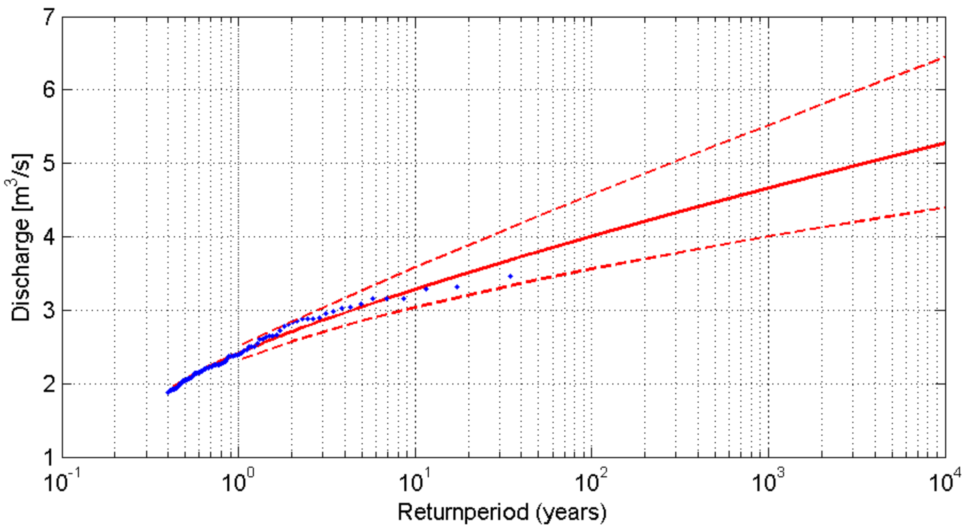
Ieperlee

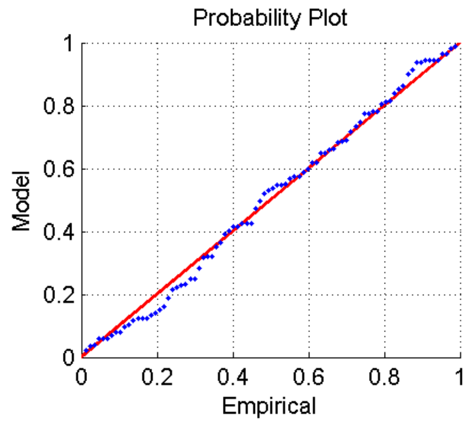
Cond. Weibull distribution

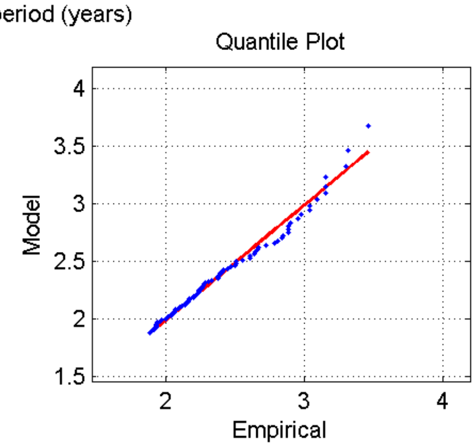
$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

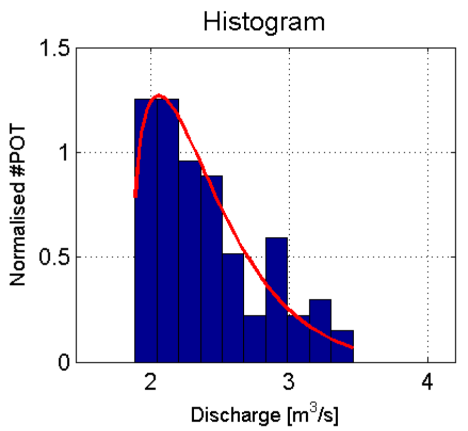
$$Returnlevel : X = u + (\frac{1}{\lambda} log(\frac{T k}{A}))^{(1/\tau)}$$

$\tau = 1.3056$
$\lambda = 2.0446$
$u = 1.863$
$A = 34.0416$
$k = 86$

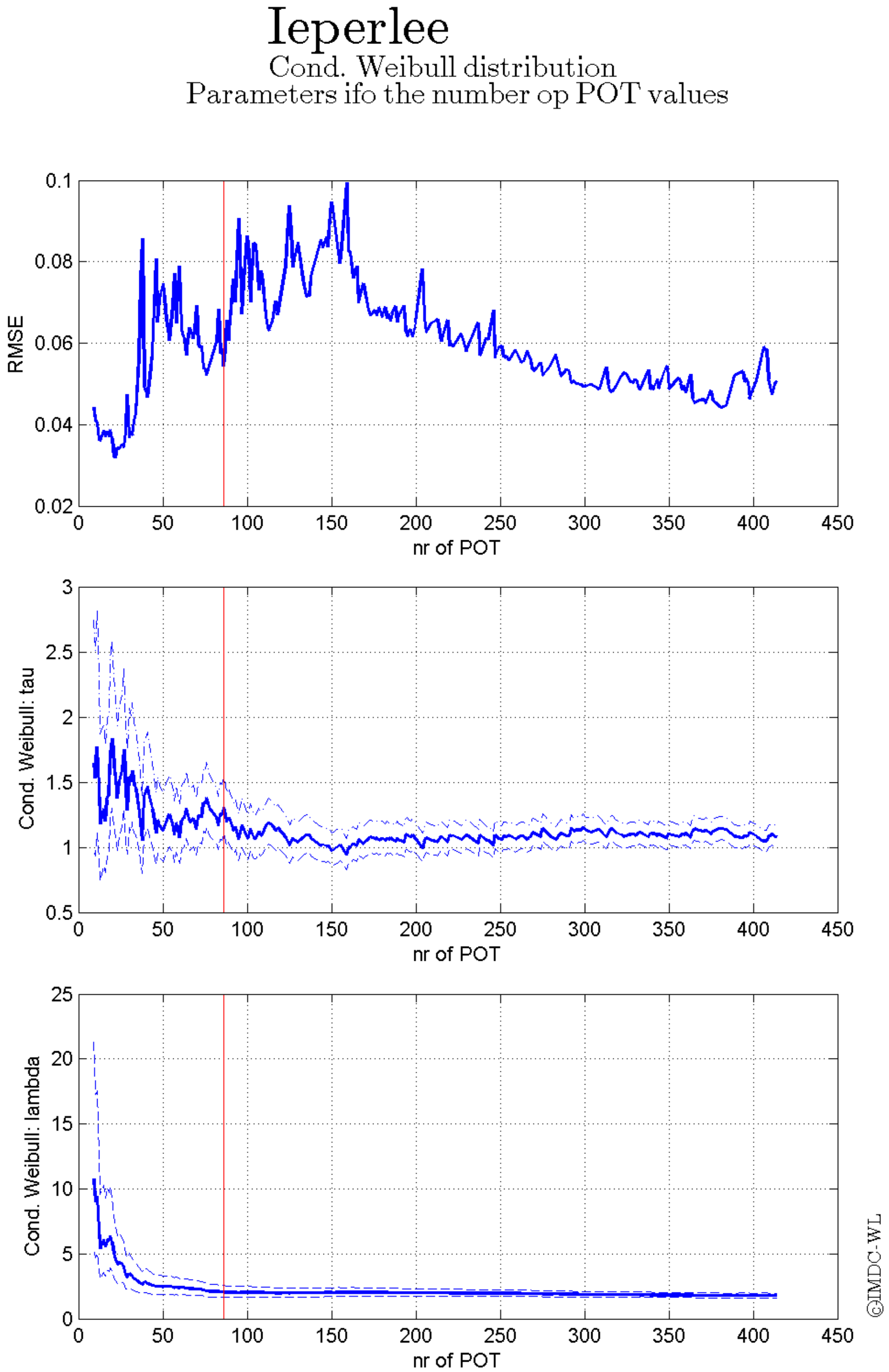




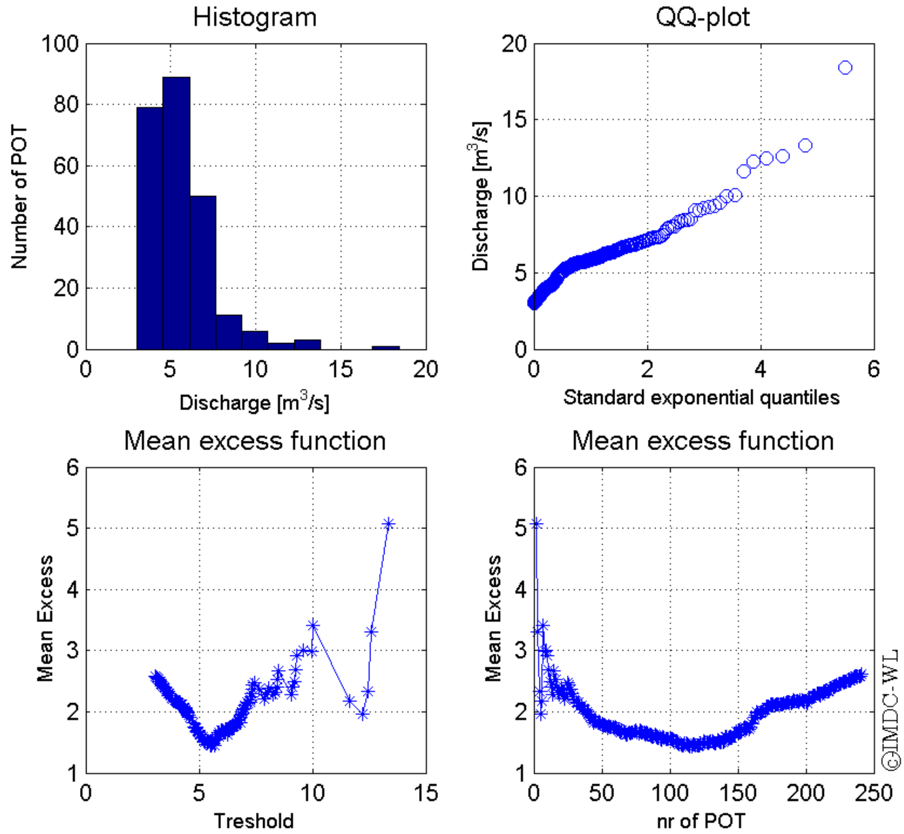


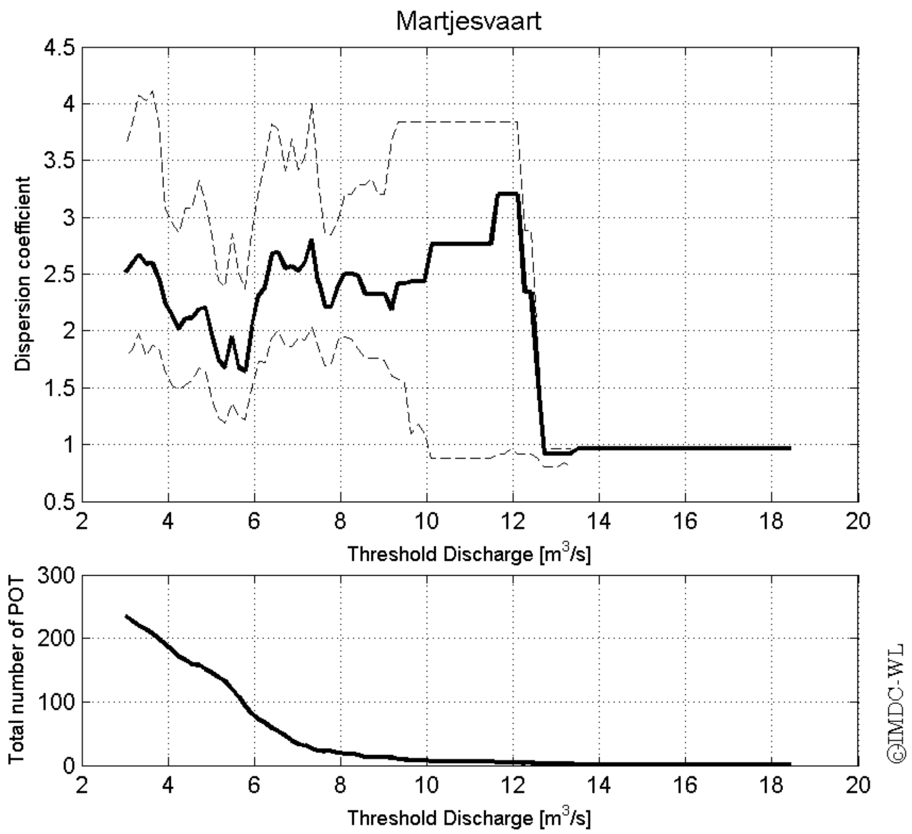


T	X	UPCI	LOCI
1.00e+00	2.41e+00	2.51e+00	2.32e+00
2.00e+00	2.70e+00	2.85e+00	2.57e+00
5.00e+00	3.04e+00	3.27e+00	2.85e+00
1.00e+01	3.28e+00	3.58e+00	3.04e+00
2.50e+01	3.58e+00	3.98e+00	3.26e+00
5.00e+01	3.80e+00	4.28e+00	3.41e+00
1.00e+02	4.01e+00	4.57e+00	3.56e+00
5.00e+02	4.47e+00	5.24e+00	3.87e+00
1.00e+03	4.66e+00	5.52e+00	4.00e+00
2.50e+03	4.91e+00	5.89e+00	4.16e+00
4.00e+03	5.03e+00	6.08e+00	4.24e+00
1.00e+04	5.27e+00	6.45e+00	4.40e+00


Ieperlee
Cond. Weibull distribution
Parameters ifo the number op POT values
RMSE
nr of POT
Cond. Weibull: tau
nr of POT
Cond. Weibull: lambda
nr of POT
©IMDC-WL

Martjesvaart





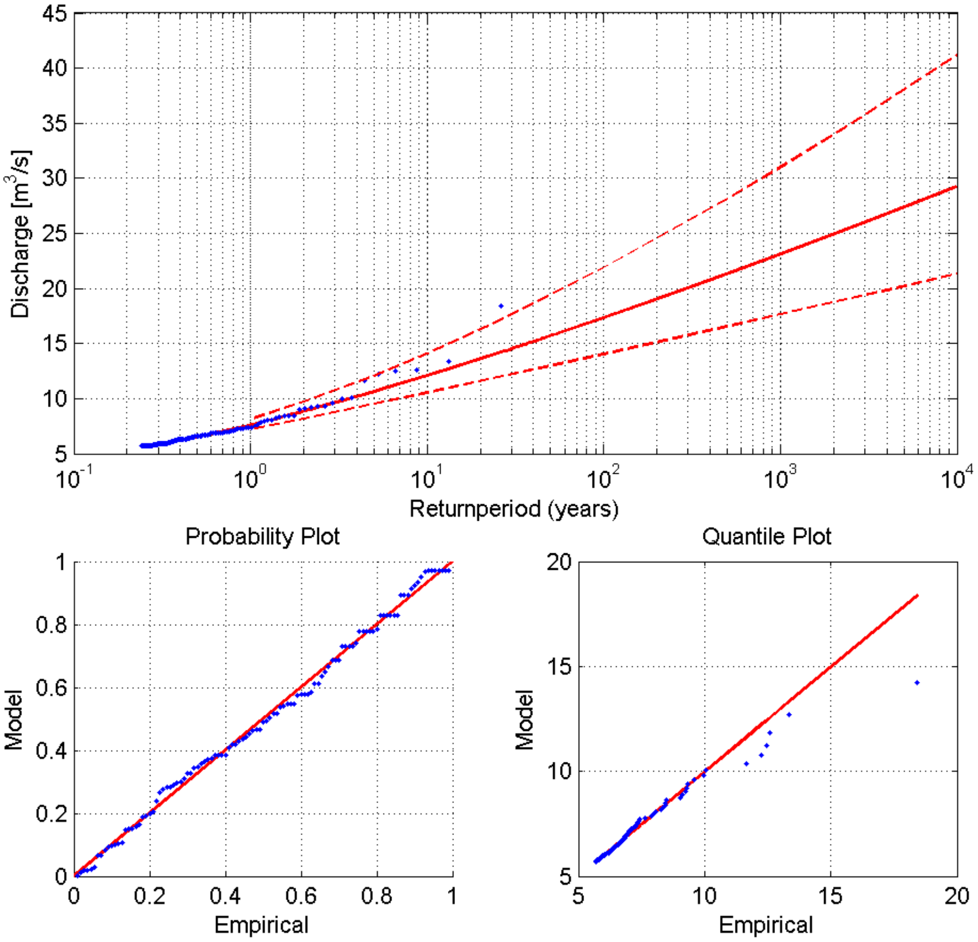
Martjesvaart

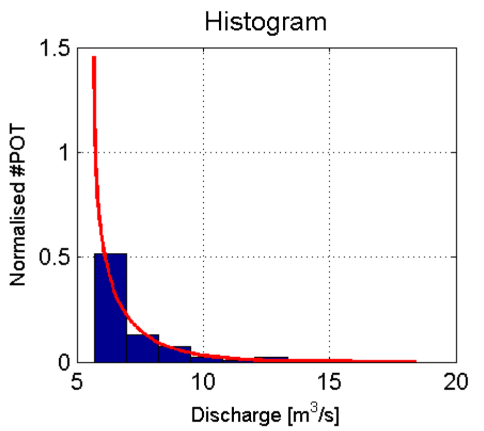
Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x - u)^{\tau})$$

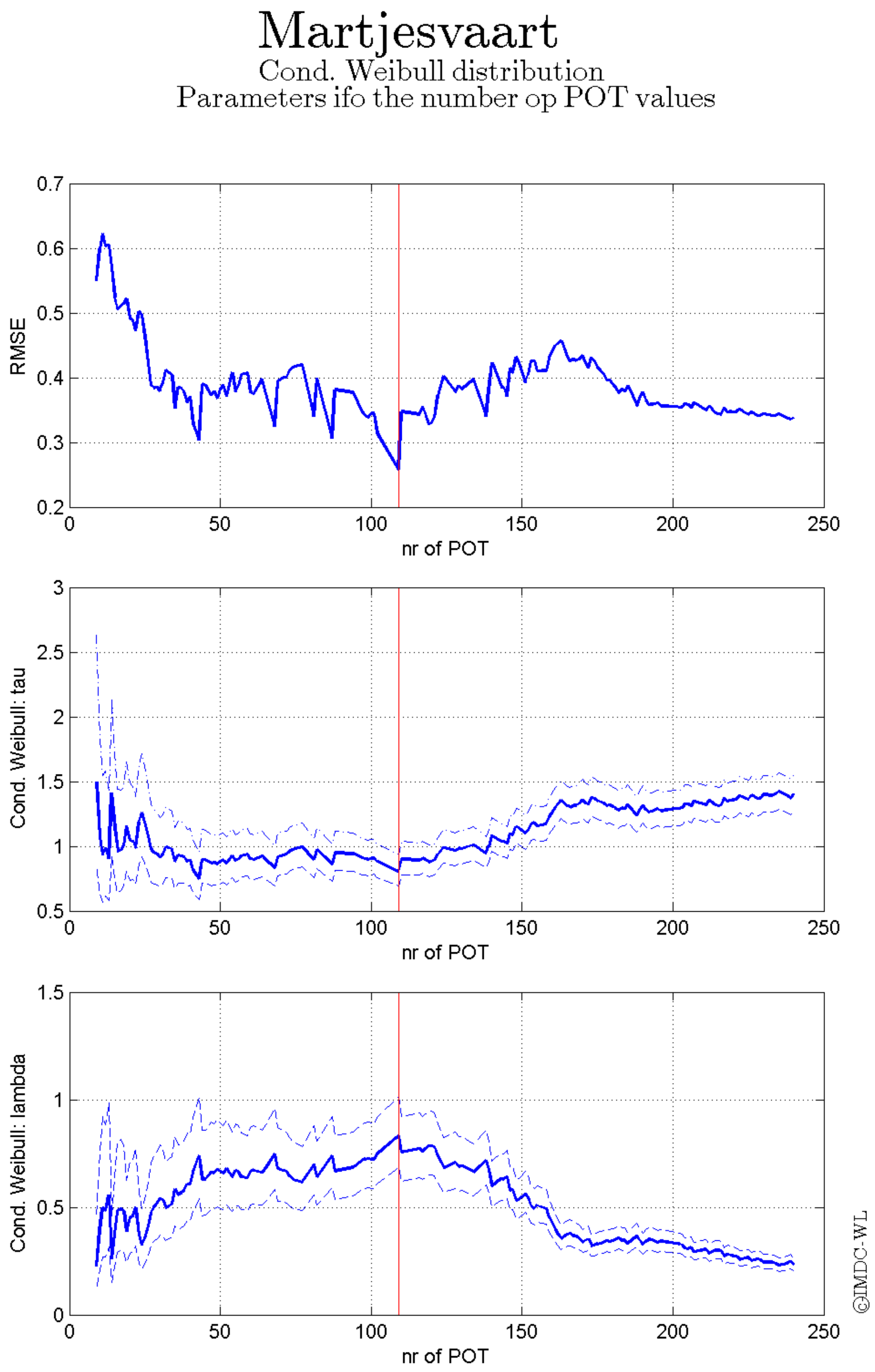
$$Returnlevel : X = u + (\tfrac{1}{\lambda} log(\tfrac{T\,k}{A}))^{(1/\tau)}$$

$\tau = 0.80587$
$\lambda = 0.83334$
$u = 5.667$
$A = 26.1072$
$k = 109$

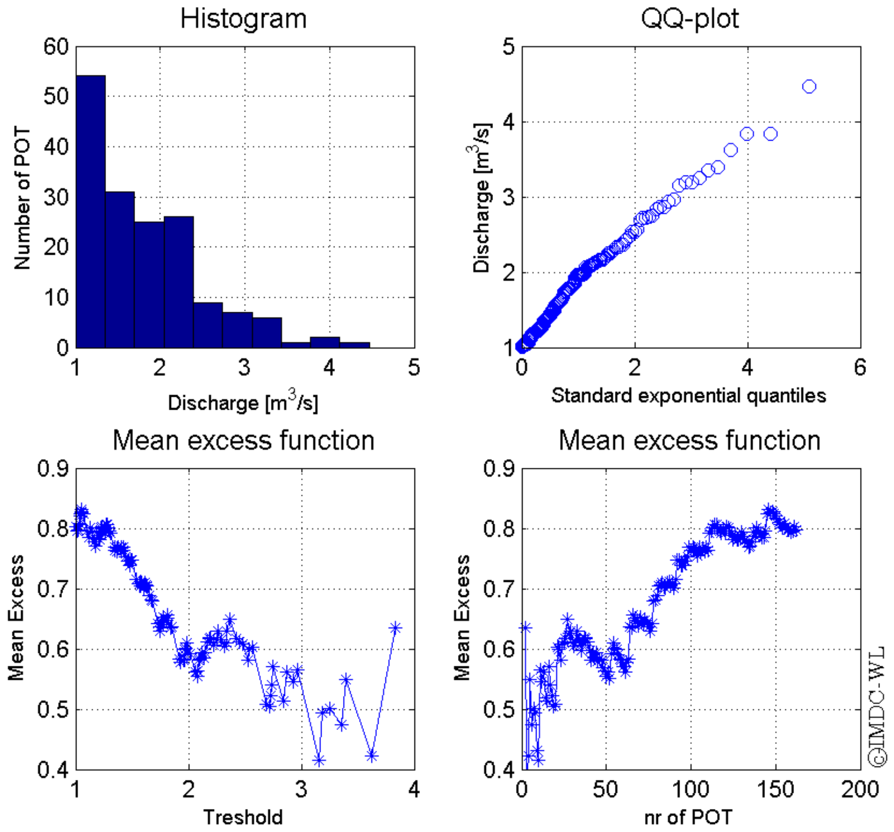


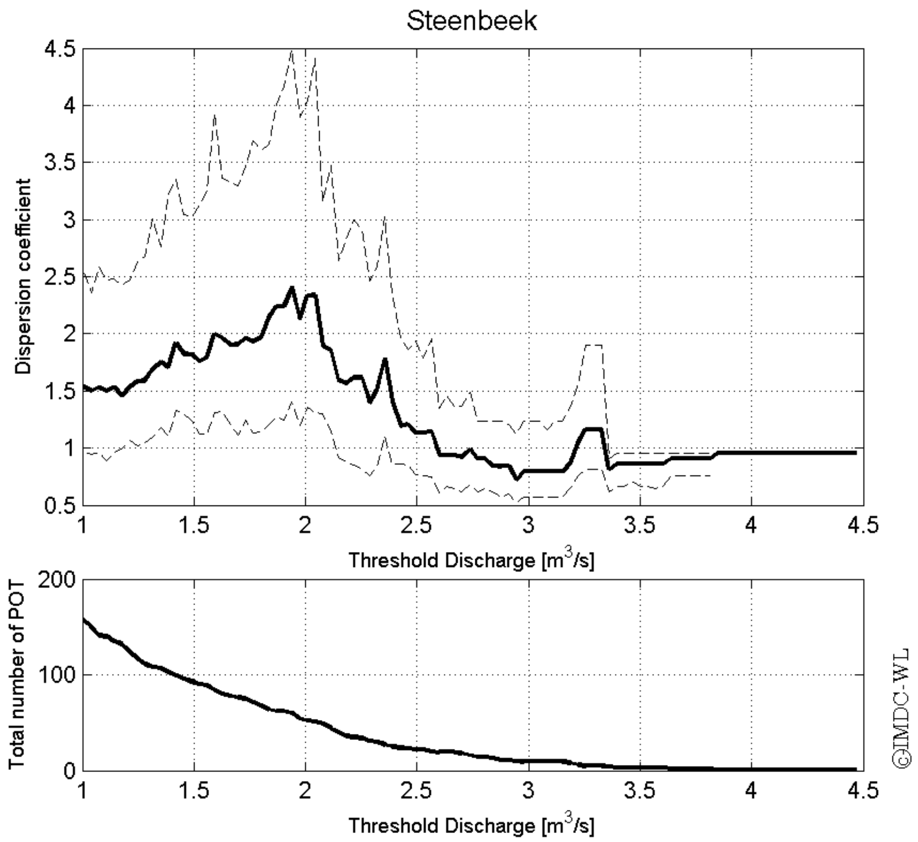


T	X	UPCI	LOCI
1.00e+00	7.62e+00	8.12e+00	7.22e+00
2.00e+00	8.86e+00	9.70e+00	8.19e+00
5.00e+00	1.06e+01	1.21e+01	9.52e+00
1.00e+01	1.21e+01	1.41e+01	1.05e+01
2.50e+01	1.41e+01	1.70e+01	1.19e+01
5.00e+01	1.57e+01	1.94e+01	1.30e+01
1.00e+02	1.73e+01	2.19e+01	1.41e+01
5.00e+02	2.13e+01	2.81e+01	1.66e+01
1.00e+03	2.31e+01	3.10e+01	1.77e+01
2.50e+03	2.55e+01	3.49e+01	1.91e+01
4.00e+03	2.68e+01	3.70e+01	1.99e+01
1.00e+04	2.92e+01	4.12e+01	2.13e+01


Martjesvaart
Cond. Weibull distribution
Parameters ifo the number op POT values
RMSE
nr of POT
Cond. Weibull: tau
nr of POT
Cond. Weibull: lambda
nr of POT
©IMDC-WL

Steenbeek


Histogram
Number of POT
Discharge [m³/s]
QQ-plot
Discharge [m³/s]
Standard exponential quantiles
Mean excess function
Mean Excess
Treshold
Mean excess function
Mean Excess
nr of POT
©IMDC-WL


Steenbeek
Dispersion coefficient
Threshold Discharge [m³/s]
Total number of POT
Threshold Discharge [m³/s]
©IMDC-WL

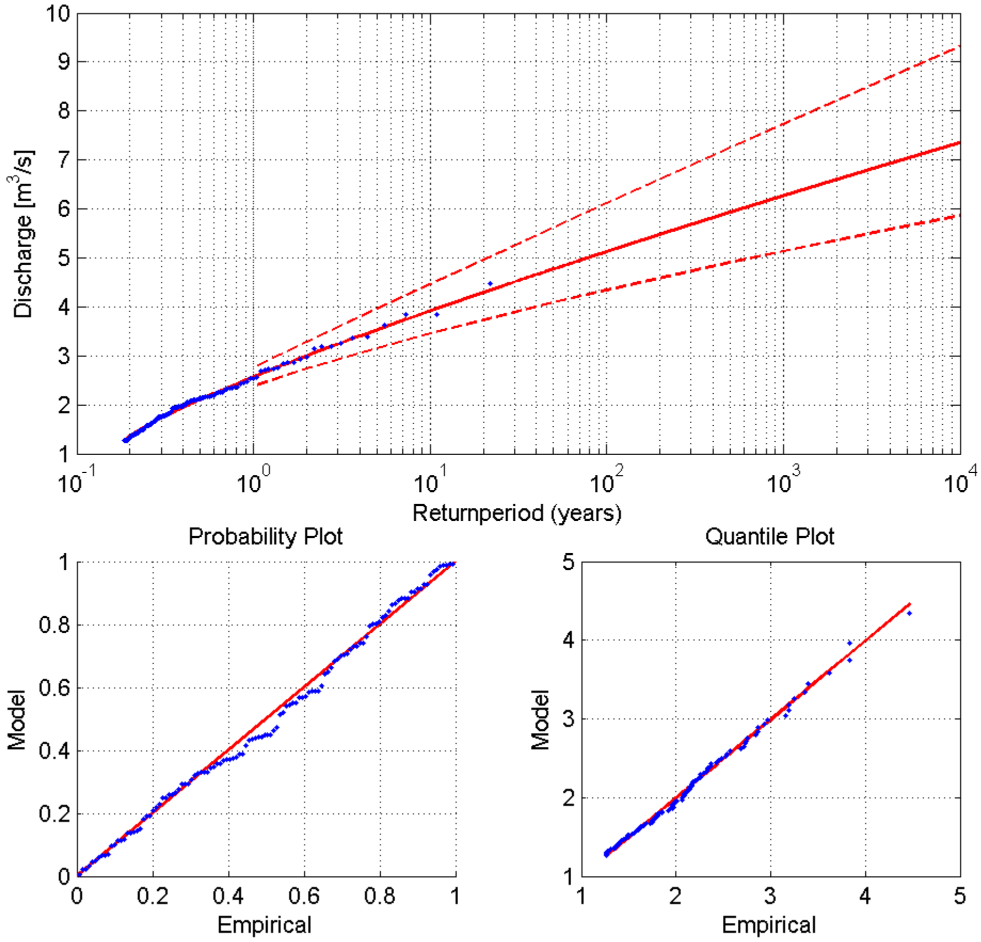
Steenbeek

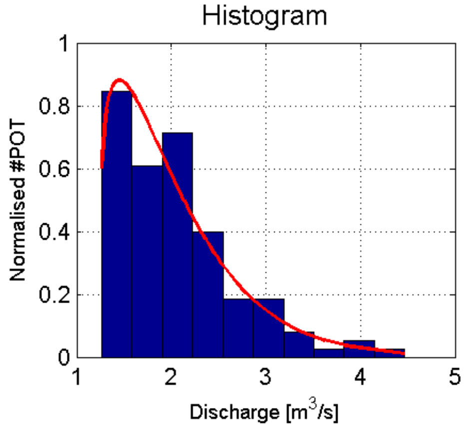
Cond. Weibull distribution

$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel: X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

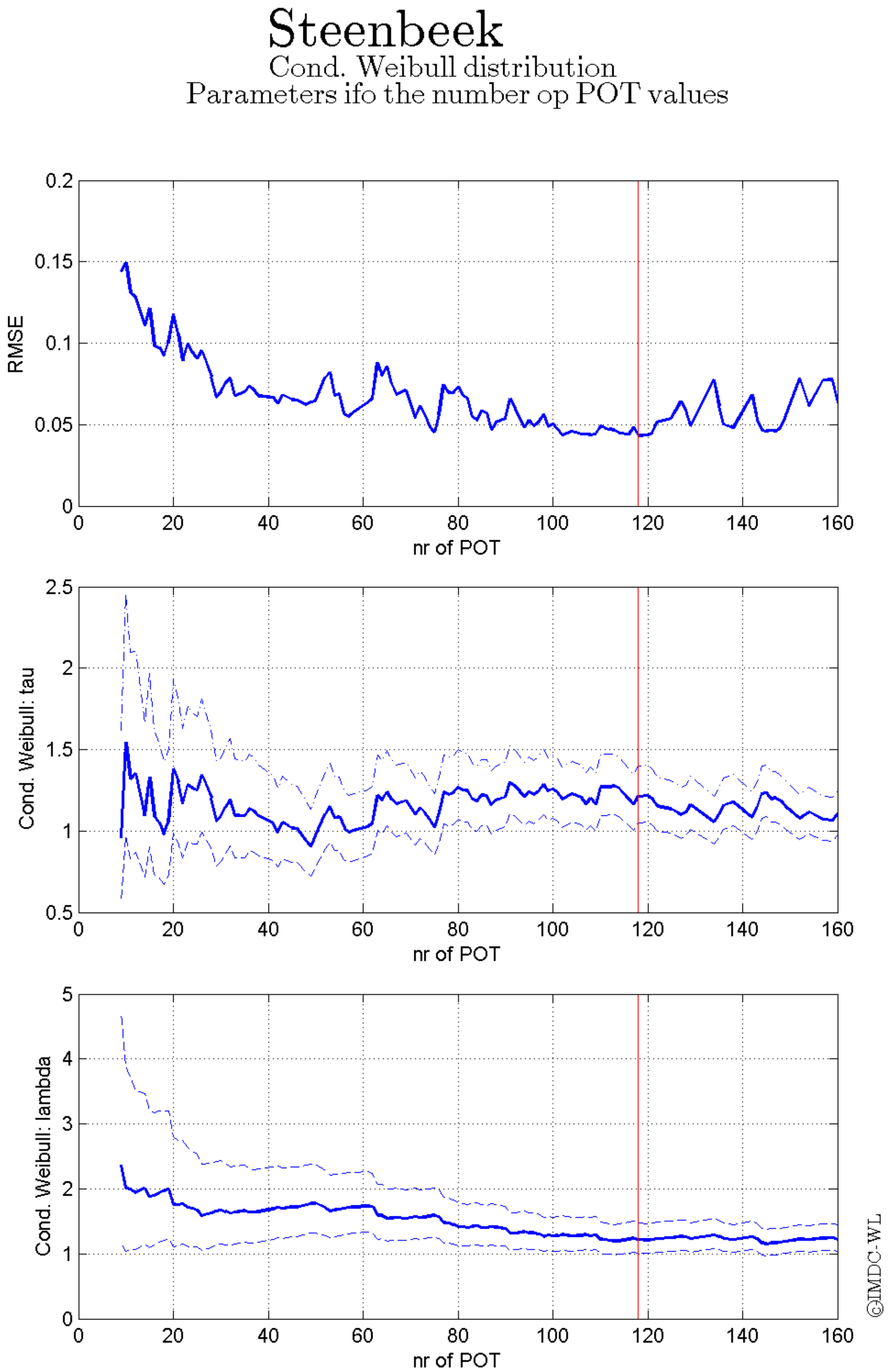
$\tau = 1.2118$
$\lambda = 1.2181$
$u = 1.249$
$A = 21.7786$
$k = 118$



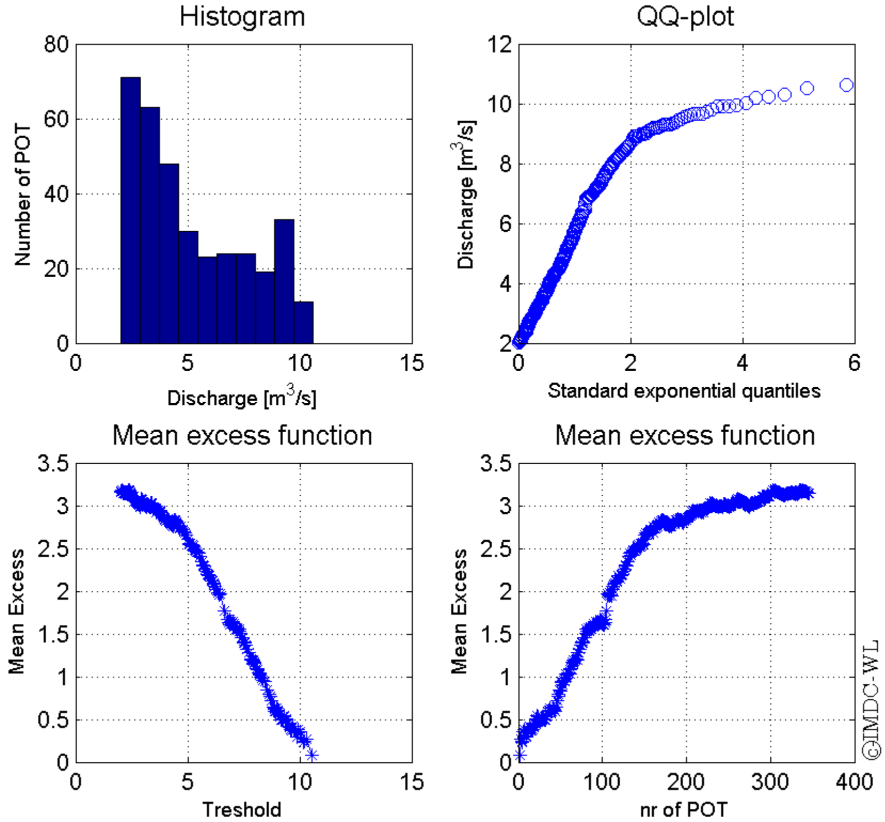


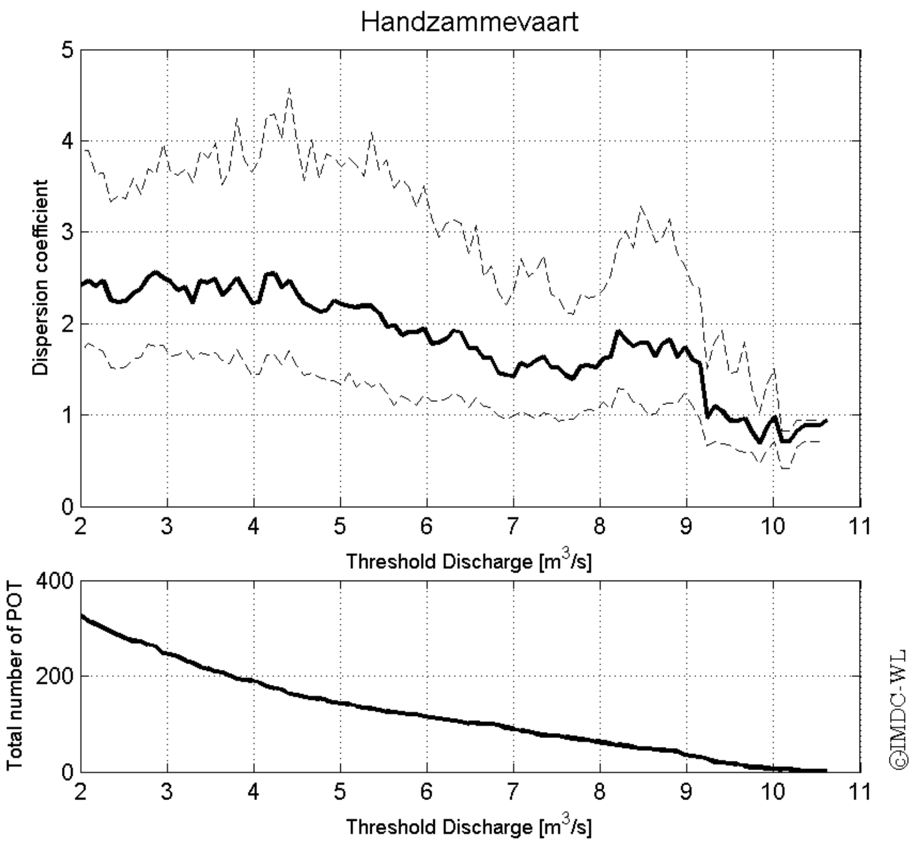
T	X	UPCI	LOCI
1.00e+00	2.56e+00	2.77e+00	2.38e+00
2.00e+00	2.99e+00	3.29e+00	2.73e+00
5.00e+00	3.52e+00	3.96e+00	3.16e+00
1.00e+01	3.91e+00	4.47e+00	3.45e+00
2.50e+01	4.41e+00	5.13e+00	3.82e+00
5.00e+01	4.77e+00	5.62e+00	4.09e+00
1.00e+02	5.13e+00	6.11e+00	4.34e+00
5.00e+02	5.93e+00	7.24e+00	4.90e+00
1.00e+03	6.27e+00	7.73e+00	5.13e+00
2.50e+03	6.70e+00	8.36e+00	5.43e+00
4.00e+03	6.92e+00	8.69e+00	5.58e+00
1.00e+04	7.35e+00	9.32e+00	5.86e+00

