3.4.2 User Interface

FEWS-RHINE is build from a series of integrated components, which all provide a specific service. This is illustrated in figure 3.11

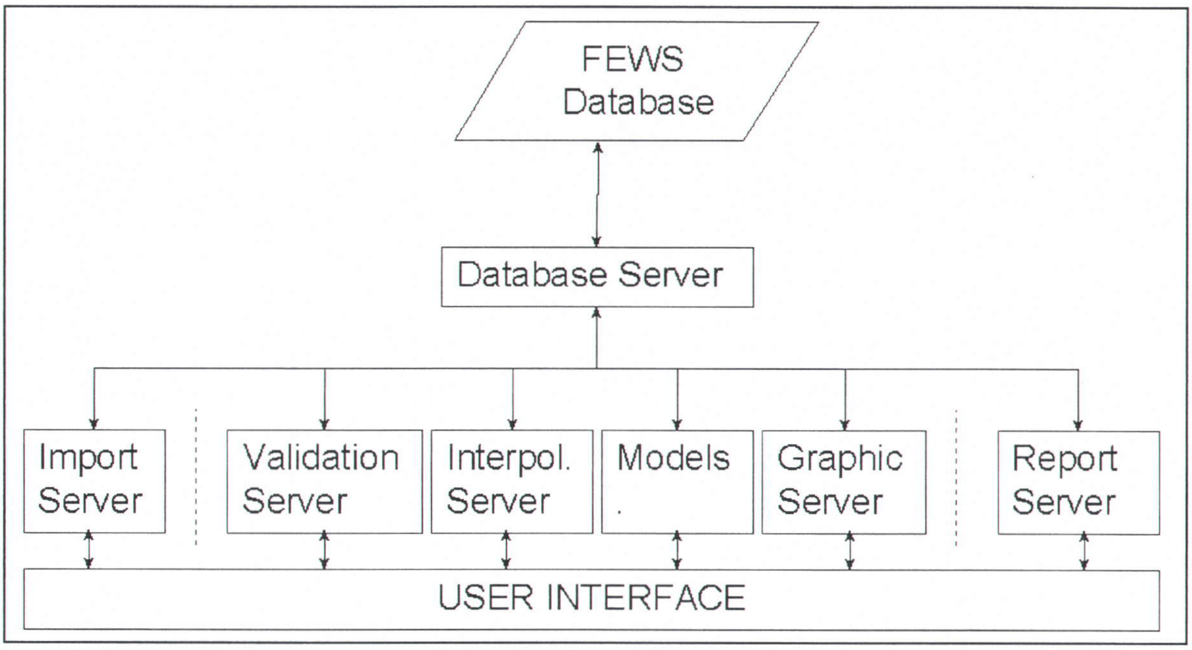


Figure 3.11 Components of the Flood Forecasting System

The interface, the FEWS-explorer, leads the user of FEWS-RHINE through the steps required for making forecasts. From the interface the user can:

- import the data required, explore the forecasted weather by viewing the weather forecasts (raster-maps) of the European Centre of Medium Range Weather Forecast and German and Swiss meteorological offices,
- validate and edit the incoming time series,
- interpolate the observed and forecasted meteorological data,
- start the required hydrological and hydraulic models (the HBV and the Sobek model),
- define alternative forecasts based on the assumption that the weather forecast may under or over estimate rainfall in the next days,
- compose reports to send to end-users.

Figure 3.12 shows the interface of FEWS-RHINE.

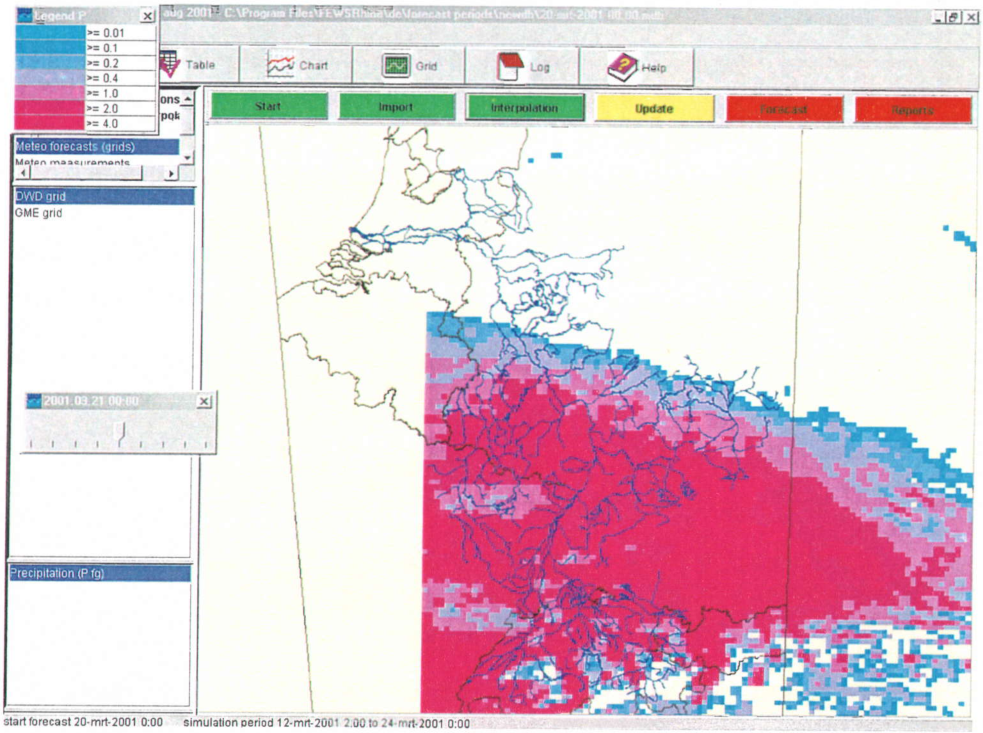


Figure 3.12 Interface of the FEWS-RHINE

In the next chapters the different components will be briefly described.

3.4.3 FEWS Database and Database module

The core modules of the FEWS are the "FEWS Database" and "Database module". These modules are responsible for the integration of all sorts of data, e.g. time series data, spatial grid data or model schematisations, and control the data flows within the FEWS. The "Database Module" has an interface through which all other modules communicate with the "FEWS Database".

The following data are stored in the FEWS-data base to create a discharge forecast:

	German section	Swiss section
Static data		
Station geographical references	x	x
Q/h relations	x	x
Interpolation relations	x	x
Hard limits		x
Soft limits	x	x
Variables		
Observed Precipitation (station)	x	x
Observed Temperature (station)	x	x
Observed Vapour Pressure (station)		x
Observed Wind speed (station)		x
Observed Discharge (station)	x	x
Observed Water level (station)	x	x
Observed Precipitation (basin)	x	x
Observed Temperature (basin)	x	x

	German section	Swiss section
Observed Vapour Pressure (basin)		x
Observed Wind speed (basin)		x
Observed 0-degree Celsius altitude (basin)		x
Forecasted Precipitation (Grid)	x	x
Forecasted Temperature (Grid)	x	x
Forecasted Vapour Pressure (Grid)		x
Forecasted Wind speed (Grid)		x
Forecasted Precipitation (basin)	x	x
Forecasted Temperature (basin)	x	x
Forecasted Vapour Pressure (basin)		x
Forecasted Wind speed (basin)		x
Forecasted 0-degree Celsius altitude (basin)		x
Forecasted Discharge (Station)	x	x
Forecasted Water level (Station)	x	x

The complete database of the Delft FEWS system is made up of three database files, model specific data and schematisation files. The last two databases are stored with the models (HBV and Sobek). The FEWS contains the following three database files:

Master database: the master database contains all master (meta) data of the FEWS, static data for a series and relations for interpolation. This meta data includes, series characteristics, station characteristics, interpolation options, filters, etc.. Figure 3.1 shows the relationships between the tables of the Master database.

Historical database: this database contains the dynamic meta data of a series for the update period and all data values. Figure 3.14 shows the relationships between the tables of the Historical database.

Forecast database: this database contains all meta data of a series for the forecast period and all forecasted data values. Figure 3.15 shows the relationships between the tables of the Forecast database.

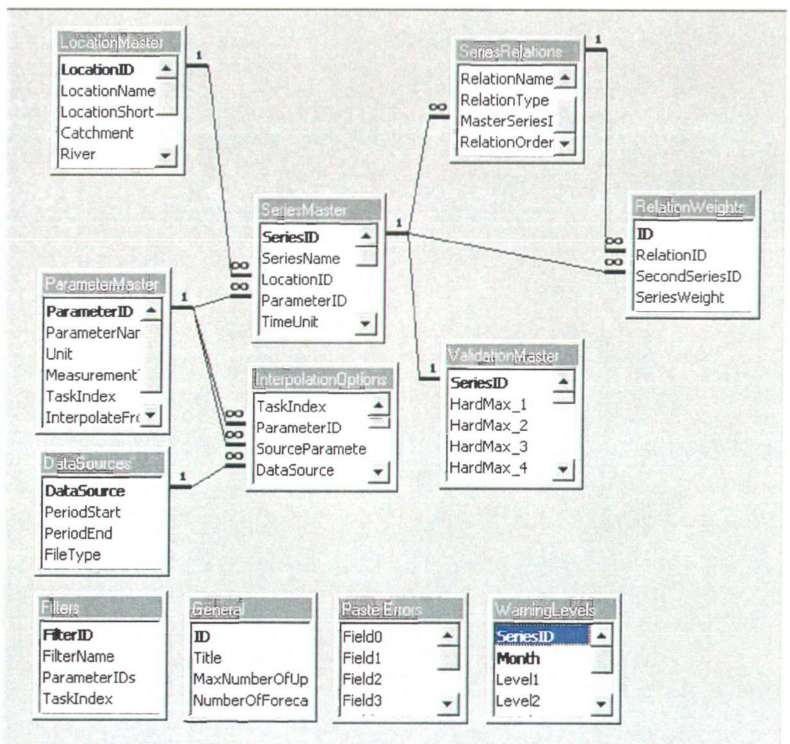


Figure 3.13 Relationships between the tables of the master database

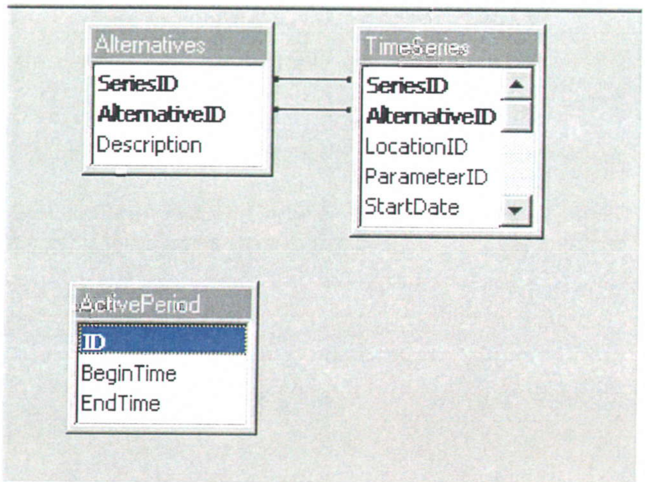


Figure 3.14 Relationships between the tables of the historical database

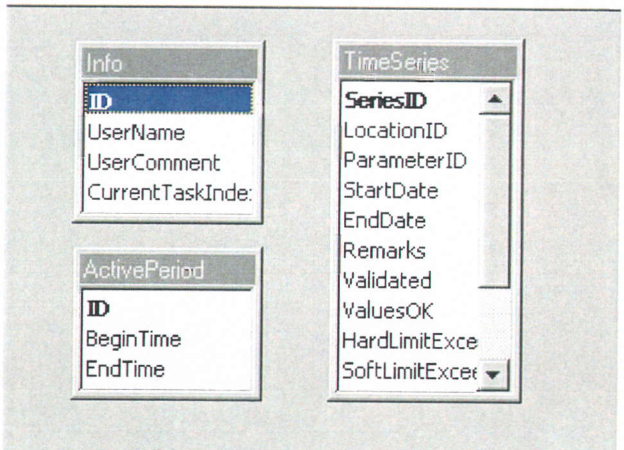


Figure 3.15 Relationships between the tables of the forecast database

3.4.4 Import module

The "Import module" reads the on-line available meteorological and hydrological data from external databases. It can handle time series - e.g. from hydrological gauging station data - as well as grid data - e.g. weather forecast data provided by meteorological services.

Hourly data for temperature, precipitation, water levels and discharges are stored for further use in the FEWS-RHINE database. The period covers T=-720 to T=0 hours. For the German basins gridded meteorological forecasts are provided by the German Weather Service (DWD). For the T=0 until T=48 hours these are the results of the LM model (7 km resolution). For the period T=48 - T=168 these are the results of the global model (50 km resolution).The variables are surface data for precipitation and temperature.

3.4.5 Validation Services

Imported data should be carefully validated before proceeding with forecasting. The generally large amount of data that is usually imported, requires that validation is done - at least partly - automatically by the system, only warning the user when pre-set criteria are not met. Standard imported data is checked for missing values, outliers and unlikely gradients in time.

In FEWS-RHINE the imported measured data are automatically checked on missing values, and exceeding of lower and upper hard and soft limits. The user receives a message when such suspect data series are imported. The stations whose data contain such suspicious values get an icon in front of their station name in the location list in the main window. These icons also appear on the map.

The system automatically completes series with missing values by either interpolation in time or in space. Also data that exceed hard limits are automatically replaced by interpolated values. For values that exceed soft limits, only a warning is provided to the user. Ignoring the warning means that the values are used later during the *update* and *forecast* procedures. The stations for which data series are completed and/or values have been replaced are indicated with an icon in both the location list containing and on the map.

Figure 3.16 explains the differences between hard and soft values to check on.

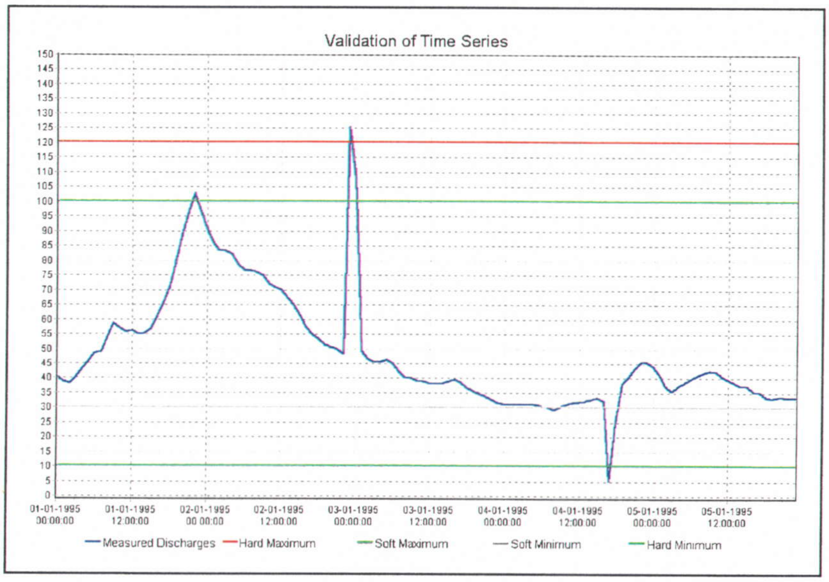


Figure 3.16 Validation of time series showing the use of hard and soft limits

If a hard level is exceeded (Hard Maximum or Hard Minimum) then the value will be set to missing. In the above figure the value of the second peak must be set to missing and also the value of the third minimum peak. The validation server will return a corrected time series with these two values set to missing, and a *series label* stating the series has extreme and missing values. The user is then forced by the user-interface to check all the series with extreme values before the forecasting process can be continued.

Figure 3.17 demonstrates the Rate of Rise and Fall values where the validation server must check the series on.

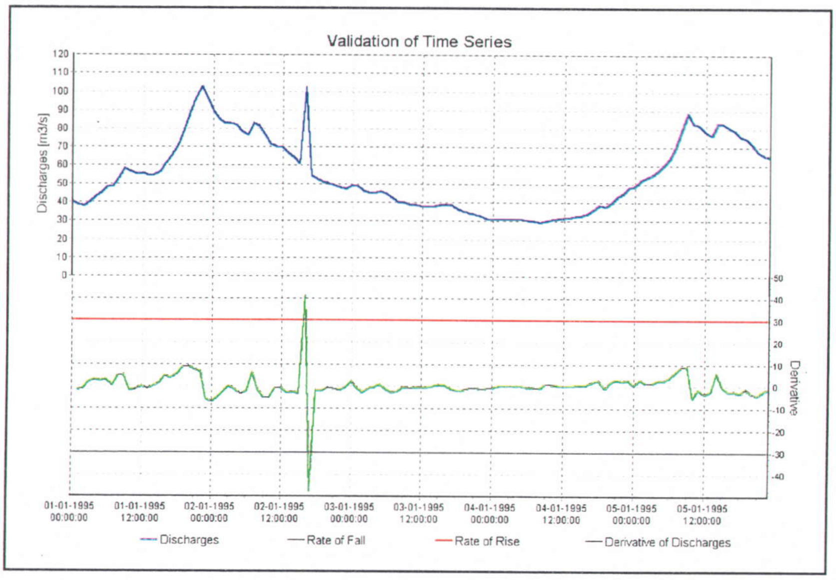


Figure 3.17 Validation of time series on rate of rise and fall

When one of these values is exceeded the user must also check the series first before a forecasting process can be continued.

3.4.6 Graphic Services

After import all data to carry out a forecast are validated and ready for use. The user may wish to view the imported data and eventually to edit these data. All data can be viewed while only the imported measured data can be edited.

To view and edit point time series data the user should first choose the variable and station. Changes are made using the window shown in figure 3.18.

Figure 3.18 Viewing and editing of imported data

The upper part shows the graph of the variable, while the lower part shows the data in table form. The user may change data from the table for the period since the time of the last update of the forecasting system. Commonly this will be the last time when a forecast was made. Older data cannot be changed anymore. The FEWS system only starts with complete data series, so when deleting data, these data need to be replaced. Completing the series can be done manually by user-defined values and or automatically by interpolation. When there are still missing values the user is asked to fill the missing data automatically. The series containing missing values will be completed using different interpolation techniques (see chapter 3.4.7 interpolation).

3.4.7 Interpolation Services

The Interpolation module generates new data by means of serial or spatial interpolation. It is applied for filling in of missing data in measured on-line data as well as to derive spatially distributed data on meteorological variables like precipitation and temperature based on point information. Within the FEWS-RHINE only spatial interpolation is used.

The spatial interpolation procedures allow for filling in of missing data and provide variable values at locations for which no measurements are available. The basis for the spatial interpolation calculations is an irregular grid with so-called "interpolation points". For each of these points the latitude, longitude and altitude are known relative to an ordinance datum such as mean sea level. The Interpolation module offers procedures to interpolate to this irregular interpolation grid from for example meteorological monitoring station data or grids of meteorological forecasts. FEWS-RHINE uses, kriging and inverse distance as interpolation methods. 3D Kriging for interpolation of temperature in the Alpine area, and normal kriging for rainfall as well as for temperature in the basin downstream of Basel. 3D kriging is used in the Alpine environment for temperature as temperature is particularly important when dealing with simulating runoff from snow melt.

