Prepared for:

RIZA and Bundesanstalt für Gewässerkunde

Water balance Maxau-Rhine branches

Phase 1: Data collection and description of methods

Report

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Ir. M.J.P. Mens, Dr. A.H. Weerts and Ir. H.J.M. Ogink

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1 Introduction

1.1 General

On 25 July 2006 Contract RI-4598/4500045718 was signed by Rijkswaterstaat RIZA and WL | Delft Hydraulics, which commissioned the latter to carry out the study "Waterbalans Maxau-Rijntakken". The study concerns analyses of water balances between 15 main hydrometric stations of the Rhine from Maxau to Lobith for low, medium and high flows in the period July 1993 and July 2004. The Terms of Reference of the Project as specified in the RIZA document BIO/1994, dated 1 May 2006 and the proposal of WL | Delft Hydraulics of 22 May with reference ZWS-18383/Q4231/tk and its supplement with reference ZWS-18688/Q4231/lj, dated 2 June 2006 form an integral part of the above agreement.

The execution of the Project takes place in three phases:

- Phase 1: Data collection and description of methods
  a) the kick-off meeting,
  b) the description and collection of the required and available data,
  c) development of a database of hourly discharges of the Rhine downstream of Maxau (measured and HBV-generated) covering the period July 1993 – July 2004; the discharge series should be sufficient to run the SOBEK-model between Maxau and Lobith,
  d) description of the method to fill-in the missing data,
  e) data validation, and
  f) description of the method to compare discharge time series.

- Phase 2: Water balance analyses between the main hydrometric stations
  g) analyses of observed and derived discharge series;
  h) analyses of discharge series using SOBEK, and analyses of discharge series obtained with the HBV-model.

- Phase 3: Analysis of sources of errors in the water balances
  i) comparison of discharge analyses between the main hydrometric stations,
  j) sensitivity analyses at catchment level to identify the most important error sources, and
  k) recommendations on improvements of the runoff forecasting.

This document describes the activities carried out in Phase 1 of the Project. The Project background, objectives and phases are described in the following sub-sections. In Chapter 2 the FEWS-Rijn model is described to identify the data requirement, followed in Chapter 3 by a presentation of the development of the database, including data collection, entry and validation. The extent of the missing water level and discharge data and procedures to fill in the gaps are dealt with in Chapter 4. In Chapter 5 the proposed water balance analyses to be carried out in Phase 2 are described.

The first step of Phase 1, the kick-off meeting of the Project, took place on 7 July, 2006 at RIZA Arnhem and was attended by representatives of RIZA, BfG and WL | Delft Hydraulics. In this meeting the background and objectives of the Project were reviewed, the extent and delivery of the required data discussed and actions agreed upon for the execution of Phase 1.

1.2 Background

For operational information on water levels and discharges of the Rhine use is made of coupled SOBEK-Rhine-section models downstream of Maxau (SOBEK-model FEWS-Rijn version 2.05 as described in Memo WRR 2005-024, 2005) fed with observed stages and flows in the Rhine basin. For forecasting also use is made of inflows generated by the HBV hydrological model.

The SOBEK models of various Rhine sections were calibrated separately. These section models were later on extended with models of the main tributaries, but were never recalibrated thereafter, nor has the coupled model downstream of Maxau been calibrated in its entirety. It seems that errors in the section models are additive in downstream direction. Unacceptable differences were observed in the low flow reach, which led to the addition of groundwater component, but still biases are encountered. Similarly, too large deviations are observed for high flow conditions. Possible reasons for these errors were discussed during the kick-off meeting, like:

- the applied discharge rating curves and omission of hysteresis effects in the stage-discharge relations.
- errors introduced for low flows, when the water levels of major tributaries like Mosel, Neckar and Main are controlled. In SOBEK then use is still being made of discharges derived from water levels and the discharge rating curve, uncorrected for the stage control. However, for these conditions also measured discharge are available from Acoustic Doppler Meter (ADM), which could be used instead.
- in the past there were doubts about station Kaub: differences existed in the water balances for the sections Mainz-Kaub and Kaub-Andernach, whereas for the section Mainz-Andernach a close match was obtained. However, according to BfG since the introduction of Acoustic Doppler Current Profiler (ADCP) -based discharge ratings, the water balances Mainz-Kaub and Kaub-Andernach match better.
- the factors applied in HBV-model for ungauged areas are taken similar to the gauged areas; the validity of these factors is questionable.

1.3 Objectives

The analysis of the possible error sources is not an objective of the Project, as such analyses will be taken up in subsequent studies. The sole objective of the Project is to visualise the discrepancies in the water balance between the 15 key stations between Maxau and Lobith using SOBEK, where the hydraulic model boundaries are either measured values or are generated by the HBV model. The Client has specified the following periods to be considered between 1993 and 2004:

- Low flow: 2003
- Medium flow: period still to be selected
- High flows: floods of 1993, 1995, 1998, 1999 (Upper Rhine), 2002 and 2003.

2 Data requirement

2.1 General

The goal of the water balance analysis is to identify and detect errors in the input data of the modelling chain (water level measurements-derived discharges-HBV-SOBEK) that is also being used in FEWS-Rijn. In FEWS-Rijn, HBV calculated discharges (small tributaries and areas close to the main river) and discharges of the larger tributaries derived from water level measurements (using a stage-discharge relationship) provide input for the SOBEK models. In this study the SOBEK model refers to the coupled SOBEK-model Maxau-Rhine delta, called FEWS-Rijn version 2.05. Analyses will be carried out between subsequent measurement points in downstream order (14 in total) in the Rhine corresponding to 13 river sections.

In this chapter first the river sections will be specified. Next, the components of the SOBEK-model FEWS-Rijn version 2.05 and the layout of the HBV-model, supplier of part of the SOBEK model boundaries, will be presented. Finally, the data requirement for the water balance analysis is specified based on the applied boundary conditions in FEWS-Rijn version 2.05.

2.2 Rhine River sections

The 13 river sections for which water balances will be made are specified in Table 2-1. The average section length amounts 35.7 km and the total basin area draining to the Rhine between Maxau and Lobith according to the table is 108,371 km^2. The latter area is based on basin and sub-basin sizes used in the HBV-model; this value is 2,086 km^2 or 2% smaller than the basin area presented by the KHR (IKHR, 1986). The section between Kaub-Koblenz (section 5) and Koblenz-Andernach (section 6) is taken as one section because the gauging station of Koblenz is located just upstream of where the Mosel enters the Rhine and is therefore unreliable due to backwater effects. Note that we refer to the section Kaub-Andernach as section 5/6 in Table 2-1.

An overview of the tributaries draining to the Rhine in the specified river sections including their key measuring station is given in Table 2-2. As will be shown in Sub-section 2.5 for the tributaries only the data of the stations put in bold are generally received in the operation of FEWS-Rijn. It implies that 91,897 km^2 of the total intermediate basin area of 108,371 km^2 between Maxau and Lobith (i.e 85%) is covered by measurements. Data of the remaining stations have been used for calibration purposes.

Table 2-1 Overview of river sections in the water balance analysis

River Section	River Km	Contributing Area (km^2)	Upstream station	Downstream station
1	362.33-400.61	2,828	Maxau	Speyer
2	400.61-443.37	15,548	Speyer	Worms
3	443.37-498.27	28,783	Worms	Mainz
4	498.27-546.23	5,075	Mainz	Kaub
5/6	546.23-591.49	7,362	Kaub	Koblenz
	591.49-613.78	28,823	Koblenz	Andernach
7	613.78-654.78	1,366	Andernach	Bonn
8	654.78-688.00	3,427	Bonn	Köln
9	688.00-744.20	3,273	Köln	Düsseldorf
10	744.20-780.80	4,977	Düsseldorf	Ruhrort
11	780.80-814.00	916	Ruhrort	Wesel
12	814.00-837.38	5314	Wesel	Rees
13	837.38-851.96	596	Rees	Emmerich
14	851.96-862.22		Emmerich	Lobith

Table 2-2 Overview of tributaries of the Rhine draining between Maxau and Lobith, with key measuring station and basin area upstream of the measuring station

Rhine Section	Section	Tributary	Station	Area (km^2)
1	Maxau-Speyer	Alb	Ettlingen	151
		Pfinz	Berghausen	236
		Erlenbach	Rheinzabern	100
		Queich	Siebeldingen	194
		Speyerbach	Neustadt	303
2	Speyer-Worms	Kraichbach	Ubstadt	161
		Neckar	**Rockenau**	12,616
		Leimbach	Wiesloch	115
3	Worms-Mainz	Pfrimm	Monsheim	196
		Weschnitz	Lorch	393
		Modau	Eberstadt	92
		Schwarzbach	Nauheim	135
		Main	**Raunheim**	26,604

Rhine Section	Section	Tributary	Station	Area (km^2)
4	Mainz-Kaub	Selz	Oberingelheim	371
		Nahe	**Grolsheim**	4,013
		Wisper	Pfaffenthal	174
5/6	Kaub-Koblenz	Lahn	**Kalkofen**	5,298
	Koblenz-Andernach	Mosel	**Cochem**	27,262
		Nette	Nettegut	368
		Wied	**Friedrichsthal**	678
7	Andernach-Bonn	Ahr	**Altenahr**	754
8	Bonn-Köln	Sieg	**Menden**	2,876
9	Köln-Düsseldorf	Wupper	**Opladen**	607
		Erft	**Neubrück**	1,595
10	Düsseldorf-Ruhrort	Ruhr	**Hattingen**	4,124
11	Ruhrort-Wesel	Emscher	**Königstrasse**	773
12	Wesel-Rees	Lippe	Schermbeck	4,860
13	Rees-Emmerich	-	-	-
14	Emmerich-Lobith	-	-	-

2.3 SOBEK model FEWS-Rijn version 2.05

The SOBEK-model FEWS-Rijn version 2.05 is a coupled version of the following SOBEK models:

1. Fews_Rijn Rhein Maxau-Mainz (with prefix MM1),
2. Fews_Rijn Rhein Mainz-Andernach (with prefix RM1),
3. Fews_Rijn Rhein Andernach-Lobith (with prefix AL1),
4. Fews_Rijn Rijntakken 2004.2 stuwen HYD control (with prefix RT2),
5. Fews_Rijn Neckar Rockenau-Muendung stuwen HYD control (with prefix NE1),
6. Fews_Rijn Main Raunheim-Muendung stuwen HYD control (with prefix MA3),
7. Fews_Rijn Lahn Kalkofen-Muendung stuwen HYD control (with prefix LA1), and
8. Fews_Rijn Mosel Cochem-Muendung (with prefix MO1).

The set up of the model is described in RIZA Memo WRR 2005-024 (Van der Veen, 2005) and RIZA Memo 24/07/06 (Lammersen, 2006). A summary is given below.

Re. 1 Fews_Rijn Rhein Maxau-Mainz

The SOBEK model Rhein Maxau-Mainz was developed in 2001 in the frame of the LAHoR-project by M. Weiand under the guidance of the BfG.. The SOBEK cross-sections were generated with BASELINE in 2000-2001. The model has been adapted for FEWS-Rijn to allow coupling with models for the Neckar and Main and the schematisation has been `updated for the 2002 conditions in the frame of the Niederrheinstudie.

Re. 2 Fews_Rijn Rhein Mainz-Andernach

The SOBEK model Rhein Mainz-Andernach was developed in 2001 in the frame of the LAHoR-project by the BfG. The SOBEK cross-sections were generated with BASELINE in 2000-2001. The model has been adapted for FEWS-Rijn to allow coupling with models for the Lahn and Mosel and the schematisation has been updated for the 2002 conditions in the frame of the Niederrheinstudie. The external groundwater interaction has been replaced by the SOBEK groundwater module.

Re. 3 Fews_Rijn Rhein Andernach-Lobith

The SOBEK model Rhein Andernach-Lobith was developed in 1997 by $HKV_{\text{lijn in water}}$, commissioned by RWS RIZA and guided by the BfG.. The SOBEK cross-sections were generated with an older version of the GIS application for SOBEK-cross sections. The model has been adapted for FEWS-Rijn and the schematisation has been updated for the 2002 conditions in the frame of the Niederrheinstudie. The external groundwater interaction has been replaced by the SOBEK groundwater module.

Re. 4 Fews_Rijn Rijntakken 2004.2 stuwen HYD control

The SOBEK-model for the Rhine branches was developed in 2004 by RIZA. In the model the river-bed is based on 2002/2003 conditions, whereas the flood plain describes the situation of 1995. The SOBEK cross-sections have been generated with BASELINE. For FEWS-Rijn the control of the barrages has been adapted to reduce instabilities.

Re. 5 Fews_Rijn Neckar Rockenau-Muendung stuwen HYD control

The SOBEK-model Neckar Plochingen-Mündung was developed in 2003 by WL | Delft Hydraulics and Björnsen BI, commissioned by the BfG. The SOBEK cross-sections have been generated with BASELINE. For FEWS-Rijn the model reach has been reduced to the section Rockenau-Mündung and the control of the barrages has been adapted to reduce instabilities.

Re. 6 Fews_Rijn Main Raunheim-Mündung stuwen HYD control

The SOBEK-model Main Würzburg-Mündung was developed in 2001 by Meander in the frame of the LAHoR Project, commissioned by RIZA. The SOBEK cross-sections have been generated with BASELINE. For FEWS-Rijn the model reach has been reduced to the section Raunheim-Mündung and the control of the barrages has been adapted to reduce instabilities.

Re. 7 Fews_Rijn Lahn Kalkofen-Mündung stuwen HYD control

The SOBEK-model Lahn Giessen-Mündung was developed in 2004 by WL | Delft Hydraulics and Björnsen BI, commissioned by the BfG. The SOBEK cross-sections have been generated with BASELINE. For FEWS-Rijn the model reach has been reduced to the section Kalkofen-Mündung and the control of the barrages has been adapted to reduce instabilities.

Re. 8 Fews_Rijn Mosel Cochem-Mündung

The SOBEK-model of the Mosel between Cochem and the river mouth was developed in 2001 by Meander in the frame of the IRMA-Sponge/DEFLOOD Project. The SOBEK cross-sections have been generated with BASELINE. For FEWS-Rijn the control of the barrages has been adapted to reduce instabilities.

Above partial models are coupled by running program COMBINE. For simulations use is made of boundary conditions consisting of a mixture of measurements (point inflows) and HBV generated lateral inflows (point or diffuse), whereas for forecasts the boundary conditions are fully based on HBV data. The measurements and HBV data are multiplied with a factor to correct for basin area and/or bias in the flows and where applicable a time shift is introduced to correct for travel time from the measuring station/HBV sub-basin outflow location to the river model. The time step used in FEWS-Rijn is 1 hour.

2.4 HBV-model

The HBV model of the Rhine between Basel and Lobith, used by FEWS-Rijn, has been described in detail in Sprokkereef et. al. (2001). The HBV model is a conceptual semi-distributed precipitation-runoff model and covers 101 sub-basins ranging in size between 500 and 2,000 km^2. Elevation zones in the sub-basins are based on the digital elevation model of the US Geological Survey, whereas the land use data have been derived from grid based GIS Landsat-TM satellite data.

Input are hourly and daily precipitation values, air temperature and mean monthly potential evaporation values. Hourly discharge data have been used for calibration purposes. Ungauged sub-basins along the Rhine were calibrated by comparison with discharges of smaller representative tributaries. Calibration/verification was done for the period 1990 to 1999, whereas the calibration period for the Mosel covered the period 1990 to 1998. Best calibration results were obtained for the Ruhr, Mosel and Lahn.

In the next sub-section the HBV sub-basins are presented to describe the FEWS-Rijn HBV based boundary conditions.

2.5 Boundary conditions used in FEWS-Rijn

Water balances will be established for the 13 river sections listed in Table 2-1.The upstream boundary is either a discharge series (derived from water levels and a stage-discharge relation) or a water level series (to account for hysteresis effects). For the lateral inflows, one can either choose measured discharges or HBV simulated discharges. In FEWS-Rijn, for almost all small tributaries use is made of the HBV simulated discharges as measured discharges for these tributaries are not operationally available at the moment. Tables 2-3 to 2-16 give an overview of the upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for each river section. In the tables bold font indicates what is **normally** being used in FEWS-Rijn. In the tables the letter Q indicates discharge, H indicates water level. The retention areas follow the convention as described below:

- _VolXX: modelled area's dike overflow Oberrhein
- _name: retention measures Oberrhein
- _O_XXX: modelled area's dike overflow Andernach-Lobith
- _D_XXX: modelled area's dike breach Andernach-Lobith
- _Y_XXX_dX: modelling of flow inside the dikes Andernach Lobith

Italic font indicates that the discharge of that area is not measured. The tables will be used in Sub-section 2.6 to specify the data requirement. Figures 2-1 to 2-12 show the spatial distribution of the HBV sub-basins that are input to the SOBEK model.

River Section 1: Maxau-Speyer

Reference is made to Figure 2-1 for an overview of the sub-basin definitions and measuring locations. It is observed that apart from station Maxau for these sections generally no measurements are in the operation of FEWS-Rijn.

Table 2-3 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 1.

River Section 1	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Maxau	**Q** or H		50,627.1	H or Q
lateral inflow (point)	Q, Ettlingen Q, Berghausen Q, Siebeldingen Q, Neustadt/Wst.	 **Q, AlbPfinz** **Q, QueichSp**	 *386.62* *496.95*	
lateral inflow (diffuse)		**Q, UpRhine1**	*1,944.01*	
lateral discharges modelled as retention areas				Q, MM1_Vol1 Q, MM1_Vol2 Q, MM1_Vol3 Q, MM1_Vol4 Q, MM1_Flotzgruen
LB Speyer	H		53,454.67	Q

River Section 2: Speyer-Worms

Reference is made to Figures 2-1 and 2-2 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Neckar, which mouth forms part of the SOBEK model. Apart from station Rockenau on the Neckar no measurement data are obtained from the section for the operation of FEWS-Rijn.

Table 2-4 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 2.

River Section 2	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Speyer	Q or H		53,454.67	H or Q
lateral inflow (point)	**Q, Rockenau** Q, Meckesheim	Q, Neckar4 **Q, Elsenz**	12,616.50 *538.50*	H
lateral inflow (diffuse)		**Q, UpRhine2** **Q, UpRhine3** **Q, Neckar5**	*855.22* *826.12* *711.70*	
lateral discharges modelled as retention areas				Q, MM1_Vol5 Q, MM1_Vol6 Q, MM1_Vol7 Q, MM1_Vol8 Q, MM1_Kollerinsel
LB Worms	H		69,002.71	Q

River Section 3: Worms-Mainz

Reference is made to Figures 2-1 and 2-3 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Main, which mouth forms part of the SOBEK model. Apart from station Raunheim on the Main no measurement data are obtained from the section for the operation of FEWS-Rijn.

Table 2-5 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 3.

River Section 3	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Worms	Q or H		69,002.71	H or Q
lateral inflow (point)	Q, Lorsch Q, Eberstadt **Q, Raunheim**	 **Q, WeschMod** Q, Main8 (totmean) **Q, Main8 (locmean)**	 *484.88* 26,604.00	H
lateral inflow (diffuse)		**Q, UpRhine4**	*1,694.51*	
lateral discharges modelled as retention areas				Q, MM1_Vol9 Q, MM1_Vol10 Q, MM1_Vol11 Q, MM1_Vol12 Q, MM1_Vol13
LB Mainz	H		97,786.09	Q

River Section 4: Mainz-Kaub

Reference is made to Figures 2-4 and 2-5 for an overview of the sub-basin definition and measuring locations. Apart from station Grolsheim on Nahe River no measurement data are obtained from the section for the operation of FEWS-Rijn.

Table 2-6 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 4.

River Section 4	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Mainz	Q of H		97,786.09	H of Q
lateral inflow (point)	Q, Oberingelheim **Q, Grolsheim** Q, Pfaffenthal	**Q, Selz** Q, Nahe3 **Q, Wisper**	*370.96* 3850 *174.36*	H
lateral inflow (diffuse)		**Q, MidRhine1**	*679.41*	
lateral discharges modelled as retention areas				Q, MM1_Vol14 Q, RM1_Vol15 Q, RM1_Vol16 Q, RM1_Vol17 Q, RM1_Vol18
LB Kaub	H		102,860.8	Q

River Section 5/6: Kaub-Koblenz

The section between Kaub-Koblenz (section 5) and Koblenz-Andernach (section 6) is taken as one section because the gauging station of Koblenz is located just upstream of where the Mosel enters the Rhine and is therefore unreliable due to backwater effects.
Reference is made to Figures 2-4 and 2-7 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Lahn, which downstream parts are included in the coupled SOBEK model. For this tributary measurement data are received for the operation of FEWS-Rijn.