©IMDC-WL


Steenbeek
Cond. Weibull distribution
Parameters ifo the number op POT values
RMSE
nr of POT
Cond. Weibull: tau
nr of POT
Cond. Weibull: lambda
nr of POT
©IMDC-WL

Handzamevaart





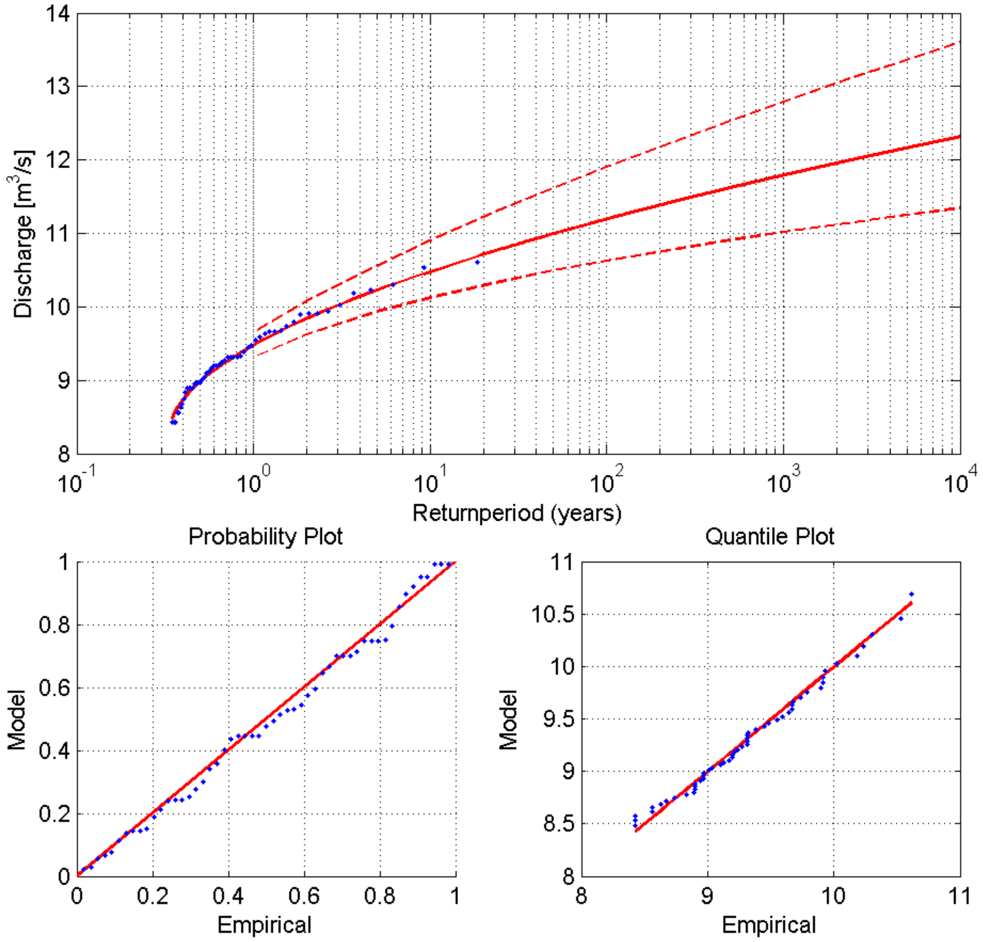
Handzammevaart

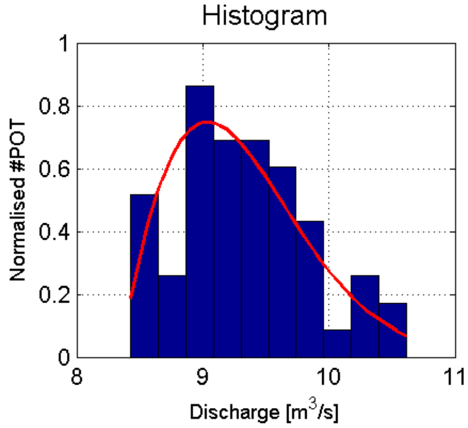
Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x - u)^{\tau})$$

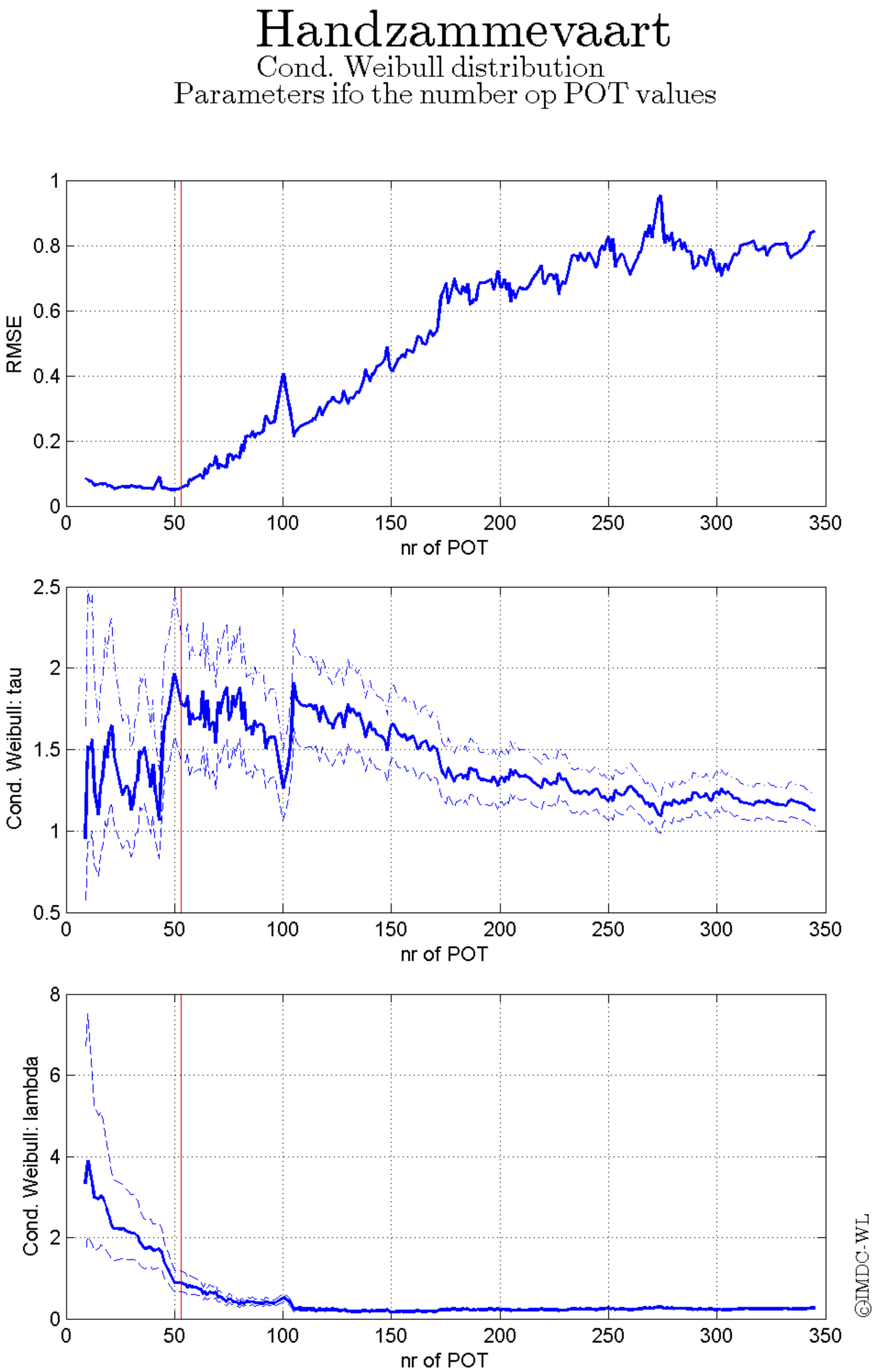
$$Returnlevel : X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.7829$
$\lambda = 0.88741$
$u = 8.364$
$A = 18.174$
$k = 53$

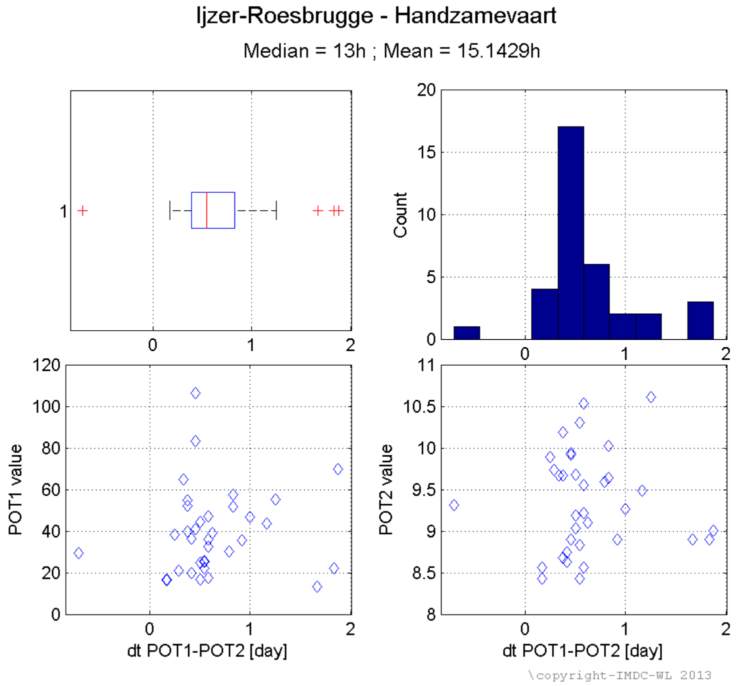




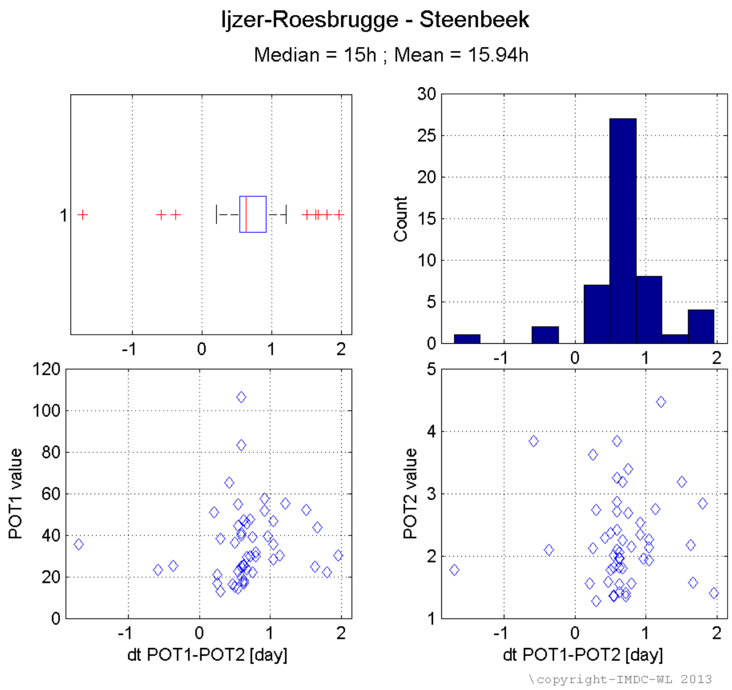
T	X	UPCI	LOCI
1.00e+00	9.47e+00	9.66e+00	9.31e+00
2.00e+00	9.83e+00	1.01e+01	9.63e+00
5.00e+00	1.02e+01	1.06e+01	9.94e+00
1.00e+01	1.05e+01	1.09e+01	1.01e+01
2.50e+01	1.08e+01	1.13e+01	1.03e+01
5.00e+01	1.10e+01	1.16e+01	1.05e+01
1.00e+02	1.12e+01	1.19e+01	1.06e+01
5.00e+02	1.16e+01	1.25e+01	1.09e+01
1.00e+03	1.18e+01	1.28e+01	1.10e+01
2.50e+03	1.20e+01	1.31e+01	1.12e+01
4.00e+03	1.21e+01	1.33e+01	1.12e+01
1.00e+04	1.23e+01	1.36e+01	1.13e+01

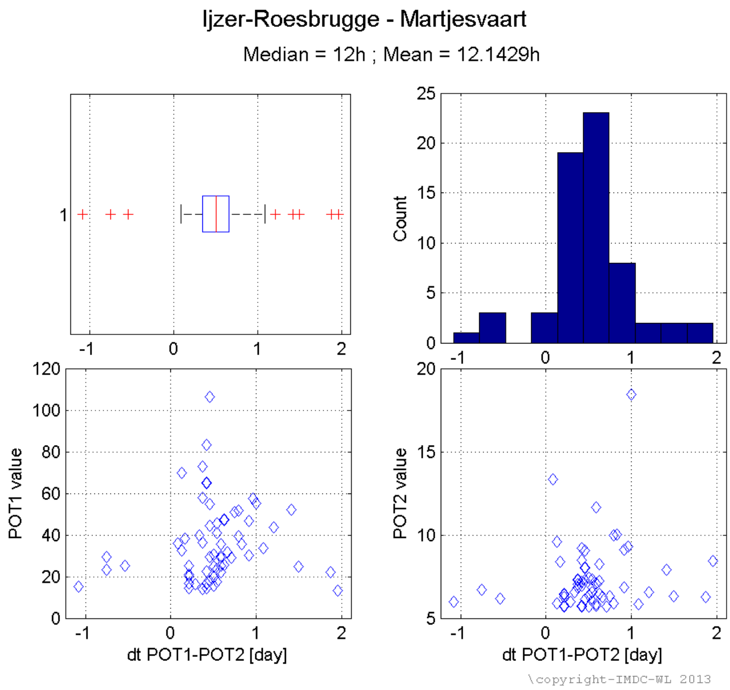

Handzammevaart
Cond. Weibull distribution
Parameters ifo the number op POT values
RMSE
nr of POT
Cond. Weibull: tau
nr of POT
Cond. Weibull: lambda
nr of POT
©IMDC-WL

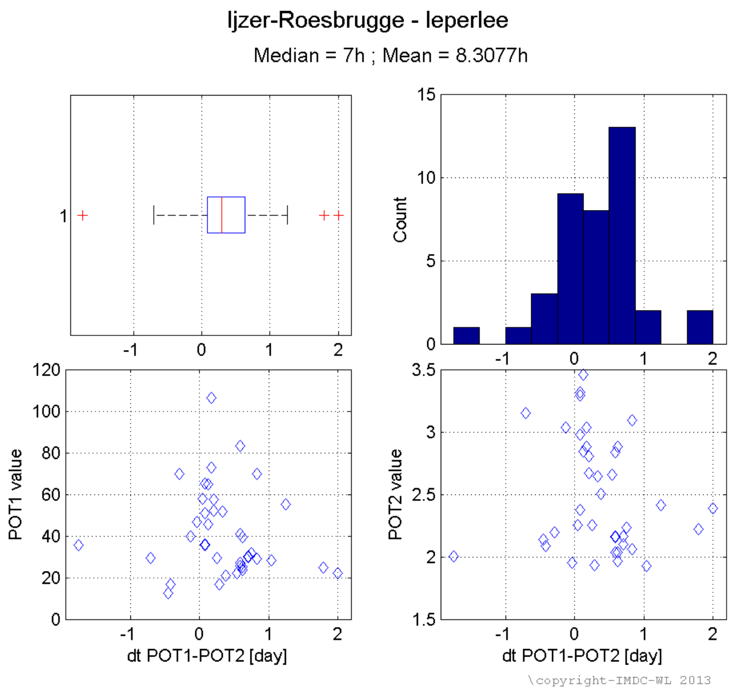
Appendix D: Time shift

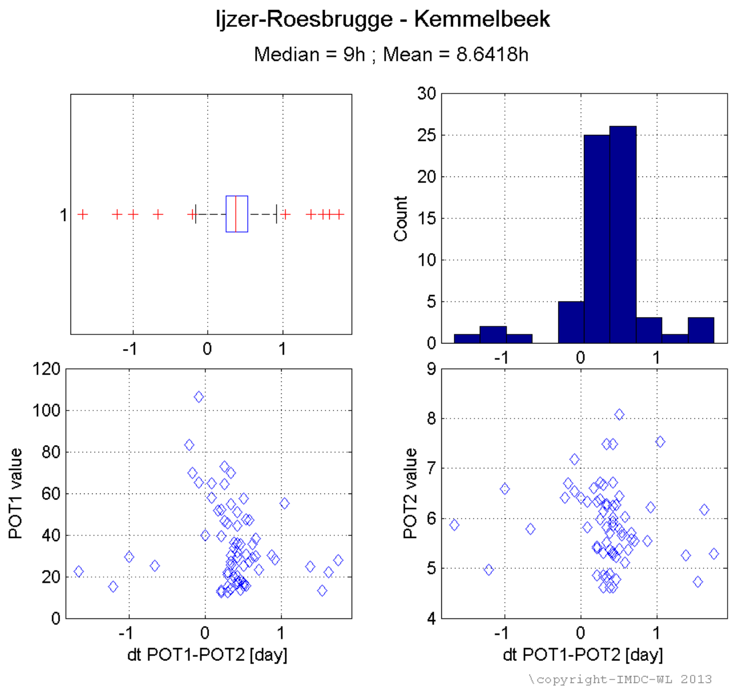


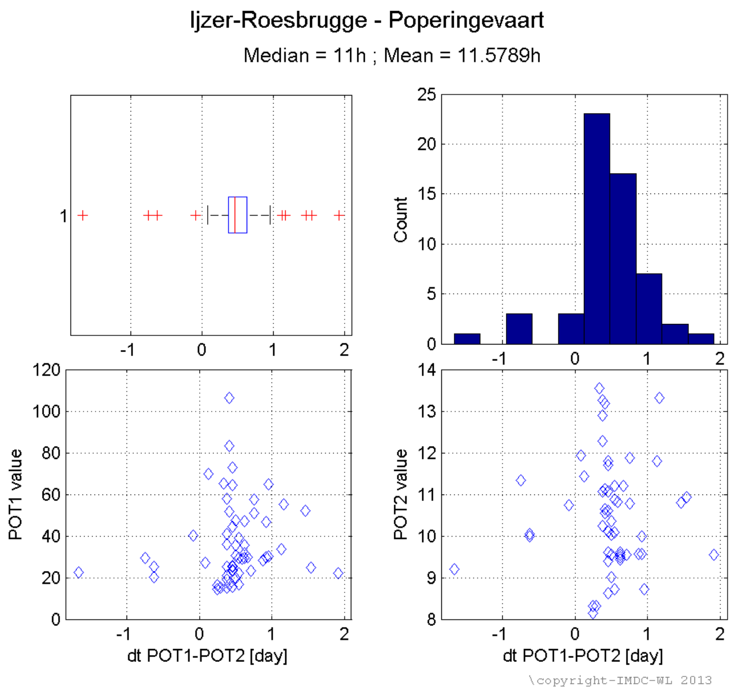
10




Ijzer-Roesbrugge - Martjesvaart
Median = 12h ; Mean = 12.1429h
Count
POT1 value
POT2 value
dt POT1-POT2 [day]
dt POT1-POT2 [day]
\copyright-IMDC-WL 2013


Ijzer-Roesbrugge - Ieperlee
Median = 7h ; Mean = 8.3077h
Count
POT1 value
POT2 value
dt POT1-POT2 [day]
dt POT1-POT2 [day]
\copyright-IMDC-WL 2013

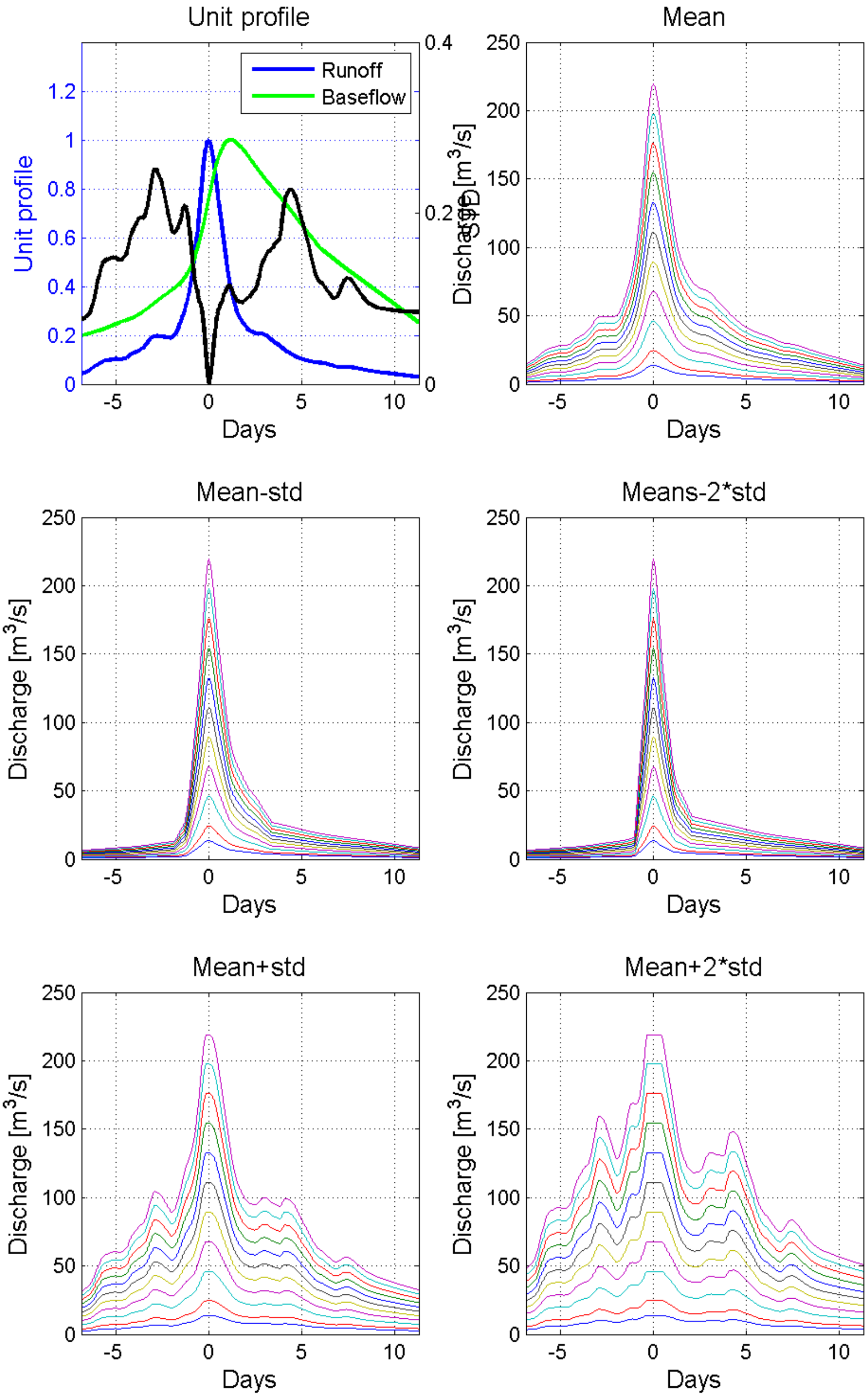

Ijzer-Roesbrugge - Kemmelbeek
Median = 9h ; Mean = 8.6418h
Count
POT1 value
POT2 value
dt POT1-POT2 [day]
dt POT1-POT2 [day]
\copyright-IMDC-WL 2013


Ijzer-Roesbrugge - Poperingevaart
Median = 11h ; Mean = 11.5789h
Count
POT1 value
POT2 value
dt POT1-POT2 [day]
dt POT1-POT2 [day]
\copyright-IMDC-WL 2013

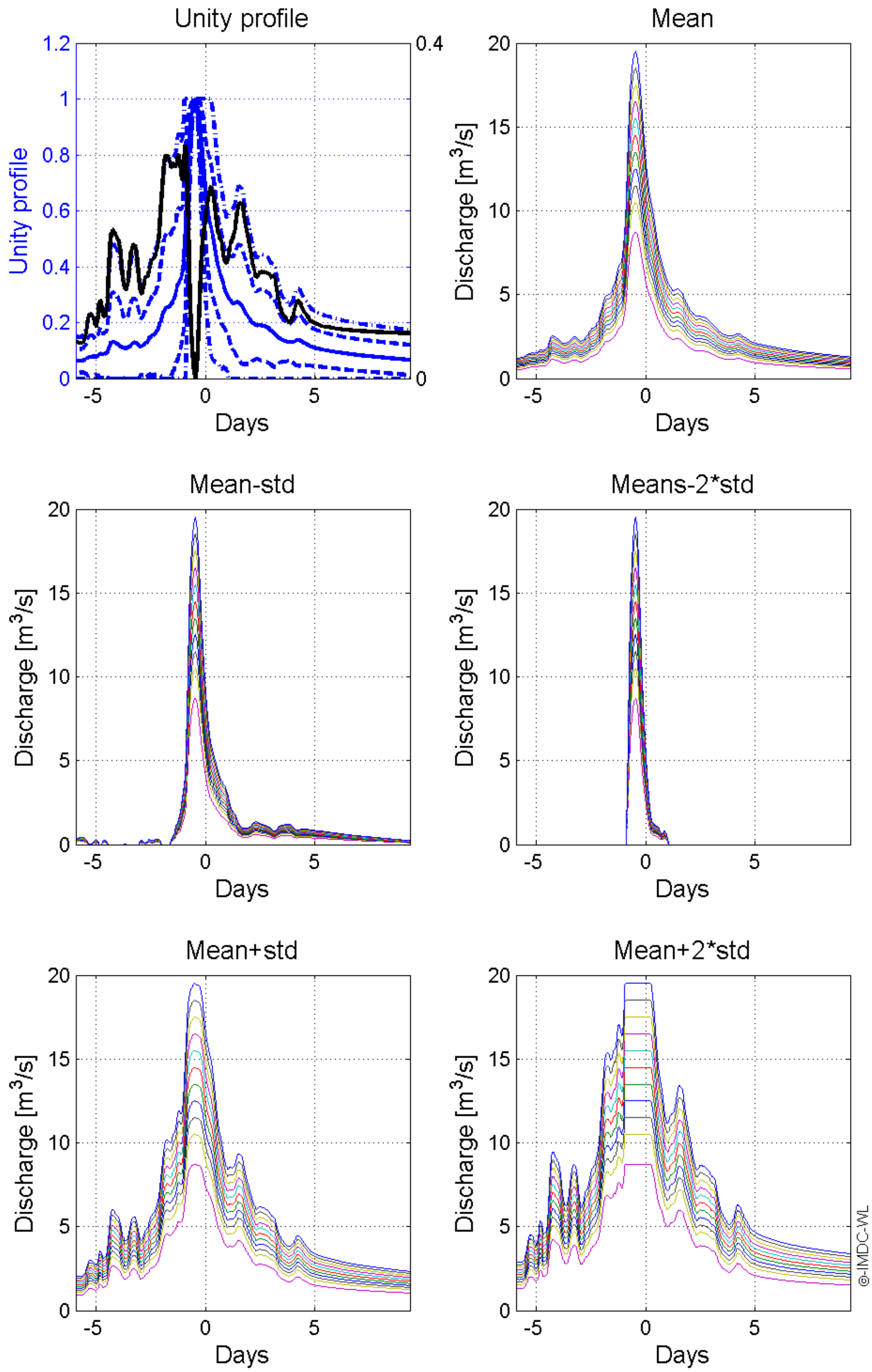
Appendix E: Unit profiles

Partial dependency Q Roesbrugge – Q Tributaries

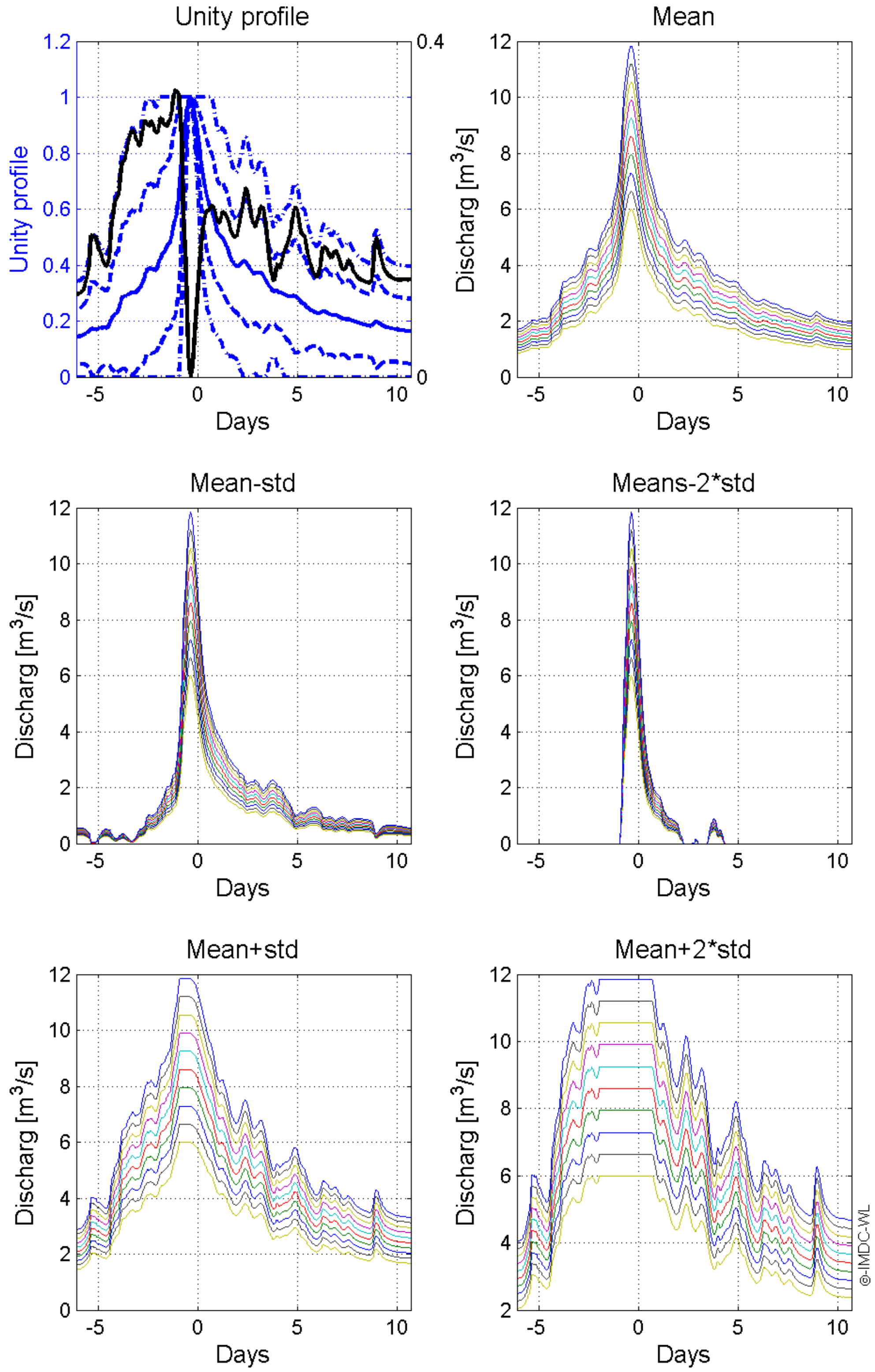
Yser Roesbrugge



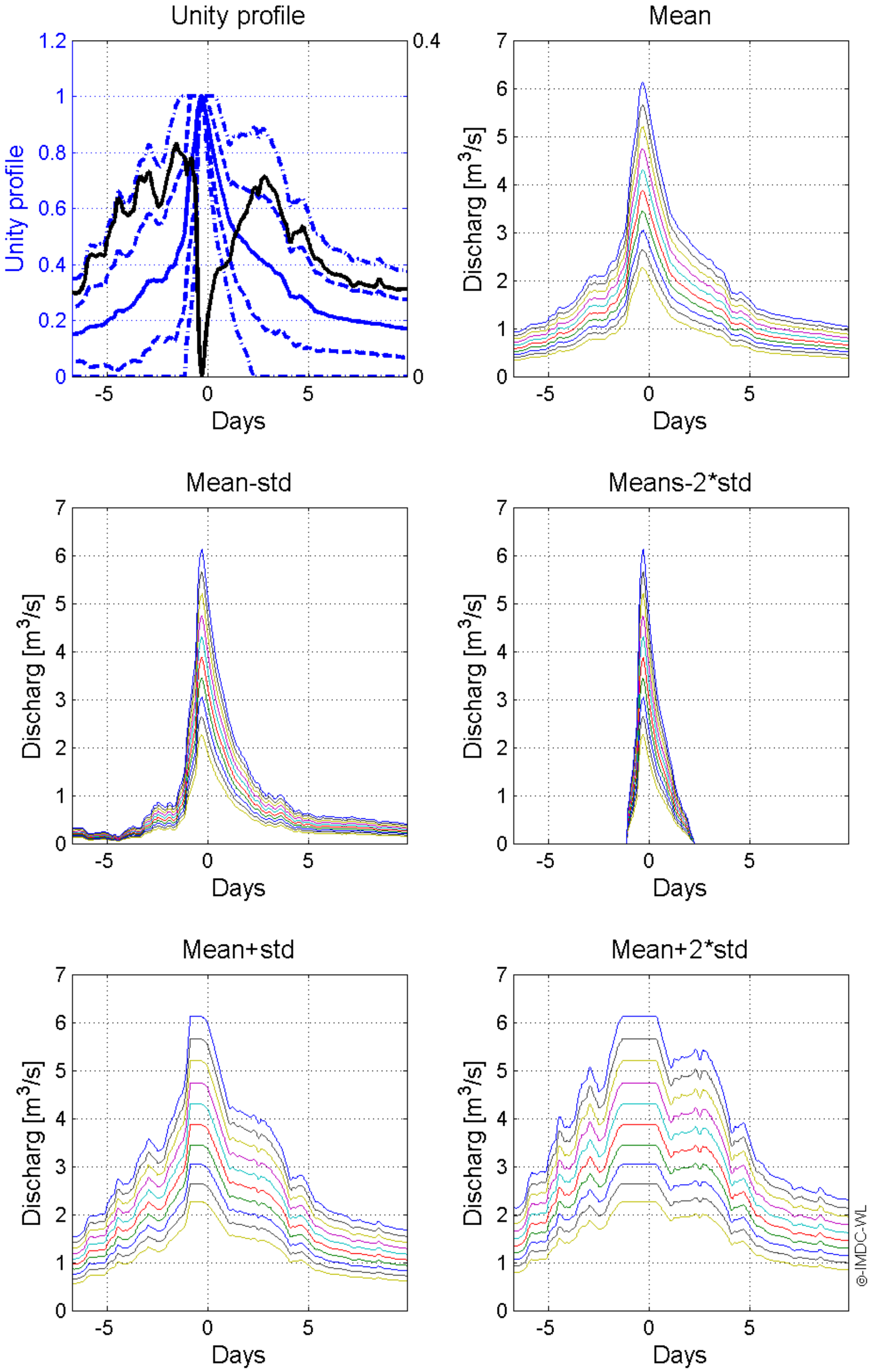
Poperingevaart



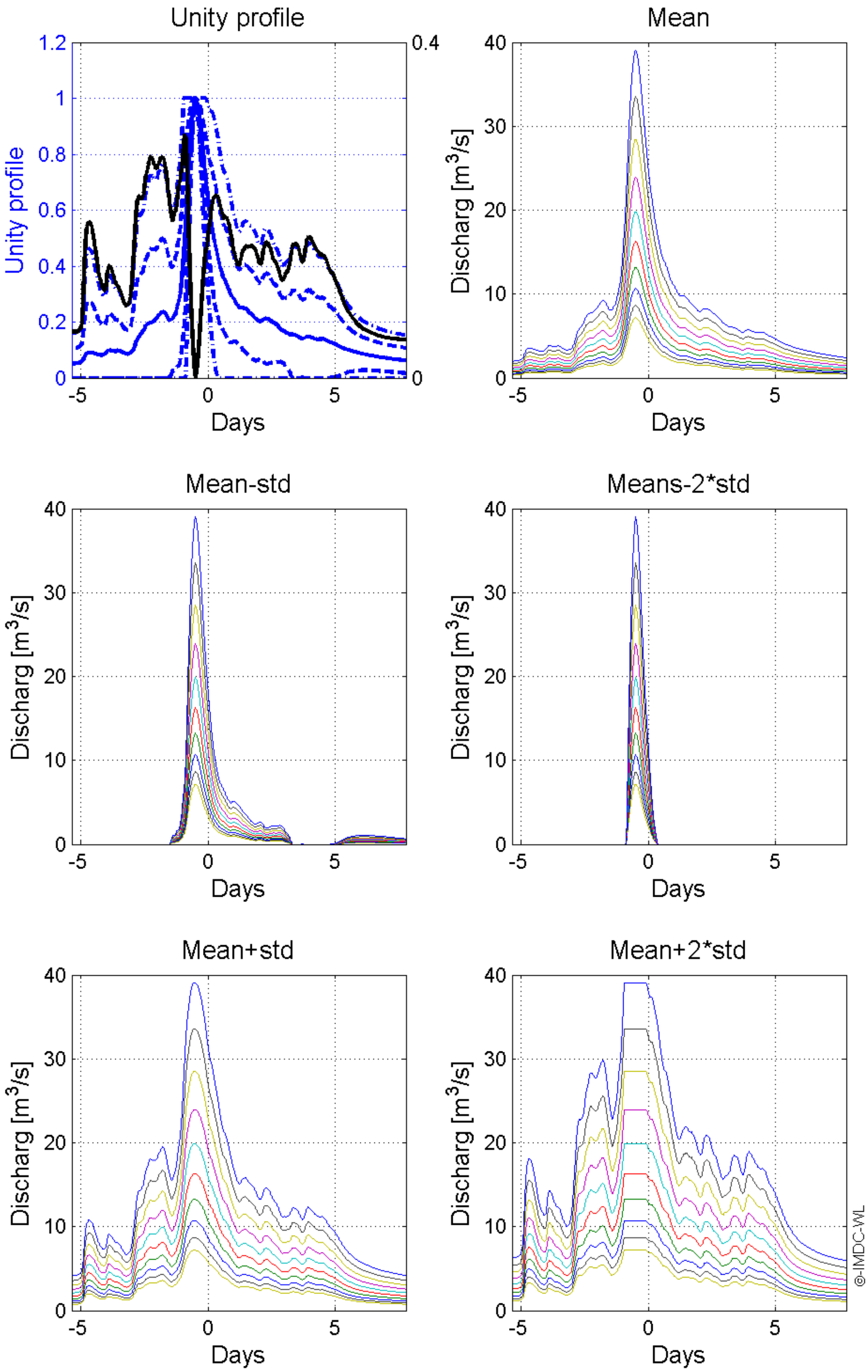
Kemmelbeek


Unity profile
Unity profile
Days
Mean
Discharg [m3/s]
Days
Mean-std
Discharg [m3/s]
Days
Means-2*std
Discharg [m3/s]
Days
Mean+std
Discharg [m3/s]
Days
Mean+2*std
Discharg [m3/s]
Days
©-IMDC-WL