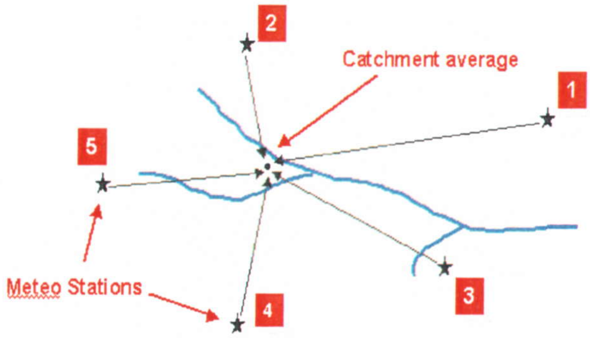


Figure 3.19 Interpolation from meteorological stations to catchment average

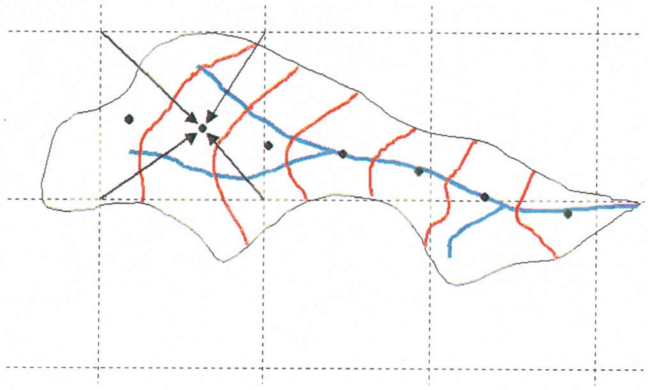


Figure 3.20 Interpolation from meteorological grid to catchment elevation zones

3.4.8 Linking of Hydraulic and Hydrological models

Hydrodynamic models are usually calibrated and run using discharge data of tributaries. Thus, the most basic approach of combining them with precipitation-runoff modelling is to simulate discharge of the gauging stations used within the hydrodynamic models by means of precipitation-runoff modelling.
This approach is followed for the gauging stations that are used as point inflow to the hydrodynamic Sobek model. Figure 3.2 shows schematically where the model districts of the main tributaries are located along the River Rhine.

Diffuse inflows into the hydrodynamic SOBEK model that will be used within the FloRIJN flood forecasting system by RIZA, are quantified during calibration using discharge data of gauging stations close to or within the area where the runoff is formed. In this case, precipitation-runoff modelling is realised for the considered area of runoff formation, not for the catchment area of the gauging station. However, the area along the River Rhine where diffuse inflow is formed is divided into sub basins corresponding to the main gauging stations within the River Rhine that are used for calibration of the hydrodynamic models.

For the incorporation of the HBV models in the FEWS forecasting system the originally 12 districts are additionally realised as one district*. However, the tributaries have not been linked in order to model the discharge of the River Rhine itself with HBV.

To link the HBV models to the FEWS shells are build around the cores of the hydrological HBV and hydraulic Sobek models. These shells are referred to as wrappers (see fig. 3.21). Wrappers are included in FEWS-RHINE to allow later for integration of other models when necessary.

The primary task of the wrappers is to arrange the communication between the models and the other components of the FEWS. A wrapper transfers data from the FEWS database to the model file format, maintains the files required for running the models (initial conditions, lateral flows, etc.), starts the model, and eventually transfers of results from the model file format to the FEWS database.

* Technically this includes an adaptation of directory paths, local definition of parameters (since the global parameters have been slightly different in some districts) and new IDs for input data (temperature input data are area related instead of station data). Due to restrictions of the modelling software, it is not possible to keep all gauging stations in the system when requiring 101 precipitation and temperature stations.

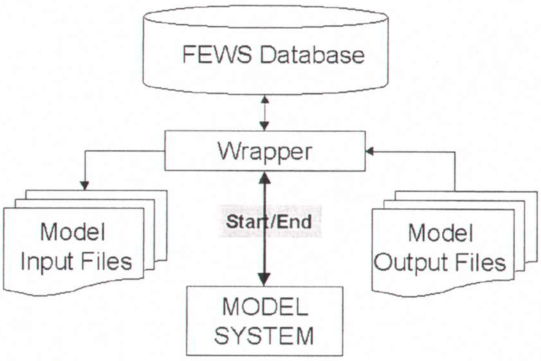


Figure 3.21 Model wrapper tasks

The wrappers are generally model dependent because each model system has its own input and output file formats. However, once a wrapper is developed for a specified modelling system, it can be applied for all models developed with this modelling system.

3.4.9 Date assimilation and updating procedures

Flood forecasting systems are employed in a real time environment, where models take information on the current and past states of the system and forecasts are made for a certain period of time into the future as a function of boundary inputs on the system.

Data assimilation or updating is a feedback system where the process models (the hydrological and hydraulic models) are conditioned using the information on the current state of the system modelled. These process models can be considered as a set of equations containing parameters and state variables, where state variables are transient in time and the parameters are generally held constant at some value determined in the calibration of the model prior to application in the real time environment. The primary goal of data assimilation is to guarantee an up to date representation of the state variables in model terms. This state is then used as an initial state for subsequent forecasts.

Within FEWS-RHINE updating is carried out by adjustment of the input variables, the precipitation and the temperature, in the hydrological model. This means that the precipitation and temperature variables over the last eight days are adjusted such that the resulting simulated hydrograph has a satisfying fit with the observed hydrograph for this period. As this fit generally will not be perfect at T= 0, an additional error will remain at the start of the forecast period. To guarantee that at the start of the forecast the simulated discharge is in agreement with the observed discharge, the simulated forecast is then adjusted with 100% of the remaining error at t=0. This adjustment decreases gradually to 0% adjustment until t = x. At t = x, the forecast is equal to the simulated discharge.

The following steps can be recognised:

1. The HBV sub-basins are updated by automatically varying the precipitation input until the error in discharge is smaller than a pre-defined limit.
2. The simulated forecast is then adjusted with 100% of the remaining error at t=0. This adjustment decreases gradually to 0% adjustment until t = x. At t = x, the forecast is equal to the simulated discharge.

For the German basin section where channel flow is simulated using the Sobek model, the system allows for an extra possibility for updating:
It is possible to adapt the final results of the computations at the forecast point at Lobith (which include the forecast period) to the measurements by shifting horizontally (in time) or vertically (water level or flow rate).

3.4.10 Report Services

The "Report module" generates output from the FEWS. It provides standard output formats that are used by RIZA and FOWG.

4 Data flow

Besides the improvement of the modelling system, another important item to improve flood forecasts is data. Recently large amounts of online hydrological and meteorological data have become available. The former statistical forecasting model uses precipitation data of eight stations in the German and French part of the Rhine basin and water level information of twelve gauges on the Rhine and it's main tributaries. In the operational FloRIJN system only the Rhine basin downstream of Andernach is considered and only two of the tributaries are modelled with a precipitation-runoff component. Therefore FloRIJN uses precipitation data of only five stations in the northern part of the Rhine basin with a temporal resolution of six hours. The precipitation forecast that is used by the statistical model as well as by FloRIJN, consists of one value per day for the entire northern part of the Rhine basin.

The water level information that is used, is transmitted every eight hours by the German Navigation Office in Mainz to the central database of Rijkswaterstaat in The Hague. FloRIJN uses water level forecasts for the upper boundary of the Sobek model at Andernach and for the Ruhr tributary. This information is passed to RIZA by the German counterparts in Mainz and Essen either by telefax or by telephone.

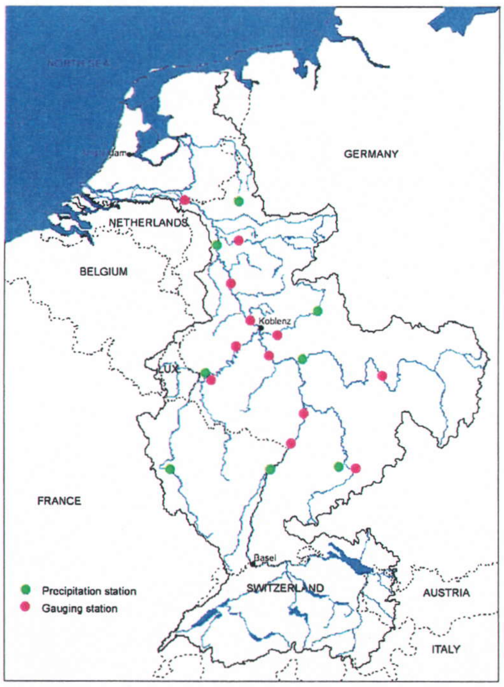


Figure 4.1 *Input stations for the statistical forecasting model*

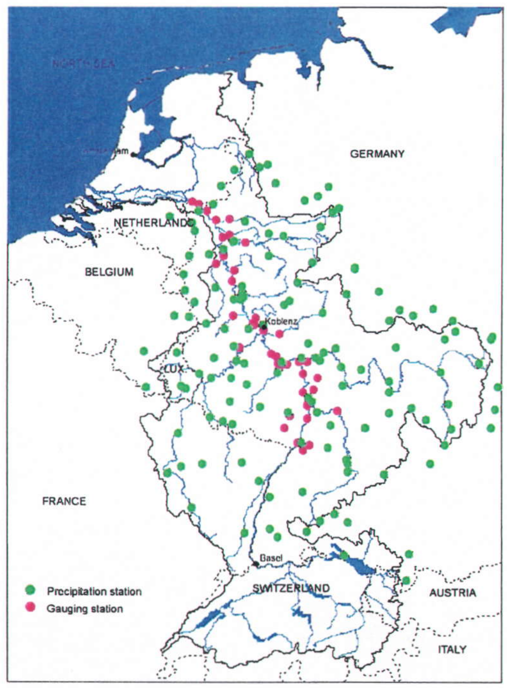


Figure 4.2 *Input stations for the FEWS Rhine system*

The new FEWS forecasting system has a much higher data demand than the existing FloRIJN system. To be able to calculate areal precipitation and areal temperature for the rainfall-runoff models, the spatial as well as the temporal resolution of meteorological observations and forecasts had to be improved significantly. Therefore agreements have been made with the German Weather Service (DWD) to make use of on-line measurements of over 130 stations in the Rhine basin. These measurements, partly with six-hour resolution and partly with one-hour resolution are transferred by FTP twice a day from DWD to RIZA. Furthermore DWD provides weather forecasts (precipitation and temperature) with an hourly time step on a 7 x 7 km grid up to two days ahead for the entire catchment of the Rhine. For the period from three till seven days ahead weather forecasts are provided on a 50 x 50 km grid. Observations and forecasts are interpolated to areal data and fed to the rainfall-runoff components of the forecasting system.

The results of the rainfall-runoff models as well as those of the Sobek model must be compared with on-line measurements. On the basis of these comparison the models can be updated, resulting in a more accurate forecast for the Lobith gauge. Therefore an agreement was made with the German Navigation Office

South-West in Mainz for the transmission of hourly water level data of 24 gauges on the Rhine and its main tributaries. Figures 4.1 and 4.2 show the increase for observed meteorological and hydrological input data from the statistical model to the new FEWS Rhine.

In can be foreseen that in the near future more data sources will become available, providing more accurate information to be used as input for the forecasting system. Extensive research is e.g. conducted to translate rainfall radar data observations into quantitative information.

In many sub catchments of the Rhine regional forecasting models are developed and/or existing models are improved. The FEWS forecasting system is set up as a modular system allowing input from alternative data sources such as regional forecasting models. Therefore the system is able to use regional forecasts at so called transmission points. The gauging station Andernach can be considered as the main transmission point for the FEWS Rhine system. For this gauge a 48-hour forecast, made by the German navigation office in Mainz, will be used as base input for the four-day forecast for Lobith. In figure 4.3 regional forecasts in the Rhine basin are shown. The grey boxes are considered as main transmission points. To meet the goals of the Action Plan on Flood Defence for the year 2005 the started linking and tuning of the forecasting centres in the Rhine basin should be continued.

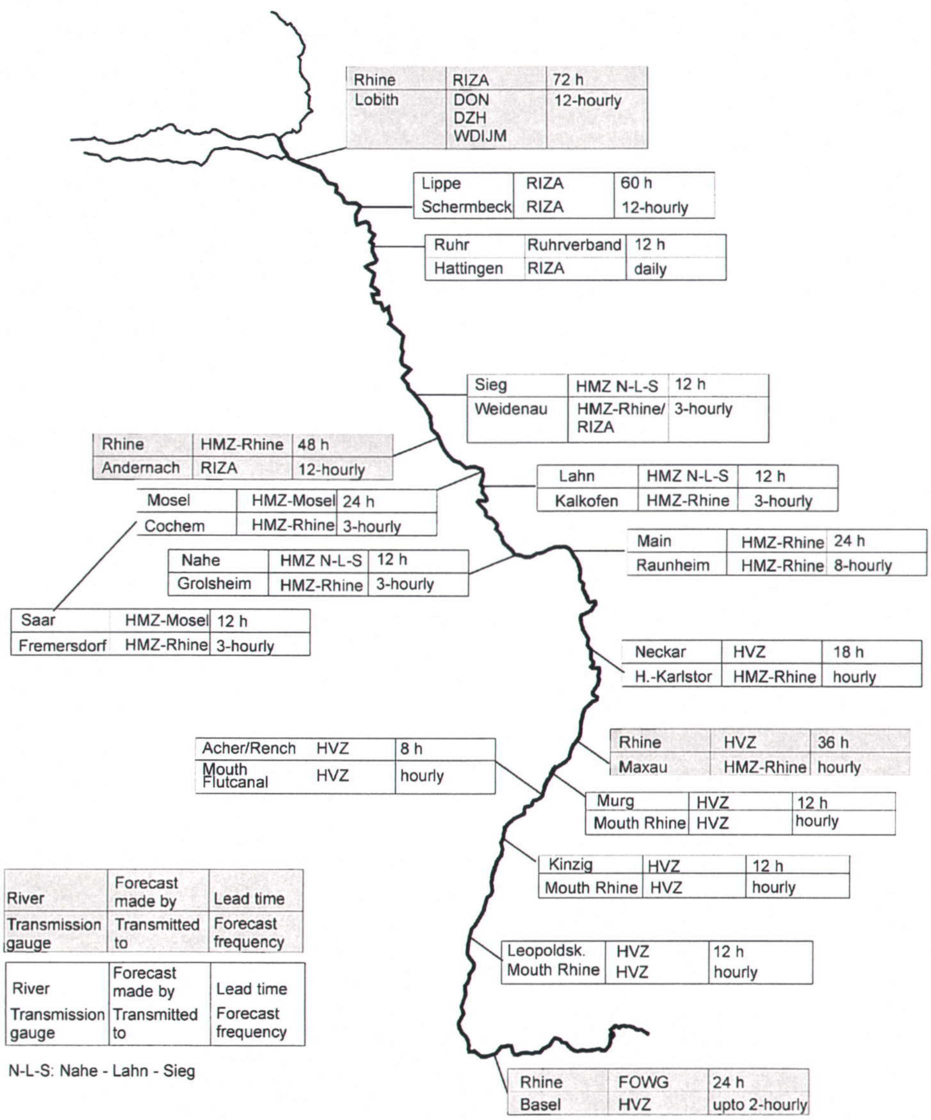


Figure 4.3 Regional forecasts and transmission gauges in the Rhine basin

5 Dissemination of forecasts

In case of a flood on the River Rhine, information bulletins containing water level forecasts are disseminated by RIZA at least twice a day. The users of this information are the Crisis Centres on national, provincial and regional levels, the press and the public. For dissemination of this information use is made of telephone, telegrams, telefax and the Monitoring System Water Levels (MSW), a computer program that allows authorized users to consult a central database for hydrological data.
For the population forecasts and flood warnings are published on the internet (http://hwg.waterland.net/hoogwater1/) and on teletext. The water level forecast for the Lobith gauge forms the upstream boundary condition for the forecasts of water levels along the downstream branches of the Rhine that are computed by the regional division of Rijkswaterstaat.

The exceedence of the water level of the Rhine at Lobith of 16,50 m +NAP is considered as an emergency situation. The protection of the population has the highest priority and the government, at different levels, puts Coordinating Crises Centres into operation and prepares decisions regarding immediate support actions or evacuations.

In case of an emergency involving more than one Province, a National Coordinating Centre within the Ministry of Interior becomes active. This Coordinating Centre is supported by technical expertise from other Ministries. The Centre coordinates logistic and communication aspects and may issue specific instructions on damage prevention or order evacuations.

At the Provincial level, the Governor is head of the Provincial Coordinating Centre. The tasks and responsibilities of the Governor are comparable to those of the Minister of the Interior, but restricted to the Province.

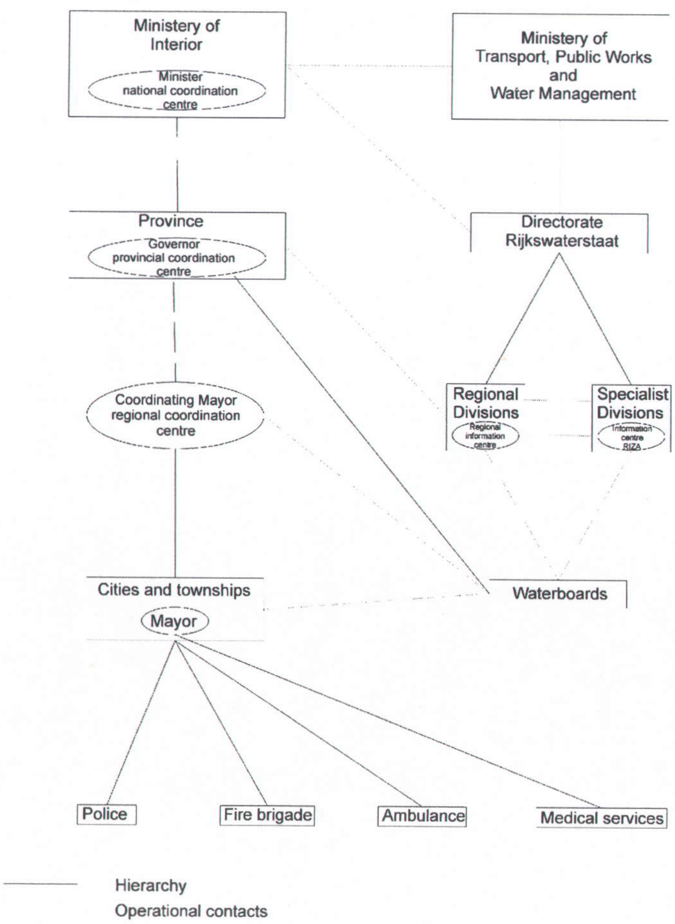


Figure 5.1 Organisation of river flood management in the Netherlands [Moll et al., 1996]

The local communities, cities and townships, have organised themselves on a regional level. The mayors in a region appoint within their region a coordinating mayor, who coordinates and directs support operations within the region by the police, fire brigade, ambulances and medical services.

In figure 5.1 a presentation of the organisation of tasks and responsibilities of flood management is given for the Netherlands. In this figure the position of the waterboards requires some explanation. Waterboards have a limited number of well-described tasks that usually include water management and the responsibility for the strength of river dikes. When a waterboard announces that that the flood situation evolves in such a way that the strength of a dike cannot be guaranteed any longer, the mayor has to decide on actions in view of his responsibility for the population.

6 Conclusions and recommendations

The prototype of the FEWS Rhine that will be available at the end of the IRMA-SPONGE project offers the functionality to import, validate, edit and interpolate all sorts of required data. The increased data availability asks for a more structured way of setting up a flood forecasting system and changes in data availability ask for a modular forecasting system. The new system provides information on the current hydrological state of the Rhine basin, runs and combines the required hydrological and hydraulic models and leads the user in a transparent way through all the steps required to make a flood forecast. The system clearly shows the possibilities and advantages of a modular way of building a Flood Early Warning System.

