CASE STUDY DATABASE

Part A. focus on the rhine basin

Report of the NeWater project -
New Approaches to Adaptive Water Management under Uncertainty

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Policy Summary

This document is the first part of the deliverable 1.5.2 of Work package 1.5. The second part is dedicated to Guadiana basin.

As recently stated by Silberstein (2006): "modelling in the absence of adequate data is not science". The same author mentions that "improvement in the management of our environment and water resources will not come with improved models in the absence of improved data collection because we cannot manage what we do not measure".

For these reasons, WP 1.5 devotes a whole task to data collection and this report presents the dataset collected on the Rhine case study.

On this large basin (160 000 km^2), the WP 1.5 task was greatly simplified as the hydrological data collection work had been already done by RIZA, one of the NeWater Partner. As RIZA is the owner of this dataset, it is not possible for WP 1.5 partners to publish it and give a free access to it. Data access will be provided by Mr. Hendrik Buiteveld from RIZA institute (Netherlands).

The dataset provided by RIZA to WP 1.5 contains rainfall, temperature and discharge daily values over the whole Rhine basin for the last 40 years. The data are of excellent quality with very few missing values.This dataset can be extremely useful to perform various analysis on climate and hydrology of the Rhine basin. They are also highly valuable to calibrate and validate hydrological models.

A simple description of this dataset was proposed. More details are available in the abundant literature on Rhine hydrology (especially the Rhine basin monograph, CHR;1977). The following comments can be made:

- **Hydrological regime**: due to different climatic influences, upstream Rhine and Rhine tributaries (mainly the Moselle, Main and Neckar) have opposite high and low-flow periods resulting in a regular discharge pattern in the downstream Rhine (for example in Lobith).
- **Floods**: large floods occur mainly between December and February due to long rainfall events over the whole basin. Maximum recorded discharge in Lobith reaches 11 885 m^3/s in January 1995.
- **Low-flows**: low-flow periods are more longer and more intense on Rhine tributaries (especially on Moselle and Neckar). The worst event for the downstream part of the basin occurred in 1976 with discharges under 1000 m^3/s for more than 30 days in Lobith.

<u>*Policy recommendations*</u>

Financial efforts on the maintenance of measurement networks are vital for the understanding of the hydrosystem. Our study on the Rhine basin was made possible due to two factors:

- The existence of long time-series on rainfall, discharge, stored volumes and water uses,
- The availability of these data through the work of RIZA.

This dual aspect of water related data (existence of a measurement network and facilitated access) is a central issue to achieve the transition toward adaptive management. The interested reader is referred to work package 1.6 of Newater project (Transition to Advanced Monitoring Systems for Adaptive Management).

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1 Introduction

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2 General presentation of the dataset

The dataset contains three kinds of data:

- Daily discharge data on 34 stations located on the Rhine river and its tributaries,
- Daily rainfall data on 134 sub-basins. These sub-basins were delimited during a study on hydrological modelling conducted by RIZA and BfG (RIZA and BfG, 2005). These sub-basins are named "HBV sub-basins" by reference to the HBV hydrological model.
- Daily temperature data on the same 134 sub-basins.

Figure 1 shows the location of the 34 gauging stations and Table 1 gives details on corresponding discharge data.

Figure 2 shows the location of the 134 HBV sub-basins with their code. Rainfall and temperature data are available for each sub-basin from the 1st January 1961 to 31st December 1995. Table 2 indicates mean annual values of rainfall for each HBV sub-basin.