Table 2-7 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 5.

River Section 5	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Kaub	Q of H		102,860.8	H of Q
lateral inflow (point)	**Q, Kalkhofen**	Q, Lahn4 (totmean)	5,298.00	H
lateral inflow (diffuse)		**Q, MidRhine2** **Q, Lahn5 (locmean)**	*1,083.24* 592.94	
lateral discharges modelled as retention areas				Q, RM1_Vol19 Q, RM1_Vol20 Q, RM1_Vol21 Q, RM1_Vol22 Q, RM1_Vol23
LB Koblenz	H		137,485	Q

River Section 5/6: Koblenz-Andernach

Reference is made to Figure 2-4 and 2-6 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Mosel, Nette and Wied rivers of which only for the Mosel and Wied measurement data are regularly received for the operation of FEWS-Rijn.

Table 2-8 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 6.

River Section 6	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Koblenz	H		137,485	Q or H
lateral inflow (point)	**Q, Cochem** **Q, Friederichsthal** Q, Nettegut	Q, Umos3 **Q, Saynbach** Q, Wied **Q, Nette**	27,262.16 *515.02* 677.53 *368.33*	H
lateral inflow (diffuse)		**Q, Umos4**	*387.88*	
lateral discharges modelled as retention areas				Q, RM1_Vol24 Q, RM1_Vol25 Q, RM1_Vol26
LB Andernach	H		139,045.9	Q

River Section 7: Andernach-Bonn

Reference is made to Figure 2-4 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Ahr for which regularly measurement data are received for the operation of FEWS-Rijn.

Table 2-9. Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 7.

River Section 7	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Andernach	Q or H		139,045.9	Q or H
lateral inflow (point)	**Q, Altenahr**	Q, Ahr	753.65	
lateral inflow (diffuse)		**Q, MidRhine3**	*612.18*	
lateral discharges modelled as retention areas				Q, AL1_W_101_103 Q, Al1_O_001
LB Bonn	H		140,411.7	Q

River Section 8: Bonn-Köln

Reference is made to Figures 2-4 and 2-8 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Sieg for which regularly measurement data are received for the operation of FEWS-Rijn.

Table 2-10 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 8.

River Section 8	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Bonn	Q or H		140,411.7	Q or H
lateral inflow (point)	**Q, Menden**	Q, Unsi	2,876.27	
lateral inflow (diffuse)		**MidRhine4**	*550.28*	
lateral discharges modelled as retention areas				Q, Al1_103 Q, Al1_1031 Q, Al1_1032 Q, Al1_O_002 Q, Al1_O_003 Q, Al1_O_004 Q, Al1_O_005 Q, Al1_O_005_d1 Q, Al1_O_005_d2 Q, Al1_O_006 Q, Al1_O_006_d1 Q, Al1_O_006_d2 Q, Al1_O_006_d3 Q, Al1_O_006_d4 Q, Al1_O_008 Q, Al1_O_008_d1 Q, Al1_O_008_d2 Q, Al1_O_009 Q, Al1_O_010 Q, Al1_O_011 Q, Al1_O_012
LB Köln	H		143,838.3	Q

River Section 9: Köln-Düsseldorf

Reference is made to Figure 2-9 and 2-10 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Erft and Wupper rivers for which regularly measurement data are received for the operation of FEWS-Rijn.

Table 2-11. Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 9.

River Section 9	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Köln	Q or H		143,838.3	Q or H
lateral inflow (point)	**Q, Opladen** **Q, Neubrueck**	Q, Wupper1 Q, Erft2	607.06 1,595.43	
lateral inflow (diffuse)		**Q, LowRhine1** Q, Erft3	*860.01* *210.19*[1]	
lateral discharges modelled as retention areas				Q, All_Mohne_d1 Q, All_Mohne_d2 Q, All_O_013 Q, All_O_014 Q, All_O_014_d1 Q, All_O_014_d2 Q, All_O_015 Q, All_O_016 Q, All_O_016_d1 Q, All_O_016_d2 Q, All_O_017 Q, All_O_018 Q, All_O_021 Q, All_O_021_d1 Q, All_O_021_d2 Q, All_O_021_d3 Q, All_O_021_d4 Q, All_O_022 Q, All_O_024 Q, All_O_025 Q, All_D_019 Q, All_D_019_d1 Q, All_D_019_d2 Q, All_D_023 Q, All_D_023_d1 Q, All_D_023_d2 Q, All_D_023_d3 Q, All_D_023_d4 Q, All_O_026 Q, All_O_027 Q, All_O_027_b Q, All_O_027_d1 Q, All_O_027_d2
LB Düsseldorf	H		147,111	Q

[1] Erft3, locmean is not used in FEWS-Rijn

River Section 10: Düsseldorf-Ruhrort

Reference is made to Figure 2-9 and 2-11 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Ruhr for which regularly measurement data are received for the operation of FEWS-Rijn.

Table 2-12 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 10

River Section 10	Measurement	HBV	Area (km^2)	SOBEK
UB Düsseldorf	Q or H		147,111	Q or H
lateral inflow (point)	**Q, Hattingen**	Q, Ruhr3	4,124.00	
lateral inflow (diffuse)		**LowRhine2** Q, Ruhr4	*492.24* *360.76*[1]	
lateral discharges modelled as retention areas				Q, AL1_O_030 Q, AL1_D_031 Q, AL1_D_031_d1 Q, AL1_D_031_d2 Q, AL1_D_033 Q, AL1_D_033_d1 Q, AL1_D_033_d2 Q, AL1_D_034 Q, AL1_D_035
LB Ruhrort	H		152,088	Q

[1] Ruhr4, locmean is not used in FEWS-Rijn

River Section 11: Ruhrort-Wesel

Reference is made to Figure 2-9 and 2-12 for an overview of the sub-basin definition and measuring locations. In this section the Rhine is joined by the Emscher river for which regularly measurement data are received for the operation of FEWS-Rijn.

Table 2-13 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 11.

River Section 11	Measurement	HBV	Area (km^2)	SOBEK
UB Ruhrort	Q or H		152,088	Q or H
lateral inflow (point)	**Q, Köningstrasse**	Q, Emscher	772.85	
lateral inflow (diffuse)		**LowRhine3**	*680.93*	
lateral discharges modelled as retention areas				Q, AL1_O_037
LB Wesel	H			Q

River Section 12: Wesel-Rees

Reference is made to Figure 2-9 for an overview of the sub-basin definition. In this section the Rhine is joined by the Lippe river for which regularly measurement data are received for the operation of FEWS-Rijn. Lateral inflow to this section is not measured (LIPPE!!) and is therefore derived by the HBV model for the operation of FEWS-Rijn.

Table 2-14 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 12.

River Section 12	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Wesel	Q or H			Q or H
lateral inflow (point)	**Q, Schermbeck**	Q, Lippe3	4,859.68	
lateral inflow (diffuse)		**LowRhine3**	see Table 2.13	
lateral discharges modelled as retention areas				Q, AL1_107
LB Rees	H		158,401.4	Q

River Section 13: Rees-Emmerich

Reference is made to Figure 2-9 for an overview of the sub-basin definition. Lateral inflow to this section is not measured and is therefore derived by the HBV model for the operation of FEWS-Rijn.

Table 2-15 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 13.

River Section 13	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Rees	Q or H		158,401.4	Q or H
lateral inflow (point)				
lateral inflow (diffuse)		**LowRhine4**	*596.40*	
lateral discharges modelled as retention areas				Q, AL1_O_39 Q, AL1_O_40 Q, AL1_O_41
LB Emmerich	H			Q

River Section 14: Emmerich-Lobith

Reference is made to Figure 2-9 for an overview of the sub-basin definition. Lateral inflow to this section is not measured and is therefore derived by the HBV model for the operation of FEWS-Rijn.

Table 2-16 Overview of upper and lower boundaries, inflows (HBV or measurement) and outflows (SOBEK) of the SOBEK model for River Section 14.

River Section 14	**Measurement**	**HBV**	**Area (km^2)**	**SOBEK**
UB Emmerich	Q or H			Q or H
lateral inflow (point)				
lateral inflow (diffuse)		**LowRhine4**	see Table 2.15	
lateral discharges modelled as retention areas				
LB Lobith	H		158.997.8	Q

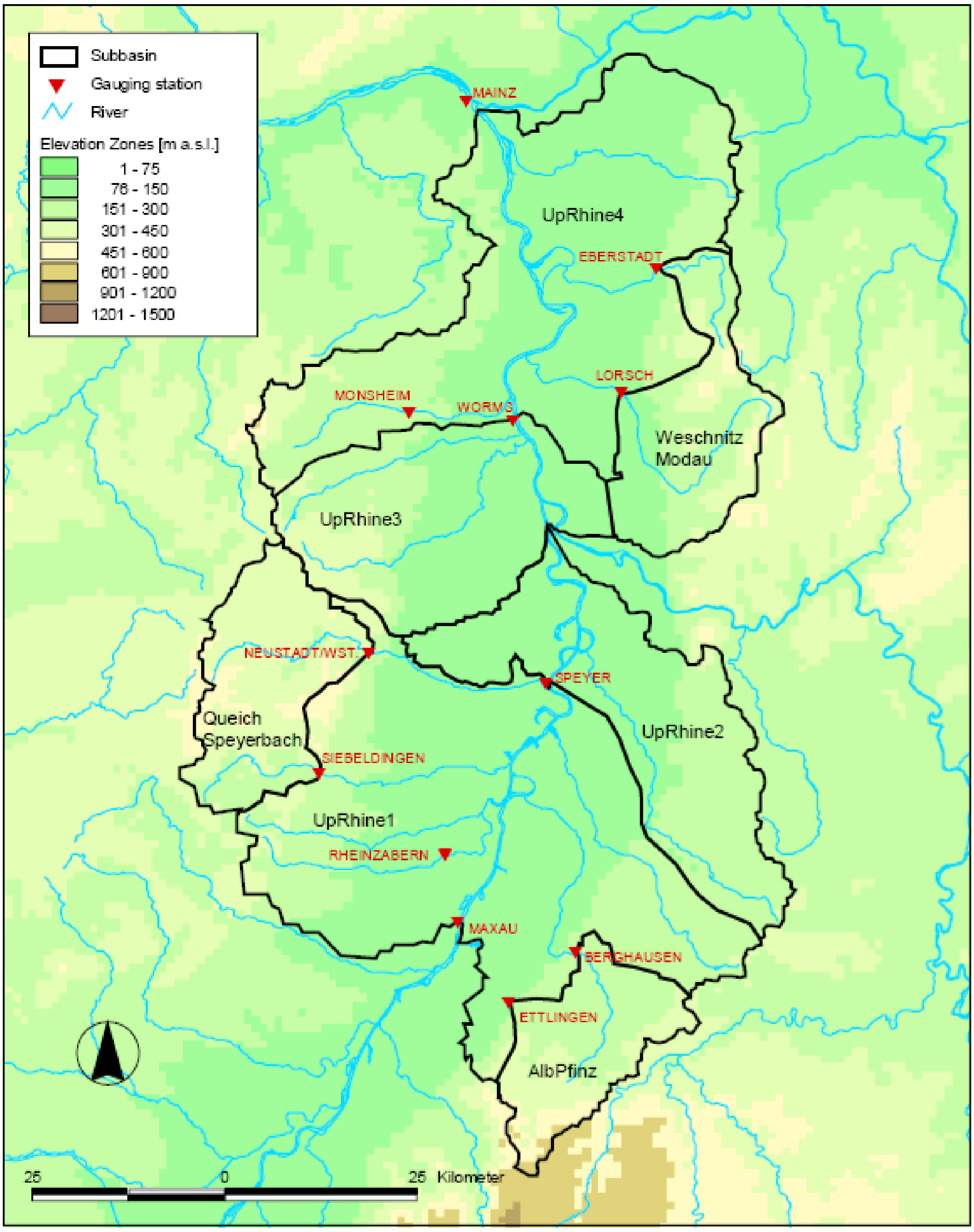

Figure 2-1. Map of sub-basins that are input into the SOBEK model between Maxau and Mainz.

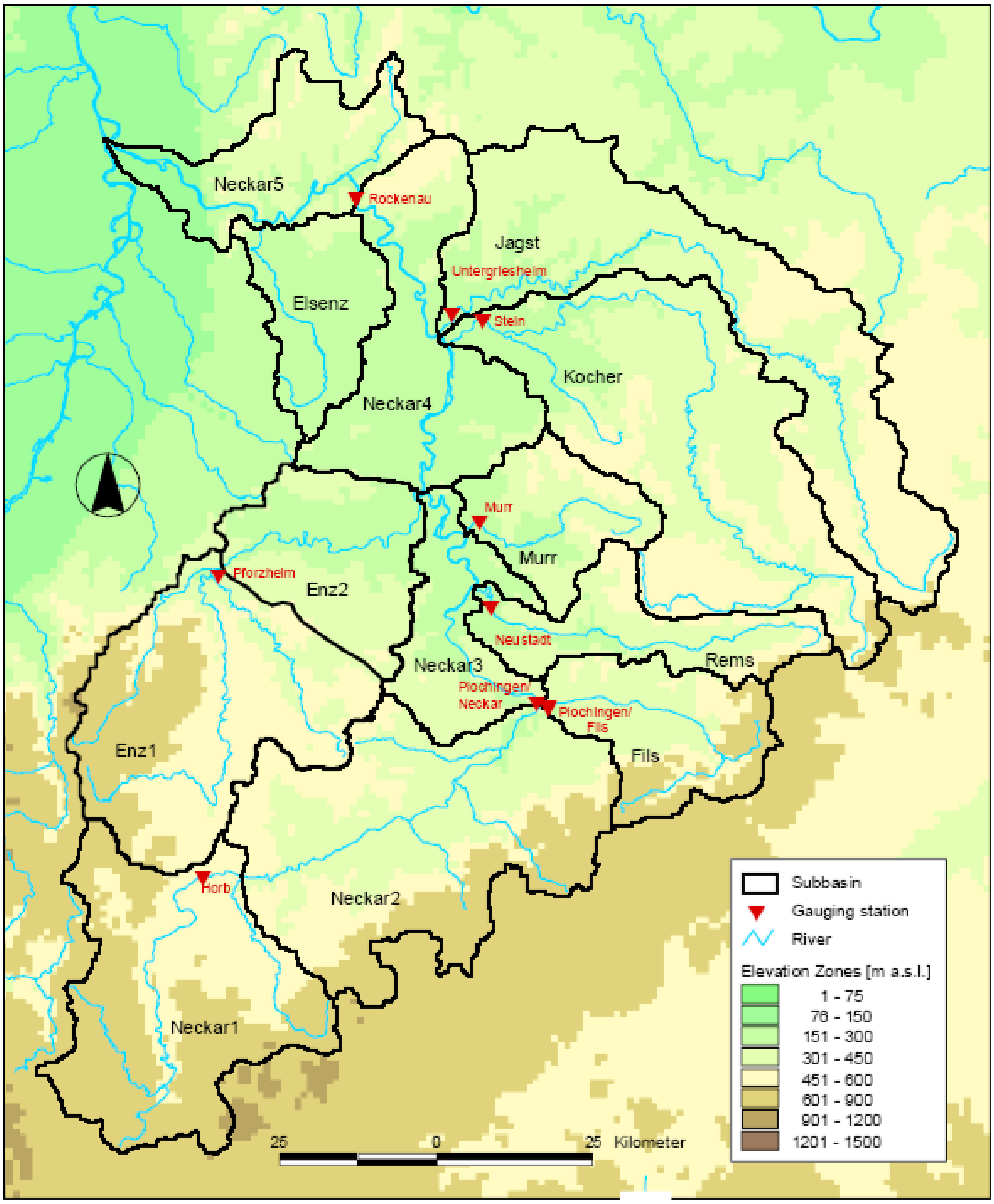

Figure 2-2. Map of sub-basins of the Neckar that are input into the SOBEK model between Speyer and Worms.

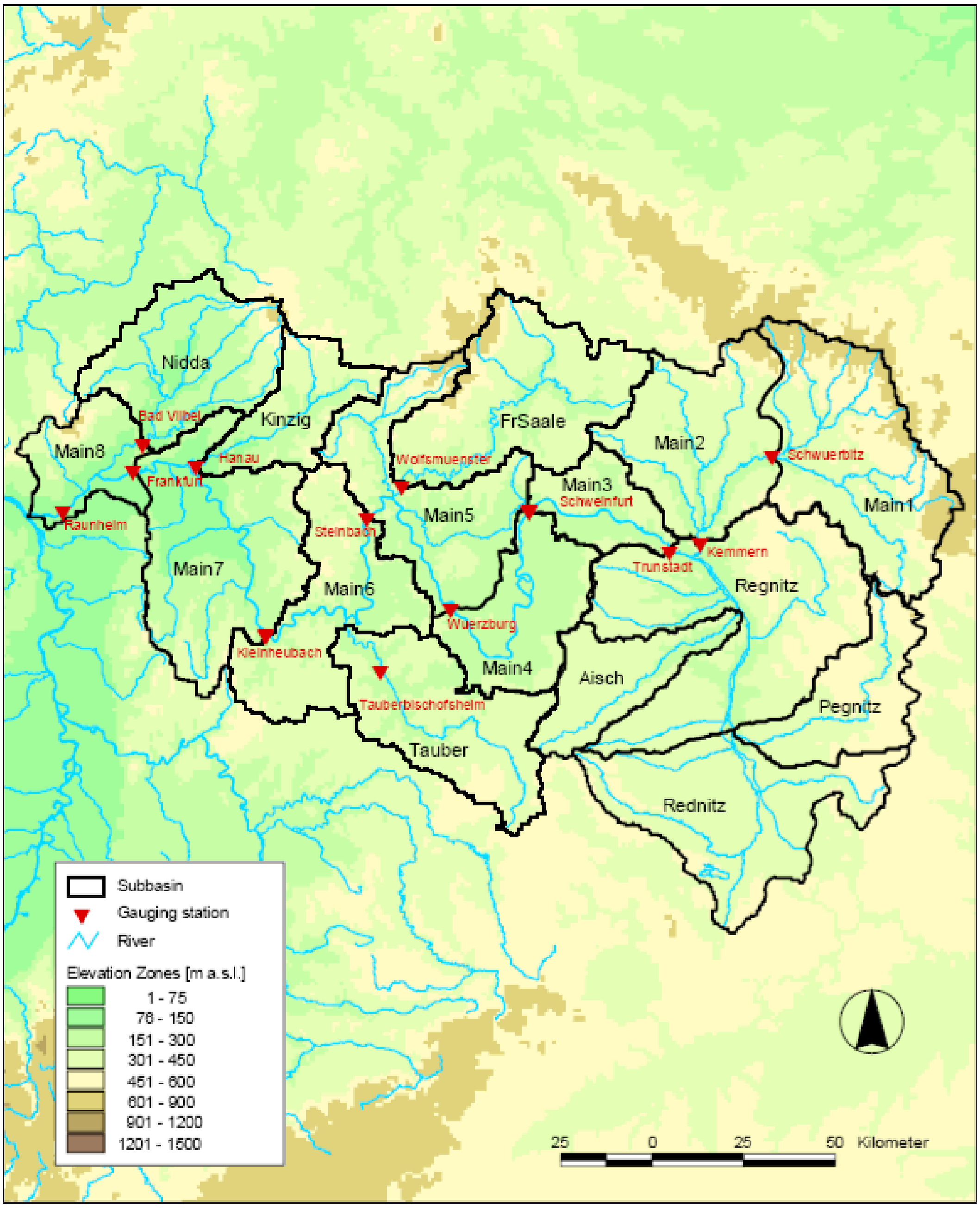

Figure 2-3. Map of sub-basins of the Main that are input into the SOBEK model between Worms and Mainz.