The individual models of the system have been calibrated. The complete system of data handling and model runs, necessary to make a forecast will be tested in a semi-operational situation. A follow-up project in which the prototype will be upgraded to an operational version of the flood forecasting system will be conducted immediately after the end of the IRMA-SPONGE project. Parallel to the testing activities, research will be done on possible improvements of the different components of the system, e.g. the schematisation of the Sobek models, the groundwater model and the HBV rainfall-runoff components.

Given the uncertainties in hydraulic and hydrological models as well as in weather forecasts it is clear that absolute safety against floods doesn't exist. Therefore it will always be necessary to indicate potential problem situation in an early stage. An extension of the lead-time of reliable flood forecasts increases the available time for preparation and execution of flood management measures. Therefore less people will be endangered and damages can be reduced.

A physically based model defeats a simple statistical model only for the long-term forecast. For the short-term forecast, where predicted rainfall is not dominant, a statistical model can hardly be beaten. First operational tests with the FloRIJN forecasting system show that the benefit of the system is mainly for flood forecasts with a lead-time of more than one day. The former statistical forecasting model produces equal or even better results for the short-term forecast. Therefore it is recommended to maintain the old model and to use its results for interpreting the FloRIJN and FEWS results for the one and two-day forecast.

Effective use of retention areas depends highly on accurate flood forecasts with a long forecasting period. If a retention basin is deployed too early or too late, the measure has no (or even a negative) effect on the top of the flood wave.

In the Rhine riparian states meteorological radar data are recorded by most of the national weather services. Data of individual radars are joined together into regional pictures that are published through various media. Radar information as a collection of successive pictures is very useful qualitative information for the assessment of precipitation development. The pictures can give a good impression of quantity and intensity of precipitation. Despite intensive research efforts, quantitative forecast of precipitation with radar data is still not possible with sufficient accuracy. Weather Services in the Rhine riparian states are working on the calibration of radar data with observed precipitation. It can be expected that quantitative precipitation measurements with radar will become more accurate in the next decennium. These developments should be followed and if necessary incorporated in the forecasting system.

The FEWS depends highly on large amounts of input data, coming from various institutes in the Rhine basin. This data supply should be formalized through written agreements. International co-operation is essential for flood forecasting in transboundary river basins. The co-operation between forecasting centres in the Rhine basin must be intensified.

Because of the fact that the travel time in the modelled system is about four days, it is expected that with the FEWS Rhine the required four-day forecast for the gauging station Lobith can be produced. In other international projects investigations are carried out, aiming at a further extension of the forecasting time by including the Alpine part of the Rhine basin as rainfall-runoff component and using long term (up to 14 days) precipitation forecasts of the European Centre for Medium Range Weather Forecast. For this purpose RIZA participates in the EC funded project "A European Flood Forecasting System (EFFS)" that investigates the possibilities to take advantage of currently available Medium-Range Weather Forecasts (4 - 10 days) to produce reliable flood warnings beyond the current flood warning period of approximately 3 days.

For flood management, there is a need for the development of a basin wide integrated modelling framework that takes into account the variable importance of the different components of the water cycle and that allows for analysis of local, regional and basin wide effects of environmental changes and spatial planning measures. The onset of such a system is provided by the FLORIJN system. This quest of the system should be for combing knowledge from different institutes rather than for the one ultimate hydrological model that can be applied everywhere. Development of such a system will enhance co-operation between hydrological research institutes, leaving liability where they are.

References

Bárdossy, A., A. Bronstert, H. Buiteveld, M. Disse, H. Engel, U. Fritsch, Y. Hundecha, R. Lammersen, D. Niehoff, and N. Ritter (2001a): LAHoR, Quantifizierung des Einflusses der Landoberfläche und der Ausbaumaßnahmen am Gewässer auf die Hochwasserbedingungen im Rheingebiet, Report IRMA-Code3/DU/1/002, 70 pp., December 2001 (in German).

Bárdossy A., A. Bronstert, H. Buiteveld, M. Disse, H. Engel, U. Fritsch, Y. Hundecha, R. Lammersen, D. Niehoff and N, Ritter (2001b) LAHoR, Quantification of the influence of land cover and river training measures on the flood condition at the Rhine river basin, final report IRMA-Code3/DU/1/002 34 pp., December 2001

Barneveld, H.J. and D.G. Meijer (1997): Sobek-model Andernach-Lobith. Model construction, calibration and verification. Report nr. PR042 HKV Lijn in Water and Geodan Geodesie. August 1997.

Bayerisches Landesamt für Wasserwirtschaft (1996): Deutsches Gewässerkundliches Jahrbuch. Rheingebiet, Teil II. Abflussjahr 1990 (in German).

Bemmel, M.S. van, D.G. Meijer and P. Weidema (2001): Sobek model of the River Moselle from Cochem to the River Rhine. Model construction and calibration. Report 10036.1-99 15 183 01/3/NL/1/164 Maarssen, Meander Consultancy and Research.

Bergström, S. (1996): The HBV Model. In: Computer Models of Watershed Hydrology. Ed. V.P. Singh, Colorado, USA.

BfG & RIZA (2002): Wellenablauf in den bedeutenden Nebengewässern des Rheins und im Rhein zwischen Maxau und Lobith. Aufgabe 3 des LAHoR-Projektes. In preparation (in German).

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2000): Hydrologischer Atlas von Deutschland. Berlin.

Capelleveen, P. van (1999a): Sobek-vakgrenzen functioneel ontwerp, opdrachtgever: Rijkswaterstaat / RIZA, Rw934.1, Witteveen+Bos (in Dutch).

Capelleveen, P. van (1999b): Sobek-vakgrenzen technisch ontwerp, opdrachtgever: Rijkswaterstaat / RIZA, Rw934.1, Witteveen+Bos (in Dutch).

CSO (1999): Baseline 3.1 Gebruikershandleiding rapportnummer 99.341. CSO Adviesbureau voor Milieuonderzoek, Bunnik (in Dutch).

Dellen, A. van and R. Schiferli (2001): Sobek schematisatie Moezel, TerraImaging, Amsterdam, G0065_ADE_01.005 (in Dutch).

Delft Hydraulics & Ministry of Transport, Public Works and Water Management (1997): SOBEK, Technical Reference Manual.

Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (draft 2001): Verdunstung in Bezug zu Landnutzung, Bewuchs und Boden. Merkblatt ATV-DVWK M 504 - draft version. Hennef (in German).

Eberle, M. (2001): Hydrological Modelling in the River Rhine Basin, Part II. Report on hourly modelling. Report BfG-1338 Federal Institute of Hydrology. Coblence, November 2001.

Emschergenossenschaft - Lippeverband (1975): Die Wasserwirtschaft im Emscher- und Lippegebiet. Essen.

Engel, H. et al. (1994): Das Hochwasser 1993/94 im Rheingebiet. Report nr. 0833 of the Federal Institute of Hydrology, Coblence, May 1994 (in German).

Erftverband (1999): Jahresbericht 1999. Bergheim (in German).

Federal Institute of Hydrology (BfG) (1999a): Hydrological Modelling in the River Rhine Basin. Final Report. Project execution R. Mülders. BfG - 1215. Coblence.

Federal Institute of Hydrology (BfG), Section Berlin (1999b): Entwicklung von Verfahren zur Berechnung langjähriger Mittelwerte der flächendifferenzierten Abflussbildung. Abschlußbericht DFG-Projekt GL 242/1-2. Berlin (in German).

Franzen, Ch. (1999): Untersuchung zur Regionalisierbarkeit von Niedrigwasserkenngrößen anhand der Hydrogeologie. University of Bonn (in German).

Hinterding, A. et al. (2000): Regionalisierung stündlicher Niederschläge in den Einzugsgebieten von Nahe und Mosel. University of Münster for the Landesanstalt für Wasserwirtschaft Rheinland-Pfalz (in German).

Hoefsloot, F., W.W. Immerzeel, U. Pakes and R. van der Veen (1999): GIS and SOBEK modelling. A manual for constructing schematisations. RIZA, GEODAN, RIZA werkdocument 99.121X, Lelystad.

Immerzeel, W. (2000): Creation of a GIS database for SOBEK models for the rivers Main and Rhine. Geodan Geodesie G9034 (contract RIZA RI-2772).

International Commission for the Protection of the Rhine (1998): Action Plan on Flood Defence. ICPR, Coblence, February 1998.

Landesamt für Wasser und Abfall Nordrhein-Westfalen (1992): Deutsches Gewässerkundliches Jahrbuch. Rheingebiet, Teil III. Abflussjahr 1989. Düsseldorf (in German).

Landesanstalt für Umweltschutz Baden-Württemberg (1994): Deutsches Gewässerkundliches Jahrbuch. Rheingebiet, Teil I. Abflussjahr 1991. Karlsruhe (in German).

Markus, A., J. Kwadijk and B. Holst (2000): FEWS-Rhine. Definition Study. Version 1.2. Report WL | Delft Hydraulics and Swedish Meteorological and Hydrological Institute nr. R 3392.00. May 2000.

Mierlo, M.C.L.M. van and R.H. Passchier (1998): Development of rainfall-runoff models for the Sieg and the Lippe. Final Report, Volume I: Main Text and Volume II: Annexes, Tables and Figures. WL | Delft Hydraulics Report R3049, February 1998.

Moll, J.R., B.W.A.H. Parmet and T.A. Sprong (1996): Floods and droughts in the Netherlands. Euraqua report. Technical meeting - Rome, October 1996.

Nash, J. and J. Sutcliffe (1970): River Flow Forecasting Through Conceptional Models. In: Journal of Hydrology No. 10. Amsterdam.

Parmet, B.W.A.H. and E. Sprokkereef (1997): Hercalibratie Model Lobith. Onderzoek naar mogelijke verbeteringen van de voorspellingen met het Meervoudig Lineaire Regressie Model Lobith na de hoogwaters van 1993 en 1995. RIZA rapport 97.061. ISBN 9036951070. Lelystad, December 1997 (in Dutch).

Ruhrverband (2001): www.ruhrverband.de/A01.htm and www.ruhrverband.de/leistd.htm, 08/2001 (River Basin Management → Export).

Schieder, T. (2001): Auswirkungen der Hochwasserrückhaltemaßnahmen am Niederrhein auf den Wellenablauf im Rhein zwischen Andernach und Lobith - Kalibrierung und

Anwendung eines hydrodynamischen Modells. Diplomarbeit, Geographische Institute der Rheinischen Friedrich-Wilhelms-Universität Bonn (in German).

Sprokkereef, E. (2001): FloRIJN 2000 - Verlenging van de zichttijd van hoogwatervoorspellingen voor de Rijn in Nederland tot drie dagen. RIZA rapport 2001.060. ISBN 9036954193. Lelystad, December 2001 (in Dutch).

Steinebach, G. and K. Wilke (2000): Flood Forecasting and Warning on the River Rhine. In: Water and Environment Management - The Journal of the Chartered Institution of Water and Environmental Management 2000, 14, February.

Swedish Meteorological and Hydrological Institute (SMHI) (1996): IMHS - Integrated Hydrological Modelling System Version 4.0, Manual. Norrköping, Sweden.

Veen, R. van der (2002): Bouw en calibratie SOBEK Rijn. Versie 2001 t/m 2003. RIZA rapport nr 2002.xxx RIZA, in prep. (in Dutch).

Vermetten, A.W.M. (1999): Gebruikersschil FloRIJN. Functioneel Detail Ontwerp. Report WL | Delft Hydraulics nr. E.0186.00. April 1999 (in Dutch).

Vermetten, A.W.M. and O. van den Akker (1999): Gebruikersschil FloRIJN. Technische Documentatie. Report WL | Delft Hydraulics nr. E.0186. April 1999 (in Dutch).

Verwaltungsvorschrift der Wasser- und Schifffahrtsdirektion Südwest (1997): Vorläufige Abfluss- und Stauzielregelung Mosel VV-WSD Südwest 22-5, October 1997 (in German).

Weiand, M. (2001): Aufbau, Kalibrierung und Validierung eines eindimensionalen hydrodynamisch-numerischen Wellenablaufmodells beispielhaft für den Rhein zwischen Maxau und Mainz, Diplomarbeit, Fachhochschule Koblenz (in German).

Weidema, P. (1998): BASELINE-application Sobek Cross-sections, User manual, PR192.10, HKV Lijn in water & Geodan Geodesie.

Weidema, P. (1999): BASELINE Applicatie Sobek-profielen, FH\G8056\90013, Geodan Geodesie & HKV Lijn in water (in Dutch).

Wendling, U. (1995): Berechnung der Gras-Referenzverdunstung mit der FAO Penman-Monteith-Beziehung. In: Wasserwirtschaft 85, H. 12.Wiesbaden (in German).

White, W. (2001): Spatio-Temporal Structure of Precipitation in the Moselle Basin with Particular Regard to Flood Events. University of Trier.

Wupperverband (2000): Jahresbericht 2000. Wuppertal (in German).

Annexes

1 Boundary conditions and lateral inflow of the Sobek model Maxau-Lobith

2 Boundary conditions and lateral inflow for the part of the Sobek model in the Netherlands

3 Climate stations that are used for the hourly hydrological models

4 Rainfall-runoff simulation results for a selection of tributaries

River Neckar

- Map of sub basins, gauging stations and elevation
- Graph of land cover distribution
- Table of parameters and simulation results
- Graphs of simulations for major flood events

River Main

- Map of sub basins, gauging stations and elevation
- Graph of land cover distribution
- Table of parameters and simulation results
- Graphs of simulations for major flood events

River Moselle

- Map of sub basins, gauging stations and elevation
- Graph of land cover distribution
- Table of parameters and simulation results
- Graphs of simulations for major flood events

River Sieg

- Map of sub basins, gauging stations and elevation
- Graph of land cover distribution
- Table of parameters and simulation results
- Graphs of simulations for major flood events

River Lippe

- Map of sub basins, gauging stations and elevation
- Graph of land cover distribution
- Table of parameters and simulation results
- Graphs of simulations for major flood events

Annexe 1 Boundary conditions and lateral inflow of the Sobek model. For the forecasting period (t>0) the output of HBV is used. For the historical period (t<0) the gauging stations are used. When there is no gauging station available at the outlet of a basin, HBV is used. The lateral inflow caused by groundwater (Abgrw) is calculated separately.

inflow	SOBEK Name	HBV-Name	Point or Diffuse	Factor HBV	Travel time HBV [hour]	Length diffuse inflow [m]	gauging Station
B	Maxau						
L	Alb	AlbPfinz	P	0.39	4.35		Ettlingen
L	Pfinz	AlbPfinz	P	0.61	7.04		Berghausen
L	Queich	QueichSp	P	0.39	5.35		Siebeldingen
L	Speyerbach	QueichSp	P	0.61	4.74		Neustadt/Wst.
L	ZWE Maxau-Speyer	UpRhine1	D	1.00	0.00	38232	HBV
L	ZWE Speyer-47616	UpRhine2	D	0.34	0.00	9383	HBV
L	ZWE 47616-Neckar	UpRhine2	D	0.66	0.00	18168	HBV
L	Neckar	Neckar4	P	1.10	11.24		Rockenau-SKA
L	ZWE Neckar-Worms	UpRhine3	D	1.00	0.00	14876	HBV
L	Weschnitz	WeschMod	P	0.81	2.50		Lorsch
L	Modau	WeschMod	P	0.19	2.78		Eberstadt
L	ZWE L Worms-Main	UpRhine4	D	0.37	0.00	53519	HBV
L	ZWE R Worms-Main	UpRhine4	D	0.63	0.00	53519	HBV
L	Main	Main8	P	1.01	3.39		Raunheim
L	Selz	Selz	P	1.00	0.00		Oberingelheim
L	ZWE_Mainz_Nahe	MidRhine1	D	0.71	0.00	31118	HBV
L	Nahe	Nahe3	P	1.01	0.00		Grolsheim
L	Wisper	Wisper	P	1.00	0.00		Pfaffental
L	ZWE_Nahe_Kaub	MidRhine1	D	0.29	0.00	16581	HBV
L	ZWE_Kaub_Lahn	MidRhine2	D	1.00	0.00	39310	HBV
L	Lahn	Lahn4	P	1.12	4.00		Kalkofen
L	Saynbach	Saynbach	P	0.43	0.00		Friedrichsthal
L	Nette	Nette	P	1.01	0.00		Nettegut
L	Wied	Wied	P	1.03	0.00		Friedrichsthal
L	ZWE_Mosel_Andernach	Saynbach	D	0.57	0.00	21621	HBV
B	Andernach						
L	Lippe	Lippe3	P	1.02	4.10		Schembeck 1
L	Emscher	Emscher	P	1.11	2.00		Koenigstrasse
L	Ahr	Ahr	P	1.00	5.00		Altenahr
L	ZWE_Ande_Bonn	MidRhine3	D	1.00	0.00	40999	HBV
L	Sieg	Unsi	P	1.00	1.50		Menden 1
L	ZWE_Bonn_Koel	MidRhine4	D	1.00	0.00	33199	HBV
L	Wupper	Wupper1	P	1.36	1.00		Opladen
L	Erft	Erft2	P	1.15	2.00		Neubrueck
L	ZWE_Koel_Dues	LowRhine1	D	1.00	0.00	56199	HBV
L	Ruhr	Ruhr3	P	1.09	10.00		Hattingen
L	ZWE_Dues_Ruhr	LowRhine2	D	1.00	0.00	36599	HBV
L	ZWE_Ruhr_Wese	LowRhine3	D	0.21	0.00	33199	HBV
L	ZWE_Wese_Rees	LowRhine3	D	0.79	0.00	23399	HBV
L	ZWE_Rees_Lobi	LowRhine4	D	1.00	0.00	24799	HBV
L	ABgrw		D	1.00	0.00	40999	ABgrw
L	BKgrw		D	1.00	0.00	33199	BKgrw
L	KDgrw		D	1.00	0.00	56199	KDgrw
L	DRgrw		D	1.00	0.00	36599	DRgrw
L	RWgrw		D	1.00	0.00	33199	RWgrw
L	WRgrw		D	1.00	0.00	23399	WRgrw
L	RLgrw		D	1.00	0.00	24799	RLgrw
L	ZWE_Cochem-Muendung	Umos4	D	1		52023	
B	Cochem	Umos3	P	1.00			Cochem

Inflow : B= boundary L = lateral inflow
Point or diffuse : P lateral inflow is point D is diffuse

Annexe 2 Boundary conditions and lateral inflow for the part of the Sobek model in the Netherlands

Boundaries	SOBEK Name	H (m +NAP)
	Eindkatdi	0
	Eindkedit	0
	WerkenMSW	1
	KrilekMSW	0

Lateral inflow		
		Q (m^3/s)
	WAAL_1	10
	WAAL_2	6
	PANKAN	6
	NEDR_1	1.5
	NEDR_2	10
	LINGE1	0.5
	NEDR_3	-8
	LEK__1	5
	LEK__2	10
	YSSEL1	1
	YSSEL2	8
	OUDEYS	40
	YSSEL3	8
	YSSEL4	15
	TWENTK	30
	YSSEL5	8
	YSSEL6	9
	YSSEL7	20
	YSSEL8	1
	Kortsl Rhederlaag1	0
	kortsl Rhederlaag2	0