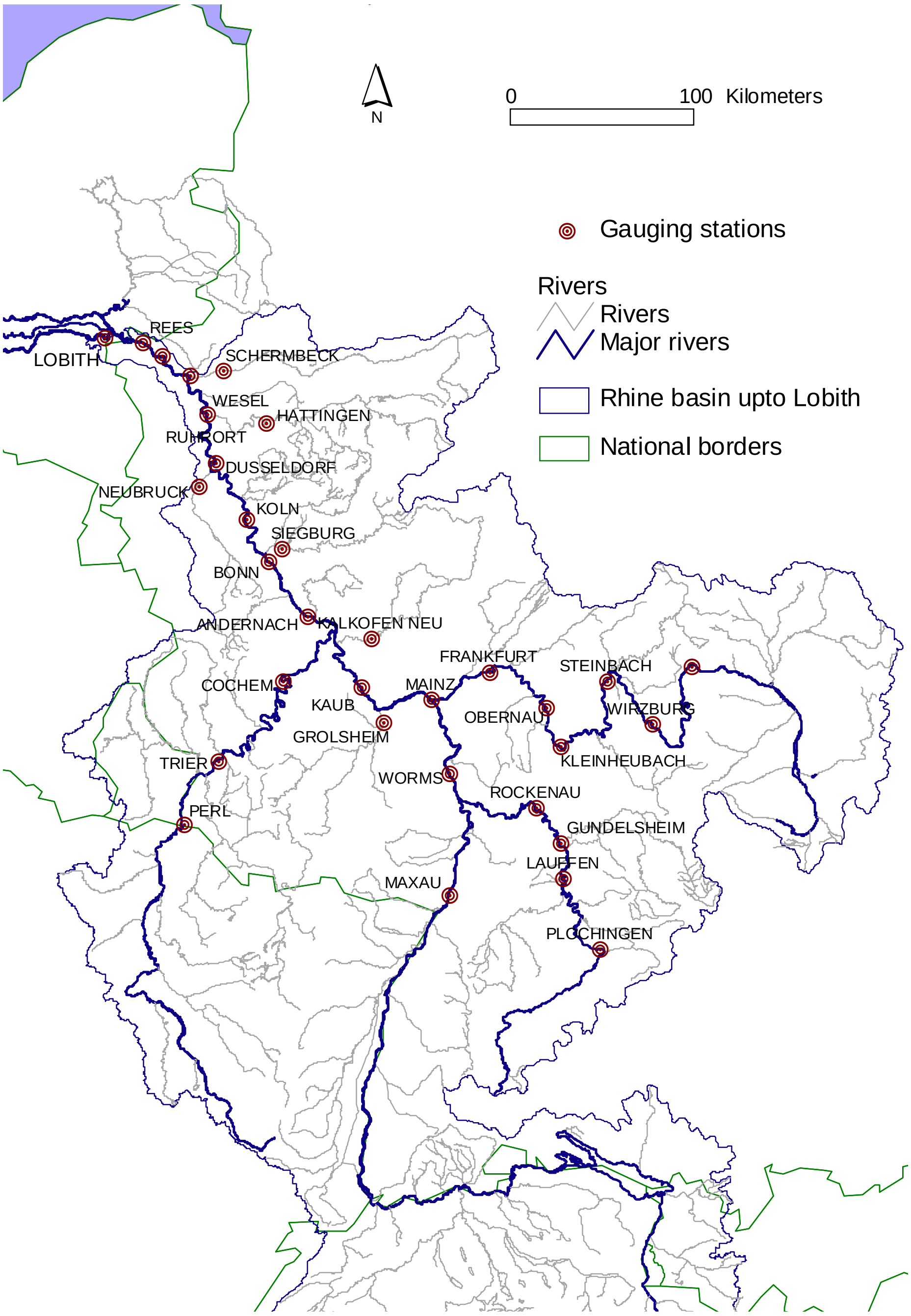

Figure 1: Location of gauging stations

River	Name	LONG (°)	LAT (°)	START	END	Mean Q (m^3/s)
Erft	NEUBRUCK	6.58	51.07	01.11.1983	31.12.1991	16
Lahn	KALKOFEN NEU	7.86	50.32	01.01.1961	31.08.2004	48
Lippe	SCHERMBECK	6.86	51.67	01.11.1961	31.12.1991	43
Main	TRUNSTADT	10.73	49.95	01.01.1980	30.06.1995	116
Main	SCHWEINFURT	10.26	50.05	01.01.1961	30.06.1995	108
Main	WÜRZBURG	9.93	49.79	01.01.1980	31.08.2004	132
Main	STEINBACH	9.61	50.02	01.01.1988	30.03.1995	143
Main	KLEINHEUBACH	9.22	49.72	01.01.1961	31.12.1990	164
Main	OBERNAU	9.14	49.92	01.01.1980	30.03.1995	167
Main	FRANKFURT	8.74	50.11	01.01.1988	31.12.1989	234
Mosel	PERL	6.37	49.47	01.11.1974	31.08.2000	163
Mosel	TRIER	6.65	49.77	01.01.1961	31.08.2004	288
Mosel	COCHEM	7.18	50.14	01.01.1961	31.08.2004	337
Nahe	GROLSHEIM	7.91	49.91	01.01.1961	31.12.1990	33
Neckar	PLOCHINGEN	9.38	48.72	01.01.1961	31.08.2004	48
Neckar	LAUFFEN	9.16	49.08	01.01.1988	31.10.1990	92
Neckar	GUNDELSHEIM	8.69	49.18	01.01.1980	30.03.1995	127
Neckar	ROCKENAU	9.00	49.43	01.11.1971	31.12.1990	140
Rhine	RHEINFELDEN	7.80	47.56	01.01.1961	23.11.2003	1045
Rhine	MAXAU	8.31	49.04	01.01.1961	31.08.2004	1 299
Rhine	WORMS	8.38	49.63	01.01.1980	31.08.2004	1 489
Rhine	MAINZ	8.29	50.00	01.01.1961	30.03.1995	1 662
Rhine	KAUB	7.76	50.09	01.01.1961	31.08.2004	1 708
Rhine	BONN	7.12	50.73	01.01.1988	30.03.1995	2 064
Rhine	ANDERNACH	7.40	50.45	01.01.1961	31.08.2004	2 116
Rhine	DÜSSELDORF	6.76	51.22	01.01.1988	30.03.1995	2 186
Rhine	KÖLN	6.97	50.94	01.01.1980	31.08.2004	2 268
Rhine	LOBITH	5.95	51.86	31.12.1969	31.12.2000	2 269
Rhine	EMMERICH	6.24	51.83	01.01.1988	30.03.1995	2 275
Rhine	WESEL	6.60	51.65	01.01.1988	30.03.1995	2 278
Rhine	RUHRORT	6.72	51.46	01.01.1961	30.03.1995	2 293
Rhine	REES	6.39	51.75	01.01.1961	30.03.1995	2 347
Ruhr	HATTINGEN	7.17	51.40	01.01.1980	31.08.2004	75
Sieg	SIEGBURG	7.23	50.79	01.01.1961	31.10.1975	34

Table 1: Gauging stations

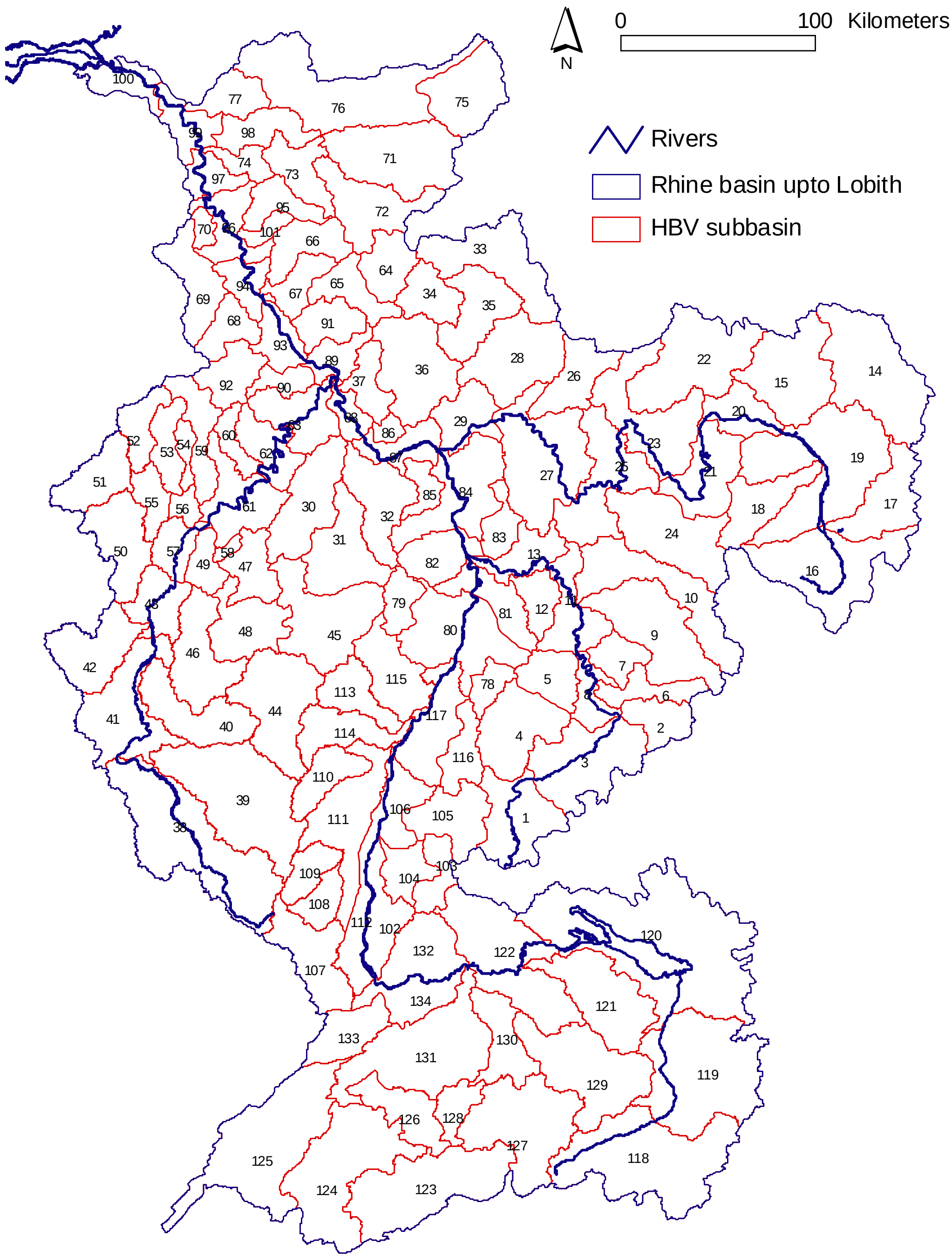

Figure 2: Location of sub-basins for rainfall and temperature data (HBV sub-basins)