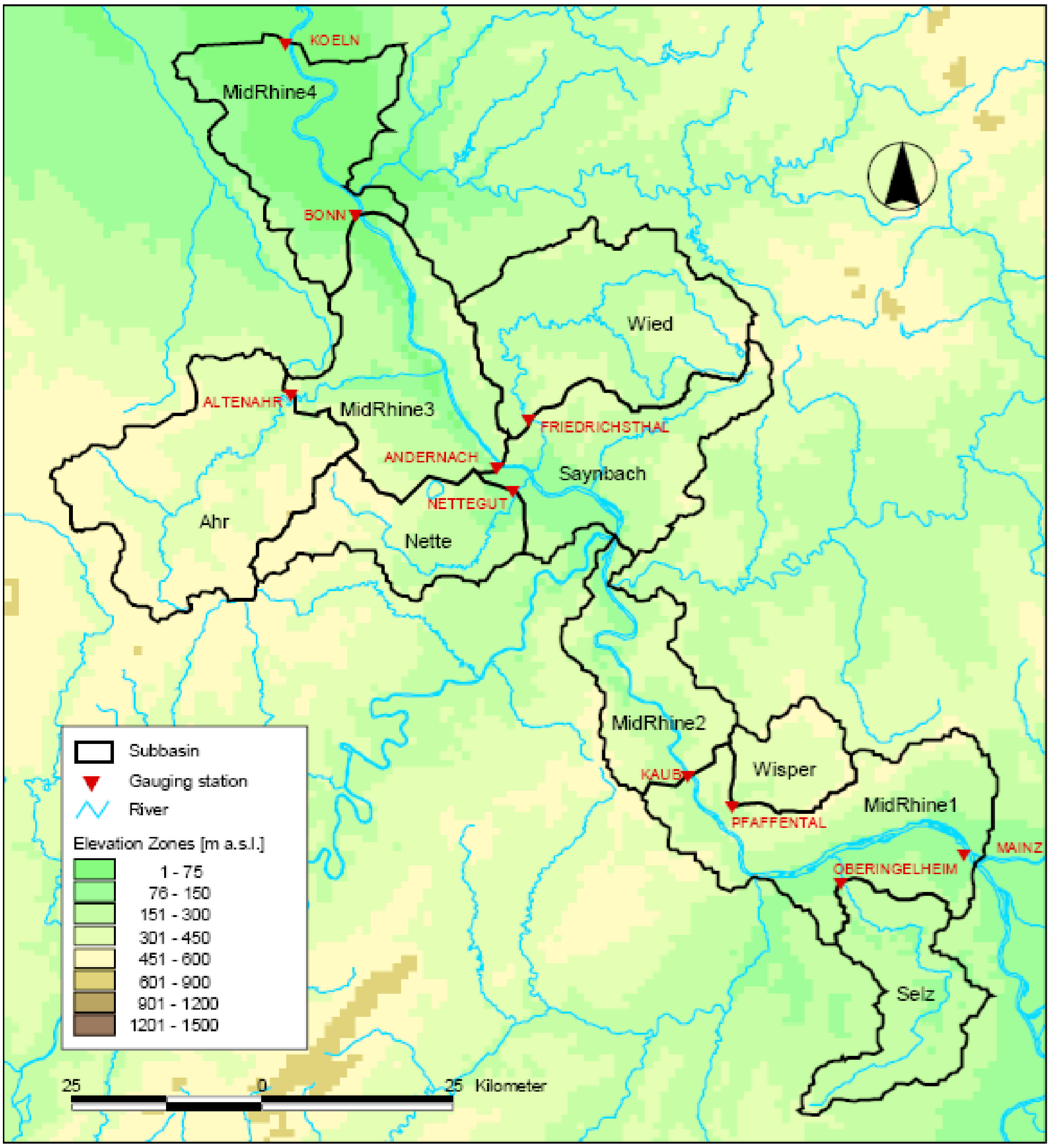

Figure 2-4. Map of sub-basins that are input into the SOBEK model between Mainz and Köln.

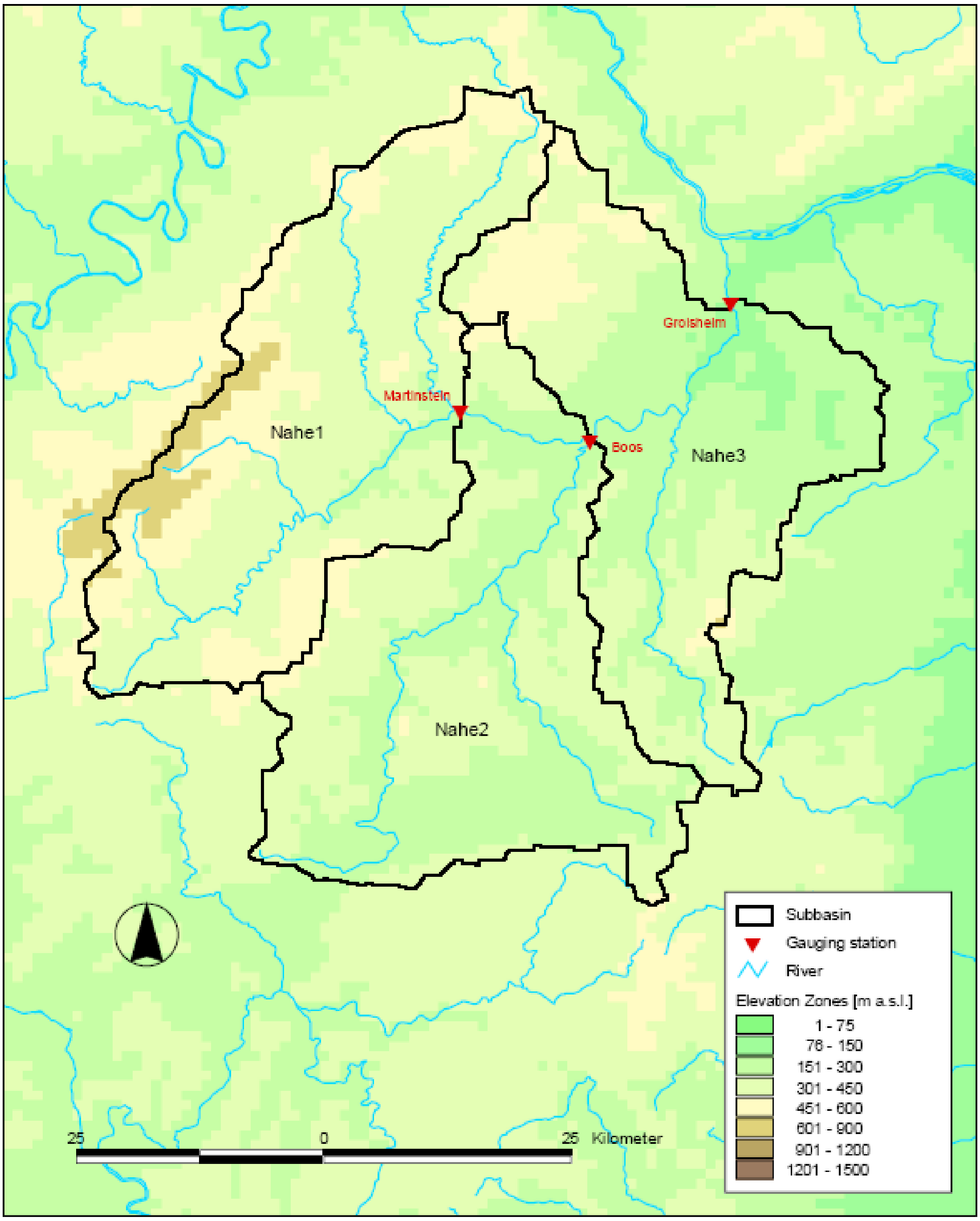

Figure 2-5. Map of sub-basins of the Nahe that are input into the SOBEK model between Mainz and Kaub.

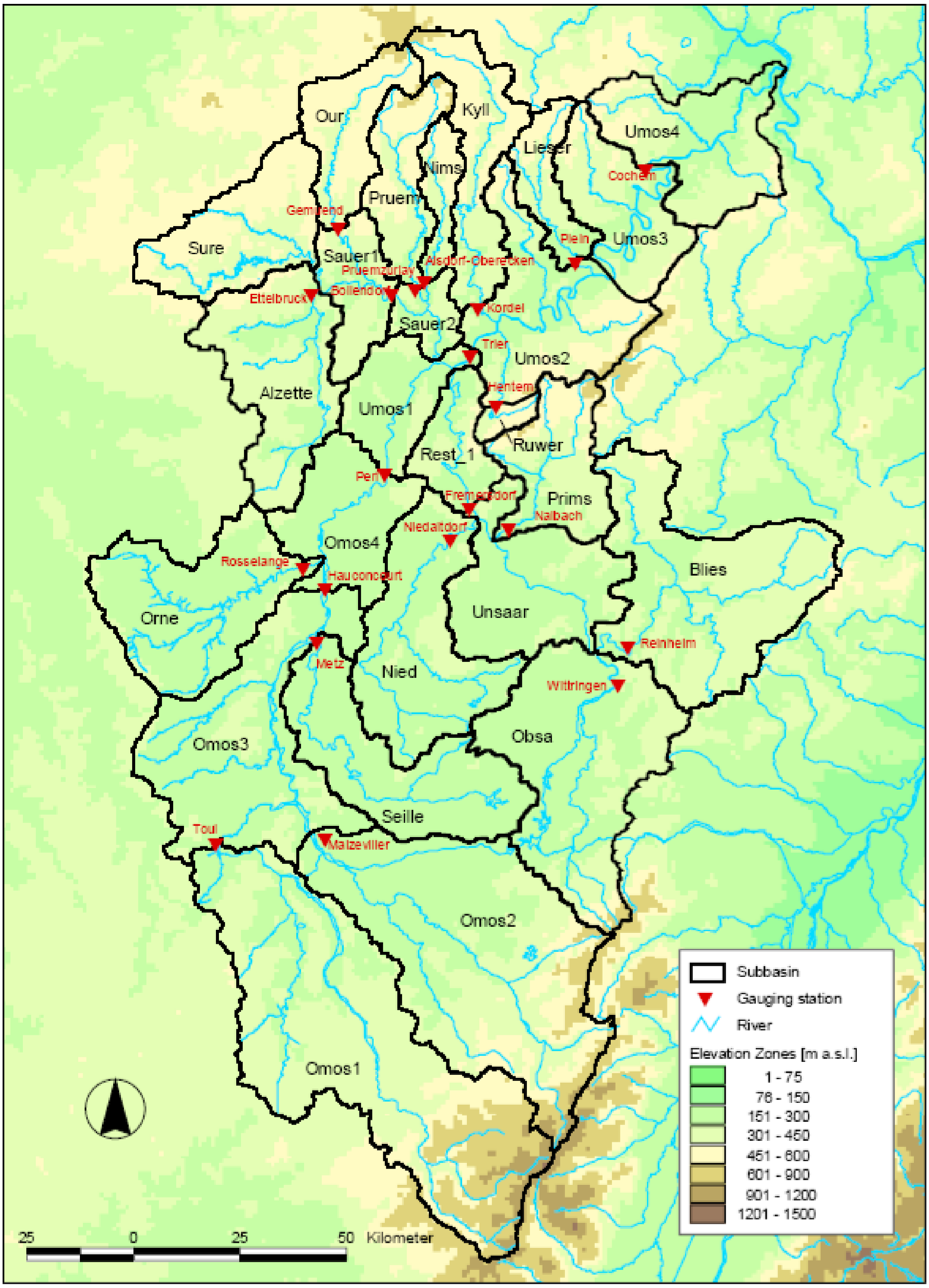

Figure 2-6. Map of sub-basins of the Mosel that are input into the SOBEK model between Kaub and Koblenz.

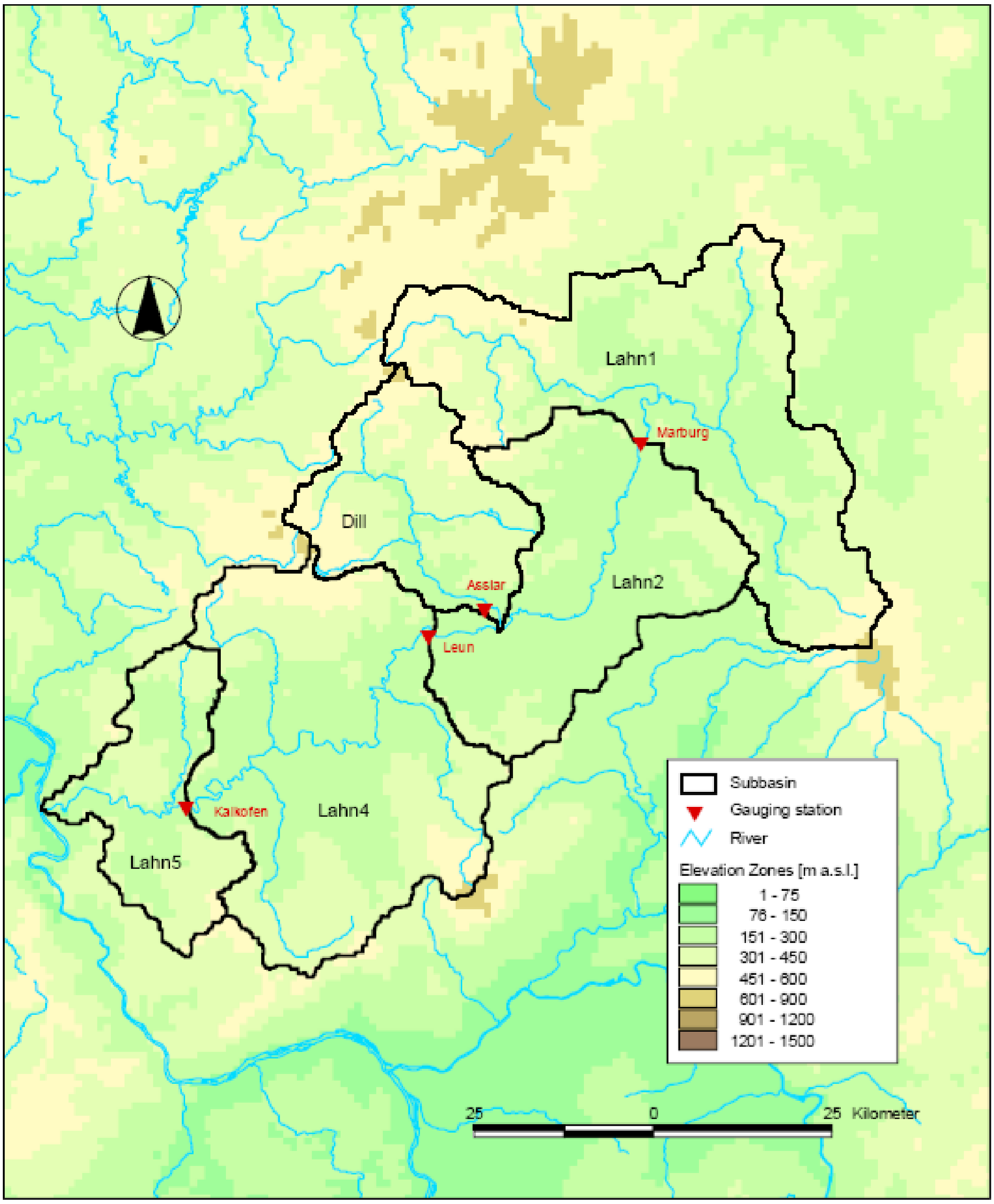

Figure 2-7. Map of sub-basins of the Lahn that are input into the SOBEK model between Kaub and Koblenz.

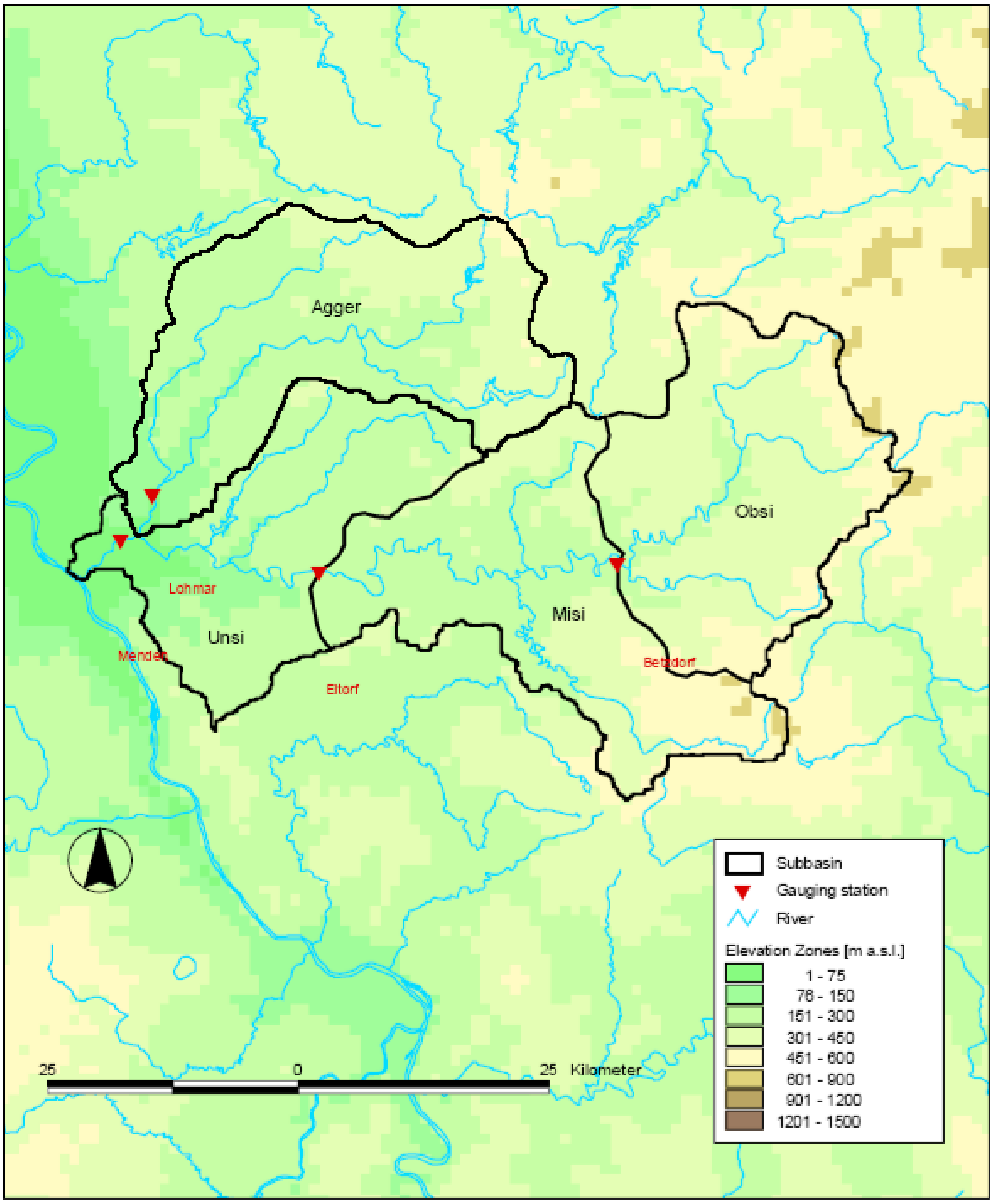

Figure 2-8. Map of sub-basins of the Sieg that are input into the SOBEK model between Bonn and Köln.