Annexe 3 Climate stations that are used for the hourly hydrological models

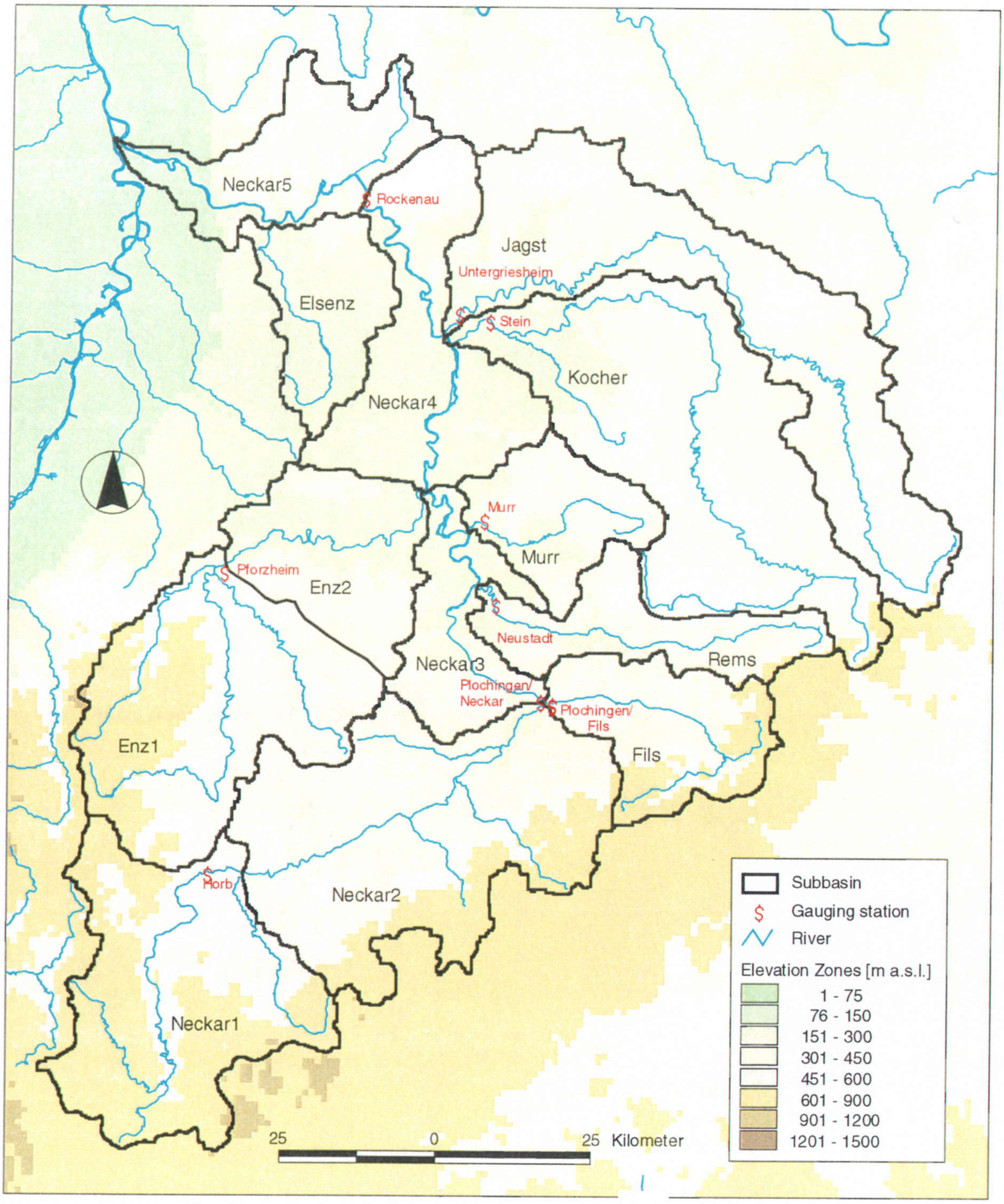
No.	Station name	Temperature data*	Precipitation data**	Altitude	Longitude	Latitude
6476	St. Hubert	x		557	5.40	50.03
6496	Elsenborn	x		570	6.18	50.47
6590	Luxembourg	x		379	6.22	49.62
7090	Metz	x		191	6.13	49.08
7180	Nancy/Essey	x		217	6.22	48.68
7823	Gerardmer	x		800	6.87	48.07
10315	Münster	x	x	53	7.70	52.13
10320	Gütersloh	x		72	8.30	51.92
10400	Düsseldorf	x	x	41	6.77	51.30
10406	Bocholt-Liedern	x	x	24	6.53	51.83
10410	Essen-Bredeney	x	x	153	6.97	51.40
10418	Lüdenscheid	x	x	392	7.65	51.25
10427	Kahler Asten	x	x	859	8.48	51.18
10430	Bad Lippspringe	x	x	158	8.83	51.78
10506	Nürburg-Barweiler	x	x	485	6.87	50.35
10513	Köln	x	x	100	7.17	50.87
10515	Bendorf	x	x	129	7.58	50.42
10526	Bad Marienberg	x		555	7.97	50.67
10532	Gießen	x	x	195	8.70	50.58
10535	Wahlen	x		350	9.13	50.82
10544	Wasserkuppe	x		925	9.95	50.50
10548	Meiningen	x	x	453	10.38	50.57
10558	Sonneberg-Neufang	x	x	630	11.18	50.38
10609	Trier-Petrisberg	x		273	6.67	49.75
10615	Deuselbach	x	x	483	7.05	49.77
10616	Hahn	x	x	498	7.27	49.95
10618	Idar-Oberstein	x		377	7.33	49.70
10628	Geisenheim	x		120	7.95	49.98
10635	Kleiner Feldberg	x	x	802	8.45	50.22
10637	Frankfurt	x	x	113	8.60	50.05
10645	Breitsol	x		581	9.43	49.90
10648	Michelstadt	x	x	455	9.10	49.72
10655	Würzburg	x	x	272	9.97	49.77
10658	Bad Kissingen	x	x	266	10.08	50.20
10671	Coburg	x	x	323	10.98	50.28
10675	Bamberg	x	x	243	10.92	49.88
10704	Berus	x		367	6.68	49.28
10706	Tholey	x	x	398	7.05	49.48
10708	Saarbrücken	x		320	7.12	49.22
10724	Weinbiet	x	x	557	8.12	49.38
10727	Karlsruhe	x	x	145	8.37	49.03
10729	Mannheim	x	x	100	8.55	49.52
10738	Stuttgart-Ech.		x	396	9.23	48.68
10739	Stuttgart	x	x	315	9.20	48.83
10742	Öhringen	x	x	277	9.52	49.22
10743	Niederstetten	x		473	9.97	49.40
10761	Weißenburg	x		424	10.97	49.02
10763	Nürnberg	x		318	11.05	49.50
10815	Freudenstadt	x	x	801	8.42	48.45
10818	Klippeneck	x	x	975	8.75	48.10
10836	Stötten	x	x	738	9.87	48.67

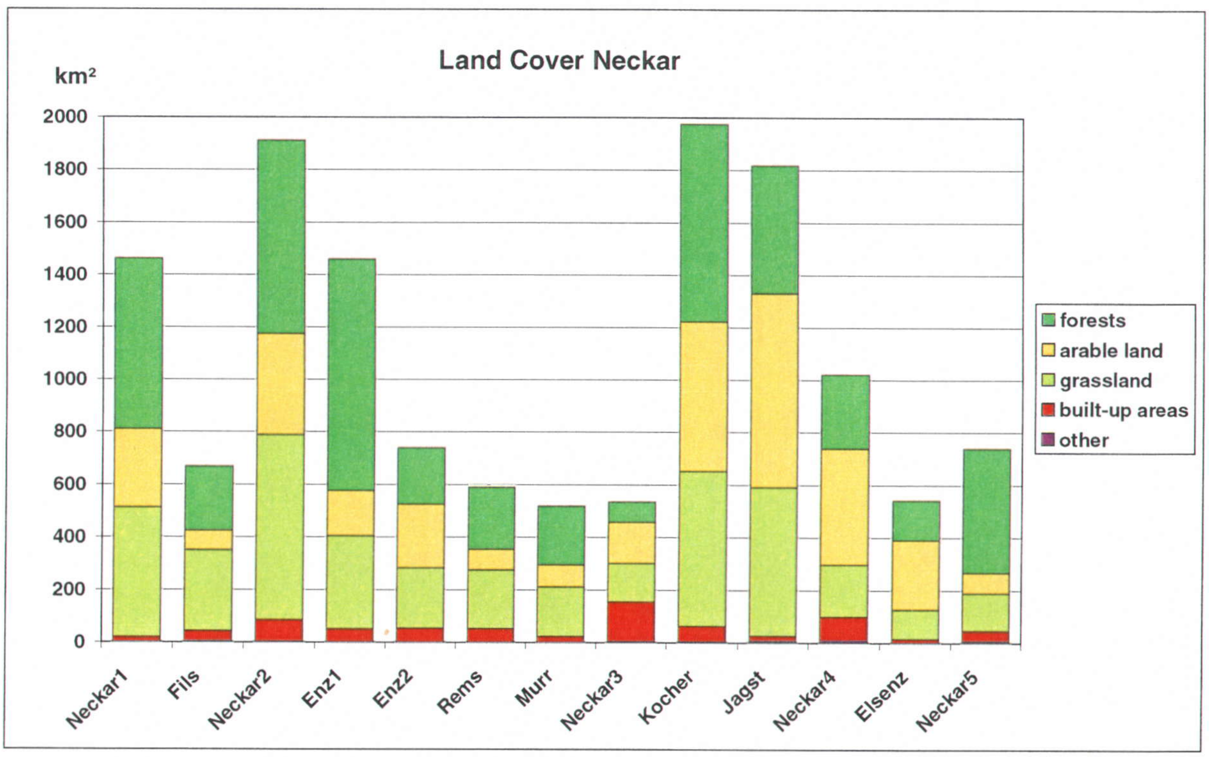
* hourly or synoptic data

** hourly data used for the distribution of area related precipitation in time

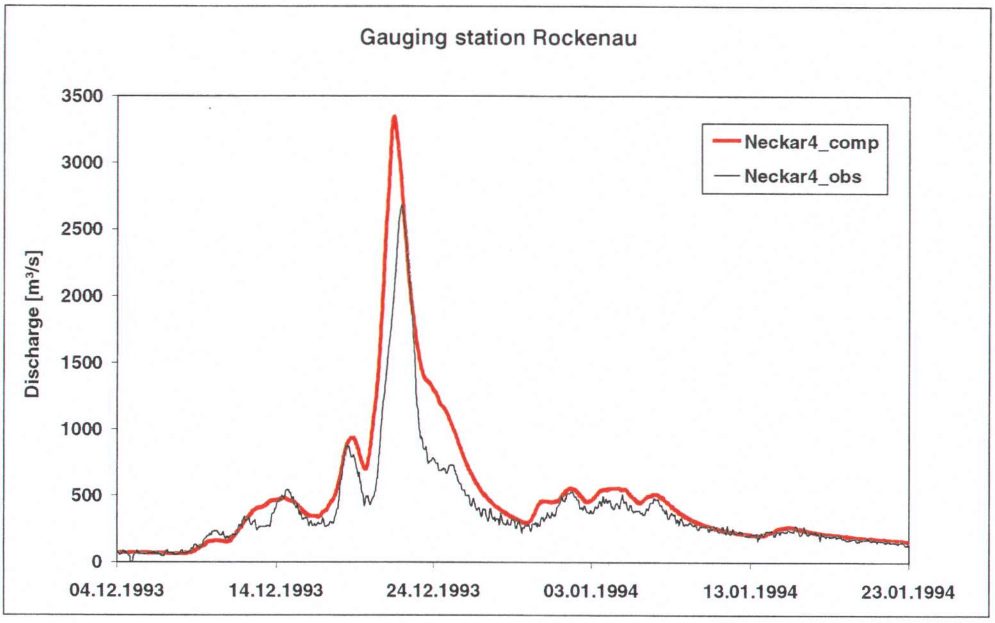
Annexe 4 Rainfall-runoff simulation results for a selection of tributaries

River Neckar

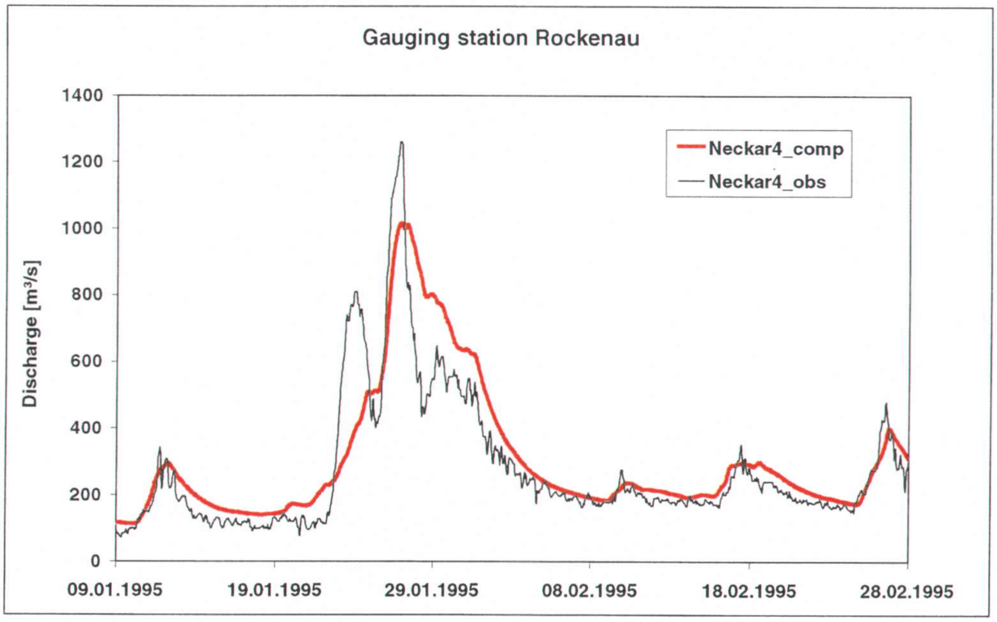



Land Cover Neckar
km²
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Neckar1
Fils
Neckar2
Enz1
Enz2
Rems
Murr
Neckar3
Kocher
Jagst
Neckar4
Elsenz
Neckar5
forests
arable land
grassland
built-up areas
other

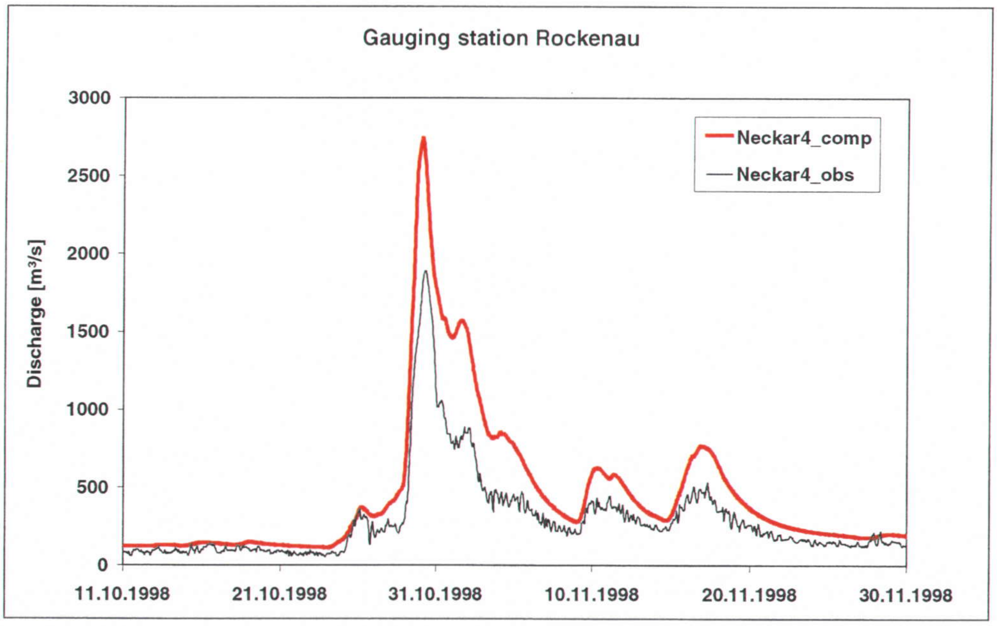
Parameters	District	Neckar1	Fils	Neckar2	Enz1	Enz2	Rems	Murr	Neckar3	Kocher	Jagst	Neckar4	Elsenz	Neckar5
'pcorr	0.01		0.0105	0.0107				0.011	0.0107	0.0102		0.0105	0.0115	0.0115
'pcaltl	0													
'tcalt	0.6													
'rfcf	1													
'sfcf	0.8	0.6	1	1	0.6	0.6	0.9	0.6		1		1	0.6	0.6
'cfmax	4	2	2.5	2	5	5	2			3.5	2	2		
'tt	0		-0.5	-0.5			-0.5	-0.5		-0.5	-0.5	-0.5	-1.5	-1.5
'dttm	0													
'tti	0.5		0.2		1	1	0	0.2		0.2	0.2	0.2	1	1
'whc	0.1	0.01								0.01	0.01			
'cfr	0.05												1	1
'fc	200	134	124	125	223	109	125	130		121	180	133	120	263
'lp	0.7	0.6	0.65	0.8	0.9	0.9	0.65	0.6	0.9	0.9	0.9	0.9		
'beta	2	1.5	1	1.5	1.5	1.5	0.9		1.5		1.5		1.5	1.5
'cflux	1.5			0.3	0.05	0.05	1	0.5	0.1	0.5	0.5	0.1	0.5	0.5
'epf	0.01	0	0	0	0	0	0	0		0	0	0	0	0
'ecorr	0.1							0.107			0.105			
'ecalt	1	0	0	0	0	0	0	0		0	0	0	0.5	0.5
'ered	0.0001	0.1	0.1	0.1	0.1	0.1	0.1	0.1		0.1	0.1	0.1	0.1	0.1
'icfo	1.5	2												
'icfi	1													
'k4	0.02513	0.05055	0.07139	0.04257	0.02916	0.02916	0.06007	0.06007		0.04761	0.05835	0.06007	0.06007	0.06007
'perc	0.2	2	1.7	0.8	0.4	0.4	1.7	1	1	2	1.5	1	1	1
'khq	0.07	0.23	0.2	0.19	0.076	0.076	0.23	0.21215		0.15	0.15	0.3	0.3	0.3
'hq	2.448	3.386	4.599	3.57	3.066	3.066	3.386	4.7129		3.831	2.944	3.386	3.386	3.386
'alfa	1	0.8	1.3		1.5	1.5	0.8			1.3		1.3		
'maxbas	1	0.34167	0.25	0.41667	0.41667	0.41667	0.5	0.5		0.625	1.04167	1.54167		
'recstep	999													
'focfmax	0.6													
'etf	0.1	0.05	0	0	0	0	0	0	0	0		0	0	0
'cevpfo	1.15													
inflow				Neckar1		Enz1			Neckar2			Neckar3		Neckar4
	Simulated period: 1/1990-12/1999			(lag=0.3)					(lag=0.3)			(lag=0.3)		Elsenz
	Initial state:1/1997			Fils					Rems			Kocher		
									(lag=0.5)			Jagst		
R²		0.74791	0.81244	0.77412	0.84582		0.15538	0.51382		0.78114	0.83209	0.75728		
rel Acc Diff		0.12570	0.00092	-0.05659	-0.06443		-0.01744	0.00334		-0.03189	-0.07786	-0.05635		
peak err		-0.07347	-0.23911	0.04631	-0.28934		-0.55498	-0.37044		-0.16503	-0.28666	-0.01608		



Gauging station Rockenau
Discharge [m³/s]
3500
3000
2500
2000
1500
1000
500
0
04.12.1993
14.12.1993
24.12.1993
03.01.1994
13.01.1994
23.01.1994
Neckar4_comp
Neckar4_obs