HBV district	**Code**	**Area (km²)**	**LONG (°)[1]**	**LAT (°)[1]**	**Mean annual rainfall (mm)**
Neckar	1	1460	8.68	48.29	987
Neckar	2	667	9.68	48.66	988
Neckar	3	1914	9.17	48.49	856
Neckar	4	1462	8.74	48.68	1024
Neckar	5	733	8.94	48.89	763
Neckar	6	590	9.65	48.84	952
Neckar	7	512	9.46	48.97	946
Neckar	8	538	9.20	48.83	757
Neckar	9	1981	9.68	49.05	917
Neckar	10	1814	10.03	49.19	835
Neckar	11	1022	9.15	49.27	849
Neckar	12	539	8.91	49.25	870
Neckar	13	739	8.81	49.50	1010
Main	14	2422	11.48	50.15	899
Main	15	1811	10.81	50.21	745
Main	16	2278	11.01	49.24	725
Main	17	1174	11.35	49.63	877
Main	18	985	10.61	49.60	686
Main	19	3277	11.26	49.74	768
Main	20	734	10.49	50.06	695
Main	21	1265	10.15	49.81	637
Main	22	2171	10.20	50.33	749
Main	23	1825	9.81	50.10	774
Main	24	1848	9.89	49.50	700
Main	25	1751	9.46	49.82	845
Main	26	929	9.32	50.29	919
Main	27	2364	9.06	49.92	821
Main	28	1649	8.87	50.39	766
Main	29	827	8.51	50.14	736
Nahe	30	1440	7.34	49.82	837
Nahe	31	1385	7.60	49.63	773
Nahe	32	1245	7.87	49.77	628
Lahn	33	1690	8.75	50.81	821
Lahn	34	712	8.31	50.72	933
Lahn	35	1168	8.67	50.61	742
Lahn	36	1756	8.19	50.38	806

[1] sub-basin center

HBV district	Code	Area (km^2)	LONG (°)[1]	LAT (°)[1]	Mean annual rainfall (mm)
Lahn	37	591	7.81	50.33	812
Moselle	38	3353	6.42	48.25	1113
Moselle	39	2912	6.66	48.39	1031
Moselle	40	1288	6.23	48.91	726
Moselle	41	1852	6.01	48.93	686
Moselle	42	1273	5.80	49.19	792
Moselle	43	823	6.23	49.37	831
Moselle	44	1855	7.03	48.83	929
Moselle	45	1910	7.44	49.28	917
Moselle	46	1369	6.57	49.15	818
Moselle	47	741	6.90	49.52	1064
Moselle	48	1127	6.88	49.29	904
Moselle	49	448	6.59	49.55	975
Moselle	50	1205	5.96	49.65	845
Moselle	51	947	5.80	49.99	970
Moselle	52	607	6.21	50.18	1013
Moselle	53	603	6.37	50.09	951
Moselle	54	241	6.49	50.05	955
Moselle	55	487	6.23	49.85	830
Moselle	56	234	6.47	49.81	846
Moselle	57	572	6.42	49.62	835
Moselle	58	102	6.75	49.61	1235
Moselle	59	816	6.61	50.12	931
Moselle	60	376	6.86	50.10	924
Moselle	61	1224	6.89	49.89	869
Moselle	62	813	7.10	50.07	778
Moselle	63	1051	7.28	50.20	698
Sieg	64	748	8.04	50.86	1140
Sieg	65	720	7.77	50.76	1081
Sieg	66	822	7.46	50.96	1198
Sieg	67	581	7.37	50.79	968
Erft	68	601	6.84	50.63	698
Erft	69	1022	6.60	50.84	677
Erft	70	196	6.71	51.09	750
Ruhr	71	2014	8.11	51.34	1043
Ruhr	72	1321	8.01	51.16	1197
Ruhr	73	783	7.42	51.31	1058
Ruhr	74	359	6.99	51.37	933

HBV district	Code	Area (km²)	LONG (°)[1]	LAT (°)[1]	Mean annual rainfall (mm)
Lippe	75	1331	8.67	51.65	899
Lippe	76	2901	7.93	51.72	800
Lippe	77	626	6.93	51.70	831
Upper Rhine	78	387	8.56	48.89	1016
Upper Rhine	79	497	7.97	49.32	857
Upper Rhine	80	1944	8.37	49.14	742
Upper Rhine	81	855	8.70	49.27	718
Upper Rhine	82	826	8.25	49.51	594
Upper Rhine	83	485	8.70	49.66	921
Upper Rhine	84	1695	8.33	49.80	651
Middle Rhine	85	371	8.16	49.83	559
Middle Rhine	86	174	7.95	50.12	756
Middle Rhine	87	679	8.00	50.02	660
Middle Rhine	88	388	7.68	50.22	724
Middle Rhine	89	515	7.62	50.47	811
Middle Rhine	90	368	7.19	50.37	700
Middle Rhine	91	678	7.58	50.61	931
Middle Rhine	92	754	6.85	50.41	781
Middle Rhine	93	612	7.20	50.57	725
Middle Rhine	94	550	6.97	50.79	737
Lower Rhine	95	607	7.32	51.19	1221
Lower Rhine	96	860	6.91	51.11	858
Lower Rhine	97	492	6.82	51.34	827
Lower Rhine	98	773	7.20	51.52	831
Lower Rhine	99	681	6.64	51.58	770
Lower Rhine	100	596	6.13	51.76	739
Lower Rhine	101	231	7.16	51.07	1126
Upper Rhine 2	102	844	7.71	47.92	993
Upper Rhine 2	103	545	8.13	48.05	1505
Upper Rhine 2	104	597	7.88	48.08	1040
Upper Rhine 2	105	1087	8.17	48.28	1406
Upper Rhine 2	106	669	7.90	48.39	926
Upper Rhine 2	107	1310	7.14	47.72	1529
Upper Rhine 2	108	496	7.22	48.00	1133
Upper Rhine 2	109	544	7.21	48.09	1211
Upper Rhine 2	110	736	7.38	48.51	1026
Upper Rhine 2	111	1654	7.47	48.25	813
Upper Rhine 2	112	890	7.56	48.11	879