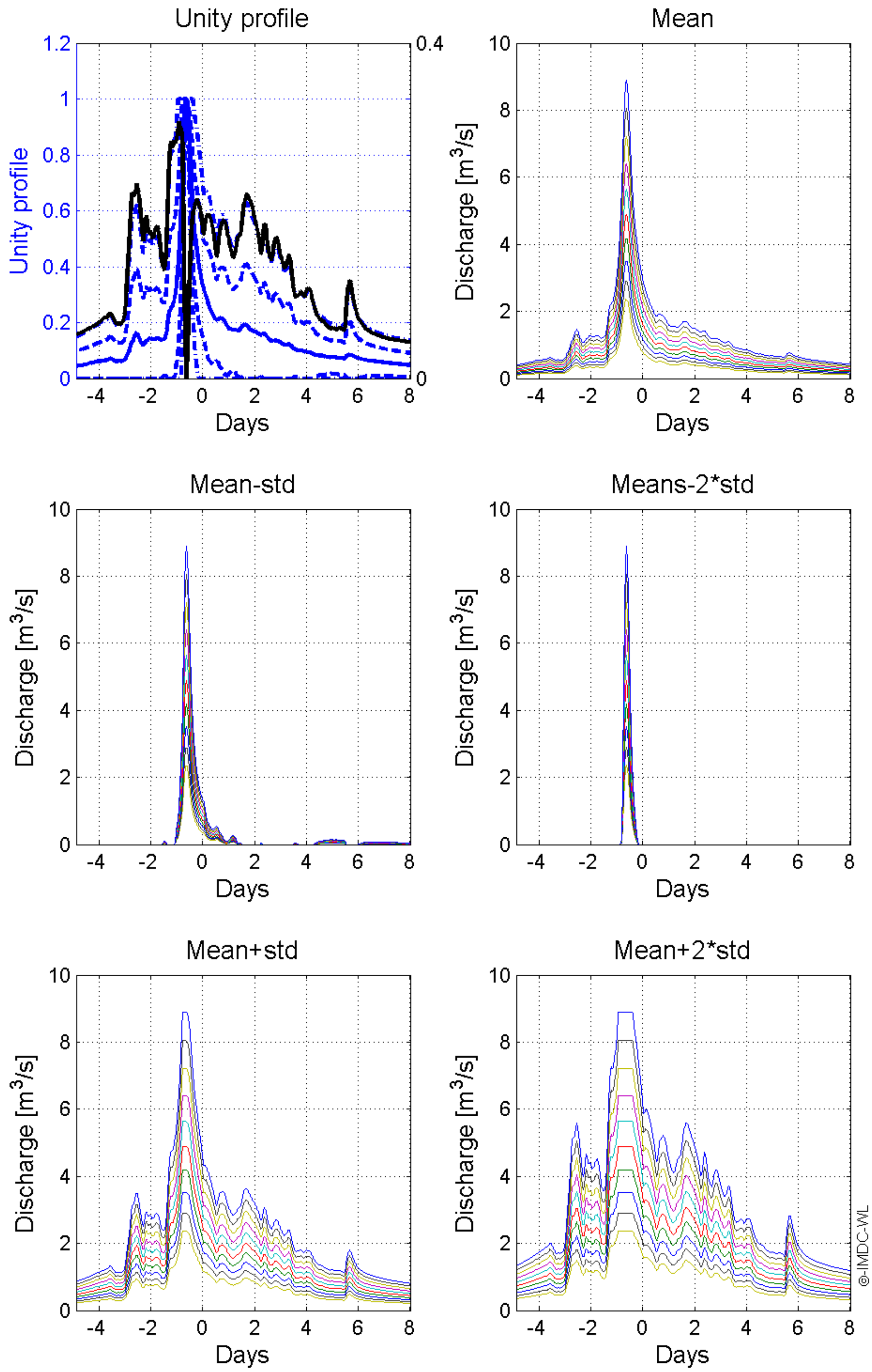
Ieperlee


Unity profile
Unity profile
Days
Mean
Discharg [m3/s]
Days
Mean-std
Discharg [m3/s]
Days
Means-2*std
Discharg [m3/s]
Days
Mean+std
Discharg [m3/s]
Days
Mean+2*std
Discharg [m3/s]
Days
©-IMDC-WL

Martjesvaart

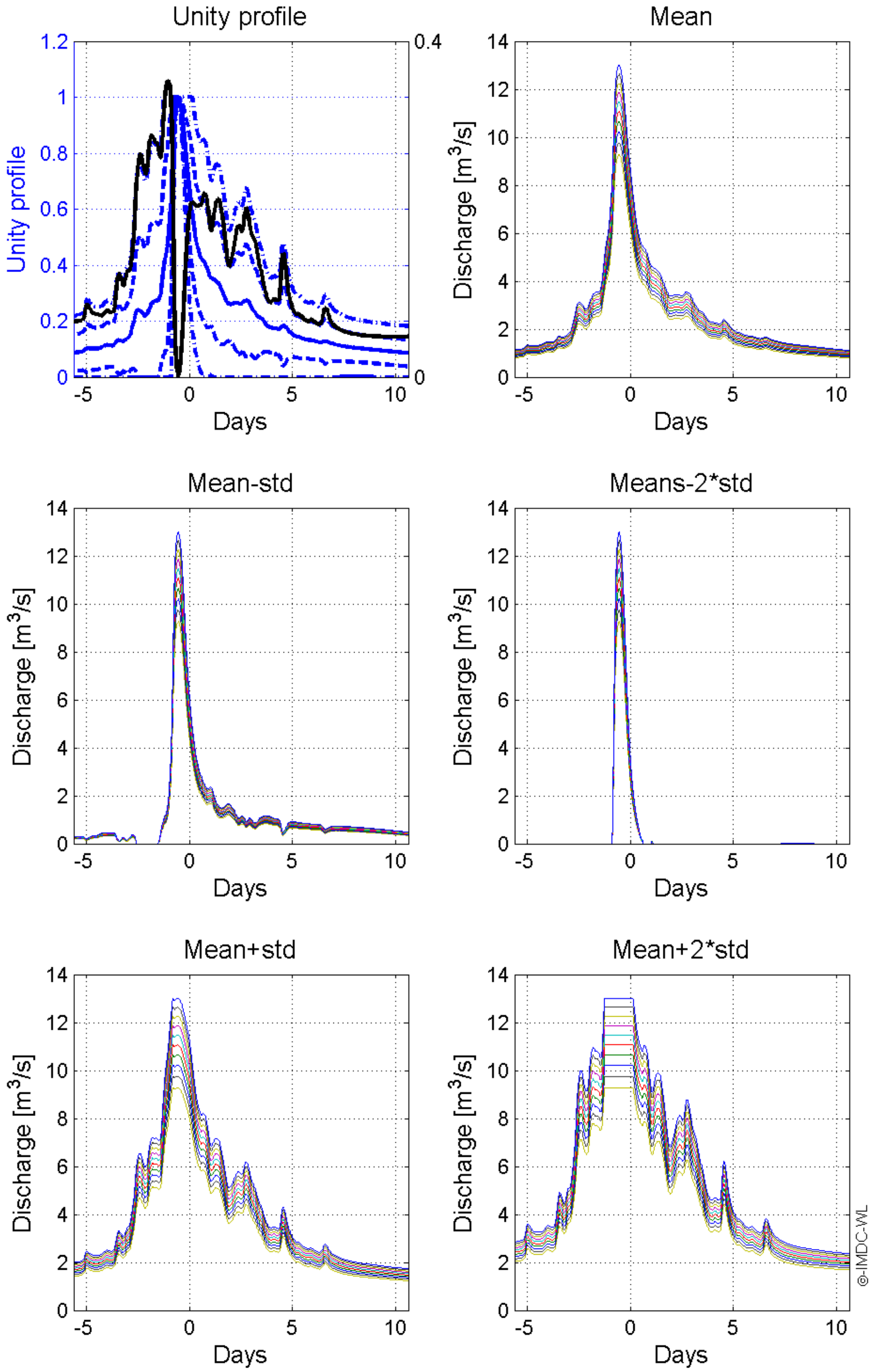


Steenbeek



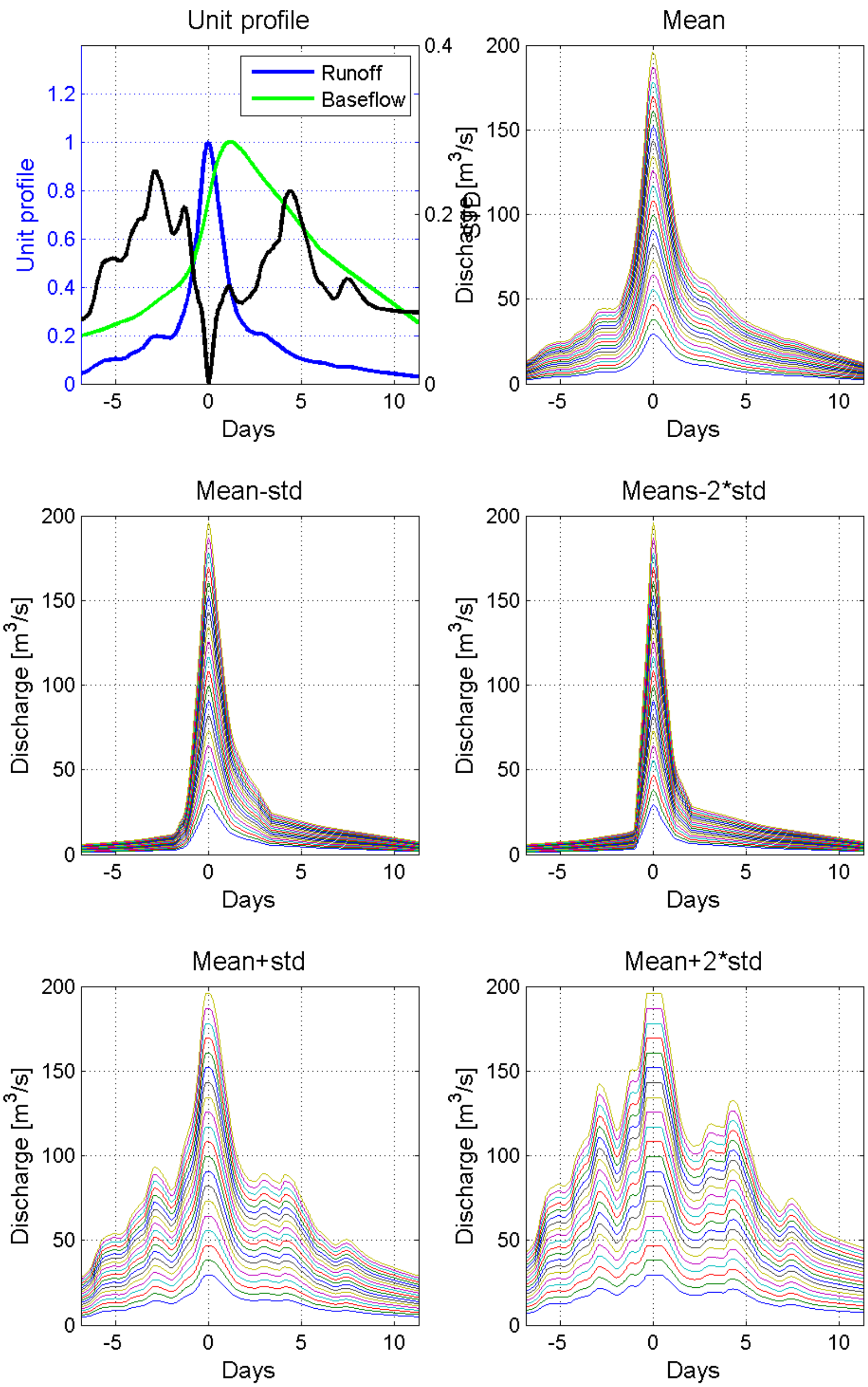
Unity profile
Mean
Mean-std
Means-2*std
Mean+std
Mean+2*std
Unity profile
Discharge [m3/s]
Days
©-IMDC-WL

Handzamevaart

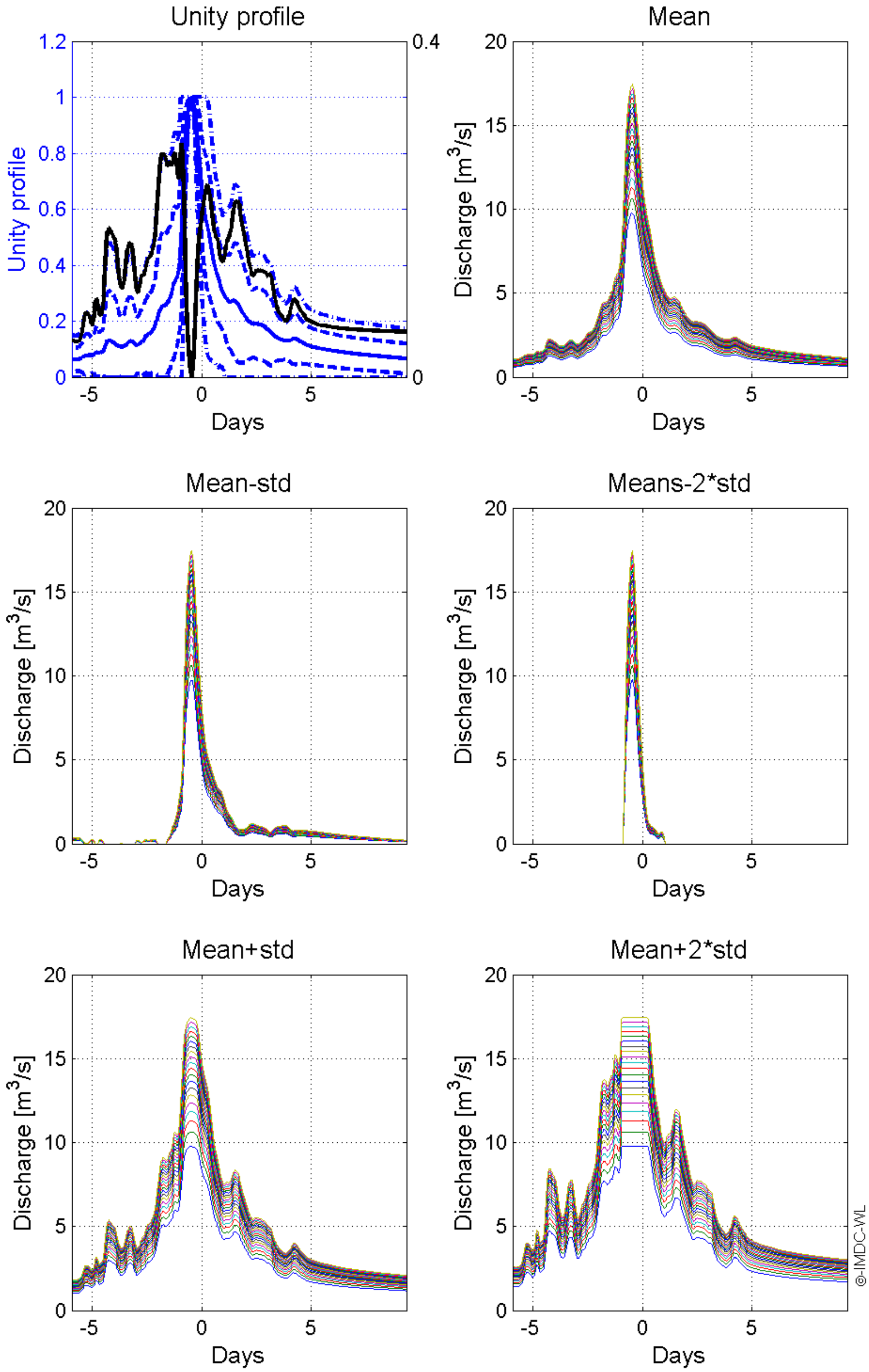


Partial dependency Q Roesbrugge – Q Tributaries

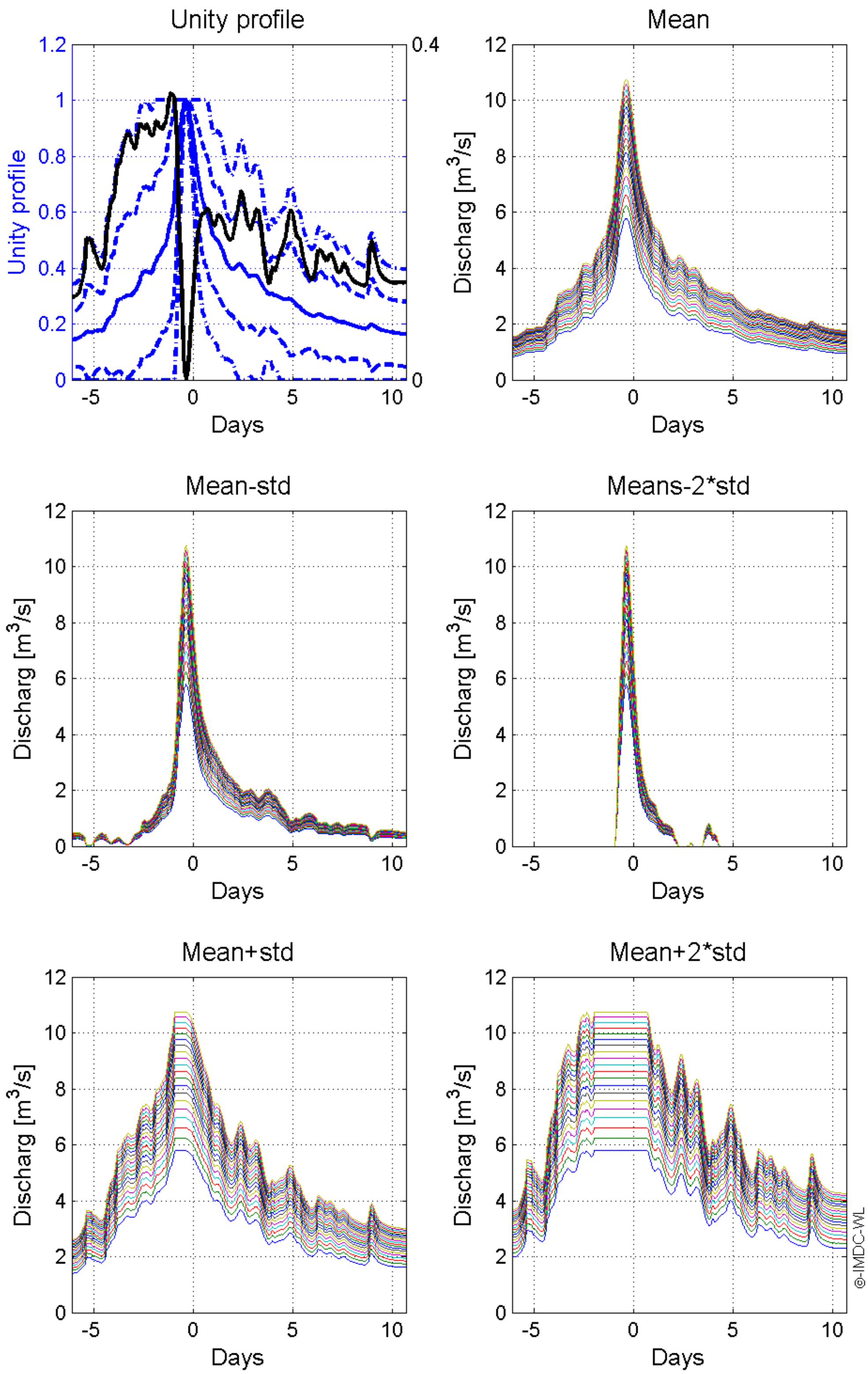
Yser Roesbrugge



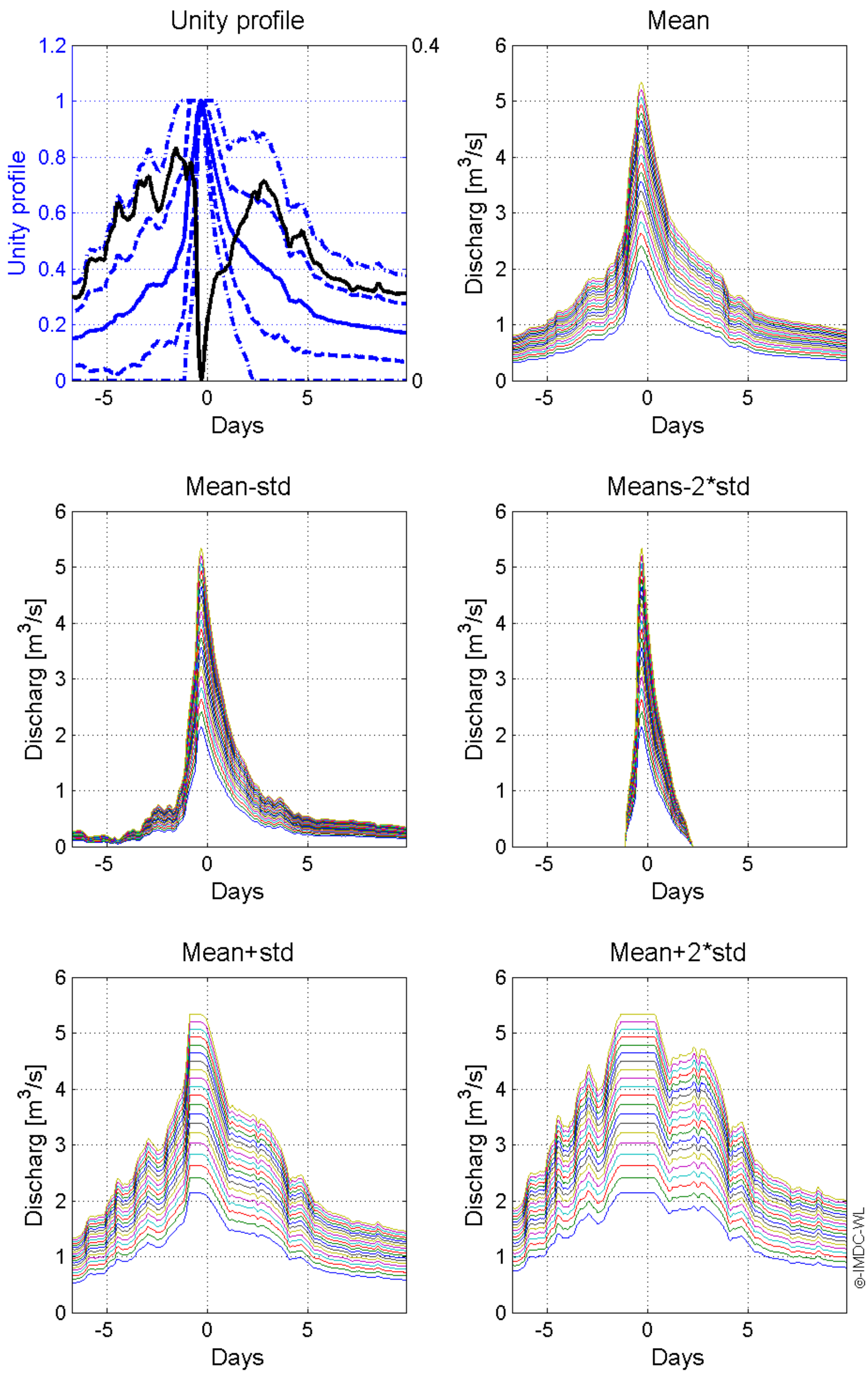
Poperingevaart



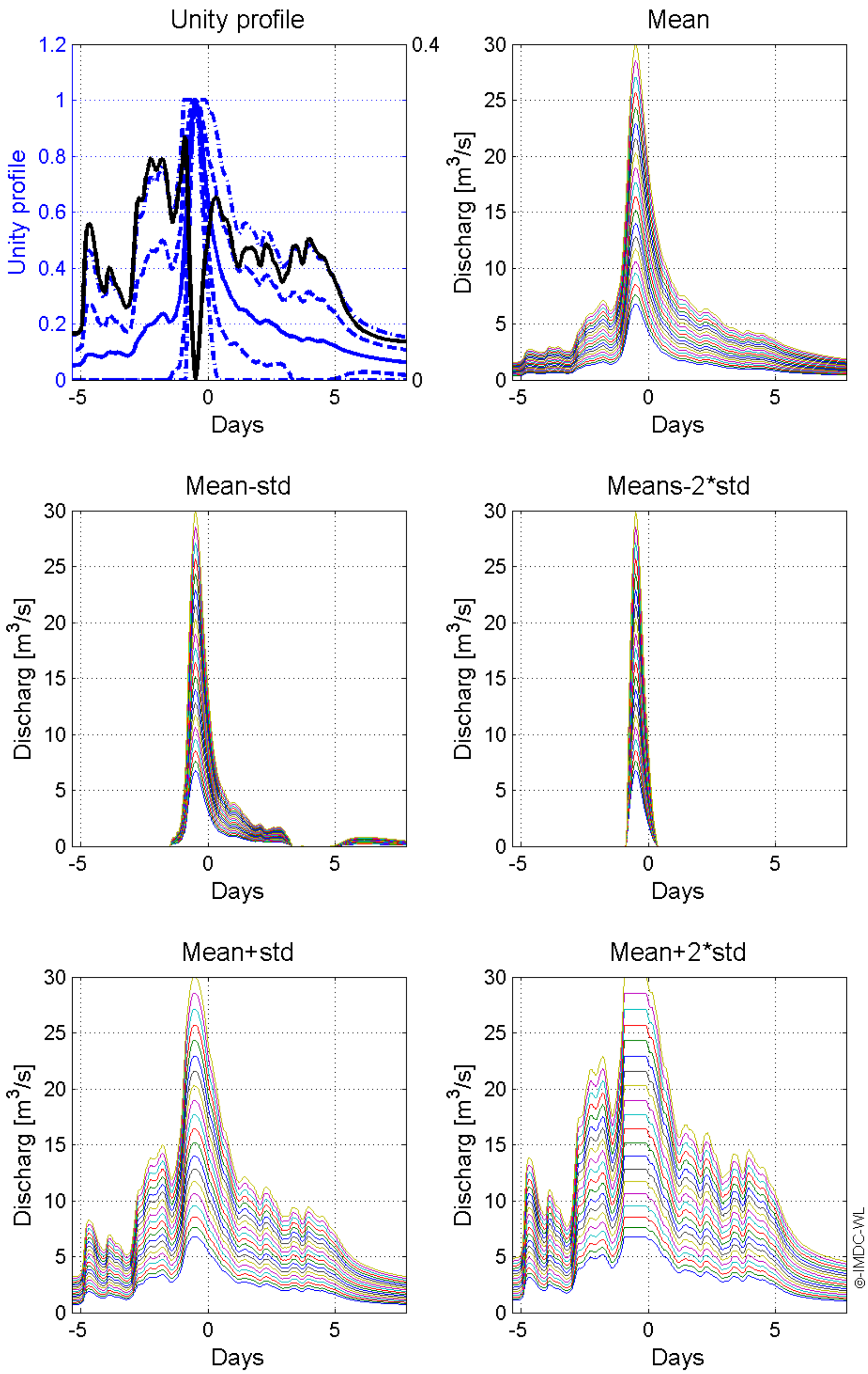
Kemmelbeek


Unity profile
Mean
Mean-std
Means-2*std
Mean+std
Mean+2*std
Unity profile
Discharg [m3/s]
Days
©-IMDC-WL

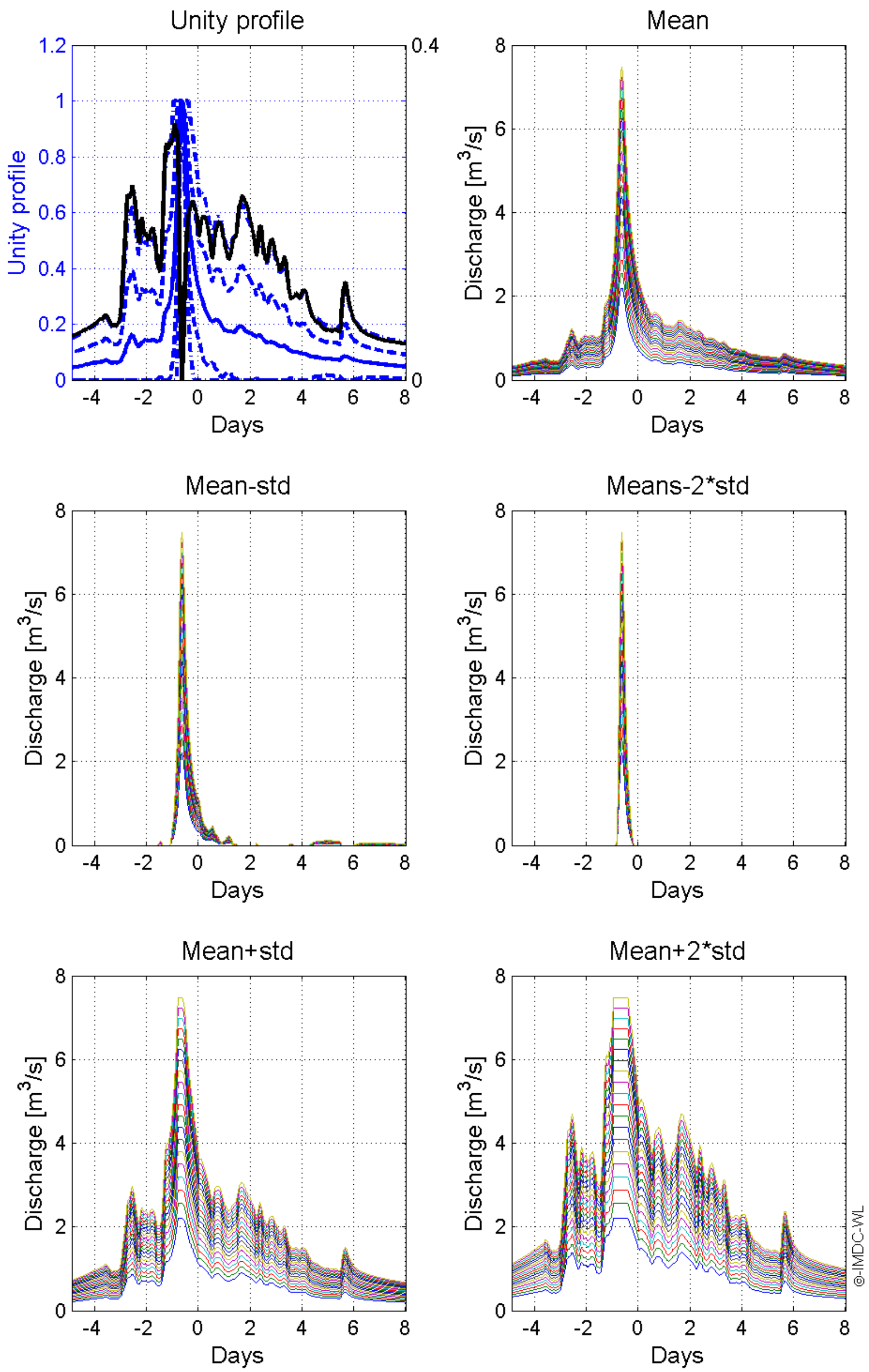
Ieperlee


Unity profile
Mean
Mean-std
Means-2*std
Mean+std
Mean+2*std
Unity profile
Discharg [m3/s]
Days
©-IMDC-WL

Martjesvaart



Steenbeek


Unity profile
Unity profile
Days
Mean
Discharge [m³/s]
Days
Mean-std
Discharge [m³/s]
Days
Means-2*std
Discharge [m³/s]
Days
Mean+std
Discharge [m³/s]
Days
Mean+2*std
Discharge [m³/s]
Days
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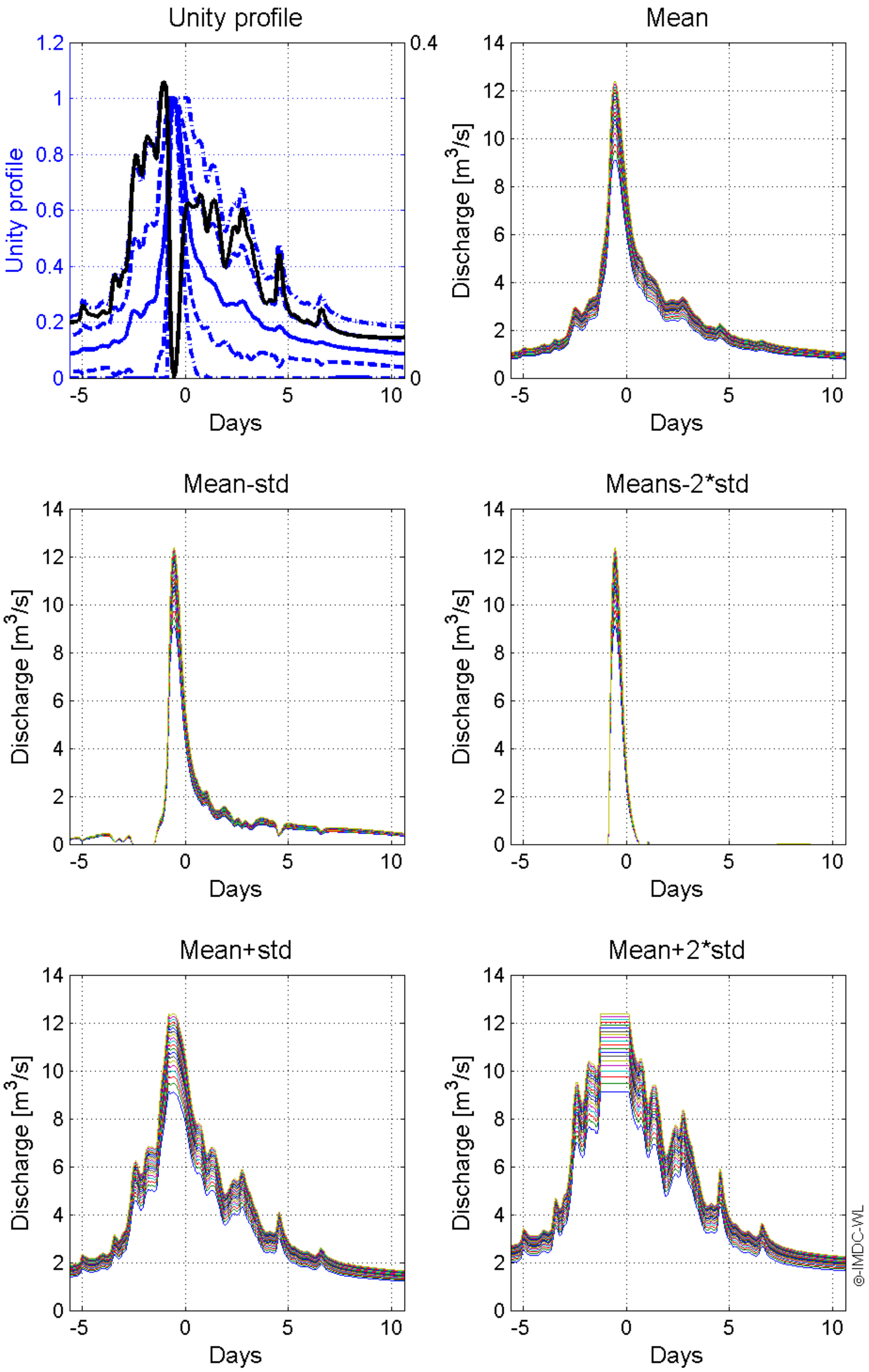
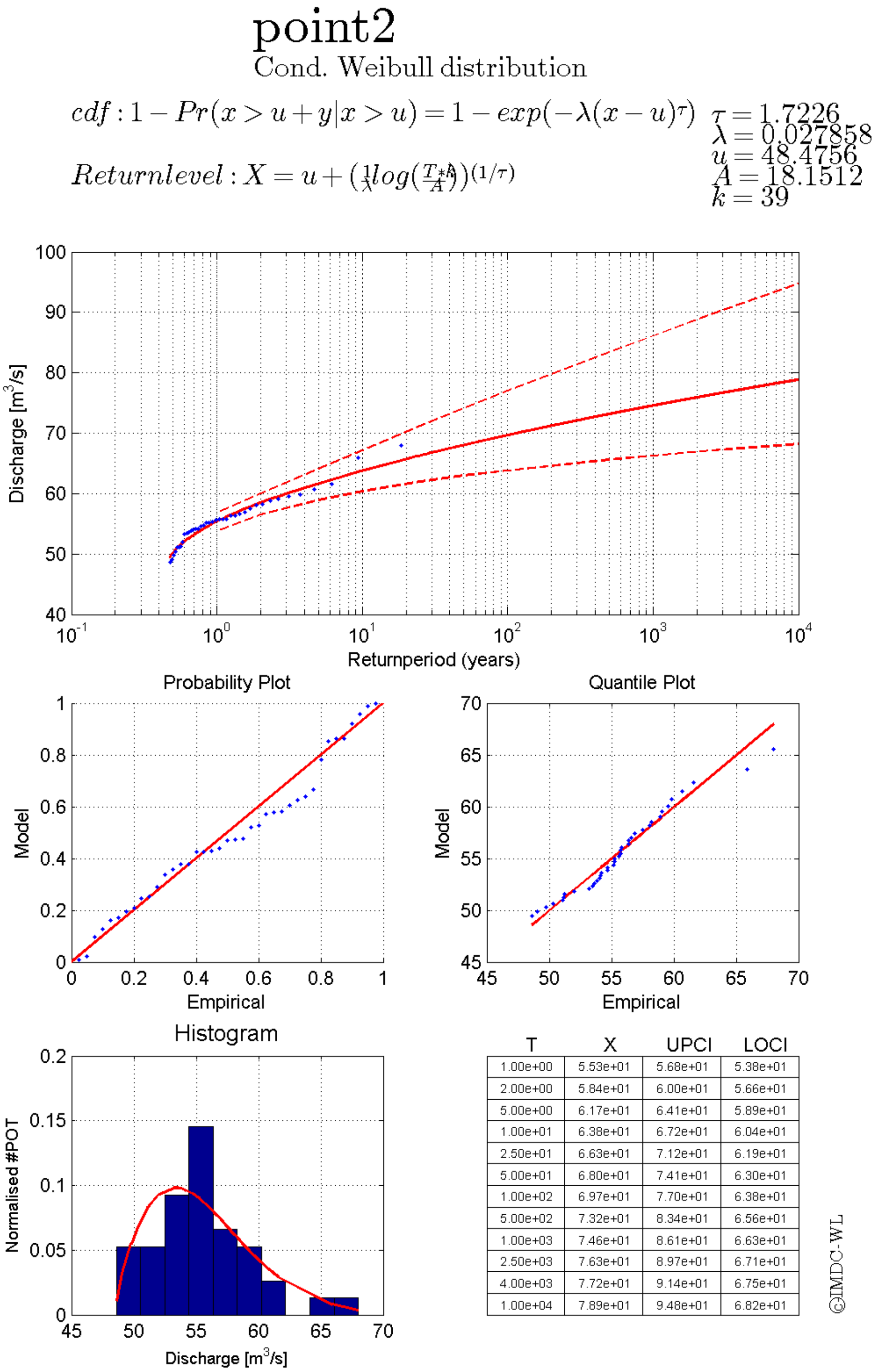
Handzamevaart