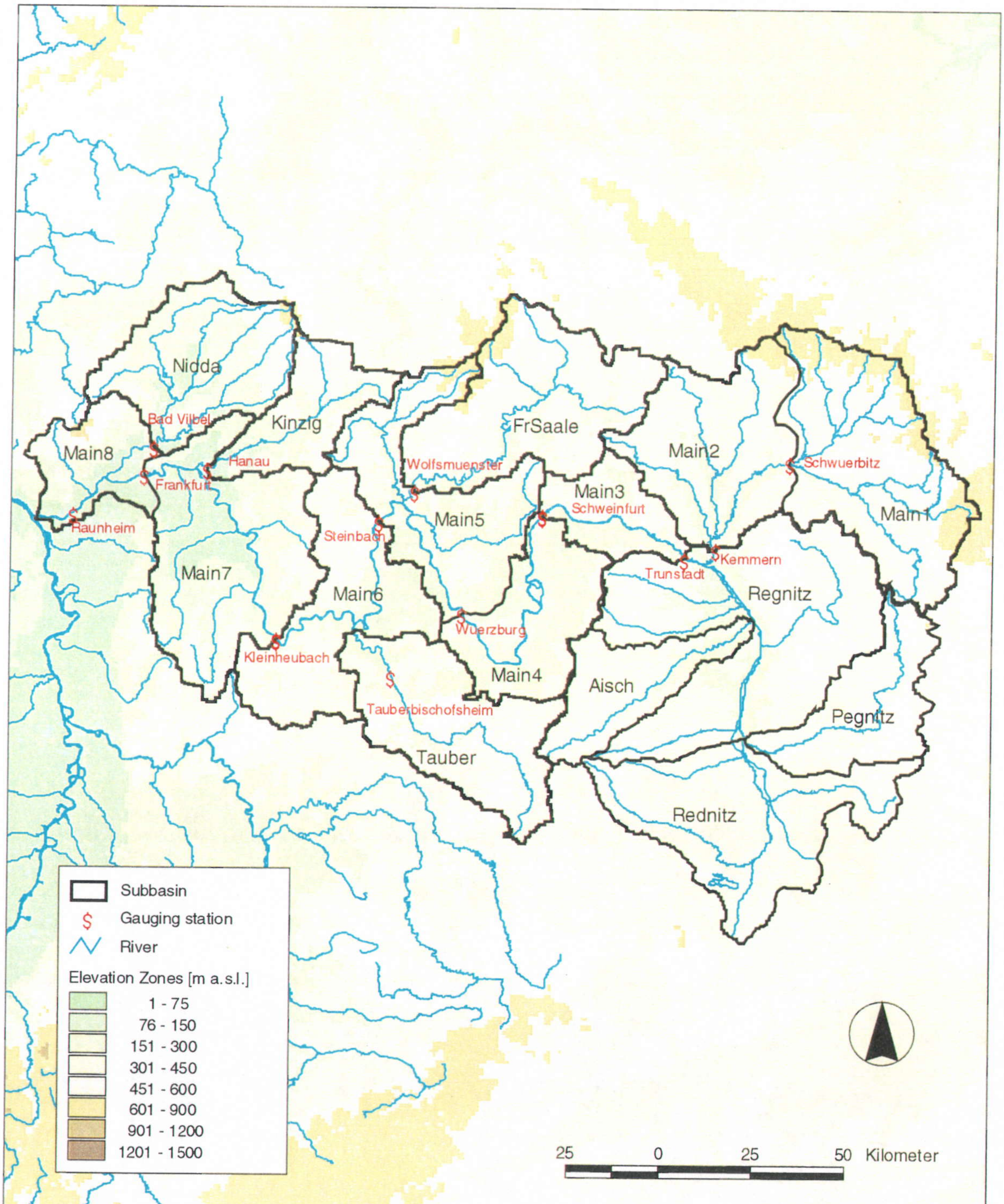


Gauging station Rockenau
Discharge [m³/s]
1400
1200
1000
800
600
400
200
0
09.01.1995
19.01.1995
29.01.1995
08.02.1995
18.02.1995
28.02.1995
Neckar4_comp
Neckar4_obs

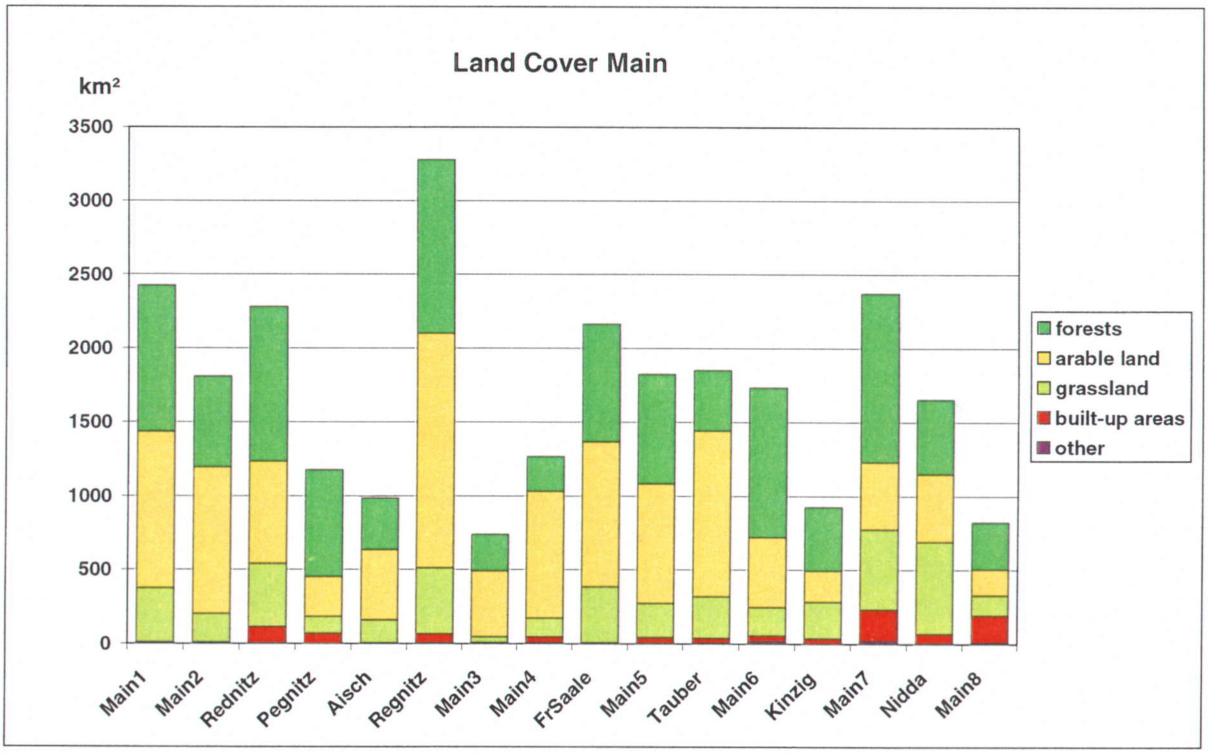


Gauging station Rockenau
Discharge [m³/s]
3000
2500
2000
1500
1000
500
0
11.10.1998
21.10.1998
31.10.1998
10.11.1998
20.11.1998
30.11.1998
Neckar4_comp
Neckar4_obs

River Main

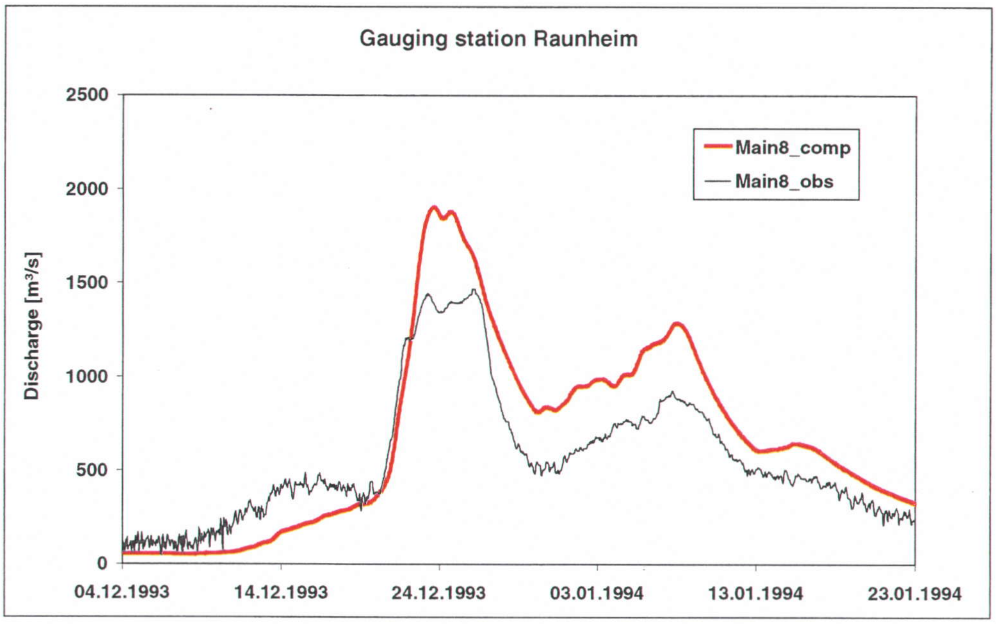


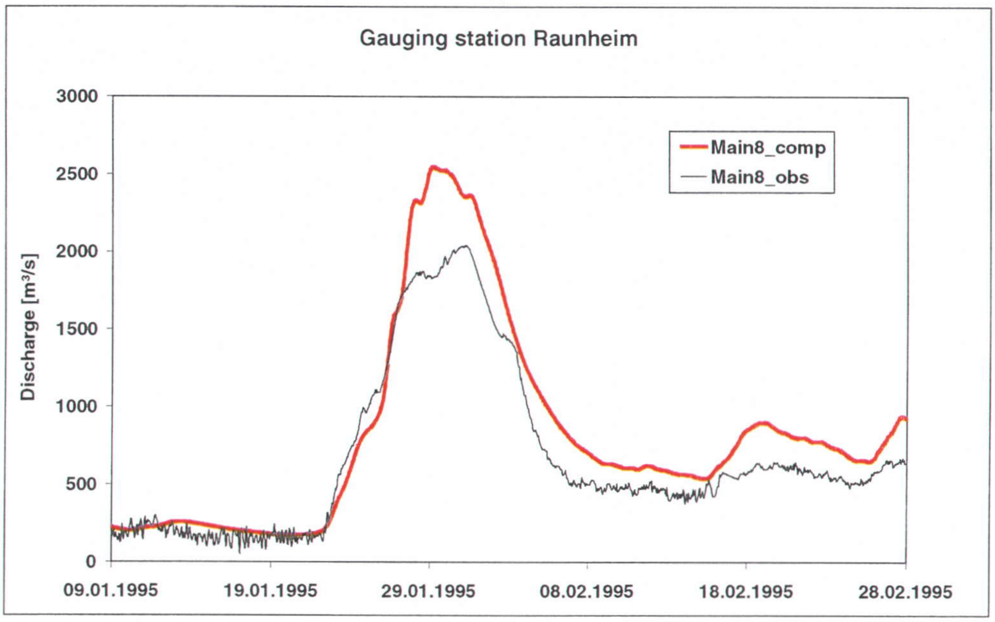
Nidda
Bad Vilbel
Kinzig
Main8
Hanau
Frankfurt
Raunheim
Main7
Steinbach
Main6
Kleinheubach
FrSaale
Wolfsmuenster
Main5
Main3
Schweinfurt
Wuerzburg
Main4
Tauberbischofsheim
Tauber
Main2
Schwuerbitz
Main1
Kemmern
Trunstadt
Regnitz
Aisch
Pegnitz
Rednitz
Subbasin
Gauging station
River
Elevation Zones [m a.s.l.]
1 - 75
76 - 150
151 - 300
301 - 450
451 - 600
601 - 900
901 - 1200
1201 - 1500
25
0
25
50
Kilometer

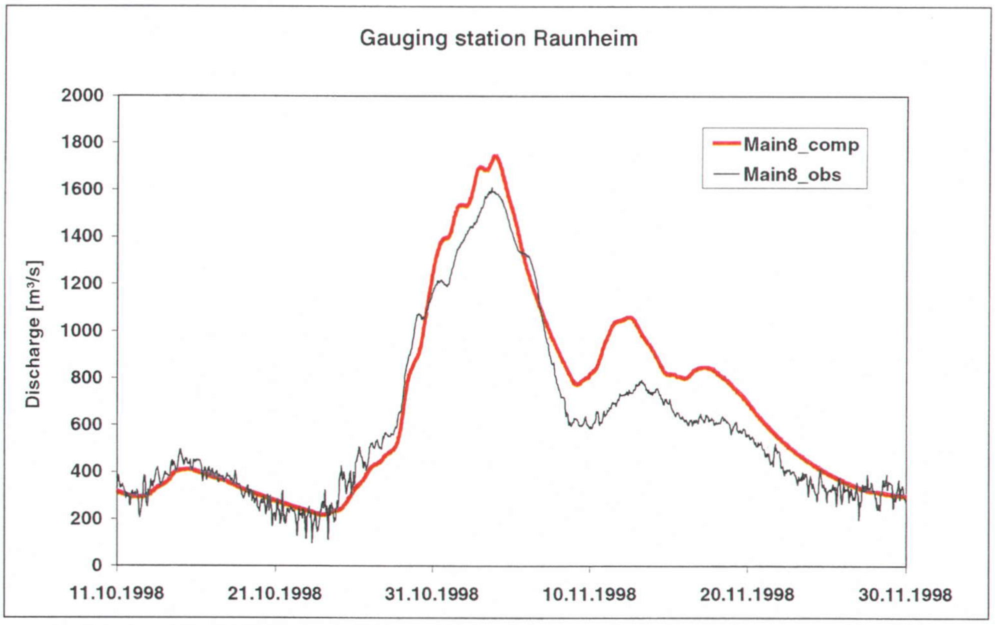


The sub basins "Rednitz", "Pegnitz", "Aisch" and "Regnitz" are part of the former sub basin "Regnitz". The basin of the River Regnitz was subdivided in order to allow different parameter values for four sub basins in the future. In the parameter table on the next page "Regnitz" refers to the former sub basin "Regnitz", i.e. the total basin.

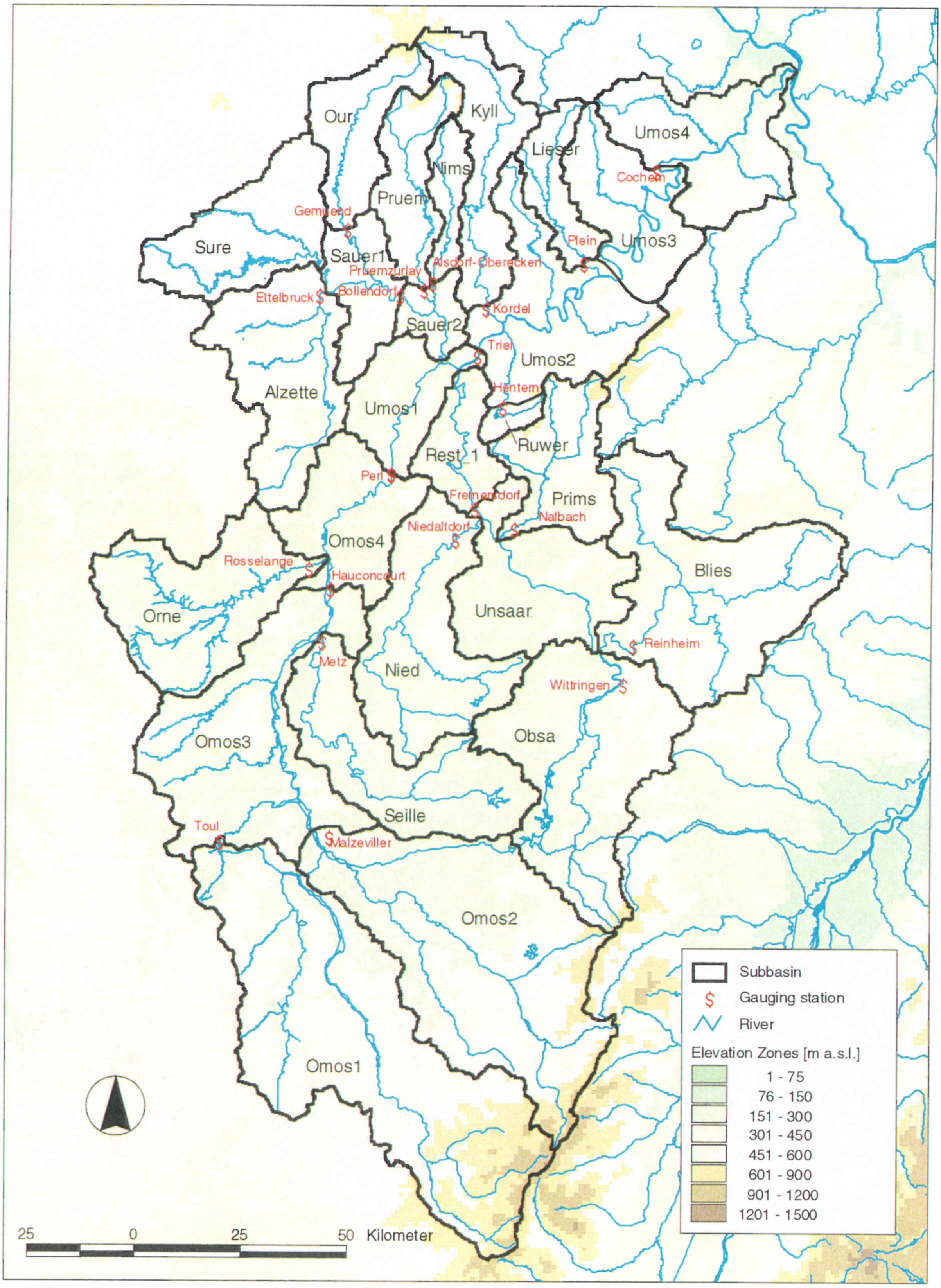
Parameters	District	main1	main2	regnitz	main3	main4	frsaale	main5	tauber	main6	kinzig	main7	nidda	main8
'pcorr	0.01	0.01025			0.0102		0.01025			0.0102	0.0103	0.0102		0.0102
'pcaltl	0													
'tcalt	0.6													
'rfcf	1													
'sfcf	0.8	1		1	1							0.9		0.9
'cfmax	4													
'tt	0	-0.5		-0.5								-0.5		-0.5
'dttm	0													
'tti	0.5	1												
'whc	0.1	0.01												
'cfr	0.05													
'fc	200	131	100	137	100	100	135	166	250	220	204	213	280	213
'lp	0.7	0.8	0.65	0.8	0.8						0.8		0.6	
'beta	2	1.2	1	1		1	1.5	1.5		2.5	1.5	2.5	1.5	2.5
'cflux	0.5			0.4		0.1	0.1		0.1				0.1	
'epf	0.01													
'ecorr	0.1													
'ecalt	0													
'ered	0.0001													
'icfo	1.5													
'icfi	1													
'k4	0.02513			0.001										
'perc	0.2	0.5		0.8	0.5	0.5	0.7		0.3			0.25	0.1	0.25
'khq	0.07	0.104		0.048					0.09	0.08		0.032		0.032
'hq	2.448	3.319	2.485	1.92		1.8	1.887		1.571		2.537	1.484	2.4	1.484
'alfa	1						1.3	1.3	1.3					
'maxbas	1	1.04167	0.54167	1.04167	0		1.04167	1.04167	0.75		1.54167		1.04167	
'recstep	999													
'focfmax	0.6													
'cevpfo	1.15													
inflow			Main1	Main2	Regnitz	Main3		Main4		Main5		Main6		Main7
			(lag=0.75)		(lag=0.5)			FrSaale		(lag=1)		Kinzig		Nidda
Simulated period: 1/1990-12/1999 Initial state:1/1997										Tauber				
R^2		0.84453	0.71435	0.73180	0.82725	0.69703	0.28143	0.73675	0.66671	0.80541	0.48912	0.78584	0.86598	0.78835
rel Acc Diff		0.06043	0.05226	-0.03955	0.00317	-0.00731	0.09227	0.11970	0.07618	0.01303	0.00056	0.11584	-0.05759	0.05436
peak err		-0.25474	-0.65456	-0.49488	-0.06334	0.00260	0.07716	-0.25869	-0.10051	0.16000	0.14128	0.19110	-0.04108	0.16849