HBV district	Code	Area (km²)	LONG (°)[1]	LAT (°)[1]	Mean annual rainfall (mm)
Upper Rhine 2	113	775	7.61	48.90	784
Upper Rhine 2	114	914	7.57	48.71	788
Upper Rhine 2	115	1131	7.87	49.02	764
Upper Rhine 2	116	658	8.28	48.62	1638
Upper Rhine 2	117	1250	8.10	48.74	1093
Schweiz	118	3221	9.31	46.64	1404
Schweiz	119	3087	9.74	47.03	1383
Schweiz	120	5440	9.40	47.63	1156
Schweiz	121	1730	9.05	47.40	1446
Schweiz	122	2574	8.51	47.63	1122
Schweiz	123	2463	7.86	46.58	1792
Schweiz	124	2661	7.36	46.68	1449
Schweiz	125	3118	6.73	46.85	1258
Schweiz	126	928	7.69	46.95	1437
Schweiz	127	2266	8.51	46.81	1849
Schweiz	128	486	8.11	46.94	1728
Schweiz	129	2178	8.97	47.09	1959
Schweiz	130	940	8.42	47.27	1236
Schweiz	131	2638	7.79	47.31	1185
Schweiz	132	1117	7.92	47.71	1455
Schweiz	133	869	7.38	47.36	1304
Schweiz	134	808	7.82	47.48	1089

Table 2: HBV sub-basins

The important facts on this dataset are:

- The rainfall and temperature data are of extremely good quality as there are no missing values in the 134 time-series (1/1/1961-31/12/1995).
- The discharge time-series show important missing values only on 3 stations: Rees (24% of missing values), Rheinfelden (14%) and Ruhrort (5%).
- On the Rhine river near to the Netherland border, the mean discharge in Rees is greater than in Lobith althought Lobith is located 25 km downstream and there is no diversion between the two stations. This fact has also been mentioned in a report on hydrological modelling on the Rhine basin published by the CHR (1999). As the value calculated here is in accordance with the data published by RIZA on its website[2] for Lobith station, we assume that discharges in Lobith are more reliable than in Rees.

Figure 3 shows the discharge time-series on 7 main gauging stations.

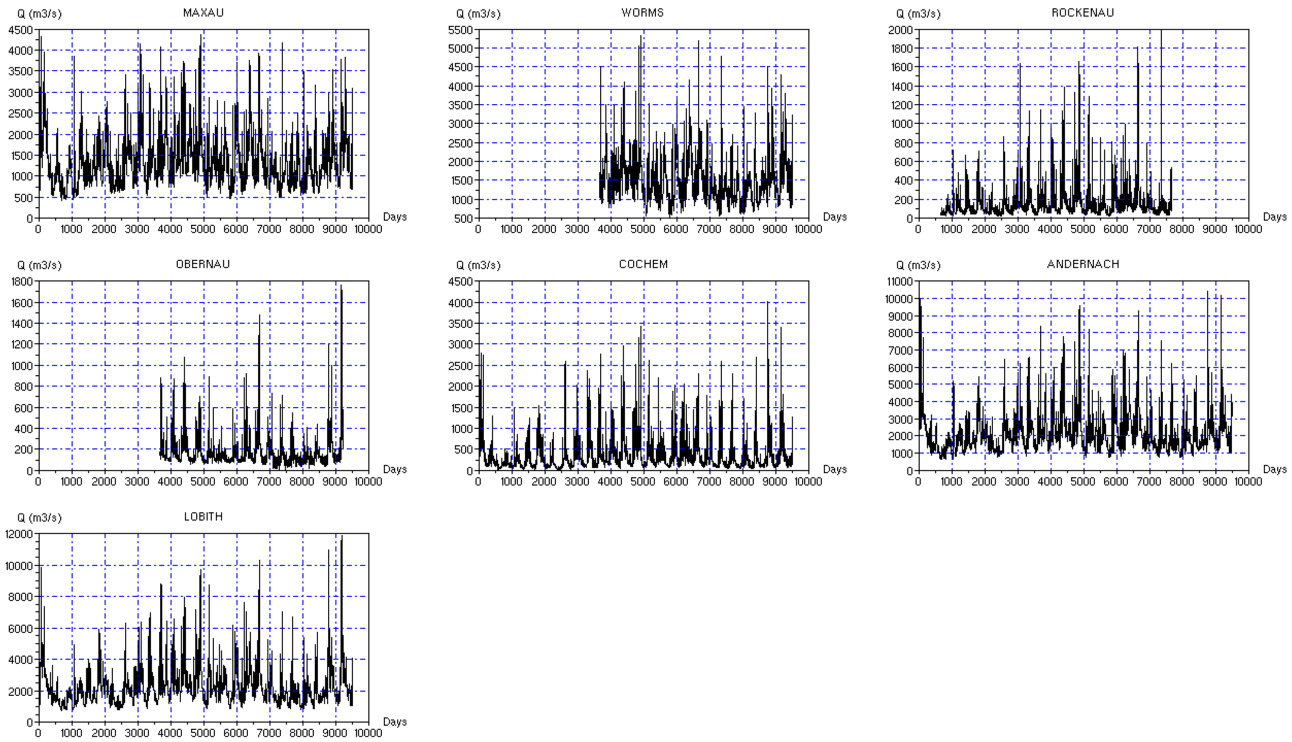

Figure 3: Discharges on 7 gauging stations on the Rhine basin

2 http://ds085.xs4all.nl/WNcgi-bin/index.pl?Taal=EN&Methode=afvoeren&Zoom=0

3 Simple data analysis

More detailed studies of Rhine basin hydrology can be found in the monograph of the Rhine basin (CHR, 1977).

After a general presentation of the dataset in the previous section, the objective is to perform simple data analysis to offer a quick overview of the Rhine hydrology.

3.1 Hydrological regime: from the Alps to the Netherlands

Rhine basin can be subdivided into three main parts from the south (upstream) to the north (downstream) according to hydrological regime:

- The upstream part located in Switzerland is dominated by snow melting processes with maximum monthly flows in June. As presented in Figure 4, the station of Rheinsfelden is a typical example of such a regime.
- The central part of the basin combines the inflows from the Alps with a growing influence of tributaries following temperate rainfall patterns (mainly the Main and Moselle). The upstream/downstream regime modification can be observed on Figure 4 for all the stations downstream of Rheinsfelden. Andernach and Lobith stations present classical features of temperate basins with high monthly flows in winter (maximum in February) and low in summer (minimum in September). In spite of the distance between Lobith and the Alps (more than 600 km), their influence can still be perceived in Lobith with a slight rising of monthly flows in June.
- In the downstream part located in the Netherlands, the Rhine enters a complex interconnected canal system as presented on RIZA website[3]. Here the hydrological regime becomes much more influenced by hydraulic structures that distribute the Rhine flow among different branches (Waal, Pannerdensch Kanaal, IJssel, Neder-Rijn).