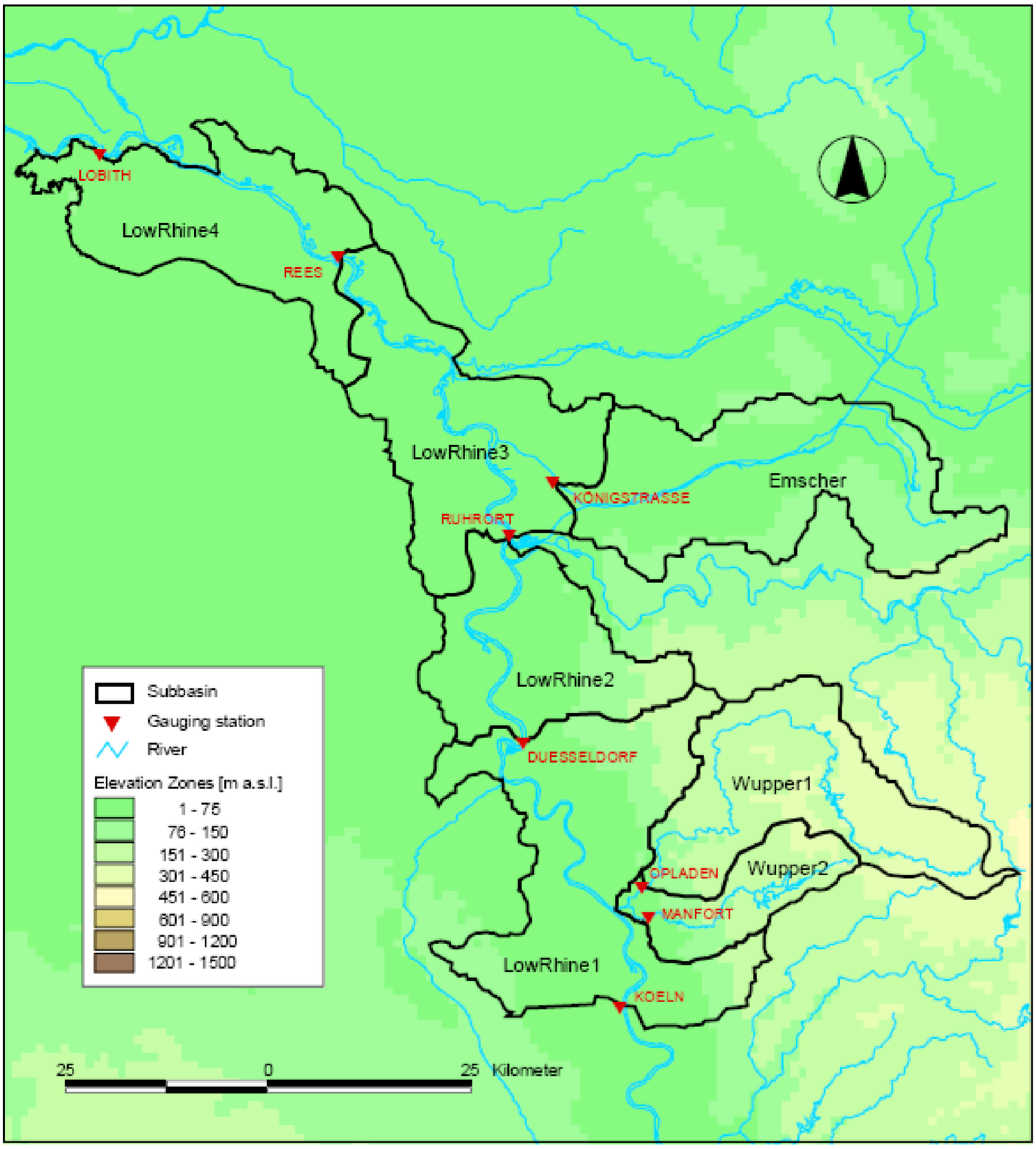

Figure 2-9. Map of sub-basins that are input into the SOBEK model between Köln and Lobith.

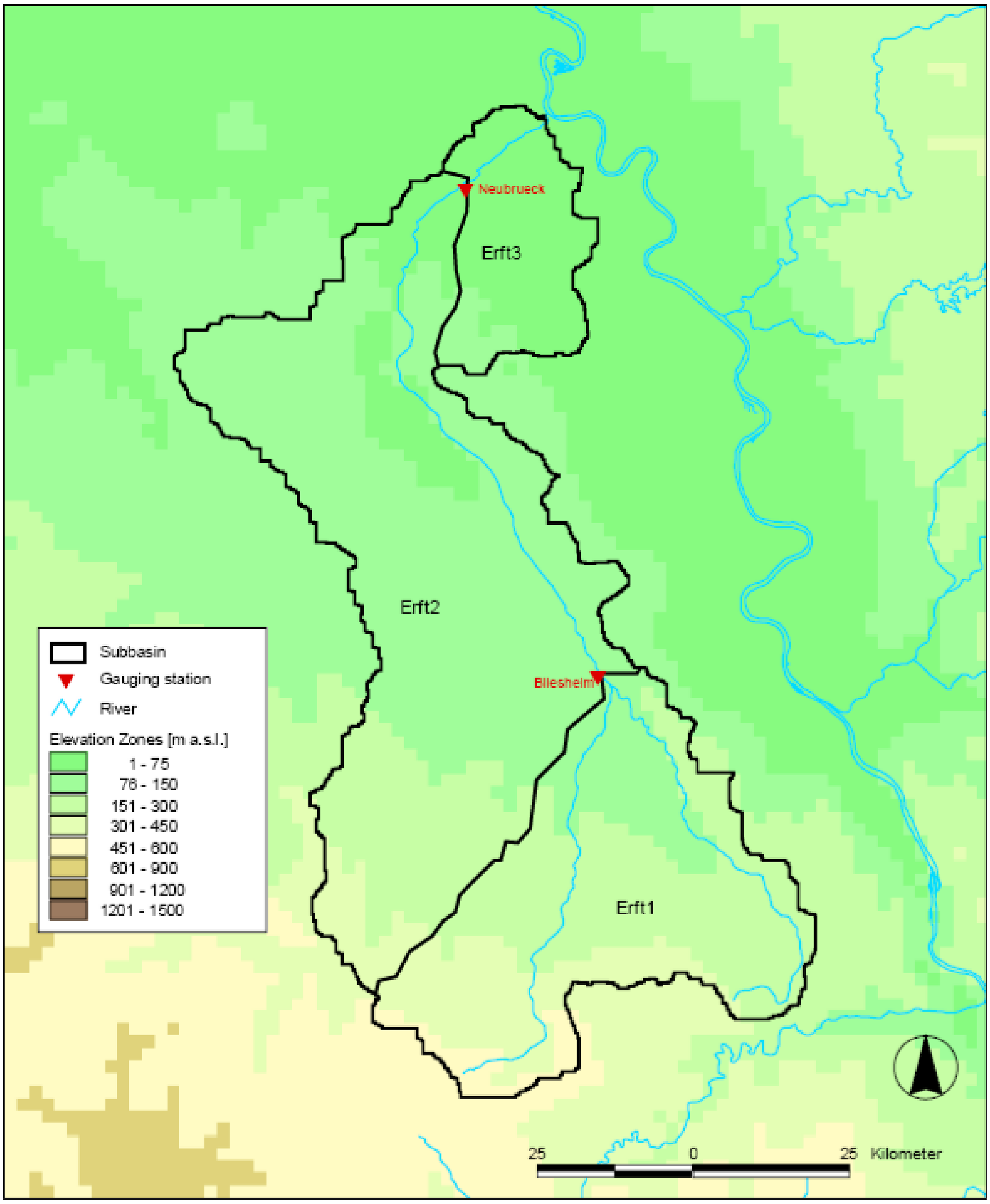

Figure 2-10. Map of sub-basins of the Erft that are input into the SOBEK model between Bonn and Köln.

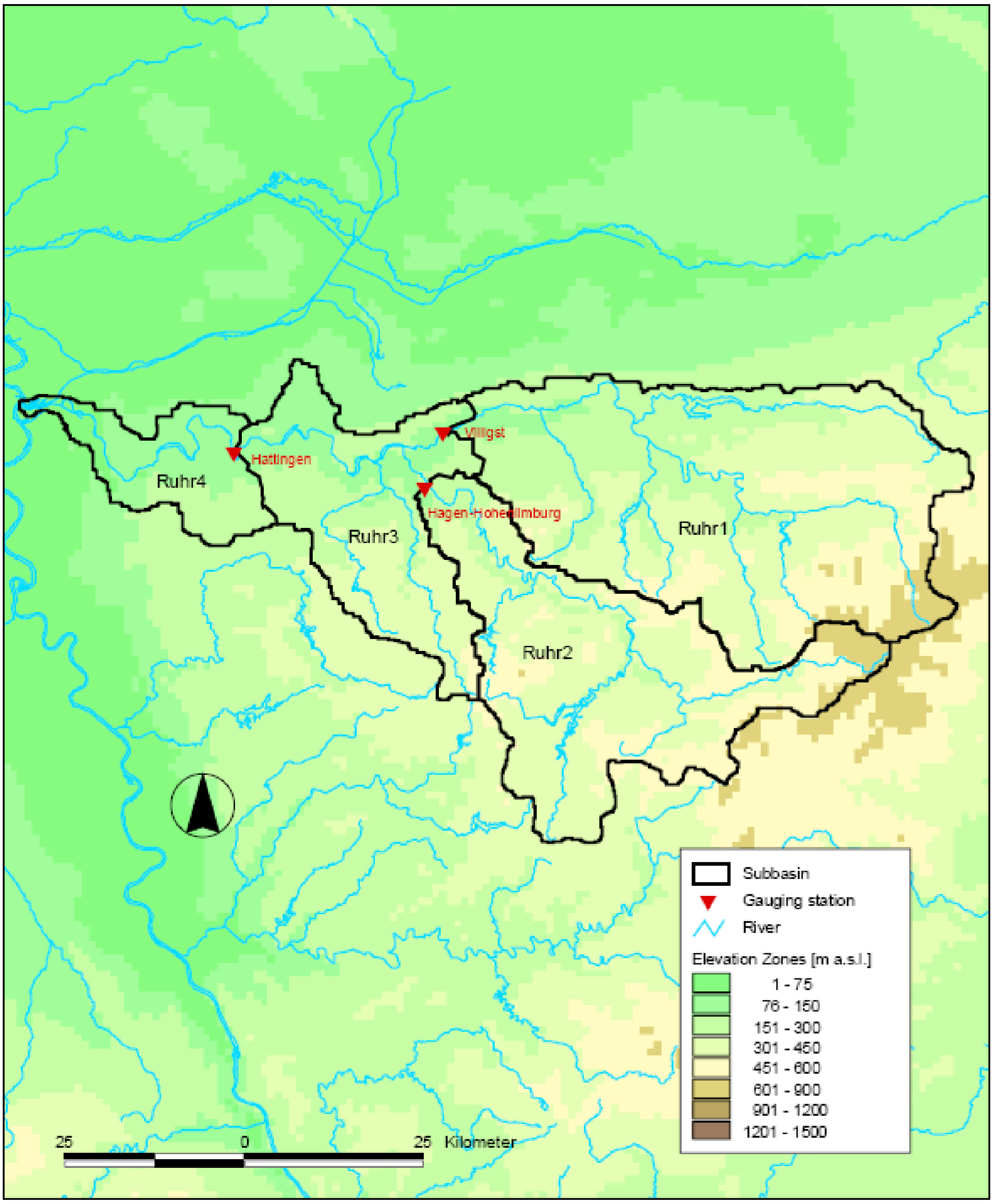

Figure 2-11. Map of sub-basins of the Ruhr that are input into the SOBEK model between Düsseldorf and Ruhrort.

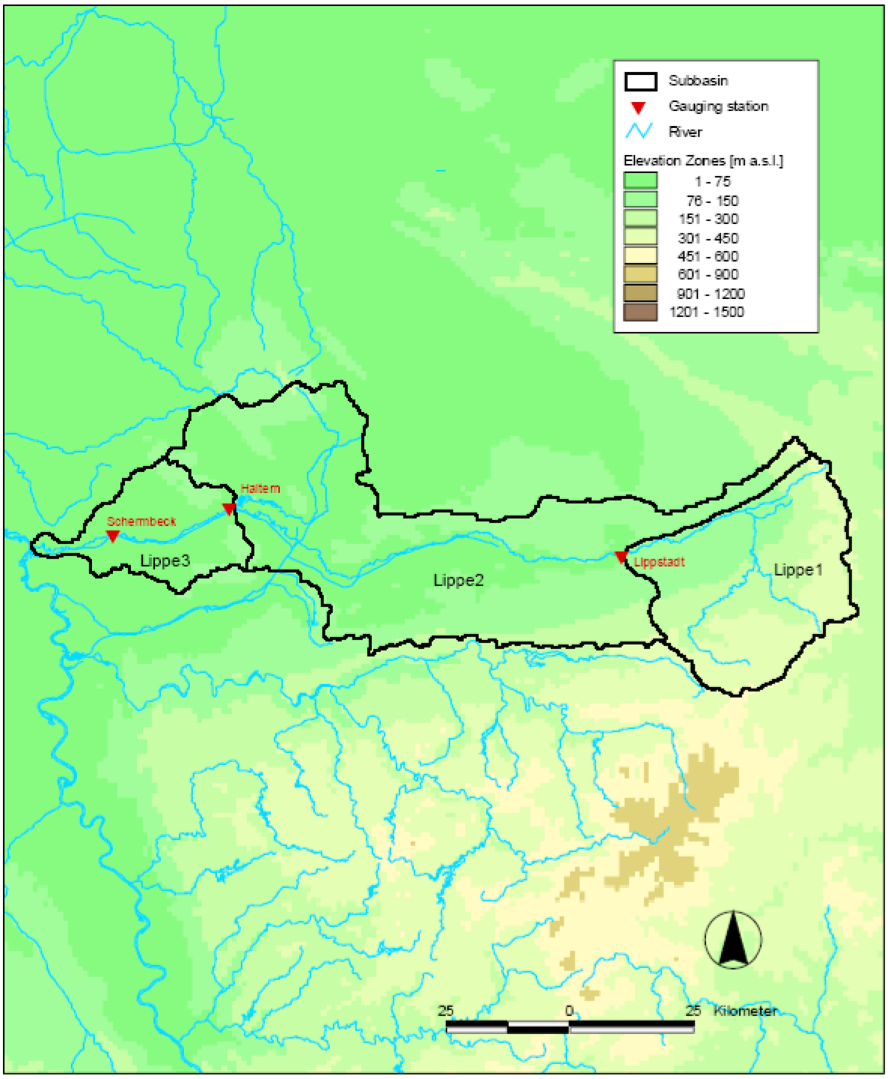

Figure 2-12. Map of sub-basins of the Lippe that are input into the SOBEK model between Ruhrort and Rees.

2.6 Specification of data requirement

For the water balance study the following boundary conditions for FEWS-Rijn are meaningful:

1. at the upper and lower boundaries of the 13 river sections water level and discharge time series, as discussed in Sub-section 2.5
2. water level and discharge time series for the Neckar, Main, Lahn and Mosel boundaries at resp. Rockenau, Raunheim, Kalkofen and Cochem
3. all measured inflows used in the calibration of the partial SOBEK models
4. all inflow data used in the operation of FEWS-Rijn prior to a forecast. This comprises basically all bold typed inflows presented in the Tables 2-3 to 2-16, which consist mainly of HBV generated flows supplemented with measurements of the major tributaries;
5. In addition to the flow data specified under 4, HBV generated flow data for the key Rhine stations and the major tributaries replacing the historical discharge series.

With the data sets specified under 1, 2, 3, 4 and 5 the quality of the input data for the SOBEK model can be assessed. The data requirement is worked out in Table 2-18 under the heading “Measurements”. Only some lateral inflow in the lower reach of the Rhine d/s of Andernach stems from the HBV model. The data requirement has been derived from the annexes to the memo’s of Van der Veen (2005) and Lammersen (2006).

With the data sets specified under 1, 2 and 4 the quality of the input data of the SOBEK model FEWS-Rijn can be analysed. The list has been derived from the Tables 2-3 to 2-16. The data requirement has been worked out in Table 2-18 under the heading “FEWS-Rijn”.

By combining the data requirements of 4 and 5 FEWS-Rijn input is obtained, which is solely derived from the HBV-model. The additional requirement is listed in Table 2-17. By a comparison of these HBV generated flows with the measured discharges the quality of the HBV-model can be assessed.

Table 2-17 HBV output at locations FEWS-Rijn normally receives measurements

River Section	Measurement	HBV
1 Maxau - Speyer	Maxau	UpRh2 3+
2 Speyer -Worms	Rockenau	Neckar4+
3 Worms - Mainz	Raunheim	Main8+
4 Mainz - Kaub	Grolsheim	Nahe3+
5/6 Kaub - Koblenz	Cochem Kalkofen	Umos3+ Lahn4+
Koblenz- Andernach	Friedrichsthal	Wied
7 Andernach - Bonn	Altenahr	Ahr
8 Bonn - Köln	Menden	Unsi+
9 Köln - Düsseldorf	Opladen Neubrück	Wupper1+ Erft2+
10 Düsseldorf - Ruhrort	Hattingen	Ruhr3+
11 Ruhrort - Wesel	Königstrasse	Emscher
12 Wesel - Rees	Schermbeck	Lippe3+-
13 Rees - Emmerich	-	-
14 Emmerich - Lobith	-	-

The above specification leads to 3 data sets:

1. All FEWS-Rijn input from measurements (as used during calibration of the SOBEK model)
2. Normal FEWS-Rijn input, and
3. All FEWS-Rijn input from HBV-model

The data series should at least cover the period July 1993 to July 2004.

Table 2-18 Overview of data requirement

River Section	ID	River/ Tributary	Measurements	Factor hydro.	Shift (hr)	FEWS-Rijn	Factor hydro.	Shift (hr)	Data req.
1	MM1_3037	Rhine	Maxau	1.00	0.00	Maxau	1.000	0.00	H, Q
Maxau	MM1_3039	Alb	Ettlingen	1.00	4.35	AlbPfinz	0.390	4.35	Q
Speyer	MM1_3040	Pfinz	Berghausen	1.00	7.04	AlbPfinz	0.610	7.04	Q
	MM1_3042	Queich	Siebeldingen	1.00	5.35	QuiechSp	0.390	5.35	Q
	MM1_3043	Speyerbach	Neustadt/Wst.	1.00	4.74	QuiechSp	0.610	4.74	Q
	MM1_3044	Erlenbach	Rheinzabern	11.02	0.00	UpRhine1	1.000	0.00	Q
	-	Rhine	Speyer	-	-	-	-	-	H, Q
2	-	Rhine	Speyer	-	-	-	-	-	H, Q
Speyer	MM1_3045	Kraichbach	Ubstadt	2.48	0.00	UpRhine2	0.341	0.00	Q
Worms	NE1_5615460	Neckar	Rockenau	1.00	0.00	Rockenau	1.000	0.00	H, Q
	NE1_24114	Elsenz	Meckesheim	2.10	2.96	Elsenz	1.000	0.00	Q
	NE1_24115	Itter	Eberbach	1.66	1.39	Neckar5	0.227	0.00	Q
	NE1_24116-24121	Neckar-lat	Eberbach	3.72	0.00	Neckar5	0.773	0.00	Q
	MM2_3046	Leinbach	Wiesloch	2.03	0.00	UpRhine2	0.659	0.00	Q
	MM1_3049	Pfrimm	Monsheim	4.24	0.00	UpRhine3	1.000	0.00	Q
	-	Rhine	Worms	-	-	-	-	-	H, Q

River Section	ID	River/ Tributary	Measurements	Factor hydro.	Shift (hr)	FEWS-Rijn	Factor hydro.	Shift (hr)	Data req.
3	-	Rhine	Worms	-	-	-	-	-	H, Q
Worms	MM1_3053	Rhine-lat	Monsheim	2.09	0.00	UpRhine4	0.370	0.00	Q
Mainz	MM1_3051	Weschnitz	Lorch	1.00	2.50	WeschMod	0.810	2.50	Q
	MM1_3052	Modau	Eberstadt	1.00	2.78	WeschMod	0.190	2.78	Q
	MM1_3054	Schwarzbach	Naunheim	5.98	0.00	UpRhine4	0.630	0.00	Q
	MA3_15910		Epstein	0.624	2.60	Main8 (sub-basin)	0.082	-	Q
	MA3_58596	Main	Raunheim	1.00	0.00	Raunheim	1.000	0.00	H, Q
	-	Rhine	Mainz	-	-	-	-	-	H, Q
4	-	Rhine	Mainz	-	-	-	-	-	H,Q
Mainz	RM1_2148	Selz	Oberingelheim	1.03	0.00	Selz	1.000	0.00	Q
Kaub	RM1_2149	Rhine-lat	Pfaffental	1.79	0.00	MidRhine1	0.710	0.00	Q
	RM1_2150	Nahe	Grolsheim	1.01	0.00	Grolsheim	1.01	0.00	Q
	RM1_2151	Wisper	Pfaffental	1.23	0.00	Wisper	1.000	0.00	Q
	RM1_2153	Rhine-lat	Pfaffental	0.77	0.00	MidRhine1	0.290	0.00	Q
	-	Rhine	Kaub	-	-	-	-	-	H, Q
5/6	-	Rhine	Kaub	-	-	-	-	-	H, Q
Kaub	RM1_2154	Rhine-lat	Pfaffenthal	2.16	0.00	MidRhine2	1.000	0.00	Q
Koblenz	LA1_5365	Lahn	Kalkofen	1.00	0.00	Kalkofen	1.000	0.00	Q
	LA1_1489	Gelbach	Weinähr	1.03	0.49	Lahn5	0.348	0.00	Q
	LA1_3563		Weinähr	1.12	0.00	Lahn5	0.381	0.00	Q
	LA1_1490	Mühlbach	Schulmühle	1.18	1.25	Lahn5	0.271	0.00	Q
	-	Rhine	Koblenz	-	-	-	-	-	H, Q