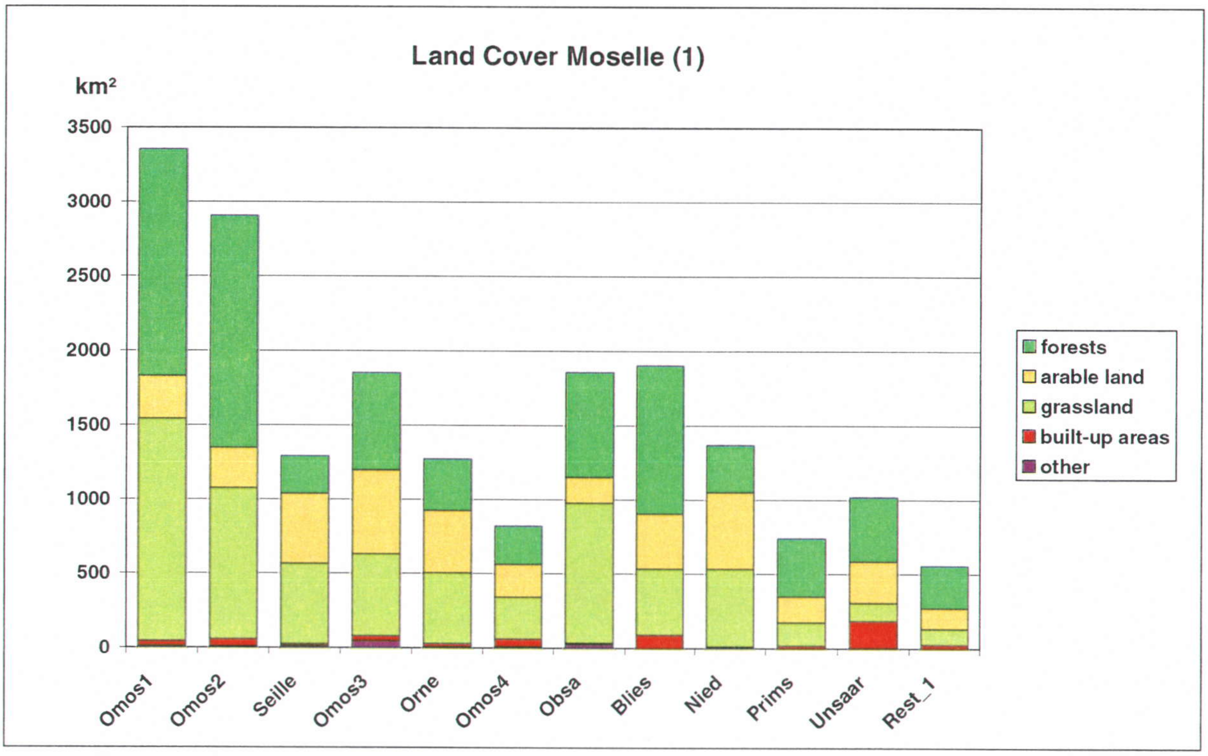

Gauging station Raunheim
Main8_comp
Main8_obs
Discharge [m³/s]
2500
2000
1500
1000
500
0
04.12.1993
14.12.1993
24.12.1993
03.01.1994
13.01.1994
23.01.1994

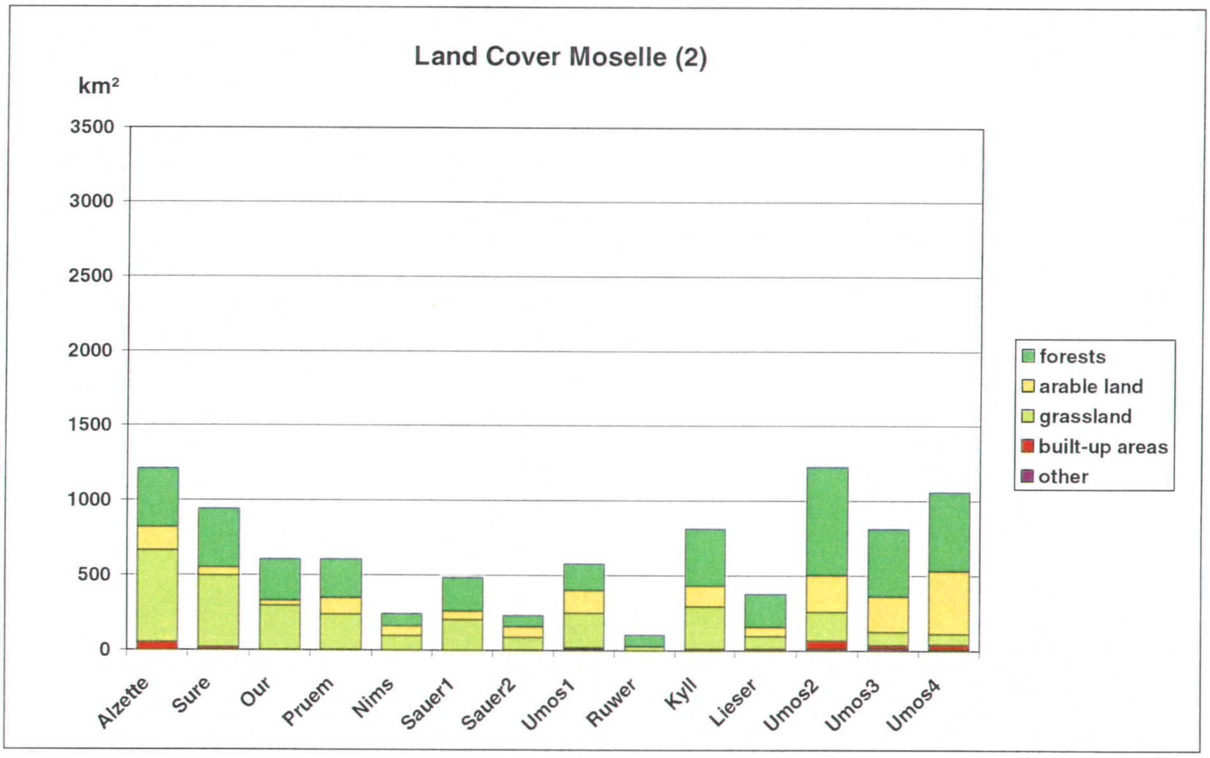

Gauging station Raunheim
Main8_comp
Main8_obs
Discharge [m³/s]
3000
2500
2000
1500
1000
500
0
09.01.1995
19.01.1995
29.01.1995
08.02.1995
18.02.1995
28.02.1995


Gauging station Raunheim
Main8_comp
Main8_obs
Discharge [m³/s]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
11.10.1998
21.10.1998
31.10.1998
10.11.1998
20.11.1998
30.11.1998

River Moselle

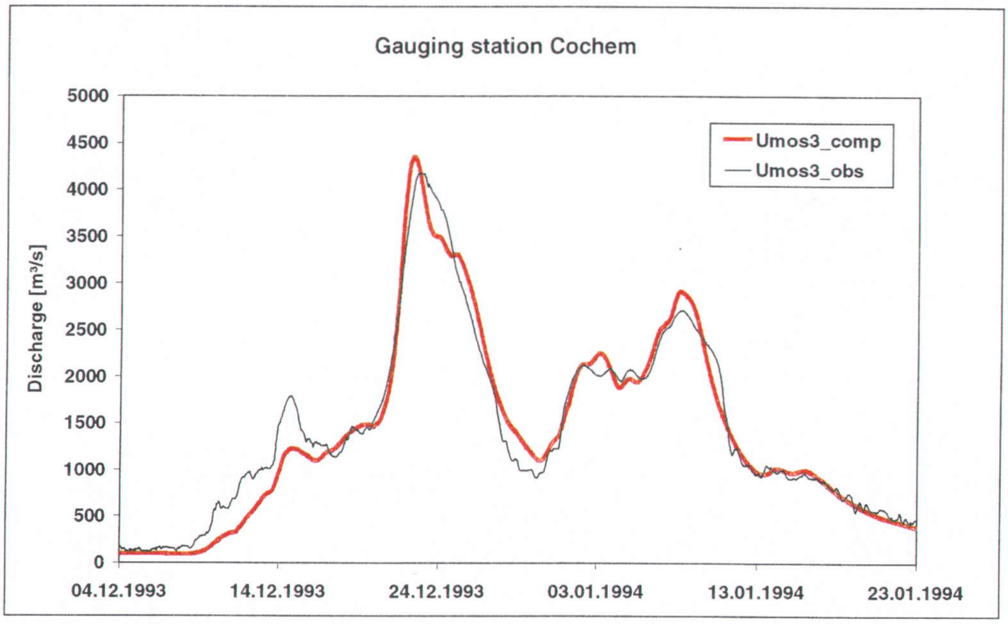


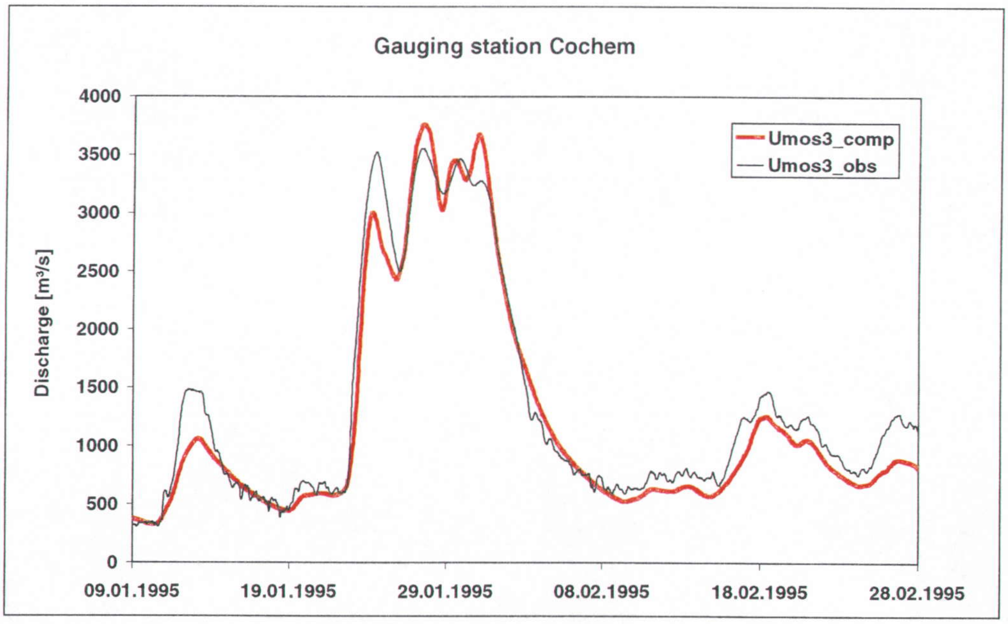

Land Cover Moselle (1)
km²
3500
3000
2500
2000
1500
1000
500
0
Omos1
Omos2
Seille
Omos3
Orne
Omos4
Obsa
Blies
Nied
Prims
Unsaar
Rest_1
forests
arable land
grassland
built-up areas
other

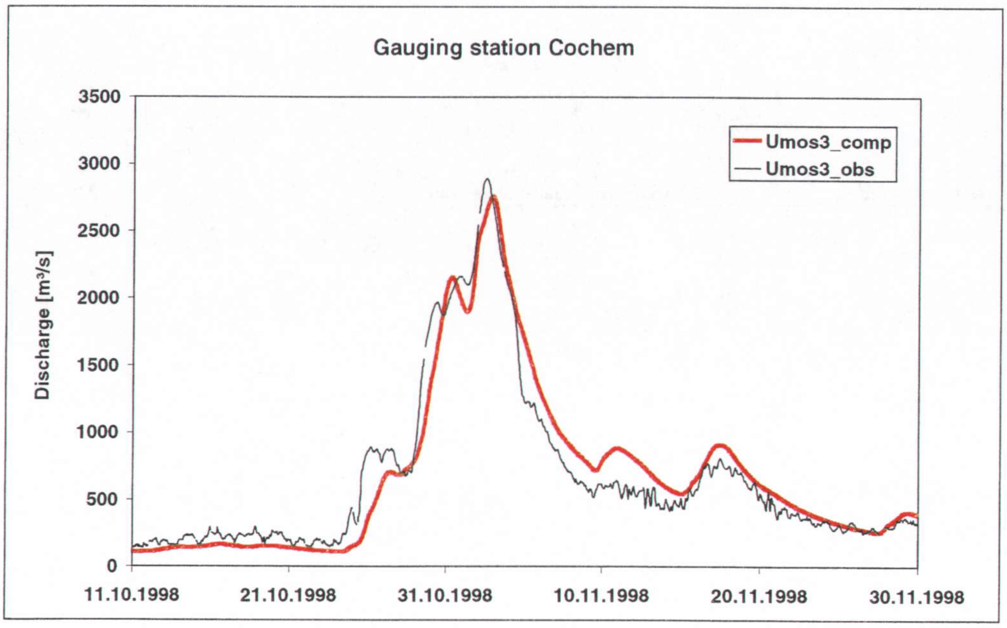

Land Cover Moselle (2)
km²
3500
3000
2500
2000
1500
1000
500
0
Alzette
Sure
Our
Pruem
Nims
Sauer1
Sauer2
Umos1
Ruwer
Kyll
Lieser
Umos2
Umos3
Umos4
forests
arable land
grassland
built-up areas
other

Parameters	District	Omos1	Omos2	Seille	Omos3	Orne	Omos4	Obsa	Blies_1	Nied_1	Prims_1	Unsaar	Rest_1
'pcorr	0.01	0.0103	0.0102		0.0108	0.0102	0.011	0.01015		0.0105			
'pcalt	0									0	0		0
'pcaltl	0												
'tcalt	0.6								0.5				
'rfcf	1								0.8				
'sfcf	0.8	1	1	1	1	1	1	0.9		1	0.9	0.8	0.8
'cfmax	4	6			6	5			3				
'tt	0	-1		-0.5	-0.5	-0.5	-0.5	-0.5	-0.8	-0.3	-0.3		
'dttm	0												
'tti	0.5	0.2								0.5	0.5	0.5	0.5
'whc	0.1												
'cfr	0.05							1		0.05	0.05	0.05	0.05
'fc	200	172	187	100	145	124	121	142		100	193	168	175
'lp	0.7	0.85	0.85	0.9	0.8	0.85	0.8	0.9	0.9	0.75	0.8	0.9	
'beta	2	1	1	1.5	0.9	1	1	1	1	1.5	2.2		
'cflux	1.5	0.5	0.5	0.2	0.1	0.1	0.1	0.8	0.8	0.8	0.3	0.8	0.8
'epf	0.01							0					
'ecorr	0.1												
'ecalt	1	0	0	0	0	0	0	0		0	0	0	0
'ered	0.0001	1						0.5	0				
'icfo	1.5												
'icfi	1												
'k4	0.02513	0.06		0.05		0.05	0.05	0.07	0.0217	0.0349	0.0224	0.05	0.05
'perc	0.2	0.5			0.8			0.3	0.8			0.6	0.6
'khq	0.07	0.141	0.091	0.05	0.087	0.101	0.085	0.103	0.1	0.097	0.142		
'hq	2.448	4.804	3.292	1.775	3.272	2.905	3.7	3.096	4	2.916	4.243	2.668	2.668
'alfa	1			1.3			1.2	1.5	1.5	1.5		2	2.5
'maxbas	1	1.375	1.33333	0.33333	0.54167			1.04167		1.04167	0.41667	0.54167	
'recstep	999												
'focfmax	0.6									0.6	0.6	0.6	0.6
'etf	0												
cevpfo	1.15												
inflow					Seille		Omos3					Nied	Unsaar
					Omos1		(lag=0.2)					Prims	
	Simulated period: 1/1990-12/1998				(lag=0.6)							Obsa	
	Initial state:1/1997				Omos2							(lag=0.25)	
					(lag=0.6)							Blies	
												(lag=0.25)	
R²		0.89076	0.79859	0.80738	0.88815	0.70674	0.85139	0.83542	0.76708	0.77488	0.85516	0.73129	
rel Acc Diff		-0.00838	0.00654	-0.04743	-0.03843	0.05009	-0.00973	-0.13551	-0.19697	-0.00154	-0.27077	-0.21956	
peak err		-0.16012	-0.09903	-0.15972	-0.07037	0.42651	-0.04948	-0.08475	-0.23237	0.07069	-0.21103	0.12109	