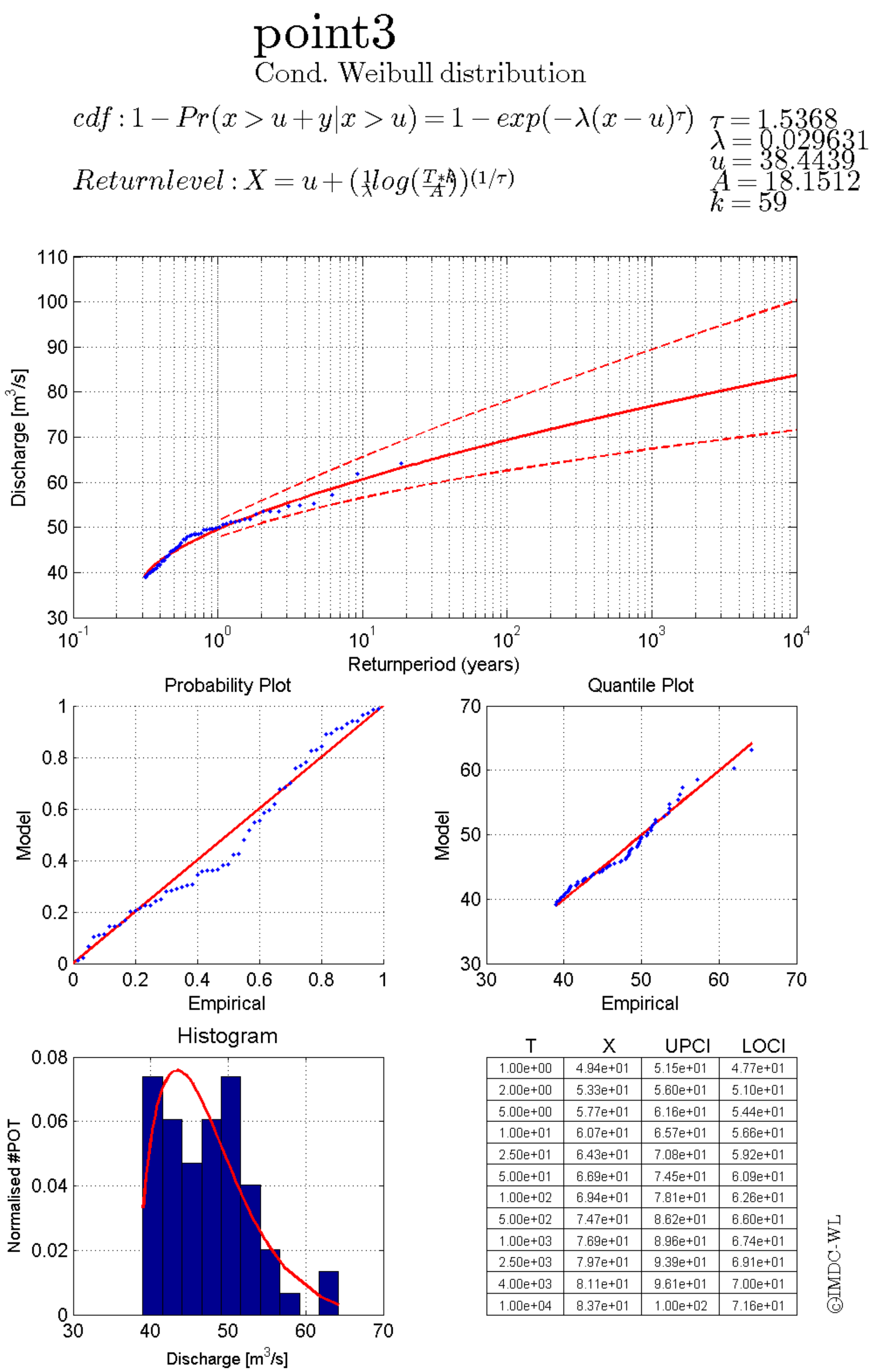


Appendix F: EVA Historical run

Discharge



T	X	UPCI	LOCI
1.00e+00	5.53e+01	5.68e+01	5.38e+01
2.00e+00	5.84e+01	6.00e+01	5.66e+01
5.00e+00	6.17e+01	6.41e+01	5.89e+01
1.00e+01	6.38e+01	6.72e+01	6.04e+01
2.50e+01	6.63e+01	7.12e+01	6.19e+01
5.00e+01	6.80e+01	7.41e+01	6.30e+01
1.00e+02	6.97e+01	7.70e+01	6.38e+01
5.00e+02	7.32e+01	8.34e+01	6.56e+01
1.00e+03	7.46e+01	8.61e+01	6.63e+01
2.50e+03	7.63e+01	8.97e+01	6.71e+01
4.00e+03	7.72e+01	9.14e+01	6.75e+01
1.00e+04	7.89e+01	9.48e+01	6.82e+01



T	X	UPCI	LOCI
1.00e+00	4.94e+01	5.15e+01	4.77e+01
2.00e+00	5.33e+01	5.60e+01	5.10e+01
5.00e+00	5.77e+01	6.16e+01	5.44e+01
1.00e+01	6.07e+01	6.57e+01	5.66e+01
2.50e+01	6.43e+01	7.08e+01	5.92e+01
5.00e+01	6.69e+01	7.45e+01	6.09e+01
1.00e+02	6.94e+01	7.81e+01	6.26e+01
5.00e+02	7.47e+01	8.62e+01	6.60e+01
1.00e+03	7.69e+01	8.96e+01	6.74e+01
2.50e+03	7.97e+01	9.39e+01	6.91e+01
4.00e+03	8.11e+01	9.61e+01	7.00e+01
1.00e+04	8.37e+01	1.00e+02	7.16e+01

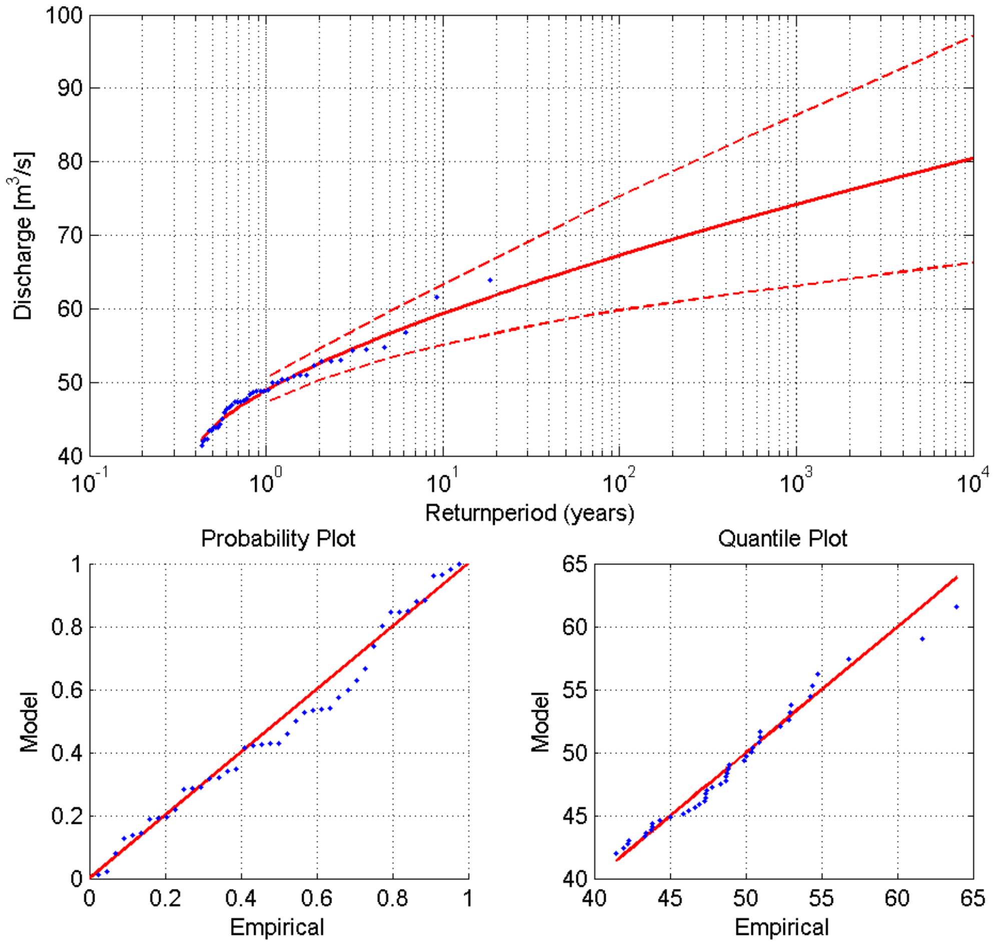
point4

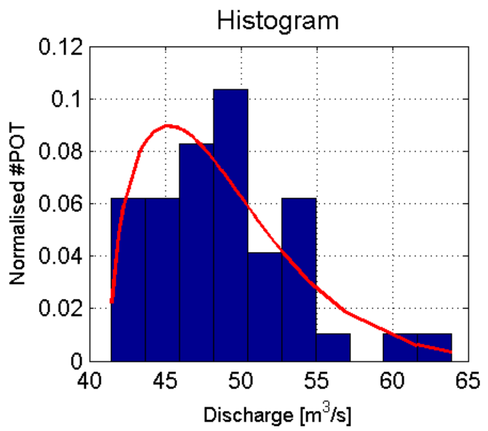
Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

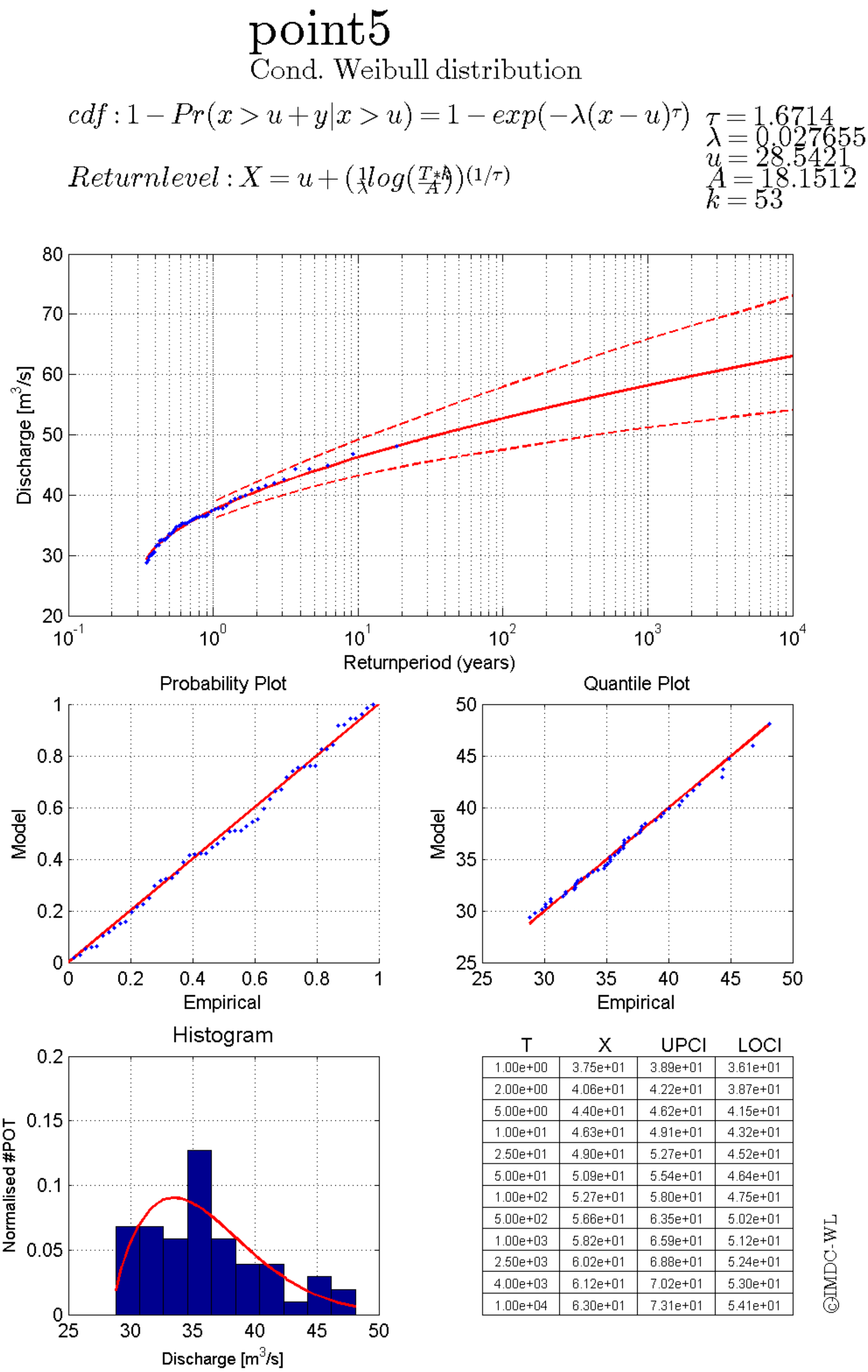
$$Returnlevel : X = u + (\frac{1}{\lambda} log(\frac{T * k}{A}))^{(1/\tau)}$$

$\tau = 1.4861$
$\lambda = 0.043347$
$u = 41.3365$
$A = 18.1512$
$k = 43$





T	X	UPCI	LOCI
1.00e+00	4.88e+01	5.06e+01	4.72e+01
2.00e+00	5.25e+01	5.46e+01	5.03e+01
5.00e+00	5.65e+01	5.96e+01	5.33e+01
1.00e+01	5.93e+01	6.33e+01	5.51e+01
2.50e+01	6.26e+01	6.81e+01	5.72e+01
5.00e+01	6.50e+01	7.17e+01	5.85e+01
1.00e+02	6.73e+01	7.53e+01	5.98e+01
5.00e+02	7.22e+01	8.31e+01	6.22e+01
1.00e+03	7.42e+01	8.64e+01	6.31e+01
2.50e+03	7.67e+01	9.06e+01	6.44e+01
4.00e+03	7.80e+01	9.27e+01	6.50e+01
1.00e+04	8.04e+01	9.71e+01	6.63e+01



T	X	UPCI	LOCI
1.00e+00	3.75e+01	3.89e+01	3.61e+01
2.00e+00	4.06e+01	4.22e+01	3.87e+01
5.00e+00	4.40e+01	4.62e+01	4.15e+01
1.00e+01	4.63e+01	4.91e+01	4.32e+01
2.50e+01	4.90e+01	5.27e+01	4.52e+01
5.00e+01	5.09e+01	5.54e+01	4.64e+01
1.00e+02	5.27e+01	5.80e+01	4.75e+01
5.00e+02	5.66e+01	6.35e+01	5.02e+01
1.00e+03	5.82e+01	6.59e+01	5.12e+01
2.50e+03	6.02e+01	6.88e+01	5.24e+01
4.00e+03	6.12e+01	7.02e+01	5.30e+01
1.00e+04	6.30e+01	7.31e+01	5.41e+01

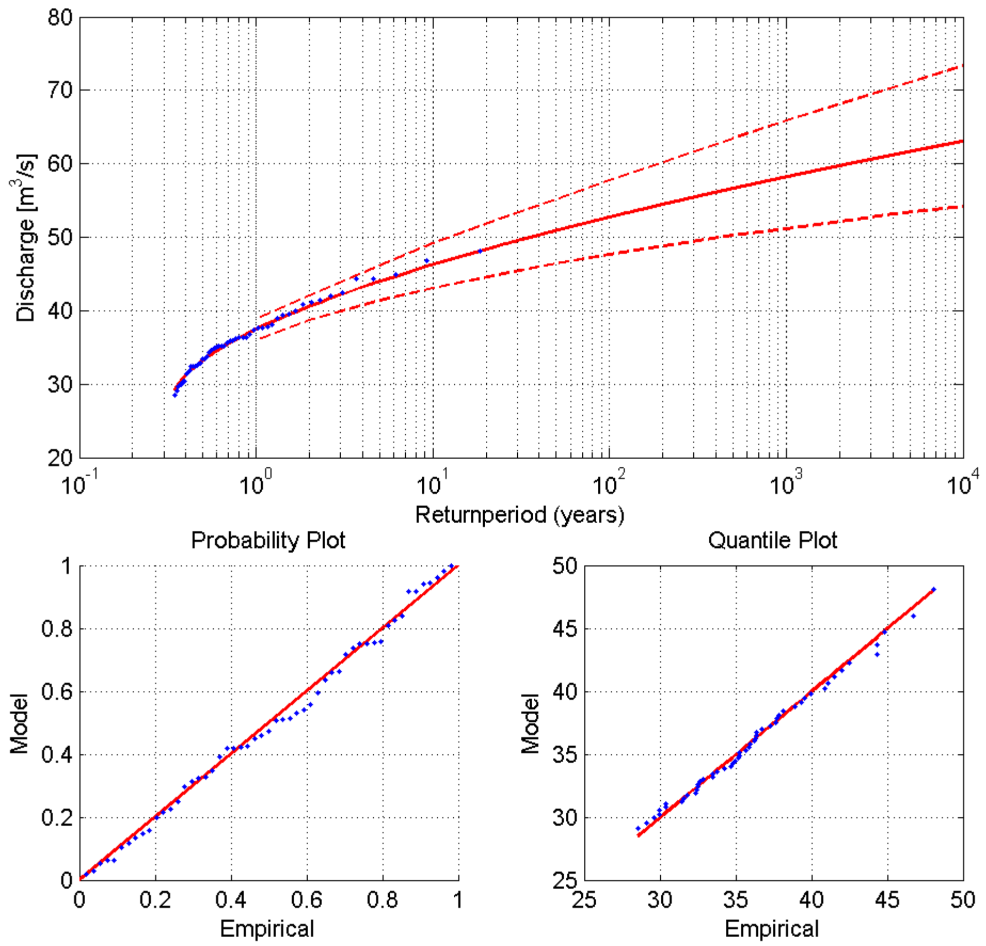
point6

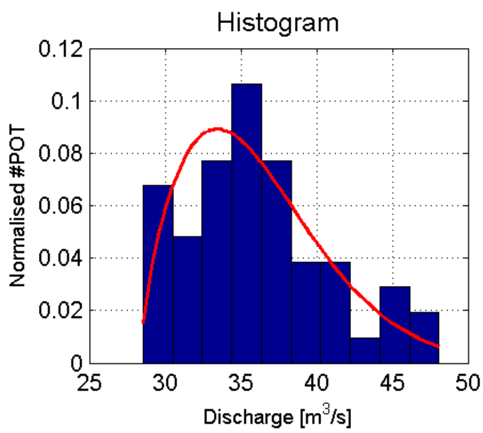
Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x - u)^{\tau})$$

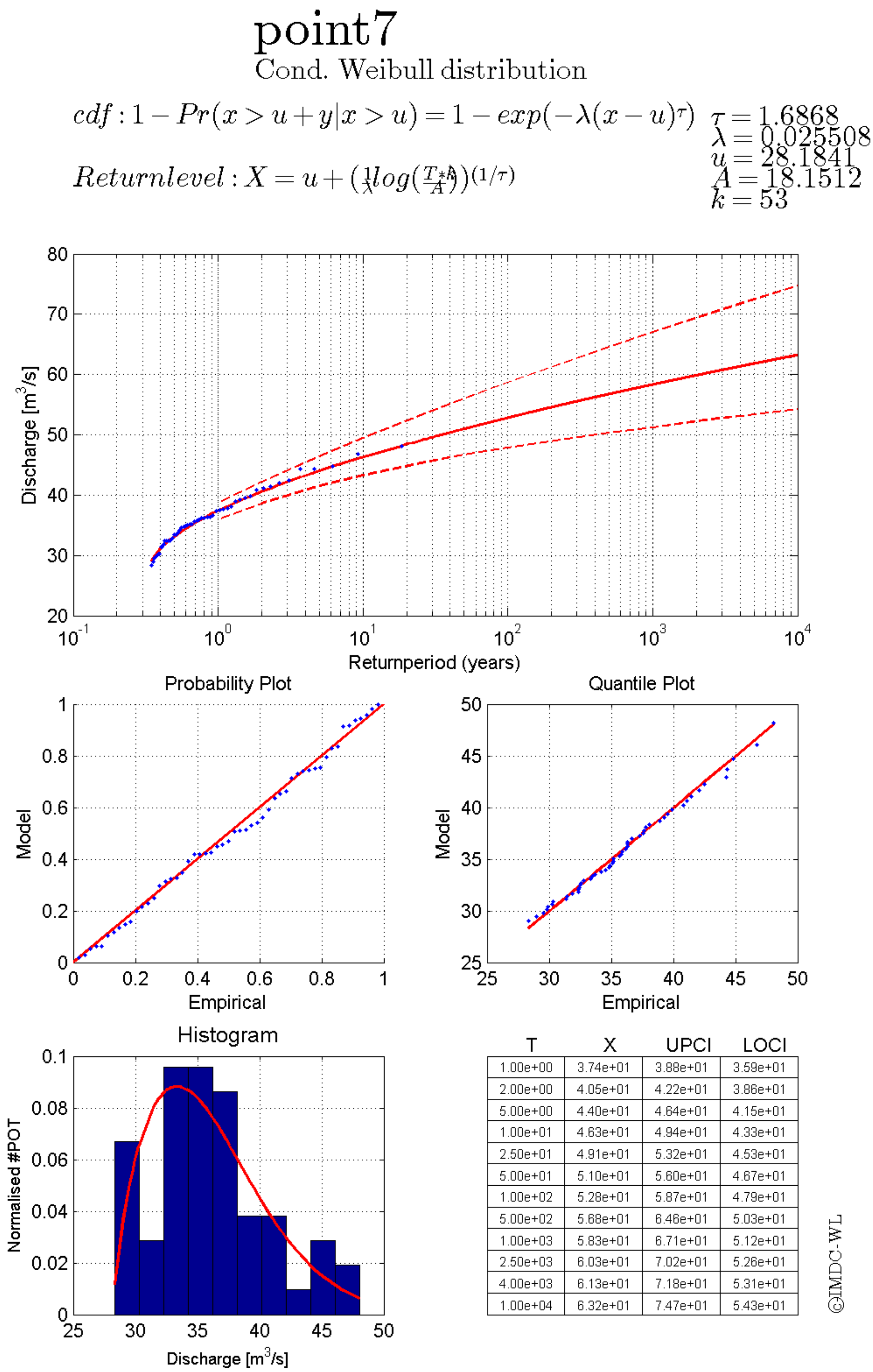
$$Returnlevel : X = u + (\tfrac{1}{\lambda} log(\tfrac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.6846$
$\lambda = 0.026099$
$u = 28.3304$
$A = 18.1512$
$k = 53$





T	X	UPCI	LOCI
1.00e+00	3.74e+01	3.88e+01	3.60e+01
2.00e+00	4.05e+01	4.21e+01	3.87e+01
5.00e+00	4.40e+01	4.62e+01	4.14e+01
1.00e+01	4.63e+01	4.91e+01	4.31e+01
2.50e+01	4.90e+01	5.27e+01	4.50e+01
5.00e+01	5.09e+01	5.52e+01	4.64e+01
1.00e+02	5.27e+01	5.78e+01	4.76e+01
5.00e+02	5.66e+01	6.35e+01	5.02e+01
1.00e+03	5.82e+01	6.58e+01	5.12e+01
2.50e+03	6.02e+01	6.88e+01	5.25e+01
4.00e+03	6.12e+01	7.04e+01	5.31e+01
1.00e+04	6.31e+01	7.33e+01	5.42e+01



T	X	UPCI	LOCI
1.00e+00	3.74e+01	3.88e+01	3.59e+01
2.00e+00	4.05e+01	4.22e+01	3.86e+01
5.00e+00	4.40e+01	4.64e+01	4.15e+01
1.00e+01	4.63e+01	4.94e+01	4.33e+01
2.50e+01	4.91e+01	5.32e+01	4.53e+01
5.00e+01	5.10e+01	5.60e+01	4.67e+01
1.00e+02	5.28e+01	5.87e+01	4.79e+01
5.00e+02	5.68e+01	6.46e+01	5.03e+01
1.00e+03	5.83e+01	6.71e+01	5.12e+01
2.50e+03	6.03e+01	7.02e+01	5.26e+01
4.00e+03	6.13e+01	7.18e+01	5.31e+01
1.00e+04	6.32e+01	7.47e+01	5.43e+01

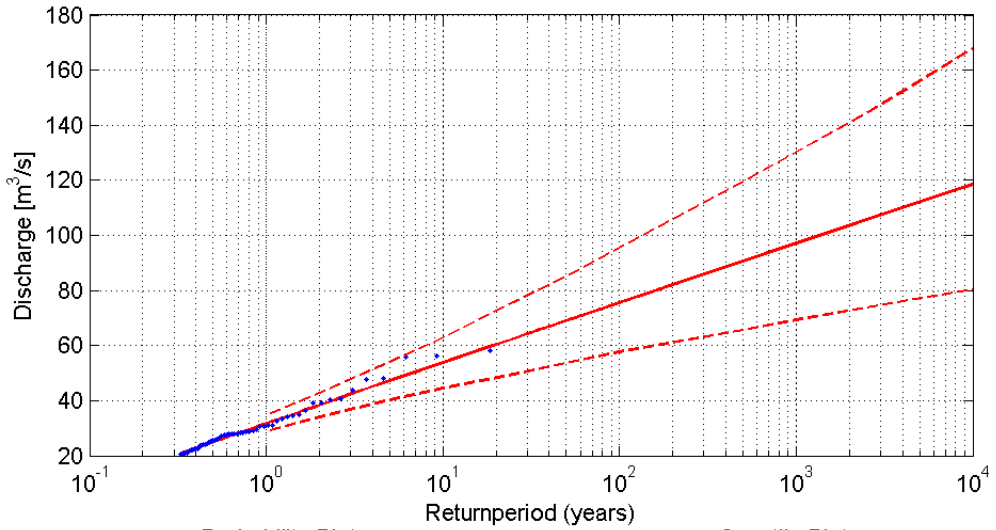
point8

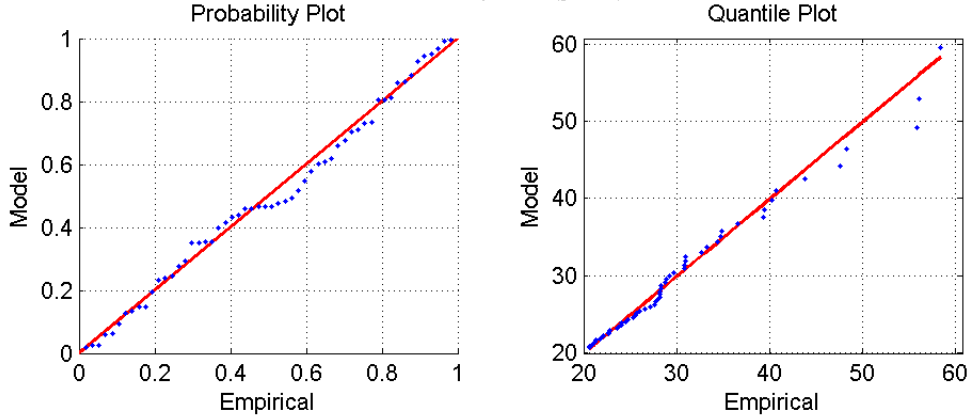
Cond. Weibull distribution

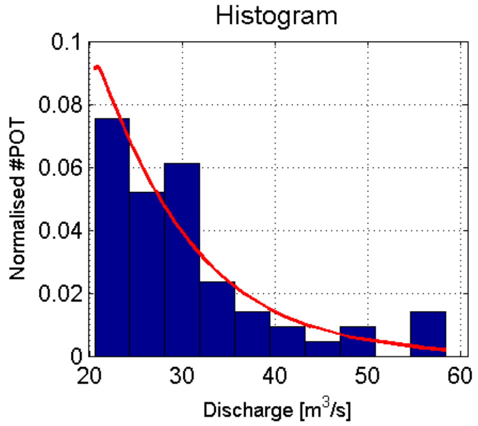
$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel: X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.0215$
$\lambda = 0.095523$
$u = 20.4407$
$A = 18.1512$
$k = 56$







T	X	UPCI	LOCI
1.00e+00	3.16e+01	3.48e+01	2.89e+01
2.00e+00	3.83e+01	4.27e+01	3.41e+01
5.00e+00	4.71e+01	5.42e+01	4.03e+01
1.00e+01	5.37e+01	6.28e+01	4.45e+01
2.50e+01	6.24e+01	7.56e+01	4.96e+01
5.00e+01	6.90e+01	8.52e+01	5.36e+01
1.00e+02	7.55e+01	9.56e+01	5.76e+01
5.00e+02	9.06e+01	1.20e+02	6.57e+01
1.00e+03	9.71e+01	1.30e+02	6.93e+01
2.50e+03	1.06e+02	1.44e+02	7.38e+01
4.00e+03	1.10e+02	1.52e+02	7.61e+01
1.00e+04	1.18e+02	1.68e+02	8.03e+01

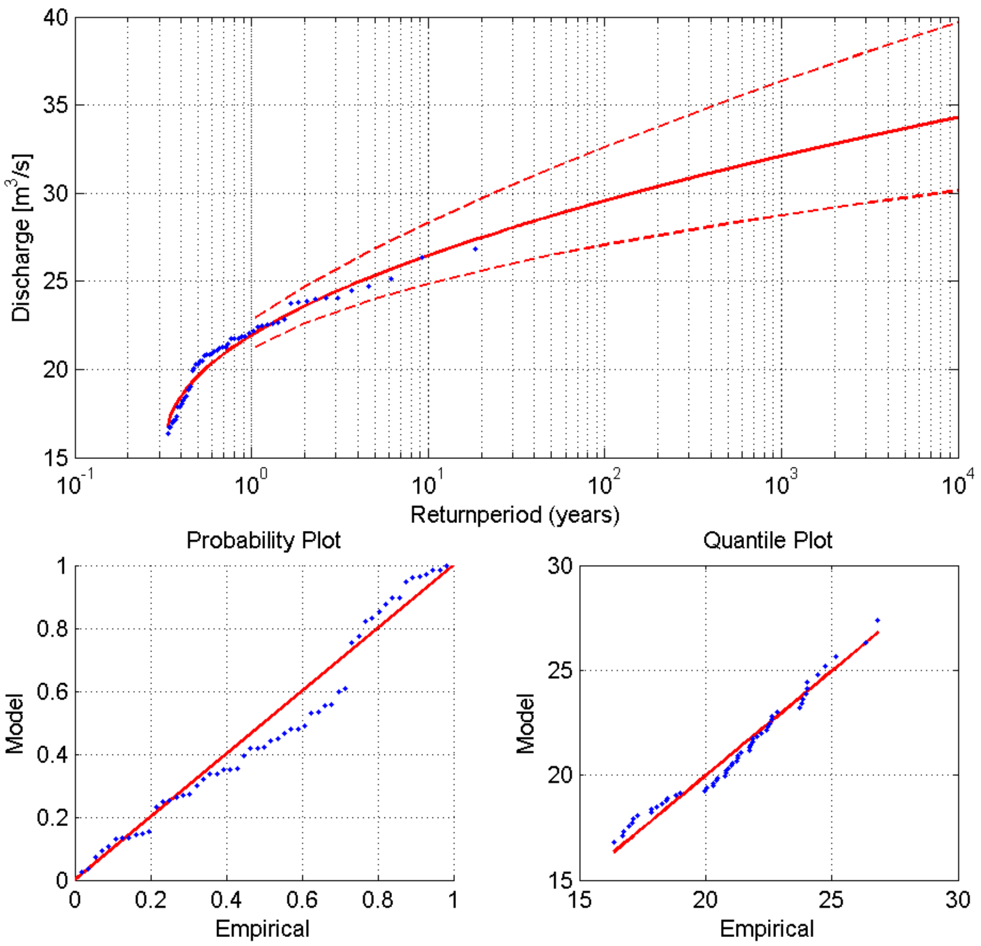
point9

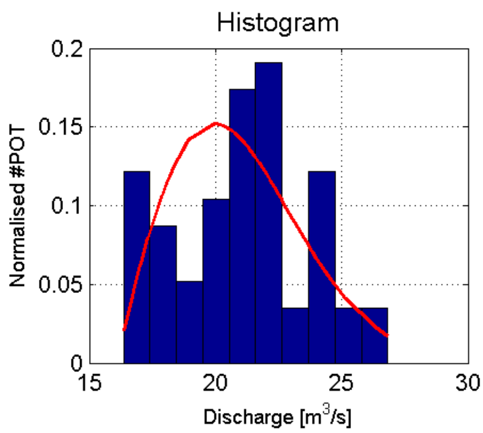
Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel : X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.9696$
$\lambda = 0.033886$
$u = 16.0566$
$A = 18.1512$
$k = 55$





T	X	UPCI	LOCI
1.00e+00	2.19e+01	2.28e+01	2.12e+01
2.00e+00	2.36e+01	2.47e+01	2.26e+01
5.00e+00	2.53e+01	2.68e+01	2.40e+01
1.00e+01	2.65e+01	2.83e+01	2.49e+01
2.50e+01	2.78e+01	3.01e+01	2.58e+01
5.00e+01	2.87e+01	3.14e+01	2.65e+01
1.00e+02	2.96e+01	3.26e+01	2.71e+01
5.00e+02	3.14e+01	3.53e+01	2.83e+01
1.00e+03	3.21e+01	3.64e+01	2.87e+01
2.50e+03	3.30e+01	3.77e+01	2.93e+01
4.00e+03	3.35e+01	3.84e+01	2.96e+01
1.00e+04	3.43e+01	3.97e+01	3.01e+01

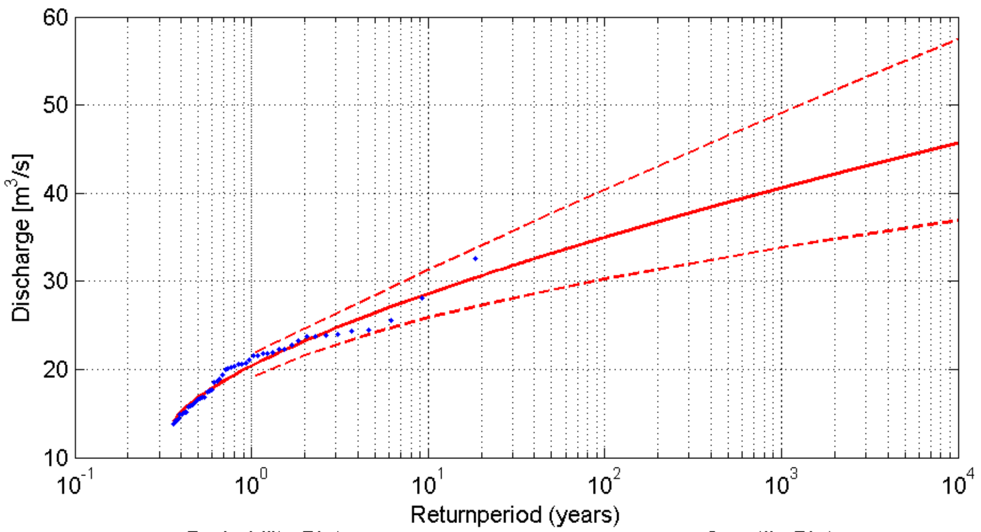
point10

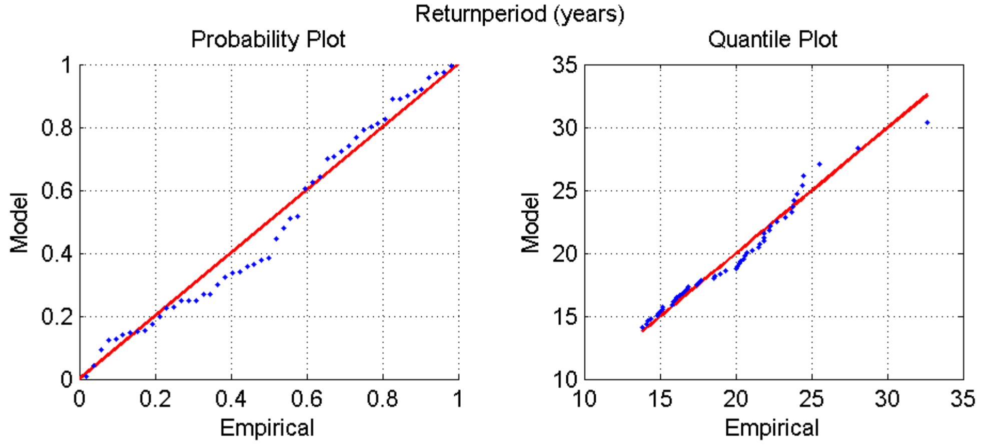
Cond. Weibull distribution

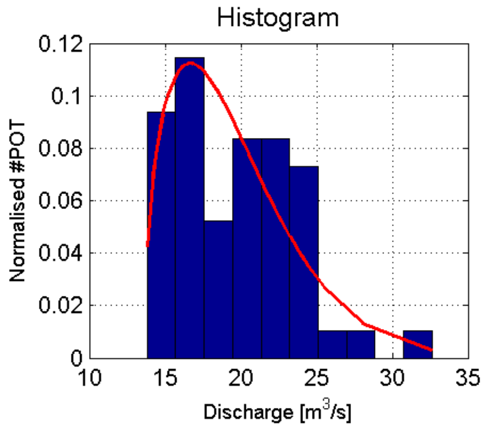
$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel : X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.4715$
$\lambda = 0.062344$
$u = 13.6212$
$A = 18.1512$
$k = 51$