River Section	ID	River/ Tributary	Measurements	Factor hydro.	Shift (hr)	FEWS-Rijn	Factor hydro.	Shift (hr)	Data req.
Koblenz	-	Rhine	Koblenz	-	-	-	-	-	H, Q
Andernach	MO1_409	Mosel	Cochem	1.00	0.00	Cochem	1.00	0.00	H, Q
	MO1_1815	Mosel-lat	n.a. (Umos4)	1.00	0.00	Umos4	1.00	0.00	Q
	RM1_2158	Nette	Nettegut	1.01	0.00	Nette	1.010	0.00	Q
	RM1_2157-59	Wied	Friedrichsthal	1.35	0.00	Friedrichsthal	1.35	0.00	Q
	RM1-2160	Rhine-lat	Friedrichsthal	0.18	0.00	Saynbach	0.570	0.00	Q
	-	Rhine	Andernach	-	-	-	-	-	H, Q
7	-	Rhine	Andernach	-	-	-	-	-	H, Q
Andernach	AL1_6	Ahr	Altenahr/Rhoven	1.00	5.00	Altenahr	1.00	5.00	Q
Bonn	AL1_1402	Rhine-lat	n.a (MidRhine3)	1.00	0.00	MidRhine3	1.00	0.00	Q
	-	Rhine	Bonn	-	-	-	-	-	H, Q
8	-	Rhine	Bonn	-	-	-	-	-	H, Q
Bonn	AL1_8	Sieg	Menden	1.00	1.50	Menden	1.00	1.50	Q
Köln	AL1_1403	Rhine-lat	n.a (MidRhine4)	1.00	0.00	MidRhine4	1.000	0.00	Q
	-	Rhine	Köln	-	-	-	-	-	H, Q
9	-	Rhine	Köln	-	-	-	-	-	H, Q
Köln	AL1_10	Wupper	Opladen	1.36	1.00	Opladen	1.36	1.00	Q
Düsseldorf	AL1_11	Erft	Neubrück	1.15	2.00	Neubrück	1.15	2.00	Q
	AL1_1404	Rhine-lat	n.a (LowRhine1)	1.00	0.00	LowRhine1	1.000	0.00	Q
	-	Rhine	Düsseldorf	-	-	-	-	-	H,Q
10	-	Rhine	Düsseldorf	-	-	-	-	-	H, Q
Düsseldorf	AL1_13	Ruhr	Hattingen	1.09	10.00	Hattingen	1.09	10.00	Q
Ruhrort	AL1_1405	Rhine-lat	n.a (LowRhine2)	1.00	0.00	LowRhine2	1.000	0.00	Q
	-	Rhine	Ruhrort	-	-	-	-	-	H,Q

River Section	ID	River/ Tributary	Measurements	Factor hydro.	Shift (hr)	FEWS-Rijn	Factor hydro.	Shift (hr)	Data req.
11	-	Rhine	Ruhrort	-	-	-	-	-	H, Q
Ruhrort	AL1_4	Emscher	Königstrasse	1.11	2.00	Königstrasse	1.11	2.00	Q
Wesel	AL1_1	Rhine	n.a (LowRhine3)	0.210	0.00	LowRhine3	0.210	0.00	Q
	-		Wesel	-	-	-	-	-	H, Q
12	-	Rhine	Wesel	-	-	-	-	-	H, Q
Wesel	AL1_1407	Rhine-lat	n.a	-	-	LowRhine3	0.79	0.00	Q
Rees	-	Rhine	Rees	-	-	-	-	-	H, Q
13	-	Rhine	Rees	-	-	-	-	-	H, Q
Rees	AL1_1408	Rhine-lat	n.a	-	-	LowRhine4	a	0.00	Q
Emmerich	-	Rhine	Emmerich	-	-	-	-	-	H, Q
14	-	Rhine	Emmerich	-	-	-	-	-	H, Q
Emmerich	AL1_1408	Rhine-lat	n.a	-	-	LowRhine4	1-a	0.00	Q
Lobith	-	Rhine	Lobith	-	-	-	-	-	H, Q

3 Database development

3.1 General

In this chapter the development of the database of observed water levels and discharges and HBV generated discharge series at the locations between Maxau and Lobith specified in Chapter 2 is dealt with, including:

- Data collection,
- Data entry,
- Series availability, and
- Data validation.

Identification of missing data and procedures to fill-in the missing data are discussed in Chapter 4.

3.2 Observed water levels and discharges

3.2.1 Data collection

Observed water level and discharge data were received on CD and by e-mail from the following sources:

- BfG:
  a) Hourly discharge data and hourly water levels for 15 main stations in the Rhine from Maxau to Emmerich
  b) Hourly and 15-minute discharge and water level data of Neckar, Main, Lahn, Mosel and tributaries, including also ADM (Ultraschall) data
  c) Non-equidistant discharge data of stations Menden, Opladen, Neubrück, Königsstrasse and Schermbeck
- RIZA
  d) Hourly discharge data and hourly water levels for Lobith.

An overview of the delivered data is presented in Table 3-2. The data are presented according to the 13 river sections as defined in Table 2-1. The following data type definition is used, conformable to the series types defined in the database:

- HH = historical water levels
- QH = historical discharges (i.e. discharged derived from water levels)
- HU = historical water levels from ADM (Ultraschall) measurements
- QU = historical discharges measured by ADM
- HA = historical water levels as used in FEWS-Rijn

From Table 3-2 it is observed that data are generally available for the period November 1989 till December 2004. Though the analyses will be limited to the period July 1993 to July 2004, the BfG has requested to develop the database as from November 1989 onward.

In the last column of the table the time interval of the series is indicated; NE means non-equidistant data.

Table 3-1 Overview of collected observed water level and discharge data Maxau-Lobith.

RS	River	Station ID	Type	period from	To	Δt (min)
1	Rhine	Maxau	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Alb	Ettlingen	QH	1-11-1989 0:00	31-12-2004 23:00	60
	Erlenbach	Rheinzabern	QH	1-11-1989 0:00	31-12-2004 23:00	15
	Pfinz	Berghausen	QH	1-11-1989 0:00	31-12-2004 23:00	60
	Quiech	Siebeldingen	QH	1-1-1990 0:00	31-12-2004 23:00	15
	Speyerbach	Neustadt	QH	1-1-1990 0:00	31-12-2004 23:00	15
2	Rhine	Speyer	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Krachbach	Ubstadt	QH	1-11-1989 0:00	31-12-2004 23:00	15
	Neckar	Rockenau	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
			QU	18-06-2001 0:00	31-12-2004 23:00	15
	Itter	Eberbach	QH	1-11-1989 0:00	31-12-2004 23:00	60
	Elsenz	Meckesheim	QH	1-11-1989 0:00	31-12-2004 23:00	60
	Leimbach	Wiesloch	QH	1-11-1989 0:00	31-12-2004 23:00	15
	Pfrimm	Monsheim	QH	1-11-1989 0:00	31-12-2004 23:00	15
3	Rhine	Worms	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Weschnitz	Lorsch	QH	1-11-1989 0:00	31-12-2004 23:00	15
	Modau	Eberstadt	QH	1-11-1989 0:00	31-12-2004 23:00	15
	Schwarzbach	Nauheim	QH	1-11-1989 0:00	31-12-2004 23:00	15
	Main	Raunheim	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
			QU	18-06-2001 0:00	31-12-2004 23:00	15
			HU	1-11-1989 0:00	31-12-2004 23:00	15
			HA	15-12-2000 0:00	29-09-2005 23:00	60
	Main	Frankfurt	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Schwarzbach	Eppstein	QH	1-11-1989 0:00	31-12-2004 23:00	15
4	Rhine	Mainz	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Selz	Oberingelheim	QH	1-1-1990 0:00	31-12-2004 23:00	15
	Nahe	Grolsheim	QH	1-11-1989 0:00	31-12-2004 23:00	15
	Wisper	Pfaffental	QH	1-11-1989 0:00	31-12-2004 23:00	15

RS	River	Station ID	Type	period from	To	Δt (min)
5/6	Rhine	Kaub	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Lahn	Kalkhofen	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Muehlbach	Schmuehle	QH	1-1-1990 0:00	31-12-2004 23:00	15
	Gelbach	Weinaehr	QH	1-1-1990 0:00	31-12-2004 23:00	15
	Rhine	Koblenz	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Mosel	Cochem	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Mosel	Alken	QU	1-11-1999 0:00	31-12-2004 23:00	15
			HU	1-11-1999 0:00	31-12-2004 23:00	15
		Nettegut	QH	1-1-1990 0:00	31-12-2004 23:00	15
		Friederichstal	QH	1-1-1990 0:00	31-12-2004 23:00	15
7	Rhine	Andernach	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Ahr	Altenahr	QH	1-11-1992 0:00	31-12-2004 23:00	60/15
8	Rhine	Bonn	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Sieg	Menden	QH	31-10-1989 0:00	31-12-2004 23:00	15
9	Rhine	Köln	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Wupper	Opladen	QH	31-10-1989 0:00	31-12-2004 23:00	15
	Erft	Neubrück	QH	1-11-1989 0:00	31-12-2004 23:00	15
10	Rhine	Düsseldorf	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Ruhr	Hattingen	QH	1-11-1989 0:00	31-12-2004 23:00	15
11	Rhine	Ruhrort	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Emscher	Koenigstrasse	QH	1-11-1989 0:00	31-12-2004 23:00	15
	Lippe	Schermbeck	QH	1-11-1989 0:00	31-12-2004 23:00	15
12	Rhine	Wesel	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
13	Rhine	Rees	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
14	Rhine	Emmerich	QH	1-11-1989 0:00	31-12-2004 23:00	60
			HH	1-11-1989 0:00	31-12-2004 23:00	60
	Rhine	Lobith	QH	1-1-1990 0:00	31-12-2005 23:00	60
			HH	1-1-1990 0:00	31-12-2005 23:00	60

3.2.2 Data entry

All historical data have been transferred to the Maxau-Lobith database under HYMOS. At the end of phase 1 the HYMOS database has also to be converted into a MS Access database. HYMOS is a data storage and processing system for hydro-meteorological data developed by WL | Delft Hydraulics. Prior to the transfer to HYMOS, the delivered data files have been screened and corrected to allow error free transfer to HYMOS. The following adjustments were made to make the original data-sets available for HYMOS:

- In the original dataset time ranges from 01:00 to 24:00. In HYMOS time ranges from 00:00 to 23:00. To make it match, 24:00 in the original set is equal to 00:00 of the next day in HYMOS.
- The missing data value in HYMOS is set to -999.99. In the original files the missing data value was coded by '---', '—', '-777.0', '999' or 'RWLuecke'. These values were replaced by -999.99.
- The series for Eberbach missed the months August and September 2000; consequently, the gap was filled in with the missing data value.
- Station Raunheim on Main misses all flow values < 500 m^3/s in the period 1993 to 2004. This is caused by the stage discharge curve, which is not valid for flow values <500 m^3/s.
- For station Rheinzabern the period 01-07-2003 to 06-07-2003 appeared twice, so one set was taken out. Similarly, for station Monsheim the doubled values for 1-11-2003 were taken out.

Before the data transfer, the characteristics of the stations in Table 3-1 have been defined in HYMOS with their geographical reference, see Figure 3.2. All equidistant time series are stored in the database with their original time interval. Aggregates are also stored to facilitate data validation.

For the stations Menden, Opladen, Neubrück, Königsstrasse and Schermbeck non-equi-distant data has been delivered. In HYMOS functions are available to quickly transform these data into equidistant data. Of the transformation options the 'linear interpolation' option has been used. It implies that the series values at hourly time steps are a linear interpolation between surrounding non-equidistant series values. In Figure 3-1 a result of the transformation for station Schermbeck is presented, showing its validity.

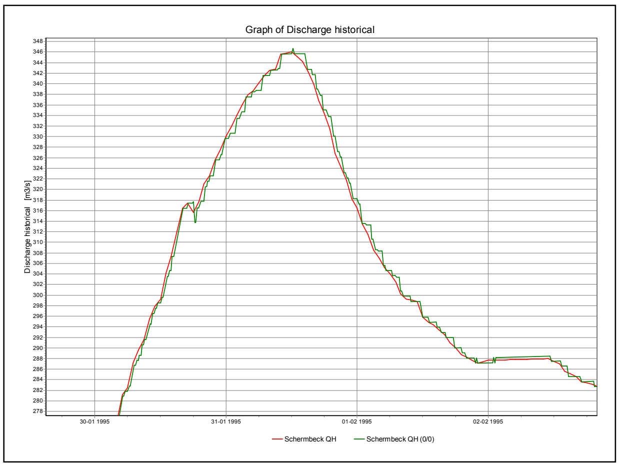

Figure 3-1 Historical discharge series of station Schermbeck, green line shows original (non-equidistant) data, red line shows the same data transformed to hourly (equidistant) values.

The layout of the station selection screen in HYMOS developed for this project is presented in Figure 3-2 showing the gauging stations in the Rhine catchment from Maxau to Lobith.

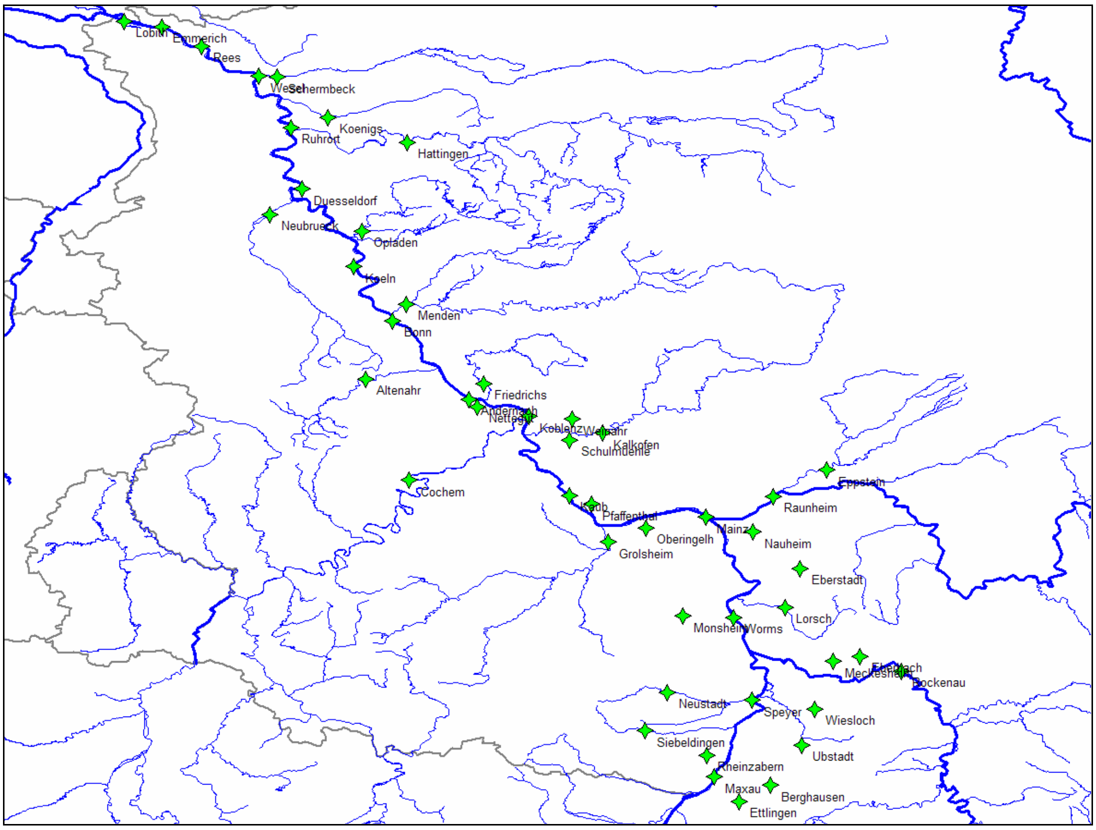

Figure 3-2 Layout of station selection screen in HYMOS for the Maxau-Lobith water balance database

3.2.3 Series availability

The observed water levels and discharges as transferred to the Maxau-Lobith database in HYMOS cover the required series for the water balance analyses fully; the available series include the required period July 1993 to July 2004. Only the ADM discharge series for Rockenau, Raunheim and Cochem (site Alken), which are intended to replace the discharge series derived from water levels by a discharge rating curve for controlled flow conditions, only partly cover the required period:

- Rockenau as from 18-6-2001
- Raunheim as from 30-1-2003, and
- Cochem as from 1-11-1999 onward.

Note however, that when the year 2003 is selected for the analysis of low flows (as suggested by the Client) the available ADM-series are sufficient. For the identification of missing data in the available series reference is made to Chapter 4.

3.2.4 Data validation

All available data have been subjected to the following primary validation procedures:

- Inspection of single hydrographs on their natural development in particularly of the flow recessions and of anomalies in the low flow behaviour in successive years, and
- Comparison of hydrographs measured at neighbouring stations on their overall resemblance and occurrence and timing of the development of flood peaks.
- Stage-discharge relations of stations, for which water level and discharge series are available, have been inspected on their variation from year to year.

The first analyses showed that the data are generally consistent. A review of observed anomalies is presented below.

River section 1: Maxau-Speyer

- The low flows for station Neustadt lift as from 1995 onward, see Figure 3.3.

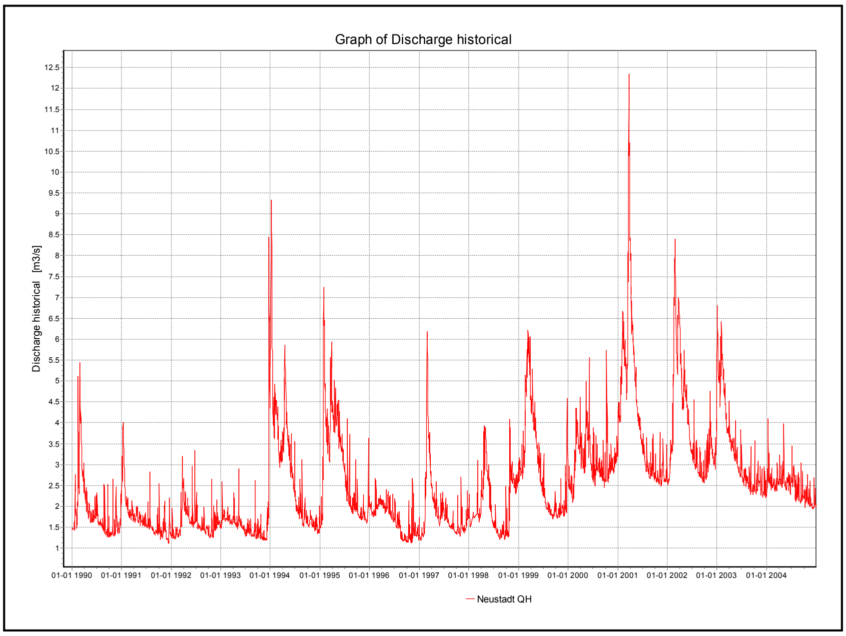

Figure 3.3 Historical discharge for station Neustadt

River section 2: Speyer-Worms

- Differences in low flow series QH (rating curve) and QU (ADM series) for station Rockenau, before 2004. The result for 2003 may be indicative for the quality of the rest of the low flow values in the QH series; historical low flows may be too high.

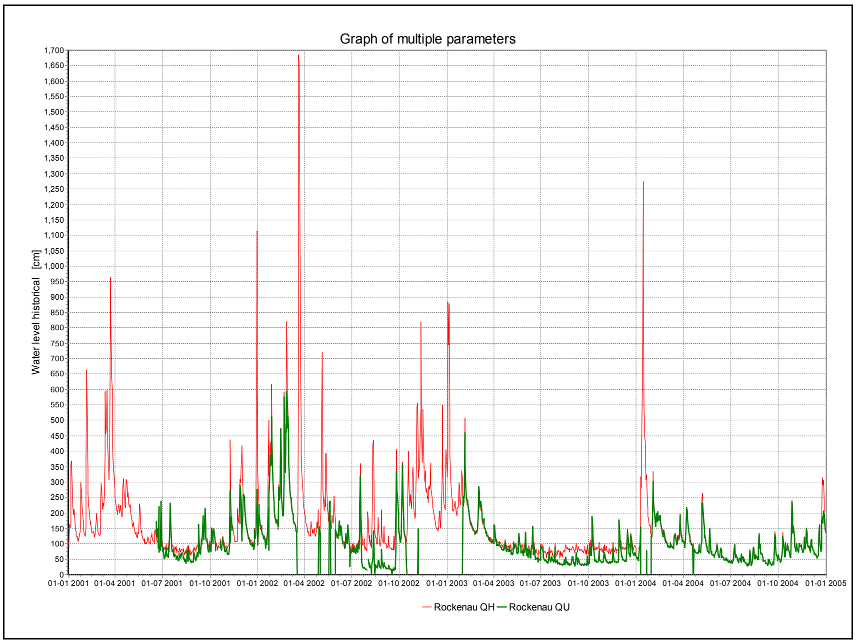

Figure 3-4 Comparison of discharge series of type QH and QU for Rockenau.