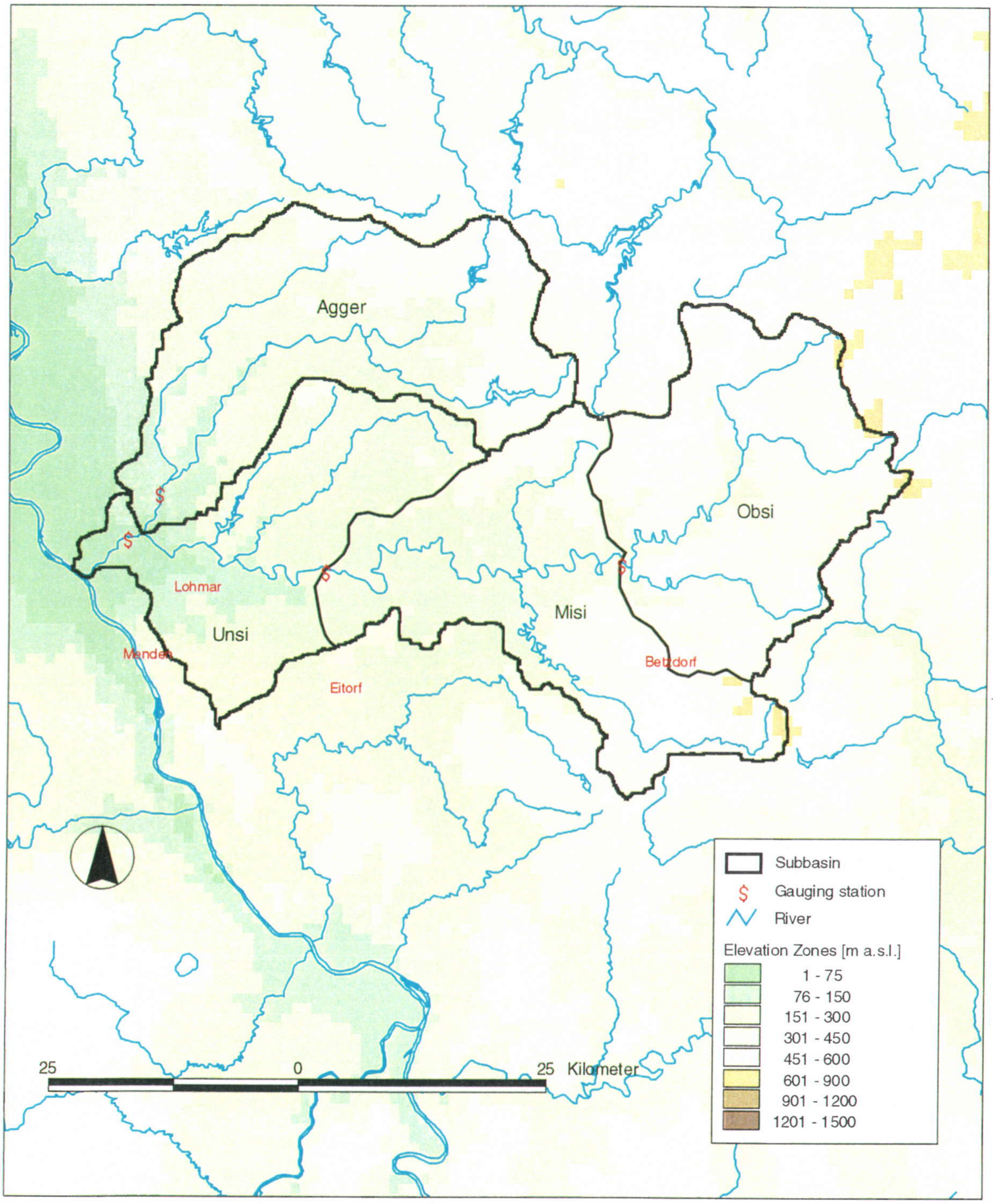
Parameters	Alzette	Sure	Our	Pruem	Nims	Sauer1	Sauer2	Umos1	Ruwer	Kyll	Lieser	Umos2	Umos3	Umos4
'pcorr	0.0105	0.0108		0.01025	0.00925	0.009	0.009		0.0105		0.0105	0.0105		
'pcalt	0	0	0	0	0	0	0							
'pcaltl														
'tcalt														
'rfcf						0.8	0.8							
'sfcf	1	1	1	1	0.9	1	1			0.9	0.9			
'cfmax		6	6	6	6	6	6				3			
'tt	-0.5	-0.5		0.5	0.5	-0.5	-0.5			-0.3	-0.5			
'dttm														
'tti														
'whc														
'cfr														
'fc	135	208	212	172	137	168	168	125	226		235	226	239	
'lp	0.9	0.9	0.9	0.9	0.9	0.9	0.5	0.9	0.6	0.9	0.9	0.9	0.9	
'beta	1	1		1.5	0.9	3	3	1.5	1.5	1.75		1.5	1.5	
'cflux	0.2	0.5	0.2	0.4	0.8	0.6	0.6	0.8	0.8	0.8	0.8	0.8	0.8	
'epf														
'ecorr			0.08			0.107	0.107	0.1025		0.103	0.103			
'ecalt	0	0	0.3	0	0	0	0	0	0	0	0	0	0	
'ered														
'icfo						1.8	1.8							
'icfi														
'k4	0.0513	0.04	0.09	0.05	0.015	0.0274	0.0274			0.0191	0.04			
'perc	0.5			0.5	0.8	1	1			0.8	0.25			
'khq	0.147	0.09	0.2	0.2	0.154	0.096	0.096			0.124	0.2			
'hq	4.135	3.541	5	4.321	4	3.281	3.281	2.618	2.618	3.617	3.617	2.618	2.618	
'alfa	1.5	1.3	1.3	1.3	1.6					1.2	1.2			
'maxbas	0.5	1.04167	1.375	1.04167	0.125	1.04167	1.04167		0	0.25	0.25			
'recstep														
'focfmax														
'etf														
cevpfo														
inflow						Alzette	Sauer1	Omos4				Umos1	Umos2	Umos3
	Simulated period: 1/1990-12/1998 Initial state:1/1997					(lag=0.25)	Prüm	Rest_1				Kyll	(lag=0.5)	
						Sure	Nims	Sauer2				Ruwer		
						(lag=0.25)						Lieser		
						Our								
R²	0.64828		0.87007	0.76428	0.59885	0.91468		0.91281	0.68653	0.68988	0.56740		0.91273	
rel Acc	0.11413		0.12449	-0.31384	-0.07613	-0.02876		-0.05666	-0.42978	-0.34422	-0.38865		-0.13556	
peak err	-0.04872		-0.09159	-0.30676	-0.00498	-0.19361		-0.00530	-0.56792	-0.31198	-0.32062		0.00549	


Gauging station Cochem
Discharge [m³/s]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Umos3_comp
Umos3_obs
04.12.1993
14.12.1993
24.12.1993
03.01.1994
13.01.1994
23.01.1994

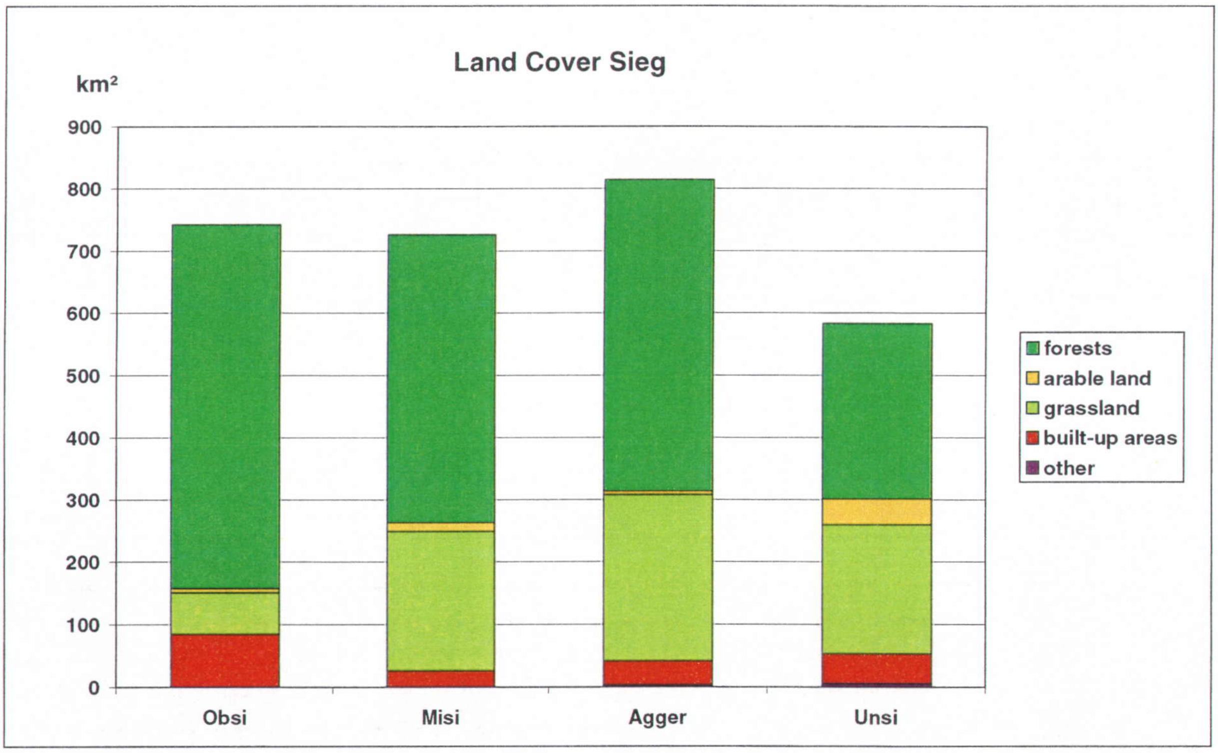

Gauging station Cochem
Discharge [m³/s]
0
500
1000
1500
2000
2500
3000
3500
4000
Umos3_comp
Umos3_obs
09.01.1995
19.01.1995
29.01.1995
08.02.1995
18.02.1995
28.02.1995


Gauging station Cochem
Discharge [m³/s]
0
500
1000
1500
2000
2500
3000
3500
Umos3_comp
Umos3_obs
11.10.1998
21.10.1998
31.10.1998
10.11.1998
20.11.1998
30.11.1998

River Sieg

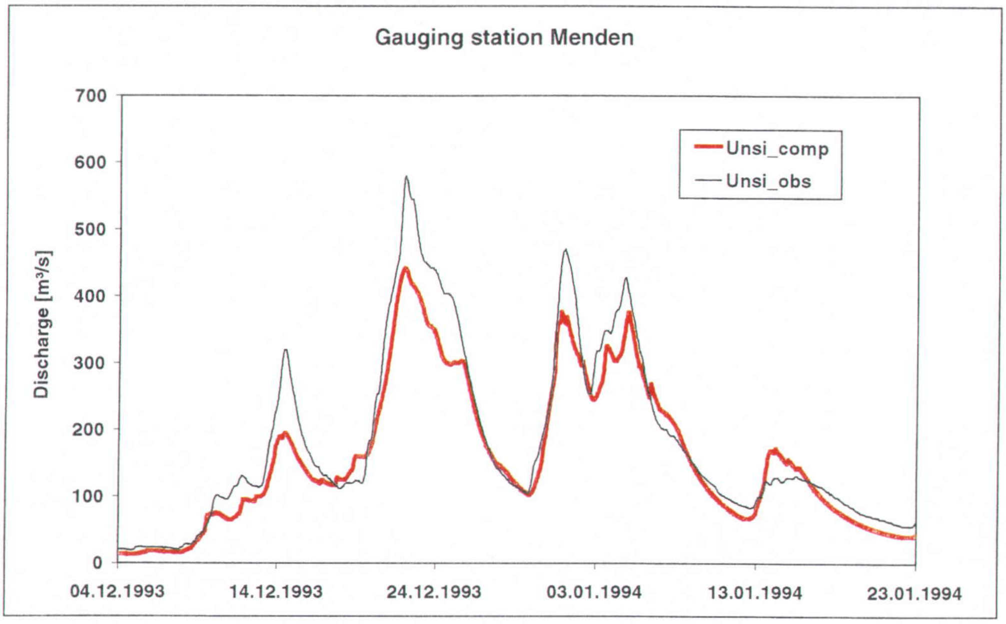


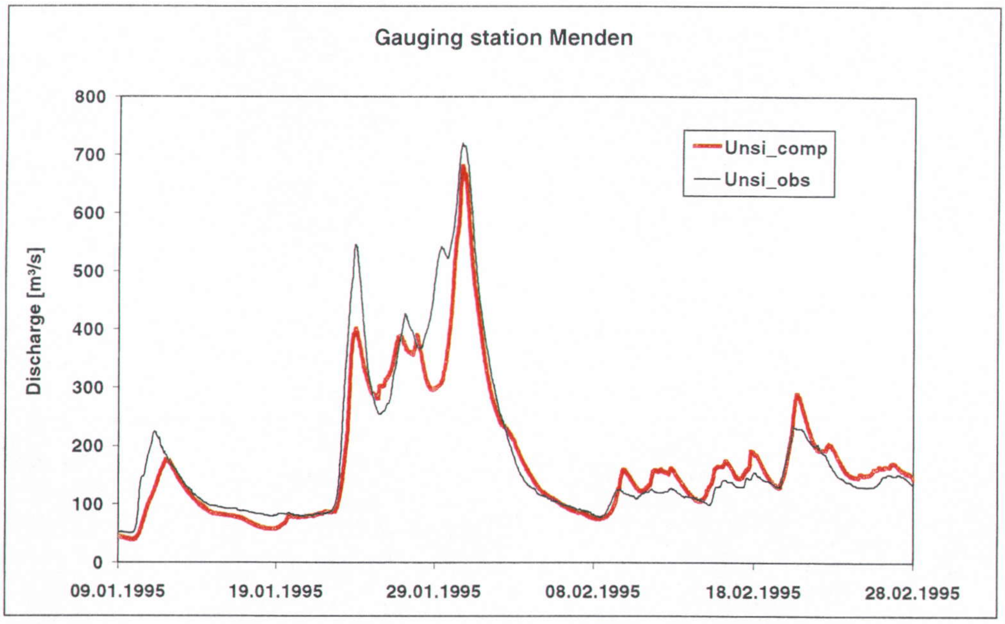
Agger
Obsi
Lohmar
Unsi
Misi
Menden
Betzdorf
Eitorf
25
0
25 Kilometer
Subbasin
Gauging station
River
Elevation Zones [m a.s.l.]
1 - 75
76 - 150
151 - 300
301 - 450
451 - 600
601 - 900
901 - 1200
1201 - 1500

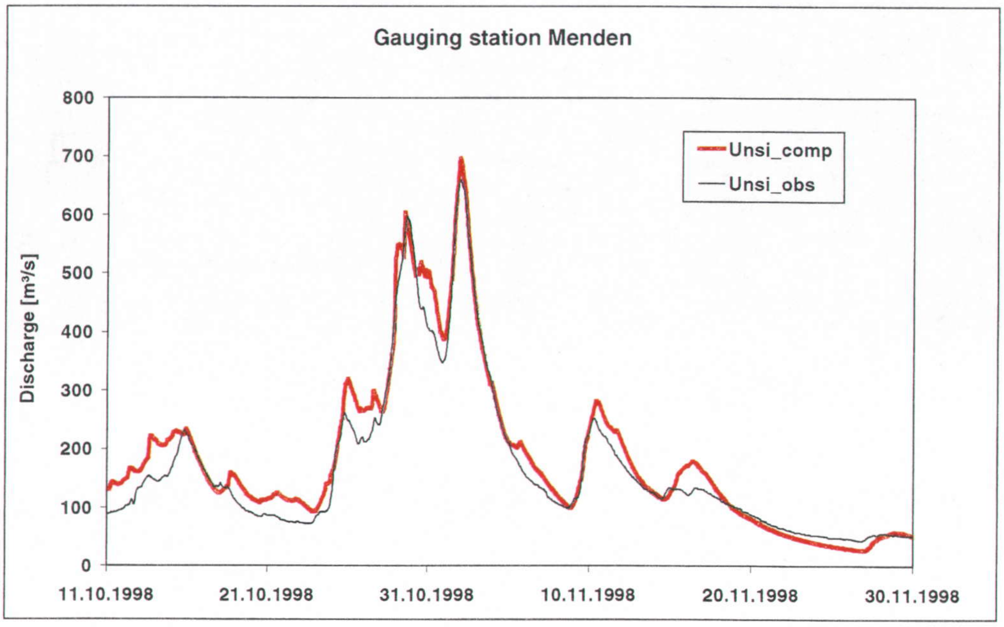

Land Cover Sieg
km²
900
800
700
600
500
400
300
200
100
0
Obsi
Misi
Agger
Unsi
forests
arable land
grassland
built-up areas
other

Parameters	District	Obsi	Misi	Agger	Unsi
'pcorr	0.01				
'pcaltl	0				
'tcalt	0.6				
'rfcf	1				
'sfcf	0.8				
'cfmax	4				
'tt	0				
'dttm	0				2
'tti	0.5				
'whc	0.1				
'cfr	0.05				
'fc	200	309	270	265	208
'lp	0.7	0.9	0.9	0.6	
'beta	2			1	1.5
'cflux	1.5	0.5	0.1	0.13	
'epf	0.01				
'ecorr	0.1				
'ecalt	1	0	0	0	0
'ered	0.0001	0	0		
'icfo	1.5				
'icfi	1				
'k4	0.02513		0.04974	0.03711	0.05482
'perc	0.2				
'khq	0.07	0.16	0.167	0.168	0.152
'hq	2.448	5.705	5.248	5.671	4.977
'alfa	1	0.9	1.4	1.2	1.2
'maxbas	1	0	1.04167	1.04167	
'recstep	999				
'focfmax	0.6				
'etf	0				
'cevpfo	1.15				
inflow			Obsi		Misi
			(lag = 0.5)		(lag = 0.417)
					Agger
R^2		0.83293	0.8368	0.78112	0.85234
rel Acc Diff		0.08370	0.11199	0.14941	0.13035
peak err		-0.27419	-0.22465	-0.15586	-0.20734

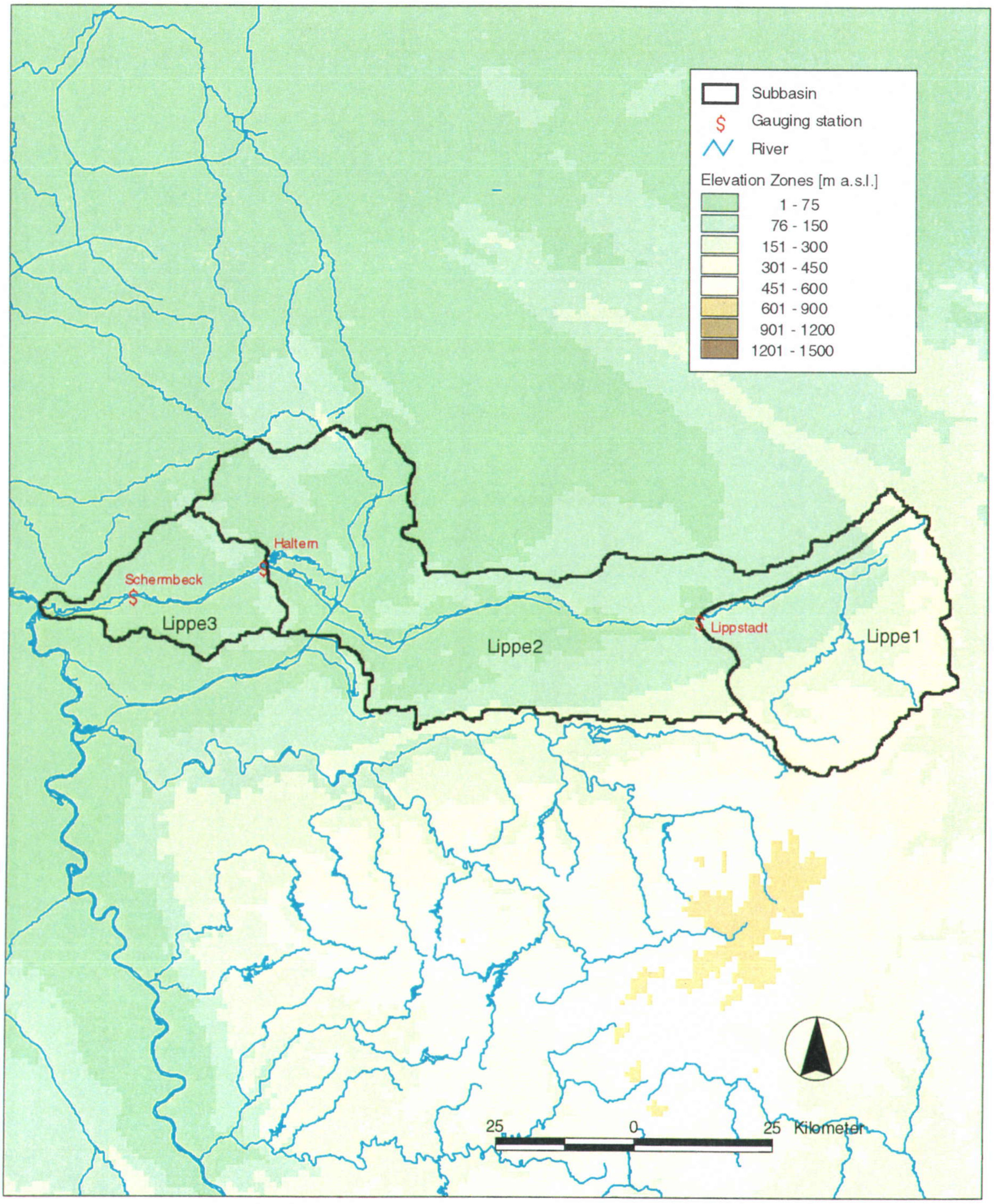
simulated period 1/1990-12/1999
initial state taken from a simulation up to 1/1997


Gauging station Menden
Unsi_comp
Unsi_obs
Discharge [m³/s]
0
100
200
300
400
500
600
700
04.12.1993
14.12.1993
24.12.1993
03.01.1994
13.01.1994
23.01.1994