[3] http://www.rijkswaterstaat.nl/wateroverzicht/index.jsp

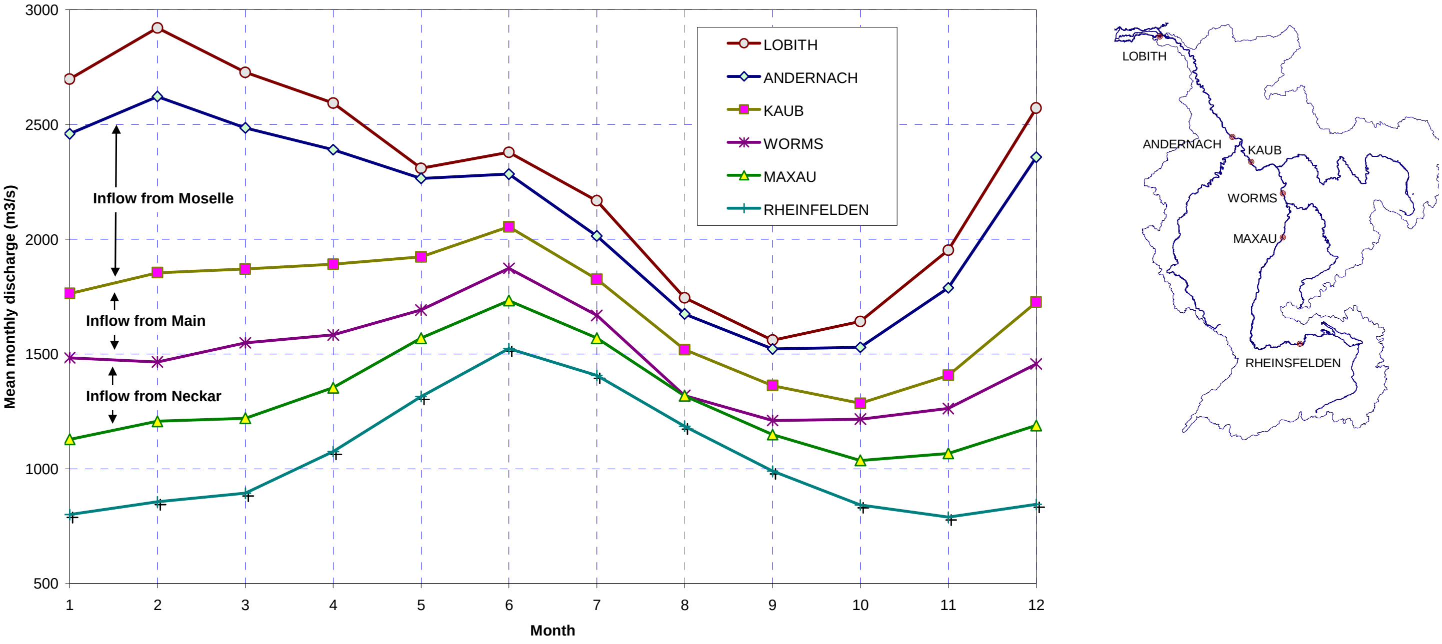

Figure 4: Mean monthly discharges on 6 gauging stations on the Rhine river

3.2 Floods

The literature on Rhine floods is extremely abundant (see Disse, 2001; Tol, 2000; Middelkoop, 2001; Middelkoop, 2004; for recent references). This paragraph aims to give basic figures on the 10 more important floods in Lobith. Table 3 presents the peak discharges on 5 gauging stations for these events. Figure 5 and Figure 6 show the corresponding hydrographs.

River	Gauging station	Flood n°1 01/1995	Flood n°2 12/1993	Flood n°3 03/1988	Flood n°4 03/1970	Flood n°5 06/1983	Flood n°6 04/1983	Flood n°7 02/1980	Flood n°8 02/1984	Flood n°9 01/1981	Flood n°10 01/1986
Rhine	Maxau	3770	2960	3930	4310	4360	4104	4070	2861	3721	2520
Neckar	Rockenau	-	-	2000	-	1512	1659	1140	1283	1384	876
Main	Obernau	1768	1196	1478	-	592	707	885	895	1077	880
Moselle	Cochem	3410	4020	2290	2780	3415	3154	2772	2628	2959	2060
Rhine	*Lobith*	*11885*	*10940*	*10274*	*9850*	*9707*	*9323*	*8811*	*8697*	*7931*	*7642*

Table 3: Peak discharges of the 10 large floods in Lobith (m3/s) with corresponding peak discharges on Rhine tributaries

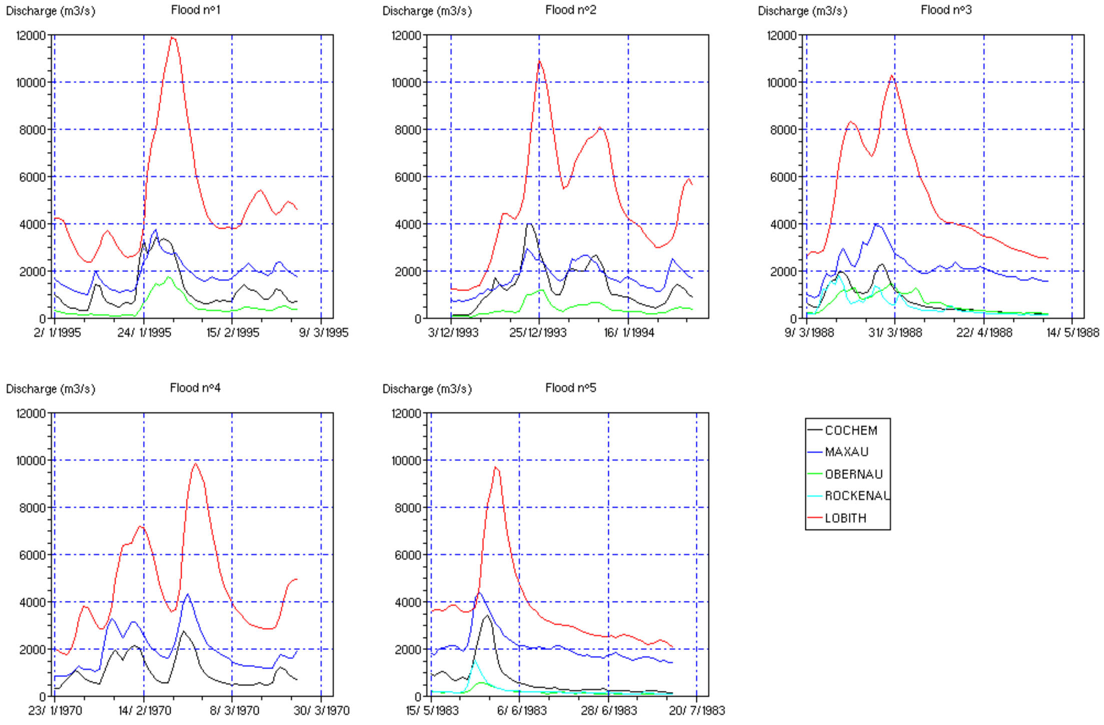

Figure 5: Major floods n° 1-5, discharges in Cochem (Moselle), Maxau (Rhine), Obernau (Main), Rockenau (Neckar) and Lobith (Rine)