River section 3: Worms-Mainz

- Station Nauheim: value for 15-4-2003 to be replaced by interpolation.
- The QH flow series for station Raunheim is very incomplete and misses all flows < 500 m3/s as from 1994 onward, see Figure 3-5. The ADM-series (QU) is only available since 2003. The peak flows at Raunheim show good resemblance with the series of Frankfurt (see Figure 3-6), though the low flows show the same anomaly as for Rockenau in comparison to the ADM (QU) series (see Figure 3-7).

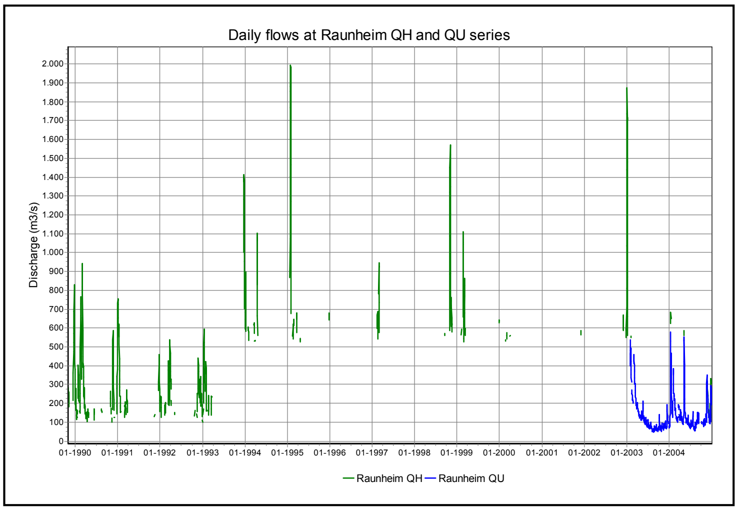

Figure 3-5 Available flow series of type QH (rating) and QU (ADM) for station Raunheim

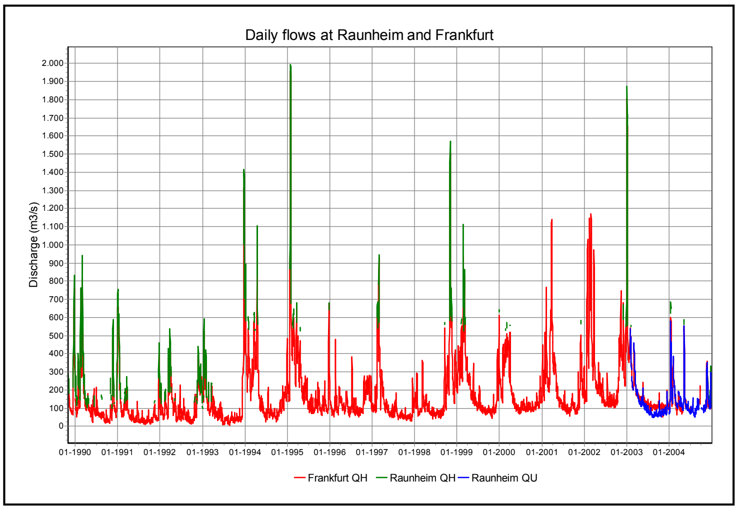

Figure 3-6 Comparison of flow series of stations Raunheim and Frankfurt

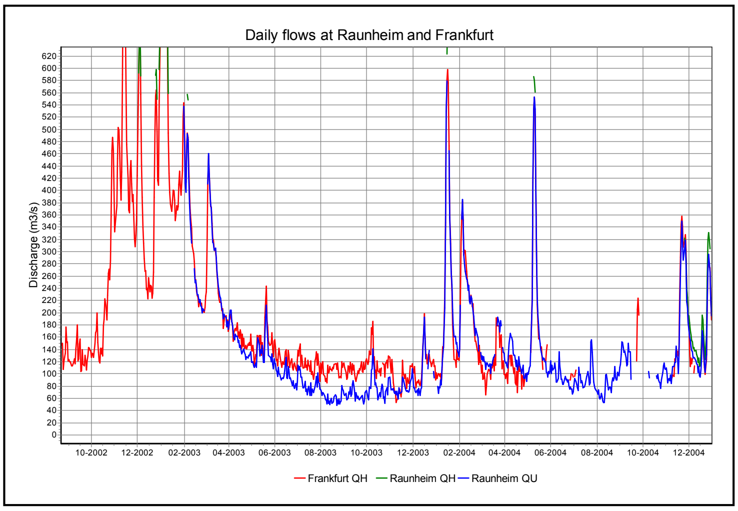

Figure 3-7 Comparison of flow series of stations Raunheim (QU) and Frankfurt (QH) for low flows

River section 4: Mainz-Kaub

- Flow series of Pfaffental unrealistic in January, March and July 2002

River section 5/6: Kaub-Koblenz & Koblenz-Andernach

- Anomalous values in water level and discharge series for Kalkofen in October 1997.
- Anomaly in QH series of Cochem relative to QU series.
- Some spikes in the water level series of Koblenz.

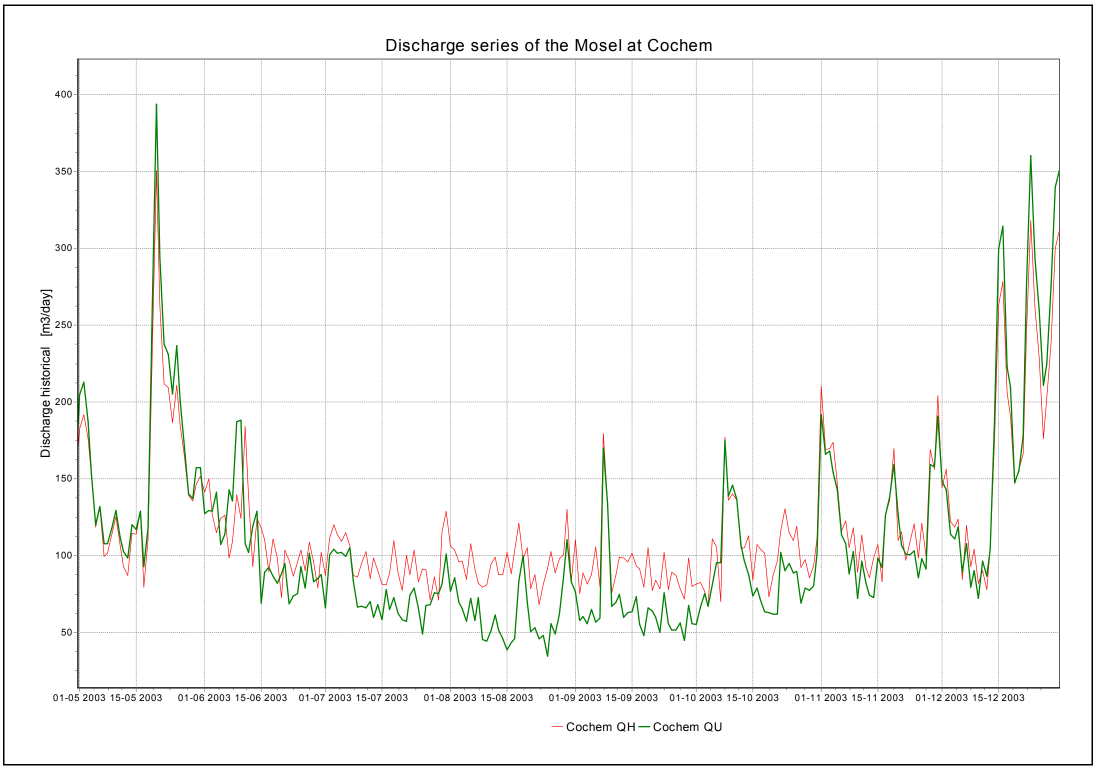

Figure 3-8 Comparison of QH and QU flow series of station Cochem

River section 14: Emmerich-Lobith

- Anomalous discharge record for Lobith between 1-8-2003 – 15-12-2003. It seems that the applied rating curve for water levels < 8 m needs adjustment.

Discharge rating curves

From an analysis of the stage – discharge relationship as derived from the available water level and discharge series it appears that a varying number of ratings have been applied in the period 1989 – 2004, as presented in Table 3-2.

Table 3-2 Number discharge ratings used for Rhine stations between 1-11-1989 ad 31-12-2004

Station	Nr of ratings	Station	Nr of ratings
Maxau	5	Köln	1
Speyer	2	Düsseldorf	2
Worms	1	Ruhrort	3
Mainz	1	Wesel	3
Kaub	1	Rees	3
Koblenz	1	Emmerich	3
Andernach	1	Lobith	5
Bonn	1		

Additional comments

A data correction report on discharge series of some key stations was available from the BfG, covering the data till 31-3-2001. The document states that validations were done on daily flow values. From this report the following is revealed for our period of interest:

- Maxau: discharge series for 1-11-1997 – 31-3-2001 have been recalculated using the official rating curve
- Cochem discharge series for 18-6-1999 – 4-12-1999 have been recomputed for water levels > 241 cm using the official rating curve
- Andernach: here you also find data correction for the time period of interest!

Also a file “Korrektur_1990-2000_Riza.xls” was obtained from the BfG containing partly corrected daily flow series of the stations Andernach, Cochem and Maxau for the period 1-11-1989 – 31-3-2001. The Maxau series were corrected as from 1-1-1997 onward. A comparison was made with the newly received flow data and particularly for Maxau significant differences were observed, as presented in the following figures.

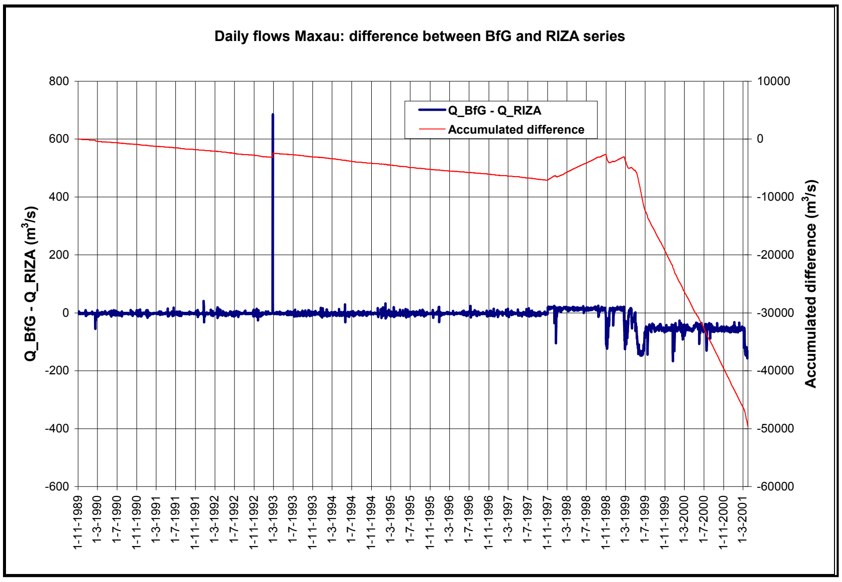

Figure 3-9 Difference and accumulated differences between discharge series for Maxau

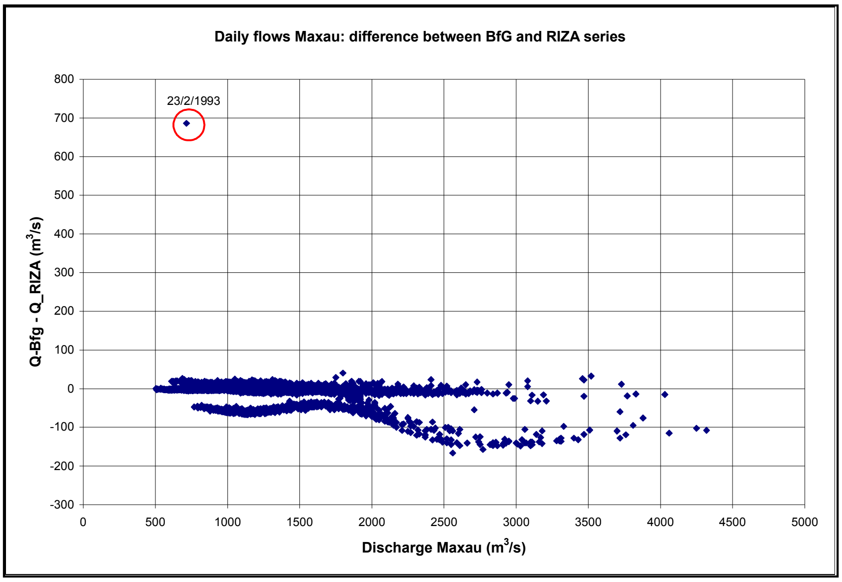

Figure 3-10 Difference between discharge series for Maxau as function of the flow rate.

It is observed that from mid 1999 onward the RIZA-series are consistently larger than the BfG series for Maxau over the full range of discharges. No information is available as to the application of the discharge series. The figures are shown as an example of effective graphical presentation of water balance results, proposed to be used in Phase 2.

3.3 HBV data

3.3.1 Data availability

In FewsNL Rhine, the laterals in the German part of the SOBEK model are derived from HBV model results. To calculate these laterals input data for the HBV model is necessary. The input data consist of synoptic (SYNOP) meteorological data and meteorological data from climate stations (TTRR) data. The SYNOP data is available from March 1996 onwards. TTRR data is available from 1990 onwards. The HBV simulations have been made from March 1996 onwards. Because of initial conditions of HBV, these data can be used from September 1996 onwards.

3.3.2 Data entry

The laterals of SOBEK have been calculated using FewsNL. The results have been exported to XML files and later on these files have been imported in the HYMOS database. Table 3.x provides an overview of the laterals, their Id in HYMOS and the corresponding Id in FewsNL.

Table 3.x. Overview of FewsNL Rhine SOBEK laterals in the database.

FewsNL Id	FewsNL parameter	SOBEK id	HYMOS Id	HYMOS Parameter
H-RN-0689	Q.uah	MM1_Maxau	Maxau	Qhbv
H-RN-0659	Q.uah	NE1_Ne10PRockenau	Rockenau	Qhbv
H-RN-1027	Q.uah	MA3_Raunheim	Raunheim	Qhbv
H-RN-0908	Q.uah	MO1_Cochem	Cochem	Qhbv
H-RN-0888	Q.uah	LA1_La05Kalkofen-neu	Kalkofen	Qhbv
H-RN-0913	Q.uah	RM1_Nahe	Grolsheim	Qhbv
H-RN-1026	Q.uah	AL1_Emscher	Koenigs	Qhbv
H-RN-0847	Q.uah	AL1_Erft	Neubrueck	Qhbv
H-RN-0900	Q.uah	AL1_Lippe	Schermbeck	Qhbv
H-RN-0957	Q.uah	AL1_Ruhr	Hattingen	Qhbv
H-RN-0984	Q.uah	AL1_Sieg	Menden	Qhbv
H-RN-1025	Q.uah	AL1_Wupper	Opladen	Qhbv
H-RN-0808	Q.uah	AL1_Ahr	Altenahr	Qhbv
H-RN-0038	Q.uh	MM1_Alb	Ettlingen	Qhbv
H-RN-0028	Q.uh	MM1_Pfinz	Berghausen	Qhbv
H-RN-0031	Q.uh	MM1_Speyerbach	Neustadt	Qhbv
H-RN-0024	Q.uh	MM1_Weschnitz	Lorsch	Qhbv
H-RN-0039	Q.uh	MM1_Modau	Eberstadt	Qhbv
H-RN-0029	Q.uh	RM1_Selz	Oberingelh	Qhbv
H-RN-0026	Q.uh	RM1_Wisper	Pfaffenthal	Qhbv
I-RN-0089	Q.uh	RM1_Saynbach	Saynbach	Qhbv
H-RN-0052	Q.uh	RM1_Nette	Nettegut	Qhbv
H-RN-0053	Q.uh	RM1_Wied	Friedrichs	Qhbv
I-RN-0012	Q.uh	NE1_Elsenz	Elsenz	Qhbv
I-RN-0013	Q.uh	NE1_Itter	Itter	Qhbv
I-RN-0037_Gelbach	Q.uh	LA1_Gelbach	Gelbach	Qhbv
I-RN-0037_Muehlbach	Q.uh	LA1_Muehlbach	Muehlbach	Qhbv
I-RN-0080	Q.uh	MM1_ZWE_Maxau-Speyer	UpRhine1	Qhbv

FewsNL Id	FewsNL parameter	SOBEK id	HYMOS Id	HYMOS Parameter
I-RN-0081a	Q.uh	MM1_ZWE_Speyer-47616	UpRhine2a	Qhbv
I-RN-0081b	Q.uh	MM1_ZWE_47616-Neckar	UpRhine2b	Qhbv
I-RN-0082	Q.uh	MM1_ZWE_Neckar-Worms	UpRhine3	Qhbv
I-RN-0084a	Q.uh	MM1_ZWE_L_Worms-Main	UpRhine4a	Qhbv
I-RN-0084b	Q.uh	MM1_ZWE_R_Worms-Main	UpRhine4b	Qhbv
I-RN-0087a	Q.uh	RM1_ZWE_Mainz_Nahe	MidRhine1a	Qhbv
I-RN-0087b	Q.uh	RM1_ZWE_Nahe_Kaub	MidRhine1b	Qhbv
I-RN-0088	Q.uh	RM1_ZWE_Kaub_Lahn	MidRhine2	Qhbv
I-RN-0089_ZWE	Q.uh	RM1_ZWE_Mosel_Andernach	Saynbach_ZWE	Qhbv
I-RN-0063	Q.uh	MO1_ZWE_Cochem-Muendung	Umos4	Qhbv
I-RN-0093	Q.uh	AL1_ZWE_Ande_Bonn	MidRhine3	Qhbv
I-RN-0094	Q.uh	AL1_ZWE_Bonn_Koel	MidRhine4	Qhbv
I-RN-0096	Q.uh	AL1_ZWE_Koel_Dues	LowRhine1	Qhbv
I-RN-0097	Q.uh	AL1_ZWE_Dues_Ruhr	LowRhine2	Qhbv
I-RN-0099a	Q.uh	AL1_ZWE_Ruhr_Wese	LowRhine3a	Qhbv
I-RN-0099b	Q.uh	AL1_ZWE_Wese_Rees	LowRhine3b	Qhbv
I-RN-0100	Q.uh	AL1_ZWE_Rees_Lobi	LowRhine4	Qhbv
I-RN-0013_ZWE_III	Q.uh	NE1_ZWE5/III	NeckarZWEIII	Qhbv
I-RN-0013_ZWE_IV	Q.uh	NE1_ZWE5/IV	NeckarZWEIV	Qhbv
I-RN-0013_ZWE_V	Q.uh	NE1_ZWE5/V	NeckarV	Qhbv
I-RN-0013_ZWE_II	Q.uh	NE1_ZWE5/II	NeckarII	Qhbv
I-RN-0013_ZWE_I	Q.uh	NE1_ZWE5/I	NeckarI	Qhbv
I-RN-0037_ZWE	Q.uh	LA1_ZEG4	Lahn5	Qhbv
I-RN-WAA1	Q.uls	RT2_WAAL_1	RT2_WAAL_1	Qhbv
I-RN-WAA2	Q.uls	RT2_WAAL_2	RT2_WAAL_2	Qhbv

FewsNL Id	FewsNL parameter	SOBEK id	HYMOS Id	HYMOS Parameter
I-RN-PANK	Q.uls	RT2_PANKAN	RT2_PANKAN	Qhbv
I-RN-NED1	Q.uls	RT2_NEDR_1	RT2_NEDR_1	Qhbv
I-RN-NED2	Q.uls	RT2_NEDR_2	RT2_NEDR_2	Qhbv
I-RN-NED3	Q.uls	RT2_NEDR_3	RT2_NEDR_3	Qhbv
I-RN-LING	Q.uls	RT2_LINGE1	RT2_LINGE1	Qhbv
I-RN-LEK1	Q.uls	RT2_LEK_1	RT2_LEK_1	Qhbv
I-RN-LEK2	Q.uls	RT2_LEK_2	RT2_LEK_2	Qhbv
I-RN-IJS1	Q.uls	RT2_YSSEL1	RT2_YSSEL1	Qhbv
I-RN-IJS2	Q.uls	RT2_YSSEL2	RT2_YSSEL2	Qhbv
I-RN-IJS3	Q.uls	RT2_YSSEL3	RT2_YSSEL3	Qhbv
I-RN-IJS4	Q.uls	RT2_YSSEL4	RT2_YSSEL4	Qhbv
I-RN-IJS5	Q.uls	RT2_YSSEL5	RT2_YSSEL5	Qhbv
I-RN-IJS6	Q.uls	RT2_YSSEL6	RT2_YSSEL6	Qhbv
I-RN-IJS7	Q.uls	RT2_YSSEL7	RT2_YSSEL7	Qhbv
I-RN-IJS8	Q.uls	RT2_YSSEL8	RT2_YSSEL8	Qhbv
H-RN-OIJS	Q.uls	RT2_OUDEYS	RT2_OUDEYS	Qhbv
H-RN-ALME	Q.uls	RT2_TWENTK	RT2_TWENTEK	Qhbv
H-RN-REMS	H.ut	RT2_eindketdi	Eindketdi	Qhbv
H-RN-RAMS	H.ut	RT2_eindkatdi	Eindkatdi	Qhbv
H-RN-KRIM	H.ut	RT2_KriLekMSW	KriLekMSW	Qhbv
H-RN-WERK	H.ut	RT2_WerkenMSW	WerkenMSW	Qhbv

4 Filling-in missing data

4.1 Overview of missing data

The missing data encountered in the observed water level and discharge series are summarized in Table 4-1.