T	X	UPCI	LOCI
1.00e+00	2.04e+01	2.17e+01	1.91e+01
2.00e+00	2.32e+01	2.46e+01	2.16e+01
5.00e+00	2.64e+01	2.84e+01	2.42e+01
1.00e+01	2.86e+01	3.13e+01	2.59e+01
2.50e+01	3.12e+01	3.50e+01	2.77e+01
5.00e+01	3.32e+01	3.77e+01	2.90e+01
1.00e+02	3.50e+01	4.04e+01	3.02e+01
5.00e+02	3.89e+01	4.65e+01	3.28e+01
1.00e+03	4.06e+01	4.92e+01	3.38e+01
2.50e+03	4.26e+01	5.25e+01	3.51e+01
4.00e+03	4.37e+01	5.42e+01	3.57e+01
1.00e+04	4.57e+01	5.75e+01	3.69e+01

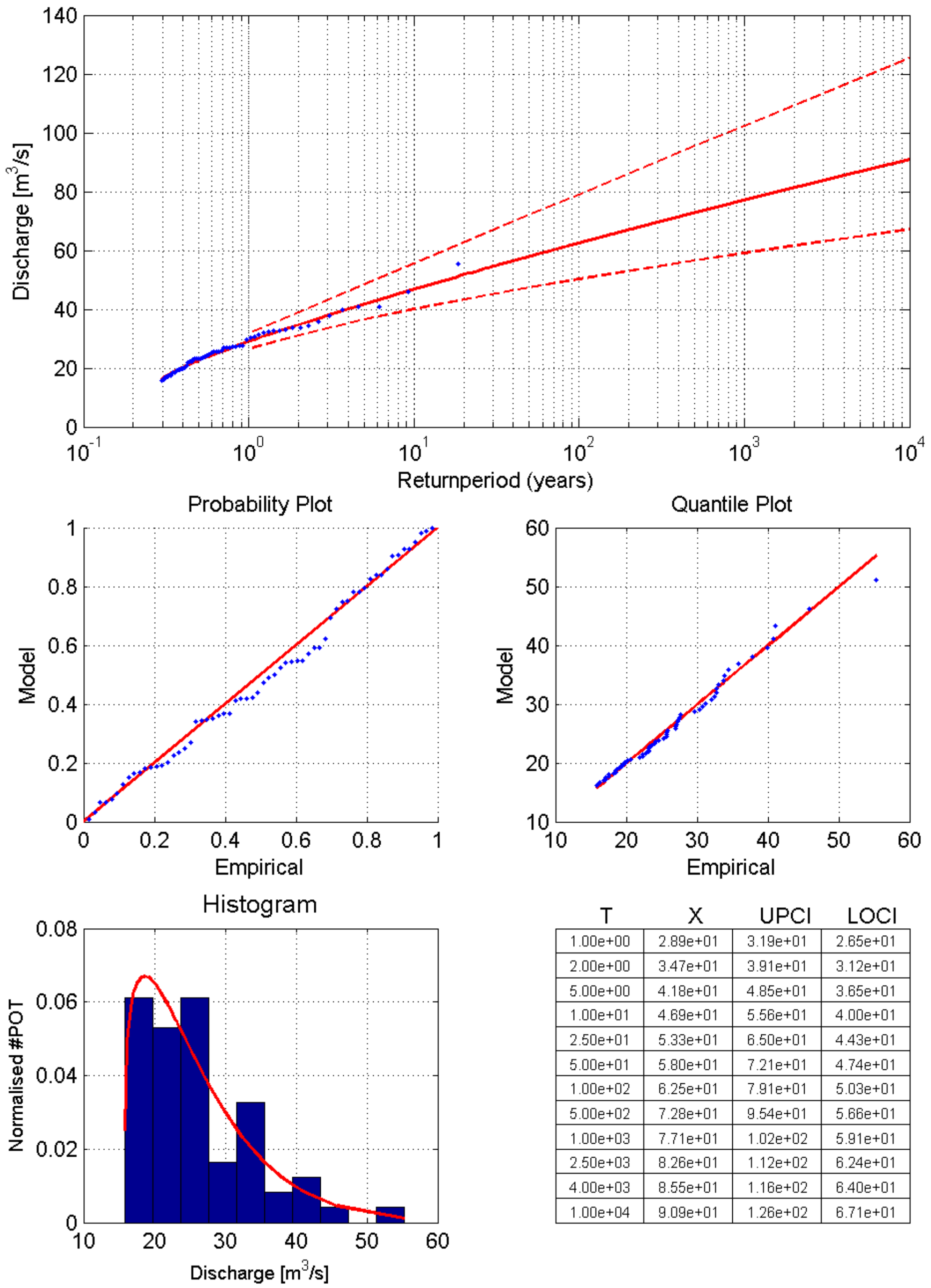
point11

Cond. Weibull distribution

$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel: X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.2281$
$\lambda = 0.051928$
$u = 15.7931$
$A = 18.1512$
$k = 62$



T	X	UPCI	LOCI
1.00e+00	2.89e+01	3.19e+01	2.65e+01
2.00e+00	3.47e+01	3.91e+01	3.12e+01
5.00e+00	4.18e+01	4.85e+01	3.65e+01
1.00e+01	4.69e+01	5.56e+01	4.00e+01
2.50e+01	5.33e+01	6.50e+01	4.43e+01
5.00e+01	5.80e+01	7.21e+01	4.74e+01
1.00e+02	6.25e+01	7.91e+01	5.03e+01
5.00e+02	7.28e+01	9.54e+01	5.66e+01
1.00e+03	7.71e+01	1.02e+02	5.91e+01
2.50e+03	8.26e+01	1.12e+02	6.24e+01
4.00e+03	8.55e+01	1.16e+02	6.40e+01
1.00e+04	9.09e+01	1.26e+02	6.71e+01

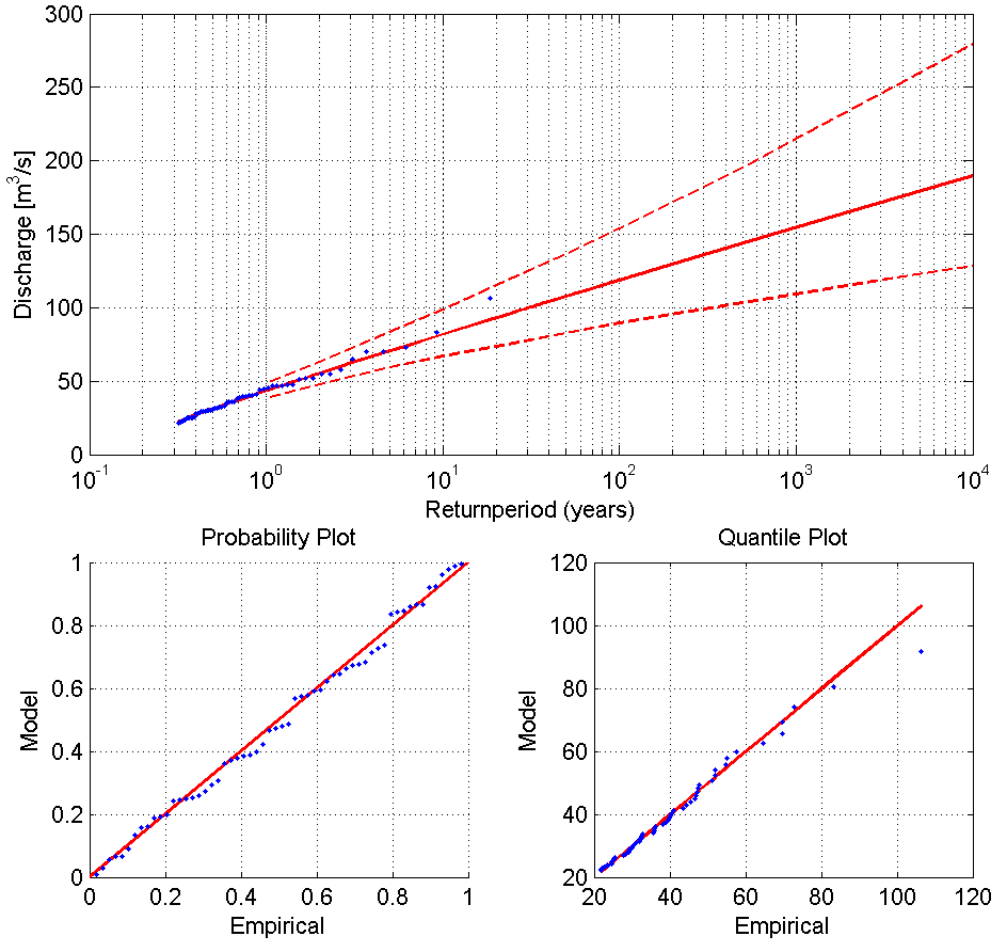
point12

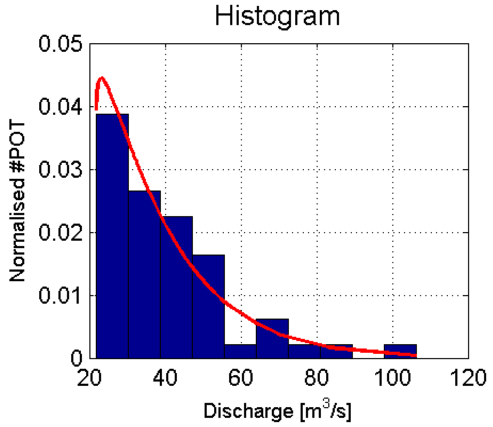
Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel : X = u + (\frac{1}{\lambda} log(\frac{T.k}{A}))^{(1/\tau)}$$

$\tau = 1.0693$
$\lambda = 0.043282$
$u = 21.66$
$A = 18.1512$
$k = 58$





T	X	UPCI	LOCI
1.00e+00	4.33e+01	4.87e+01	3.85e+01
2.00e+00	5.53e+01	6.30e+01	4.79e+01
5.00e+00	7.06e+01	8.38e+01	5.93e+01
1.00e+01	8.19e+01	9.90e+01	6.69e+01
2.50e+01	9.67e+01	1.20e+02	7.58e+01
5.00e+01	1.08e+02	1.36e+02	8.26e+01
1.00e+02	1.19e+02	1.54e+02	8.94e+01
5.00e+02	1.44e+02	1.96e+02	1.03e+02
1.00e+03	1.55e+02	2.15e+02	1.09e+02
2.50e+03	1.69e+02	2.40e+02	1.17e+02
4.00e+03	1.76e+02	2.54e+02	1.21e+02
1.00e+04	1.90e+02	2.80e+02	1.28e+02

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Water level

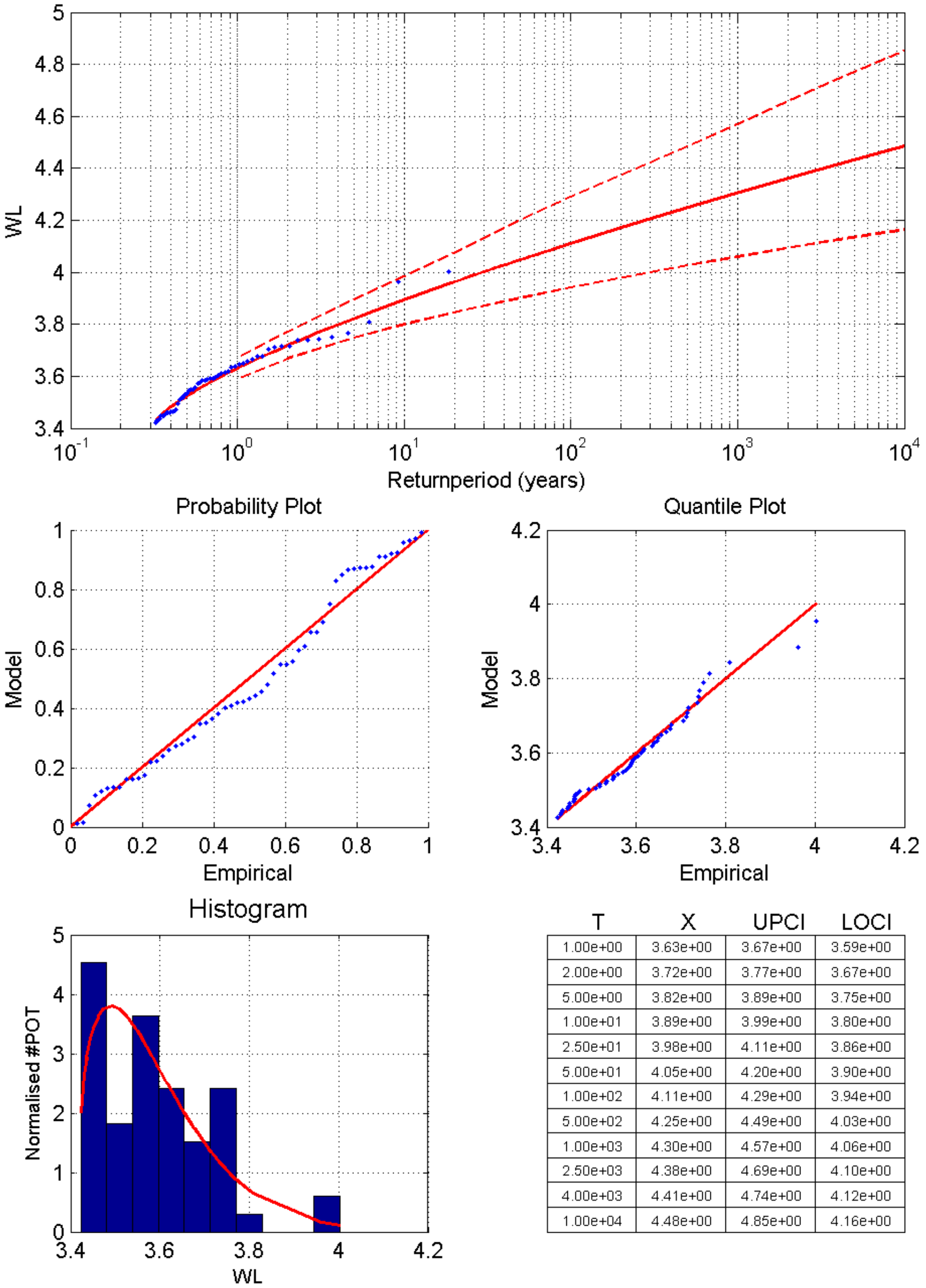
Point2

Cond. Weibull distribution

$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel: X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.3641$
$\lambda = 9.4619$
$u = 3.4165$
$A = 18.1512$
$k = 57$



T	X	UPCI	LOCI
1.00e+00	3.63e+00	3.67e+00	3.59e+00
2.00e+00	3.72e+00	3.77e+00	3.67e+00
5.00e+00	3.82e+00	3.89e+00	3.75e+00
1.00e+01	3.89e+00	3.99e+00	3.80e+00
2.50e+01	3.98e+00	4.11e+00	3.86e+00
5.00e+01	4.05e+00	4.20e+00	3.90e+00
1.00e+02	4.11e+00	4.29e+00	3.94e+00
5.00e+02	4.25e+00	4.49e+00	4.03e+00
1.00e+03	4.30e+00	4.57e+00	4.06e+00
2.50e+03	4.38e+00	4.69e+00	4.10e+00
4.00e+03	4.41e+00	4.74e+00	4.12e+00
1.00e+04	4.48e+00	4.85e+00	4.16e+00

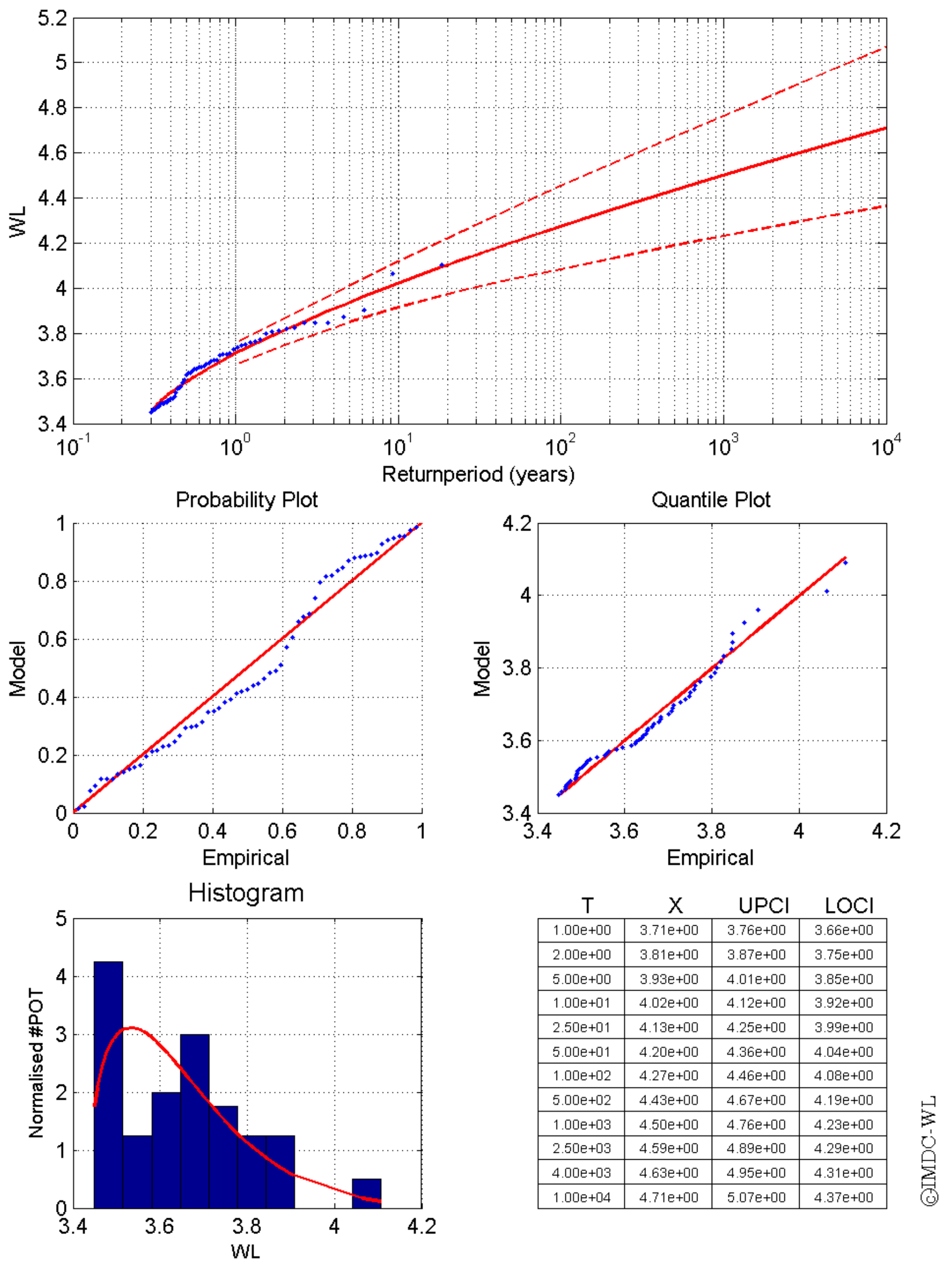
Point3

Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel : X = u + (\frac{1}{\lambda} log(\frac{T * k}{A}))^{(1/\tau)}$$

$\tau = 1.3911$
$\lambda = 7.4642$
$u = 3.4381$
$A = 18.1512$
$k = 61$



T	X	UPCI	LOCI
1.00e+00	3.71e+00	3.76e+00	3.66e+00
2.00e+00	3.81e+00	3.87e+00	3.75e+00
5.00e+00	3.93e+00	4.01e+00	3.85e+00
1.00e+01	4.02e+00	4.12e+00	3.92e+00
2.50e+01	4.13e+00	4.25e+00	3.99e+00
5.00e+01	4.20e+00	4.36e+00	4.04e+00
1.00e+02	4.27e+00	4.46e+00	4.08e+00
5.00e+02	4.43e+00	4.67e+00	4.19e+00
1.00e+03	4.50e+00	4.76e+00	4.23e+00
2.50e+03	4.59e+00	4.89e+00	4.29e+00
4.00e+03	4.63e+00	4.95e+00	4.31e+00
1.00e+04	4.71e+00	5.07e+00	4.37e+00

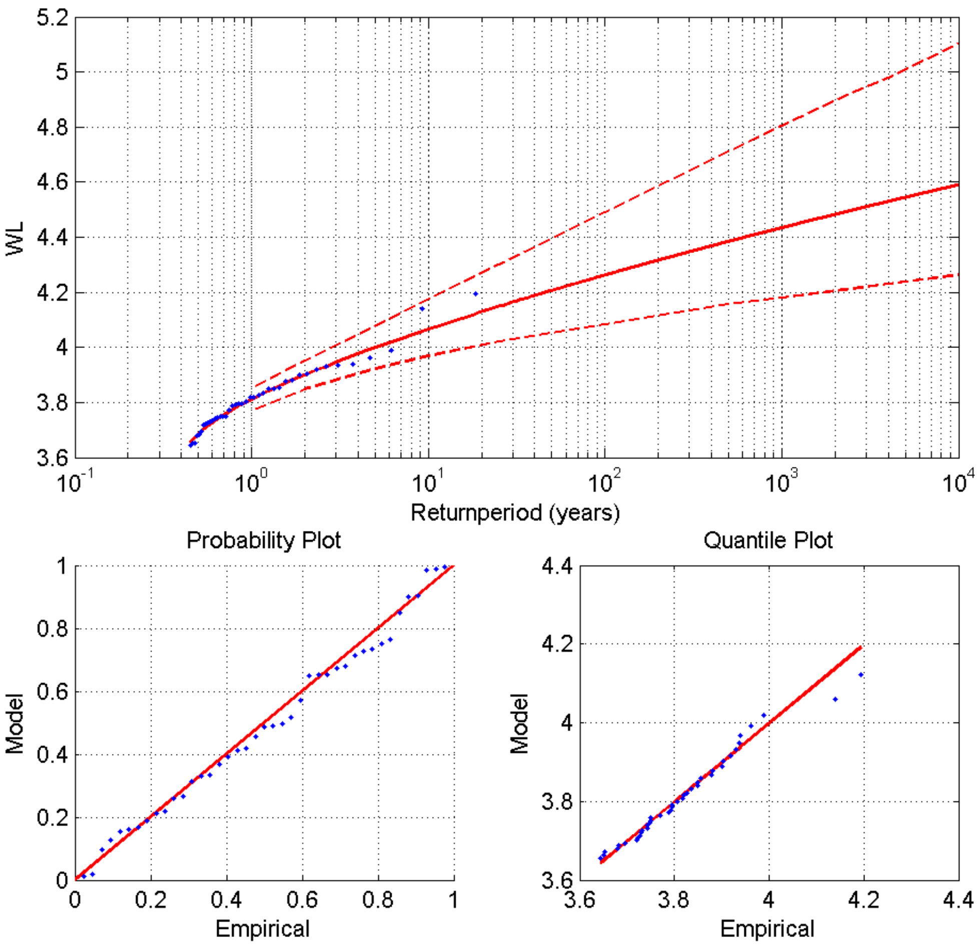
Point4

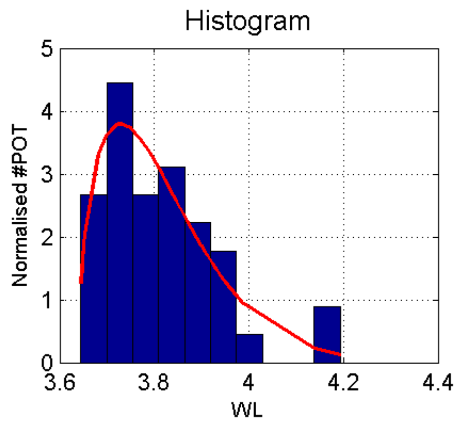
Cond. Weibull distribution

$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x - u)^{\tau})$$

$$Returnlevel : X = u + (\frac{1}{\lambda} log(\frac{T * k}{A}))^{(1/\tau)}$$

$\tau = 1.4542$
$\lambda = 10.8101$
$u = 3.6406$
$A = 18.1512$
$k = 41$





T	X	UPCI	LOCI
1.00e+00	3.81e+00	3.85e+00	3.77e+00
2.00e+00	3.90e+00	3.95e+00	3.85e+00
5.00e+00	4.00e+00	4.08e+00	3.92e+00
1.00e+01	4.07e+00	4.18e+00	3.97e+00
2.50e+01	4.15e+00	4.30e+00	4.02e+00
5.00e+01	4.21e+00	4.40e+00	4.05e+00
1.00e+02	4.26e+00	4.49e+00	4.08e+00
5.00e+02	4.38e+00	4.71e+00	4.16e+00
1.00e+03	4.43e+00	4.80e+00	4.18e+00
2.50e+03	4.50e+00	4.92e+00	4.21e+00
4.00e+03	4.53e+00	4.98e+00	4.23e+00
1.00e+04	4.59e+00	5.10e+00	4.26e+00

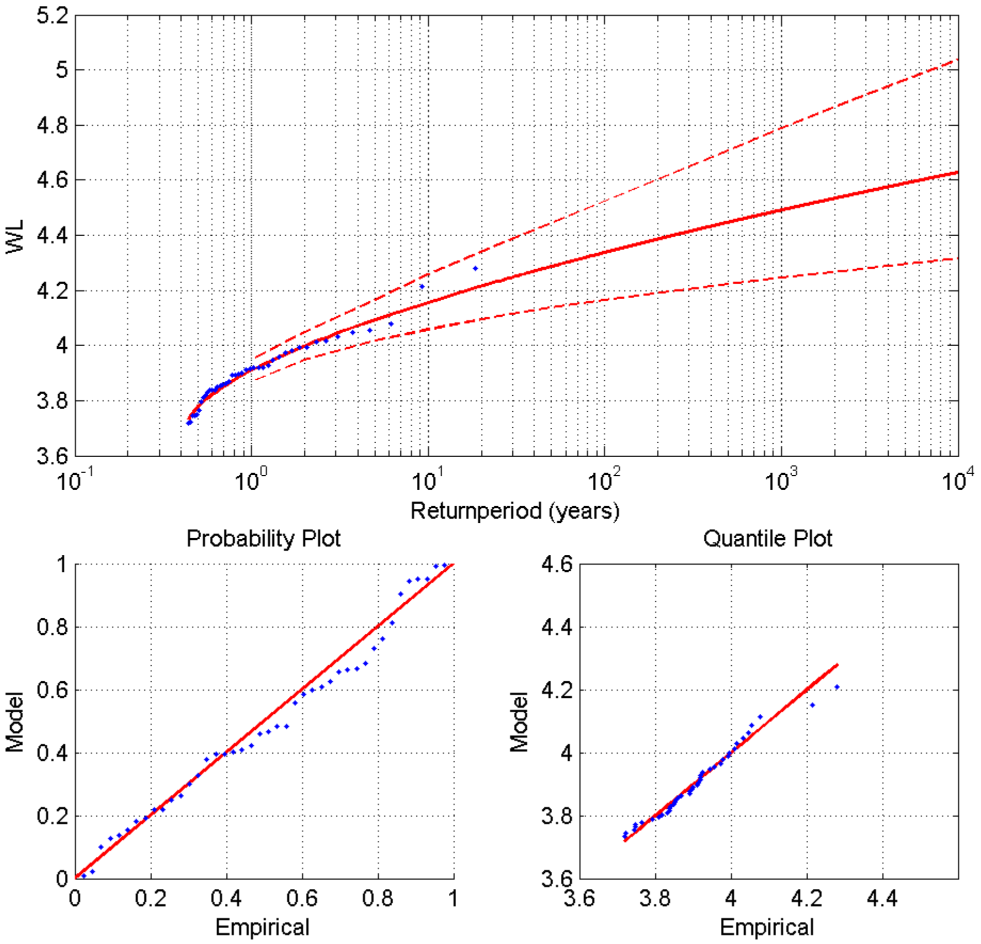
Point5

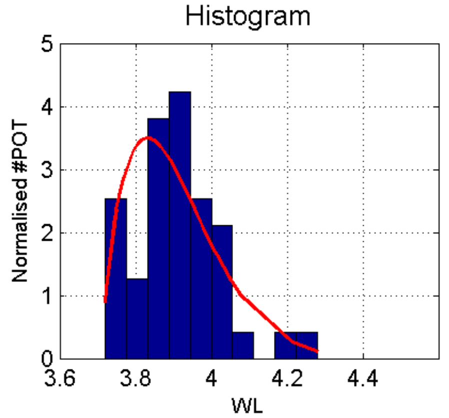
Cond. Weibull distribution

$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel: X = u + \left(\frac{1}{\lambda} log\left(\frac{T*k}{A}\right)\right)^{(1/\tau)}$$

$\tau = 1.6069$
$\lambda = 11.5769$
$u = 3.7123$
$A = 18.1512$
$k = 42$





T	X	UPCI	LOCI
1.00e+00	3.91e+00	3.95e+00	3.87e+00
2.00e+00	4.00e+00	4.05e+00	3.95e+00
5.00e+00	4.09e+00	4.17e+00	4.02e+00
1.00e+01	4.16e+00	4.26e+00	4.06e+00
2.50e+01	4.23e+00	4.37e+00	4.11e+00
5.00e+01	4.29e+00	4.45e+00	4.14e+00
1.00e+02	4.34e+00	4.52e+00	4.16e+00
5.00e+02	4.45e+00	4.71e+00	4.22e+00
1.00e+03	4.49e+00	4.79e+00	4.25e+00
2.50e+03	4.55e+00	4.89e+00	4.27e+00
4.00e+03	4.58e+00	4.94e+00	4.29e+00
1.00e+04	4.63e+00	5.04e+00	4.32e+00

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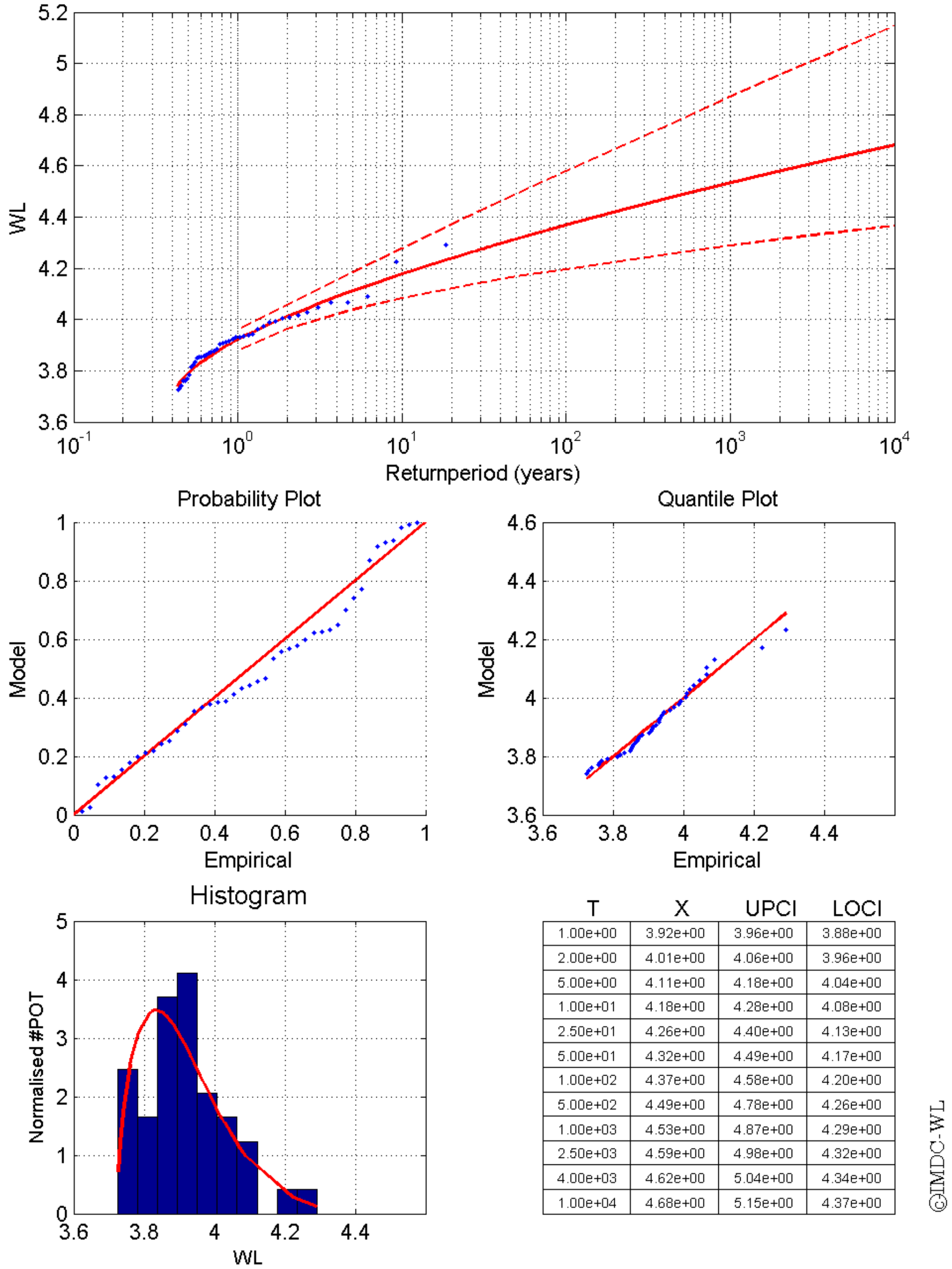
Point6

Cond. Weibull distribution

$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel: X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.5527$
$\lambda = 10.7556$
$u = 3.7223$
$A = 18.1512$
$k = 43$



T	X	UPCI	LOCI
1.00e+00	3.92e+00	3.96e+00	3.88e+00
2.00e+00	4.01e+00	4.06e+00	3.96e+00
5.00e+00	4.11e+00	4.18e+00	4.04e+00
1.00e+01	4.18e+00	4.28e+00	4.08e+00
2.50e+01	4.26e+00	4.40e+00	4.13e+00
5.00e+01	4.32e+00	4.49e+00	4.17e+00
1.00e+02	4.37e+00	4.58e+00	4.20e+00
5.00e+02	4.49e+00	4.78e+00	4.26e+00
1.00e+03	4.53e+00	4.87e+00	4.29e+00
2.50e+03	4.59e+00	4.98e+00	4.32e+00
4.00e+03	4.62e+00	5.04e+00	4.34e+00
1.00e+04	4.68e+00	5.15e+00	4.37e+00

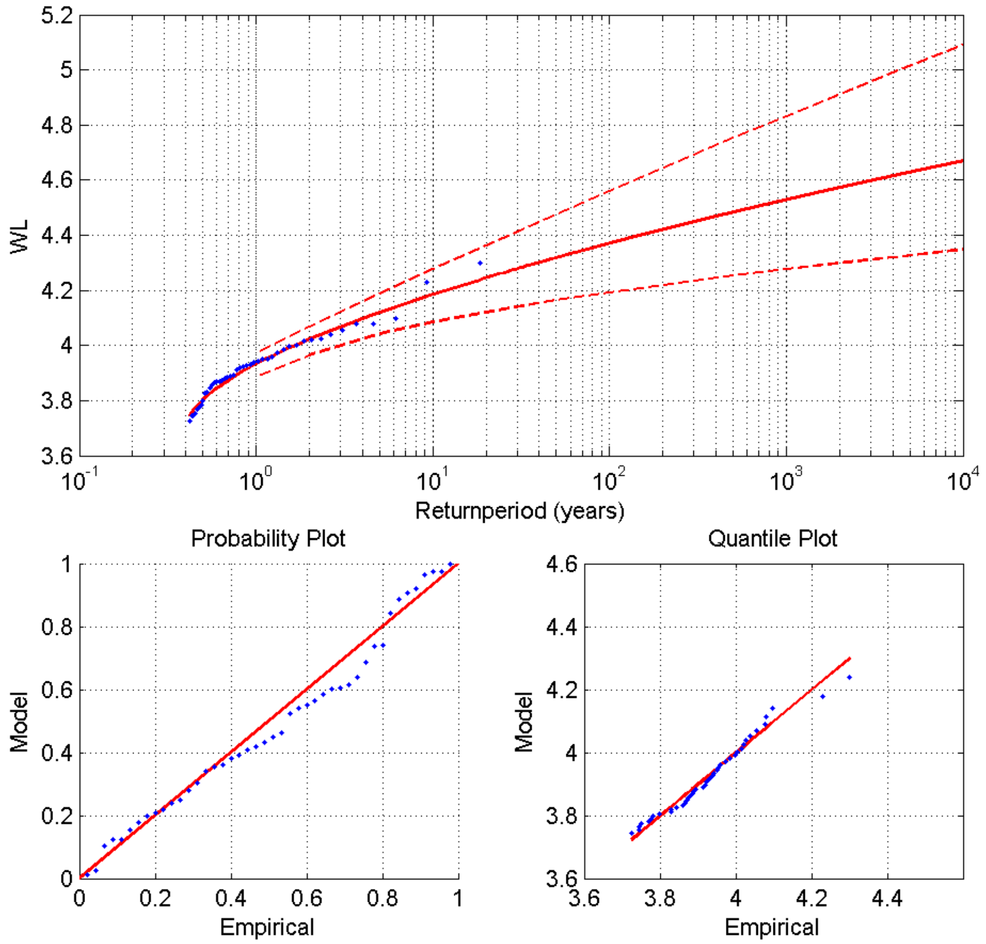
Point7

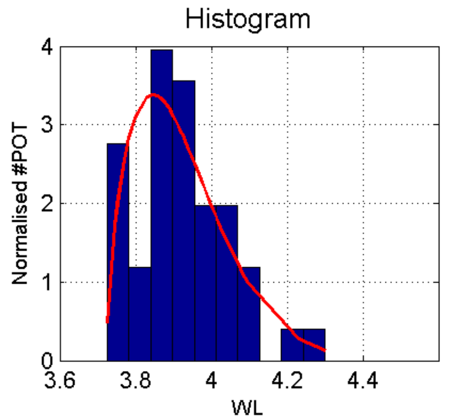
Cond. Weibull distribution

$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

$$Returnlevel: X = u + (\frac{1}{\lambda}log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.6087$
$\lambda = 11.0101$
$u = 3.7223$
$A = 18.1512$
$k = 44$