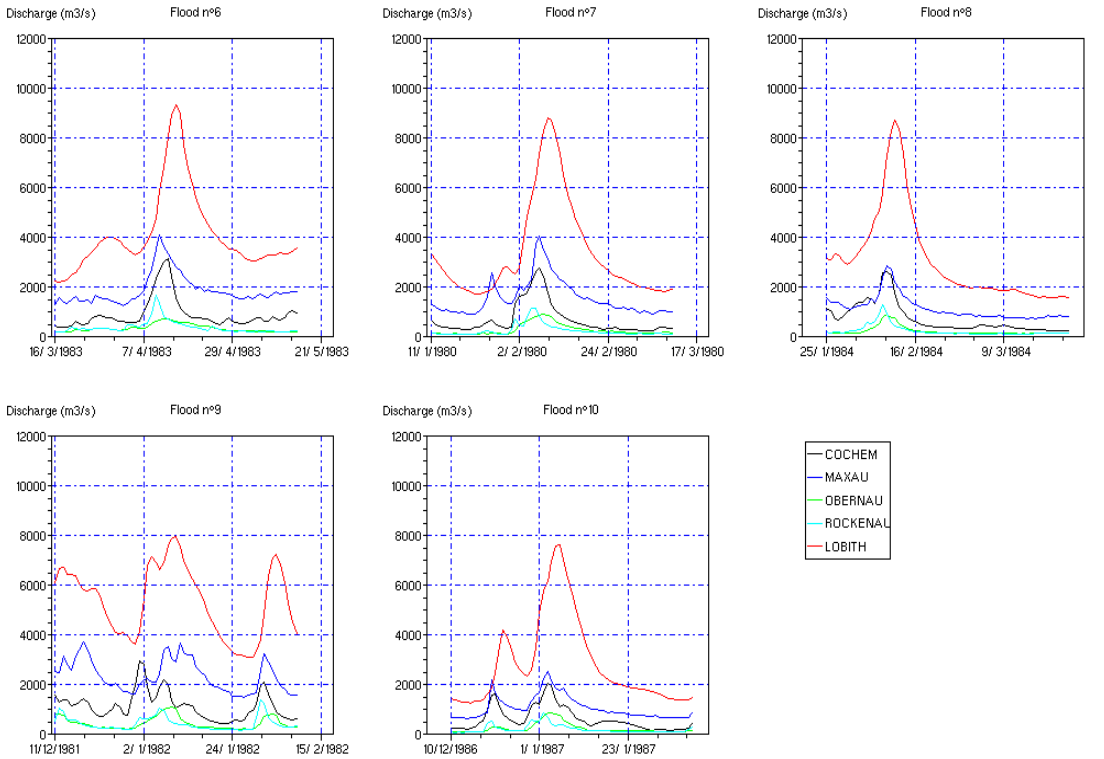

Figure 6: Major floods n° 6-10, discharges in Cochem (Moselle), Maxau (Rhine), Obernau (Main), Rockenau (Neckar) and Lobith (Rine)

The general comments on the largest floods are the followings:

- The maximum daily discharges in Lobith for the period 1969-2000 is **11 885 m^3/s** (flood n°1, January 1995),
- Important floods in Lobith occur mainly in winter (between December and March),
- Most floods show a large single peak,
- Hydrograph rising speed in Lobith ranges between 1000 and 2000 $m^3/s/day$, this figures are high considering the magnitude of floods involved.
- Upper Rhine (Maxau) contributes upto 30 to 40% of peak discharges in Lobith. Mosel is the second contributor with 20 to 30%.
- Time lag between the flood peaks in upstream stations and Lobith are the following :
    - Cochem (Mosel) – Lobith: 2 to 3 days,
    - Rockenau (Neckar) – Lobith: 4 to 5 days,
    - Maxau (Upper Rhine) – Lobith: 3 to 4 days,
    - Andernach (Middle Rhine) – Lobith: 1 to 2 days.

3.3 Low flows

As shown in Figure 4, low flow periods vary according to the part of the basin considered:

- Near the Alps, low-flows are observed in winter between November and January,
- In the center of the basin, low-flows occur earlier around October,
- In the downstream part, the low-flow period starts at the end of the summer (August) and extends upto October.

Figure 7 presents the number of days during which discharge is lower than half of the annual mean discharge on 6 gauging stations. This variable gives informations on the duration of low-flow periods. The graph reveals two things:

- The Moselle and the Neckar appear to have much longer low-flow periods than the Rhine and the Main: Moselle and Neckar regularly show low discharge values during more than 200 days per year. Whereas in Lobith, for example, it is exceptional that the low-flow period lasts more than 100 days.
- The longest dry periods (largest number of days with discharges under half of the mean annual discharge) are listed in Table 4 for 5 stations. 1976 appears to be a particularly dry year in Rockenau, Cochem and Lobith. No data is available on Worms for this year. On Maxau in contrast with the other stations, 1976 is not particularly exceptional.

Here we have again an illustration of the heterogeneity of hydrological regimes in the Rhine basin: a dry period in the downstream part does not imply a severe drought near the Alps for the same year.