Table 4-1 Overview of missing data in observed water level and discharge series with filling-in method

RS	River	Station ID	Type	Missing values	Filling
1	Rhine	Maxau	QH	23-02-1993	Linear interpolation
			HH	23-02-1993	Linear interpolation
2	Neckar	Rockenau	QH	Jul-92	Linear interpolation
			HH	Jul-92, Oct-04	Linear interpolation
	Itter	Eberbach	QH	Aug-00	Linear interpolation
	Elsenz	Meckesheim	QH	Feb-1990, Dec-1993, June-1994, Feb-1997, Oct-1998, Feb-1999, Mar-2002, May-2003	Regression on Wiesloch QH
3	Rhine	Worms	QH	Jan-1999, Feb-1999, Nov-1999 and Dec-1999	Regression on Speyer QH
	Weschnitz	Lorsch	QH	Parts of 2002 and 2003	Regression on Eberstadt and Eberbach
	Modau	Eberstadt	QH	Parts of 2002 and 1991	Linear interpolation and regression on Lorsch QH
	Schwarzbach	Nauheim	QH	15-04-2003	Linear interpolation
	Main	Raunheim	QH	1993-2004	Regression using water levels and Ultraschall discharge [1]

RS	River	Station ID	Type	Missing values	Filling
4	Rhine	Mainz	QH	23-02-1993 and 11-2004	Linear interpolation
			HH	23-02-1993	Linear interpolation
	Wisper	Pfaffental	QH	parts of 2002 and Jan-2003	Linear interpolation
5		Kalkofen	QH	Jul-1992 and Oct-1997	Linear interpolation
			HH	Jul-1992 and Oct-1997	Linear interpolation
	Mosel	Cochem	QH	Jul-92	Linear interpolation
6	Rhine	Koblenz	QH	Parts of 1993, 1995, 1998, 1999, 2000, 2001, 2003 and 2004	qh-relation
			HH	Parts of 1993, 1995, 1998, 1999, 2000, 2001, 2003 and 2004	Regression on Andernach
10	Ruhr	Hattingen	QH	Jun-94	Linear interpolation
11	Rhine	Ruhrort	QH	Jan-93	Linear interpolation
			HH	Jan-93	Linear interpolation
	Emscher	Koenigsstrasse	QH	Jul-90	Linear interpolation
14	Rhine	Emmerich	QH	Dec-91	Linear interpolation
			HH	Dec-91	Linear interpolation
	Rhine	Lobith	QH	Oct-2003	qh-relation

[1] For Raunheim the following procedure has been followed: A relation has been made between water levels (HH) and Ultraschall Discharge (QU) data for the period 01-03-2003. This relation and the HH-series are used to fill in the missing values in the QH-series for the period 1993-2004.

Generally, gaps in the series are small with a few exceptions:

- Water level series for Speyer
- Discharge series for Raunheim
- Water level series for Koblenz

4.2 Procedures to fill in missing data

In Table 4-1 last column the proposed method for filling in missing or replacing erroneous values is presented. Small gaps in recessions can generally be filled in by linear interpolation. Larger parts or for peaks regression with neighbouring stations will be required. Following remarks are made:

- To complete the series for Raunheim regression on station Frankfurt will be most appropriate. It appears that till February 1997 the discharge series have been derived from a single discharge rating curve, as shown in Figure 4-1. It is not clear why this procedure has been abandoned thereafter. However, application of the curve to complete the series is not an option at present, in view of the unreliable stage record of Raunheim as from February 1997 onward.
- To complete the water level series for Koblenz regression with appropriate time shift on station Andernach is advocated. Subsequently, by using the Koblenz stage-discharge relation the discharge series can be completed. It is noted that probably filling in of the Koblenz discharge series using the water balance between Koblenz and Andernach is to be preferred, but this will invalidate the present water balance analysis.

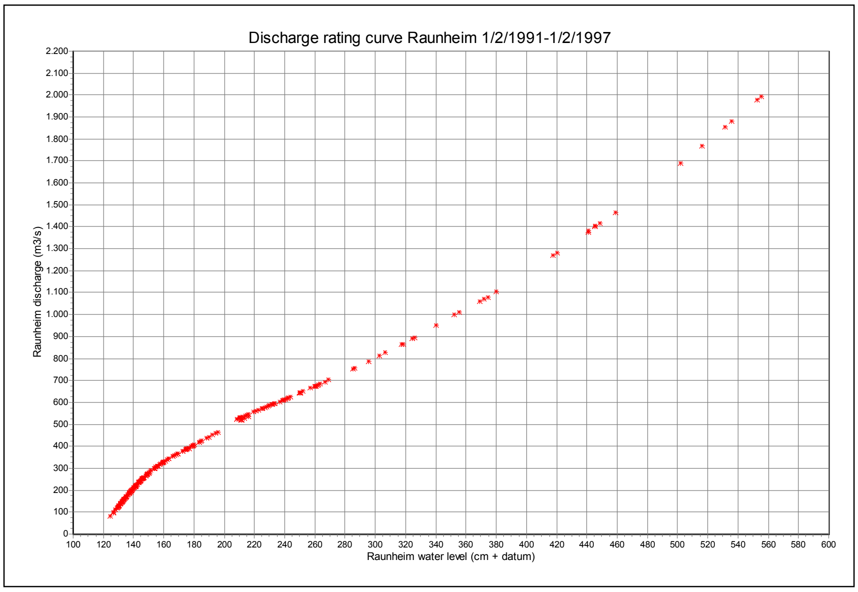

Figure 4-1 Discharge rating curve applied for station Raunheim from 1-2-1992 till 1-2-1997

5 Proposed analyses for Phase 2

5.1 General

The goal of the analysis in Phase 2 is to identify and detect errors in the input data (water level measurements-derived discharges and/or HBV simulations) of the SOBEK model that is also being used in FEWS-Rijn. This means that in Phase 2 no solutions are being provided but only errors will be detected. Possible sources of error are:

- stage-discharge relationship at the upstream and downstream measurement point,
- discharge model boundaries,
- hysteresis effects in the stage-discharge relationship,
- errors in the lateral inflows between measurement points in the main river,
- retention-effects,
- interaction with groundwater (between Andernach and Lobith),
- river management over the years

In FEWS-Rijn, HBV calculated discharges (small tributaries and areas close to the main river) and discharges of the larger tributaries derived from water level measurements (using a stage-discharge relationship) provide input for the SOBEK models. Most notable differences between the SOBEK model and measured water levels occur during low flow and during peaks.

Water balance analyses will be carried out between 14 subsequent measurement points in the river Rhine leading to the 13 river sections as presented in Table 2-1.

5.2 Analysis and Simulations

The idea of the analysis is to find periods where anomalies in the water balance occur for each of the 13 river sections. The water balance can be calculated using three scenarios for determining the lateral inflows into the Rhine in combination with the derived discharge of the gauging stations in the river Rhine:

1. SOBEK lateral inflows used during calibration (i.e. only measured data and data derived from measured data)
2. SOBEK lateral inflows used in operational FEWS-Rijn (i.e. data partly directly measured and partly resulting from HBV simulations)
3. SOBEK lateral inflows solely derived from HBV simulations

An example of such an analysis is given in the Figures 5.1-5.7 that shows the water balance for Section 2: Speyer-Worms by making use of the SOBEK lateral inflows used during the calibration (Scenario 1). Within the Section Speyer-Worms, the measurements from the tributaries are added to the derived discharge measurements at Speyer (‘Worms QC’).

Some of the discharge measurement series need a factor to account for the area for which no measurement stations exist. Also the time shift of the different series needs to be taken into account. The factor and the time shift are taken from the Memo ‘Oorspronkelijke opzet “SOBEK-FEWS Rijn” versie 2.05’. Time shift for Speyer (in order to compare to Worms) is estimated at 0.4 days by HYMOS. The *s*eries are aggregated to daily values and Worms QH is subtracted from Worms QC.

In the beginning of Phase 2, a short analysis of the effect of the determination of the time shift will be made. However, it is clear that the time shift will be determined using hourly values. And the water balance will be made using daily data. Therefore, when necessary the hourly time series first are shifted and afterwards daily data is generated.

Figure 5.1 shows the water balance for the whole period 1993-2004 including the accumulative difference of QC-QH. From this picture, it can be deduced that for the period 1993-November 1999 the water entering the section Speyer-Worms is larger than what is being measured at Worms. After November 1999 the opposite is true. This change in behaviour of the difference QC-QH during the years is caused by a change in Q-H relationship and is further clarified by the Figures 5.8-5.10. In 2003 and 2004, this behaviour changes again with out clear cause.

Figure 5.2-5.7 are close ups of Figure 5.1 and show QC, QH and QC-QH. These figures show that during most flood peaks there is a relatively large discrepancy between the derived discharge measured at Worms and what is being calculated on the basis of derived discharge measured at Speyer and all the lateral inflows between Speyer and Worms. These relatively large errors can easily occur because of small errors in the timing of the peak, but should be balanced out some time after the flood, when no systematic balance error occurs. Therefore, SOBEK simulations are necessary to investigate further what is going on in detail and to see if there are problems with the SOBEK lateral inflows or with the Q-H relationships of either Speyer or Worms.

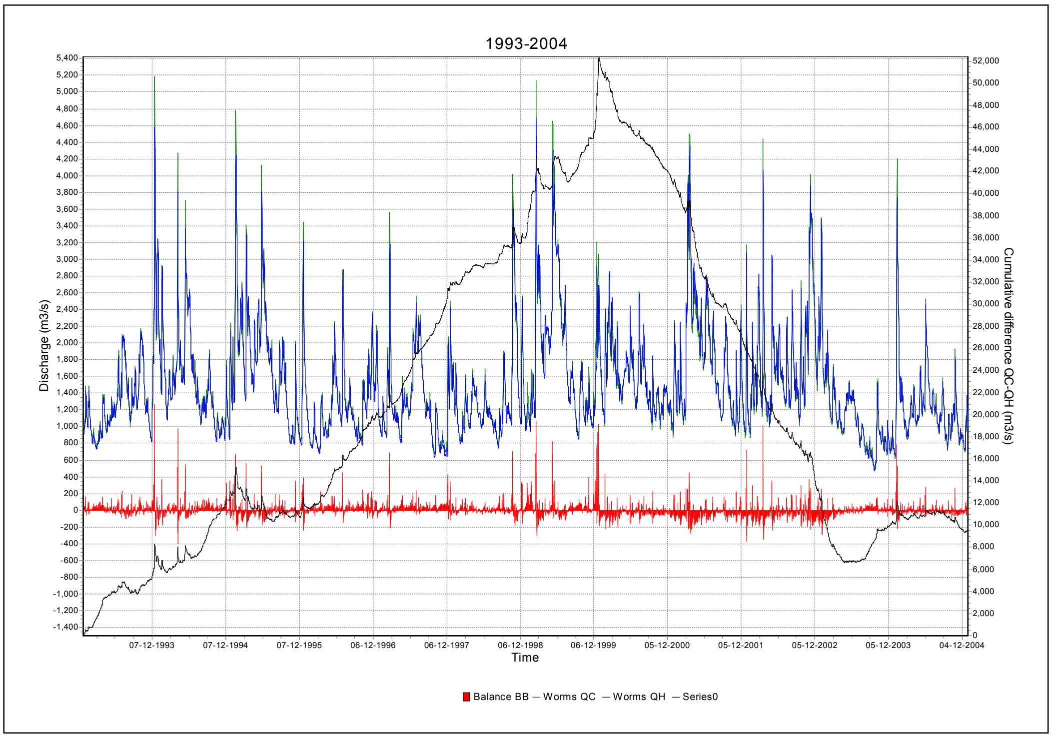

Figure 5-1. Water balance for section 2: Speyer-Worms by making use of the laterals as used during the calibration (scenario 1) of the SOBEK model for the period 1989-2004. QC (green) is the calculated discharge at Worms, QH (blue) is the measured discharge at Worms, BB (red) is the difference between QC-QH and the accumulative difference (black) between QC and QH is also shown.

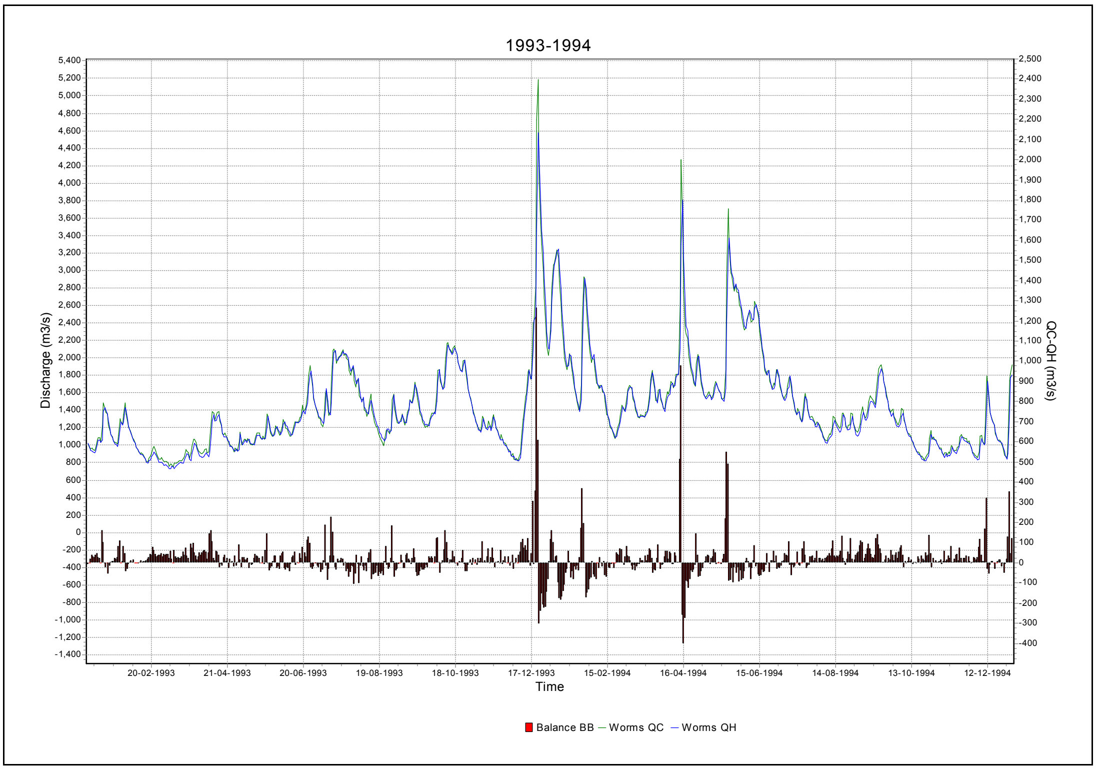

Figure 5-2. Water balance for section 2: Speyer-Worms by making use of the data used during the calibration (scenario 1) for 1993-1994.

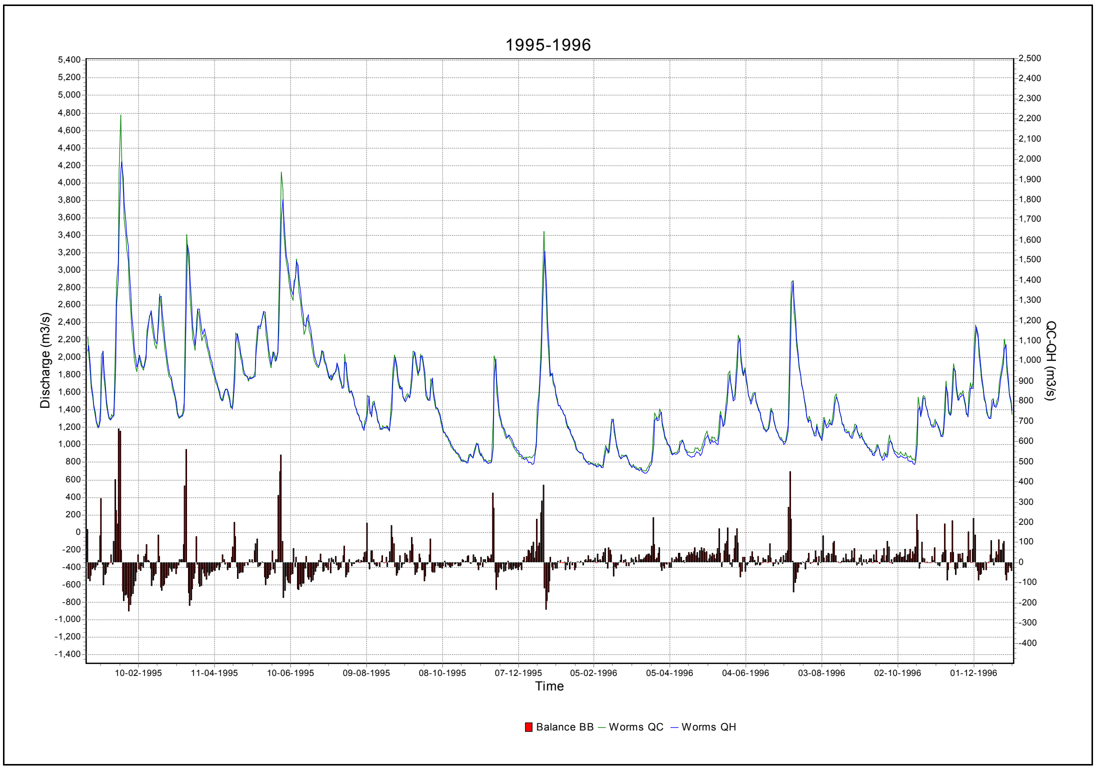

Figure 5-3. Water balance for section 2: Speyer-Worms by making use of the data used during the calibration (scenario 1) for 1995-1996.

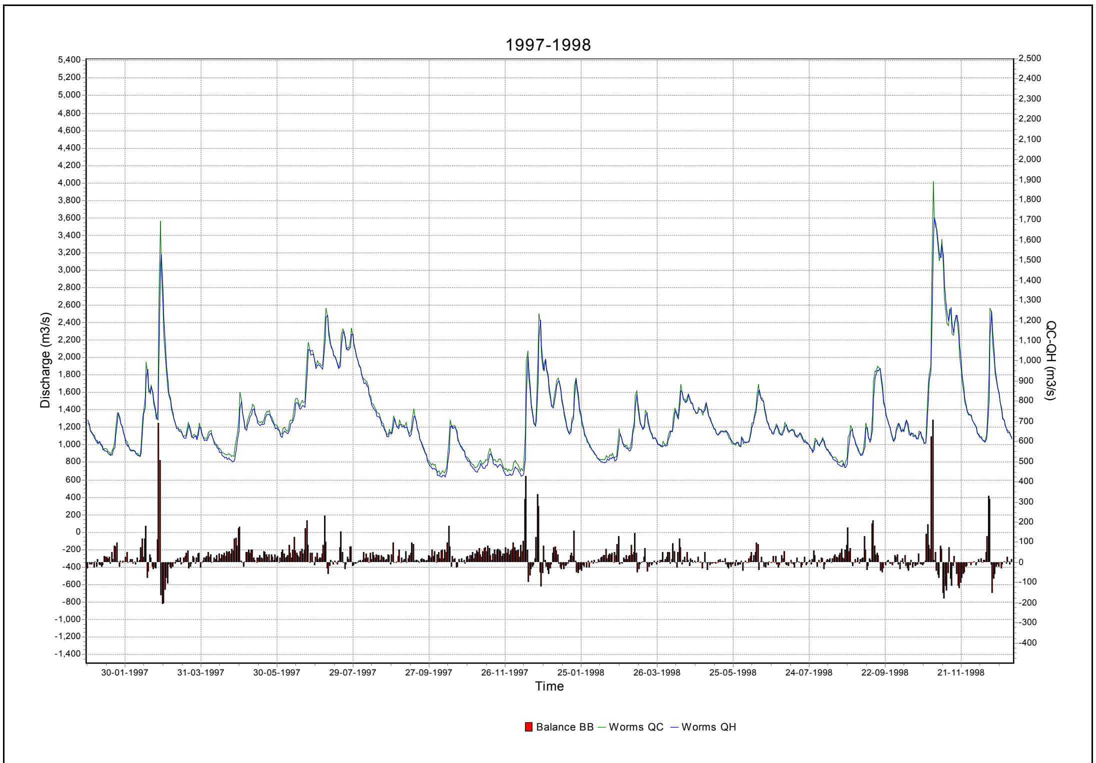

Figure 5-4. Water balance for section 2: Speyer-Worms by making use of the data used during the calibration (scenario 1) for 1997-1998.