T	X	UPCI	LOCI
1.00e+00	3.93e+00	3.97e+00	3.89e+00
2.00e+00	4.02e+00	4.07e+00	3.96e+00
5.00e+00	4.12e+00	4.19e+00	4.04e+00
1.00e+01	4.19e+00	4.28e+00	4.08e+00
2.50e+01	4.26e+00	4.39e+00	4.13e+00
5.00e+01	4.32e+00	4.47e+00	4.16e+00
1.00e+02	4.37e+00	4.56e+00	4.19e+00
5.00e+02	4.48e+00	4.75e+00	4.25e+00
1.00e+03	4.53e+00	4.83e+00	4.28e+00
2.50e+03	4.59e+00	4.94e+00	4.31e+00
4.00e+03	4.62e+00	4.99e+00	4.32e+00
1.00e+04	4.67e+00	5.09e+00	4.35e+00

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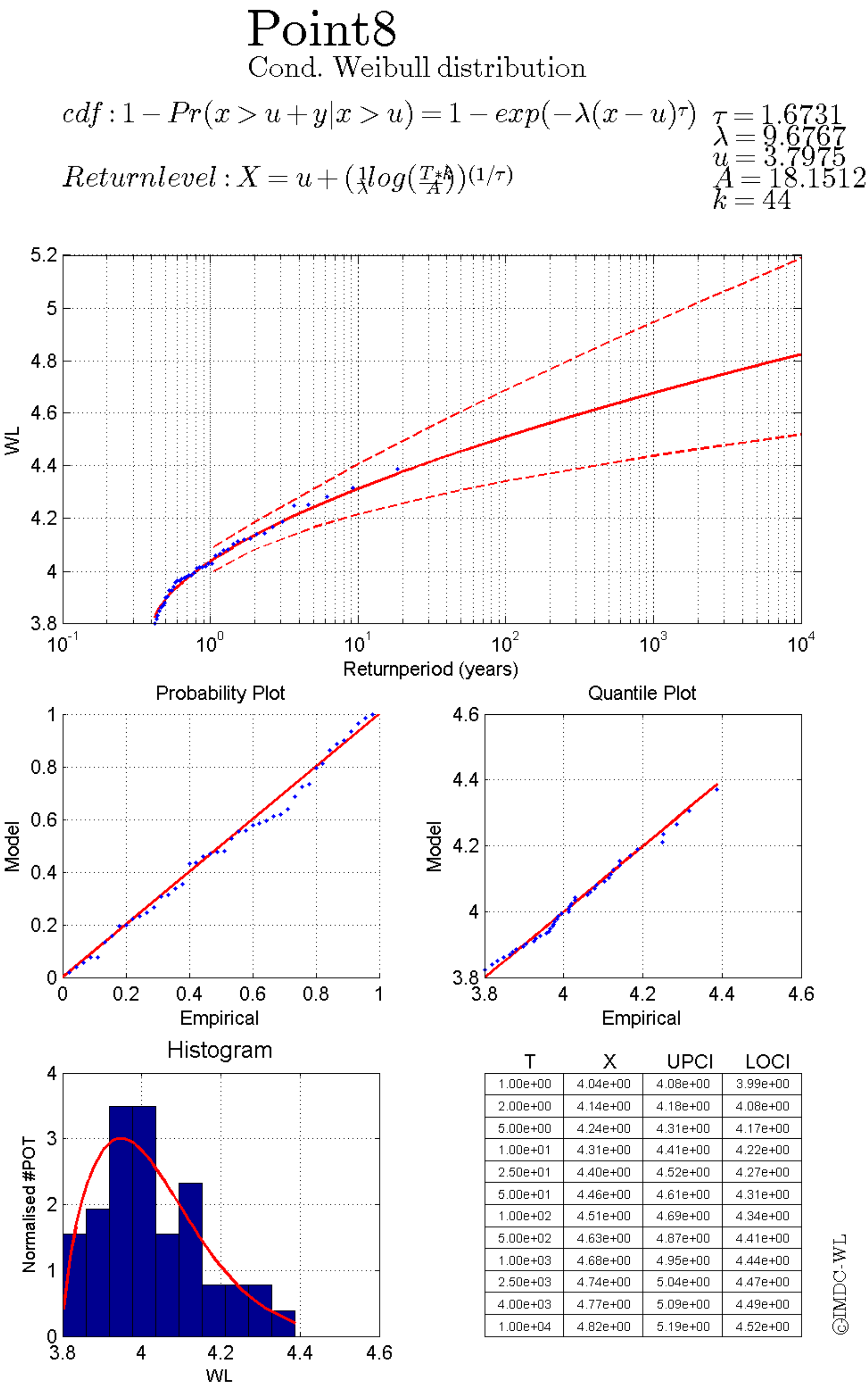


T	X	UPCI	LOCI
1.00e+00	4.04e+00	4.08e+00	3.99e+00
2.00e+00	4.14e+00	4.18e+00	4.08e+00
5.00e+00	4.24e+00	4.31e+00	4.17e+00
1.00e+01	4.31e+00	4.41e+00	4.22e+00
2.50e+01	4.40e+00	4.52e+00	4.27e+00
5.00e+01	4.46e+00	4.61e+00	4.31e+00
1.00e+02	4.51e+00	4.69e+00	4.34e+00
5.00e+02	4.63e+00	4.87e+00	4.41e+00
1.00e+03	4.68e+00	4.95e+00	4.44e+00
2.50e+03	4.74e+00	5.04e+00	4.47e+00
4.00e+03	4.77e+00	5.09e+00	4.49e+00
1.00e+04	4.82e+00	5.19e+00	4.52e+00

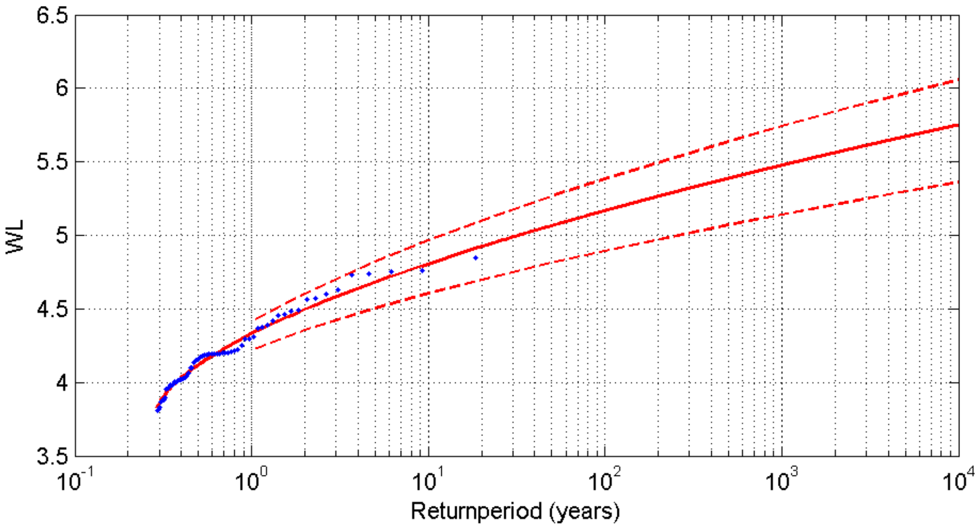
Point9

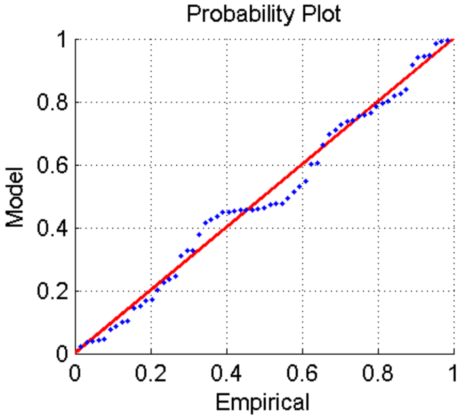
Cond. Weibull distribution

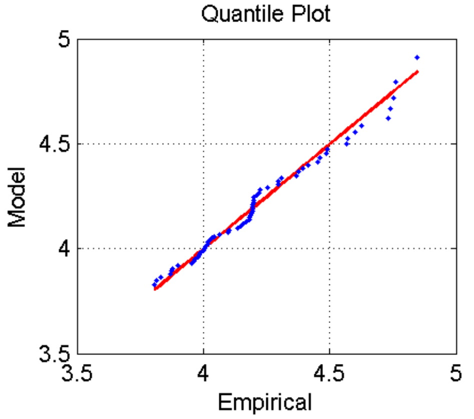
$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

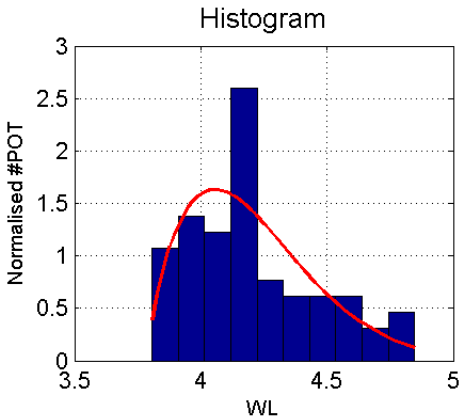
$$Returnlevel: X = u + (\frac{1}{\lambda} log(\frac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.6439$
$\lambda = 3.4572$
$u = 3.7908$
$A = 18.1512$
$k = 63$









T	X	UPCI	LOCI
1.00e+00	4.33e+00	4.41e+00	4.22e+00
2.00e+00	4.49e+00	4.60e+00	4.35e+00
5.00e+00	4.68e+00	4.82e+00	4.50e+00
1.00e+01	4.81e+00	4.97e+00	4.60e+00
2.50e+01	4.96e+00	5.14e+00	4.73e+00
5.00e+01	5.07e+00	5.27e+00	4.81e+00
1.00e+02	5.17e+00	5.38e+00	4.89e+00
5.00e+02	5.39e+00	5.64e+00	5.07e+00
1.00e+03	5.48e+00	5.74e+00	5.14e+00
2.50e+03	5.59e+00	5.87e+00	5.23e+00
4.00e+03	5.64e+00	5.94e+00	5.28e+00
1.00e+04	5.75e+00	6.06e+00	5.36e+00

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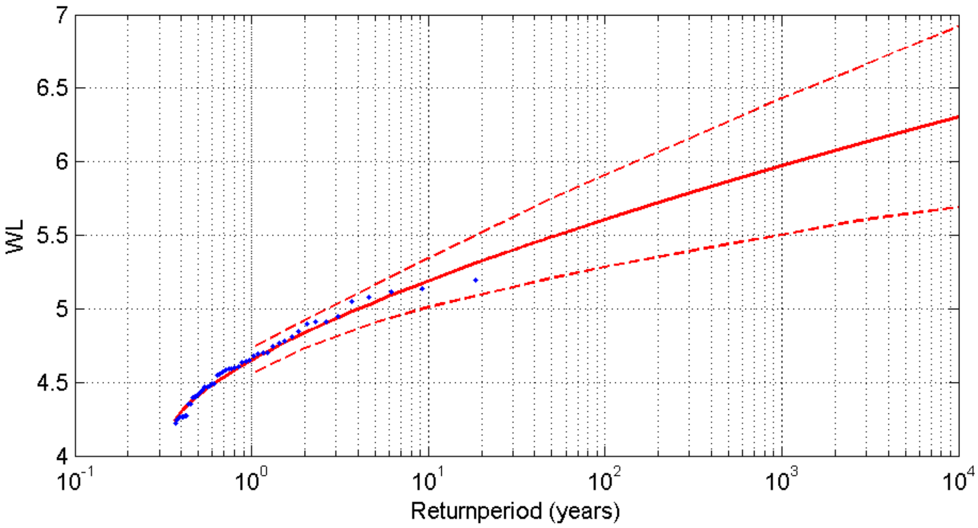
Point10

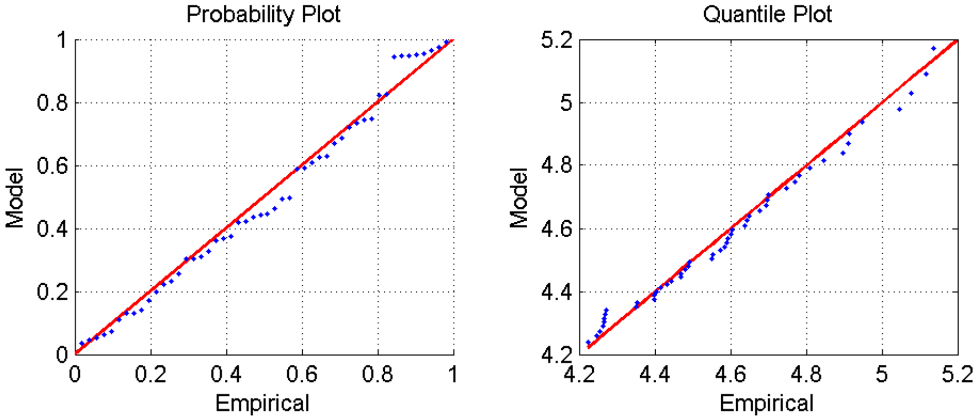
Cond. Weibull distribution

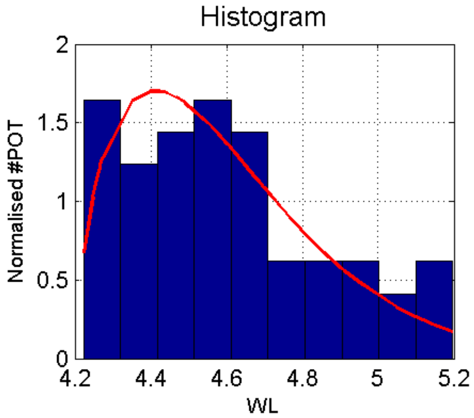
$$cdf : 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x - u)^{\tau})$$

$$Returnlevel : X = u + (\tfrac{1}{\lambda} log(\tfrac{T*k}{A}))^{(1/\tau)}$$

$\tau = 1.4802$
$\lambda = 3.421$
$u = 4.2082$
$A = 18.1512$
$k = 50$







T	X	UPCI	LOCI
1.00e+00	4.65e+00	4.73e+00	4.56e+00
2.00e+00	4.83e+00	4.92e+00	4.73e+00
5.00e+00	5.04e+00	5.16e+00	4.91e+00
1.00e+01	5.19e+00	5.35e+00	5.01e+00
2.50e+01	5.36e+00	5.58e+00	5.12e+00
5.00e+01	5.49e+00	5.75e+00	5.21e+00
1.00e+02	5.61e+00	5.91e+00	5.28e+00
5.00e+02	5.87e+00	6.27e+00	5.44e+00
1.00e+03	5.97e+00	6.43e+00	5.50e+00
2.50e+03	6.11e+00	6.62e+00	5.59e+00
4.00e+03	6.17e+00	6.73e+00	5.63e+00
1.00e+04	6.30e+00	6.92e+00	5.69e+00

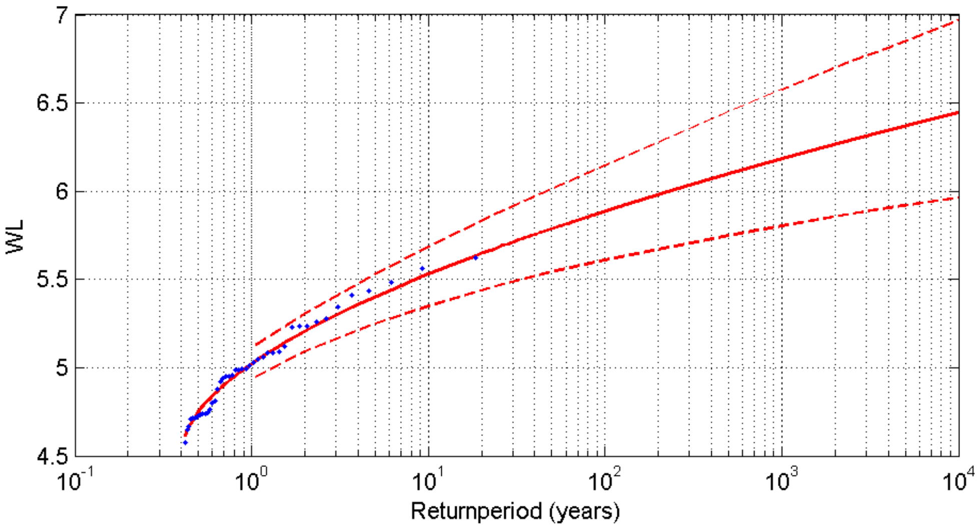
Point11

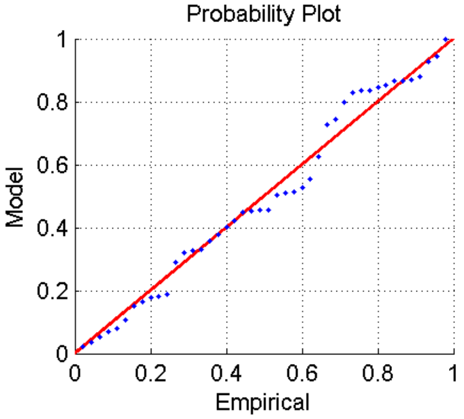
Cond. Weibull distribution

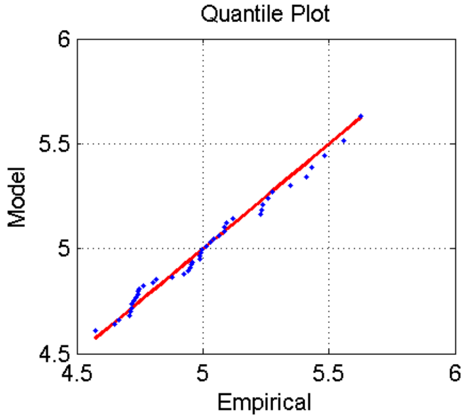
$$cdf: 1 - Pr(x > u + y | x > u) = 1 - exp(-\lambda(x-u)^{\tau})$$

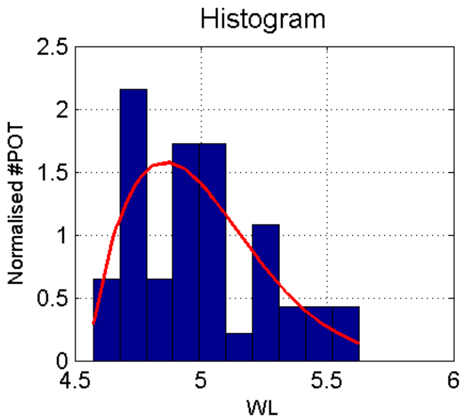
$$Returnlevel: X = u + \left(\frac{1}{\lambda} log\left(\frac{T * k}{A}\right)\right)^{(1/\tau)}$$

$\tau = 1.7363$
$\lambda = 3.3434$
$u = 4.5551$
$A = 18.1512$
$k = 44$

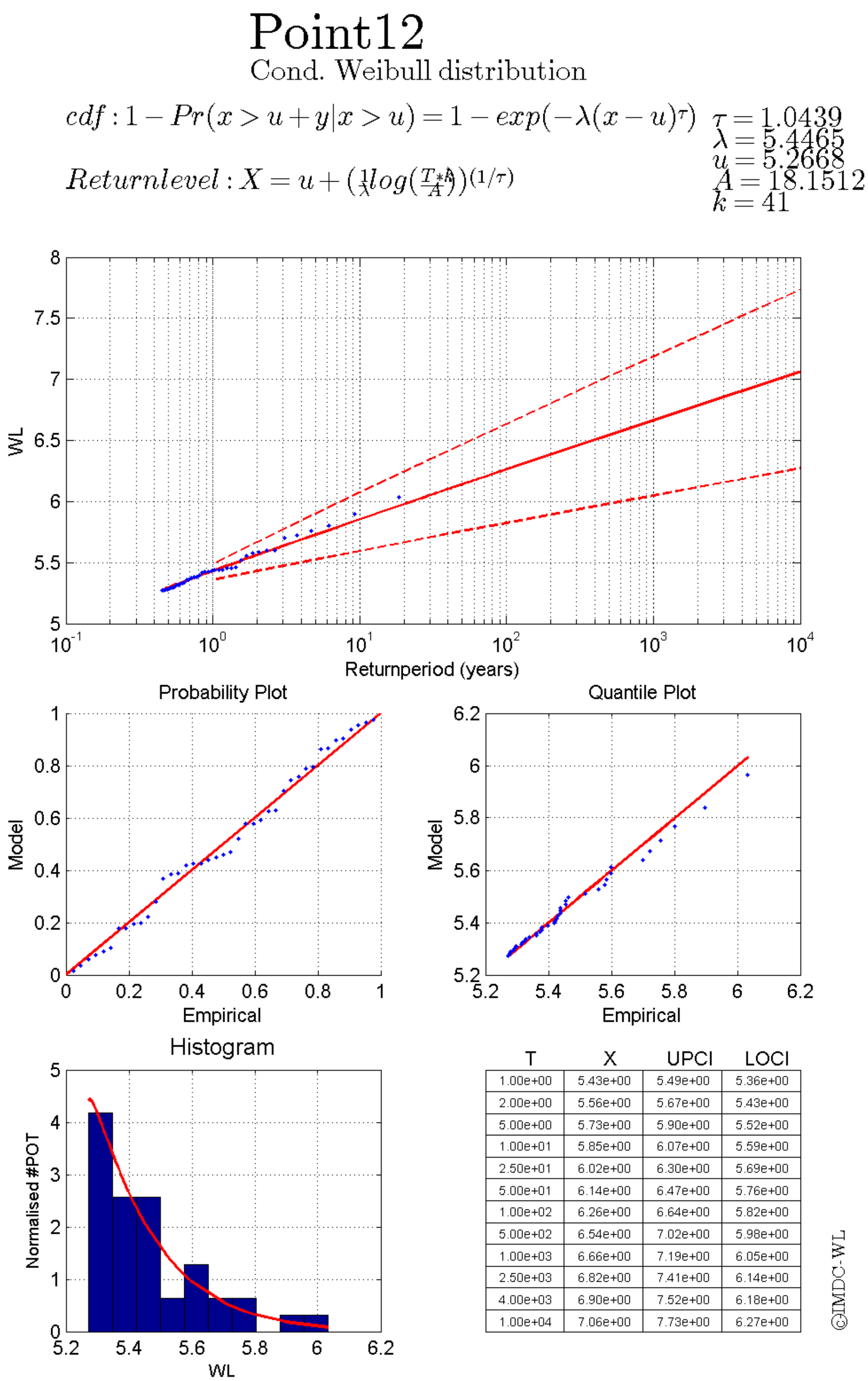








T	X	UPCI	LOCI
1.00e+00	5.02e+00	5.11e+00	4.94e+00
2.00e+00	5.20e+00	5.30e+00	5.09e+00
5.00e+00	5.40e+00	5.53e+00	5.25e+00
1.00e+01	5.53e+00	5.68e+00	5.35e+00
2.50e+01	5.68e+00	5.88e+00	5.47e+00
5.00e+01	5.79e+00	6.02e+00	5.54e+00
1.00e+02	5.89e+00	6.15e+00	5.61e+00
5.00e+02	6.10e+00	6.45e+00	5.75e+00
1.00e+03	6.18e+00	6.58e+00	5.80e+00
2.50e+03	6.29e+00	6.74e+00	5.87e+00
4.00e+03	6.34e+00	6.81e+00	5.91e+00
1.00e+04	6.44e+00	6.97e+00	5.96e+00



T	X	UPCI	LOCI
1.00e+00	5.43e+00	5.49e+00	5.36e+00
2.00e+00	5.56e+00	5.67e+00	5.43e+00
5.00e+00	5.73e+00	5.90e+00	5.52e+00
1.00e+01	5.85e+00	6.07e+00	5.59e+00
2.50e+01	6.02e+00	6.30e+00	5.69e+00
5.00e+01	6.14e+00	6.47e+00	5.76e+00
1.00e+02	6.26e+00	6.64e+00	5.82e+00
5.00e+02	6.54e+00	7.02e+00	5.98e+00
1.00e+03	6.66e+00	7.19e+00	6.05e+00
2.50e+03	6.82e+00	7.41e+00	6.14e+00
4.00e+03	6.90e+00	7.52e+00	6.18e+00
1.00e+04	7.06e+00	7.73e+00	6.27e+00

Appendix G: Validation

Return level-Return period

Figure G-1: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 2, the red line is the distribution fitted through the historical POT values

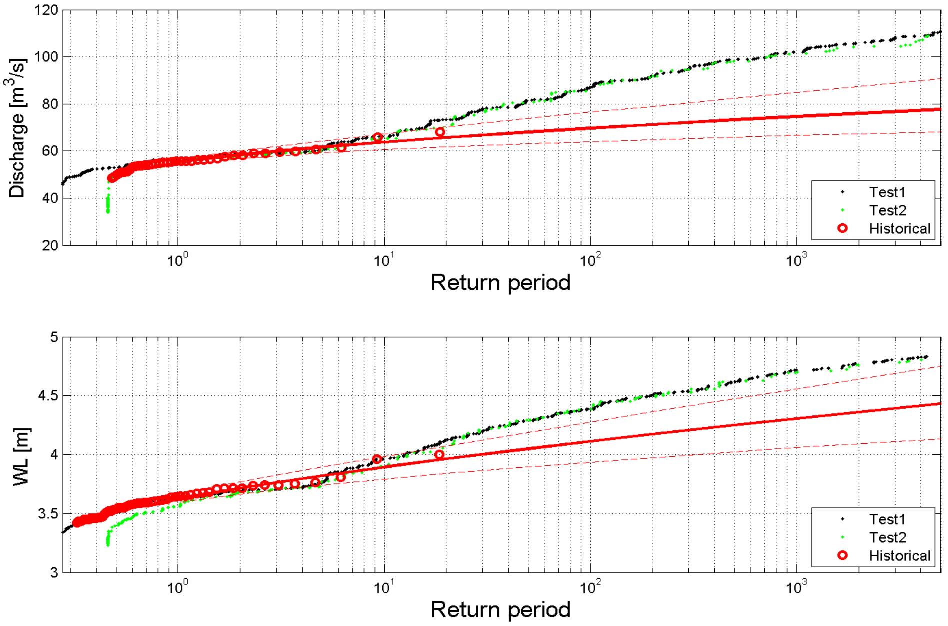


Figure G-2: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 2 (Zoom), the red line is the distribution fitted through the historical POT values

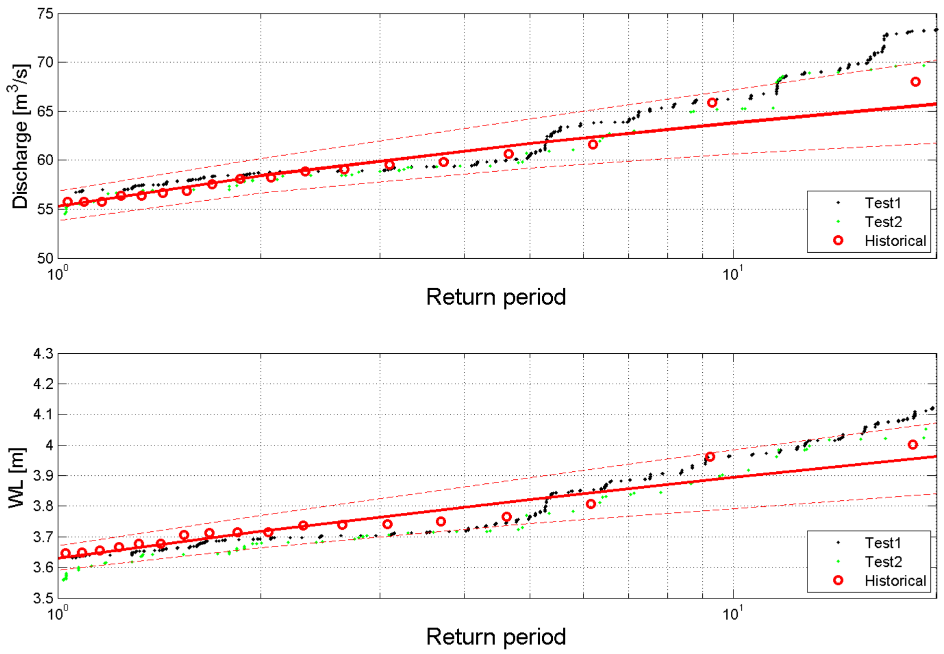


Figure G-3: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 3, the red line is the distribution fitted through the historical POT values

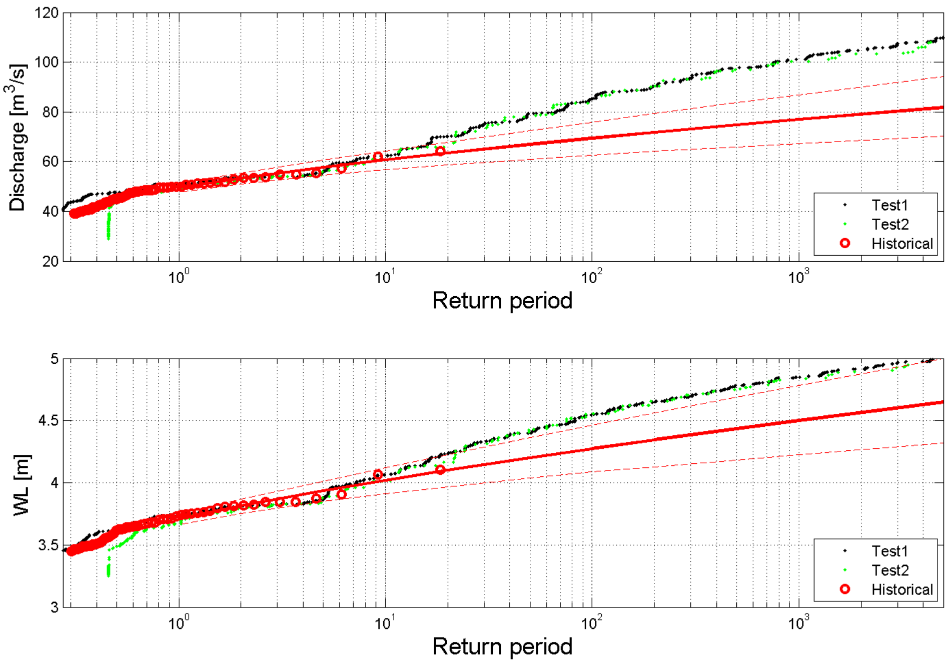


Figure G-4: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 3 (Zoom), the red line is the distribution fitted through the historical POT values

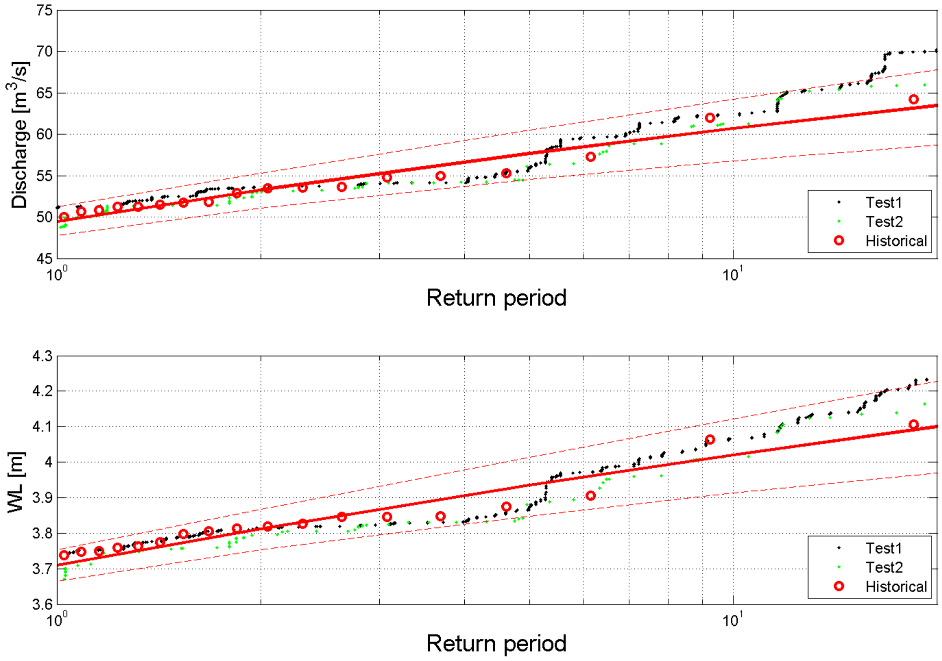


Figure G-5: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 4, the red line is the distribution fitted through the historical POT values

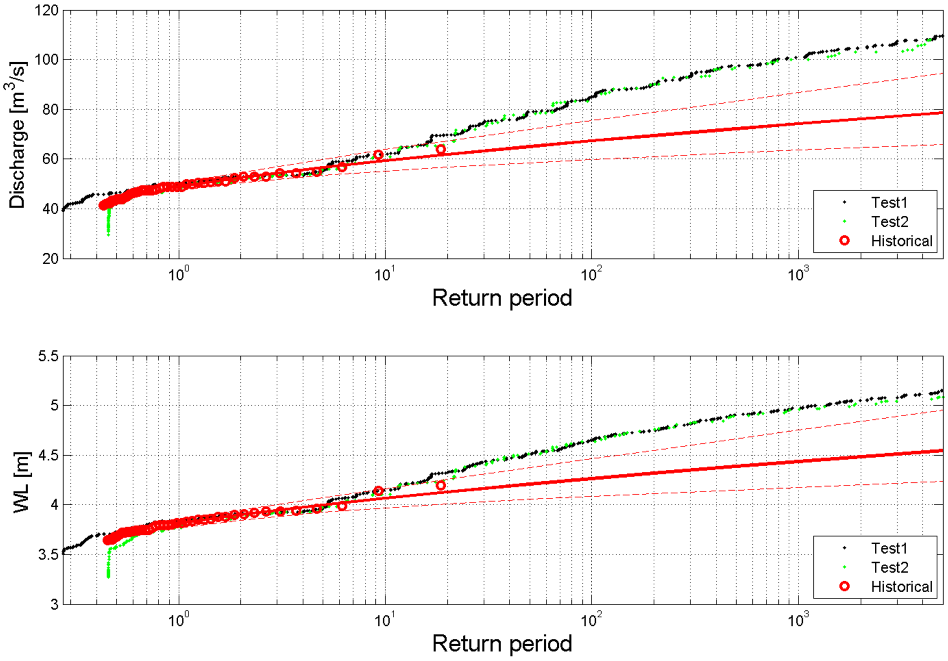


Figure G-6: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 4 (Zoom), the red line is the distribution fitted through the historical POT values

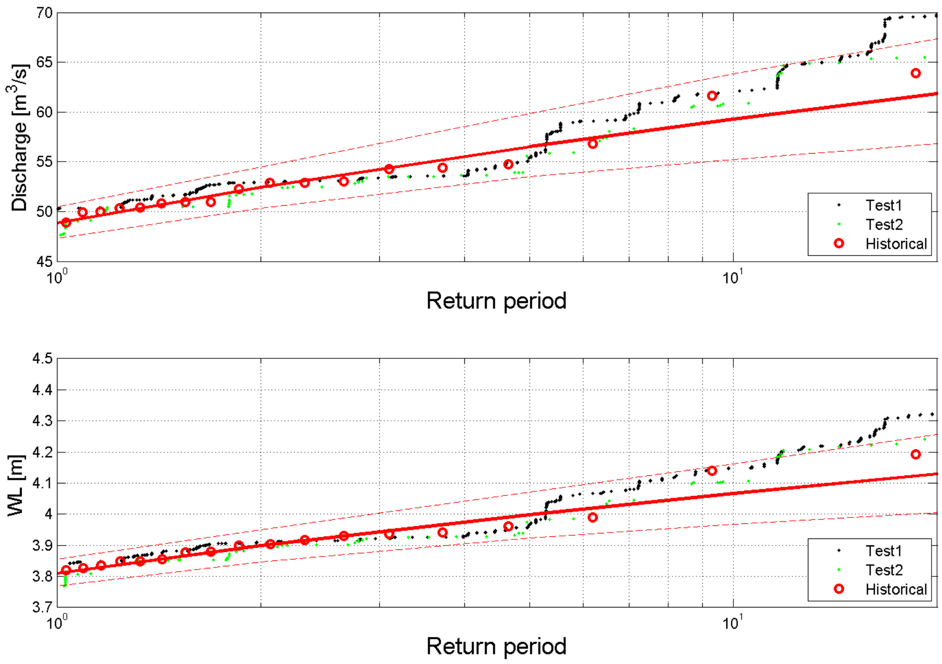


Figure G-7: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 5, the red line is the distribution fitted through the historical POT values

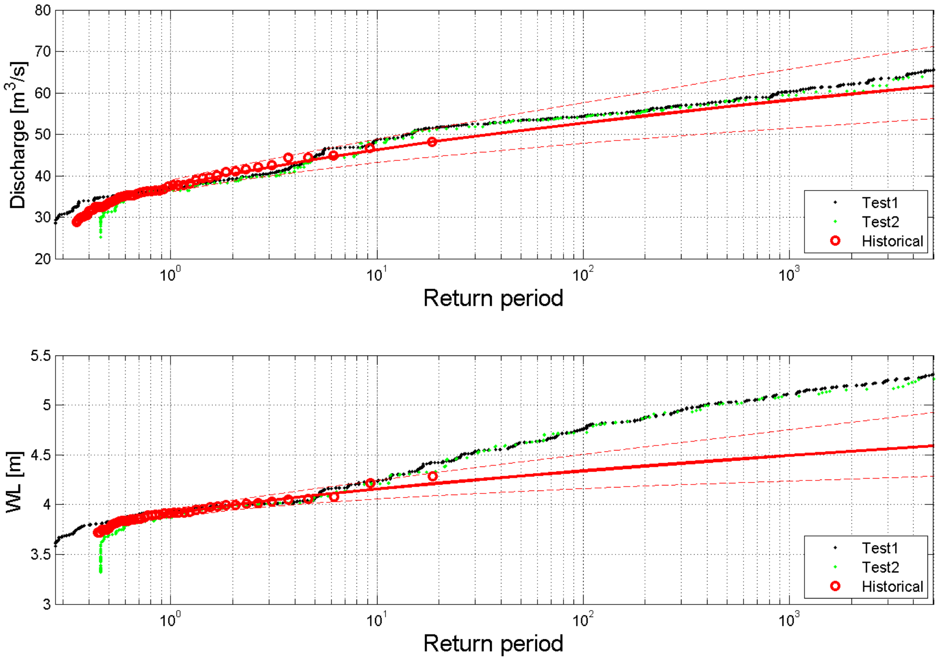


Figure G-8: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 5 (Zoom), the red line is the distribution fitted through the historical POT values