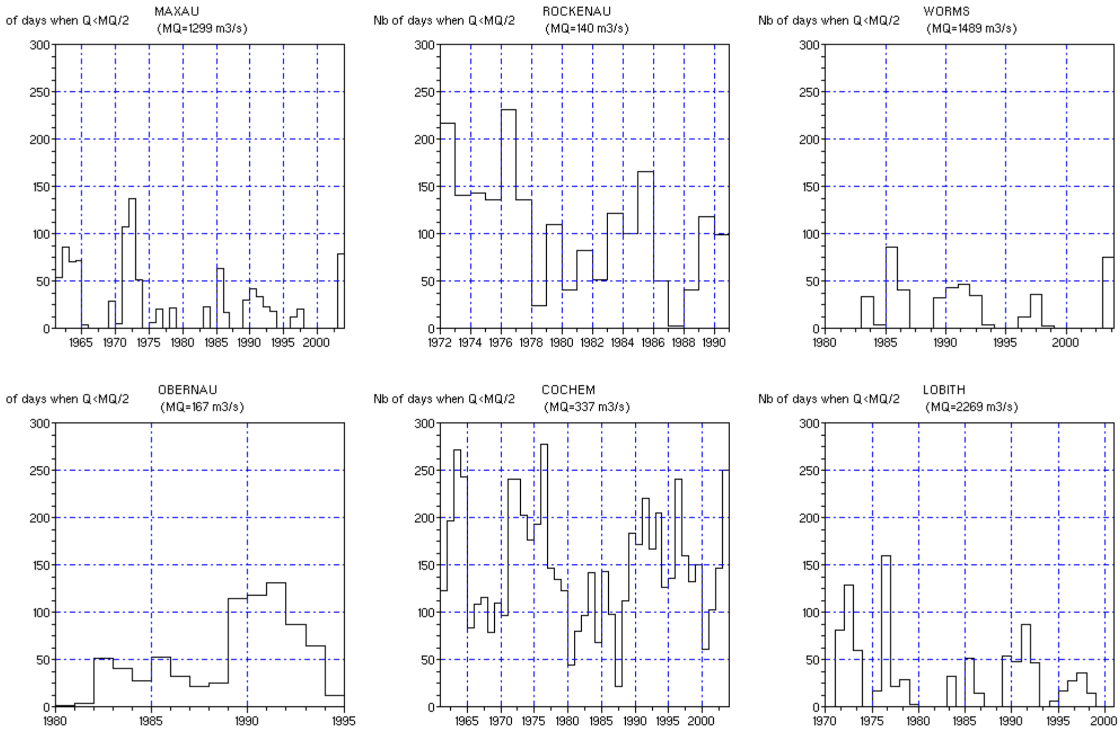

Figure 7: Number of days where the daily discharge is inferior to half of the annual mean discharge on the stations of Maxau, Rockenau, Worms, Obernau, Cochem and Lobith

Gauging station	**Low-flow period n°1**	**Low-flow period n°2**	**Low-flow period n°3**	**Low-flow period n°4**	**Low-flow period n°5**
Maxau	1973	1972	1962	2003	1964
Rockenau	1976	1972	1985	1974	1973
Worms	1985	2003	1991	1990	1986
Cochem	1976	1963	2003	1964	1972
Lobith	1976	1972	1991	1971	1973

Table 4: 5 longest low-flow periods (largest number of days with discharges under half of the mean annual discharge) on the stations of Maxau, Rockenau, Worms, Cochem and Lobith

Figure 9 presents another perception of low-flow periods: the graphs show, for each year, the minimum discharges not exceeded during 30, 60 and 90 days on the stations of Maxau, Rockenau, Worms, Cochem and Lobith. This variable is more an estimation of the intensity of the low-flow periods in terms of streamflow values. Figure 8 provides an illustration of the methodology to calculate it.