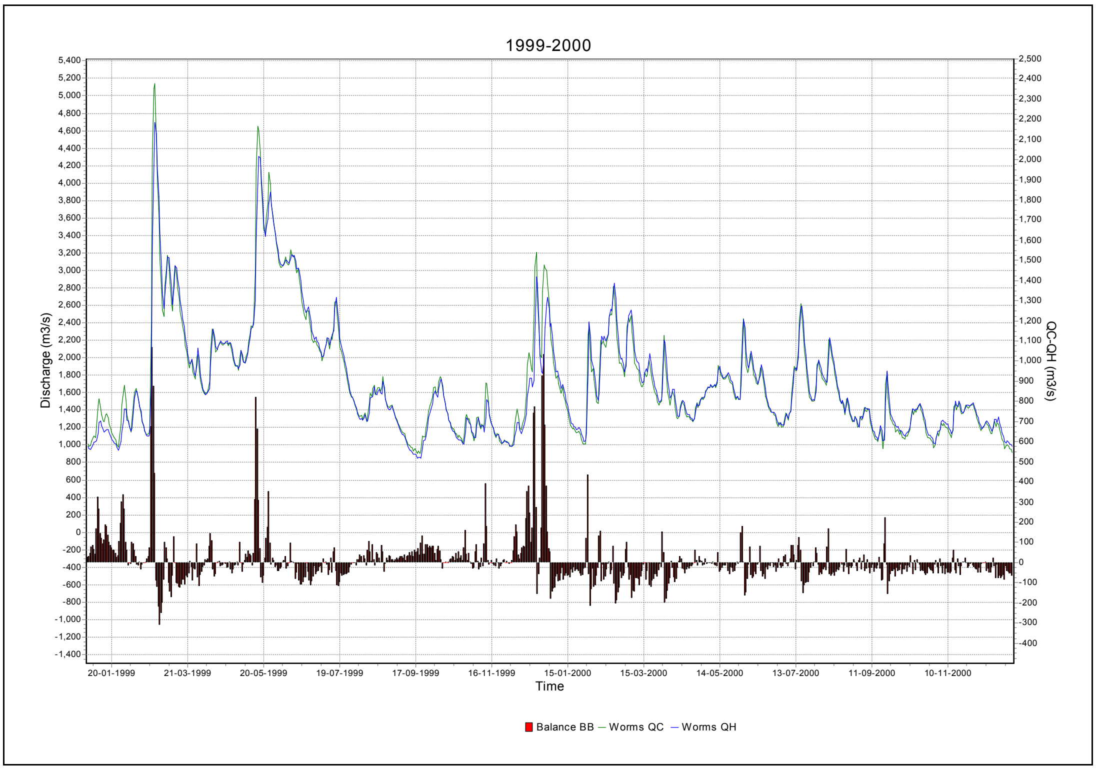

Figure 5-5. Water balance for section 2: Speyer-Worms by making use of the data used during the calibration (scenario 1) for 1999-2000.

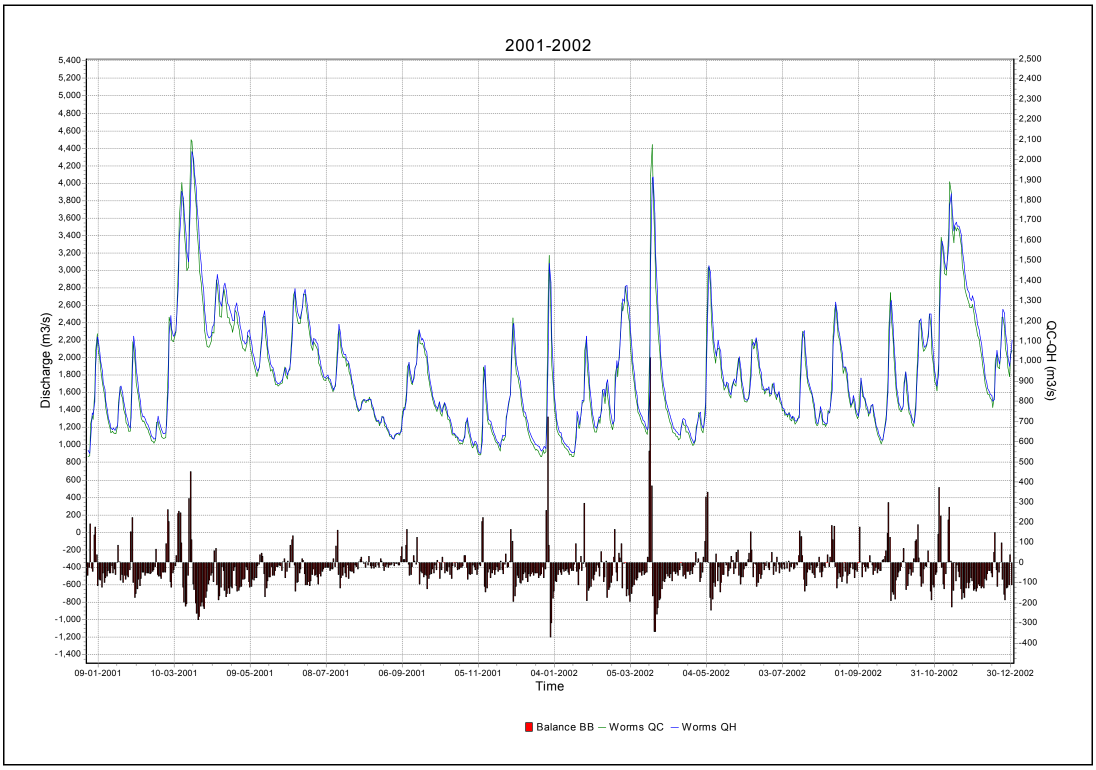

Figure 5-6. Water balance for section 2: Speyer-Worms by making use of the data used during the calibration (scenario 1) for 2001-2002.

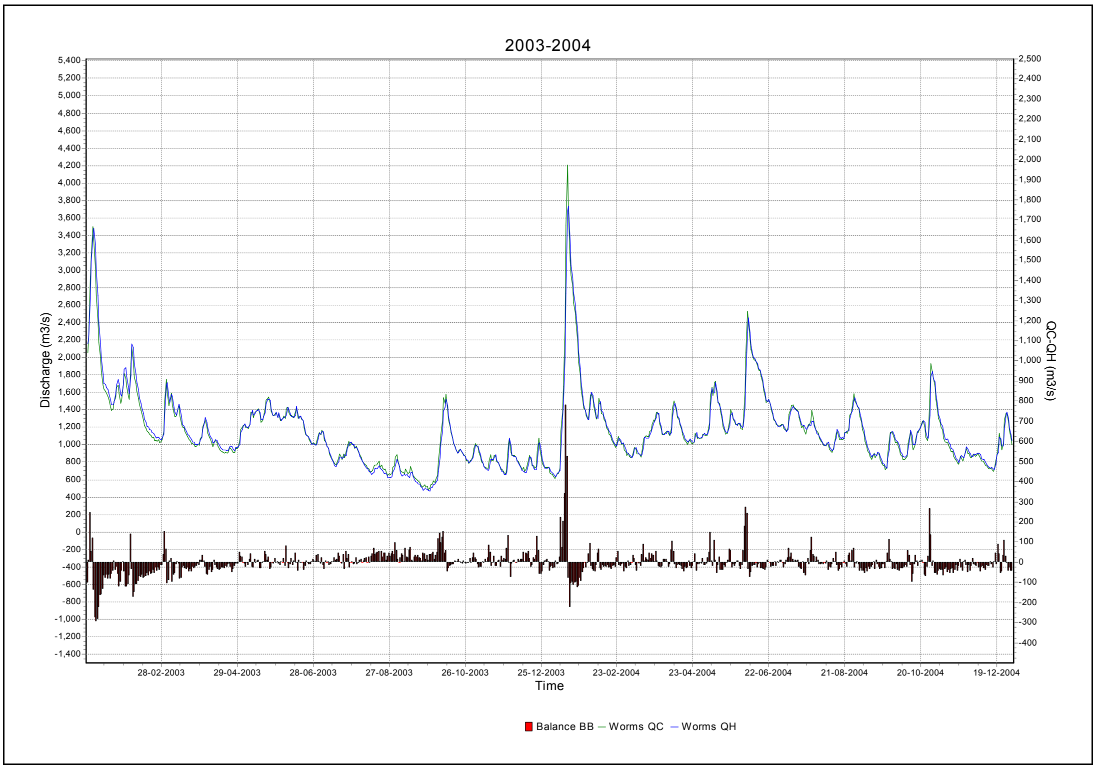

Figure 5-7. Water balance for section 2: Speyer-Worms by making use of the data used during the calibration (scenario 1) for 2003-2004.

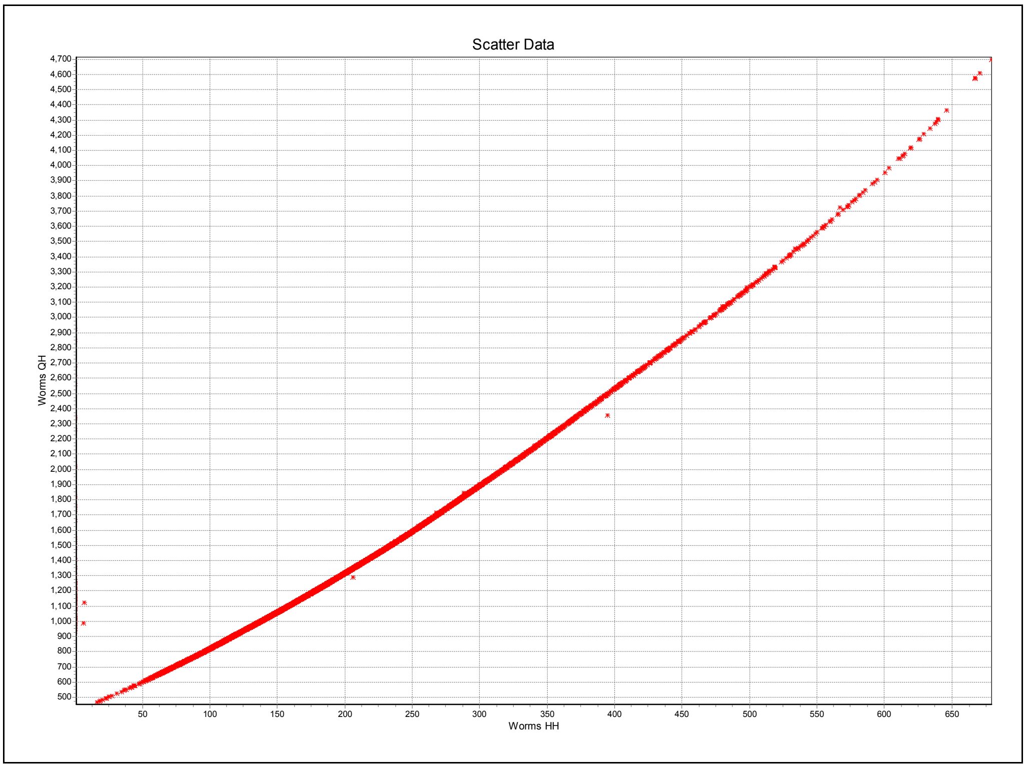

Figure 5-8. Q-H relationship Worms (1989-2005).

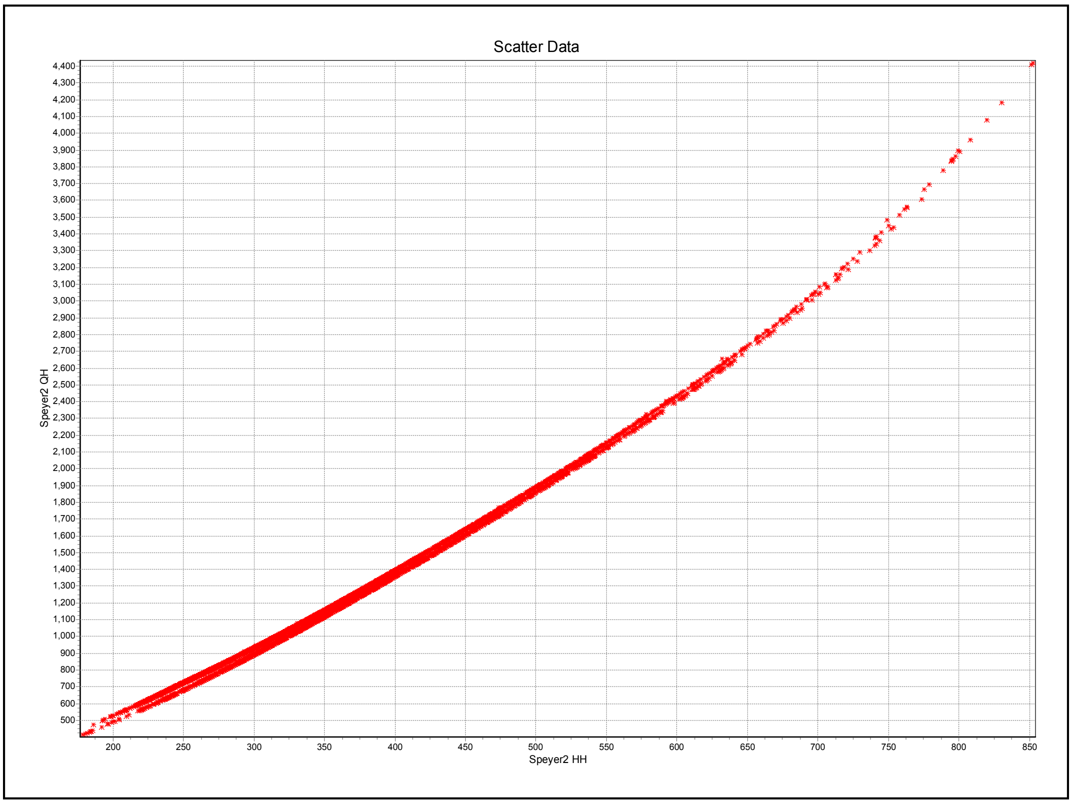

Figure 5-9. Q-H relationship Speyer (1989-2005).

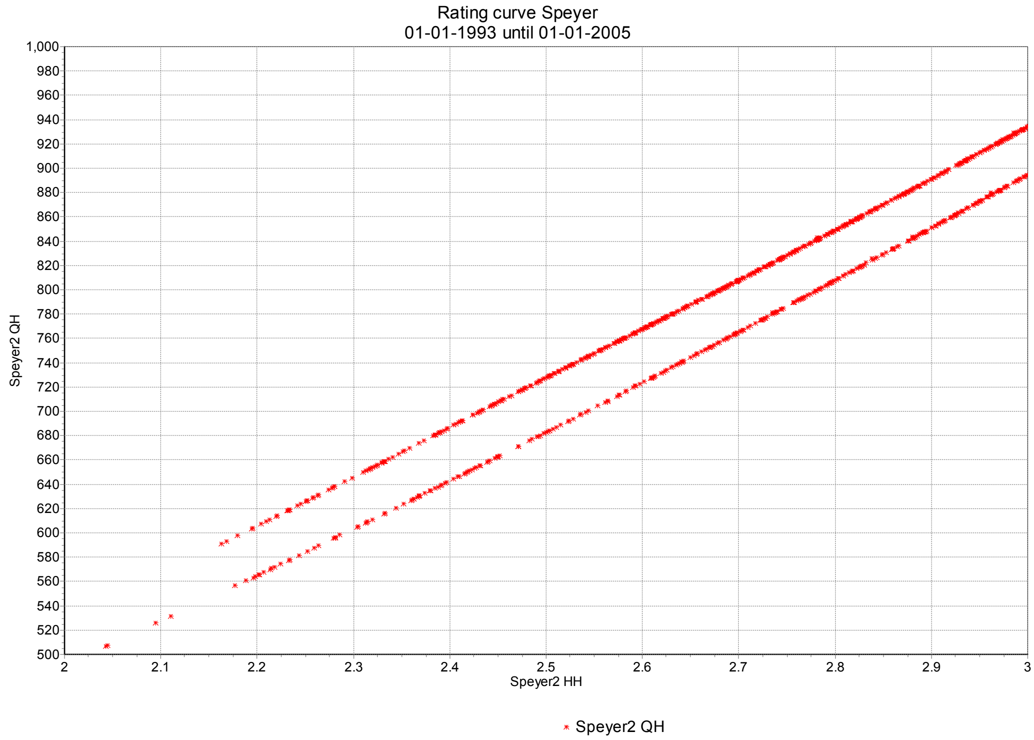

Figure 5-10.(a) Close up the QH curve for Speyer 1993-October 1999 (upper) and November 1999-January 2005 (lower). The water level (HH) in meters.

In Phase 2 SOBEK simulations will be carried out for

- each river section using by Client specified periods (low flow: 2003, floods: 1993, 1995,1998, 1999 (only for the Upper Rhine), 2002 and 2003).
- for selected periods using the analysis described above within a certain river section

For the upstream boundary of the SOBEK model two alternatives exist:

1. a discharge boundary, where the discharge series is derived from water levels using a single stage-discharge relation, or
2. measured water level.

For the lateral inflows, we can either choose between:

- measured discharges,
- mixed measured and HBV simulated discharges as in the FEWS-Rijn operating practice, as presented in Sub-section 2.5, or
- HBV generated discharges.

To identify and detect possible error sources, for the river section the following simulations will be performed:

1. SOBEK simulation with:
   - Upper boundary:
     - the observed discharge
   - SOBEK laterals:
     - as used during calibration
     - as used in operational FEWS-Rijn
     - if necessary/useful solely derived from HBV

2. SOBEK simulation with:
   - Upper boundary:
     - the observed water level
   - SOBEK laterals:
     - as used during calibration
     - as used in operational FEWS-Rijn
     - if necessary/useful solely derived from HBV

3. SOBEK simulation between Andernach and Lobith with groundwater model switched off:
   - Upper boundary:
     - the observed discharge
   - SOBEK laterals:
     - as used in operational FEWS-Rijn

The lower model boundary will de determined with RIZA and the BfG. Note that the simulations for 1993 and 1995 will only be carried out with the SOBEK laterals as used during the calibration. For the period 1989 until March 1996 no meaningful HBV simulations can be carried out with FewsNL because of a lack of synoptic data for this period. It might be possible to evaluate the HBV results using measurements and what is being used during the calibration. If this analysis is satisfactory, the SOBEK simulations with laterals solely derived from HBV will not be carried out.

For each river section the following analysis, using the above mentioned simulations, will be made:

- Comparison of time series of upstream measurements vs time series upstream model results
- Comparison of time series of downstream measurements vs time series downstream model results
- Comparison of HBV simulated lateral inflow and main stream flows with discharge measurements (if available)
- Evaluation of the HBV lateral inflows where no measurements are available (normally the diffuse lateral inflows)

The graphical presentation of the results will include the following:

- Time series comparison
- Difference time series and accumulated differences (see e.g. Figure 5.1-5-7).

6 References

Lammersen, R. (2006); Waterbalans FEWS Rijn 2.05; RIZA Memo dd 24-7-2006

Sprokkereef, E., K. Wilke, P. Krahe and M. Eberle (2001); Hydrological Modelling in the Rhine Basin, Part II; NCR, IRMA and BfG, Koblenz

Veen, R. van der (2005); Bouw SOBEK-model FEWS Rijn 2.03 and 2.04; RIZA Memo 2005-024

Weerts, A.H. and J. Kwadijk (2006); Hydrological Hindcast APL; WL | Delft Hydraulics