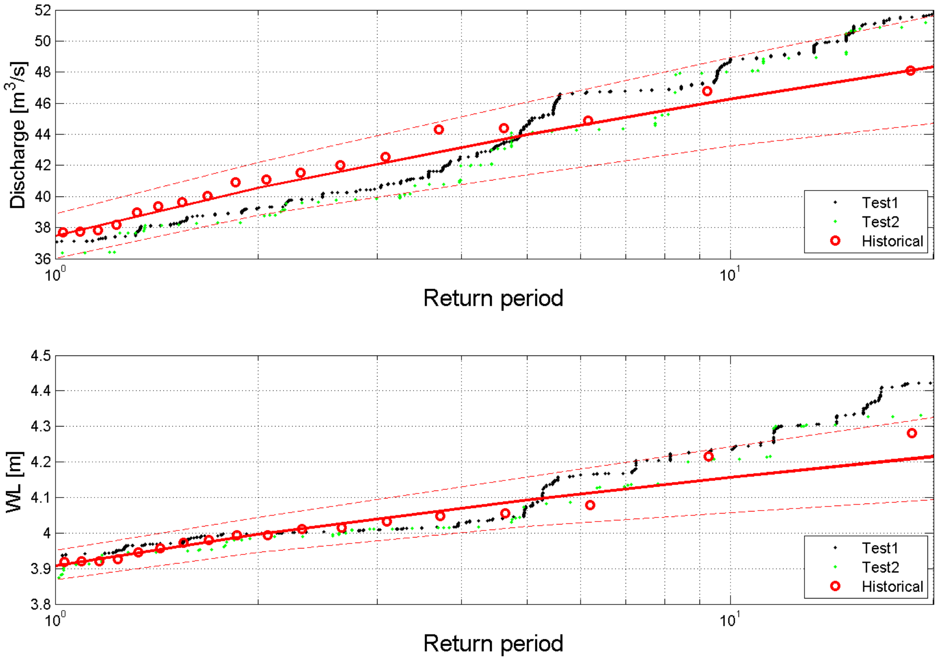


Figure G-9: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 6, the red line is the distribution fitted through the historical POT values

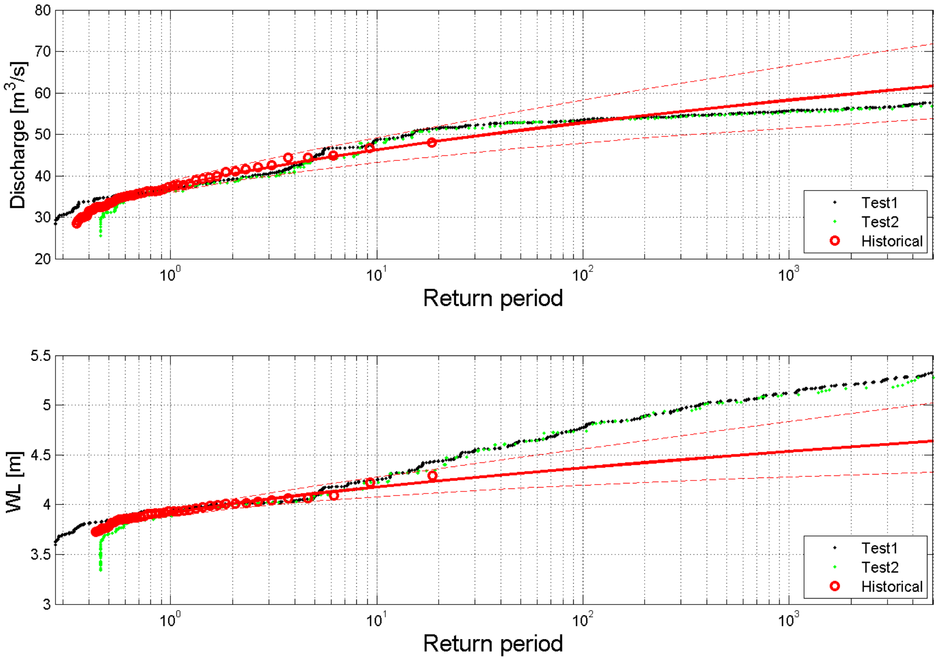


Figure G-10: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 6 (Zoom), the red line is the distribution fitted through the historical POT values

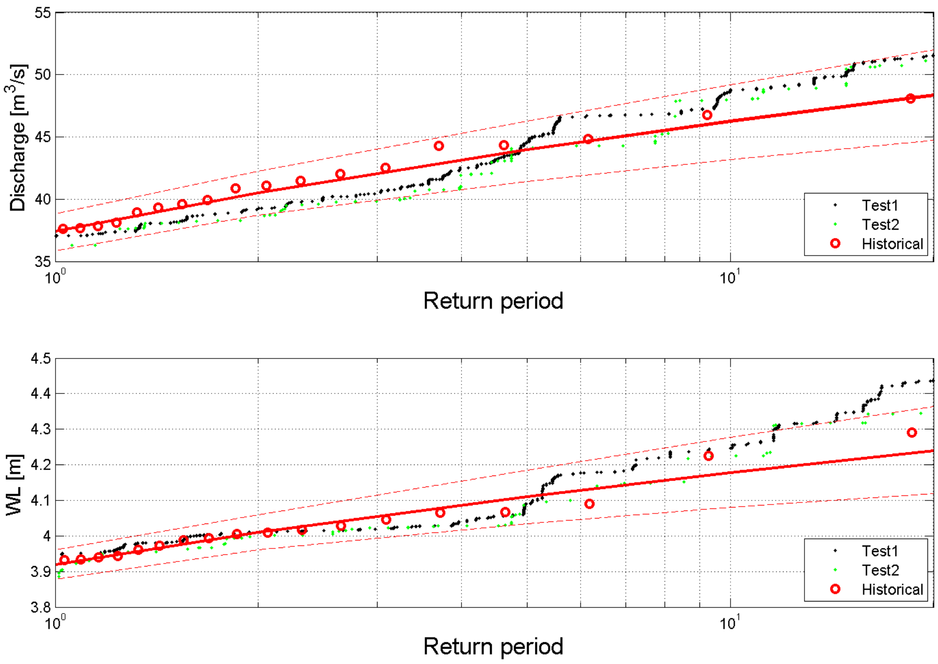


Figure G-11: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 7, the red line is the distribution fitted through the historical POT values

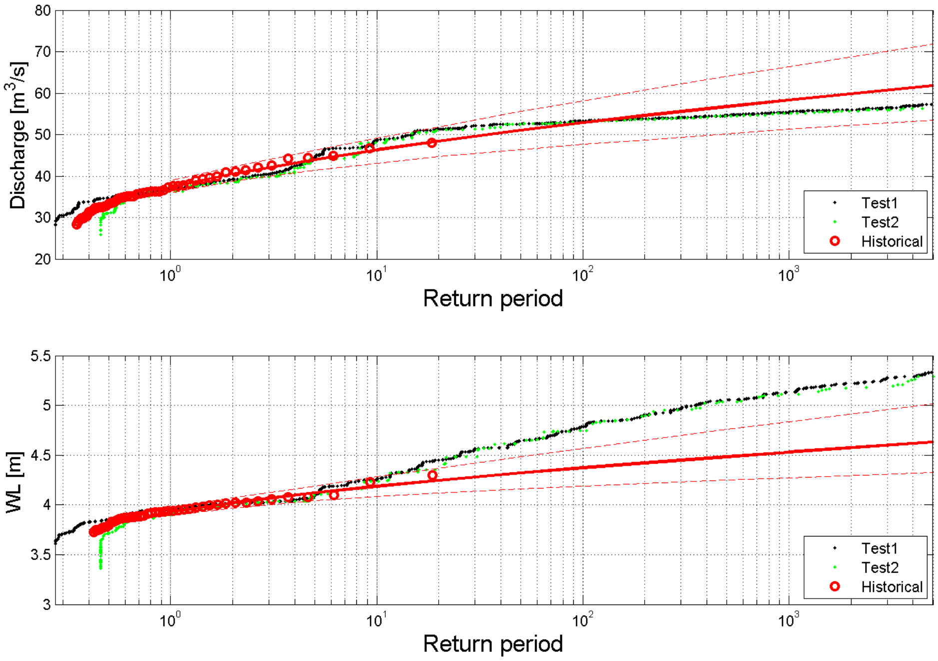


Figure G-12: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 7 (Zoom), the red line is the distribution fitted through the historical POT values

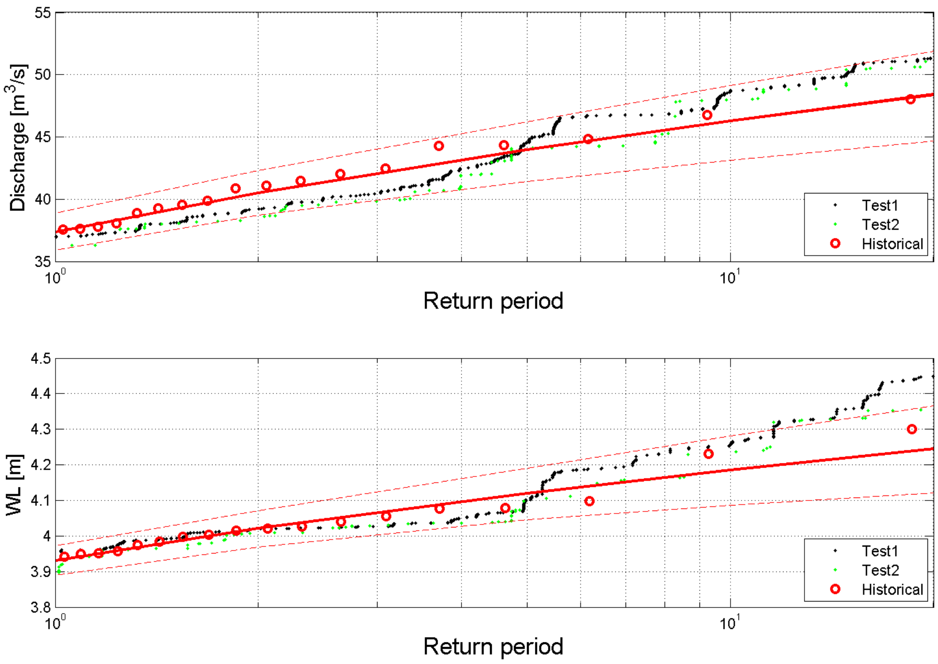


Figure G-13: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 8, the red line is the distribution fitted through the historical POT values

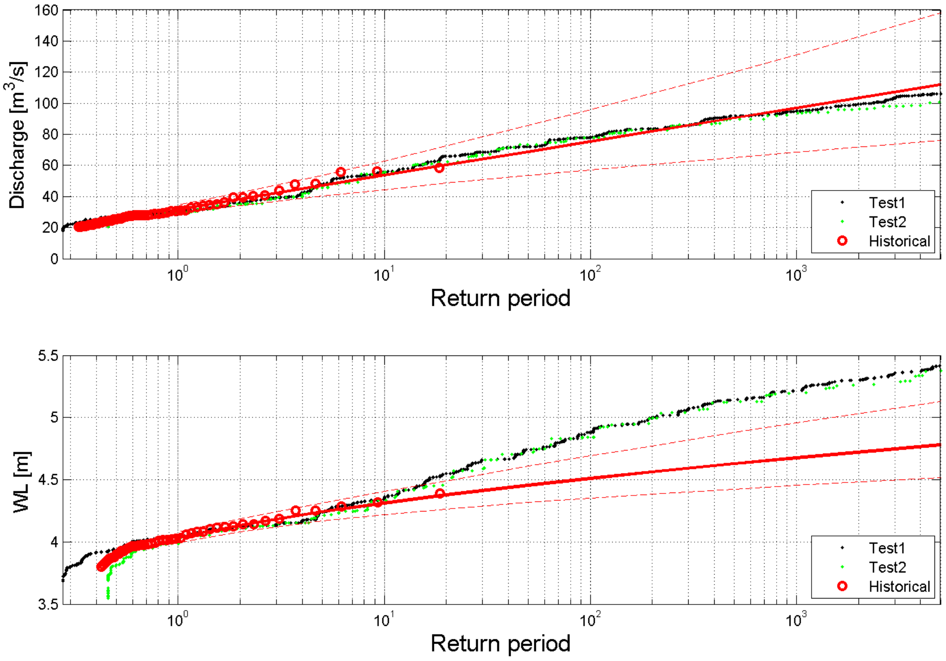


Figure G-14: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 8 (Zoom), the red line is the distribution fitted through the historical POT values

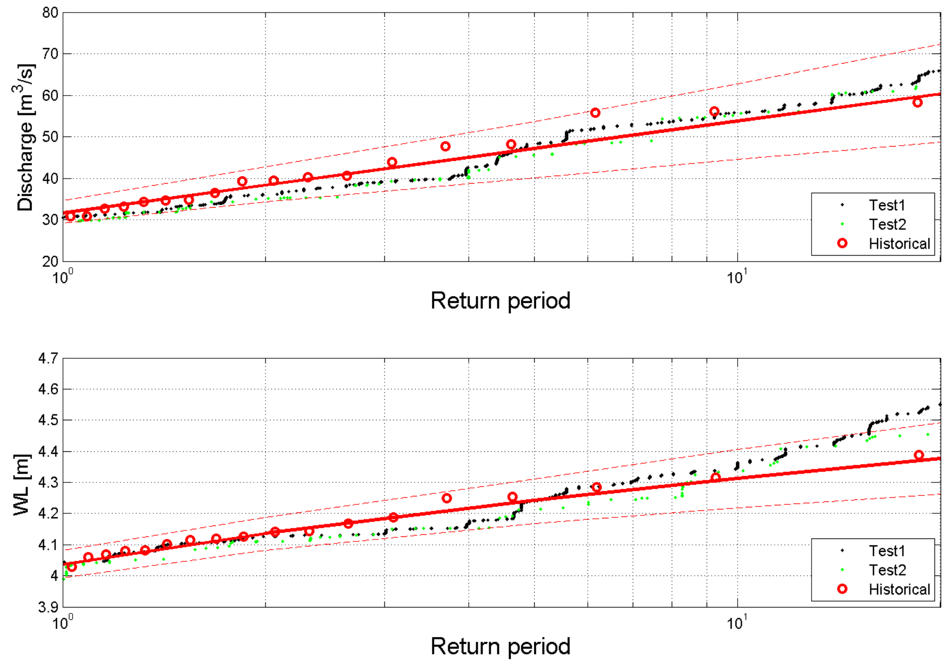


Figure G-15: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 9,
the red line is the distribution fitted through the historical POT values

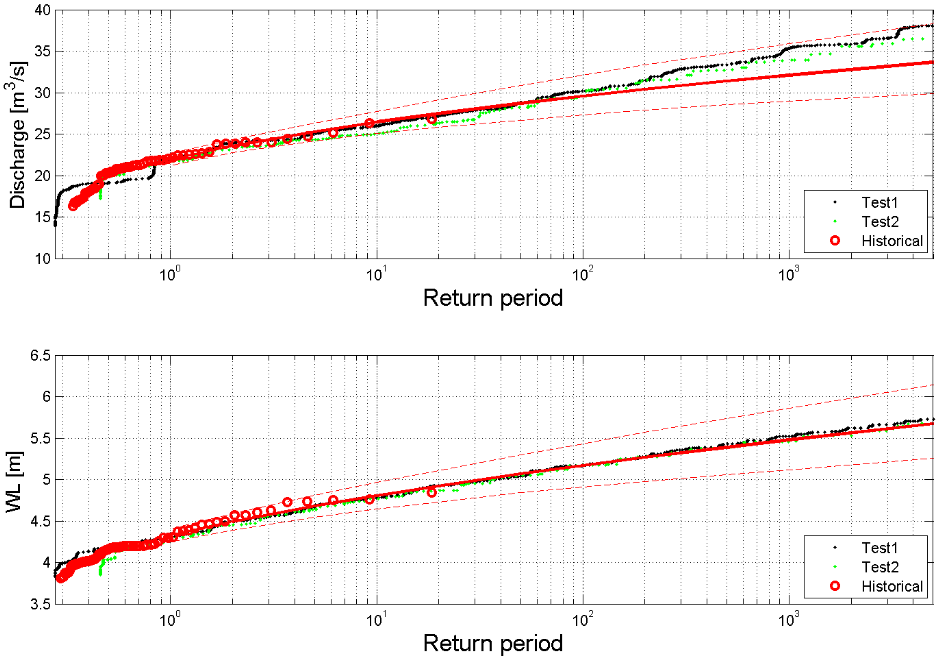


Figure G-16: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 9 (Zoom),
the red line is the distribution fitted through the historical POT values

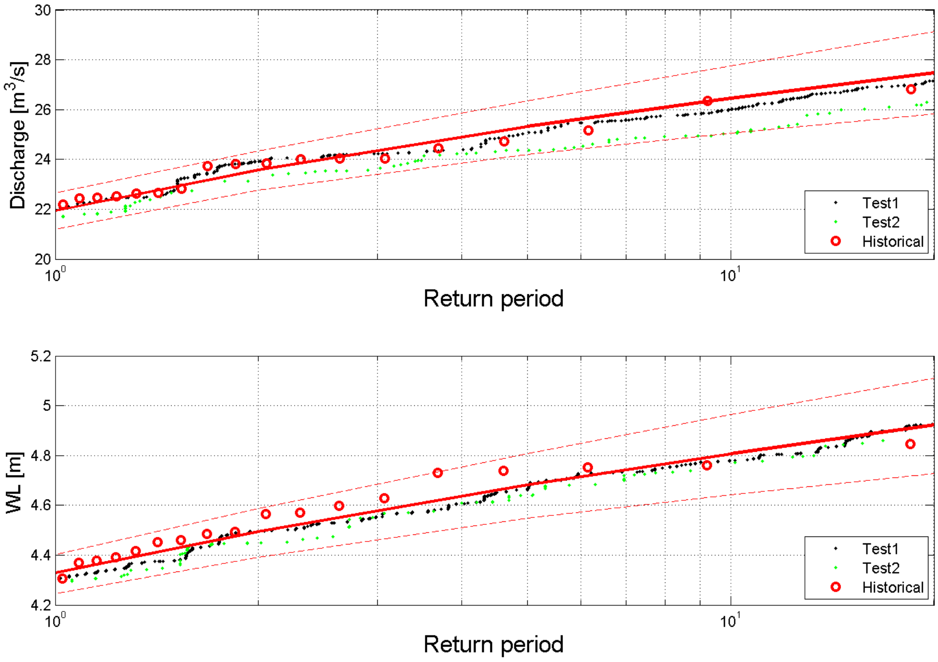


Figure G-17: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 10, the red line is the distribution fitted through the historical POT values

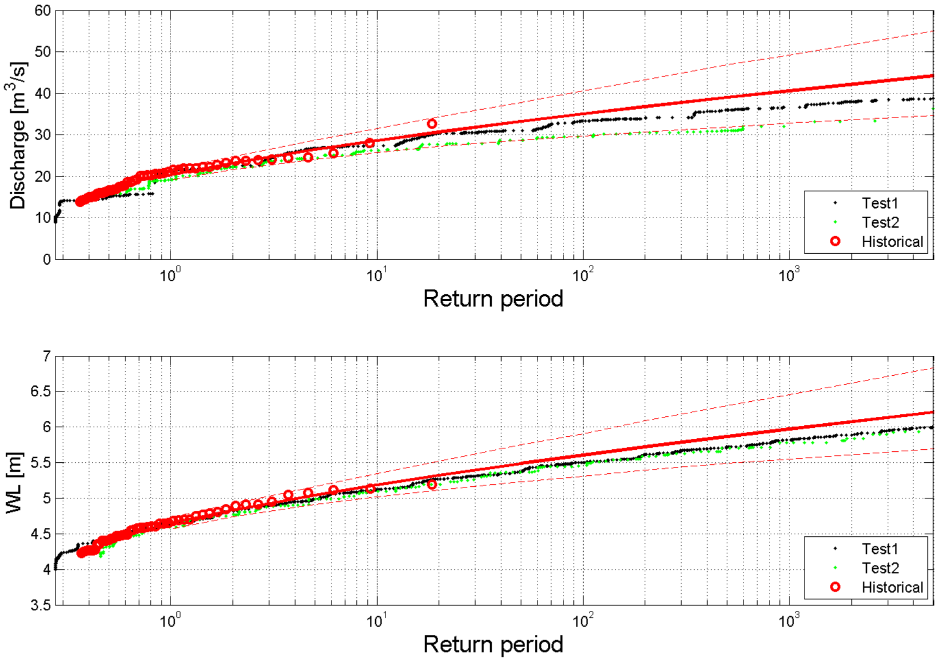


Figure G-18:Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 10 (Zoom), the red line is the distribution fitted through the historical POT values

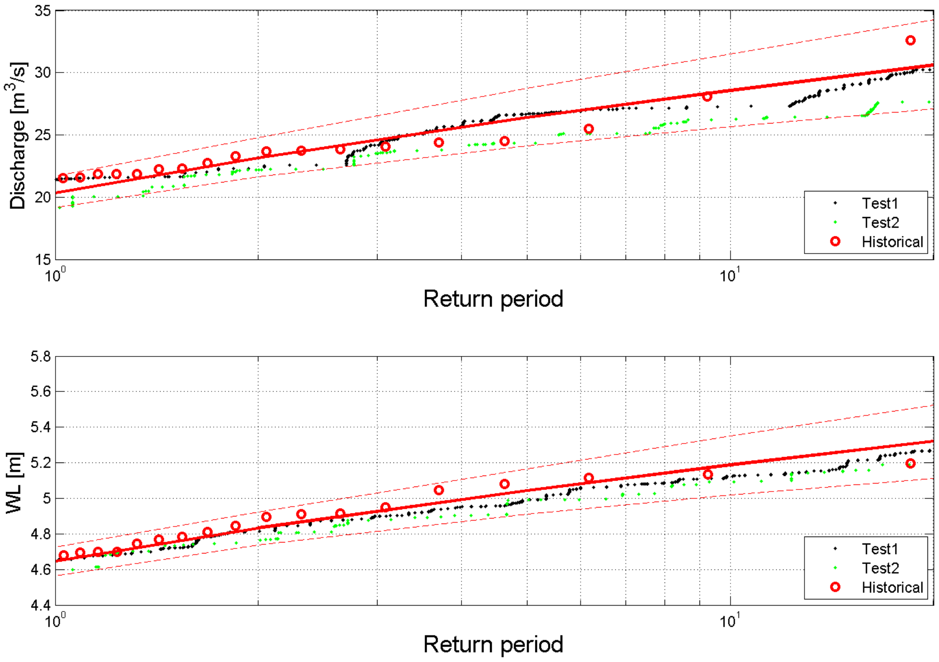


Figure G-19: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 11, the red line is the distribution fitted through the historical POT values

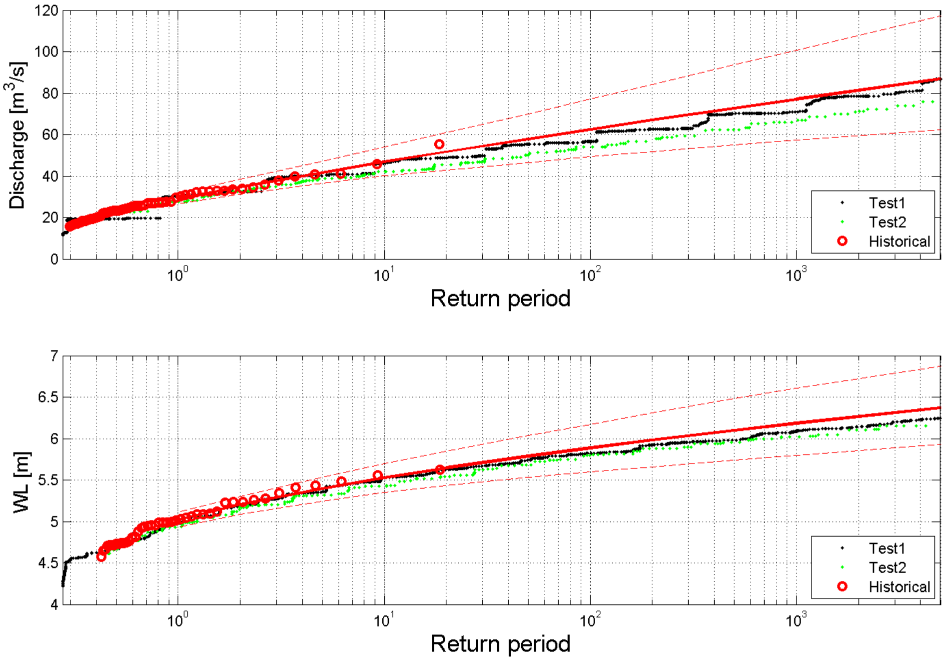


Figure G-20: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 11 (Zoom), the red line is the distribution fitted through the historical POT values

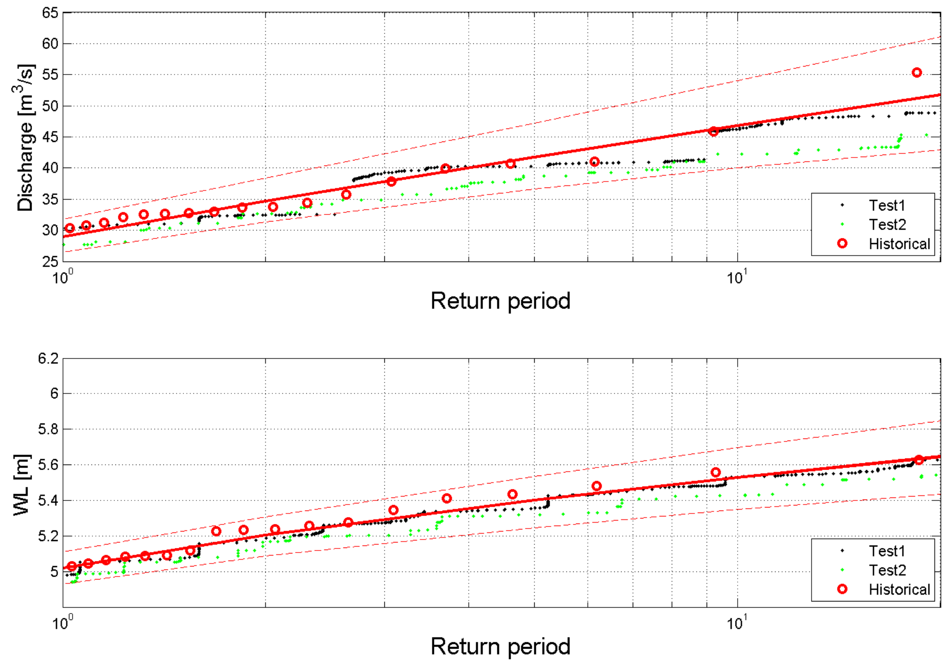


Figure G-21: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 12, the red line is the distribution fitted through the historical POT values

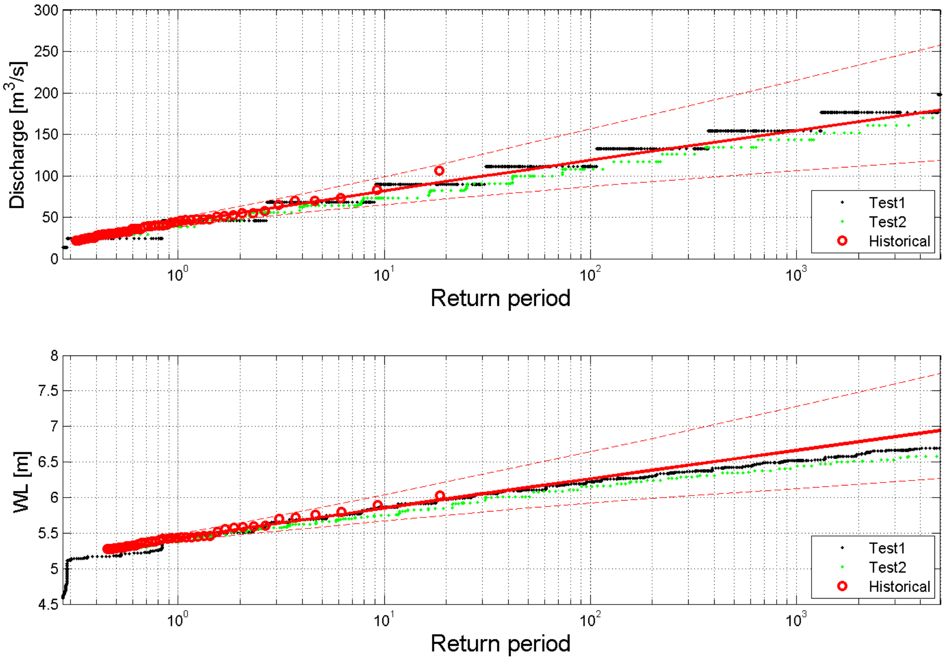
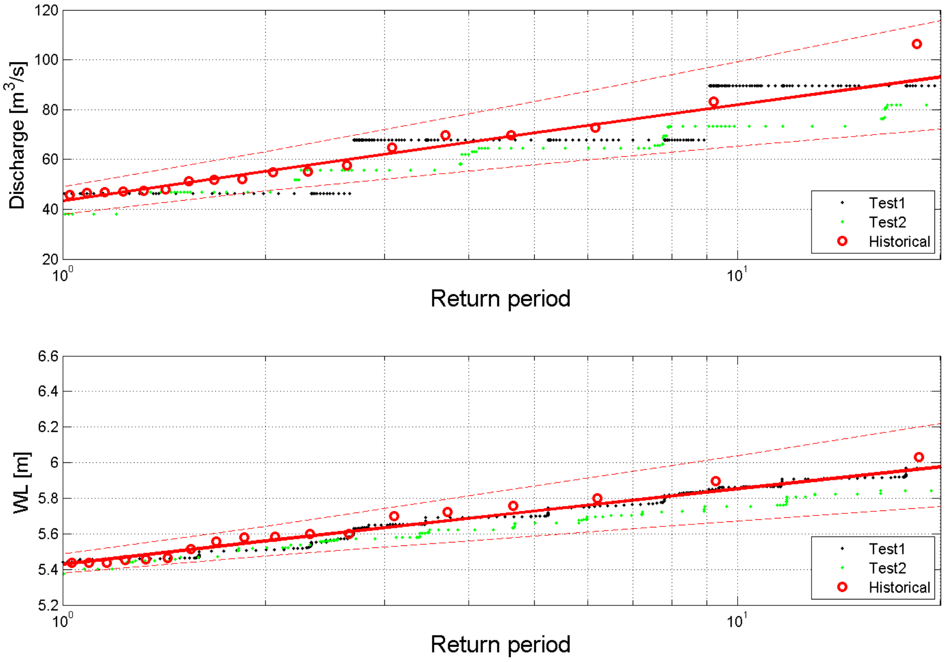


Figure G-22: Comparison of the tests with partial (test 1) and full (test2) dependency of discharges for the Yser in Roesbrugge and the tributaries with the historical run at the Yser checkpoint 12 (Zoom), the red line is the distribution fitted through the historical POT values



Time of peak

Figure G-23: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 2 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

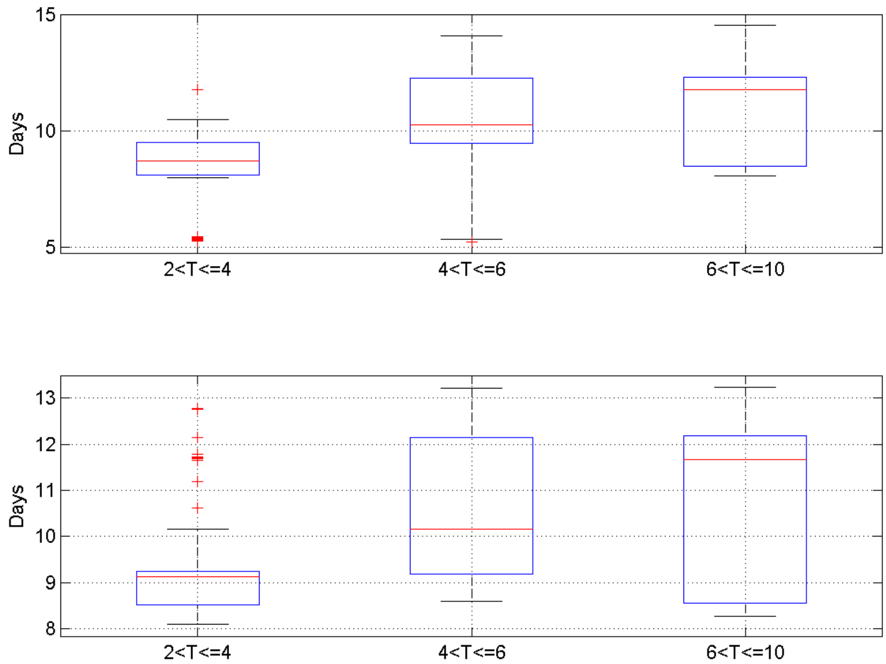


Figure G-24: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 4 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries

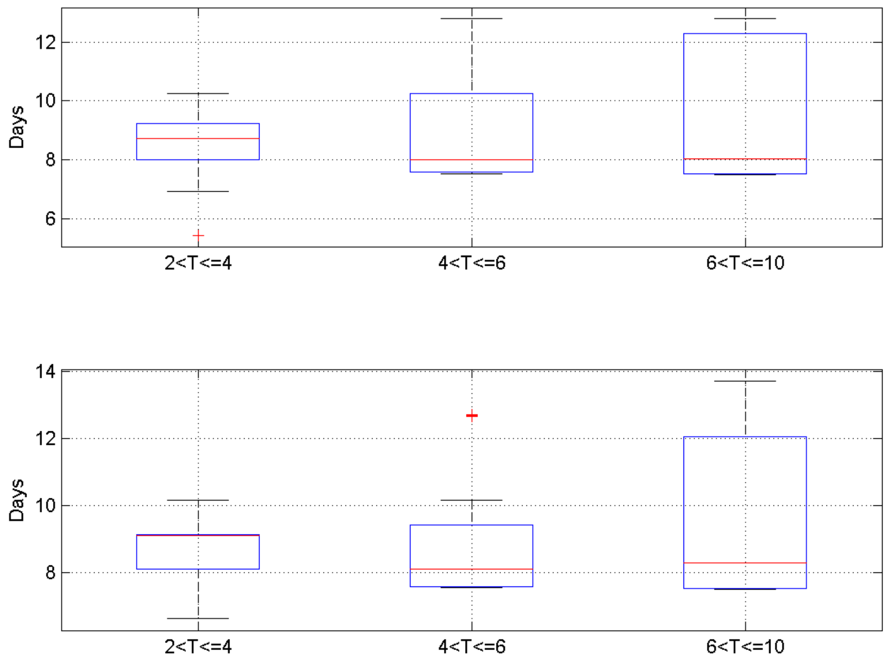
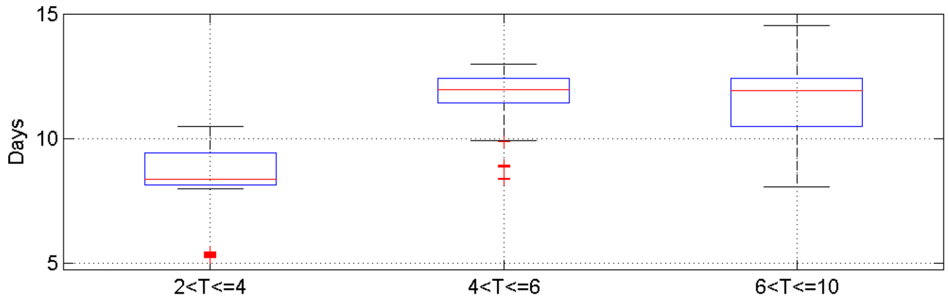


Figure G-25: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 3 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries



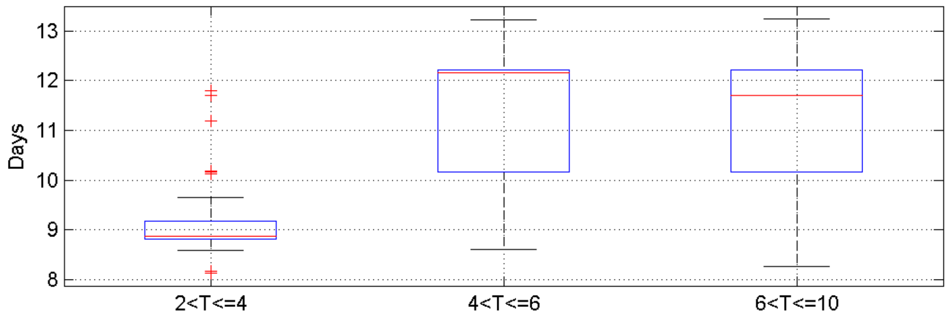
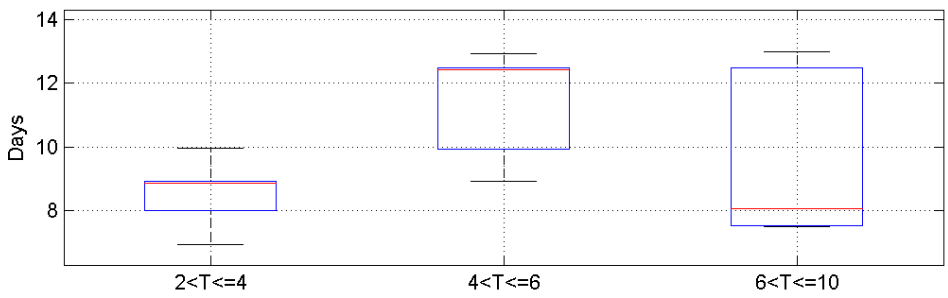


Figure G-26: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 3 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries



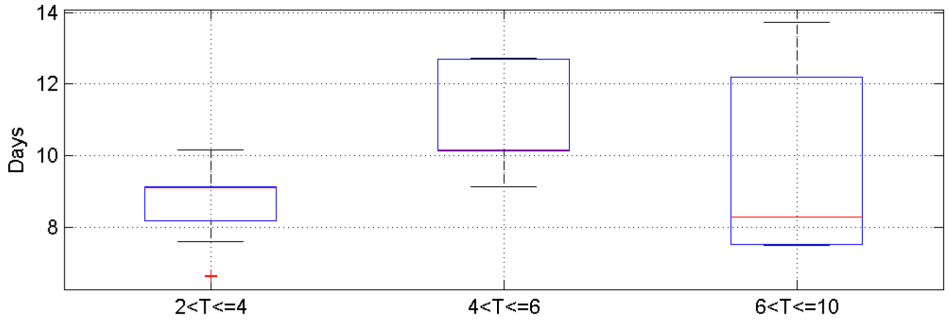


Figure G-27: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 4 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