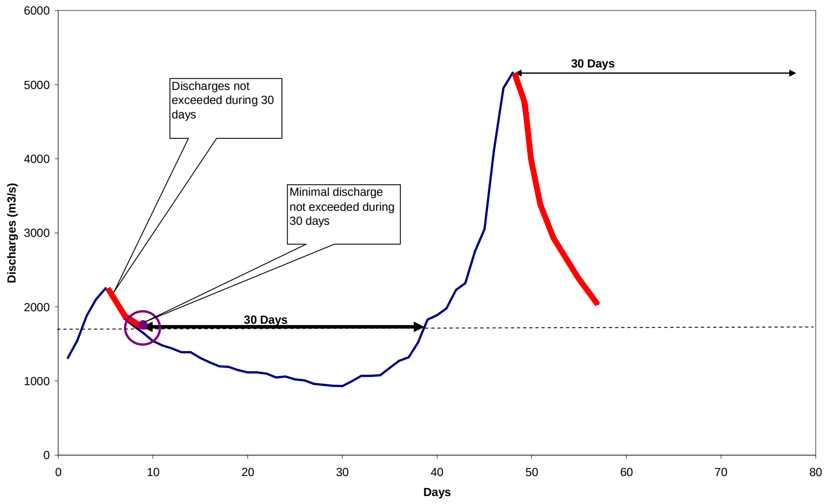

Figure 8: Calculation of "not exceeded" discharges

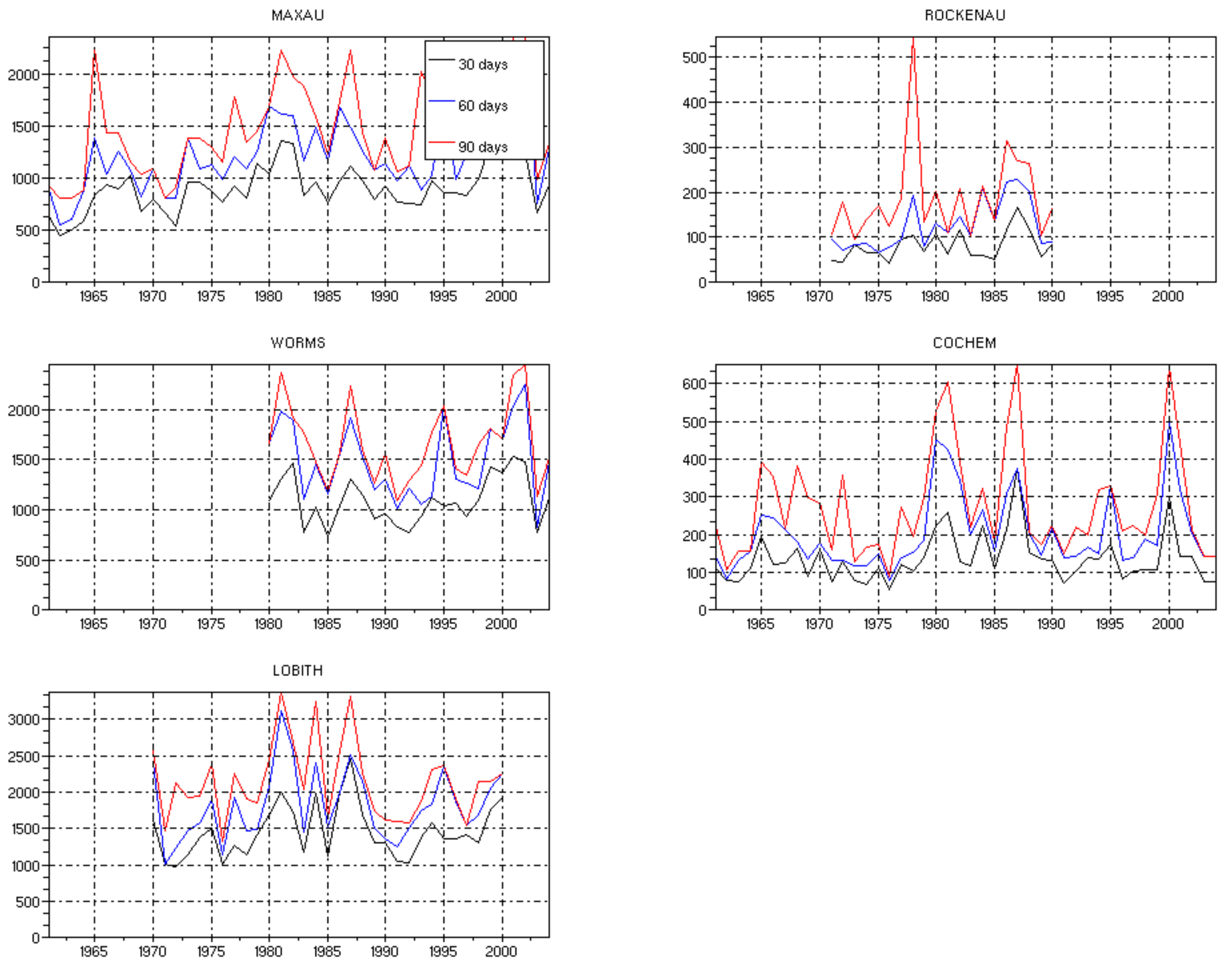

Figure 9: Minimal daily discharge not exceeded during 30, 60 and 90 days on the stations of Maxau, Rockenau, Worms, Cochem and Lobith

The following observations can be formulated:

- Like on Figure 7, the year 1976 appears to be particularly dry in Lobith (1000m^3/s not exceeded during 30 days), Cochem (60m^3/s not exceeded during 30 days) and Rockenau (50m^3/s not exceeded during 30 days). To give an idea of the magnitude of such low-flows, according to Van Lanen (2006): "If the flow drops below 1250 m3/s [in Lobith] then limitations for navigation will start and costs will steeply rise". On the 20th of July 2006 (latest low-flow period), discharges in Lobith were about 1400 m^3/s (Van Lanen, 2006).
- In low-flow conditions, the upstream part constitutes more than 90% of the flow in Lobith. This explains the moderate severity of low flows in the downstream Rhine: upstream Rhine and Rhine tributaries (mainly the Moselle, Main and Neckar) have opposite low-flow periods (see Figure 4) resulting in high discharges in the Rhine even at the end of the summer.

4 Conclusion

The dataset provided by RIZA to WP 1.5 contains rainfall, temperature and discharge daily values over the whole Rhine basin for the last 40 years. The data are of excellent quality with very few missing values.

This dataset can be extremely useful to perform various analysis on climate and hydrology of the Rhine basin. They are also highly valuable to calibrate and validate hydrological models.

A simple description of this dataset was proposed. More details are available in the abundant literature on Rhine hydrology (especially the Rhine basin monograph, CHR;1977). The following comments can be made:

- **Hydrological regime**: due to different climatic influences, upstream Rhine and Rhine tributaries (mainly the Moselle, Main and Neckar) have opposite high and low-flow periods resulting in a regular discharge pattern in the downstream Rhine (for example in Lobith).
- **Floods**: large floods occur mainly between December and February due to long rainfall events over the whole basin. Maximum recorded discharge in Lobith reaches 11 885 m^3/s in January 1995.
- **Low-flows**: low-flow periods are more longer and more intense on Rhine tributaries (especially on Moselle and Neckar). The worst event for the downstream part of the basin occurred in 1976 with discharges under 1000 m^3/s for more than 30 days in Lobith.

5 References

CHR (1977). Le bassin du Rhin, CHR.

CHR (1999). Development and testing of a GIS based water balance model for the Rhine drainage basin. CHR.

Disse, M. and H. Engel (2001). "Flood events in the Rhine basin: Genesis, influences and mitigation." Natural Hazards **23**(2-3): 271-290.

Middelkoop, H., K. Daamen, et al. (2001). "Impact of climate change on hydrological regimes and water resources management in the Rhine basin." Climatic Change **49**(1-2): 105-128.

Middelkoop, H., M. B. A. Van Asselt, et al. (2004). "Perspectives on flood management in the Rhine and Meuse rivers." River Research and Applications **20**(3): 327-342.

Pinter, N., R. Vand der Ploeg, et al. (2006). "Flood magnification on the River Rhine." Hydrological Processes **20**(1): 147-164.

RIZA and BfG (2005). Hydrological Modelling in the River Rhine Basin Part III - Daily HBV Model for the Rhine Basin**:** 227.

Silberstein, R. P. (2006). "Hydrological models are so good, do we still need data?" Environmental Modelling & Software **21**(9): 1340-1352.

Tol, R. S. J. and A. Langen (2000). "A concise history of dutch river floods." Climatic Change **46**(3): 357-369.

Van Lanen, H. A. J. (2006). "2006 Drought in the Netherlands (20 July 2006)." from http://www.geo.uio.no/edc/.

CHR (1977). Le bassin du Rhin, CHR.

CHR (1999). Development and testing of a GIS based water balance model for the Rhine drainage basin. CHR.

Disse, M. and H. Engel (2001). "Flood events in the Rhine basin: Genesis, influences and mitigation." Natural Hazards **23**(2-3): 271-290.

Institute for Inland Water Management and Waste Water Treatment and Federal Institute of Hydrology (2005). Hydrological Modelling in the River Rhine Basin Part III - Daily HBV Model for the Rhine Basin**:** 227.

Middelkoop, H., K. Daamen, D. Gellens, W. Grabs, J. C. J. Kwadijk, H. Lang, B. W. A. H. Parmet, B. Scha?dler, J. Schulla and K. Wilke (2001). "Impact of climate change on hydrological regimes and water resources management in the Rhine basin." Climatic Change **49**(1-2): 105-128.

Middelkoop, H., M. B. A. Van Asselt, S. A. Van T Klooster, W. P. A. Van Deursen, J. C. J. Kwadijk and H. Buiteveld (2004). "Perspectives on flood management in the Rhine and Meuse rivers." River Research and Applications **20**(3): 327-342.

Rhin, C. I. d. l. H. d. B. d. (1977). Le bassin du Rhin, CHR.

Silberstein, R. P. (2006). "Hydrological models are so good, do we still need data?" Environmental Modelling & Software **21**(9): 1340-1352.

Tol, R. S. J. and A. Langen (2000). "A concise history of dutch river floods." Climatic Change **46**(3): 357-369.

Van Lanen, H. A. J. (2006). "2006 Drought in the Netherlands (20 July 2006)." from http://www.geo.uio.no/edc/.