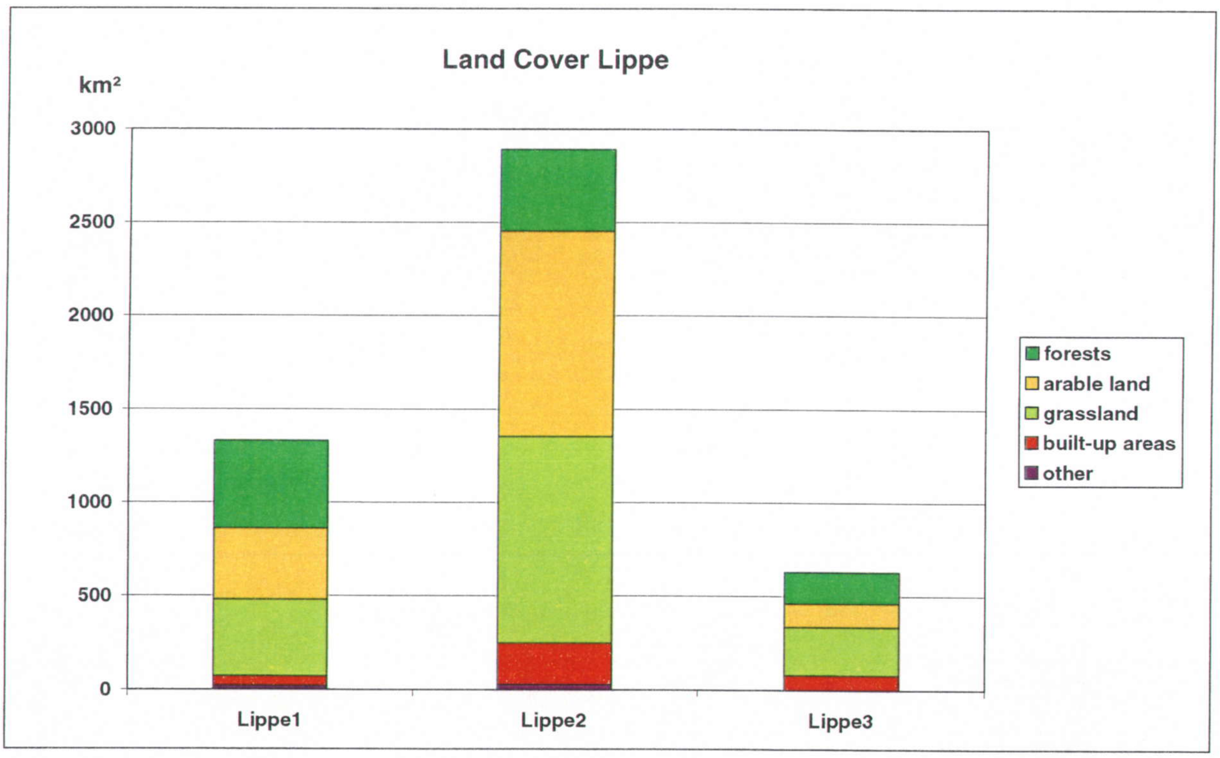

Gauging station Menden
Unsi_comp
Unsi_obs
Discharge [m³/s]
0
100
200
300
400
500
600
700
800
09.01.1995
19.01.1995
29.01.1995
08.02.1995
18.02.1995
28.02.1995


Gauging station Menden
Unsi_comp
Unsi_obs
Discharge [m³/s]
0
100
200
300
400
500
600
700
800
11.10.1998
21.10.1998
31.10.1998
10.11.1998
20.11.1998
30.11.1998

River Lippe

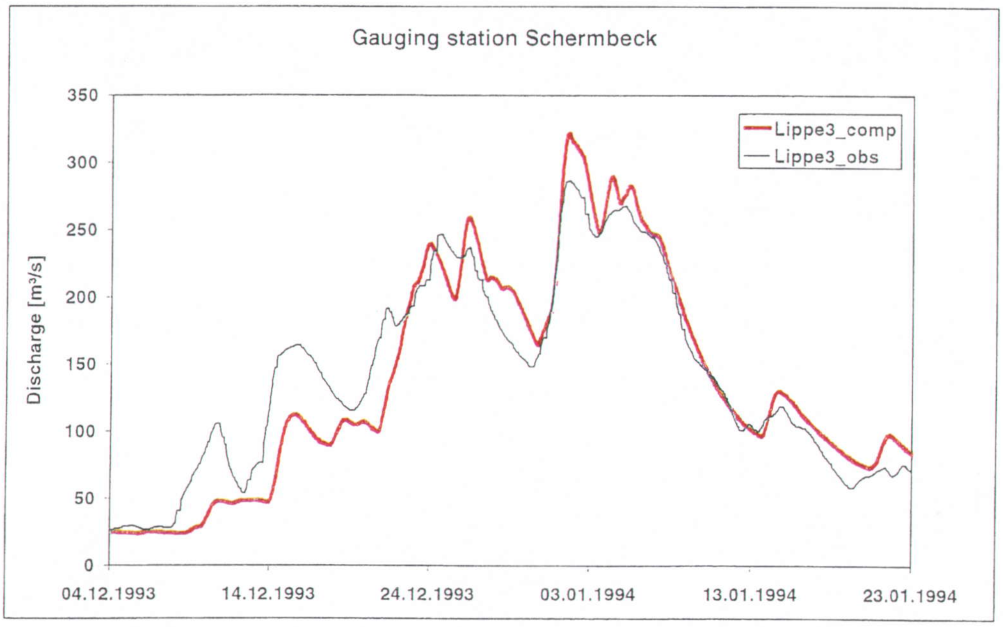


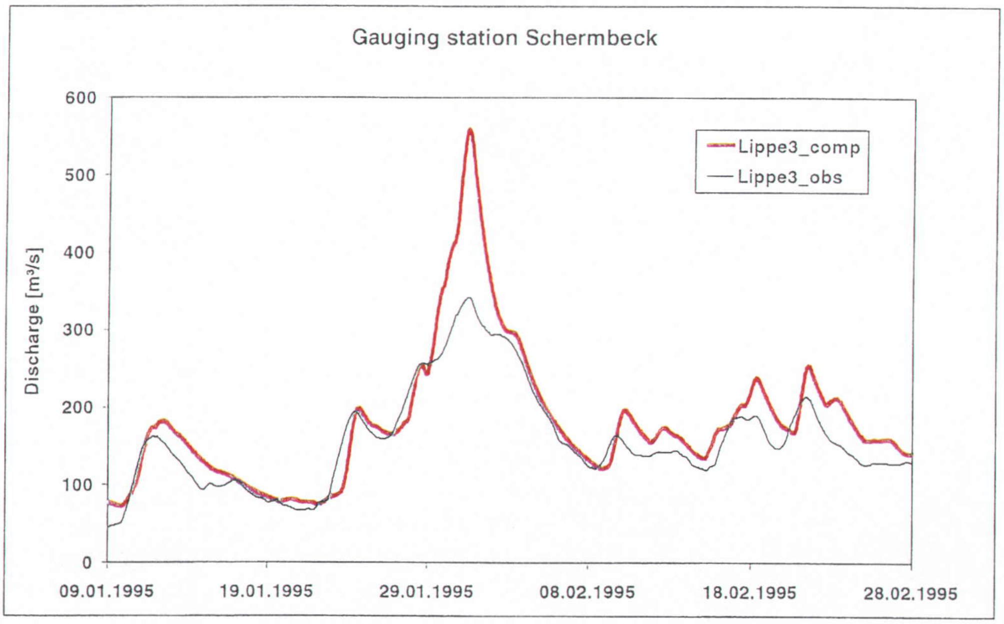
Subbasin
Gauging station
River
Elevation Zones [m a.s.l.]
1 - 75
76 - 150
151 - 300
301 - 450
451 - 600
601 - 900
901 - 1200
1201 - 1500
Haltern
Schermbeck
Lippe3
Lippe2
Lippstadt
Lippe1
25
0
25 Kilometer

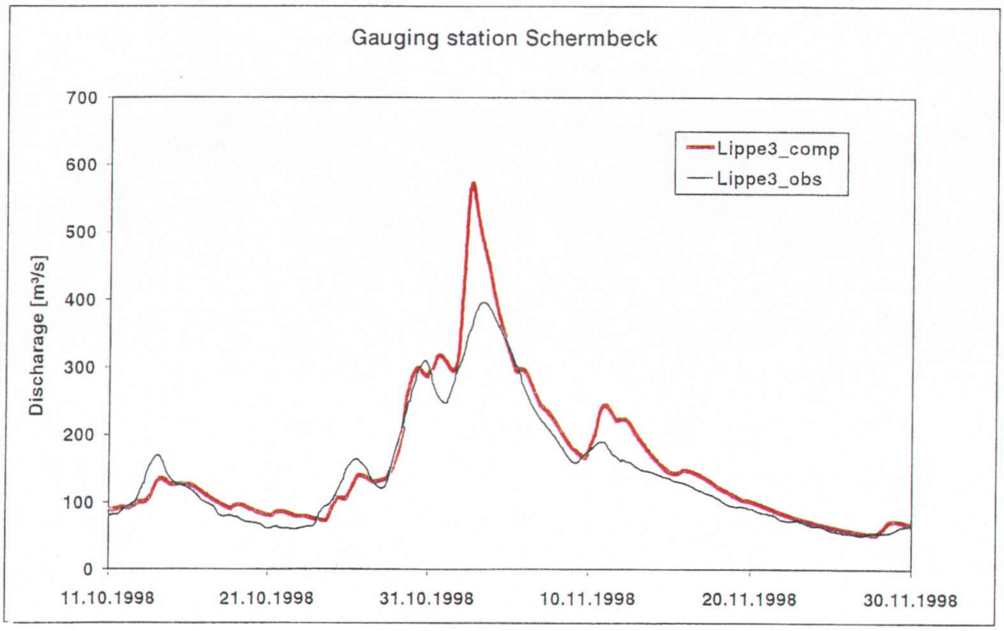

Land Cover Lippe
km²
3000
2500
2000
1500
1000
500
0
Lippe1
Lippe2
Lippe3
forests
arable land
grassland
built-up areas
other

Parameters	**District**	**Lippe1**	**Lippe2**	**Lippe3**
'pcorr	0.01	0.0105	0.0098	
'pcaltl	0			
'tcalt	0.6			
'rfcf	1			
'sfcf	0.8	1	0.6	0.6
'cfmax	4	8	3	8
'tt	0	-0.5	-0.5	
'dttm	0			
'tti	0.5			
'whc	0.1			
'cfr	0.05			
'fc	200	147	250	114
'lp	0.7	0.9	0.6	0.6
'beta	2	1	3	1
'cflux	1.5	0.1	0.1	0.8
'epf	0.01			
'ecorr	0.1		0.17	0.18
'ecalt	1	0	0.4	0
'ered	0.0001			
'icfo	1.5			
'icfi	1			
'k4	0.02513	0.021	0.02	0.02
'perc	0.2	0.5		0.6
'khq	0.07	0.035	0.125	0.026
'hq	2.448	1.734	2	1.223
'alfa	1	1.2	0.8	
'maxbas	1	0.3333		
'recstep	999			
'focfmax	0.6			
inflow			Lippe1	Lippe2
				(lag = 0.833)
R^2		0.77554	0.89703	0.87911
rel AccDiff		0.14387	0.02985	0.04279
peak err		0.17480	0.13929	0.22826

simulated period 1/1990-12/1999
initial state taken from a simulation up to 1/1997


Gauging station Schermbeck
Lippe3_comp
Lippe3_obs
Discharge [m³/s]
350
300
250
200
150
100
50
0
04.12.1993
14.12.1993
24.12.1993
03.01.1994
13.01.1994
23.01.1994


Gauging station Schermbeck
Lippe3_comp
Lippe3_obs
Discharge [m³/s]
600
500
400
300
200
100
0
09.01.1995
19.01.1995
29.01.1995
08.02.1995
18.02.1995
28.02.1995


Gauging station Schermbeck
Lippe3_comp
Lippe3_obs
Discharage [m³/s]
700
600
500
400
300
200
100
0
11.10.1998
21.10.1998
31.10.1998
10.11.1998
20.11.1998
30.11.1998

Publications

In this series the following publications were printed:

NCR-publication n°:	Title
00-2000	"Delfstoffenwinning als motor voor rivierverruiming; kansen en bedreigingen", editors Prof.dr. A.J.M. Smits and G.W. Geerling (in Dutch; out of stock, but can be downloaded from the NCR Internet site)
01-2000	"NCR Programma, versie 1999 – 2000", editors Dr. R. Leuven and A.G. van Os (in Dutch)
02-2000	"NCR workshop, de weg van maatschappelijke vraag naar onderzoek", editors A.F. Wolters and E.C.L. Marteijn (in Dutch)
03-2001	"NCR dagen 2000, het begin van een nieuwe reeks", editors A.F. Wolters, dr. C.J. Sloff and E.C.L. Marteijn (partly in Dutch)
04-2001	"Umbrella Program IRMA-SPONGE, Background, Scope and Methodology", editors dr. A. Hooijer and A.G. van Os
05-2001	"Summary of NCR Programme, version 2001 – 2002", editor A.G. van Os (also downloadable from the NCR Internet site)
06-2001	"The Netherlands centre for River Studies, a co-operation of the major developers and users of expertise in the area of rivers", editors A.G. van Os and H. Middelkoop
07-2001	"NCR days 2001, from sediment transport, morphology and ecology to river basin management", editors E. Stouthamer and A.G. van Os
08-2001	"Gelderse Poort: Land van levende rivieren, SOVON" (in Dutch)
09-2001	"Guidelines for rehabilitation and management of floodplains, ecology and safety combined" editors H.A.Wolters, M. Platteeuw and M.M.Schoor
10-2001	"Living with floods: resilience strategies for flood management and multiple land use in the river Rhine basin", editors M. Vis, F. Klijn and M. van Buuren
11-2001	"Development and application of BIO-SAFE, a policy and legislation based model for the assessment of impacts of flood prevention measures on biodiversity in river basins", authors R.J.W. de Nooij, D. Alard, G. de Blust, N. Geilen, B. Goldschmidt,. V. Huesing, H.J.R. Lenders, R.S.E.W. Leuven, K. Lotterman, S. Muller, P.H. Nienhuis and I. Poudevigne
12-2001	"Extension of the Flood Forecasting Model FloRIJN", authors E. Sprokkereef, H. Buiteveld, M. Eberle and J. Kwadijk
13-2001	"DSS Large Rivers. Interactive Flood Management and Landscape planning in River Systems", authors R.M.J. Schielen, C.A. Bons, P.J.A. Gijsbers and W.C. Knol
14-2001	"Cyclic floodplain rejuvenation: a new strategy based on floodplain measures for both flood risk management and enhancement of the biodiversity of the river Rhine", editor H. Duel
15-2001	"Intermeuse: the Meuse reconnected", authors N. Geilen, B. Pedroli, K. van Looij, L. Krebs, H. Jochems, S. van Rooij and Th. van der Sluis

Colofon

Eric Sprokkereef (RIZA) (Editor)

Design cover
KumQuat Dordrecht

Print
JB&A, Wateringen

Number of prints
125

ISSN 1568-234X

Keywords
NCR, Rivers, Research, Flood, Forecast, Rhine

To be cited as
Eric Sprokkereef (RIZA) (Editor), 2001 Extension of the Flood Forecasting Model FloRIJN
NCR-publication 12-2001, ISSN 1568-234X.

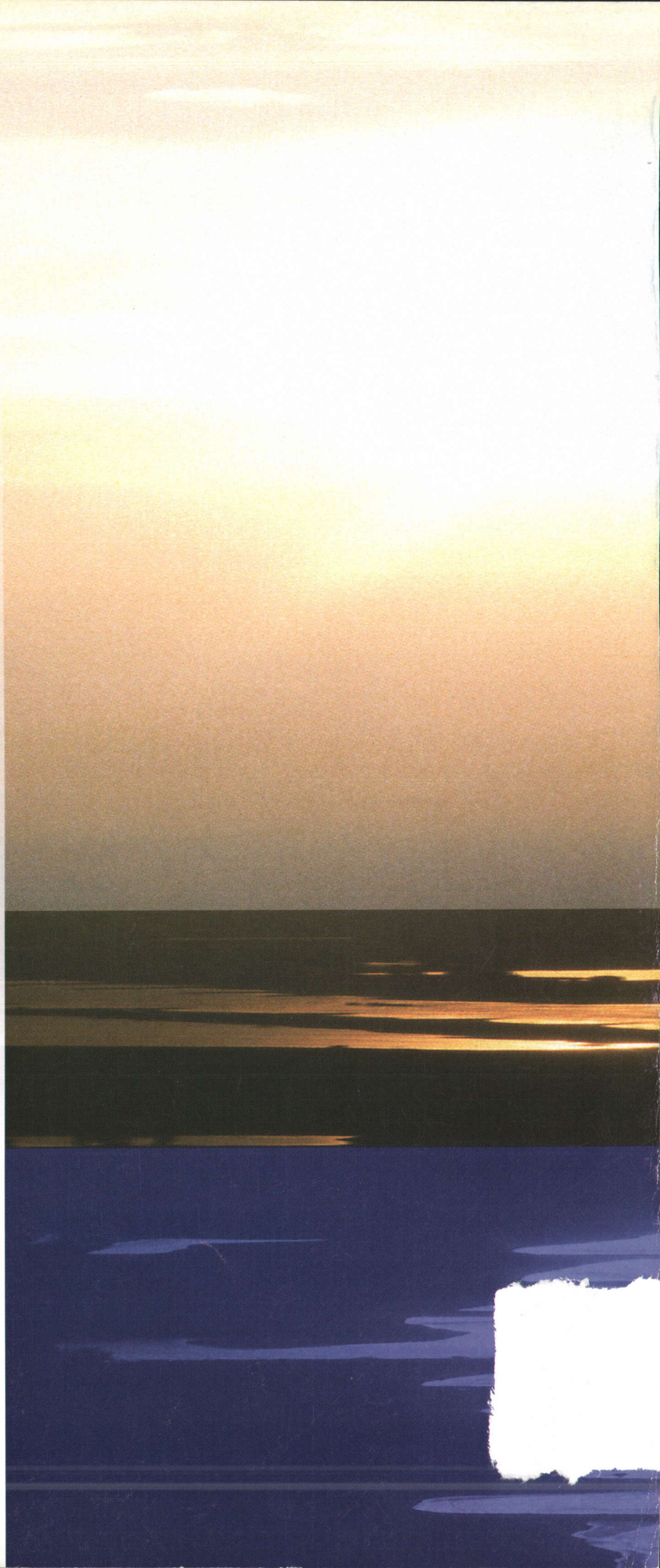
The Netherlands Centre for River Studies (NCR) is a collaboration of the major developers and users of expertise in the Netherlands in the area of rivers, viz. the universities of Delft, Utrecht, Nijmegen and Twente, IHE, ALTERRA, TNO-NITG, RIZA and WL | Delft Hydraulics

NCR's goal is to build a joint knowledge base on rivers in the Netherlands and to promote co-operation between the most important scientific institutes in the field of river studies in the Netherlands. This co-operation will also strengthen the national and international position of Dutch scientific research and education

NCR's address:
NCR, c/o WL | Delft Hydraulics
P.O.Box 177
2600 MH Delft
the Netherlands

[t] +31 15 2858577
[f] +31 15 2858582
[e] ncr@wldelft.nl
[I] http://www.ncr-web.org

ISSN 1568-234X



NCR