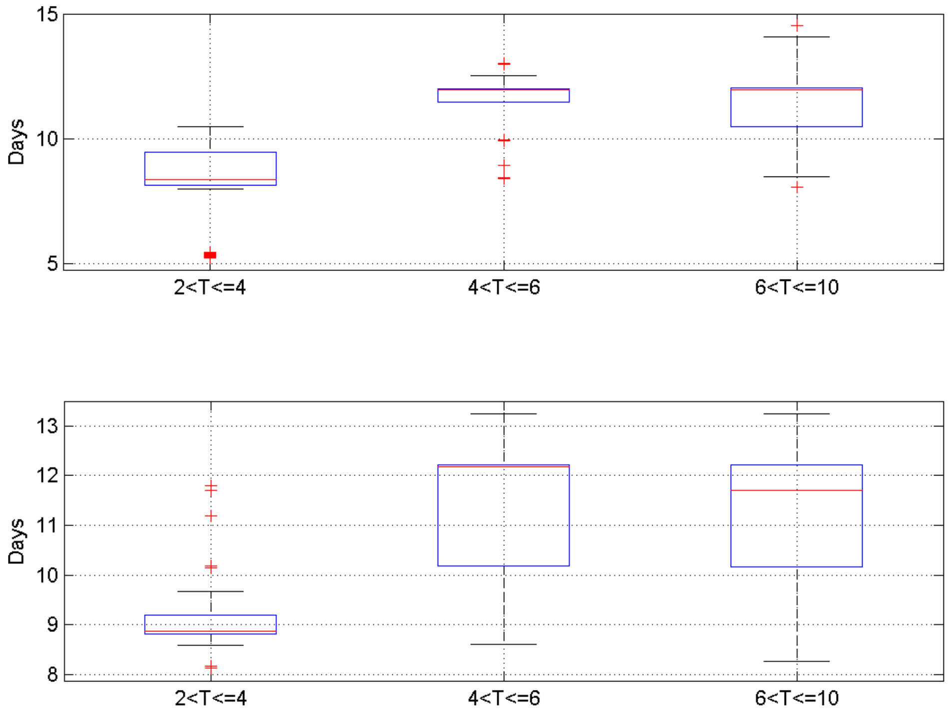


Figure G-28: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 4 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries

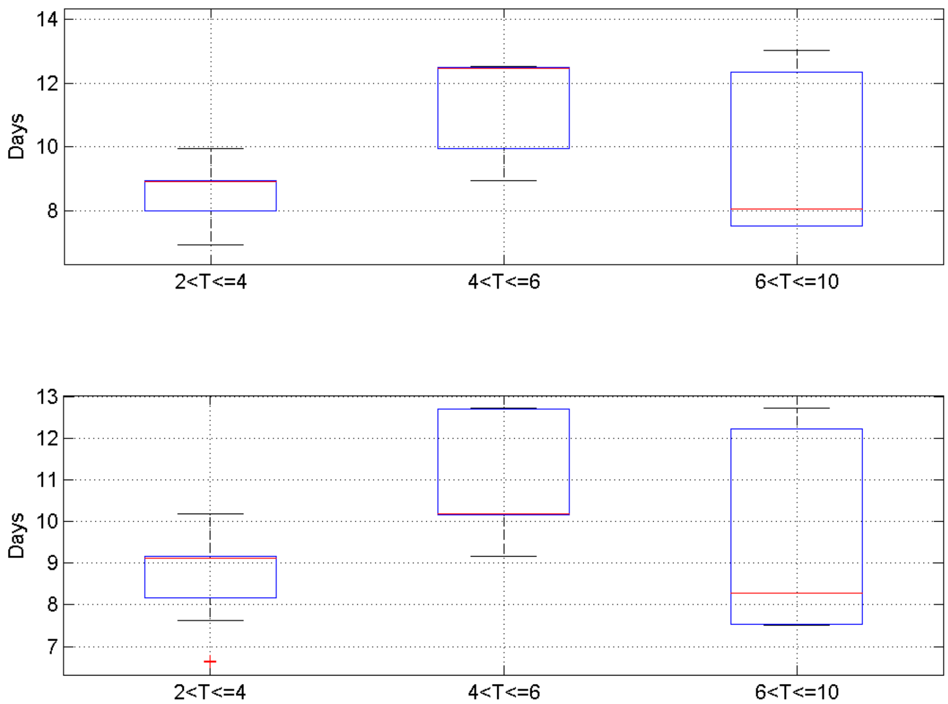


Figure G-29: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 5 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

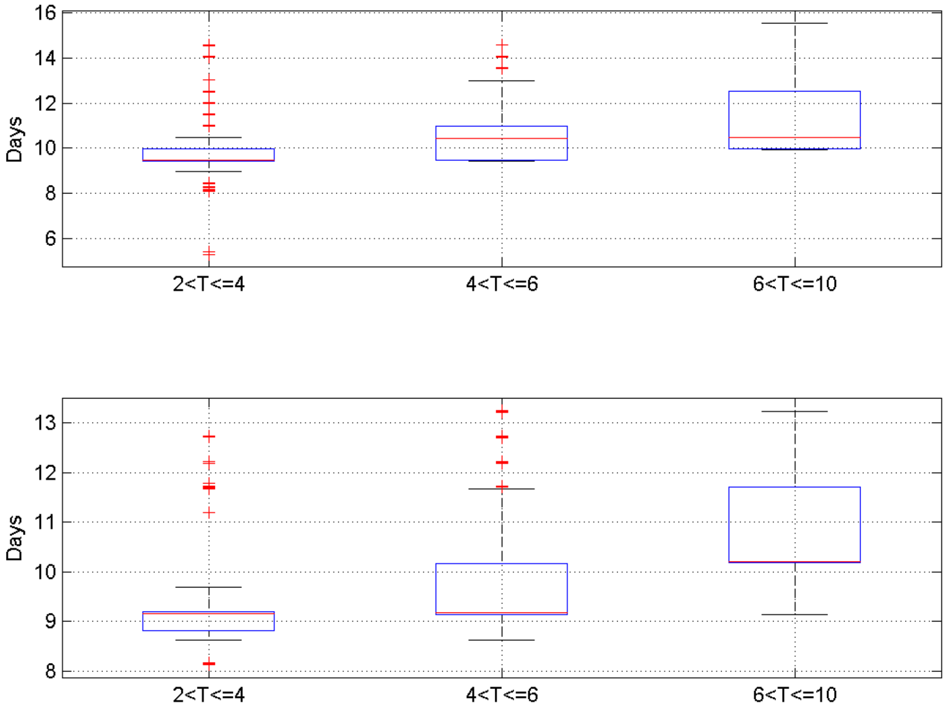


Figure G-30: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 5 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries

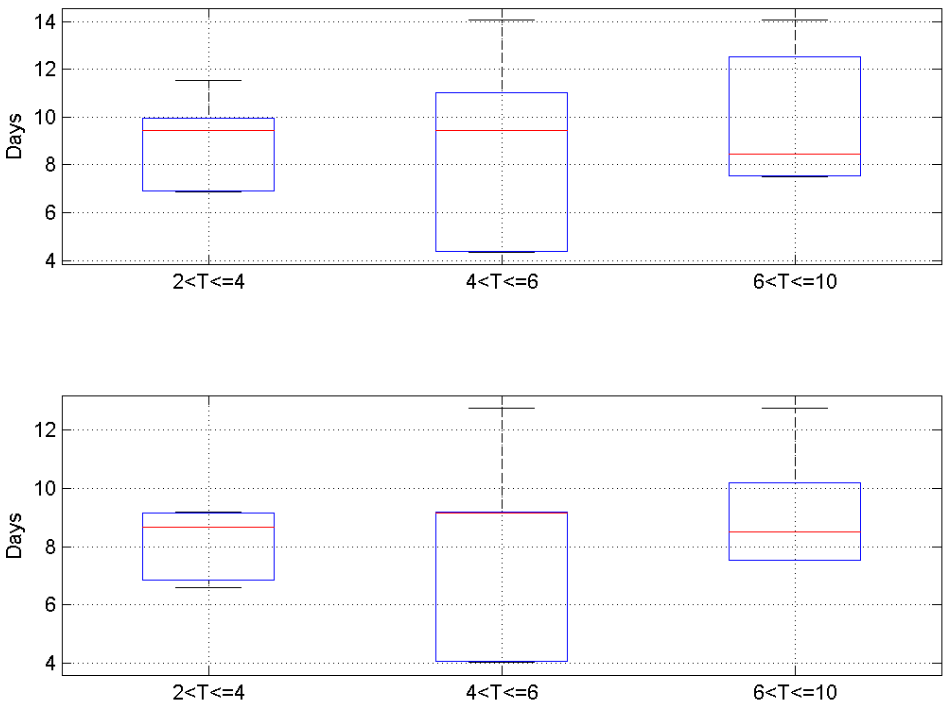


Figure G-31: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 6 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

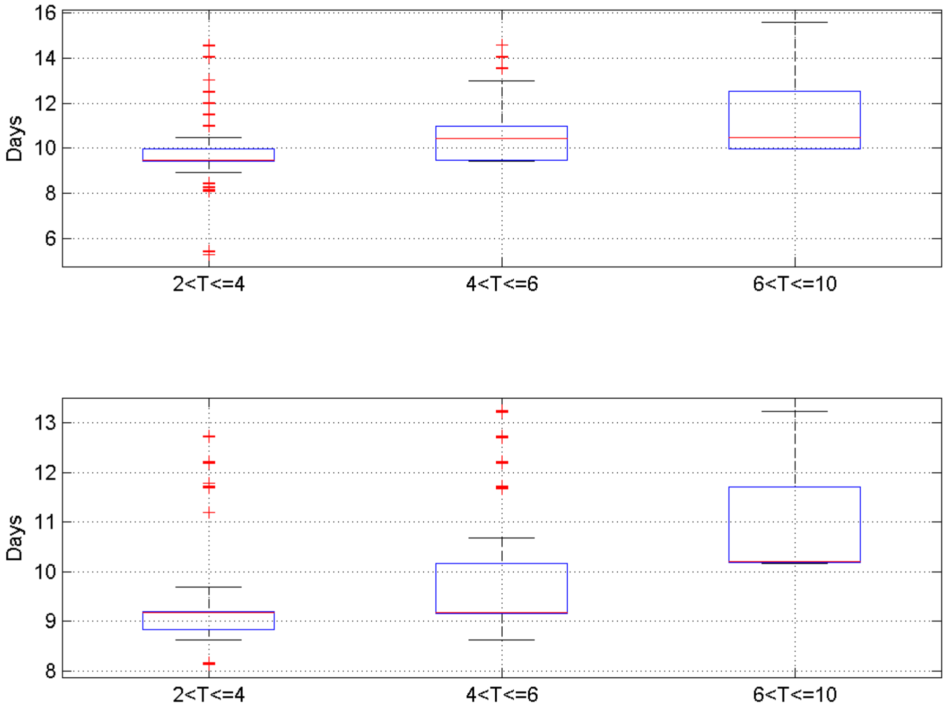


Figure G-32: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 6 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries

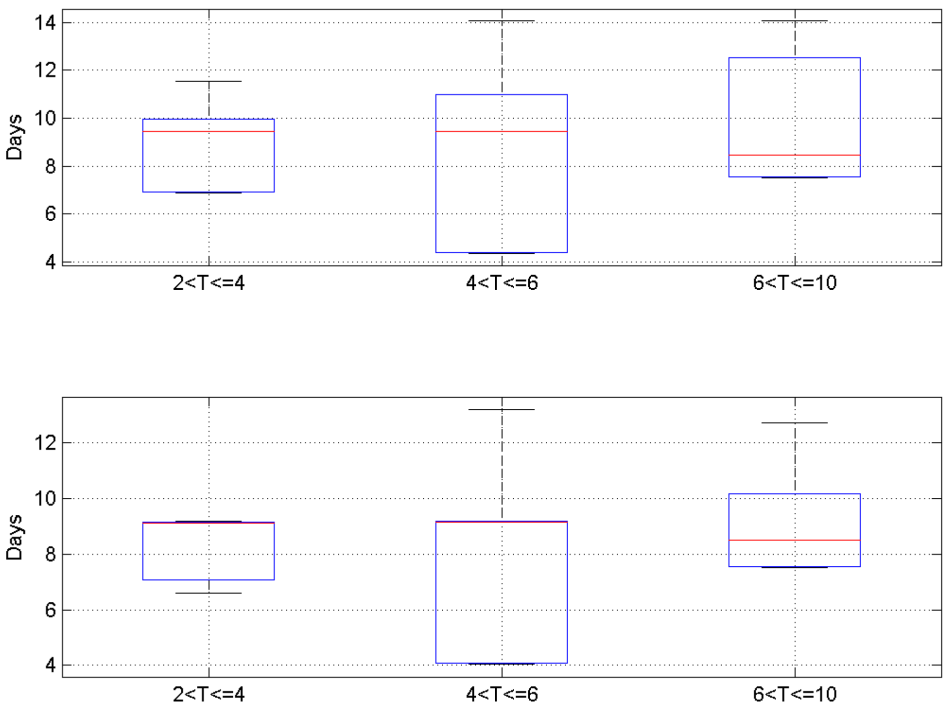
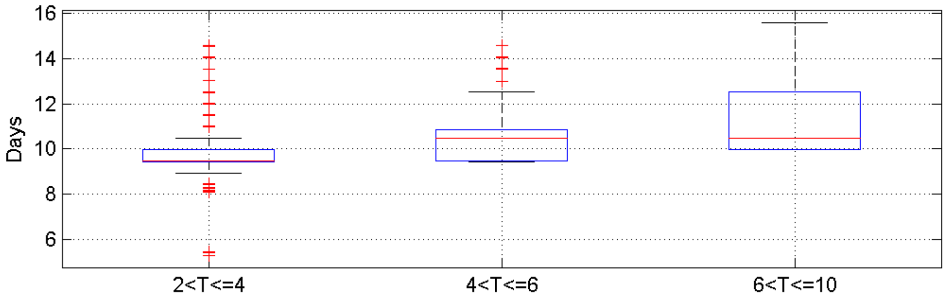


Figure G-33: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 7 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries



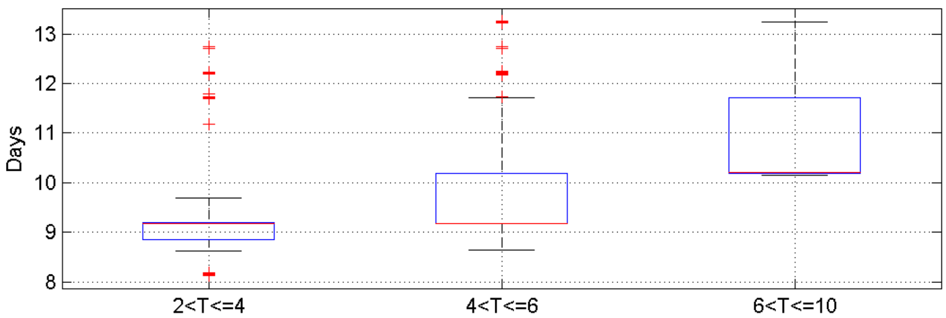
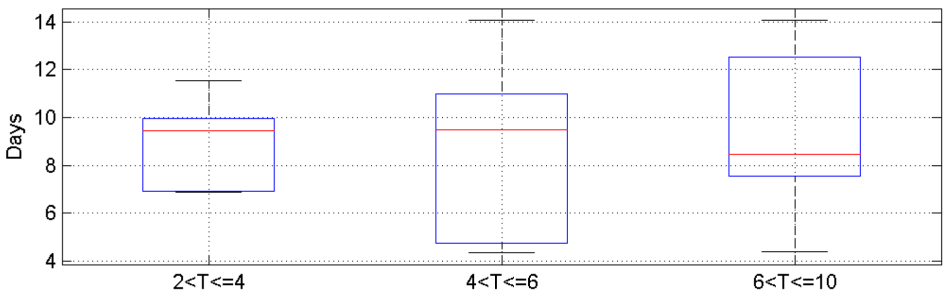


Figure G-34: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 7 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries



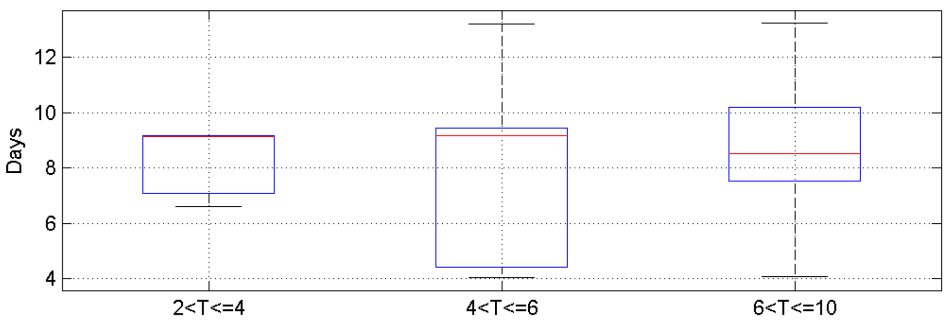


Figure G-35: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 8 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

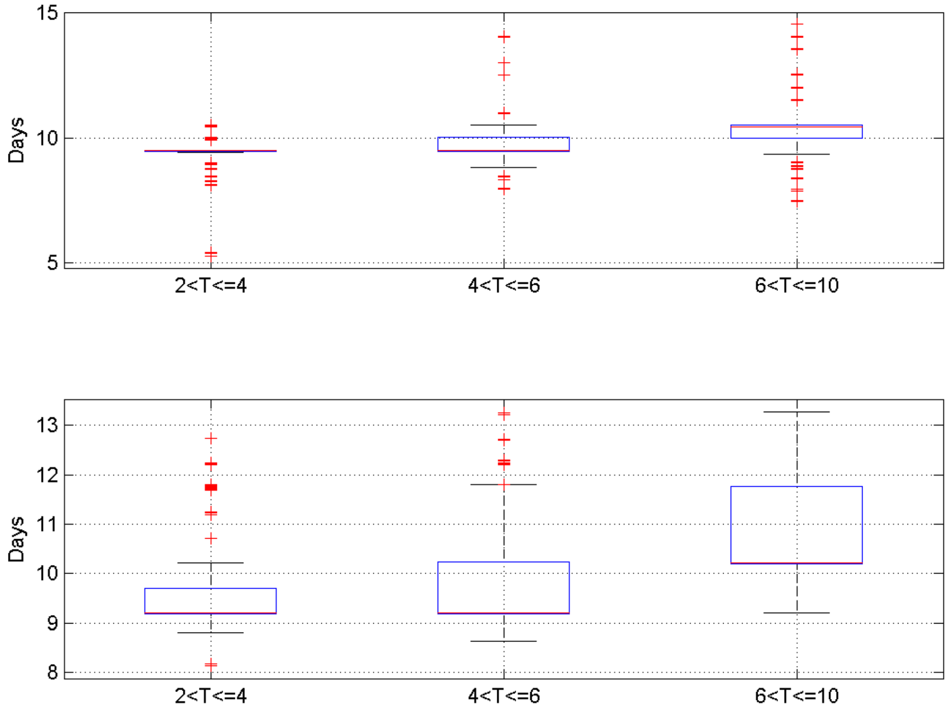


Figure G-36: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 8 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries

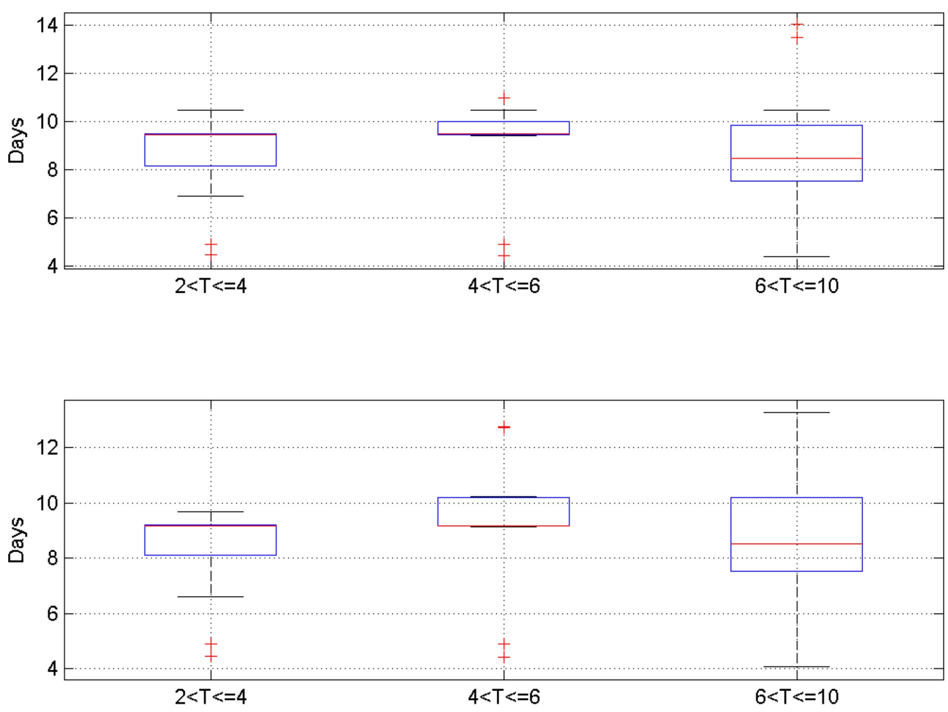


Figure G-37: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 9 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

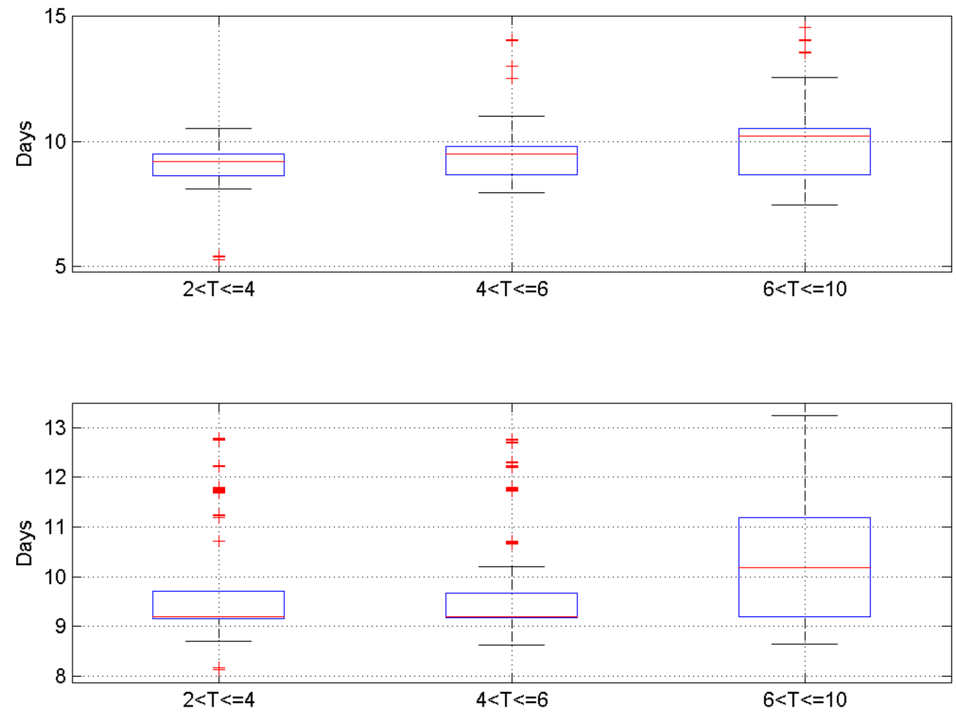


Figure G-38: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 9 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries

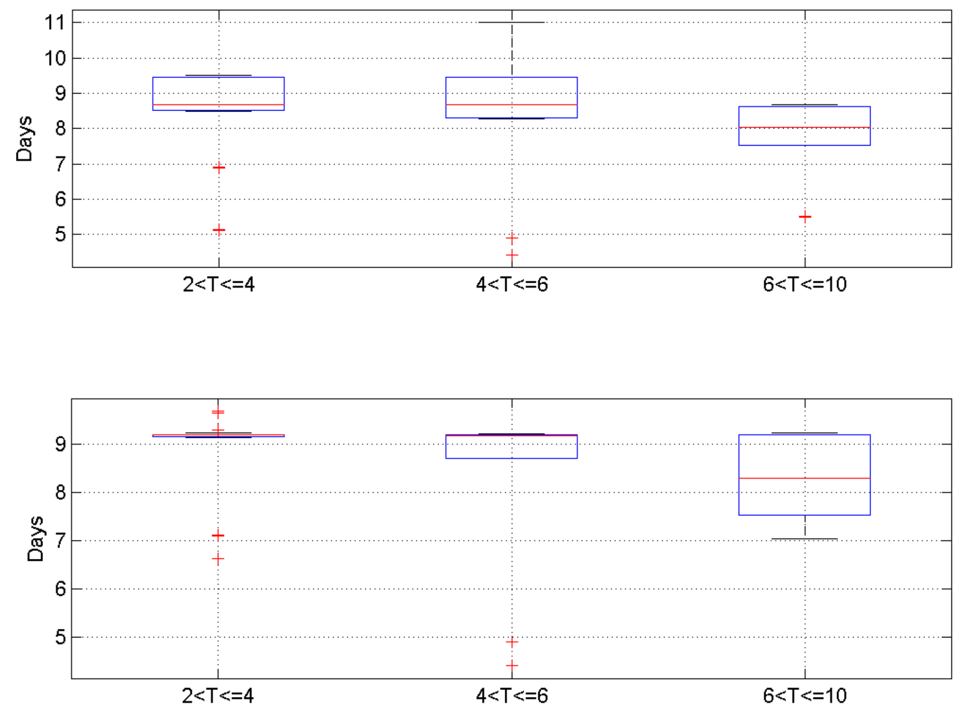


Figure G-39: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 10 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

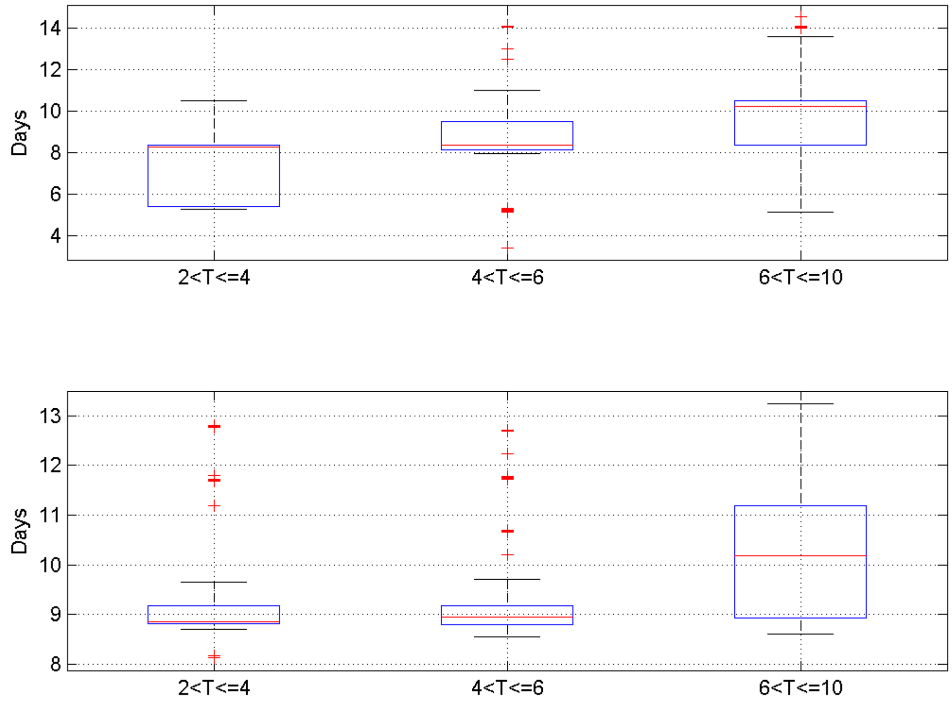


Figure G-40: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 10 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries

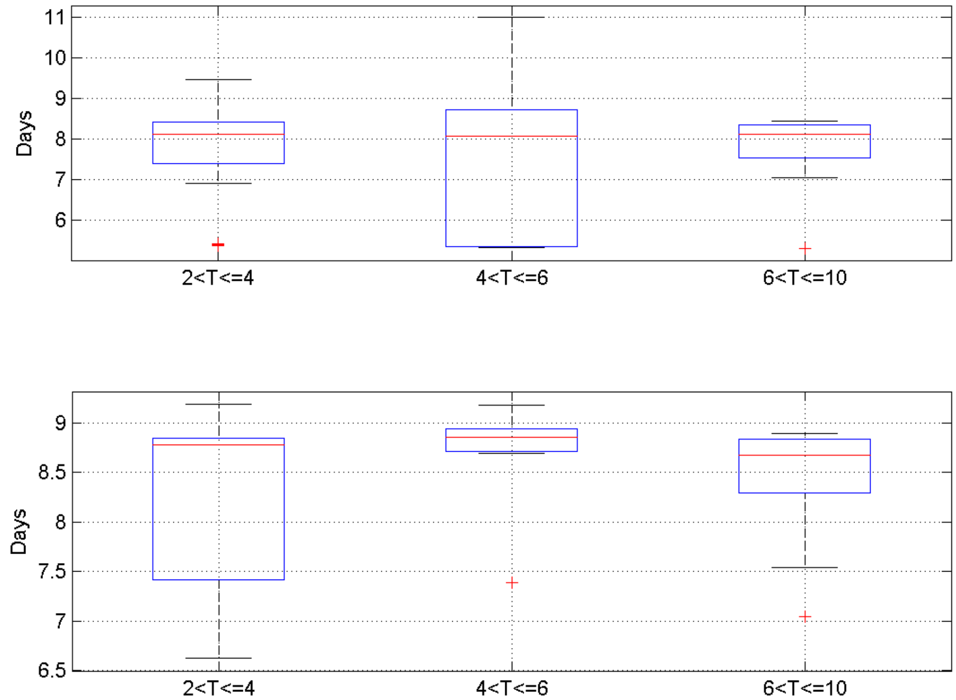


Figure G-41: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 11 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

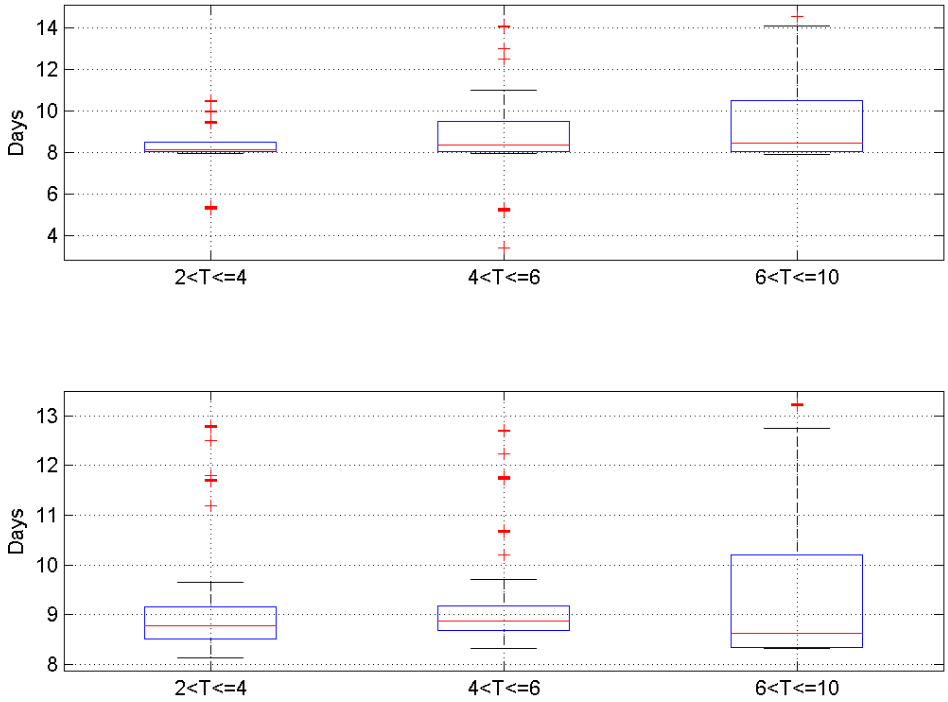


Figure G-42: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 11 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries

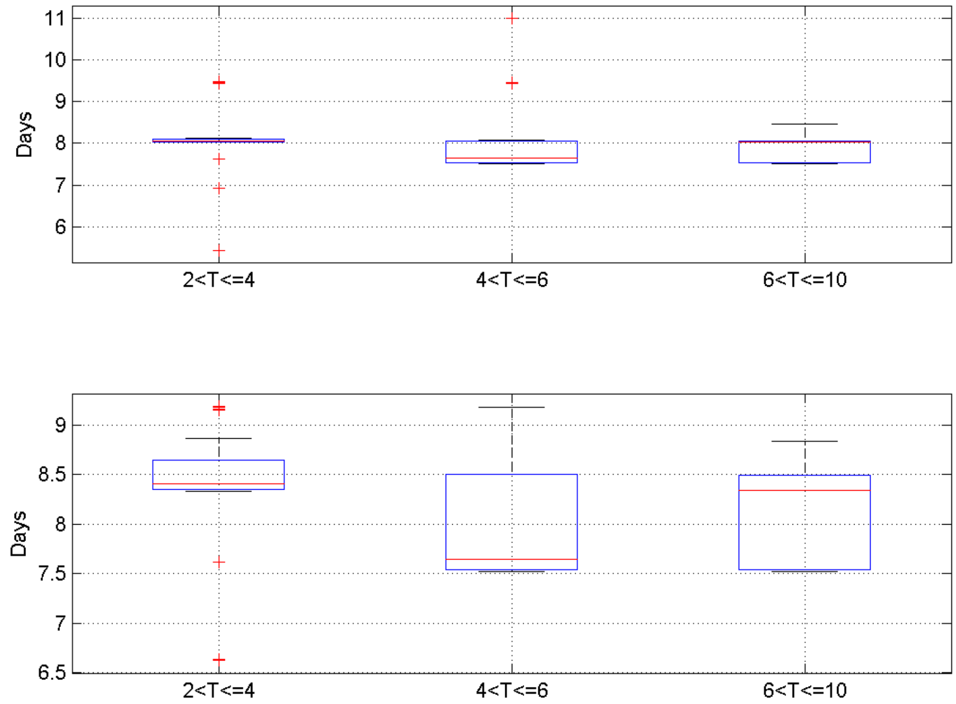


Figure G-43: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 12 and in the test with partial dependency of discharges for the Yser in Roesbrugge and the tributaries

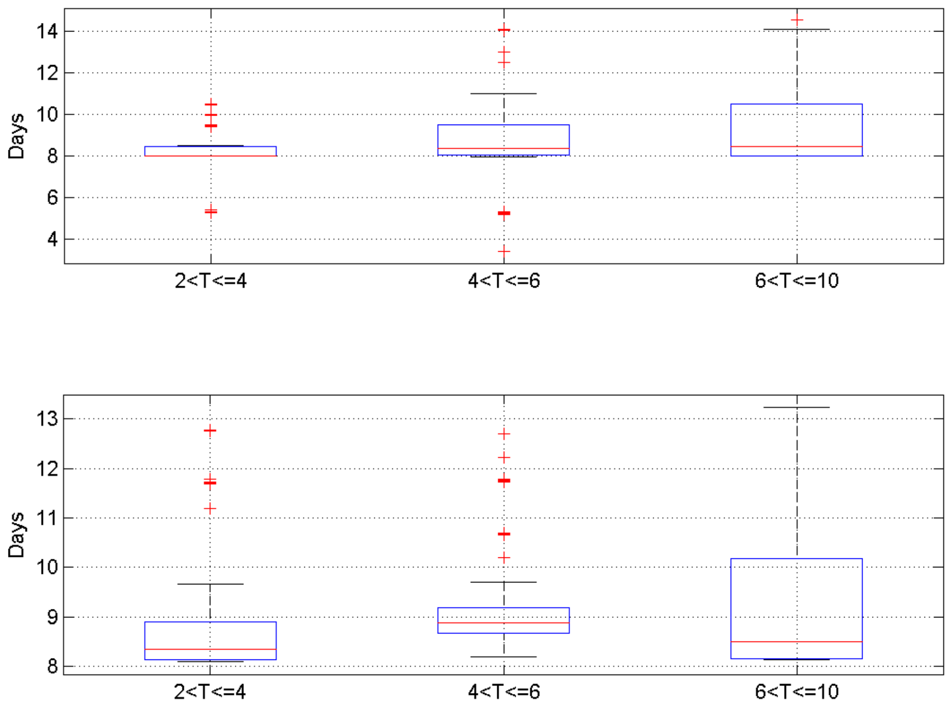
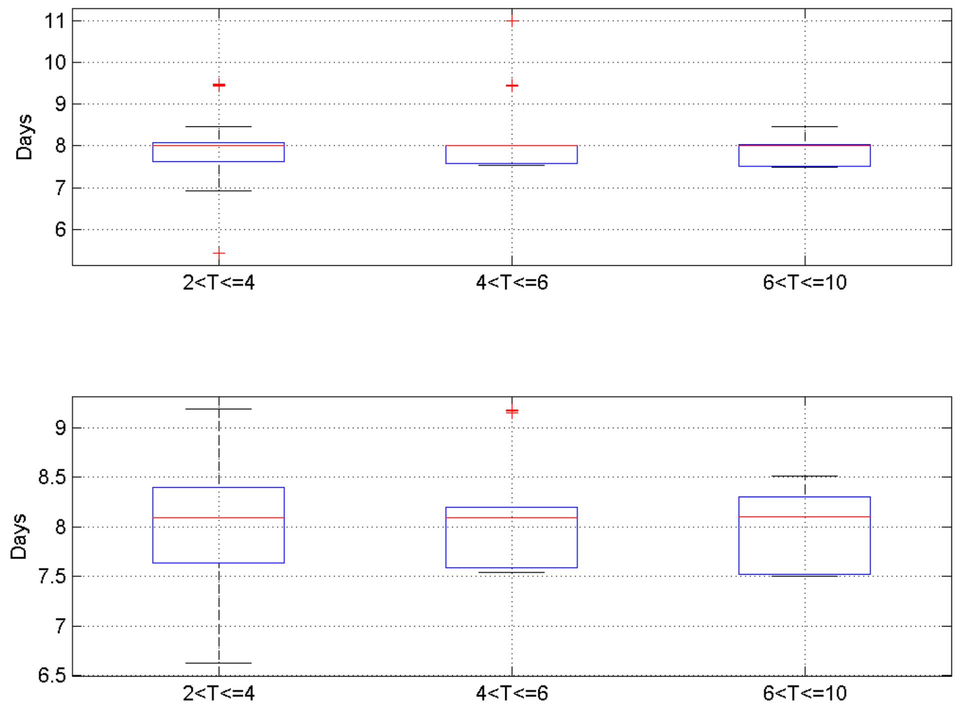


Figure G-44: Box plot of the time to maximal discharge (above) and water level (below) as a function of the return period [days from start of simulation] at Yser checkpoint 12 and in the test with full dependency of discharges for the Yser in Roesbrugge and the tributaries



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